

# Inland Waters & Catchment Ecology

## Coorong Fish Condition Monitoring 2008–2020: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouth hardyhead (*Atherinosoma microstoma*) populations



Qifeng Ye, Luciana Bucater, David Short and George Giatas

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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 as a consequence of diminished freshwater inflows and substantial increases in salinity. To restore and enhance the environmental values of the LLCMM region, an Environmental Water Management Plan (2014) was developed, which included ecological fish targets for the Coorong. Fish condition monitoring commenced in 2008/09 to evaluate the ecological targets, guided by the TLM Condition Monitoring Plan (revised, 2017). This report presents the findings of 12 years’ monitoring (2008/09–2019/20) for smallmouth hardyhead (*Atherinosoma microstoma*), black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*) in the Murray Estuary, North Lagoon and South Lagoon of the Coorong. During the study period, there were variable hydrological conditions, including extreme drought (2008/09 and 2009/10, no flow), low flows (e.g. 2013–2016, 2017–2020, <1,000 GL y<sup>-1</sup>) and flood/high flows (2010–2012 and 2016/17, >6,000 GL y<sup>-1</sup>), which allowed investigation of biological responses to flow variability and population recovery over time. This monitoring involved evaluation of two fish ecological objectives: (1) Maintain abundant self-sustaining populations of smallmouth hardyhead in the North Lagoon and South Lagoon of the Coorong (F-3); and (2) Restore resilient populations of black bream and greenback flounder in the Coorong (F-4).

Monitoring for smallmouth hardyhead indicated that the ecological objective F-3 was not achieved in 2019/20, with low river inflows. The population condition was classified as ‘moderate’, which was reflected by a broad distribution of both adults and new recruits throughout the North Lagoon and South Lagoon; and higher abundance of new recruits (1,355 fish.UE<sup>-1</sup>) compared to the ecological target (>800 fish.UE<sup>-1</sup>), but less extensive recruitment throughout the Coorong. Smallmouth hardyhead plays an important role in the trophic ecology of the region. As a small-bodied, solely estuarine species, it is highly responsive to river flows to the Coorong, showing rapid increases in abundance, recruitment and distribution post high flows. This was corroborated by significant improvement and ‘good/very good’ population conditions in 2011/12, 2012/13 and 2016/17, following flood/high flows, as well as the ‘extremely poor’ population condition that occurred in 2008/09 and 2009/10 during the latter part of the Millennium Drought. The population condition declined to ‘moderate’ in 2017/18, 2018/19 and 2019/20, with reduced inflows and increased salinities in the Coorong. This study supports the importance of freshwater flows to the

population ecology of smallmouth hardyhead in the Coorong, and the flow related biological responses observed displayed its population resilience in this region.

In contrast, for black bream and greenback flounder, results from the monitoring suggest that the ecological objective (F-4) to restore resilient populations of these species in the Coorong has not been achieved over the last 12 years. For black bream, the population condition ranged from 'extremely poor' to 'poor' in the Coorong in all years except 2017/18 and 2019/20 when it was 'moderate'. The 'moderate' condition in 2019/20 was an improvement from 2018/19 ('very poor'), and was characterised by:

- An increasing 4-year catch trend (meeting the target about a positive trend);
- Increased distribution of the commercial catches (63% from the southern Coorong, meeting the target: >50%);
- The presence of two strong cohorts with both <5 years (meeting the target) despite 17% of the catches >10 years of age (vs the target: >20%);
- No detection of YOY (vs the target CPUE: >0.77 fish.net night<sup>-1</sup>);
- A low relative abundance (annual commercial catch of 1.6 t vs the target: ≥8 t).

For greenback flounder, the population condition improved from 'extremely poor' during the drought in 2008/09 and 2009/10, to 'moderate' during three post-drought years (2011/12–2013/14). It then declined to 'poor' in 2014/15 and 2015/16, with low river inflows (<1,300 GL y<sup>-1</sup>). In 2016/17, the population condition improved to 'moderate' following high river flows, although it declined again with flow reductions in the subsequent three years. In 2019/20, the population condition was 'poor', characterised by:

- A very low relative abundance (annual commercial catch 0.2 t vs the target: >24 t);
- A decreasing 4-year trend in catches (not meeting the target);
- A low level of recruitment (YOY CPUE 0.3 fish.seine net<sup>-1</sup> vs the target: >1.04 fish.seine net<sup>-1</sup>) with a contracting distribution (present at 33% sites vs the target: >50% sites);
- The presence of a very strong cohort (95% 1 year olds, meeting the target: >60%);
- A broad distribution of commercial catches (>99% from the southern Coorong, meeting the target: >70%).

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 12 years. Therefore, we suggest that future evaluation of the ecological objective

F-4 be separated for these two species, whereas specific targets remain as defined in the LLCMM Icon Site Condition Monitoring Plan (revised, 2017):

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

Freshwater flow is important in facilitating successful recruitment of black bream and greenback flounder, likely through maintaining/restoring estuarine habitats (providing a favourable salinity gradient and environmental conditions) and increasing productivity in the Coorong. As a marine-estuarine opportunist and relatively fast growing species with a moderate life-span (~10 years), greenback flounder seem to be more responsive to river flow increases to the Coorong than black bream, which is a slower growing, solely estuarine long-lived fish. For black bream, despite periodic recruitment occurring over the 12 study years, no significant improvement in the population abundance has been observed. This was potentially due to the depleted spawning biomass and truncated age structure, which compromised its population resilience in the Coorong.

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

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

## 1. INTRODUCTION

### 1.1. Background

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

The Coorong is a long (about 110 km) and narrow (<4 km) estuarine lagoon system with a strong north–south salinity gradient, generally ranging from brackish/marine in the Murray Estuary near the Murray Mouth to hypersaline in the North and South lagoons (Geddes and Butler 1984; Geddes 1987). Salinities are spatio-temporally variable and highly dependent on freshwater flows from the River Murray, with varied salinities supporting different ecological communities (Brookes *et al.* 2009). In addition, the southern end of the South Lagoon receives small volumes of fresh/brackish water (mean = 16.4 GL y<sup>-1</sup> between 2001/02–2019/20) from a network of drains (the Upper South East Drainage Scheme) through 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<sup>-1</sup> to 4,733 GL y<sup>-1</sup>; 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) until December 2010. During the drought, the Coorong was transformed into a marine–extremely hypersaline environment (Brookes *et al.* 2009). Many native fish species that resided in the Coorong and depended on its habitat for breeding, nursery and feeding grounds were negatively affected (Noell *et al.* 2009; Ye *et al.* 2015a; 2016), and recruitment of diadromous fish failed due to a lack of connectivity between freshwater and marine environments (Zampatti *et al.* 2010).

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

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

The current report presents the findings of fish condition monitoring from 2008–2020, with a focus on assessing whether the ecological targets and objectives have been achieved for the populations of the three fish species in the Coorong in 2019/20. The assessment builds on previous data collected from commercial fishery (fishery-dependent) and fishery-independent research sampling between 2008/09–2018/19 (Ye *et al.* 2020c).

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

Characteristic	Description
Ecological Objective	<i>Restore resilient populations of black bream and greenback flounder in the Coorong</i>
Ecological Targets	<b>Black bream</b>
	1. <b>Relative abundance (based on the commercial fishery catch, t/year)</b> – Annual catch $\geq 8$ t or positive trend over previous four years (linear regression) (C)
	2. <b>Distribution</b> – $>50\%$ of the catch from southern part of the Coorong (south of Mark Point) (C)
	3. <b>Age structures</b> – 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; $\geq 2$ strong cohorts in the population (C). (Strong cohort is defined as a cohort representing $\geq 15\%$ of the population)
	4. <b>Recruitment</b> – Catch per unit effort (CPUE) of young-of-the-year (YOY) $>0.77$ fish.net night <sup>-1</sup> by fyke net (R) – YOY distribution in the Coorong: $> 50\%$ sites with black bream YOY present (R)
	<b>Greenback flounder</b>
	1. <b>Relative abundance (based on the commercial fishery catch, t/year)</b> – Annual catch $\geq 24$ t or positive trend over previous four years (linear regression) (C)
	2. <b>Distribution</b> – $>70\%$ of the catch from southern part of the Coorong (south of Mark Point) (C)
	3. <b>Age structure</b> – 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. <b>Recruitment</b> – CPUE of YOY $>1.04$ fish.seine net <sup>-1</sup> – YOY distribution in the Coorong: $>50\%$ sites with greenback flounder YOY present (R)

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

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



## 1.2. Objectives

This project undertook condition monitoring for black bream, greenback flounder and smallmouth hardyhead in the Coorong in 2019/20, aiming to assess their recruitment and population status against specific quantitative targets (Tables 1.1 and 1.2) and to report on overall condition scores of these fish species. Specific monitoring objectives for each species were to:

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

## 2. BIOLOGY/ECOLOGY OF FISH SPECIES

### 2.1. Black bream

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

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

Given its ecological and economic importance, black bream is a key species that has been studied in the Coorong over the last decade. Cheshire *et al.* (2013) found that black bream in the Coorong, similar to that from Victorian estuaries, has a spring spawning season (Coutin *et al.* 1997; Norriss

*et al.* 2002) with a peak in the gonadosomatic index (GSI) occurring in October and November. A more recent study suggested that spawning of this species can extend to late summer, based on back calculated spawning date of young-of-year black bream (Ye *et al.* 2019a). The study also demonstrated the presence of halocline conditions associated with releases of water for the environment to the Coorong, which supported successful recruitment of black bream in 2017/18 (Ye *et al.* 2019a).

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

## **2.2. Greenback flounder**

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

Greenback flounder is a 'marine-estuarine opportunist' species, which by definition, are marine fishes that enter estuaries regularly, in substantial numbers, often as juveniles, but also use marine waters to varying degrees as alternative nurseries (Potter *et al.* 2015; Bice *et al.* 2018). Greenback flounder is a 'medium-bodied' fast-growing species that can live to more than 10 years of age with early maturity and high fecundity at about one year of age (Crawford 1986; Sutton *et al.* 2010; Earl *et al.* 2014). These traits suggest a life history strategy that is intermediate between opportunist and periodic strategies (Ferguson *et al.* 2013). Regarded as a multiple batch spawner

with asynchronous oocyte development (Kurth 1957; Barnett and Pankhurst 1999), this species has a protracted spawning season during autumn/winter/spring (Crawford 1984b; Earl 2014). Spawning is known to occur in the deeper areas of tidal rivers and estuaries, as well as offshore (Kurth 1957; Crawford 1984a; Earl 2014).

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

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

In South Australia, almost all commercial catches of greenback flounder are taken from the Coorong by the Lakes and Coorong Fishery (LCF), which is a multi-species and multi-gear fishery (Earl 2014). Long-term statistics for this fishery indicate large inter-annual and spatial variation in population biomass and abundance of greenback flounder (Earl and Ye 2016; Ye *et al.* 2020c). Age structures of this species within the Coorong are truncated with a dominant class of 1 or 2 year olds, potentially resulting from removal of older individuals through commercial and recreational fishing (Ferguson 2012; Ye *et al.* 2020c). However, Earl *et al.* (2016) suggested that temporal and spatial variation of biomass and abundance could also be related to the migration of older individuals to the sea.

Given their ecological and commercial importance to the LCF, greenback flounder has been a key focus species in several research and monitoring projects in recent years (e.g. Earl 2014; Ye *et al.* 2013; Earl *et al.* 2017; Ye *et al.* 2020c). Individuals have been recorded in the Coorong up

to 50 km from the Murray Mouth (salinity ~74 psu) during the drought (Noell *et al.* 2009) and 70 km from the Murray Mouth (~80 psu) after increased river flows post 2010/11 (Ye *et al.* 2015a). Nevertheless, this species shows a preference for brackish and near-marine salinities (Earl *et al.* 2017).

### 2.3. Smallmouth hardyhead

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

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

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

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

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

### 3. METHODS

#### 3.1. General approach

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

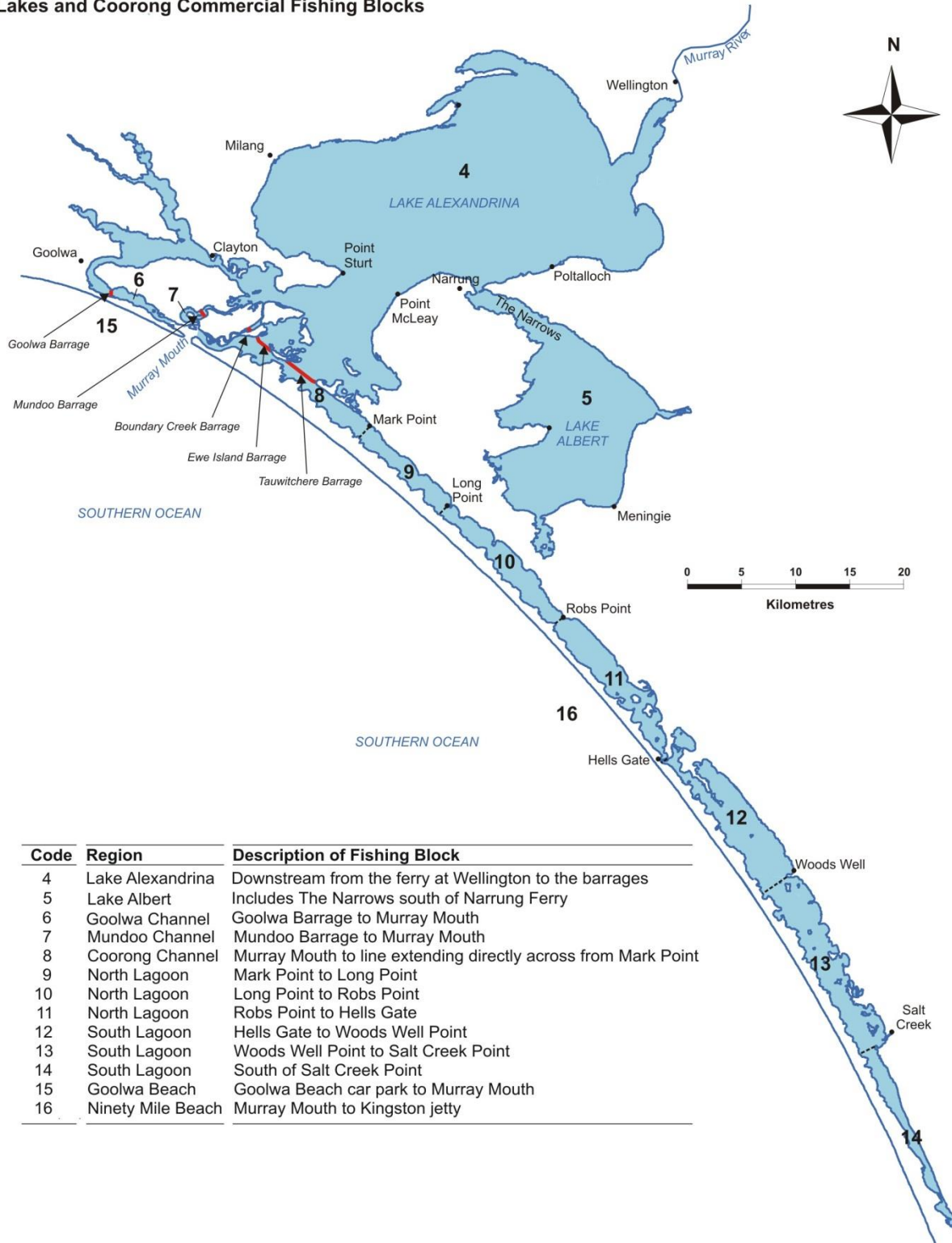
#### 3.2. Fishery catch and freshwater flows

##### 3.2.1. Data

Commercial fishery data (1984/85 to 2019/20) for black bream and greenback flounder from the LCF were obtained from the SARDI Information Services, including annual catch (kg) and spatial reporting of fishing blocks (Figure 3.1). The Coorong region encompasses fishing blocks 6 to 14.

Monthly freshwater discharge across the barrages was available for the period from July 1984 to June 2020, based on the estimates of the regression-based Murray hydrological model (MDM, BIGMOD, Murray–Darling Basin Authority, MDBA) and on daily discharge calculated by the Department for Environment and Water (DEW). In addition, daily salinity and freshwater discharge data from the Salt Creek inlet to the South Lagoon of the Coorong (Station A2390568) were obtained from the Water Connect website of the Department for Environment and Water (DEW 2020).

**Lakes and Coorong Commercial Fishing Blocks**



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



### **3.2.2. Analysis**

Annual fishery catches of black bream and greenback flounder, and barrage flows were plotted for each financial year for the period between July 1984 and June 2020. Temporal trends of catch were analysed to indicate the fluctuation in abundance of these species in the Coorong. The annual catch of each species was compared against the target values to determine whether the target has been met (Table 1.1). Additionally, linear regression analysis was performed on the annual catches of the last 4-year period to describe the trend of increase or decrease in population biomass over recent years. To assess fish distribution, proportional catch from southern part of the Coorong (south of Mark Point) was calculated based on the catch from fishing blocks 9–14.

## **3.3. Age/size structures of fishery species**

### **3.3.1. Samples**

Sampling of black bream and greenback flounder from commercial catches was conducted in the Murray Estuary and North Lagoon of the Coorong from 2008/09–2019/20 to establish the age/size structures of fishery catches. In each year, adult black bream were collected from various sites (e.g. Goolwa Channel, Newells, Sugars Beach, Boundary Creek, Pelican Point, Long Point and Seven Mile) (Figure 3.2) mostly during spring/early summer, and greenback flounder were collected from multiple sites (e.g. the Goolwa Channel, Mark Point, Long Point, Sam Island, Seven Mile and Needles) (Figure 3.3) mainly during winter.

### **3.3.2. Laboratory processing and analysis**

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

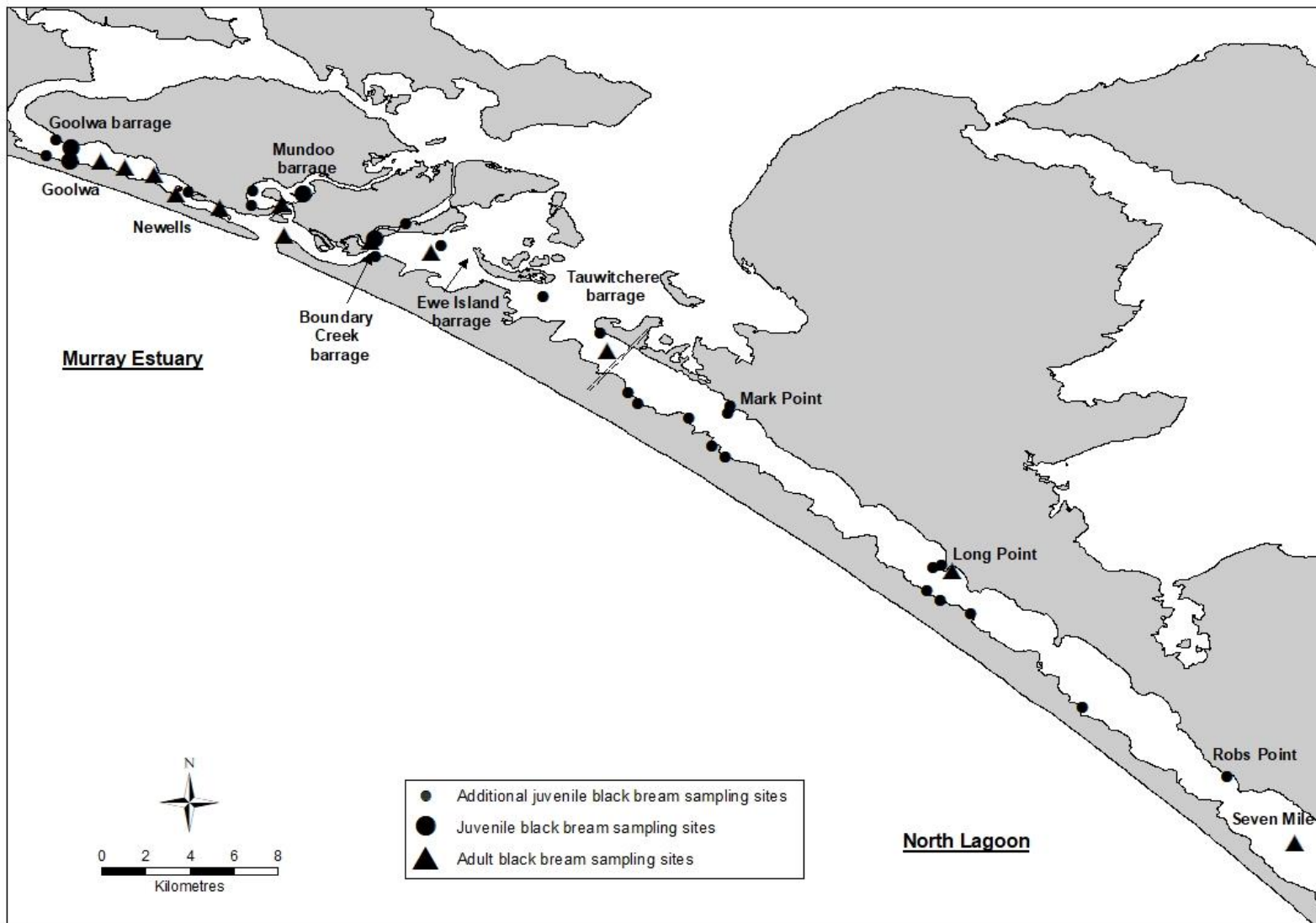


Figure 3.2. Condition monitoring sampling sites for adult and juvenile black bream at the Coorong. Adult black bream sampling sites represent commercial fishery sampling sites.

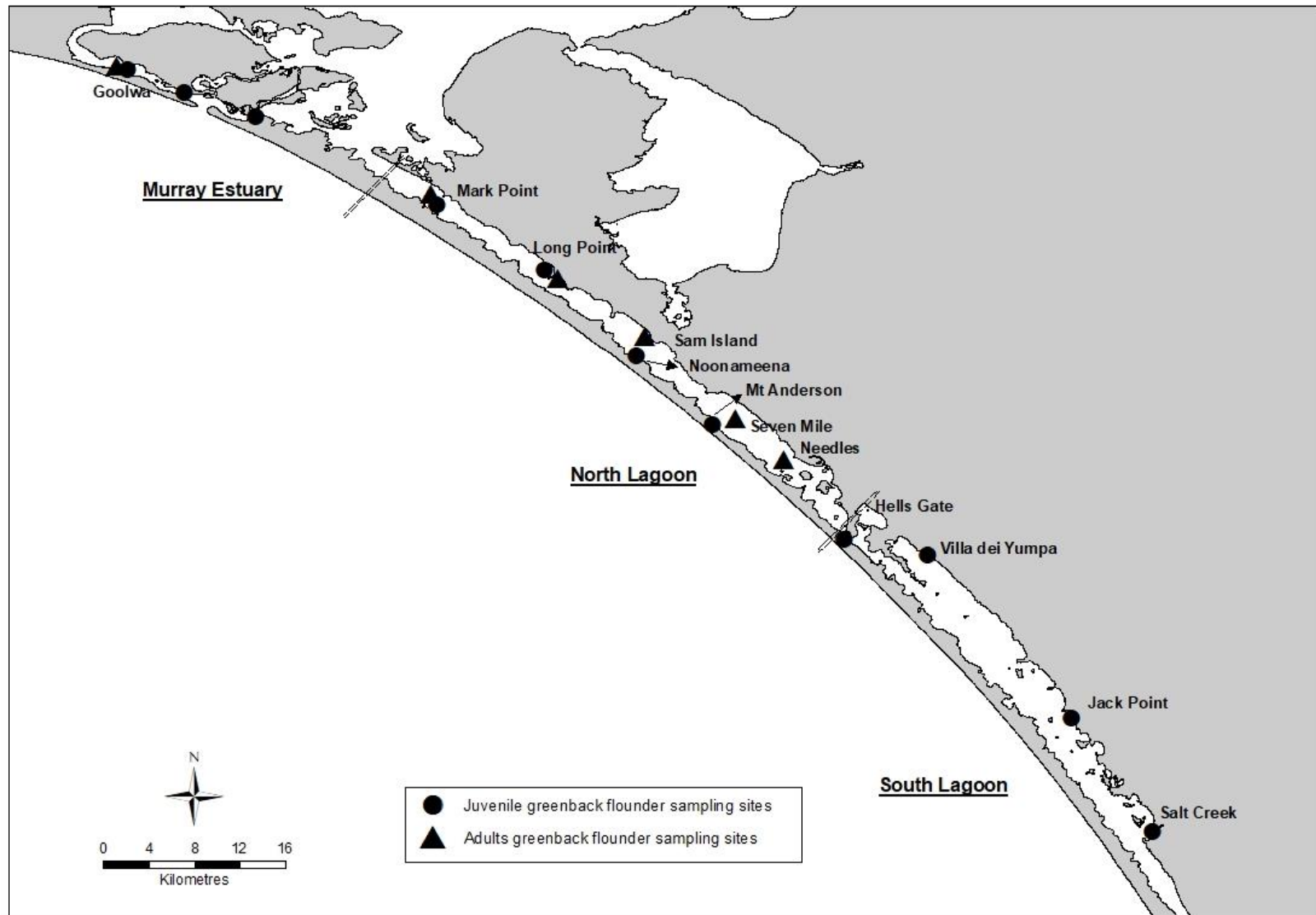


Figure 3.3. Condition monitoring sampling sites for adult and juvenile greenback flounder in the Coorong. Adult greenback flounder sampling sites represent commercial fishery sampling sites.

### 3.4. Recruitment

#### 3.4.1. Sampling

Additional sampling was carried out to quantify the abundance of juvenile black bream and greenback flounder, to assess annual recruitment of YOY. In late summer/autumn (February–April) from 2008/09–2019/20, sampling was conducted to target YOY black bream at four regular sites (i.e. two below the Goolwa Barrage, one in Boundary Creek and one below Mundoo Barrage) using single-wing fyke nets ( $n = 1–3$  trips per year) (Figure 3.2). In most years, exploratory sampling was also conducted at other sites (e.g. Beacon 19, Swan Point, Godfrey's Landing, Ewe Island, Cattle Point, Mark Point and Long Point) to determine the distribution of juveniles. The single-wing fyke nets were 8.6 m long (3 m wing plus 5.6 m funnel) with a mesh size of 8 mm and a hoop diameter of 0.6 m. On most sampling occasions, eight fyke nets were set overnight at each site. A summary of sampling effort for juvenile black bream is presented in Appendix A.

Greenback flounder juvenile sampling was conducted at 7–9 sites along the length of the Coorong (Figure 3.3). During spring–summer from 2008/09–2019/20, sampling was conducted using standard (large) seine net hauls/shots ( $n = 1–3$  trips per year) (Figure 3.2). The seine net was 61 m long and consisted of two 29 m-long wings (22 mm mesh) and a 3 m-long bunt (8 mm mesh). It was deployed in a semi-circle, sampled to a maximum depth of 2 m and swept an area of about 592 m<sup>2</sup> per shot. A standardised sampling regime comprising three replicate shots was conducted at each site. A summary of sampling effort for juvenile greenback flounder is presented in Appendix B.

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

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

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

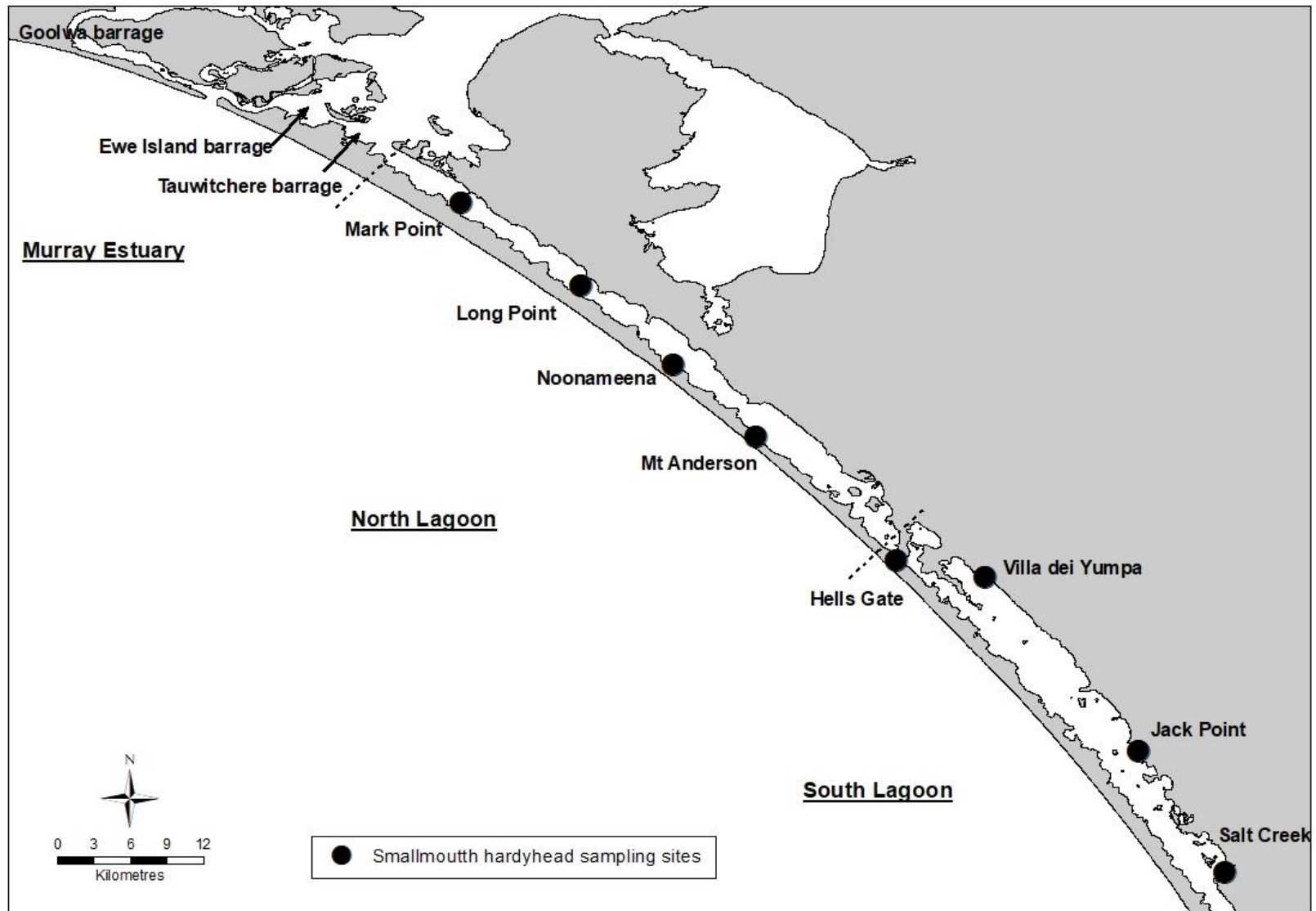


Figure 3.4. Condition monitoring sampling sites for smallmouth hardyhead in the Coorong.

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

**Table 3.1. List of sampling sites, species targeted, and sampling gear used for fishery-independent sampling during the Coorong fish condition monitoring from 2008/09–2019/20. Both seine nets = large and small seine nets.**

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

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

### 3.4.2. Analysis

Estimates of CPUE (fish.net night<sup>-1</sup>) of YOY black bream were analysed to compare recruitment through time, using fyke net data collected at the four regular sites. To determine the distribution of YOY, data collected from exploratory sampling sites were also included. The reduced sampling

effort, in 2014/15 and 2015/16, limited the capacity for assessing distribution. During this time, there was no/little additional sampling other than fyke netting at the regular sites (Appendix A).

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

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

For black bream and greenback flounder, YOY abundance and distribution provided an indication of the level of recruitment in the sampling year. In addition, age structures of fishery catches were analysed to identify year class strength, suggesting strong recruitment in specific years, although it usually took 3–5 years for black bream and 1–2 years for greenback flounder to recruit to the Coorong fisheries (Ye *et al.* 2020c).



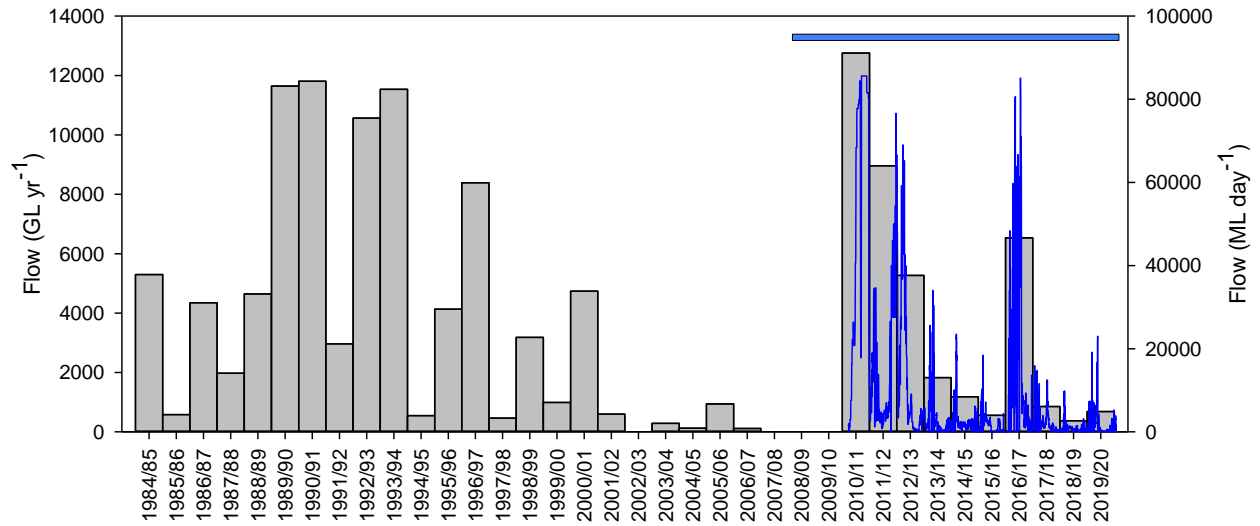
## 4. RESULTS

### 4.1. Freshwater flow

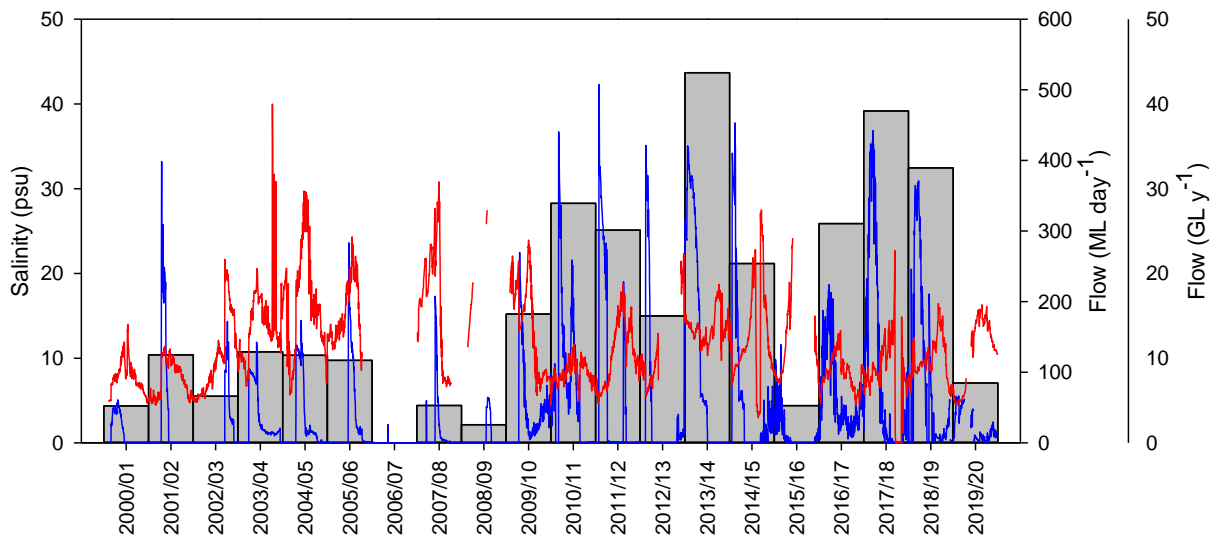
From 1984/85–2019/20, freshwater flow from the River Murray to the Coorong fluctuated substantially. Annual discharge was >4,000 GL in nine out of the 17 years between 1984/85 and 2000/01 (Figure 4.1). During the drought (2001–2010), the mean annual barrage discharge was 229 GL, with no freshwater released from 2007/08–2009/10. After September 2010, significant flow increases in the MDB led to substantial barrage releases, with an annual discharge of ~12,800 GL in 2010/11. Flow decreased in the subsequent five years, however, in 2016/17, flooding in the MDB resulted in a 10-fold increase in barrage discharge to ~6,500 GL compared to 2015/16. Over the last three dry years, annual barrage flows ranged between 337 and 850 GL, almost entirely supported by the delivery of water for the environment. Daily discharge was highly variable with peaks occurring at different times (i.e. seasons) in different years. During 2019/20, daily flow was highest (23,004 ML) around late October 2019.

Similarly, freshwater flows from Salt Creek into the South Lagoon were highly variable among years from 2000/01 to 2019/20 (Figure 4.2). Annual discharges were generally low between 2000/01 and 2009/10 (mean 7.3 GL), and increased substantially thereafter (mean 24.2 GL), with the exception of 2015/16 and 2019/20 when annual discharges were 4.4 GL and 7.1 GL, respectively. Freshwater flows were highly seasonal in most years, with peak discharges occurring from July to October (winter–spring). Salinity in Salt Creek was also variable and seasonal, ranging between 0 and 27.5 psu from 2010 onwards.

For this 12-year study, based on the freshwater flows from the River Murray to the Coorong, 2008/09 and 2009/10 are defined as drought years, whereas 2010/11–2019/20 are defined as post-drought years. Within the post-drought period, 2010/11 was a flood year; 2011/12 and 2016/17 were high flow years; 2012/13 was a moderate flow year; and 2013/14–2015/16 and 2017/18–2019/20 were low flow years.



**Figure 4.1.** Annual (grey bar) and daily (blue line) freshwater flows across the barrages from July 1984 to June 2020 (sources: MDBA and DEW). 1984 refers to start of the 1984/85 financial year, i.e. 1<sup>st</sup> July 1984. Blue bar indicates the years when fish condition monitoring was conducted.



**Figure 4.2.** Annual (grey bar) and daily (blue line) discharge through the Salt Creek outlet, with salinity levels (red line) from July 2000 to June 2020 (DEW 2020, Water Connect website, Station A2390568). 2000 refers to start of the 2000/01 financial year, i.e. 1<sup>st</sup> July 2000.

## 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 12-year monitoring period was 18, 42 and 96 psu in the Murray Estuary and North and South lagoons, respectively (Table 4.1 and Figure 4.3). Noticeable salinity reduction occurred at all sites/sub-regions in post-drought years from 2010/11 to 2014/15 and in 2016/17–2017/18. In the drought years (2008/09–2009/10), mean salinities were 41 psu in the Murray Estuary, 75 psu in the North Lagoon and 144 psu in the South Lagoon. Mean salinities during the flood/high flow years (2010/11, 2011/12 and 2016/17) were 5 psu in the Murray Estuary, 31 psu in the North Lagoon and 83 psu in the South Lagoon; whereas in the low flow years (2013/14–2015/16 and 2017/18–2019/20), they were 23 psu in the Murray Estuary, 44 psu in the North Lagoon and 92 psu in the South Lagoon.

Conversely, water transparency remained lowest and generally stable in the South Lagoon (Secchi disc depth mostly <0.6 m), compared to the Murray Estuary and North Lagoon in all years, except for 2010/11 and 2016/17 (Figure 4.3). In the Murray Estuary and North Lagoon, water transparency increased during the drought and low flow years and decreased considerably in flood and high flow years.

**Table 4.1. Mean salinity across Coorong sub-regions during the last 12 years of monitoring (2008/09 – 2019/20). Highlighted cells show annual mean salinity  $\leq$  long term mean for the sub-region.**

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

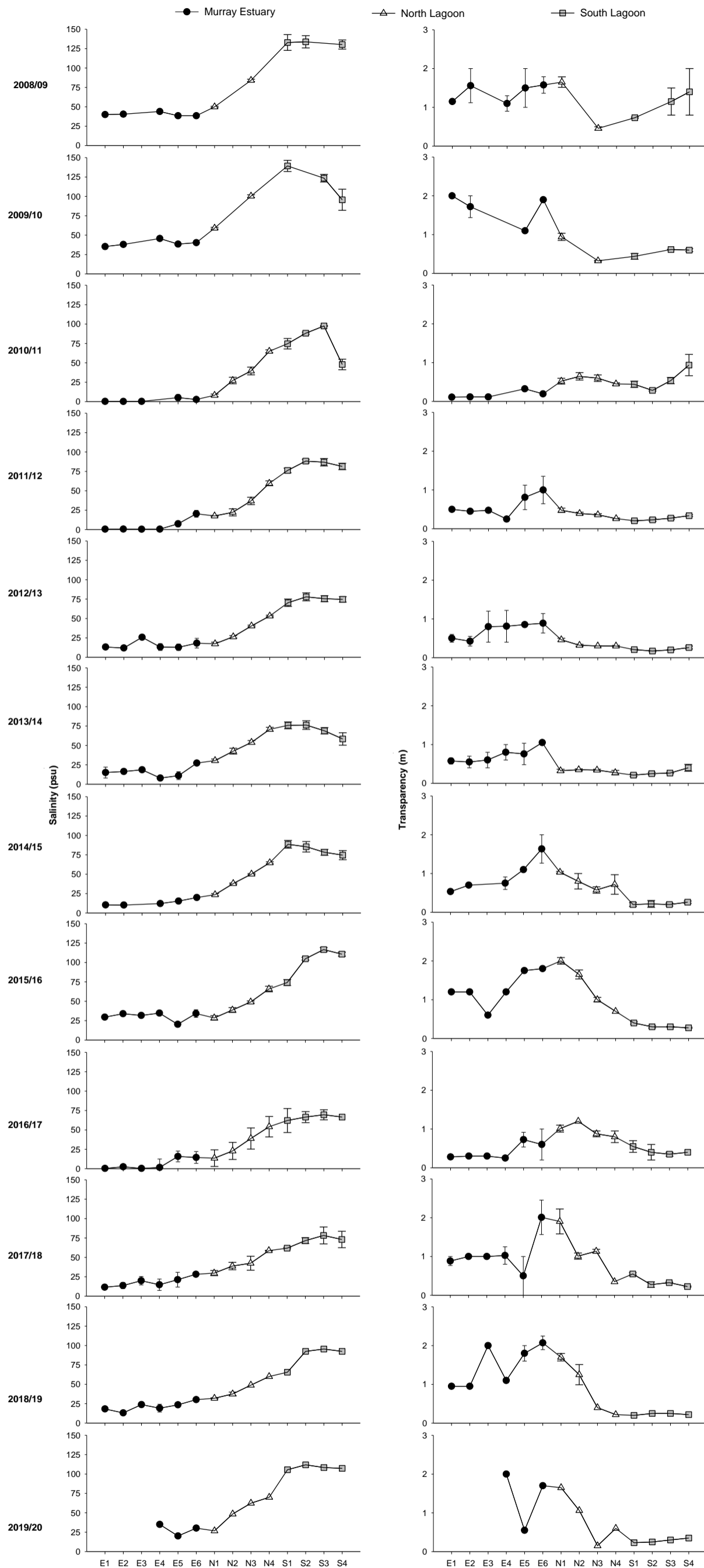
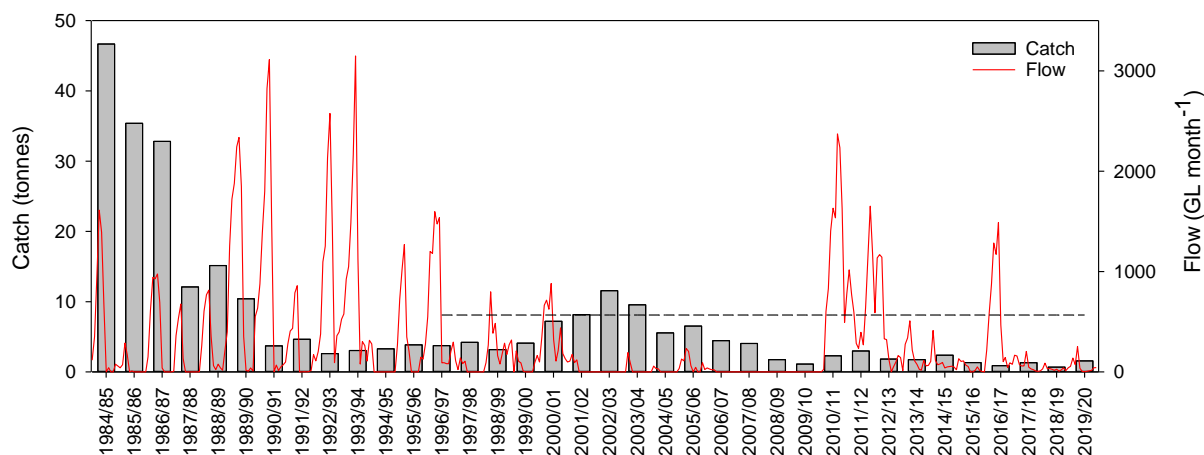


Figure 4.3. Mean values  $\pm$  S.E. of salinity (psu) (left) and transparency (secchi disc depth, m) (right) over the core sampling period (January–March) at each sampling site (data from all sampling occasions pooled) in the Coorong between 2008/09 and 2019/20. See Table 3.1 for site code.

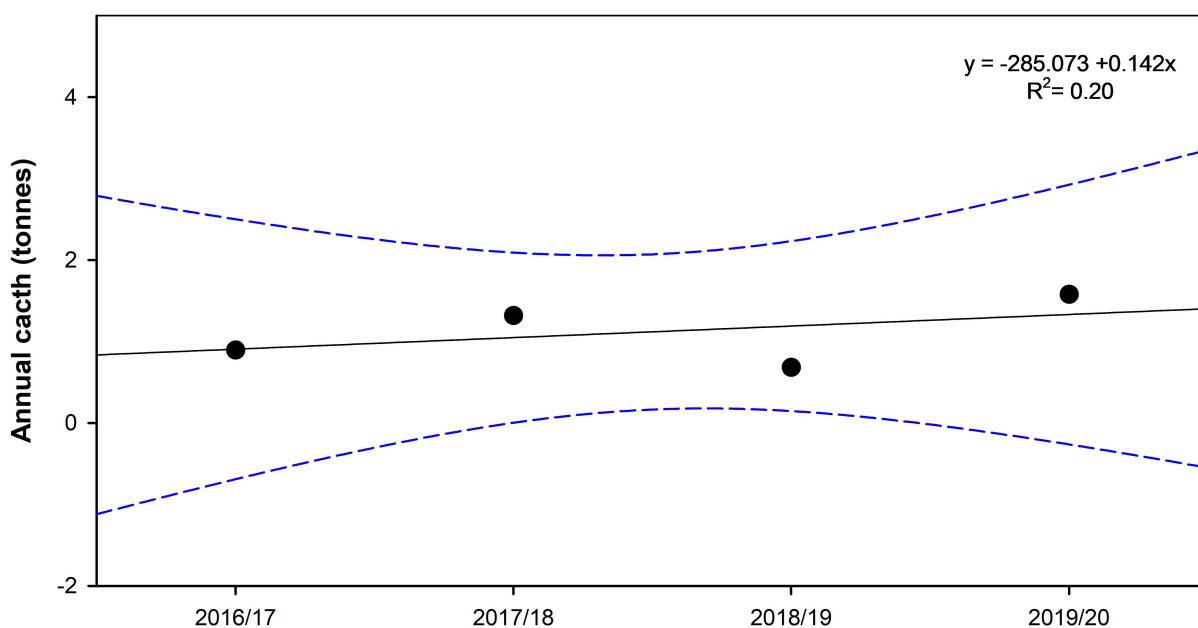
### 4.3. Black bream

#### 4.3.1. Relative abundance (fishery catch)

The annual catch of black bream was less than 3 t in all years of this study (2008/09–2019/20) (Figure 4.4). The catch in 2019/20 was 1.6 t, which was more than double the 2018/19 catch, however it remained considerably below the ecological target of 8 t (20%). The annual catch of the last 4-year period showed a positive trend, suggesting a general increase in the population abundance/biomass from 2016/17 to 2019/20 (Figure 4.5).



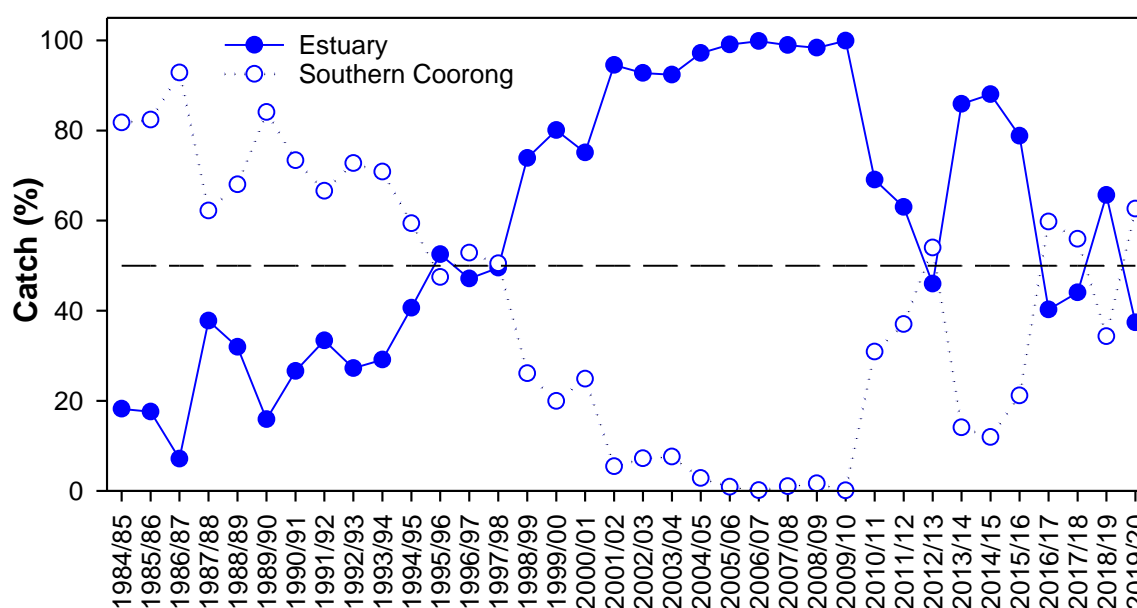
**Figure 4.4.** Annual commercial catch of black bream from the Coorong between 1984/85 and 2019/20. The redline represents modelled monthly flow discharge to the Coorong (GL month<sup>-1</sup>) between July 1984 and June 2019 (Data source: MDBA). Dotted black line represents the target value based on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



**Figure 4.5.** Trend in the black bream catches over four years (2016/17–2019/20). 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 36 years (Figure 4.6). Prior to the mid-1990s, the majority of black bream catches were from the southern Coorong (south of Mark Point), whereas during the Millennium Drought (2001–2010), >90% of the catch came from the Estuary (north of Mark Point). Following the substantially increased barrage flows from 2010/11–2012/13, the proportional catch from the southern Coorong gradually increased, reaching 54% in 2012/13. In the following seven years, this proportion was >50% only in 2016/17, 2017/18 and 2019/20 (e.g. 63% in 2019/20).



**Figure 4.6. Black bream commercial fishery catches from different areas (proportional catches from the north (Estuary) vs the south of Mark Point in the Coorong (Southern Coorong)) between 1984/85 and 2019/20. Dashed black line indicates 50%.**

### 4.3.3. Age structure

From 2008/09 to 2019/20, black bream sampled from commercial fishery catches ranged in age from 2 to 32 years, although most fish were <10 years old (Figure 4.7). In 2008/09 and 2009/10, fish >10 years old were more abundant (30% and 36%, respectively).

The time-series of annual age structures in the last 12 years indicated several relatively strong cohorts (i.e.  $\geq 15\%$  of the sampled population) of black bream present in the Coorong, mostly with one or two strong cohorts in each year. In the first three years, the strongest cohort was the 2003/04 year class. This cohort was present as 5 year olds in 2008/09, and persisted as 6 and 7 year olds in 2009/10 and 2010/11, respectively. The

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

In 2011/12, another strong cohort (i.e. 2006/07) of 5 year olds appeared, which remained the most dominant in the following five years. A moderate cohort (i.e. 2009/10) of 4 year olds was observed in 2013/14, which persisted as 5, 6 and 8 year olds in 2014/15, 2015/16 and 2017/18, respectively. In 2016/17, a 2012/13 cohort became distinct as 4 year olds in the age structure, along with the dominant 2006/07 cohort as 10 year old fish. The 2012/13 cohort dominated the age structure as 5 year olds in 2017/18, although this cohort was not apparent in later years.

In 2018/19, the age structure was evenly distributed with 73% of fish ranging between 3 and 6 year olds. In 2019/20, the black bream age structure was dominated by the 2016/17 and 2015/16 cohorts (3 and 4 year olds, respectively), whilst the 2006/07 cohort was still distinct in the age structure, as 13 year olds.

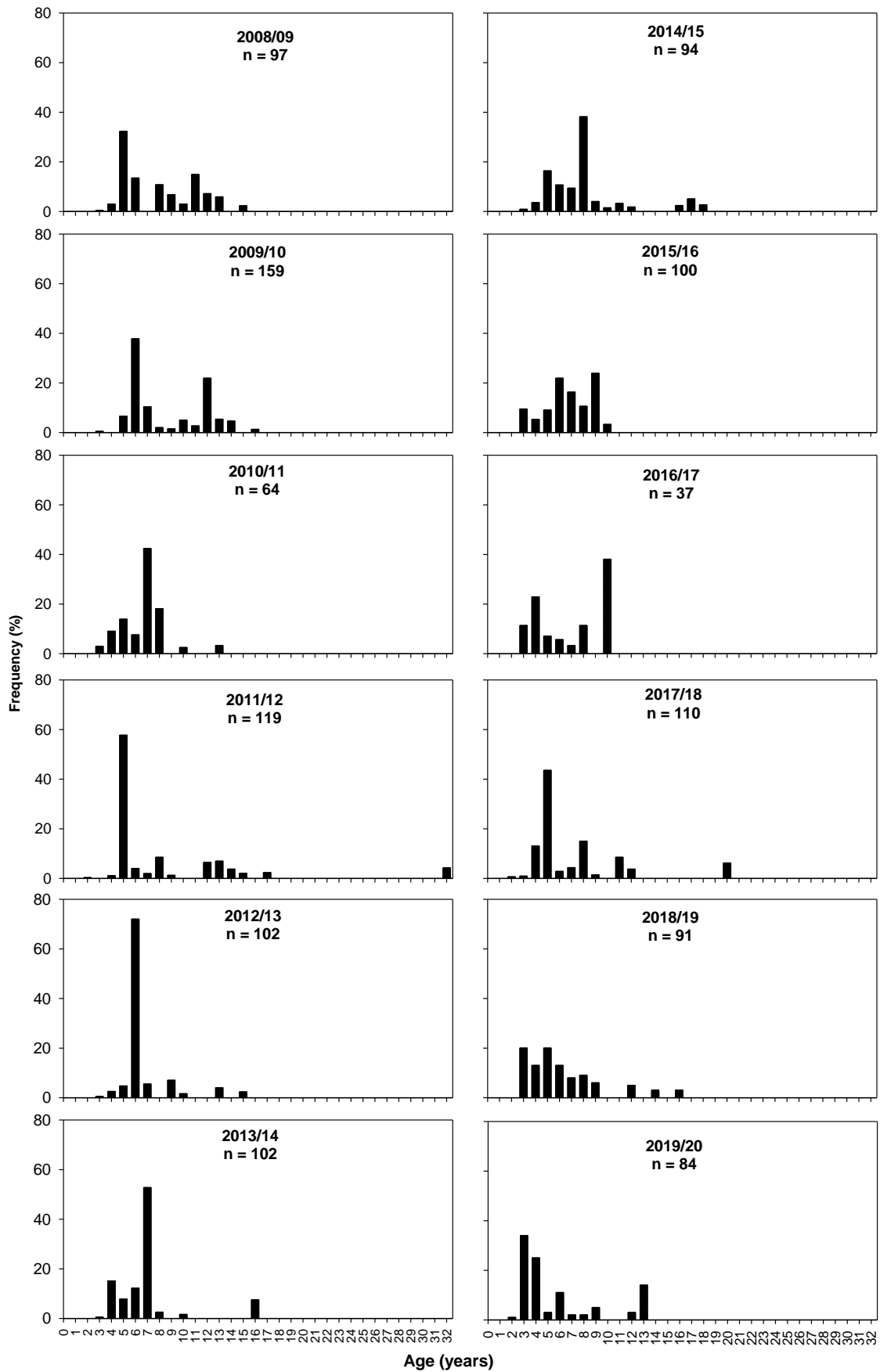


Figure 4.7. Age structure of black bream from the Coorong from 2008/09 to 2019/20 (commercial fishery samples).



#### **4.3.4. Recruitment**

Relative abundance (fyke net CPUE, fish.net night<sup>-1</sup>) of black bream YOY generally remained low and varied across sampling sites in the Coorong over the last 12 years (2008/09–2019/20) (Table 4.1). Mean CPUE across the regular sites declined from 2.03 fish.net.night<sup>-1</sup> in 2008/09 to 0.86 fish.net.night<sup>-1</sup> in 2012/13, and no YOY were caught in 2014/15, 2016/17, 2018/19 and 2019/20. Notably, in 2017/18 relative abundance of YOY was the highest of all years (2.06 fish.net.night<sup>-1</sup>). Black bream YOY were collected in >50% of the sites only in 2008/09 and 2017/18, although in the earlier year, sampling was generally restricted within the Murray Estuary.

#### **4.3.5. Condition assessment**

Based on the above analyses of indicators and indices against ecological targets (reference points), scores were assigned to each indicator and a total score of population condition was calculated for black bream in each year (Table 4.2). In 10 out of the 12 years, the black bream population condition in the Coorong, was 'extremely poor', 'very poor' or 'poor'. In 2017/18, the condition improved to 'moderate', when there was a substantial increase in abundance and distribution of YOY. In 2019/20, the population condition was also 'moderate', reflected by an increasing trend in population abundance/biomass, >50% of commercial catch from the southern Coorong and the presence of two strong, recently recruited cohorts (2016/17 and 2015/16).

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

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

**Table 4.3. Condition assessment for black bream populations in the Coorong from 2008/09 to 2019/20. 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.**

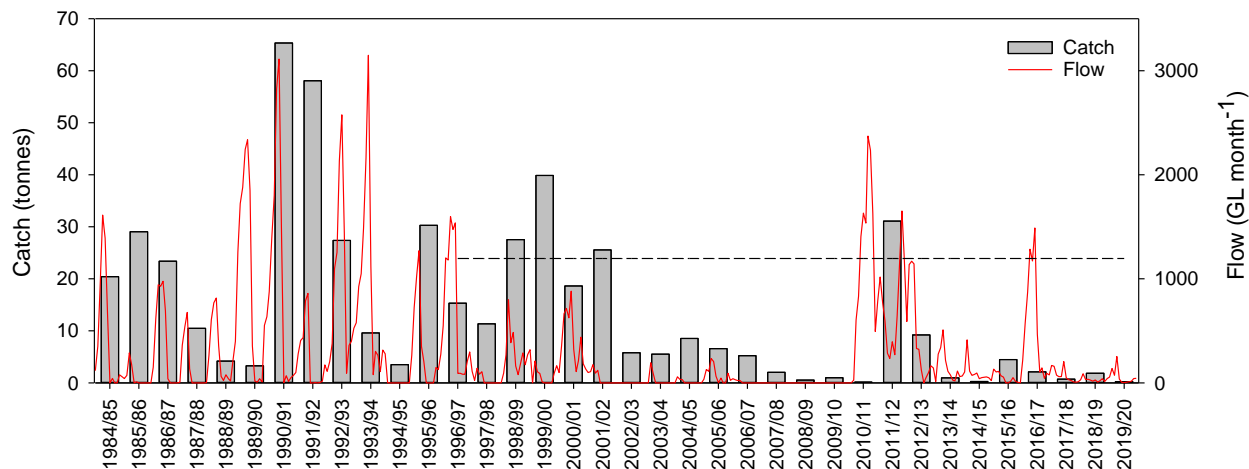
Population Indicator	Indices	Condition Assessment												Ecological Target (Reference Point)
		2008/09 Drought	2009/10 Drought	2010/11 Flood	2011/12 High flow	2012/13 Moderate flow	2013/14 Low flow	2014/15 Low flow	2015/16 Low flow	2016/17 High flow	2017/18 Low flow	2018/19 Low flow	2019/20 Low flow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

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

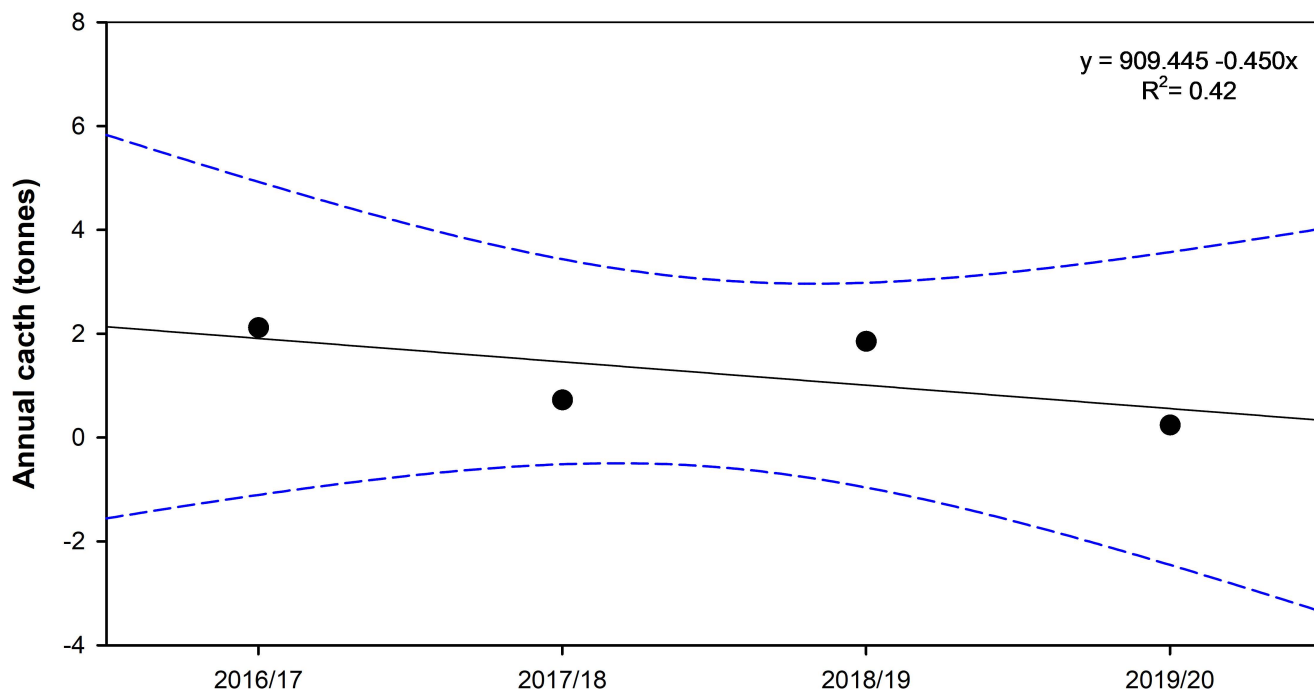
## 4.4. Greenback flounder

### 4.4.1. Relative abundance (fishery catch)

The annual catch of greenback flounder was below the ecological target ( $\geq 24 \text{ t y}^{-1}$ ) in all study years, except 2011/12 (Figure 4.8). The high catch in 2011/12 (31 t) indicated an increase in relative abundance following high flows in 2010/11 and 2011/12. Catches, however, decreased in the following three years. Despite a slight increase to 3.5 t in 2015/16, the catches remained  $\leq 2.1 \text{ t y}^{-1}$  over the following four years, with the catch in 2019/20 being the lowest (0.2 t) among historical records. Additionally, the annual catches of the last 4-year period showed a negative trend, suggesting a general decrease in the population abundance/biomass from 2016/17 to 2019/20 (Figure 4.9).



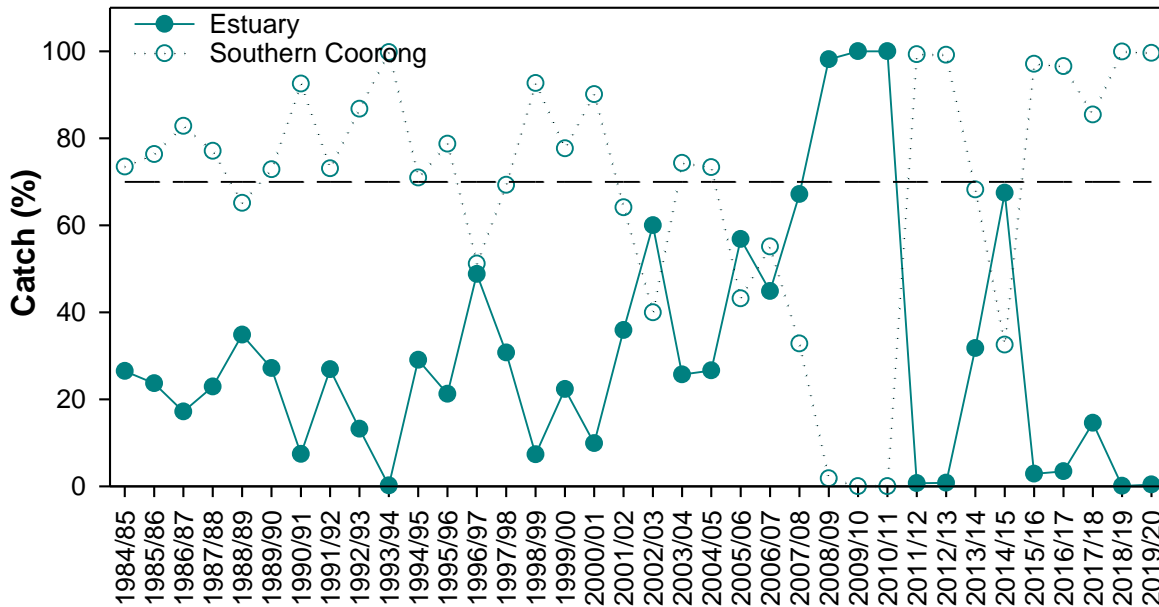
**Figure 4.8. Annual commercial catch of greenback flounder from the Coorong between 1984/85 and 2019/20. The red line represents modelled monthly flow discharge to the Coorong (GL/month) between July 1984 and June 2019 (Data source: MDBA). Dotted black line represents the target value based on the mean annual catch (24 t) between 1995/96 and 2001/02.**



**Figure 4.9. Trend in the greenback flounder catches over four years (2016/17–2019/20). 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 36 years (Figure 4.10). Prior to 2001, most of the catches were from the southern Coorong. During 2000/01–2010/11, there was an increase in the proportional catch from the Murray Estuary such that in 2009/10 and 2010/11, 100% of catches were from this sub-region. Following high flows from 20010/11–2011/12, fish from the southern Coorong again dominated the catch, whereas the proportional catches from the Murray Estuary increased in 2013/14 and 2014/15, associated with reduced flows. From 2015/16 onwards, the majority (~85–99%) of the catch was from the southern Coorong, thus meeting the ecological target (>70%).



**Figure 4.10. Greenback flounder commercial fishery catches from different areas (proportional catches from the north (Estuary) vs the south of Mark Point (southern Coorong)) in the Coorong between 1984/85 and 2019/20. Dashed black line indicates 70%.**

#### 4.4.3. Age structure

Greenback flounder, sampled from the commercial fishery between 2009–2020, ranged in age from 0 to 5 years, and most individuals caught in the Coorong were 1–3 years old (Figure 4.11). In all years, the age structure was dominated by 2 year olds except for 2011, 2015 and 2020.

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

Similarly, in 2015, the age structure was dominated by 1 year olds (i.e. 2014 cohort), which persisted as 2 and 3 years olds in 2016 and 2017, respectively, although the sample size was very low in 2016 ( $n = 8$ ). In 2020, a very strong cohort (> 95%) of 1 year olds was present. In all years, there was at least one cohort of age 0–2 years representing >40% in the fishery age structure, although only in 2014, 2017 and 2018 were there >20% of fish older than 2 years.

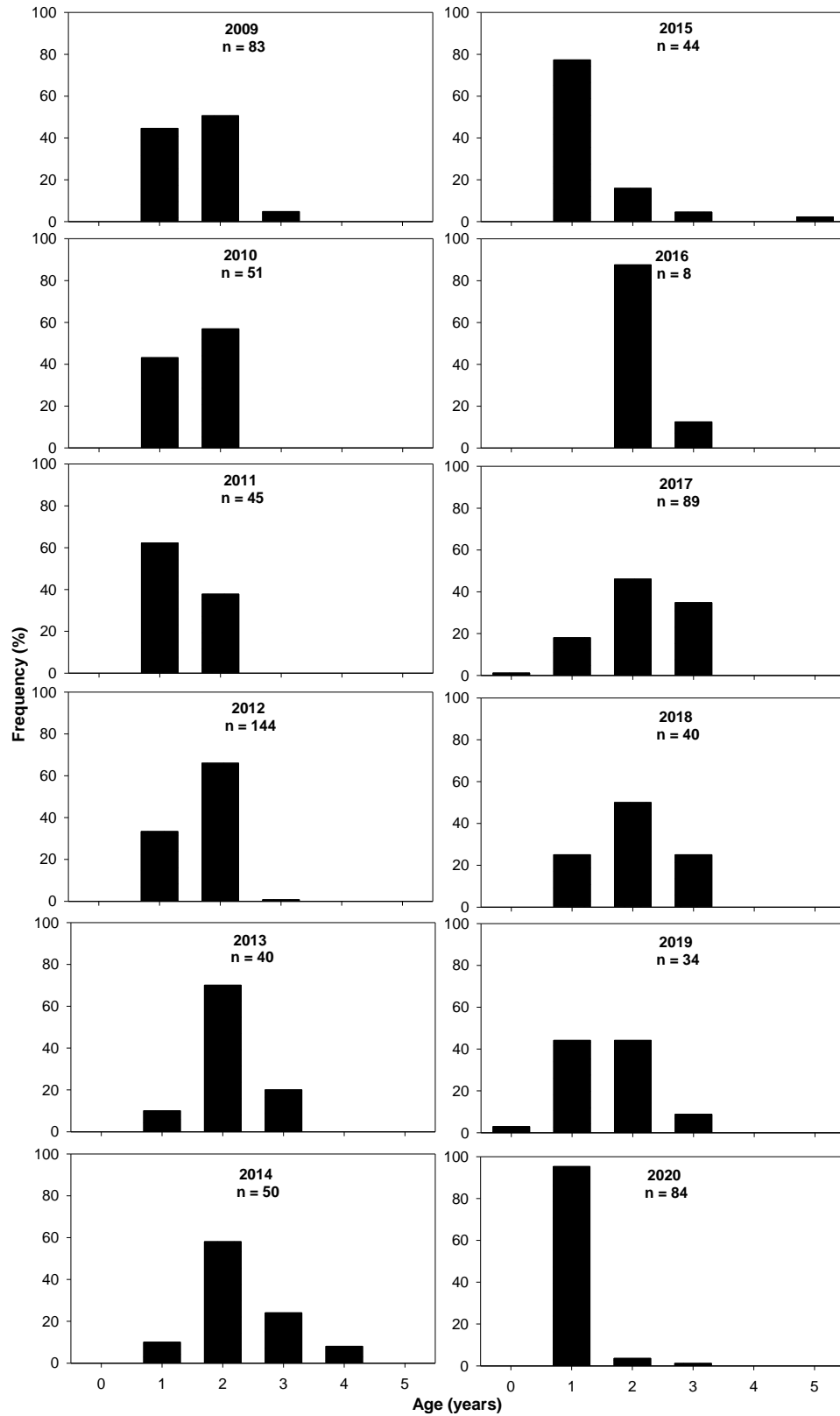


Figure 4.11. Age structure of greenback flounder from the Coorong from 2009 to 2020 (commercial fishery samples).

#### **4.4.4. Recruitment**

Relative abundance (CPUE, fish.seine net<sup>-1</sup>) of greenback flounder YOY varied across sampling sites in the Coorong over the last 12 years (2008/09–2019/20) (Table 4.4). Whilst CPUE of YOY appeared high during the drought years (2008/09–2009/10), the distribution of YOY was largely confined to the Murray Estuary. From 2010/11 to 2014/15 (post-drought years), the distribution of YOY expanded considerably into the South Lagoon, and mean CPUE showed an increasing trend from 2011/12 to 2014/15. However, in 2015/16, both abundance and distribution declined compared to previous years. Since then, mean CPUE across sampling sites has remained <1 fish.seine net<sup>-1</sup>, although the distribution appeared broader in 2016/17 and 2017/18 than the other two years. In 2019/20, the abundance of YOY was only ~30% of the target value (1.04 fish.seine net<sup>-1</sup>) and they were only present at 25% of the sites, in contrast to the target (>50%).

#### **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.



**Table 4.4. Relative abundance (CPUE, fish.seine net<sup>-1</sup>) of young-of-year greenback flounder at sampling sites within the Coorong from 2008/09 to 2019/20.**

CPUE (fish per seine net)	2008/09		2009/10		2010/11		2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		2018/19		2019/20	
<b>Regular sites</b>	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sugars Beach	10.8	3.1	27.7	8.8	0.7	0.4	2.9	1.1	0.4	0.2	6.1	2.4												
Beacon 19													1.1	0.0	0.0	0.0	0.8	0.6	1.3	1	0.0	0.0	0.3	0
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
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
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
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
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
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
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
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
<b>Mean across sites</b>	<b>4.2</b>	<b>2.7</b>	<b>4.7</b>	<b>3.9</b>	<b>1.2</b>	<b>0.6</b>	<b>0.7</b>	<b>0.3</b>	<b>1.0</b>	<b>0.7</b>	<b>1.5</b>	<b>0.7</b>	<b>2.1</b>	<b>1.5</b>	<b>0.5</b>	<b>0.3</b>	<b>0.2</b>	<b>0.1</b>	<b>1.0</b>	<b>0.3</b>	<b>0.5</b>	<b>0.3</b>	<b>0.3</b>	<b>0.2</b>
<b># Sites sampled</b>	<b>7</b>		<b>7</b>		<b>9</b>		<b>9</b>		<b>9</b>		<b>9</b>		<b>9</b>		<b>9</b>		<b>9</b>		<b>9</b>		<b>9</b>		<b>9</b>	
<b># Sites greenback flounder YOY present</b>																								
	<b>3</b>		<b>3</b>		<b>5</b>		<b>6</b>		<b>6</b>		<b>6</b>		<b>6</b>		<b>4</b>		<b>6</b>		<b>7</b>		<b>3</b>		<b>3</b>	
<b>% of site YOY present</b>																								
	<b>43%</b>		<b>43%</b>		<b>56%</b>		<b>67%</b>		<b>67%</b>		<b>67%</b>		<b>67%</b>		<b>44%</b>		<b>67%</b>		<b>78%</b>		<b>33%</b>		<b>33%</b>	

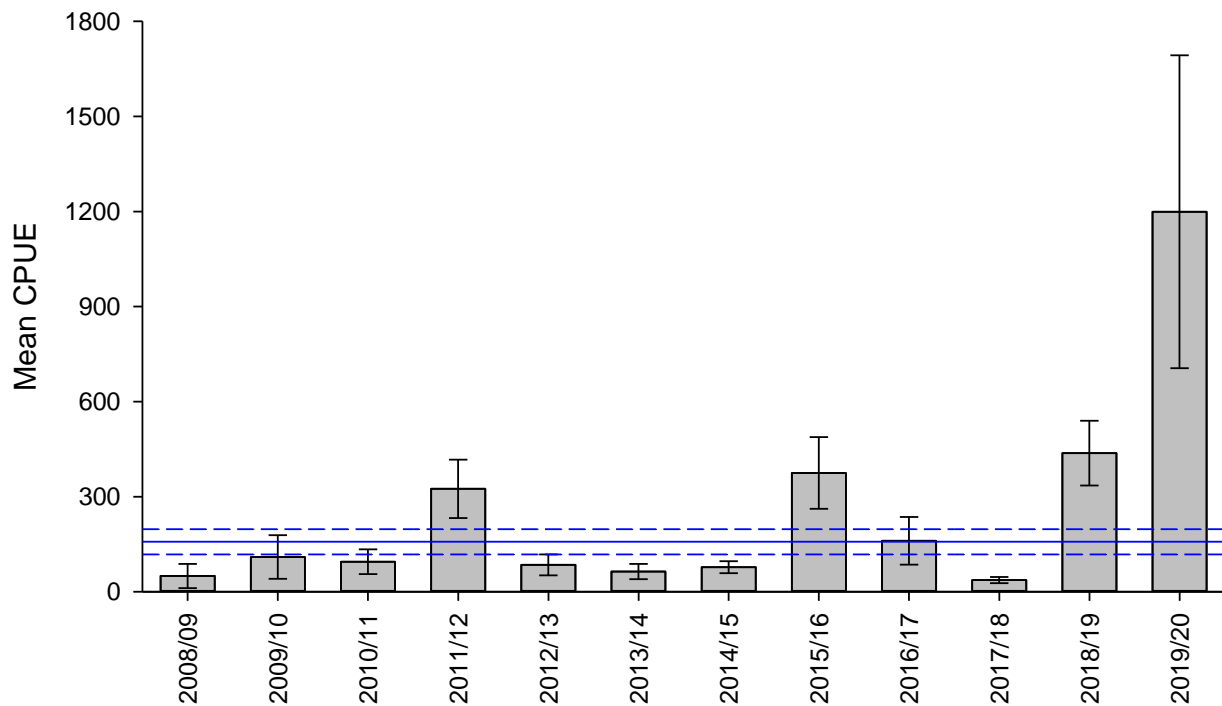
**Table 4.5. Condition assessment for greenback flounder population in the Coorong from 2008/09 to 2019/20. Please note, age composition was based on calendar year. Rule of scoring: each indicator receives 1 point if indices meet the following requirements: (1) Relative abundance – one of the indices 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 (Reference Point)
		2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	
		Drought	Drought	Flood	High flow	Moderate flow	Low flow	Low flow	Low flow	High flow	Low flow	Low flow	Low flow	
Relative abundance	Annual catch	No	No	No	Yes	No	No	No	No	No	No	No	No	≥24 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	Yes	No	No	No	Positive (slope)
	Score	0	0	0	1	1	0	0	0	1	0	0	0	
Distribution	% catch	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	>70% from southern part
	Score	0	0	0	1	1	1	0	1	1	1	1	1	
Age structure	A very strong cohort	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	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	≥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	
Recruitment	YOY CPUE	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	>1.04 fish.seine net <sup>-1</sup>
	YOY distribution	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	>50% sites
	Score	0	0	1	0	0	1	1	0	0	0	0	0	
Icon site total score		0	0	2	3	3	3	2	2	3	2	1	2	
Greenback flounder condition		Extremely poor	Extremely poor	Poor	Moderate	Moderate	Moderate	Poor	Poor	Moderate	Poor	Very Poor	Poor	

## 4.5. Smallmouth hardyhead

### 4.5.1. Relative abundance

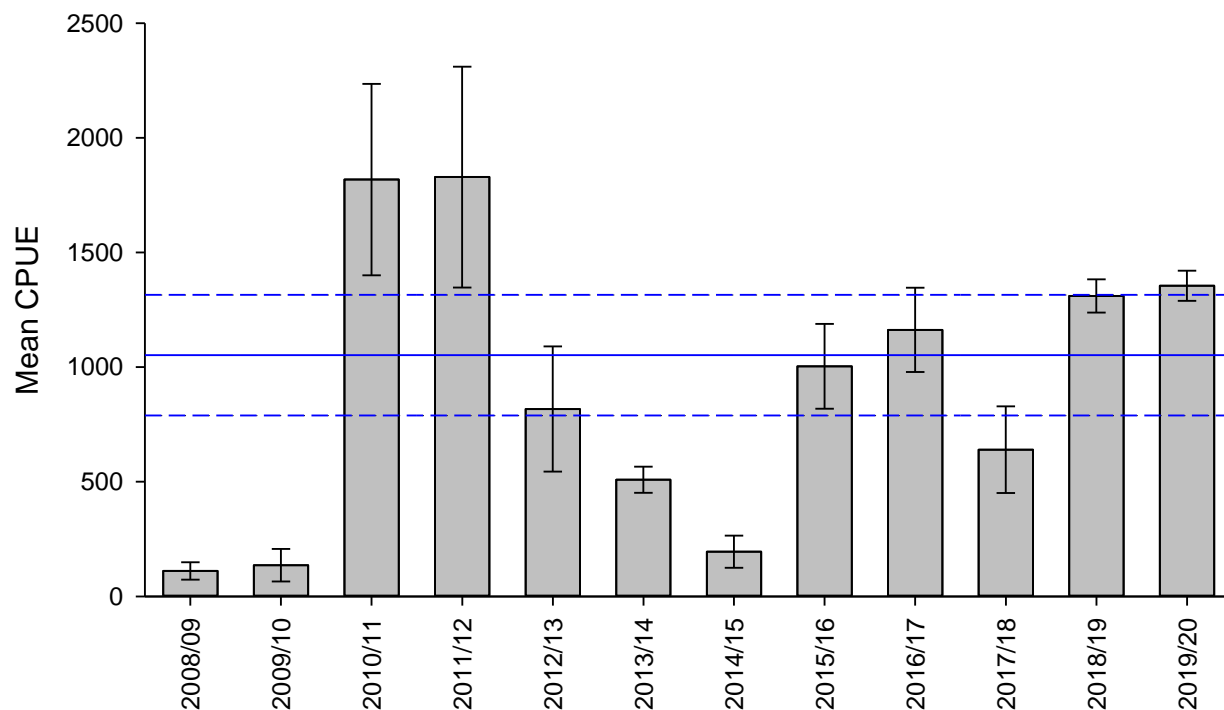
Relative abundance of adult smallmouth hardyhead in the Coorong varied over the last 12 years (Figure 4.12). The mean CPUE was above the ecological target value (120 fish.UE<sup>-1</sup>) in five of the 12 years (i.e. 2011/12, 2015/16, 2016/17, 2018/19 and 2019/20). See Appendix D for more detailed information on adult CPUE by sampling site. 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.



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

#### 4.5.2. Recruitment

Relative abundance of new recruits (smallmouth hardyhead <40 mm TL) showed a rapid response to the 2010/11 flood, with significant increases in January/February 2011 and 2012 (Figure 4.13). Abundance declined over the next three years from 817 fish.UE<sup>-1</sup> in 2012/13 to 195 fish.UE<sup>-1</sup> 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<sup>-1</sup> in 2016/17. Following a decrease in 2017/18, it increased again in 2018/19 and 2019/20 (>1,355 fish.UE<sup>-1</sup>) to above the ecological target (800 fish.UE<sup>-1</sup>). More detailed information on new recruit CPUE by sampling site is presented in Appendix E.



**Figure 4.13. Mean seine net catch per unit effort (CPUE)  $\pm$  SE of smallmouth hardyhead new recruits (late summer/autumn; <40 mm TL) in the Coorong from 2008/09 to 2019/20. Note: Reference point (solid blue line) is established using the mean CPUE from 2011/12–2013/14. Confidence intervals are  $\pm$  25% (dashed blue lines with the lower line set as the ecological target >800 fish.UE<sup>-1</sup>). 2014/15 value is based on large seine net data only.**

### **4.5.3. Extent of recruitment**

In 2008/09 and 2009/10, only 20% of sites showed significant recruitment (i.e. having >60% of fish being new recruits) (Table 4.5). In contrast, the proportion of sites showing significant recruitment substantially increased in the post-drought years, and the ecological target (of >75% of sites with significant recruitment) was met in six years of these years (i.e. 2010/11–2013/14 and 2016/17–2017/18), which all followed high flows. In 2018/19 and 2019/20 with continued low flows, 75% and 63% of the sites, respectively, had significant recruitment, not meeting the ecological target. 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 new recruit abundance, whereas data from February/March instead of November/December that was used in 2015/16, 2018/19 and 2019/20 may have over-estimated adult abundance, thus leading to the potential under-estimation of the extent of recruitment.

### **4.5.4. Distribution**

The presence of smallmouth hardyhead adults and new recruits across sampling sites was used as an indication of their distribution across the Coorong from 2008/09 to 2019/20 (Table 4.6). In 2008/09 and 2009/10, new recruits and adults were present in no more than 60% of the sites, which failed to meet the ecological target for distribution (>87% sites). Since 2010/11, new recruits have been present across all sampling sites (100%) and adults at most sites (88%–100%) (except for 2010/11), meeting the ecological target (>87% sites).

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

**Table 4.7. Distribution of smallmouth hardyhead adults and new recruits from 2008/09 to 2019/20 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
# Sites sampled	5	5	8	8	8	8	8	8	8	8	8	8
# Sites smallmouth hardyhead new recruits present	2	3	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
<b>% of site new recruits present</b>	<b>40%</b>	<b>60%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>
<b>% of site adults present</b>	<b>60%</b>	<b>80%</b>	<b>75%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>88%</b>	<b>100%</b>	<b>100%</b>

#### **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'. Since 2013/14, the population condition has remained 'moderate', including in 2019/20, except for 2014/15 when the condition was 'poor' and 2016/17 when the condition improved to 'very good' following high flows.

**Table 4.8. Condition assessment for smallmouth hardyhead populations in the Coorong from 2008/09 to 2019/20. 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	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	
	Drought	Drought	Flood	High flow	Moderate flow	Low flow	Low flow	Low flow	High flow	Low flow	Low flow	Low flow	
<b>Relative abundance</b> CPUE of adults	No	No	No	Yes	No	No	No	*	Yes	No	*	*	CPUE >120 fish.UE <sup>-1</sup>
<b>Recruitment</b> CPUE of juveniles	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	CPUE >800 fish.UE <sup>-1</sup>
Extent of recruitment	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	>75% sites with >60% juveniles
<b>Distribution</b> Adults	No	No	No	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	
<b>Icon site score</b>	<b>0</b>	<b>0</b>	<b>3</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>	<b>3</b>	<b>5</b>	<b>3</b>	<b>3</b>	<b>3</b>	
<b>Smallmouth hardyhead condition</b>	<b>Extremely Poor</b>	<b>Extremely Poor</b>	<b>Moderate</b>	<b>Very Good</b>	<b>Good</b>	<b>Moderate</b>	<b>Poor</b>	<b>Moderate</b>	<b>Very Good</b>	<b>Moderate</b>	<b>Moderate</b>	<b>Moderate</b>	

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



## 5. DISCUSSION

### 5.1. Freshwater flow

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

Over the last 12 years of monitoring, barrage flows were highly variable, including two years (2008/09 and 2009/10) of drought, followed by moderate–high flows in 2010/11–2012/13, and subsequent low flows until 2019/20, except for a high flow year in 2016/17. During low flow years, water for the environment plays a significant role in maintaining barrage flows and connectivity, increasing salt export out of the MDB, reducing salt import to the Coorong, and thus maintaining estuarine habitat and biodiversity in the Coorong (Ye *et al.* 2020a). In 2018/19 and 2019/20, barrage flows were 377 GL and 685 GL, respectively, entirely (100%) comprised of Commonwealth environmental water (Ye *et al.* 2021). Monthly inflows were highly variable over the last 12 years, with peaks occurring at different seasons. In 2019/20, there was a winter flow pulse in August (up to ~19,000 ML d<sup>-1</sup>) and a spring flow pulse in October (up to ~23,000 ML d<sup>-1</sup>), whereas barrage flows were generally <8,500 ML d<sup>-1</sup> in other months.

Salt Creek flows into the South Lagoon were also highly variable in the last 12 years, ranging between 4–44 GL y<sup>-1</sup>, with salinities ranging between 0–27.5 psu. Peak flows usually occurred during winter–spring. Inflows have shown to affect local salinities in the South Lagoon (e.g. Ye *et al.* 2011b; 2020b). In 2019/20, annual inflow (7.1 GL) was the third lowest among all monitoring years.

### 5.2. Water quality

Salinity has been highly variable in the Coorong, mainly influenced by inflows from the barrages and interplay with tides, driven by oceanic water-level fluctuations, and winds (Gibbs *et al.* 2018). The hydrology and geomorphology of the Coorong, however, also produces a salinity gradient, with salinity increasing from the Murray Estuary southeast to the South Lagoon, irrespective of freshwater inflow (Gibbs *et al.* 2018). During the drought (2008/09 and 2009/10), the lack of freshwater inflows led to a general increase in salinity throughout the Coorong, which ultimately

resulted in contraction and loss of a salinity gradient, from brackish to marine; and salinity in the South Lagoon increased to greater than four times that of seawater. Connectivity between estuarine and freshwater habitats was substantially reduced or lost due to barrage closure (e.g. 2007–early 2010) and continuous dredging was required to maintain opening of the Murray Mouth (i.e. estuarine–marine connectivity) (DEWNR 2015). Increased salinities and reduced connectivity had a pronounced impact on fish assemblages in the Coorong with generally reduced abundance and species diversity (Noell *et al.* 2009; Zampatti *et al.* 2010; Ye *et al.* 2012; 2016; Bice *et al.* 2018).

Post 2010, increased flows including delivery of water for the environment, reduced salinity substantially throughout the Coorong. The salinity gradient (freshwater–brackish–marine) was restored in the Murray Estuary and northern part of the North Lagoon and mean salinity was predominantly (80%) <100 psu in the South Lagoon. There were some increases in salinity during low flow years (e.g. 2015/16, 2019/20), but the levels were much lower across the system than during the drought years (2008/09 and 2009/10). Importantly, connectivity between freshwater, estuarine and marine environments was restored and has been maintained since late-2010. As a result, fish assemblages in the Coorong showed a general increase in species diversity, abundance and distribution, particularly for estuarine and diadromous species (Ye *et al.* 2012; 2016; 2020b; Bice *et al.* 2020). Similar fish responses were observed in 1983/84 when high flows post-drought reduced salinities to brackish (<30 psu) in the North Lagoon and moderately hypersaline (55–70 psu) in the South Lagoon (Geddes 1987).

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

### **5.3. Black bream**

As a solely estuarine species, black bream can complete its entire life-cycle within the Coorong estuary. Overall, the abundance, as indicated by commercial fishery catches, has declined substantially in the Coorong since 1984/85. The annual catches during the 12 years of this study (2008/09–2019/20) were less than 3 t, compared to the peak in 1984/85 (46.7 t). In 2019/20, the

catch remained low (1.6 t) at 20% of the ecological target (8 t), suggesting low abundance/biomass of black bream (legal size for fishery  $\geq 30$  cm TL) in the Coorong. The most recent fishery assessment classified the Coorong population as depleted (Earl and Bailleul 2021). Our monitoring indicated 'poor' to 'extremely poor' population conditions in all years except 2017/18 and 2019/20 ('moderate' condition). 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). Nevertheless, the current low catch was of a similar magnitude to those in years prior to the introduction of long-nosed fur seals.

Despite the low abundance, there was a trend of a slight increase in catches over the last four years, and in three of these years (including 2019/20), >50% of the catch came from the southern Coorong. The positive trajectory in catch and increased distribution may be attributed to habitat improvement across the Coorong following 2016/17 high inflows with additional support of water for the environment particularly in subsequent dry years (2017/18 to 2019/20) (Ye *et al.* 2021). Freshwater flow plays a pivotal role in maintaining suitable salinities and extending favourable estuarine habitat for black bream in the Coorong. This was well demonstrated by the contraction of fishing area to the Murray Estuary sub-region during the Millennium Drought (2001/02 to 2009/10) when there was a lack of freshwater inflow and substantially increased salinities in the Coorong, and the expansion of fishery catch in the southern Coorong during high flow periods (e.g. 1989/90 to 1992/93). An acoustic tagging study, examining the movement and habitat use of black bream in the Coorong, also showed an increased distributional range of this species during 2011/12 (high flow) compared to 2009/10 (drought) (SARDI unpublished data). The fish intervention monitoring in the Coorong also found an increased distribution of black bream into the South Lagoon during 2011/12–2013/14 (Ye *et al.* 2015a).

The age structures of black bream samples from the commercial catches between 2008/09 and 2019/20 indicated episodic recruitment of this species in the Coorong. Several moderate to strong cohorts were identified, mostly corresponding to fish originating from spawning in low to moderate flow years (e.g. 1997/98, 2003/04, 2006/07, 2012/13 and 2015/16). The 2012/13 and 2015/16 cohorts were also detected as YOY during the Coorong Fish Condition Monitoring starting in 2008/09 (see Section 4.3.4). The results suggest that the recruitment of black bream may be benefited by small-scale barrage releases in this modified Coorong estuary, post river regulation. Indeed, this was further supported by the strong recruitment of black bream YOY in 2017/18 (a hydrologically dry year), facilitated by low to moderate barrage flows (up to 12,000 ML d<sup>-1</sup>) made

up predominantly of water for the environment to the Coorong during spring–summer (Ye *et al.* 2019a). Such inflows during the months prior to and during the spawning season of black bream (spring to summer) may have benefited recruitment by: (1) attracting spawning aggregations of black bream, which could be important given the low biomass in this region; and (2) providing favourable habitat by influencing salinity gradients (i.e. salt wedge conditions) and increasing biological productivity (i.e. food availability) in the Coorong, which could increase survival and growth in the early life stages (eggs, larvae and juveniles) and ultimately lead to recruitment success.

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

Interestingly, in 2019/20, the age structure of the commercial catches of black bream showed a new distinct cohort of 3 year olds, which was generated from spawning events in 2016/17, a high flow year. During this year, no black bream YOY were detected in the Coorong, suggesting that the 2016/17 cohort could have originated from spawning in other estuaries and migrated into the Coorong in later years. Although black bream typically complete their lifecycle within estuaries, and many studies suggest little emigration from estuaries or large-scale movements (e.g. Butcher and Ling 1962; Lenanton 1977; Hall 1984; Hoeksema *et al.* 2006; Hindell *et al.* 2008), inter-estuarine movements may occur particularly after flood/high flows (Hall 1984). Currently, a PhD project (University of Adelaide) is studying the population structure and connectivity of black bream across southern Australia, which will further our understanding of the spatial scale that populations operate within and interactions between populations, including that of the Coorong.

Black bream is a slow-growing, long-lived estuarine species (Norriss *et al.* 2002). The maximum age reported from the Coorong population in this study was 32 years. Nevertheless, few individuals (mean <5% per year) greater than 13 years old were present from 2008/09 to 2019/20, and the ecological target of >20% of fish being older than 10 years was only met in three of the 12 years. Given that black bream typically confine their lifecycle within estuaries (e.g. Lenanton 1977; Hall 1984; Hindell *et al.* 2008), the truncated age structures were probably caused by the removal of larger and older individuals by fishing (Hilborn and Walters 1992; Planque *et al.* 2010; Walsh *et al.* 2010; Ferguson *et al.* 2013; Earl *et al.* 2016). Nevertheless, processes occurring over broader spatial scales (e.g. inter-estuarine movements) may also influence population dynamics of black bream (Hall 1984; Gillanders *et al.* 2015). A study using otolith chemistry identified different contingents of black bream population in the Coorong with 63% of fish categorised as residents and the remainder as migratory (Gillanders *et al.* 2015), although it is unknown if the movements of migratory fish were between the estuarine and marine environment or between areas of contrasting salinities within the LLCMM.

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

*et al.* 2019a; 2019b). Concurrently, fishery management should continue to seek to protect the remnant spawning biomass and maximise the survival of new recruits to rebuild population abundance and resilience in this region.

#### **5.4. Greenback flounder**

As a marine-estuarine opportunist species, greenback flounder regularly enter the Coorong estuary in substantial numbers, using it as a nursery ground (Bice *et al.* 2018). Their population condition over the last 12 years was generally responsive to freshwater inflows to the Coorong, with relatively better condition (i.e. 'moderate') in 2011/12–2013/14 and 2016/17 after flood/high flows. This was reflected by increased abundance and recruitment, expanded spatial distribution, and the establishment of new, strong cohort(s). In contrast, the population condition was 'very poor' or 'poor' over the last three dry years (2017/18–2019/20). Most recent fishery assessment also defined the stock status of greenback flounder in the Coorong as 'depleted' (Earl and Bailleul 2021).

During the extended drought years (2002–2010), the biomass of greenback flounder (legal minimum size is 25 cm TL in South Australia) experienced an order of magnitude decline in the Coorong (mean commercial catch  $\sim 4 \text{ t y}^{-1}$ ), compared to the peak levels in 1990–1992 (mean catch  $62 \text{ t y}^{-1}$ ). The distribution of this species substantially contracted northward with the fishing area largely (99%) confined to the Murray Estuary in late drought years (2008–2010). Such reduction in abundance and distribution was probably due to habitat deterioration including extremely hypersaline conditions throughout most of the Coorong, in conjunction with likely reduced productivity and food resources during the extended low flow period (Ye *et al.* 2016; Giatas *et al.* 2018). After the Millennium Drought broke in late 2010, a remarkable increase in annual catch ( $\sim 30 \text{ t}$ ) occurred in 2011/12 (high flow), with the harvest broadly distributed throughout the North and South lagoons. This catch increase was driven by an increase in the abundance of recent recruits including a strong cohort that originated in the 2010/11 flood year. The 2010 cohort continued to dominate the age structure in 2012 and was present in the fishery catch in subsequent years until 2015. Regardless, the abundance declined drastically after 2012/13 and remained at a low level (commercial catches  $< 4 \text{ t y}^{-1}$ ) over the last seven years, likely due to the predominant low flow conditions, except for 2016/17 when there were high barrage flows. The low catch level was unlikely to exceed the ecological target of abundance ( $\geq 24 \text{ t y}^{-1}$ ), even with the consideration of seal interference on fishing in recent years. Across the 12 study years, the abundance target ( $\geq 24 \text{ t}$ ) was only met in one year (2011/12), but the target of increasing 4-year trend in catch was achieved in 2011/12, 2012/13 and 2016/17, which were

moderate to high flow years. Freshwater flow has been considered an important factor explaining the variability in abundance of greenback flounder in the Coorong (Hall 1984; Earl 2014). Strong recruitment from flow events often translate to increased fishery production after a 1–2 year lag (Earl *et al.* 2014).

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

Freshwater flow is important to facilitate the recruitment of greenback flounder in estuaries, likely by influencing salinity regime, providing favourable estuarine habitat, and increasing food resources (Gillanders and Kingsford 2002; Robins and Ye 2010; Ye *et al.* 2020c). Over the last 12 years, recruitment of YOY occurred annually in the Coorong, although the CPUE and distribution varied among years. As this species has a strong preference for brackish and near-marine conditions (Earl *et al.* 2017), and salinity can influence its reproduction with optimum fertilization rates occurring between 35–45 psu and egg tolerance range of 14–45 psu after fertilization (Hart and Purser 1995), the YOY distribution seemed highly responsive to freshwater inflows and subsequent changes in salinities along the Coorong gradient. In late drought years, YOY were almost completely excluded from the North and South lagoons due to the elevated hypersaline salinities which made the habitat unfavorable for this species. Therefore, the exceptionally high YOY CPUE in 2008/09 and 2009/10 were more likely due to the aggregation of juveniles into reduced habitat within the Murray Estuary leading to increased catchability. In post-drought years, YOY distribution showed extensive expansion into the North and South lagoons, although the CPUE only met the ecological target (1.04 fish.seine net<sup>-1</sup>) in three of the ten years (i.e. 2010/11, 2013/14 and 2014/15). This, in conjunction with current low population biomass, suggests that greenback flounder is still in recovering mode 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 12 years.

The best population condition was observed in 2011/12 and 2016/17 due to increased recruitment, abundance and distribution of this species during high flows and reduced salinities. Accordingly, the ‘extremely poor’ condition occurred in the drought years (i.e. 2008/09 and 2009/10). In the last three low flow years, including 2019/20, the population condition remained ‘moderate’, mainly due to a reduced extent in recruitment.

As an euryhaline species, smallmouth hardyhead can tolerate high salinities (up to 106 psu) (Lui 1969). However, the extreme hypersaline conditions in the late drought years (e.g. 2007/08 and 2008/09) restricted its southerly distribution, when salinities increased to 4–5 times that of seawater (i.e. >140 psu) in summer/autumn (Noell *et al.* 2009; Ye *et al.* 2011b). These years represented an extremely hypersaline phase in the long-term salinity fluctuations of the Coorong as a consequence of no freshwater flows following a protracted drought in the MDB. In 2009/10, localised salinity reduction in the South Lagoon (due to increased inflows from Salt Creek 15.2 GL in 2009/10 compared to 2.1 GL in 2008/09) may have facilitated patchy increases in abundance of this species; but the scale of effect was insufficient to meet any ecological target levels. Since 2010/11, following substantial increases in barrage flows, salinities considerably reduced, with the mean ranging between 36–51 psu in the North Lagoon, and generally below 100 psu in the South Lagoon. Adults and new recruits showed a broad distribution almost across all sampling sites in the Coorong.

The abundance increases of this small-bodied fish were mostly driven by enhanced spawning and recruitment following increased inflows from the River Murray to the Coorong. Seasonal reductions of salinity by freshwater inflow has been suggested as a partial cue to spawning in smallmouth hardyhead (Molsher *et al.* 1994). Freshwater inflows not only help maintain a suitable salinity gradient, but also enhance productivity (e.g. zooplankton food resources, Shiel and Tan 2013; Furst *et al.* 2014), and thus improved habitat quality and extent for this species across the Coorong. At times (e.g. 2009/10), dispersion of the remnant population and new recruits from Salt Creek could also help maintain the population in the South Lagoon, as suggested by earlier monitoring (Ye *et al.* 2011b). Furthermore, changing numbers of piscivorous predators and/or competitors in the Coorong could also affect the abundance of smallmouth hardyhead given this prey species plays an important role in the trophic ecology of the region (Giatas and Ye 2016; Giatas *et al.* 2018).

Smallmouth hardyhead can reproduce in hypersaline waters (Lenanton 1977). However, when salinities exceeded 100 psu, such as the levels observed in the southern Coorong during the



drought period (2006/07–2009/10), the abundance and recruitment of this species was negatively impacted (Noell *et al.* 2009; Ye *et al.* 2010b). This was demonstrated by the lowest CPUE of new recruits during late drought (2008/09 and 2009/10) among the 12 year study. High salinity is known to impact the reproductive performance of other atherinids (e.g. Carpelan 1955; Hedgpeth 1967). Although a previous Coorong study did not identify any clear effect of salinity on reproduction of smallmouth hardyhead at a lower salinity range (32–74 psu), it suggested that salinity may limit food resources and thus affect recruitment (Molsher *et al.* 1994).

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

With lower barrage flows in 2018/19 and 2019/20, mean salinity increased to 87 and 108 psu in the South Lagoon respectively. However, the CPUE of new recruits did not reduce, and in fact, showed increases in both North and South lagoons. A similar pattern occurred in 2015/16 after three consecutive years of low flow. Such unexpected results could be due to reduced abundance of predators/competitors caused by further increased salinities, as observed during fish assemblage monitoring in the Coorong (e.g. Ye *et al.* 2015a). Also to note, increased water turbidity and filamentous algae abundance in recent years may have reduced prey accessibility and thus reduced predation efficiency of piscivorous waterbirds in the Coorong (Dan Rogers, 2020, pers. comm.). Additionally, increased presence of *Ruppia* over the last five years in the southern Coorong (Waycott *et al.* 2020) may potentially benefit the reproduction of smallmouth hardyhead. 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; Ivanstovff and Crowley 1996).

## 6. CONCLUSION

Condition monitoring for smallmouth hardyhead since 2008/09 indicated that the ecological objective (F-3) to maintain abundant self-sustaining populations of this species in the North and South lagoons of the Coorong was only achieved in three high flow years (2011/12, 2012/13 and 2016/17). In 2019/20, a low flow year (685 GL  $y^{-1}$ ), the population condition remained 'moderate', not meeting the ecological target (F-3). The population during this year was characterised by a broad distribution of both new recruits and adults throughout the North and South lagoons; and high abundance of new recruits (1,355 fish.UE<sup>-1</sup>) above the ecological target (>800 fish.UE<sup>-1</sup>); but less extensive recruitment, not meeting the target (>75% of sites). Also, there was no spring/early summer sampling to provide a reliable estimate of adult abundance that is comparable to the target. The decline in population condition from 'very good' in 2016/17 to 'moderate' in the last three years corresponded with reduced barrage releases and increased salinities in the Coorong.

In contrast, for black bream and greenback flounder, the monitoring suggests that the ecological objective (F-4) to restore resilient populations of these species in the Coorong has not been met over the last 12 years. For black bream, the population condition ranged from 'extremely poor' to 'poor' in the Coorong in all years except 2017/18 and 2019/20 when it was 'moderate'. The 'moderate' condition in 2019/20 was an improvement from 2018/19 ('very poor'), and was characterised by:

- An increasing 4-year catch trend (meeting the target about a positive trend);
- Increased distribution of the commercial catches (63% from the southern Coorong, meeting the target: >50%);
- The presence of two strong cohorts with both <5 years (meeting the target) despite 17% of the catches >10 years of age (vs the target: >20%);
- No detection of YOY (vs the target CPUE: >0.77 fish.net night<sup>-1</sup>);
- A low relative abundance (annual commercial catch of 1.6 t vs the target: ≥8 t)

For greenback flounder, the population condition improved from 'extremely poor' during the late drought (2008/09 and 2009/10) to 'moderate' during the three post-drought years (2011/12–2013/14). It then declined to 'poor' in 2014/15 and 2015/16, with low river inflows (<1,300 GL  $y^{-1}$ ). In 2016/17, the population condition improved to 'moderate' following high flows to the Coorong although it declined again with flow reductions in subsequent three years. In 2019/20, the population condition was 'poor', characterised by:

- A very low relative abundance (annual commercial catch 0.2 t vs the target: >24 t);

- A decreasing 4-year trend in catches (not meeting the target);
- A low level recruitment (YOY CPUE 0.3 fish.seine net<sup>-1</sup> vs the target: >1.04 fish.seine net<sup>-1</sup>) with a contracting distribution (present at 33% sites vs the target: >50% sites);
- The presence of a very strong cohort (95% 1 year olds, meeting the target: >60%);
- A broad distribution of commercial catches (>99% from the southern Coorong, meeting the target: >70%).

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 12 years. Therefore, we suggest that future evaluation of the ecological objective F-4 be separated for these two species, by setting up the following two objectives, whereas specific targets remain as defined in the LLCMM Icon Site Condition Monitoring Plan (revised, 2017):

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

Freshwater flow is important in facilitating successful recruitment of black bream and greenback flounder, likely through maintaining/restoring estuarine habitats (providing a favourable salinity gradient and environmental conditions) and increasing productivity in the Coorong. As a marine-estuarine opportunist and relatively fast growing species with a moderate life-span (~10 years), greenback flounder seem to be more responsive to river flow increases to the Coorong than black bream, which is a slower growing, solely estuarine long-lived fish (~32 years). Despite periodic black bream recruitment occurring over the 12 study years, no significant improvement in the population abundance was observed. This was potentially due to the depleted spawning biomass (Earl *et al.* 2016) and a heavily truncated age structure, which compromised the population resilience of this long-lived species in the Coorong.

This study suggests that river inflows and allocations of water for the environment are critical to improve estuarine fish habitats (salinities, connectivity and productivity), enhance fish recruitment and abundance, and improve population resilience in the Coorong. Importantly, flow management should consider inter-annual and intra-annual flow regimes, including small to moderate freshwater releases that may meet different environmental or life-history process requirements of different species (e.g. low to moderate flows, as per the releases in 2003/04, 2006/07, 2012/13 and 2017/18 associated with stronger black bream recruitment). The management needs to be supported by detailed knowledge, which could be obtained through further investigations to: (1) understand the influence of freshwater flows on population dynamics and recruitment of medium-

and large-bodied estuarine species; (2) evaluate the benefit/impact of various flow scenarios (both natural and managed flows including environmental water) for these populations; and (3) assess population recovery (abundance and demographics). Furthermore, given the depleted populations of medium- and large-bodied species in the Coorong, particularly the solely estuarine black bream, fishery management should continue to seek to protect the remnant spawning biomass and maximise the survival of new recruits to rebuild population abundance and age structure to improve resilience.

The fish monitoring over the last 12 years (2008/09–2019/20) provided valuable information on the abundance, distribution, age/size structures and recruitment ecology of the black bream, greenback flounder and smallmouth hardyhead populations in the Coorong. Moreover, the study occurred over an extended period with substantial hydrological variability, including extreme drought (2008/09 and 2009/10, no flow), low flows (e.g. 2014–2016, 2017–2020, <1,000 GL y<sup>-1</sup>) and flood/high flows (2010–2012 and 2016/17, >6,000 GL y<sup>-1</sup>), which allowed an assessment of biological responses to flow variability and an investigation on population recovery. This report is based on the framework of fish condition assessment in the Coorong using a multiple lines of evidence approach. It facilitated annual quantitative assessment of the ecological targets and objectives for the three species and the classification of population condition for each species. In recent years, there was a reduction in sampling effort (e.g. in 2015/16, 2018/19 and 2019/20, no spring/early summer sampling occurred for adult smallmouth hardyhead) due to funding constraints, which limited our capacity to evaluate some of the ecological targets. Therefore, future monitoring should restore/maintain the sampling regime as recommended in the LLCMM Condition Monitoring Plan (revised, DEWNR 2017). Overall, the results of this study form an important basis for the delivery of environmental flows and adaptive management to ensure 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 2008/09–2019/20. sw=saltwater, fw=freshwater, HI=Hindmarsh Island, SRP=Sir Richard Peninsula, YHP=Young Husband Peninsula, Phrag. Opp= *Phragmites* opposite Rumbelow shack.**

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

**Appendix B. Sampling effort (number of seine net shots) for collecting juvenile greenback flounder using large seine net at the Coorong from 2008/09–2019/20. 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
Sugars Beach/Beacon 19	9	9	9	15	9	9	12	6	9	6	3	3
Godfrey's Landing	9	9	15	15	15	15	12	6	9	6	3	3
Mark Point	12	15	15	15	15	15	12	6	9	6	3	3
Noonameena	12	15	15	15	15	15	12	6	9	6	3	3
Mt Anderson	NS	NS	9	15	15	15	12	6	9	6	3	3
Hells Gate	12	15	15	15	15	15	12	6	9	6	3	3
Villa dei Yumpa	NS	NS	9	15	15	15	12	6	9	6	3	3
Jack Point	12	15	15	15	15	15	12	6	9	6	3	3
Salt Creek	12	15	15	15	15	15	12	6	9	6	3	3
<b>Overall</b>	<b>78</b>	<b>93</b>	<b>117</b>	<b>135</b>	<b>129</b>	<b>129</b>	<b>108</b>	<b>54</b>	<b>81</b>	<b>54</b>	<b>27</b>	<b>27</b>

**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 2008/09–2019/20. NS=no sampling. Note: 2014/15 data are from 'Coorong fish intervention monitoring'; no small seine netting was conducted.**

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

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

Year	2008/09		2009/10		2010/11		2011/12		2012/13		2013/14		2014/15		2015/16		2016/17		2017/18		2018/19		2019/20	
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
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
Long Point (N2)					152	29	251	78	14	7	22	3	97	36	476	126	93	35	16	6	322	192	3967	1299
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
Mt Anderson (N4)					0	0	279	103	68	19	59	15	51	21	462	182	27	12	9	5	342	38	609	68
<b>Mean (NL)</b>	<b>124</b>	<b>124</b>	<b>269</b>	<b>72</b>	<b>166</b>	<b>48</b>	<b>408</b>	<b>155</b>	<b>23</b>	<b>16</b>	<b>79</b>	<b>50</b>	<b>53</b>	<b>19</b>	<b>368</b>	<b>58</b>	<b>97</b>	<b>25</b>	<b>14</b>	<b>6</b>	<b>497</b>	<b>137</b>	<b>2192</b>	<b>689</b>
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
Villa de Yumpa (S2)					0	0	69	12	98	18	66	31	57	18	84	252	663	131	52	5	115	42	119	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
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
<b>Mean (SL)</b>	<b>1</b>	<b>0</b>	<b>5</b>	<b>5</b>	<b>25</b>	<b>23</b>	<b>242</b>	<b>104</b>	<b>148</b>	<b>49</b>	<b>50</b>	<b>13</b>	<b>104</b>	<b>31</b>	<b>381</b>	<b>474</b>	<b>225</b>	<b>152</b>	<b>60</b>	<b>7</b>	<b>378</b>	<b>166</b>	<b>207</b>	<b>76</b>
<b>Overall</b>	<b>50</b>	<b>38</b>	<b>110</b>	<b>69</b>	<b>95</b>	<b>39</b>	<b>325</b>	<b>92</b>	<b>85</b>	<b>33</b>	<b>64</b>	<b>24</b>	<b>78</b>	<b>19</b>	<b>375</b>	<b>113</b>	<b>161</b>	<b>75</b>	<b>37</b>	<b>10</b>	<b>438</b>	<b>102</b>	<b>1199</b>	<b>494</b>

**Appendix E. Mean CPUE (fish.UE<sup>-1</sup>) of smallmouth hardyhead new recruits (i.e. <40 mm TL) sampled by large and small seine nets in January and February across eight sites in the North Lagoon (NL) and South Lagoon (SL). SE: Standard error. Sub-regional and overall means are presented in bold (also see Figure 4.13). Note: 2014/15 values are based on large seine net data only; 2015/16 and 2016/17 values are based on sampling conducted in February and March, whilst 2015/16, 2018/19 and 2019/20 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	
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
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
Long Point (N2)					3352	1525	499	152	161	25	345	42	23	14	523	126	561	80	319	81	1148	473	521	82
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
Mt Anderson (N4)					2863	816	2248	495	423	72	562	65	9	4	641	182	1101	277	160	22	454	55	1534	345
<b>Mean (NL)</b>	<b>111</b>	<b>38</b>	<b>300</b>	<b>58</b>	<b>2340</b>	<b>578</b>	<b>1922</b>	<b>1030</b>	<b>265</b>	<b>80</b>	<b>447</b>	<b>88</b>	<b>26</b>	<b>8</b>	<b>533</b>	<b>55</b>	<b>773</b>	<b>122</b>	<b>606</b>	<b>371</b>	<b>839</b>	<b>164</b>	<b>890</b>	<b>275</b>
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
Villa de Yumpa (S2)					2337	916	1470	172	373	26	688	195	364	130	1264	252	1974	518	363	20	1009	211	2003	108
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
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
<b>Mean (SL)</b>			<b>27</b>	<b>27</b>	<b>1296</b>	<b>1097</b>	<b>1736</b>	<b>137</b>	<b>1370</b>	<b>373</b>	<b>571</b>	<b>70</b>	<b>364</b>	<b>61</b>	<b>1473</b>	<b>97</b>	<b>1551</b>	<b>205</b>	<b>673</b>	<b>167</b>	<b>1782</b>	<b>270</b>	<b>1819</b>	<b>662</b>
<b>Overall</b>	<b>111</b>	<b>38</b>	<b>136</b>	<b>71</b>	<b>1818</b>	<b>418</b>	<b>1829</b>	<b>482</b>	<b>817</b>	<b>273</b>	<b>509</b>	<b>57</b>	<b>195</b>	<b>70</b>	<b>1003</b>	<b>185</b>	<b>1162</b>	<b>184</b>	<b>640</b>	<b>189</b>	<b>1310</b>	<b>72</b>	<b>1355</b>	<b>66</b>