Coorong Fish Condition Monitoring 2008–2019: 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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PO Box 120 Henley Beach SA 5022

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South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024
Telephone: (08) 8207 5400
Facsimile: (08) 8207 5415
http://www.pir.sa.gov.au/research

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Author(s):	Qifeng Ye, Luciana Bucater, David Short and George Giatas
Reviewer(s):	Kate Frahn (SARDI) and Adrienne Rumbelow (DEW)
Approved:	Prof. Xiaoxu Li Science Leader - Aquaculture
Signed:	
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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. It is also an 'icon site' under The Living Murray (TLM) initiative. During the Millennium Drought (2001–2010) in the Murray–Darling Basin (MDB), the Coorong ecosystem became increasingly degraded as a consequence of diminished freshwater flows and subsequent increases in salinity. In order to restore and enhance the environmental values of the LLCMM region, an Icon Site Management Plan was developed, within which ecological targets were set for fish in the Coorong. A Condition Monitoring Plan has been implemented to evaluate whether these targets have been achieved. Following a recent review of the TLM Condition Monitoring Program, refined ecological objectives and quantitative targets were established. This report presents the findings of 11 years of the monitoring program (2008/09–2018/19) 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. There was substantial hydrological variability during the study period, including extreme drought (2008/09 and 2009/10, no flow), low flows (e.g. 2013–2016, 2017–2019, <1,000 GL y^{-1}) and flood/high flows (2010–2012 and 2016/17, >6,000 GL y^{-1}). The varying hydrological conditions allowed an assessment of biological responses to flow variability and an investigation on population recovery. This monitoring involved evaluation of two fish ecological objectives within the LLCMM Icon Site Environmental Water Management Plan (MDBA 2014): (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 2018/19, with low river inflows. The population condition was classified as 'moderate', which was reflected by a broad distribution for both new recruits and adults throughout the North Lagoon and South Lagoon; and higher abundance of new recruits (1,310 fish.UE^{-1}) compared to the ecological target (>800 fish.UE^{-1}), but less extensive recruitment throughout the Coorong. Smallmouth hardyhead is a key prey species that 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 a significant improvement in its population condition from 'extremely poor' during the drought (2008/09 and 2009/10) to 'moderate' in the subsequent flood year (2010/11), and a further improvement to 'very

good'/'good' in the years with high to moderate barrage releases (>3,000 GL y^{-1}) (2011/12, 2012/13 and 2016/17), meeting the ecological objective F-3. It was further evident by the condition decline to 'moderate' in 2017/18 and 2018/19, which corresponded with lower barrage flows and increased salinities in the Coorong. Increased freshwater flows post 2010/11 led to broadly decreased salinities in the Coorong, with salinity in the South Lagoon generally maintained <100 psu, well below the extremely high levels during the drought (e.g. 166 psu in 2008/09). This, in conjunction with flow-induced improvements to productivity and habitat conditions (e.g. *Ruppia* abundance) likely facilitated the general improvement of the smallmouth hardyhead population post-drought. Our findings support the importance of freshwater flows to the population ecology of this species. Moreover, flow related biological responses observed in this monitoring displayed the resilience of the smallmouth hardyhead population in the Coorong.

In contrast, for black bream and greenback flounder, results from the monitoring program suggest that the ecological objective (F-4) to restore resilient populations of these species in the Coorong has not been achieved over the last 11 years. For black bream, the population condition ranged from 'extremely poor' to 'poor' in the Coorong in all years except 2017/18 when it improved to 'moderate' due to extensive recruitment of YOY associated with managed barrage flow releases supported by environmental water. In 2018/19, the population condition declined to 'very poor', characterised by:

- A low relative abundance (annual commercial catch of 0.7 t vs the target: ≥8 t);
- A declining 4-year catch trend (vs the target: a positive trend);
- No detection of new recruits (YOY CPUE not meeting the target: >0.77 fish.net $night^{-1}$);
- Decreased distribution (35% commercial catches from the southern Coorong, not meeting the target: >50%); and
- A truncated age structure (only 12% fish >10 years of age vs the target: >20%) although the presence of two strong cohorts with both <5 years (meeting the target).

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 two years. In 2018/19, the population condition was 'very poor', characterised by:

- A low relative abundance (annual commercial catch 1.9 t vs the target: ≥24 t);

- An decreasing 4-year trend in catches (not meeting the target);
- The presence of a recent strong cohort although only ~9% of the fish being 3 years old (not meeting the target: >40% in Year 0–2 and >20% of fish >2 years of age); and
- A low level recruitment (YOY CPUE 0.54 fish.seine net^{-1} vs the target: >1.04 fish.seine net^{-1}) with a contracting distribution (present at 38% sites vs the target: >50% sites); but
- A broad distribution (>99% commercial catches 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 11 years. Therefore, we have suggested that evaluation of the ecological objective F-4 be separated for these two species, to 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 in 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 seemed 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 11 study years, no significant improvement in the population abundance has been observed. This was potentially due to the depleted spawning biomass and a heavily truncated age structure, which compromised the population resilience of this long-lived species in the Coorong.

This study suggests that environmental water allocation is critical to improve estuarine fish habitats (salinities, connectivity and productivity), enhance fish recruitment and abundance, and maintain or rebuild 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, conservation management should seek to protect the remnant populations of these medium- and large-bodied estuarine species and rebuild the age structures to improve population resilience. 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 resilience in this region. 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) region is located at the terminus of Australia's largest river system, the Murray–Darling. It is recognised internationally as a Ramsar Wetland, providing an important breeding and feeding ground for waterbirds, and supporting significant populations of numerous fish and invertebrates species (Phillips and Muller 2006; Bice and Ye 2009). The region is classified as 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 the 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 (2.1–43.7 GL y^{-1} between 2007/08–2018/19) from a network of drains (the Upper South East Drainage Scheme) through Salt Creek.

As the terminal system of the Murray–Darling Basin (MDB), the Coorong region has been heavily impacted by river regulation and water extraction since European settlement. The mean annual flow at the Murray Mouth has declined by 61% since 1895 (from 12,333 GL y^{-1} to 4,733 GL y^{-1}; CSIRO 2008). The construction of five tidal barrages in the 1940s significantly reduced the area of the original Murray 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 2019). 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.* 2012, 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 led to substantial barrage releases to the Coorong and the restoration of connectivity between the freshwater and marine environments (with barrages and fishways opening). 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, 2018; Bice *et al.* 2018, 2019a, 2019b).

Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouth hardyhead (*Atherinosoma microstoma)* are target species in the LLCMM Icon Site Environmental Water Management Plan (MDBA 2014). A scientifically robust monitoring program was designed in 2008/09 and condition monitoring has been implemented since then for these species in the Coorong (Maunsell Australia Pty Ltd. 2009); to assess whether the following targets have been achieved (Ye *et al.* 2015b):

- Target F-3: Provide optimum conditions to improve recruitment success of smallmouth hardyhead in the South Lagoon.
- Target F-4: Maintain or improve recruitment of black bream and greenback flounder in the Murray Estuary and North Lagoon.

Following a review of the TLM Condition Monitoring Program undertaken by Robinson (2015), data collected from the Coorong fish condition monitoring project (2008/09–2013/14) was analysed to develop new quantitative targets for black bream, greenback flounder and smallmouth hardyhead (Ye *et al.* 2014). Revised ecological targets, along with refined objectives for these species, are presented in Tables 1.1 and 1.2. These have been incorporated in the revised Condition Monitoring Plan (DEWNR 2017).

The current report presents the findings of fish condition monitoring from 2008–2019, with a focus on assessing whether the revised targets and ecological objectives have been achieved for the populations of the three fish species in the Coorong in 2018/19. The assessment built on previous data collected between 2008/09–2017/18 (Ye *et al.* 2019a), which were from both commercial fishery (fishery-dependent) and fishery-independent research sampling.

Table 1.1. Revised ecological objective and targets for black bream and greenback flounder. (Samples from C = commercial samples, R = Research samples, CR = Commercial and research samples combined).

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

Table 1.2. Revised ecological objective and targets for smallmouth hardyhead.

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

1.2. Objectives

This project undertook condition monitoring for black bream, greenback flounder and smallmouth hardyhead in the Coorong in 2018/19, 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 objectives for each species were to:

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

2. BIOLOGY/ECOLOGY OF FISH SPECIES

2.1. Black bream

Black bream (*Acanthopagrus butcheri*) is a sparid, endemic to the estuaries and coasts of southern Australia (Stewart and Grieve 1993; Haddy and Pankhurst 2000; Gomon *et al.* 2008). They are an important commercial and recreational fisheries species (Rowland and Snape 1994; Haddy and Pankhurst 1998; Sarre and Potter 2000) and have a reputation for hardiness as they possess a wide environmental tolerance with respect to temperature, salinity and dissolved oxygen concentration (Norriss *et al.* 2002; Partridge and Jenkins 2002). Even though they show a preference for brackish waters (Hindell *et al.* 2008), black bream 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*. 2013a).

Black bream provide a rare example as a large-bodied teleost species which can complete its entire life cycle within its natal estuary (Sarre *et al.* 2000; Burridge *et al.* 2004), and is classified as a ‘solely estuarine’ species (Potter *et al.* 2015; Bice *et al.* 2018). They are multiple batch spawners 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 are considered periodic strategists (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 their ecological and economical importance, black bream have been a key species 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, have a spring spawning season (Coutin *et al.* 1997; Norriss *et al.* 2002) with a peak in the gonadosomatic index (GSI) occurring in October and November. 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.* 2019b). The study also demonstrated the presence of halocline conditions associated with environmental water releases to the Coorong, which supported successful recruitment of black bream in 2017/18 (Ye *et al.* 2019b).

Variability in freshwater flows has been identified as a key factor influencing recruitment of black bream in estuaries (Sarre and Potter 2000; Nicholson *et al.* 2008; Jenkins *et al*. 2010; Williams *et al*. 2012), with greatest recruitment success during years of intermediate river flows and poor recruitment following periods of extremely low or high flows (Jenkins *et al.* 2010). In the substantially modified estuary of the Coorong, recent studies suggest strong cohorts are associated with low to moderate river flows (e.g. up to 12,000 ML day^{-1} barrage discharge) (Ye *al.* 2018, 2019c). As black bream generally complete their entire life cycle within a single estuary (Sherwood and Blackhouse 1982; Elsdon and Gillanders 2006), their 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 (Barnett and Pankhurt 1999; Van den Enden *et al.* 2000), where they support commercial and recreational fisheries (Kailola *et al.* 1993; Froese and Pauly 2013; Earl 2014). They have a high salinity tolerance (up to 74 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). 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 occytes 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 using 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.* 2013a).

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 (Ye *et al*. 2013a; Earl and Ye 2016). 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 *et al.* 2012; Ye *et al*. 2013a). However, Earl *et al.* (2016) suggested that temporal and spatial variation of biomass and abundance could also be related to possible migration of older individuals to the sea.

Given their ecological and commercial importance to the LCF, greenback flounder has been a key focus species recently in several research and monitoring projects (e.g. Earl 2014; Ye *et al.* 2015b; Earl and Ye 2016; Earl *et al.* 2017). Greenback flounder have been recorded in the Coorong up to 50 km from the Murray Mouth (salinity ~74.1 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.* 2013a). Nevertheless, this species shows a preference for brackish and near-marine salinities (Earl *et al.* 2017).

2.3. Smallmouth hardyhead

Smallmouth hardyhead (*Atherinosoma microstoma*) are 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). They are 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 are one of the most salt-tolerant fish species in the world (Molsher *et al.* 1994). They have a wide range of salinity tolerance from 3.3–108 psu in aquaria (Lui 1969) and an even greater tolerance range under natural conditions where they 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; Ye *et al.* 2013b). 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*. 2013a) and reaches sexual maturity at 45 mm TL (Molsher *et al.* 1994).

In the Coorong, the diet of smallmouth hardyhead consists mainly of zooplankton, particularly ostracods and copepods, which are more abundant in winter and spring (Molsher *et al.* 1994; Hossain *et al.* 2017) and during freshwater flows (Geddes 2005). The importance of macrophytes to atherinids has also been well documented, as they provide a sessile medium to which eggs can adhere and be retained within the areas of favourable salinity, thus facilitating enhanced egg survival and subsequent recruitment (Molsher *et al.* 1994; Ivanstoff and Crowley 1996).

In the Coorong, smallmouth hardyhead demonstrated a rapid population recovery within two years of resumption of flows and reduced salinities following their extirpation from approximately 60% of their range during the drought (Wedderburn *et al.* 2016). Nonetheless, maintaining and/or improving the abundance and distribution of smallmouth hardyhead is pivotal, since they are a critical component of the Coorong ecosystem, serving as a major prey item for piscivorous fishes and water birds (Brookes *et al.* 2009; Paton 2010; Giatas *et al.* 2018). The importance of smallmouth hardyhead in the Coorong was strongly supported by recent trophic dynamic and fish diet studies in the Coorong (Deegan *et al.* 2010; Giatas and Ye 2015).

3. METHODS

3.1. General approach

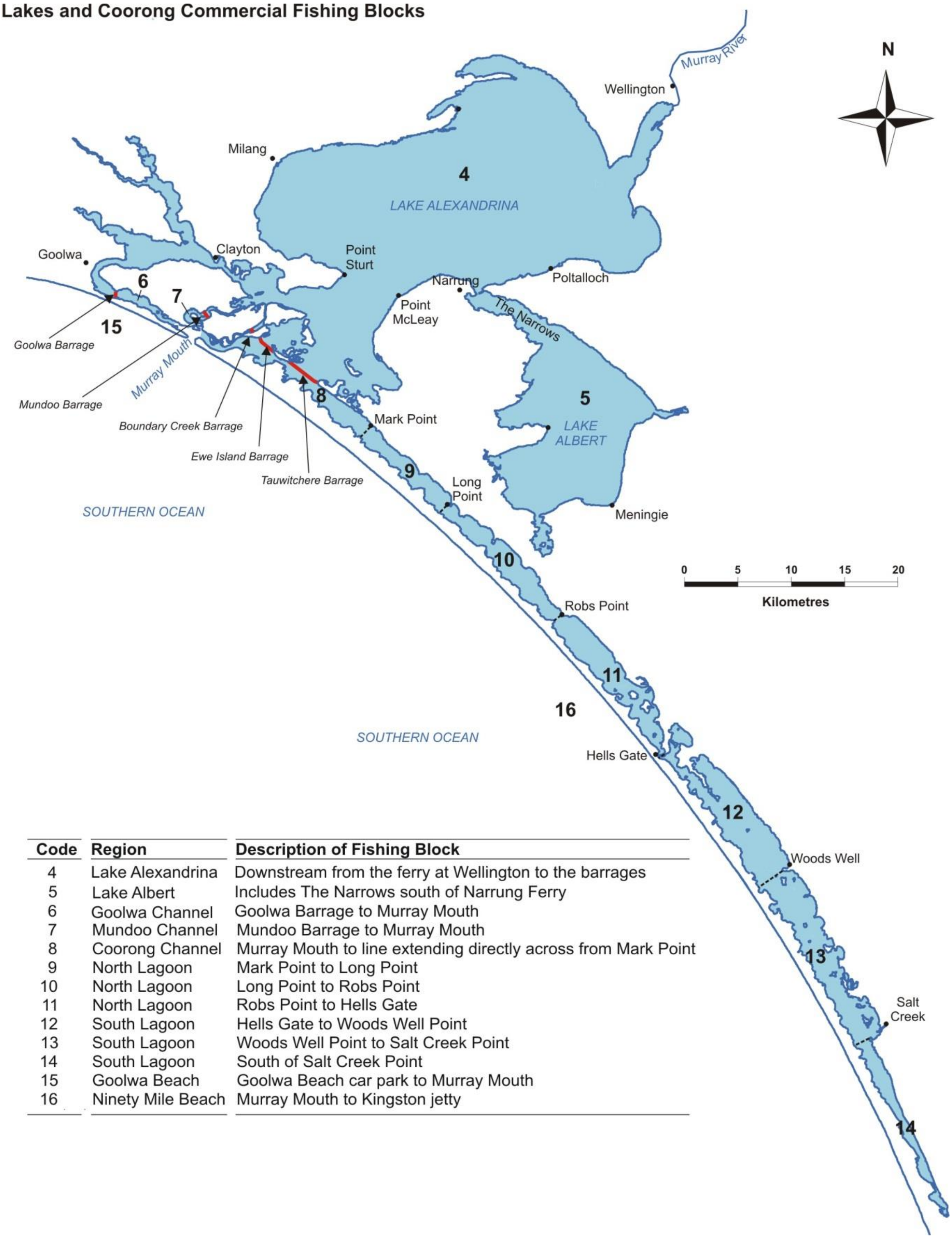
Based on the revised Condition Monitoring Plan, four indicators were established for each species to assess the condition of the black bream, greenback flounder and smallmouth hardyhead populations in the Coorong (Ye *et al.* 2014), with each indicator having 1–2 quantitative targets (Tables 1.1 and 1.2). For the two larger 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 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 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 2018/19) 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 2019, based on the estimates of the regression-based Murray hydrological model (MDM, BIGMOD, Murray–Darling Basin Authority, MDBA). 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 2019).



Lakes and Coorong Commercial Fishing Blocks

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

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

3.2.2. Analysis

Annual fishery catches of black bream and greenback flounder, and barrage flows were plotted for each financial year for the period between July 1984 and June 2019. Temporal trends of catch were analysed to indicate the fluctuation in relative 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 between 2008/09 and 2018/19 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 the 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).

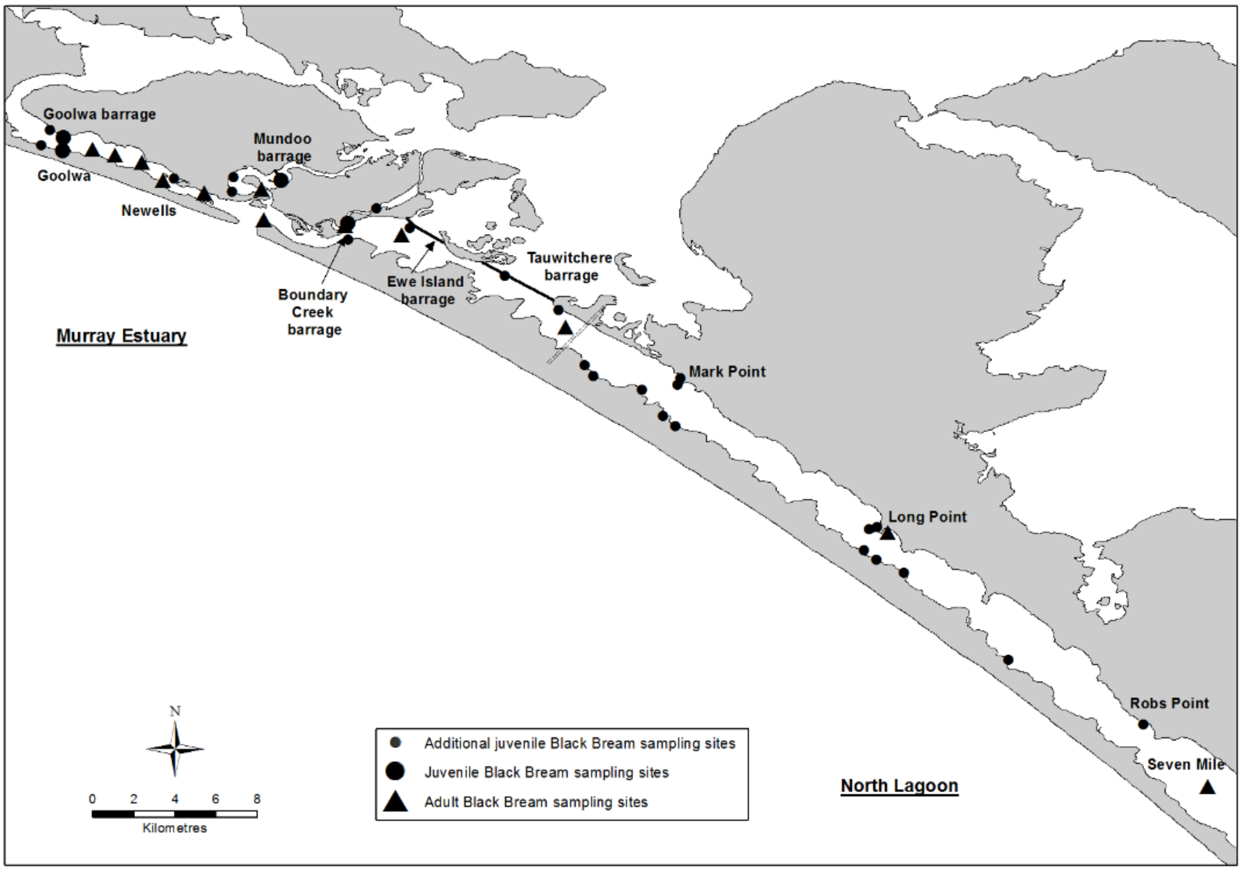


Figure 3.2. Condition monitoring sampling sites for adult and juvenile black bream at the Coorong. Adult black bream sampling sites represent commercial fishery sampling sites.

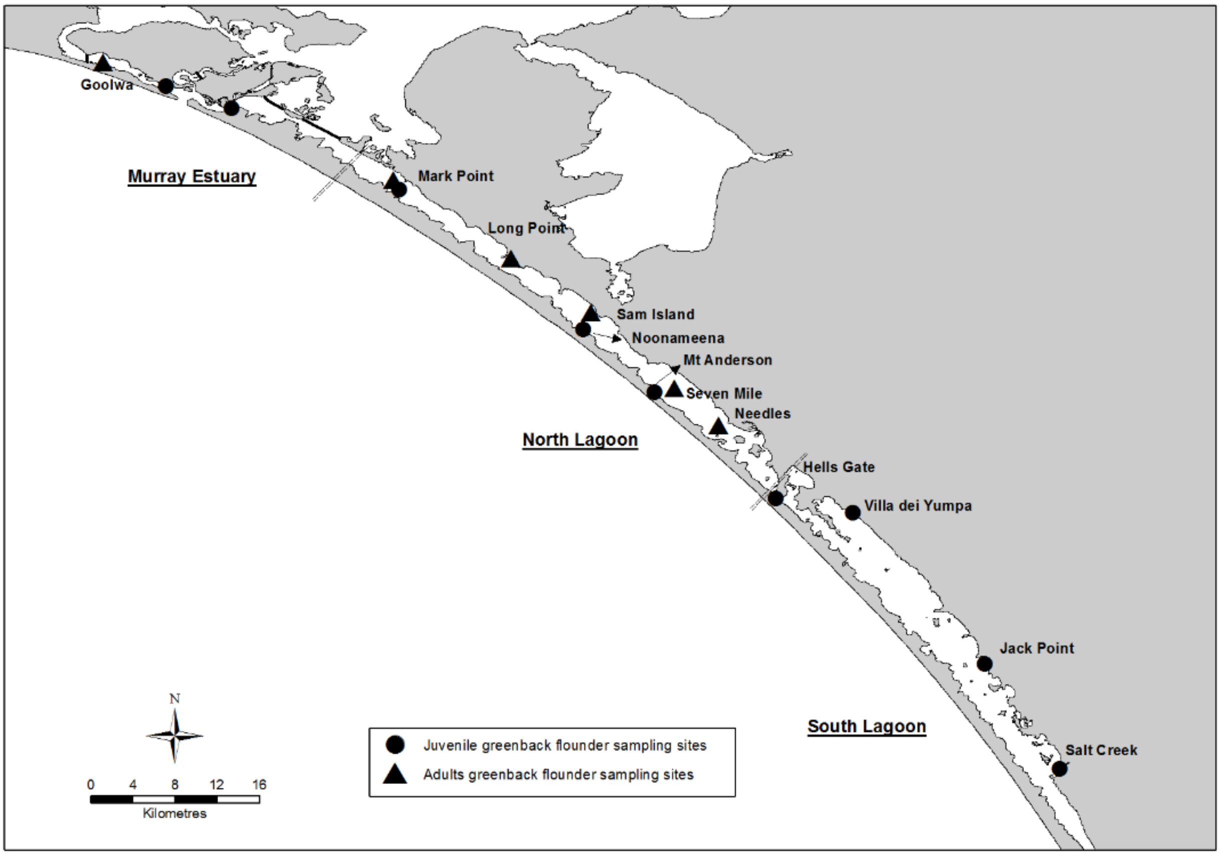


Figure 3.3. Condition monitoring sampling sites for adult and juvenile greenback flounder in the Coorong. Adult greenback flounder sampling sites represent commercial fishery sampling sites.

3.4. Recruitment

3.4.1. Sampling

Additional sampling was carried out to quantify the abundance of juvenile black bream and greenback flounder, in order to assess annual recruitment of YOY. For black bream, sampling of juveniles was conducted in late summer/autumn (February–April) 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). The Mundoo Barrage site was added in 2010/11. In most years, exploratory sampling was also conducted at other sites (e.g. Beacon19, 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). Sampling was conducted using standard (large) seine net hauls/shots during spring–summer each year (*n* = 1–3 trips per year) (Figure 3.2). The seine net was 61 m long and consisted of two 29 m-long wings (22 mm mesh) and a 3 m-long bunt (8 mm mesh). It was deployed in a semi-circle, sampled to a maximum depth of 2 m and swept an area of about 592 m^2 per shot. A standardised sampling regime comprising 3 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 six regular sites along the North and South lagoons of the Coorong. In January and February 2011, two additional sites (Mt Anderson and Villa dei Yumpa) were sampled and became part of regular sampling sites from 2011/12 onwards (Figure 3.4). Sampling was conducted at each site during spring–early autumn over 11 years (2008/09–2018/19) (*n* =1–4 trips per year), targeting the main spawning and recruitment season when possible. However, no sampling was conducted in spring/early summer in 2015/16 and 2018/19 due to funding constraints, providing no data to evaluate the ecological target of adult abundance for this species. A small seine net was also used from December 2008 onwards as a complimentary method to more efficiently target new recruits (juveniles). The small seine net was 8 m long with a 2 m drop and a mesh size of 2 mm. It was hauled through water less than 0.5 m deep over a distance of 20 m by two people walking 5 m apart, thus sampling an area of about 100 m^2. Sampling was replicated (i.e. three standard shots) at each site for each seine net type. A summary of sampling effort for smallmouth hardyhead is presented in Appendix C.

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 condition 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).

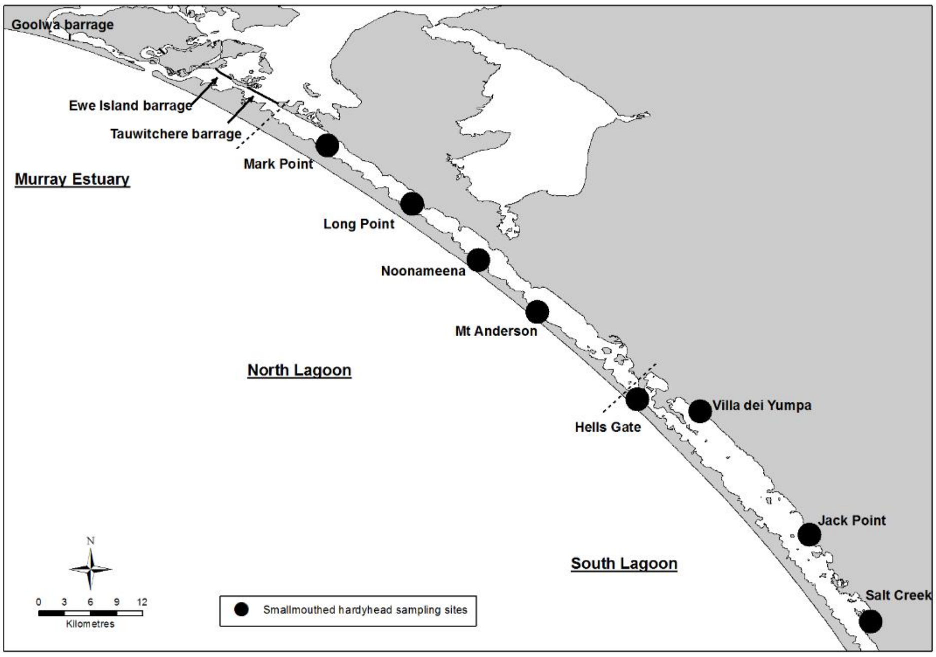


Figure 3.4. Condition monitoring sampling sites for smallmouth hardyhead in the Coorong.

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 11 years of fish monitoring in the Coorong, and thus were 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 targeted at each location.

Table 3.1. List of sampling sites, species targeted and sampling gear used for fishery-independent sampling during the Coorong fish condition monitoring from 2008/09–2018/19. Both seine nets = large and small seine nets.

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

*Note: Exploratory sampling sites for black bream juveniles are not included.

3.4.2. Analysis

For black bream, estimates of CPUE of juveniles (fish.net night^{-1}) 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. In 2014/15 and 2015/16, when no additional sampling other than fyke netting at the regular sites, the reduced sampling effort limited the capacity for assessing distribution.

For greenback flounder, estimates of CPUE of juveniles (fish.seine net^{-1}) 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 and 2018/19 due to funding constraint.

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

Furthermore, recruitment success of black bream and greenback flounder could be corroborated using year class strength in the fishery age structures from 2008–2019. For smallmouth hardyhead, length-frequency distributions of both large and small seine net data also provided complementary information to investigate recruitment success. Using length data to estimate the presence of new recruits (evidence of recent reproduction) was considered an appropriate method for this small-bodied fish given the one-year life cycle of this species (Molsher *et al.* 1994).

4. RESULTS

4.1. Freshwater flow

From 1984–2019, freshwater flow from the River Murray to the Coorong fluctuated substantially. Annual discharges were consistently high during the late 1980s and early 1990s, ranging between 10,500 and 12,000 GL, with the exception of 1991/92 when it declined to 3,000 GL (Figure 4.1). From 1994/95 to 2000/01, inflows to the Coorong generally reduced. 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 and ~9,000 GL in 2011/12. There was a reduction in the annual discharge to 5,270 GL in 2012/13 and a further reduction during the subsequent three years to ~560 GL in 2015/16. In 2016/17, flooding in the MDB resulted in 10 folds increase in barrage discharge to ~6,500 GL than 2015/16. However, in the last two dry years, annual barrage flows reduced to ~850 GL in 2017/18 and 337 GL in 2018/19.

River inflows were seasonal with peaks in monthly discharge occurring at different times in different years (Figure 4.1). For example, the highest monthly inflow occurred in autumn during 2010/11 and 2011/12; whereas it occurred in spring during 2012/13 and 2013/14, in winter during 2014/15, 2015/16 and 2018/19, and in early summer for 2016/17 and 2017/18.

Freshwater flows from Salt Creek into the South Lagoon were highly variable among years from 2000/01 to 2018/19 (Figure 4.2). Inflows were highly seasonal in most years, with peak discharges occurring from mid-July to early September. Annual discharges were generally low between 2000/01 and 2009/10 (mean 7.3 GL), whereas they increased substantially between 2010/11 and 2014/15 (mean 26.7 GL). In 2015/16, annual discharge reduced to about 17% (4.4 GL) of that in previous years (2010/11–2014/15), nevertheless there was continuous inflow from July to November. From 2016/17 to 2018/19, annual inflows increased again to 25.9 GL, 39.2 GL and 32.5 GL, respectively, with discharge occurring almost throughout the year. Salinity in Salt Creek was also variable and seasonal, ranging between 0 and 26 psu from 2010 onwards.

For the purpose of this 11-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 2010/11–2018/19 are defined as post-drought years. For 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 as well as 2017/18–2018/19 were low flow years.

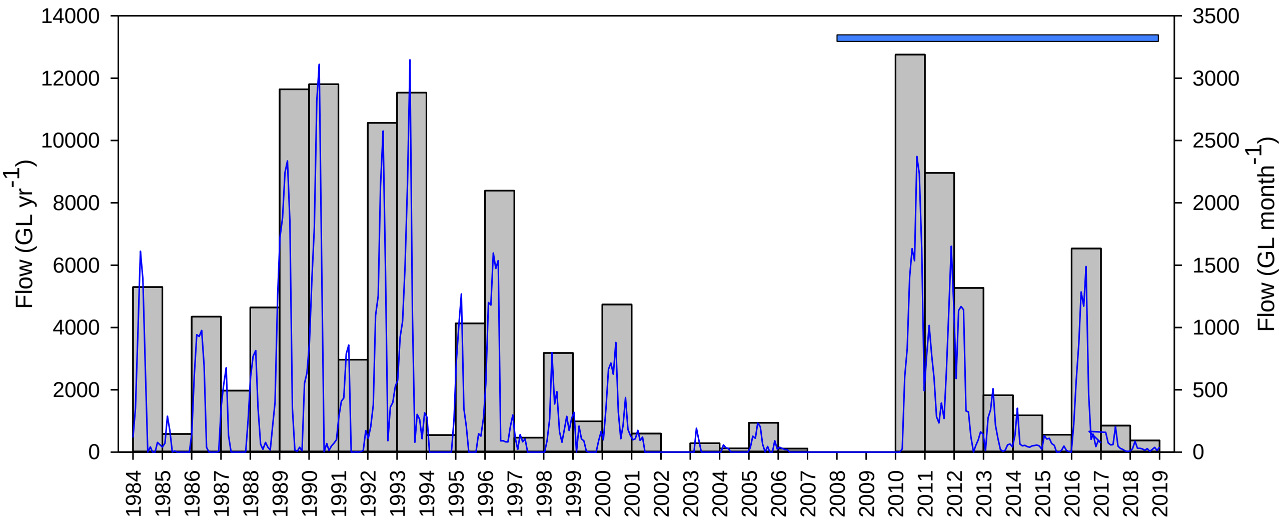


Figure 4.1. Annual (grey bar) and monthly (blue line) freshwater flows across the barrages from July 1984 to June 2019 (source: MDBA). 1984 refers to start of the 1984/85 financial year, i.e. 1st July 1984. Blue bar indicates when fish condition monitoring was conducted.

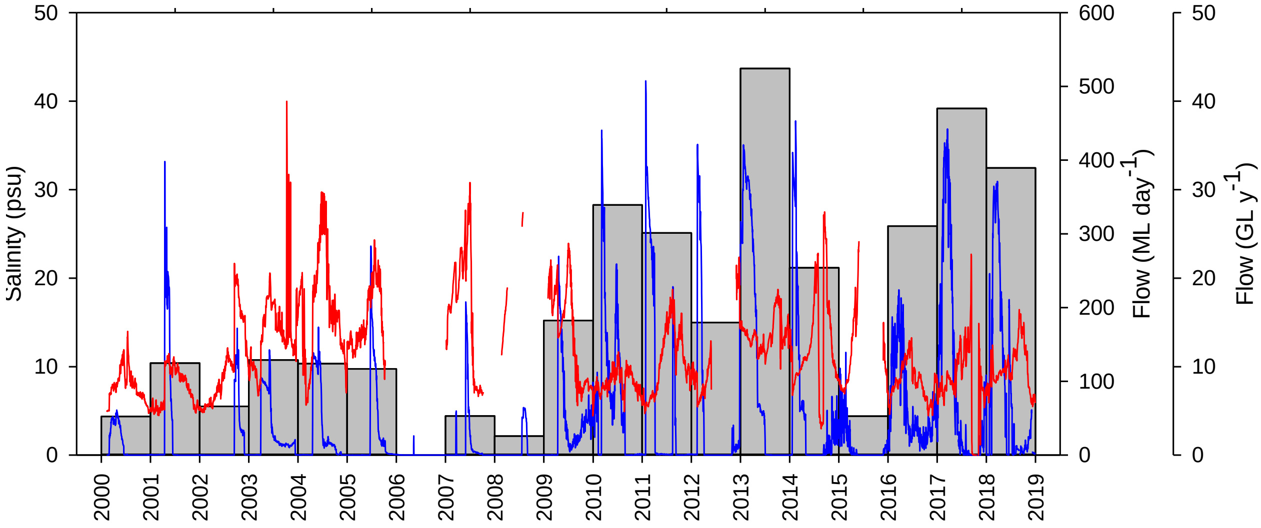


Figure 4.2. Annual (grey bar) and daily (blue line) discharge through the Salt Creek outlet, with salinity levels (red line) from July 2000 to June 2019 (DEWNR 2017b, Water Connect website, Station A2390568). 2000 refers to start of the 2000/01 financial year, i.e. 1st July 2000.

4.2. Water quality

Mean values of salinity and water transparency over the sampling period at each sampling site are presented in Figure 4.3. A north-south gradient of increasing salinity was present in all years. However, there were substantial reductions in mean salinity at all sites after increased barrage releases from 2010/11 to 2014/15, and in 2016/17–2017/18. In 2008/09 and 2009/10, mean salinities ranged from 35–46 psu in the Murray Estuary, 49–100 psu in the North Lagoon, and 95–139 psu in the South Lagoon. In contrast, from 2010/11 to 2014/15, salinities decreased to 0–27 psu in the Murray Estuary, 8–71 psu in the North Lagoon, and 48–98 psu in the South Lagoon. In 2015/16, there was an increased salinity in all sub-regions, with the Murray Estuary being close to marine condition (30–35 psu) and the South Lagoon salinity ranging 74–117 psu. Following increased barrage inflows in 2016/17, mean salinities decreased to 6–21 psu in the Murray Estuary, 14–54 psu in the North Lagoon and 62–70 psu in the South Lagoon. However, with reduced barrage discharge in following two years, salinities generally increased in all three regions in 2018-19: Murray Estuary (13–30 psu), North Lagoon (32–60 psu) and South Lagoon (66–96 psu).

Water transparency was the highest during the drought years (no inflow, 2008/09–2009/10), followed by a substantial decline, particularly in the Murray Estuary, after the flood and high flows in 2010/11–2013/14. In 2014/15–2015/16 and 2017/18–2018/19, with reduced flow, water transparency increased to a similar level of the drought years' in the Murray Estuary and North Lagoon; whereas high flow in 2016/17 resulted in a substantial decline in transparency in these regions. In the South Lagoon, water transparency remained stable and low (Secchi disc depth mostly <0.6 m) over the study period except for 2008/09, when transparency increased in the southern sites to ≥1.2 m.

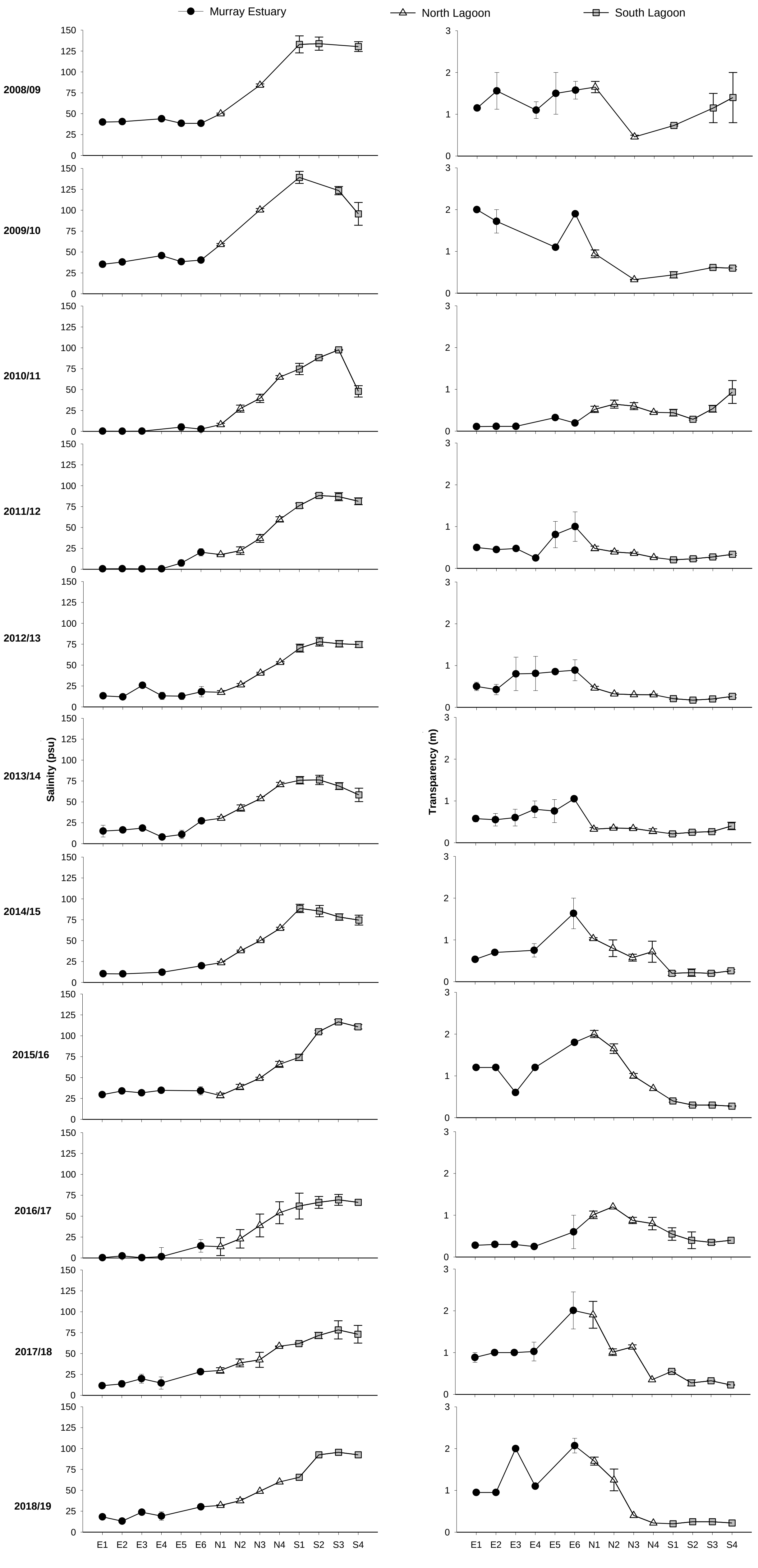


Figure 4.3. Mean values ± S.E. of salinity (psu) (left) and transparency (secchi disc depth, m) (right) over the sampling period at each sampling site (data from all sampling occasions pooled) in the Coorong between 2008/09 and 2018/19.

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 (2008/09–2018/19) (Figure 4.4). The catch in 2018/19 was 0.7 t, which was the lowest recorded since 1984/85 and considerably below the target of 8 t (less than 10%). The annual catch of the last 4-year period showed a negative trend, suggesting a general decrease in the population abundance/biomass from 2015/16 to 2018/19 (Figure 4.5).

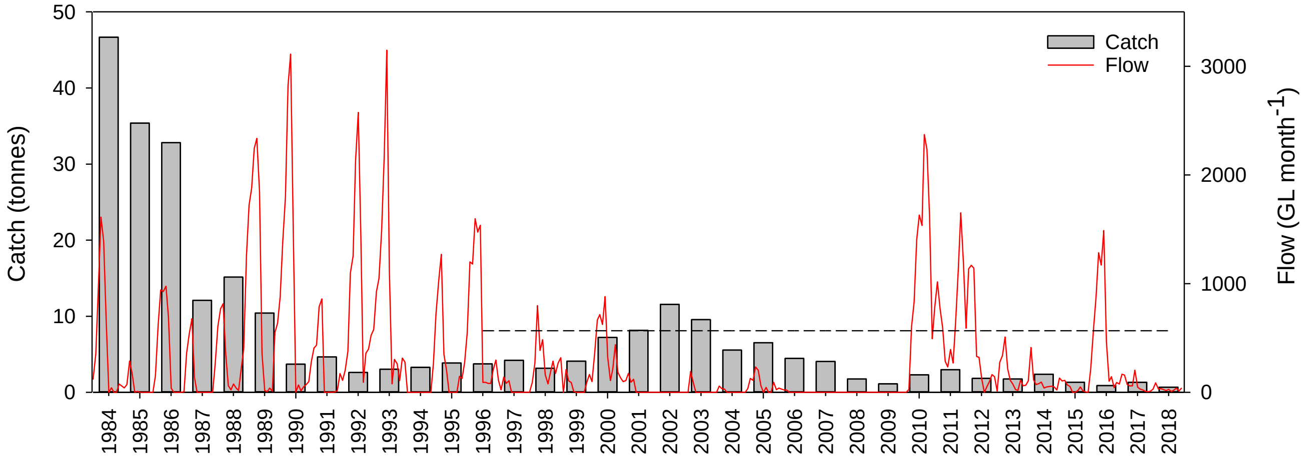


Figure 4.4. Annual commercial catch of black bream from the Coorong between 1984/85 and 2018/19 (note that 1984 refers to 1984/85 financial year). The redline represents modelled monthly flow discharge to the Coorong (GL month^{-1}) between July 1984 and June 2019 (Data source: MDBA). Dotted black line represents the target value based on the mean annual catch (8 t) between 2000/01 and 2005/06.

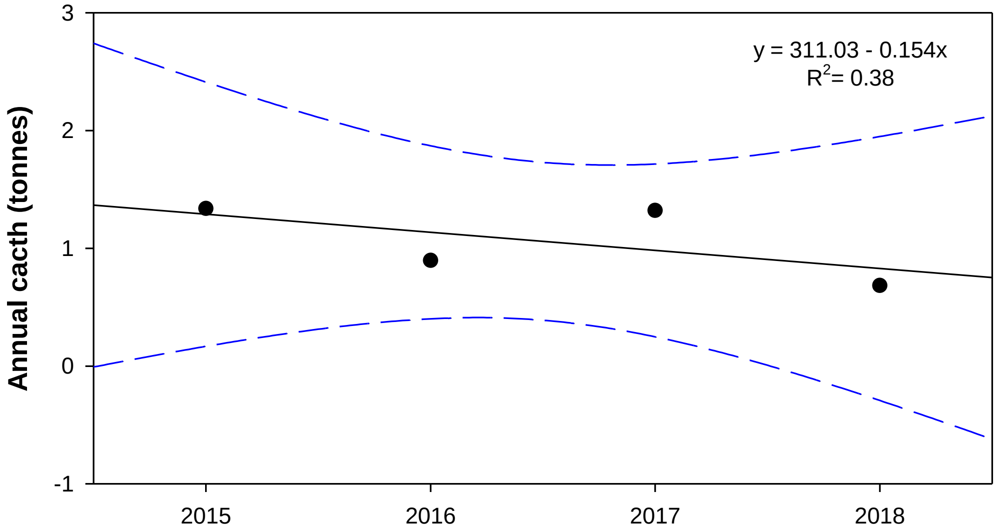


Figure 4.5. Trend in the black bream catches over four years (2015/16–2018/19). Blue dash lines show 95% confidence intervals.

4.3.2. Distribution

The spatial distribution of commercial fishery catches of black bream varied across the Coorong over the last 35 years (Figure 4.6). Prior to the mid-1990s, the majority of black bream catches were from the North and South lagoons of the Coorong, whereas during the drought (2001–2010), >90% of the catch came from the Murray Estuary. 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. However, it declined from 2013/14–2015/16 after flow reduced. Following high flows in 2016-17, over 55% of the catch was from the southern Coorong (south of Mark Point) in 2016/17–2017/18. Contrastingly, with reduced flows since 2017/18, only 34% of the black bream catch came from this area in 2018/19.

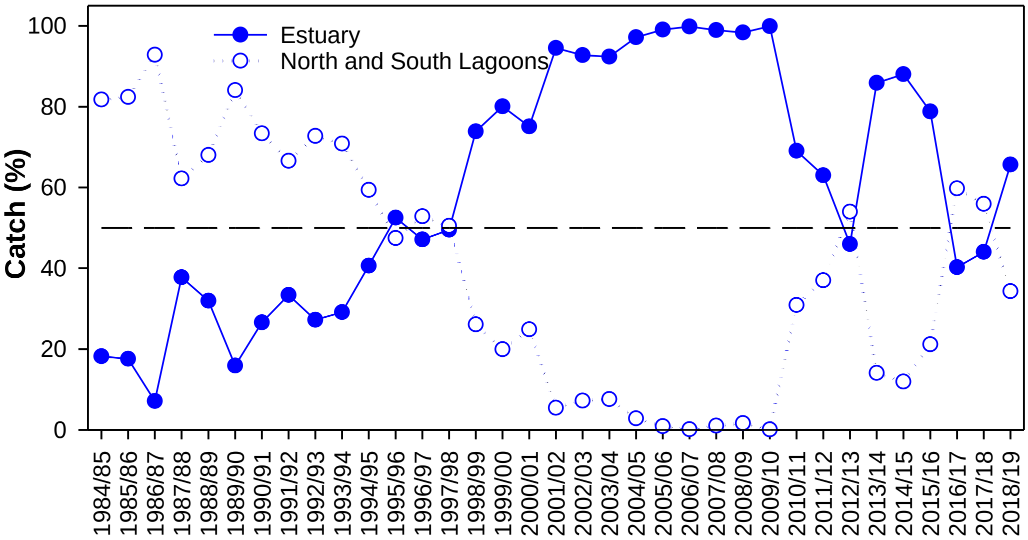


Figure 4.6. Black bream commercial fishery catches from different areas (proportional catches from Estuary vs the North and South lagoons) in the Coorong between 1984/85 and 2018/19. Dashed line indicates 50%.

4.3.3. Age structure

From 2008/09 to 2018/19, ages of black bream, sampled from commercial fishery catches, ranged from 2 to 32 years, although most fish were <10 years old (Figure 4.7). Nevertheless, in 2008/09 and 2009/10 older fish (>10 years of age) comprised 30.2% and 36%, respectively, of the age composition.

The time-series of annual age structures in the last 11 years indicates several relatively strong cohorts 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. After 2010/11, this year class was not clearly represented in age structures. The second strongest cohort originated in 1997/98, and persisted as 11 and 12 year olds in 2008/09 and 2009/10, respectively.

In 2011/12, another strong cohort of 5 year olds appeared, which were spawned in 2006/07. This cohort remained distinct in the following five years. In 2013/14, a moderate cohort of 4 year olds was observed, representing the 2009/10 year class. This cohort persisted in 2014/15 and 2015/16 as 5 and 6 year olds, respectively. In 2015/16, the age structure was more evenly distributed compared to other years, with 2009/10 and 2006/07 cohorts continuing to be distinct and a new 2012/13 cohort appearing. The 2012/13 cohort became more distinct as 4 year olds in the age structure of 2016/17, along with the dominant 2006/07 cohort as 10 year old fish. In 2017/18, the age structure was dominated by 2012/13 cohort (4 year olds) although other cohorts (2009/10, 2006/07 and 1997/98) continued to be present. In 2018/19, the age structure was evenly distributed with 73% of fish ranging between 3 and 6 year olds.

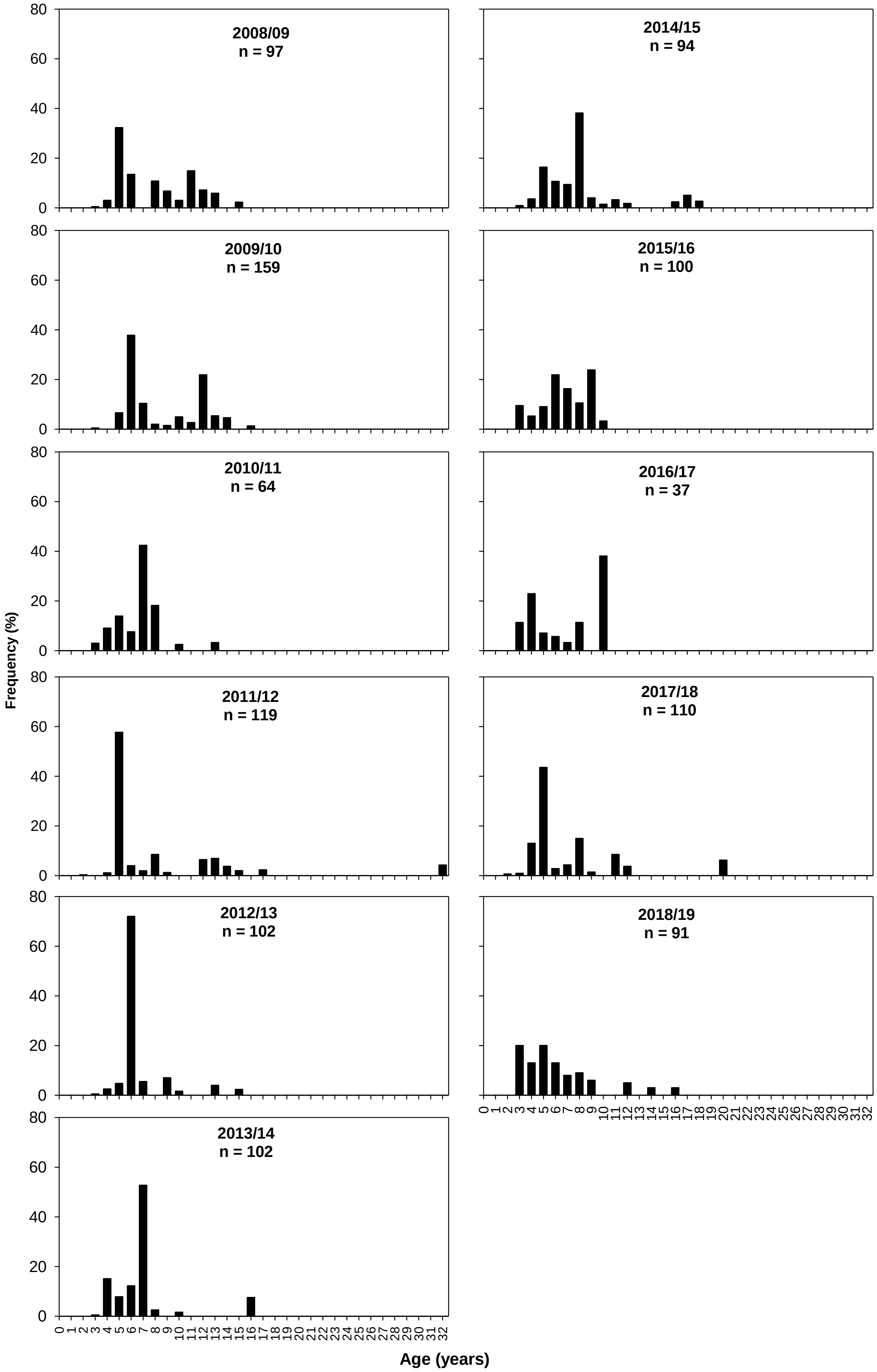


Figure 4.7. Age structure of black bream from the Coorong from 2008/09 to 2018/19 (commercial fishery samples).

4.3.4. Recruitment

Relative abundance (CPUE, fish.net night^{-1} by fyke net) of black bream YOY generally remained low and varied across sampling sites in the Coorong over the last 11 years (2008/09–2018/19) (Table 4.1). The CPUE was at a peak of 2.03 fish.net.night^{-1} in 2008/09, followed by a reduction to 0.86 fish.net night^{-1} in 2012/13, and a substantial decline thereafter with no YOY caught in 2014/15 and 2016/17. Notably, in 2017/18 relative abundance of YOY black bream was the highest of all years (2.06 fish.net night^{-1}), whilst no YOY was collected in 2018/19. Black bream YOY were only collected in >50% of the sites in 2008/09 and 2017/18, although in the earlier year, sampling was generally restricted within the Murray Estuary. Length frequency distribution of YOY between 2008/09–2018/19 are presented in Appendices D, E and F.

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 11 years, the black bream population condition in the Coorong, was ‘extremely poor’, ‘very poor’ or ‘poor’. In 2017/18, the condition improved to ‘moderate’, due to a substantial increase in abundance and distribution of black bream YOY. Nevertheless, in 2018/19, the population condition declined to ‘very poor’ in the Coorong.

Table 4.1. Relative abundance (CPUE, fish.net night^{-1}) of juvenile black bream for different sampling sites in the Coorong (SE= standard error). (HI = Hindmarsh Island, SRP = Sir Richard Peninsula, YHP = Young Husband Peninsula).

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**	
Regular sites	**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	**3.54**	**1.32**	**0.42**	**0.16**	**0.00**	**0.00**	**0.00**	**0.00**	**0.92**	**0.32**	**0.00**	**0.00**	**0.00**	**0.00**	**0.38**	**0.26**	**0.00**	**0.00**	**2.25**	**0.75**	**0.00**	**0.00**
Goolwa Barrage saltwater side SRP e	**4.25**	**1.31**	**1.25**	**0.33**	**0.00**	**0.00**	**0.02**	**0.02**	**1.06**	**0.34**	**0.03**	**0.03**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.75**	**0.42**	**0.00**	**0.00**
Mundoo Barrage	**0.25**	**0.25**			**0.00**	**0.00**	**0.04**	**0.03**	**1.47**	**0.82**	**0.00**	**0.00**			**0.00**	**0.00**	**0.00**	**0.00**	**4.25**	**1.01**	**0.00**	**0.00**
Boundary Creek	**0.06**	**0.06**	**0.00**	**0.00**			**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Additional sites																						
Goolwa Barrage FW HI end	0.00	0.00																				
Goolwa Barrage FW SRP end	0.00	0.00	0.00	0.00																		
Beacon 19																					0.00	0.00
Swan Point							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
Ewe Island																			1.25	0.75	0.00	0.00
Ewe Island Causeway	0.00	0.00	0.00	0.00																		
Opposite Tauwitchere Barrage	1.33	1.33	0.00	0.00																		
Pelican Point	0.00	0.00																				
Pelican Point YHP	0.13	0.13																				
Pelican Pt. YHP Opp. Rumbelow Shack							0.00	0.00														
Cattle Point					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							1.25	0.25	0.00	0.00
South Cattle Point							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
Mark Point beach							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
Long Point beach							0.00	0.00	0.00	0.00	0.00	0.00										
Long Point reef							0.00	0.00	0.00	0.00	0.00	0.00										
Long Point sand dune					0.00	0.00													2.00	1.68	0.00	0.00
Long Point YHP Side; opp. Jetty							0.00	0.00	0.00	0.00												
Robs Point					0.00	0.00																
Noonameena					0.00	0.00																
Average across regular sites	**2.03**	**1.09**	**0.56**	**0.32**	**0.00**	**0.00**	**0.02**	**0.01**	**0.86**	**0.31**	**0.01**	**0.01**	**0.00**	**0.00**	**0.09**	**0.09**	**0.00**	**0.00**	**2.06**	**0.87**	**0.00**	**0.00**
Average across sites	**1.64**	**0.40**	**0.42**	**0.10**	**0.00**	**0.00**	**0.03**	**0.01**	**0.68**	**0.20**	**0.01**	**0.01**	**0.00**	**0.00**	**0.05**	**0.03**	**0.00**	**0.00**	**0.70**	**0.18**	**0.00**	**0.00**
# Sites sampled	13		6		9		17		12		11		6		4		6		14		12	
# Sites black bream YOY present	8		2		0		3		3		1		0		1		0		8		0	
% of site YOY present	62%		33%		0%		18%		25%		9%		0%		25%		0%		57%		0%	

Table 4.2. Condition assessment for black bream populations in the Coorong from 2008/09 to 2018/19. 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. 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	
Relative abundance	Catch (t/year)	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	Positive (slope)
	Score	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	
Distribution	Proportional catch	No	No	No	No	Yes	No	No	No	Yes	Yes	No	>50% from southern part
	Score	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	
Age structure	% fish >10 years	Yes	Yes	No	Yes	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	At least one strong cohort (≥ 15%)
	Number of strong cohorts in population	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	≥2 strong cohorts
	Score	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	
Recruitment indices	YOY CPUE	Yes	No	No	No	Yes	No	No	No	No	Yes	No	>0.77 YOY.net night^{-1}
	YOY distribution	---*	No	No	No	No	No	No	No	No	Yes	No	>50% sites (detected)
	Score	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	
Icon site total score		**1**	**1**	**0**	**2**	**2**	**1**	**1**	**0**	**2**	**3**	**1**	
Black bream condition		**Very poor**	**Very poor**	**Extremely poor**	**Poor**	**Poor**	**Very poor**	**Very poor**	**Extremely poor**	**Poor**	**Moderate**	**Very poor**	

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

4.4. Greenback flounder

4.4.1. Relative abundance (fishery catch)

The annual catch of greenback flounder was below the ecological target (≥24 t y^{-1}) in all study years, except 2011/12 (Figure 4.8). The high catch in 2011/12 (31 t) indicated an increase in relative abundance following high flows in 2010/11 and 2011/12. However the catches decreased in the following three years. Despite a slight increase to 4.5 t in 2015/16, the catches remained ≤2.1 t y^{-1} over the last three years, with 1.9 t in 2018/19. These levels were considerably below the ecological target of 24 t. Additionally, the annual catches of the last 4-year period showed a negative trend, suggesting a general decrease in the population abundance/biomass from 2015/16 to 2018/19 (Figure 4.9).

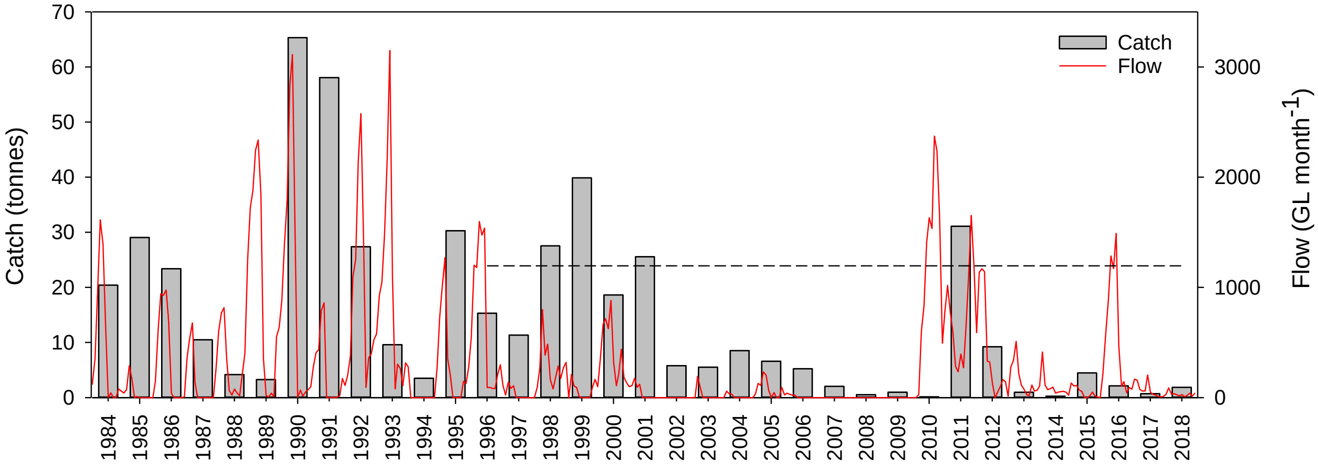


Figure 4.8. Annual commercial catch of greenback flounder from the Coorong between 1984/85 and 2018/19 (note that 1984 refers to 1984/85 financial year). The red line represents modelled monthly flow discharge to the Coorong (GL/month) between July 1984 and June 2019 (Data source: MDBA). Dotted black line represents the target value based on the mean annual catch (24 t) between 1995/96 and 2001/02.

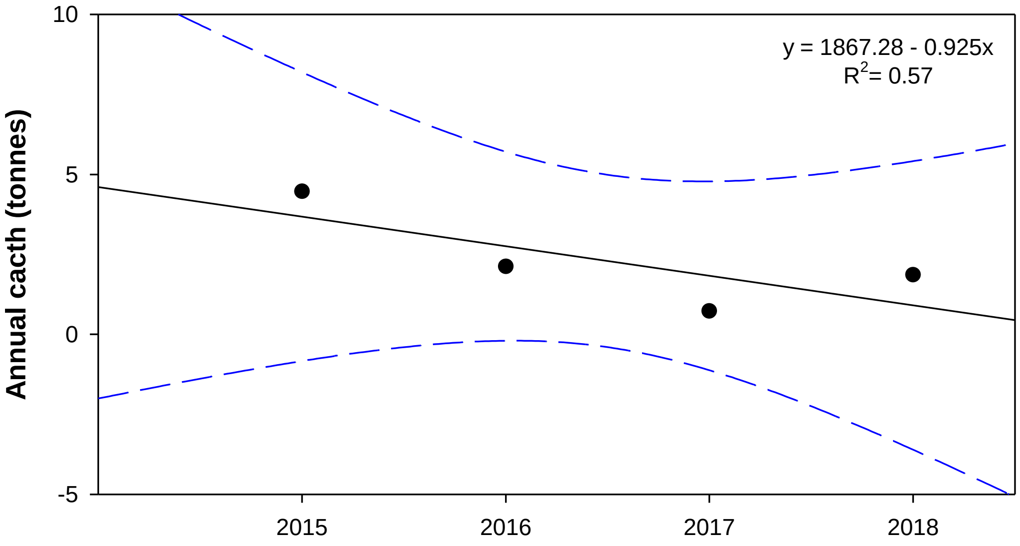


Figure 4.9. Trend in the greenback flounder catches over four years (2015/16–2018/19). Blue dash lines show 95% confidence intervals.

4.4.2. Distribution

The spatial distribution of commercial fishery catches of greenback flounder varied across the Coorong over the last 35 years (Figure 4.10). Prior to 2001, the majority of the catches were from the North and South lagoons of the Coorong. During 2001–2010, there was an increase in the proportional catch from the Murray Estuary such that by 2009/10 and 2010/11, 100% of catches were from the Estuary. Following high flows in 2010–2013, fish from the North and South lagoons again dominated the catch, whereas the proportional catches from the 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 North and South lagoons, thus meeting the ecological target (>70%).

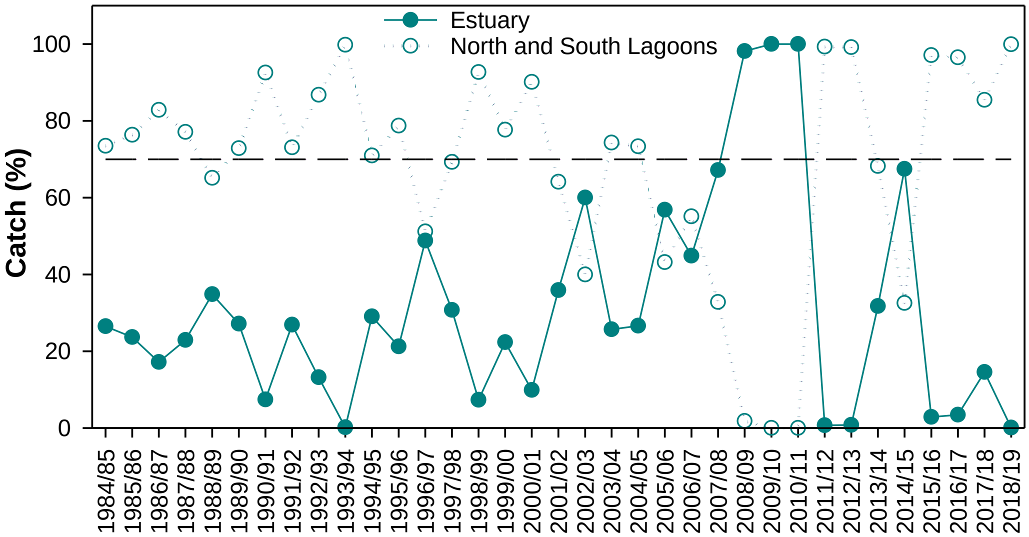


Figure 4.10. Greenback flounder commercial fishery catches from different areas (proportional catches from the Estuary vs the North and South lagoons) in the Coorong between 1984/85 and 2018/19. Dashed line indicates 70%.

4.4.3. Age structure

Ages of greenback flounder, sampled from the commercial fishery between 2009–2019, ranged from 0 to 5 years; and the majority of individuals caught in the Coorong were <3 years (Figure 4.11). In 2011, the age structure comprised a very strong cohort (i.e. >60% of samples) of 1 year olds, that were spawned in 2010 and recruited to the Coorong following the substantial increases of barrage releases after September 2010. This year class persisted as a dominant cohort of 2 year olds (66%) in 2012. In 2013, a very strong cohort (70% of samples) of 2 year olds, spawned in the 2011 high flow year, dominated the age structure. In 2015 and 2016, fish spawned in 2014 dominated as 1 and 2 year olds, respectively, although the sample size was very low in 2016 (n=8). In 2017, 2018 and 2019 the 2 year old cohort represented >45% of the fishes aged. 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 and 2017, there were >20% of fish older than 2 years.

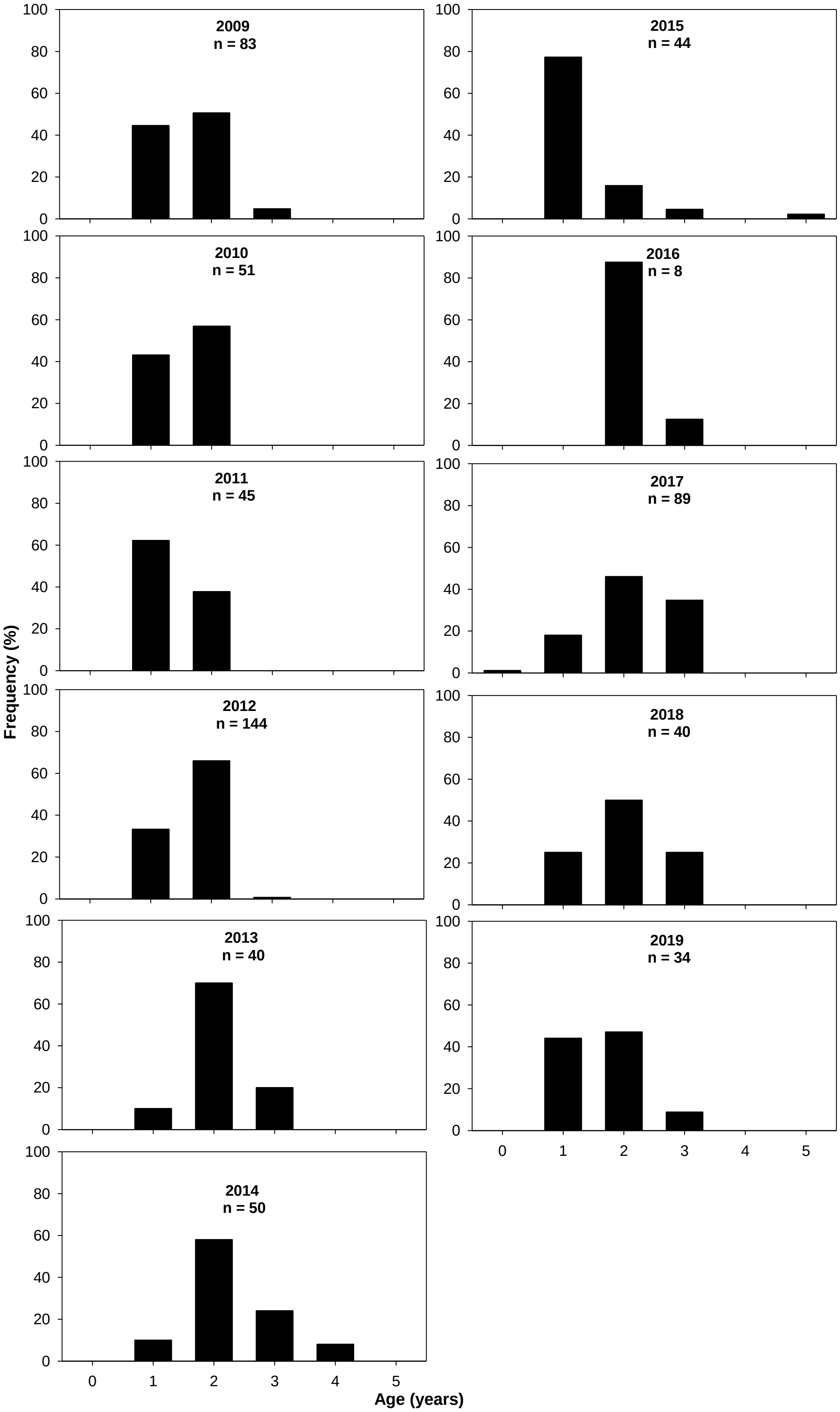


Figure 4.11. Age structure of greenback flounder from the Coorong from 2009 to 2019 (commercial fishery samples).

4.4.4. Recruitment

Relative abundance (CPUE, fish.seine net^{-1}) of greenback flounder YOY varied across sampling sites in the Coorong over the last 11 years (2008/09–2018/19) (Table 4.3). 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 abundance of YOY showed a general increasing trend with the spatial distribution extending southward in the Coorong. However, in 2015/16, both abundance and distribution declined compared to previous years. Since then, mean CPUE has remained <1 fish.seine net^{-1} across sampling sites, although the distribution appeared broader in 2016/17 and 2017/18 than the other two years. In 2018/19, the abundance and distribution of YOY did not meet the target value of 1.04 fish.seine net^{-1} at >50% of the sites. Length frequency distribution of YOY between 2008/09–2018/19 are presented in Appendices G, H and I.

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 4.4). The population condition of this species in the Coorong was ‘extremely poor’ in 2008/09 and 2009/10. It improved to ‘moderate’ during 2011/12–2013/14, following high flows, 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’ and ‘very poor’ in 2017/18 and 2018/19, respectively, and coincided with continued reduced flows.

Table 4.3. Relative abundance (CPUE, fish.seine net^{-1}) of juvenile greenback flounder at sampling sites within the Coorong from 2008/09 to 2018/19.

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	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Sugars Beach	10.78	3.08	27.67	8.82	0.67	0.37	2.87	1.09	0.44	0.24	6.11	2.38										
Godfrey's Landing	17.44	3.18	4.33	1.09	5.33	1.96	0.80	0.53	1.07	0.40	3.53	2.02	1.92	0.75	1.33	0.84	0.33	0.17	1.50	0.85	2.33	1.86
Mark Point	0.92	0.43	0.75	0.33	2.07	0.57	2.00	1.05	6.53	2.02	2.80	0.60	1.25	0.39	1.33	0.76	0.22	0.22	2.00	1.81	1.67	0.88
Noonameena	0.00	0.00	0.00	0.00	0.33	0.27	0.67	0.37	1.07	0.56	0.67	0.35	14.33	2.98	2.17	0.91	0.11	0.11	2.83	1.11	0.00	0.00
Mt Anderson					2.00	0.94	0.07	0.07	0.07	0.07	0.53	0.24	0.42	0.23	0.17	0.17	0.22	0.15	0.67	0.67	0.33	0.33
Hells Gate	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.14	0.00	0.00	0.07	0.07	0.08	0.08	0.00	0.00	0.22	0.15	0.17	0.17	0.00	0.00
Villa dei Yumpa					0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jack Point	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salt Creek	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.00	0.00
Mean across sites	**4.16**	**2.67**	**4.68**	**3.88**	**1.16**	**0.59**	**0.73**	**0.34**	**1.03**	**0.70**	**1.52**	**0.72**	**2.25**	**1.74**	**0.63**	**0.30**	**0.14**	**0.05**	**0.88**	**0.31**	**0.54**	**0.33**
# Sites sampled	**7**		**7**		**9**		**9**		**9**		**9**		**8**		**8**		**8**		**8**		**8**	
# Sites greenback flounder YOY present	**3**		**3**		**5**		**5**		**6**		**6**		**5**		**4**		**5**		**6**		**3**	
% of site YOY present	**43%**		**43%**		**56%**		**56%**		**67%**		**67%**		**63%**		**50%**		**63%**		**75%**		**38%**	

Table 4.4. Condition assessment for greenback flounder population in the Coorong from 2008/09 to 2018/19. Please note, age composition was based on calendar year. Rule of scoring: each indicator receives 1 point if indices meet the following requirements: (1) Relative abundance – one of the indices meets the reference point; (2) Distribution – meet the reference point; (3) Age structure – one of the indices meets the reference point and (4) Recruitment – both indices meet the reference points. Overall score – fish population condition: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor.

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

4.5. Smallmouth hardyhead

4.5.1. Relative abundance

Relative abundance of adult smallmouth hardyhead in the Coorong varied over the last 11 years (Figure 4.12). The mean CPUE was higher and above the ecological target value (120 fish.UE^{-1}) in four of the 11 years (i.e. 2011/12, 2015/16, 2016/17 and 2018/19). Flows to the Coorong were high in 2011/12 and 2016/17, whereas the other two were dry years. The highest CPUE in 2015/16 and 2018/19 may have been an over-estimate of relative abundance of adults because no spring–early summer sampling occurred in these years, and instead, data collected in late summer/early autumn (February/March) were used. Further information on adult CPUE by sampling site are presented in Appendix P.

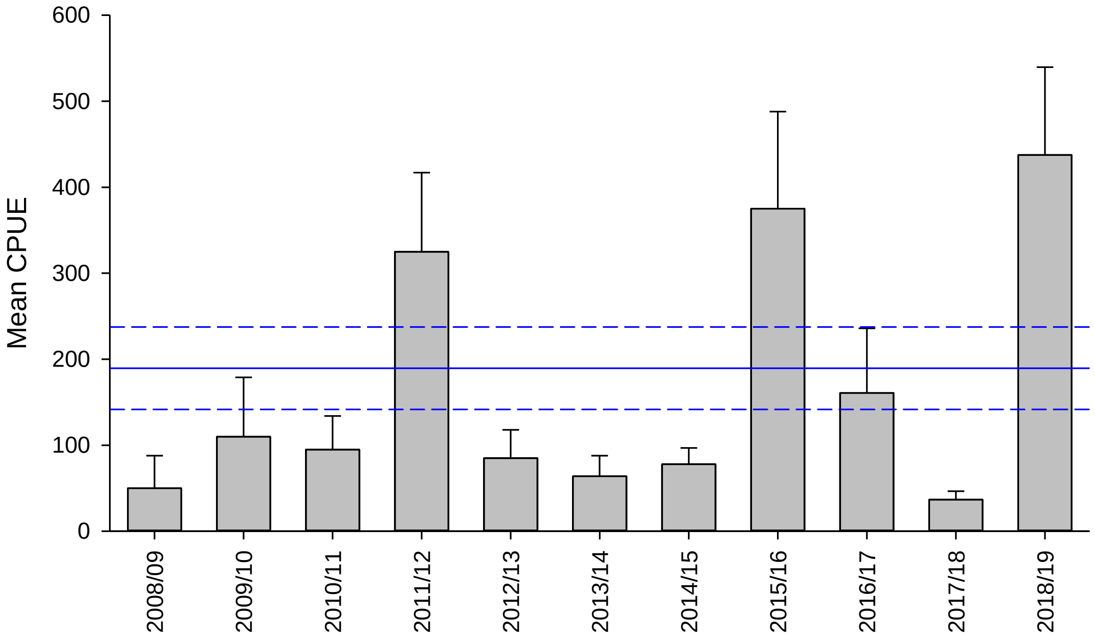


Figure 4.12. Mean seine net catch per unit effort (CPUE) ± SE of adult (spring/early summer; ≥40 mm TL) smallmouth hardyhead in the Coorong from 2008/09 to 2018/19. Note: Reference point (solid blue line) is established using the mean CPUE from 2011/12–2013/14. Confidence intervals are ± 25% (dashed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

4.5.2. Recruitment (relative abundance of new recruits)

Relative abundance of new recruits (smallmouth hardyhead <40 mm TL) showed a rapid response to the 2010/11 flood, with significant increases in January/February 2011 and 2012 (Figure 4.13). Abundance declined over the next three years from 817 fish.UE^{-1} in 2012/13 to 195 fish.UE^{-1} in 2014/15. However, it should be noted that the 2014/15 value may have been under-estimated because only large seine net data were available from intervention monitoring in this year whereas the small seine net has been more effective in sampling new recruits. Abundance of new recruits increased over the next two years to 1,162 fish.UE^{-1} in 2016/17. Following a decrease in 2017/18, it increased again in 2018/19 (1,782 fish.UE^{-1}) to above the ecological target (800 fish.UE^{-1}). Length frequency distributions of smallmouth hardyead samples from both large and small seine nets from 2008/09–2018/19 are presented in Appendices J–O. More detailed information on new recruit CPUE by sampling site are presented in Appendix Q.

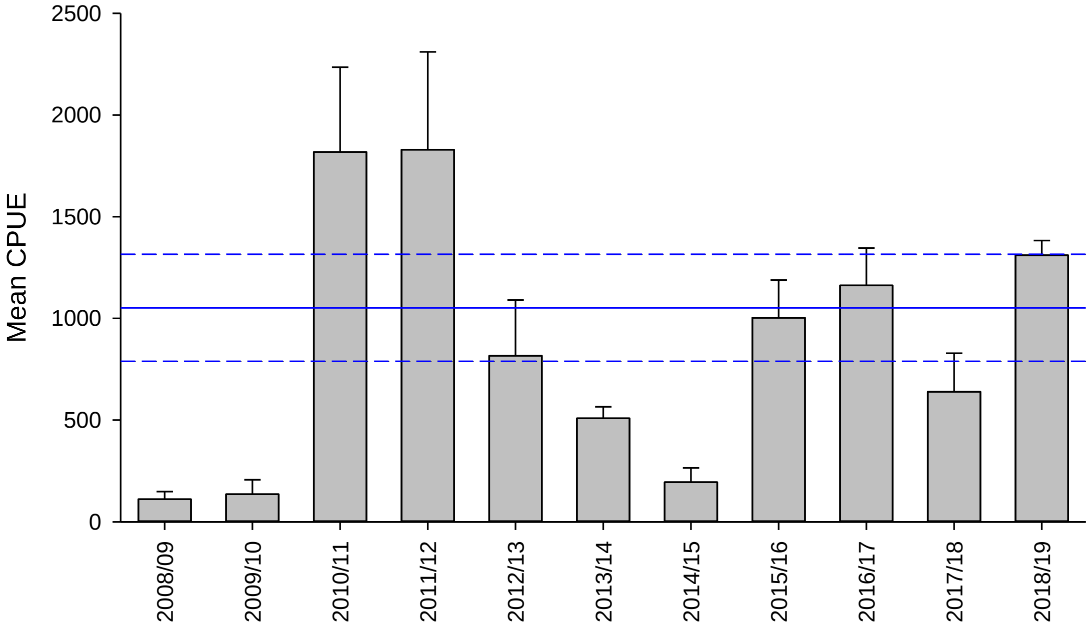


Figure 4.13. Mean small seine net catch per unit effort (CPUE) ± SE of new recruit (late summer/autumn; <40 mm TL) smallmouth hardyhead in the Coorong for 2008/09 to 2018/19. Note: Reference point (solid blue line) is established using the mean CPUE from 2011/12–2013/14. Confidence intervals are ± 25% (dashed blue lines with the lower line set as the ecological target >800 fish.UE^{-1}). 2014/15 value is based on large seine net data only.

4.5.3. Extent of recruitment

In 2008/09 and 2009/10, only 20% of sites showed significant recruitment (i.e. having >60% of fish being new recruits) (Table 4.5). In contrast, for post-drought years following increased flows (2010/11–2013/14), the majority of sites (88–100%) had >60% recruits. With reduced flow to the Coorong in 2014/15 and 2015/16, significant recruitment occurred in only 63% of the sampling sites. Following high flows in 2016/17, all sites (100%) showed significant recruitment in 2016/17 and 2017/18. However, in 2018/19 with low flows, this occurred only at 75% of the sites (just missed the target of >75%). Over the last 11 years, the ecological target was met in six years (i.e. 2010/11–2013/14 and 2016/17–2017/18), which all followed high flows. Important to note, the results of 2014/15, 2015/16 and 2018/19 should be interpreted with caution. As previously indicated, only large seine net data were available in 2014/15 which may have under-estimated the level of new recruits, whereas in 2015/16 and 2018/19 using data from February/March instead of November/December may have over-estimated adult numbers, thus leading to a potential under-estimate of the extent of recruitment.

4.5.4. Distribution

The presence of adult and new recruit smallmouth hardyhead across sampling sites indicated their distribution across the Coorong from 2008/09 to 2018/19 (Table 4.6). In the first two years under drought conditions, 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%). Although adults were only present in 50% of the sites in 2010/11, they have been sampled across most sites (88%–100%) since 2011/12, meeting the ecological target (>87% sites).

Table 4.5. 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 2018/19. Note: 2014/15 values are based on large seine net data only; 2015/16 and 2018/19 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**
Site	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**	**CPUE**
Abundance of new recruits											
Mark Point (N1)	73	357	699	233	99	254	48	582	620	230	683
Long Point (N2)			3352	499	161	345	23	523	561	319	1148
Noonameena (N3)	149	242	2447	4707	378	626	26	385	810	1716	1069
Mt Anderson (N4)			2863	2248	423	562	9	641	1101	160	454
Hells Gate (S1)		0	2123	1654	1740	578	527	1658	1806	1103	1808
Villa de Yumpa (S2)			2337	1470	373	688	364	1264	1974	363	1009
Jack Point (S3)		0	141	1699	2098	646	333	1618	1336	460	2180
Salt Creek (S4)		80	583	2120	1269	371	231	1351	1090	765	2129
Total abundance (new recruits + adults)											
Mark Point (N1)	73	698	790	463	100	263	55	848	761	230	1587
Long Point (N2)			3504	750	175	367	120	999	654	335	1470
Noonameena (N3)	396	439	2701	5578	387	849	84	653	936	1746	1492
Mt Anderson (N4)			2863	2527	491	621	60	1103	1128	169	797
Hells Gate (S1)	1	0	2194	2185	2028	616	632	2740	1999	1173	2253
Villa de Yumpa (S2)			2337	1539	471	754	421	1348	2636	415	1123
Jack Point (S3)	0	1	143	1814	2170	721	525	1724	1377	506	3000
Salt Creek (S4)	1	94	584	2373	1402	391	292	1602	1093	837	2260

Proportional abundance of new recruits (%)											
Mark Point (N1)	100	51	88	50	99	97	88	69	81	100	43
Long Point (N2)			96	67	92	94	19	52	86	95	78
Noonameena (N3)	38	55	91	84	98	74	31	59	87	98	72
Mt Anderson (N4)			100	89	86	90	15	58	98	95	57
Hells Gate (S1)	0	0	97	76	86	94	83	61	90	94	80
Villa de Yumpa (S2)			100	96	79	91	86	94	75	87	90
Jack Point (S3)	0	0	99	94	97	90	63	94	97	91	73
Salt Creek (S4)	0	85	100	89	91	95	79	84	100	91	94
% of sites with significant recruitment	**20**	**20**	**100***	**88***	**100***	**100***	**63**	**63**	**100***	**100***	**75%**

Table 4.6. Distribution of smallmouth hardyhead adults and new recruits from 2008/09 to 2018/19 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 finding constrains.

	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
# Sites sampled	5	5	8	8	8	8	8	8	8	8	8
# Sites new recruits present	2	3	8	8	8	8	8	8	8	8	8
# Sites adults present	1	3	4	8	7	8	8	8	7	7	8
% of sites new recruits present	**40%**	**60%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
% of sites adults present	**20%**	**60%**	**50%**	**100%**	**88%**	**100%**	**100%**	**100%**	**88%**	**88%**	**100%**

4.5.5. Condition assessment

Based on the above analyses of indicators and indices against ecological targets (reference points), scores were assigned to each indicator and a total score of population condition was calculated for smallmouth hardyhead in each year (Table 4.7). 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). With substantially increased flows, the condition improved from ‘moderate’ to ‘very good’ in 2010/11–2012/13. Since 2013/14, the population condition has remained ‘moderate’ or ‘poor’ associated with generally low flows except for 2016/17 when the condition was ‘very good’ following high flows.

Table 4.7. Condition assessment for smallmouth hardyhead populations in the Coorong from 2008/09 to 2018/19. Scoring system: each index receives 1 point if it is ‘yes’. Icon site score: 0 = Extremely Poor, 1 = Very Poor, 2 = Poor, 3 = Moderate, 4 = Good and 5 = Very Good.

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

*Note: In 2015/16 and 2018/19, 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 and salinity

Over a decade (2001–2010), extensive drought in the MDB, combined with river regulation and water extraction, led to a significant reduction in freshwater flow to the Coorong. During the drought, annual discharges were <1,000 GL y^{-1}, significantly below the long-term mean (1984/85–2016/17; 3,800 GL y^{-1}), and there was no discharge between 2007/08 and 2009/10. Following increased rainfall in the MDB and high flows in the River Murray, the Lower Lakes were refilled and freshwater releases to the Coorong increased substantially in 2010/11 to be amongst the highest (~12,800 GL y^{-1}) since 1984. The flow remained high in 2011/12 and in 2012/13 (>5,000 GL y^{-1}). Since 2013/14, high barrage discharge (~6,500 GL y^{-1}) only occurred in 2016/17 when there was an extensive flood in the MDB. In contrast, barrage releases were <1,000 GL y^{-1} in recent dry years (e.g. 2014/15, 2015/16, 2017/18 and 2018/19), most of which was environmental water, including Commonwealth environmental water, TLM water and other sources (e.g. Victorian Environmental Water Holder, River Murray Increased Flows) (Ye *et al.* 2020).

Salinities in the Coorong are highly variable, mainly driven by freshwater flows from the River Murray and tidal seawater exchange through the Murray Mouth (Geddes and Butler 1984). From 2006–2009, the Coorong was essentially a marine/hypersaline environment due to the lack of barrage releases (Noell *et al.* 2009). During this period, salinities in the southern part of the North Lagoon exceeded 100 psu and those in the South Lagoon were about 3–4 times that of seawater (~140 psu). These salinities were higher than those recorded during the 1982 drought, when the mean was 80 psu in the North Lagoon and 90–100 psu in the South Lagoon (Geddes and Butler 1984), and may represent the highest levels ever recorded in the Coorong. Increased salinities throughout the Murray Mouth and Coorong during the drought had a pronounced impact on fish assemblages in the region with generally reduced abundance and species diversity (Noell *et al.* 2009; Zampatti *et al.* 2010; Ye *et al.* 2012; 2016).

Substantial freshwater flows following September 2010 led to reduced salinities throughout the Coorong from 2010/11–2014/15, with fresh to brackish conditions restored in the Murray Estuary and an extended area of the North Lagoon, and salinities reducing to <100 psu in the South Lagoon. As a result, there was a general improvement in the fish assemblage in this region with increased diversity, abundance and distribution, particularly for estuarine and diadromous species (Ye *et al.* 2012, 2016). Similar responses were observed in 1983/84 when high River Murray 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).

From 2012/13 to 2014/15, with reduced flows from the River Murray, salinity levels increased in the Murray Estuary; whereas they remained less than 80 psu in the North and South lagoons, reflecting a lag in the response time in the southern part of the Coorong due to its distance from the Murray Mouth. In 2015/16, with continued low flows to the Coorong, salinity increased in all three sub-regions. In 2016/17, however, high inflows freshened the entire Coorong, reducing salinities to similar levels of other flood or high flow years (2010/11 and 2011/12). Noticeably, flow releases from Salt Creek also helped with a localised salinity reduction in the southern end of the South Lagoon in 2009/10 and 2010/11, although this effect was not as pronounced in other years.

5.2. Black bream

5.2.1. Relative abundance

The relative abundance of black bream, as indicated by commercial fishery catches, has declined substantially in the Coorong since 1984/85. The mean annual catches during the 11 years of this study (2008/09–2018/19) were <4% of the peak level of catch in 1984/85 (46.7 t), and ~16% of a recent small peak in 2002/03 (11.6 t). The annual catches over the last three years were the lowest since 1984/85 (no more than 1.6 t), suggesting that the current abundance of black bream (legal size for fishery ≥30 cm TL) in the Coorong is historically low. It should be noted that since 2009, commercial fishing practice 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). Regardless, the catch levels in the last three years were of a similar magnitude to those in years prior to the introduction of long-nosed fur seals. Also in 2018-19, there was a seasonal fishing closure for black bream in the Coorong from 1 September to 30 November, which would have reduced the catch in 2018/19. Nevertheless, the very low catches (0.7 t) from other months of this year suggested that the ecological target of 8 t was unlikely to be met even without the closure. Furthermore, there was a general trend of a decrease in catches over the last four years. Therefore, the ecological target of an increasing trend in abundance was not met for black bream in the Coorong. A recent fishery stock assessment also concluded that the biomass of black bream in the Coorong was at a low level and the population was classified as ‘over-fished’ (Earl *et al.* 2016).

5.2.2. Distribution

Commercial catches of black bream provided a useful indicator of change in distributional range along the Coorong. From the early 1990s to 2010/11, there was a contraction of the fishing area from the North and South lagoons to the Murray Estuary, and almost all black bream were harvested within the Murray Estuary from 2005/06 to 2009/10, the latter half of the Millennium Drought. Previous reporting showed that the contraction of fishing area was concurrent with increases in catch rates (CPUE) from 1993/94 to 2007/08 (Ye *et al.* 2015b). This suggests an increase in catchability of black bream, as the population contracted into a reduced area of favourable habitat due to poor environmental conditions in the Coorong as a result of the drought. The freshening of the Coorong after 2010/11 coincided with a steady increase in the proportional catch from the North and South lagoons from 2010/11 to 2012/13, indicating a range extension for this species. 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 program in the Coorong also demonstrated the increased range of black bream as it extended into the South Lagoon in 2011/12–2013/14 (Ye *et al.* 2015a). This range extension likely reflected the increase in area of favourable salinities and associated conditions, despite that black bream can tolerate high salinities (up to 88 psu in aquaria) (McNeil *et al.* 2013). From 2013/14 to 2015/16, the proportional fishery catches from the North and South lagoons declined to 12–21%, corresponding to reduced inflows and increased salinities in the Coorong. Nevertheless, the proportion increased again to 60% with high inflows in 2016/17, meeting the ecological target (i.e. >50% of the catch from the southern part of the Coorong (south of Mark Point)). The above findings indicate that freshwater flow plays a pivotal role in maintaining and extending favourable estuarine habitat for black bream in the Coorong. This was further supported by the gradual catch reduction from the southern Coorong associated with decreased flows in 2017/18 and 2018/19. The 34% catch from the southern Coorong in 2018/19 was below the ecological target.

5.2.3. Age structure

The time-series of age structures from 2008/09 to 2018/19 indicated episodic recruitment of black bream in the Coorong with several moderate to strong cohorts identified, corresponding to fish spawned in 1997/98, 2003/04, 2006/07, 2009/10 and 2012/13. Interestingly, none of them were generated in high flow years, which suggests that the recruitment of black bream may benefit from small-scale flow releases through the Murray barrages in this modified estuary post river regulation. For instance, barrage releases in 1997/98, 2003/04 and 2006/07 (all <500 GL), which coincided with strong cohorts, were all discharged into the system in late winter/spring. Given that black bream spawning typically occurs during spring–summer in the Coorong (Ye *et al.* 2013b; Ye *et al.* 2019b), such small volumes of freshwater releases to the estuary in the months prior to and during the spawning season may have benefited recruitment by: (1) attracting spawning aggregation of black bream, which could be important given the low biomass in this region; and (2) providing favourable habitat by influencing salinity gradients (levels and stratification) 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.

Many studies have identified freshwater inflows as a key factor influencing black bream recruitment (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 variability, are unique to each estuary based on characteristics of catchment, channel topography and connection to the sea (Jenkins *et al.* 2010). For example, the highest recruitment 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).

Black bream is a slow-growing, long-lived estuarine species (Norriss *et al.* 2002). The maximum age of black bream from the Coorong population reported in this study was 32 years. Nevertheless, few individuals (mean <5% per year) greater than 13 years old were present from 2008/09 to 2018/19, and the target of >20% of fish being older than 10 years was only met in three of the 11 years. The truncation of age structures has previously been reported for the Coorong population in the early to mid-2000s (Ferguson and Ye 2008). Given black bream typically complete their lifecycle within estuaries, and numerous studies suggest little emigration from estuarine systems or large-scale movements between estuaries (e.g. Butcher and Ling 1962; Lenanton 1977; Hall 1984; Hoeksema *et al.* 2006; Hindell *et al.* 2008), the most likely explanation for the highly truncated age structures is that the removal of older and larger individuals by fishing (Hilborn and Walters 1992; Planque *et al.* 2010; Walsh *et al.* 2010) has impacted the population (Ferguson *et al.* 2013; Earl *et al.* 2016; Ye *et al.*, 2018). 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 recent 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.

For long-lived fish such as black bream, rebuilding and maintaining age structure is important for population resilience. 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 estuarine habitats (Harvey 1996) and the ecosystem is still in a recovering mode from the severe impact of recent drought (2001–2010). Since 2010/11, with a number of high flow years (e.g. 2010/11−2012/13, 2016/17), and a concerted effort in environmental water deliveries to the Coorong, there have been some improvements in freshwater−estuarine connectivity and habitat for estuarine fishes in the Coorong. Indeed, a strong cohort of black bream YOY was recruited in 2017/18, facilitated by environmental water releases to the Coorong during spring−summer (Ye *et al.* 2019b). This cohort persisted in 2018/19, detected as one year olds by research sampling in the Coorong (Ye *et al.* 2019c). It is anticipated that they would be recruited to the fishery at ~3–4 years of age. Nevertheless, the extent of their contribution to the population recovery in the Coorong remains uncertain given the low abundance of remnant population and substantially reduced spawning biomass (Earl *et al.* 2016). Furthermore, there is a risk of further flow reduction in the MDB and to the Coorong in the future with 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. To inform management, targeted investigations have been undertaken recently to improve our 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. 2019b, c).

5.2.4. Recruitment of YOY

There was high variability in CPUE of YOY black bream in the Murray Estuary, suggesting different levels of recruitment between years (2008/09–2018/19). No simple correlation was observed between the relative abundance of YOY and the volume of annual barrage releases, implying a complex nature of flow effect on the recruitment of this large-bodied, solely estuarine species. Studies suggested that salt wedge/halocline conditions form an important nursery habitat for estuarine spawning fishes, like black bream, and other species with larvae that develop in estuaries (Williams *et al.* 2012). A study in 2017/18 demonstrated successful recruitment of YOY following managed barrage releases, supported by environmental flows, which created salt wedge conditions in the Coorong (Ye *et al.* 2019b). As such habitat is quite dynamic, exhibiting a high degree of temporal and spatial variability, the spawning behaviour and reproductive success of species that use estuaries are also likely to be dynamic and highly variable in time and space. This could partially explain variable levels of recruitment success of black bream in the Coorong (Ye *et al.* 2015c).

In this study, the CPUE of YOY black bream met the ecological target (>0.77 fish fish.net night^{-1}) only in three of the 11 years (i.e. 2008/09, 2012/13 and 2017/18), and the next highest CPUE was in 2009/10. All these years were characterised by drought, low flow or moderate flow conditions. In 2017/18, the YOY catch rate was the highest and the distribution was the broadest across the Murray Estuary and North Lagoon of the Coorong, meeting the YOY distribution target (>50% across the sites). This strong cohort has not yet recruited to the fishery, whereas the YOY spawned in 2009/10 and 2012/13 have appeared as moderate to strong cohorts in the age structures of fishery catches. It should be noted that although there were no recorded freshwater flows to the Coorong from 2007/08 to 2009/10 (TLM Coorong fish condition monitoring commenced in 2008/09), some unintentional releases (e.g. for barrage maintenance work) or leakage of freshwater probably occurred at various times (most likely at the Goolwa Barrage), which may have created suitable environmental conditions below the barrages and facilitated the recruitment of black bream.

Overall, the catch of YOY black bream remained low in the Coorong in most of the study years, likely due to the lack of favourable estuarine habitat for recruitment as well as a low spawning biomass. However, the CPUE could have also been influenced by patchy distribution and varying catchability, particularly when sampling effort was limited in the Coorong. This was exacerbated following high flows when the freshening of the Coorong expanded suitable habitats, increased fish dispersion or re-distribution and reduced density. The contrary was observed, during the drought years, when juveniles were confined to reduced estuarine habitat below barrages. This may explain the absence of a strong year class in subsequent fishery catches despite the second highest recorded CPUE of YOY in 2008/09.

5.2.5. Condition assessment

Overall, the population condition of black bream in the Coorong ranged from 'poor' to 'extremely poor' over the past 11 years except 2017/18, when the condition improved to 'moderate' due to strong recruitment of YOY. In 2018/19, the condition declined to 'very poor'. This was due to: (1) a low relative abundance (annual commercial catch 0.7 t compared to the target: ≥8 t); (2) a 4-year declining trend in catches; (3) reduced distribution (34% of catches from the southern Coorong compared to the target: >50%); (4) nil catch of YOY; and (5) a truncated age structure (7% fish >10 years of age compared to the target >20%); despite (6) the presence of two strong cohorts with both ≤5 years. The ecological objective (F-4a) to restore a resilient population of black bream in the Coorong has not been achieved for this species.

5.3. Greenback flounder

5.3.1. Relative abundance

The relative abundance of greenback flounder, as indicated by commercial fishery catches, declined substantially in the Coorong during the drought period (2002–2010) compared to earlier years. Annual catches were historically low between 2008/09 and 2010/11 (≤1 t), suggesting very low abundance of harvestable fish (legal minimum size is 25 cm TL for commercial fisheries in South Australia). In 2011/12, the substantial increase of the annual catch to just above 30 t was likely due to enhanced recruitment following the 2010/11 flood. This was corroborated by the dominant 2010 cohort in the age structures of commercial catches in 2011 and 2012. Noticeably, the 2010 cohort from the flood year continued to be present as 5 years olds in the age structure in 2015. After 2012/13, annual catches of greenback flounder remained <5 t, as there has been generally low flow conditions except for 2016/17 when barrage inflow was above average. Across the 11 study years, the ecological target of relative abundance (≥24 t) was met in only 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/flood years. Freshwater flow has been suggested as an important factor explaining the variability in the 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 years lag (Earl *et al.* 2014).

5.3.2. Distribution

Spatially resolved fishery catches indicated extensive re-distribution and changing abundance of greenback flounder in the Coorong between 1984/85 and 2018/19. Prior to 2000/01, >70% of commercial catches were from the North and South lagoons. From 2001/02 to 2009/10, the significant reduction in freshwater flow and a general increase in salinity in the Coorong led to a contraction of estuarine habitat. Consequently, the proportional catch of greenback flounder from the Murray Estuary increased. By 2008/09 and 2009/10, almost all fishery catches (99%) were from the Murray Estuary. In 2010/11, although there were substantial inflows, fishery catches of this species were still restricted to the Murray Estuary, likely due to a very low abundance of harvestable sized fish (a historical low of annual catch, ~0.1 t) in the region. Nevertheless, an increase in the abundance of juvenile greenback flounder was evident in the same year at multiple sites in the North Lagoon following the flood and reduced salinities throughout the system in 2010/11 (Ye *et al.* 2012), demonstrating the positive effect of freshwater flows on restoring estuarine habitat (favourable salinities) and facilitating the recruitment of greenback flounder. This new cohort of juvenile fish contributed to the subsequent peak catch in 2011/12, with harvest widely distributed throughout the North and South lagoons, comprising 99% of total catch by the LCF. In 2012/13, although the annual catch reduced, this species remained broadly distributed throughout the Coorong, likely due to continued maintenance of suitable salinities in the North and South lagoons. In subsequent low flow years (i.e. 2013/14 and 2014/15), there was a reduced distribution of this species in conjunction with elevated salinities, particularly in the North Lagoon. Conversely, increased flows corresponded to a range expansion in 2016/17, with 97% of the catch from the North and South lagoons. Proportional catches remained high (>85%) in the southern Coorong in subsequent two low years (2017/18 and 2018/19), although the data should be interpreted with caution given the very low catches.

5.3.3. Age structure

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 LCF, although most of the fish caught were ≤3 years. Over the last 11 years, the ecological target of having >20% of fish older than 2 years was only met in 2013/14, 2016/17 and 2017/18. The highly truncated age structures suggest that fishing may have impacted on this species by the removal of larger, older individuals (Hall 1984; Ferguson *et al.* 2013; Earl and Ye 2016). However, the influence of emigration of greenback flounder after their second or third years of life from the estuary and their subsequent role in offshore habitats remain poorly understood in terms of their population dynamics (Earl *et al* 2017).

The time series of age structures comprised strong cohorts, particularly relating to spawning in 2010 and 2011. As previously discussed, these cohorts likely benefited from the high flows, when reduced salinities, extended favourable estuarine habitat, improved connectivity among habitats and increased productivity and food resources would have led to more successful recruitment of this species in the Coorong (Earl and Ye 2016; Ye *et al.* 2015a, 2016, 2017). Noticeably, a 2010 cohort was evident in the age structures of fishery catches for at least five years (2011 to 2015). In addition, age 0+ fish, spawned in 2016, were shown to recruit to the fishery following 2016/17 high flows. These further support the conceptual understanding of the critical role of flows in driving the recruitment and abundance of greenback flounder in the Coorong.

Furthermore, it is notable that the population of greenback flounder was dominated by females (>90%) in the Coorong (Ye *et al.* 2015b). Sex-specific habitat selection and spawning aggregation of females were reported in other studies (Kurth 1957; Crawford 1984a). A recent acoustic study found that mature females utilised both shallow flats and deeper channels/holes in the Coorong and some levels of movement were observed between the Coorong and offshore habitats in the Southern Ocean during the spawning season (Earl *et al.* 2017). It is possible that sex-related habitat partitioning occurs on a much broader spatial scale for this species than previously expected (i.e. male fish occupy offshore habitats, while females utilise habitats in the estuary). Being a marine-estuarine opportunist species (i.e. spawn in the marine environment with larvae/juveniles recruiting to adjacent estuaries), the spawning biomass of greenback flounder in the near-shore marine environment is likely a contributing factor to their recruitment ecology in the Coorong. Further research is required to assess the abundance and distribution of male and female greenback flounder in these marine habitats adjacent to the Murray Mouth to understand the overall population dynamics of this species.

5.3.1. Recruitment of YOY

The presence of YOY and the length frequency distributions of juveniles (Appendices C and D) indicated that recruitment of greenback flounder occurred annually in the Coorong, although the

CPUE and distribution of YOY varied over the last 11 years. During the drought years (2008/09 and 2009/10), although the CPUE of YOY appeared to be the highest, it was probably due to the aggregation of juveniles in the Murray Estuary which substantially increased the catchability. This was supported by the distribution data, showing a contracted range of juveniles (present only at 43% of sites). Greenback flounder have a strong preference for brackish and near-marine conditions in the Coorong (Earl *et al.* 2017), and the elevated hypersaline salinities in the North and South lagoons during the drought did not provide favourable habitats for this species.

In post-drought years between 2010/11 and 2014/15, the relative abundance of YOY has either been above or close to the ecological target value (1.04 fish.seine net^{-1}) and their distribution has increased extensively to the North and South lagoons. Such recruitment responses could be attributed to the increased flows to the Coorong, which extended suitable nursery habitat (reduced salinities, increased productivity and better connectivity) for this species. Indeed, a substantial reduction in freshwater flow in 2015/16 led to a decrease in both abundance and distribution of greenback flounder YOY in the Coorong. Following high flows in 2016/17, the distribution of YOY increased in this and subsequent year (2017/18), although the CPUE only showed an increased in later year, suggesting a delayed flow response in recruitment or perhaps a reduced density of YOY due to range expansion in the Coorong. Due to continued low flows in 2018/19, the distribution and abundance of YOY decreased.

Freshwater flow is a key driver of the salinity regime in the Coorong (Geddes and Butler 1984; Geddes 1987; Brookes *et al.* 2009; Ye *et al.* 2012, 2016) and can lead to enhanced productivity and additional food resources for fish in the Coorong (Bice *et al.* 2016). The recruitment of greenback flounder is likely influenced by these changes, particularly because this species spawns before the typical high flow season during autumn/winter (Crawford 1984b), and salinity can influence the reproductive biology and early life history of this species (Hart and Purser 1995). During years of no barrage discharge, e.g. 2008/09 and 2009/10, mean salinities in the North and South lagoons increased to 49–134 psu (Figure 4.3), excluding a large area of the Coorong as a suitable habitat for early life stage development, and thus having a negative effect on recruitment. However, it is worth mentioning that juvenile greenback flounder are more tolerant of hypersaline conditions than eggs/larvae, with laboratory estimates of lethal concentration for 50% tested fish (LC_{50}) ranging from 79–88 psu (Ye *et al.* 2013b). Tolerance data are consistent with the field collection of juvenile greenback flounder along the temporarily different salinity gradient in the Coorong during the drought (Noell *et al.* 2009) and post-drought periods (Ye *et al.* 2015a).

5.3.2. Condition assessment

The population condition of greenback flounder in the Coorong varied between ‘extremely poor’ to ‘moderate’ over the last 11 years. In general, this species was responsive to freshwater flows, with enhanced recruitment and abundance, expanded spatial distribution, and the establishment of strong cohorts in post-drought years. Therefore, the population condition showed an improvement from ‘extremely poor’ during the drought (2008/09 and 2009/10) to ‘moderate’ during the three post-drought years (2011/12–2013/14). Similarly, the population condition declined to ‘poor’ with flows reducing to <1,300 GL y^{-1} in 2014/15 and 2015/16, whereas it improved to ‘moderate’ with high flows (~6,500 GL y^{-1}) in 2016/17. The condition then declined to ‘poor’ and ‘very poor’ in 2017/18 and 2018/19, respectively, associated with substantially reduced flows to the Coorong.

The ‘very poor’ population condition in 2018/19 was reflected by (1) a low relative abundance (annual commercial catch 1.9 t compared to the target: ≥24 t); (2) a decreasing 4-year trend in catches; (3) having a recent strong cohort although only ~9% of the fish being 3 years old and (4) a low level recruitment (YOY CPUE 0.54 fish.seine net^{-1} compared to the target: >1.04 fish.seine net^{-1}) with a contracting distribution (present at 38% sites compared to the target: >50% sites); despite a broad distribution (99% commercial catches from the southern Coorong, meeting the target: >70%). The ecological objective (F-4b) to restore a resilient population of greenback flounder in the Coorong has not been achieved for this species in 2018/19 or in any year this monitoring program has been in place.

5.4. Smallmouth hardyhead

5.4.1. Relative abundance and distribution

Smallmouth hardyhead is an annual fish species, generally living up to one year (Molsher *et al.* 1994). Despite the high salinity tolerance of this species (Lui 1969; Noell *et al.* 2009), the extreme hypersaline conditions in the late drought years (e.g. 2008/09) restricted its southerly distribution, where salinities ranged from 109–166 psu during the sampling season (November to February). The spatial pattern was similar to that reported in the previous drought year, 2007/08 (Noell *et al.* 2009). Both of 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, the relative abundance of smallmouth hardyhead increased compared to 2008/09, despite both years being characterised by drought. Ye *et al.* (2011b) suggested that the abundance increase in the South Lagoon was likely due to increased flow from Salt Creek (15.2 GL in 2009/10 compared to 2.1 GL in 2008/09), and the increase in the North Lagoon was potentially due to: (1) reduced abundance of predators/competitors in the North Lagoon with further increased salinities; and/or (2) established *Ruppia tuberosa* in the southern areas of the North Lagoon (Frahn *et al.* 2012; Paton and Bailey 2012), which improved habitat quality and availability for smallmouth hardyhead (Molsher *et al.* 1994). The importance of macrophytes to atherinids has been 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 leading to subsequent recruitment improvement (Molsher *et al.* 1994; Ivanstoff and Crowley 1996).

Following the extensive barrage releases after 2010/11 and substantial reductions in salinity throughout the Coorong, smallmouth hardyhead abundance increased markedly (~3–6 times to the CPUE in drought years) in 2011/12 as a result of greatly enhanced recruitment in the previous year. Indeed, 2011/12 and 2016/17 (another flood year) were the only two years when the ecological target of adult abundance was met (i.e. CPUE >120 fish.UE^{-1}), disregarding the high CPUE in 2015/16 and 2018/19, when sampling data from a different period (late summer/autumn) were used due to lack of sampling in spring/early summer and may not be comparable. Therefore, we suggest that the estimates of adults not be included in the ecological target assessment in these two years.

Since 2010/11, mean salinities across sampling occasions at sampling sites have ranged from 8–71 psu in the North Lagoon and 48–98 psu in the South Lagoon, except for 2015/16 when salinity increased to 74–117 psu in the South Lagoon, coinciding with low inflows from the River Murray (~560 GL y^{-1}) and Salt Creek (4.4 GL y^{-1}). Maintaining salinities generally below 100 psu has resulted in a broad distribution of smallmouth hardyhead across North and South lagoons over the last nine years despite abundance varied. The increases in abundance of this small-bodied fish were mostly driven by enhanced spawning and recruitment following increased inflows from the River Murray to the Coorong. Freshwater inflows not only help maintain a suitable salinity gradient, but also enhance productivity (e.g. zooplankton food resources, Furst *et al.* 2014), and thus improved habitat quality and extent for this species across the Coorong. Additionally, our earlier monitoring suggested that dispersion of the remnant population and new recruits from the source within Salt Creek into the South Lagoon may also contribute to population increases in the South Lagoon (Ye *et al*. 2011b, 2015b). Furthermore, changing numbers of piscivorous fish and birds in the Coorong, thus the level of predation, could also affect the abundance of this prey species given smallmouth hardyhead plays an important role in the trophic ecology of the region (Giatas and Ye 2016).

5.4.2. Recruitment

Smallmouth hardyhead are euryhaline species and can reproduce in hypersaline waters (Lenanton 1977). However, when salinities exceeded 100 psu, such as the levels in the southern part of the Coorong during the drought period (2006/07–2009/10), the abundance and recruitment of this species was severely impacted (Noell *et al.* 2009; Ye *et al.* 2018). In 2008/09 and 2009/10, the CPUE of new recruits were the lowest in 11 years of this study, with a restricted distribution (not meeting the ecological targets). The constant high salinities (>109 psu) during the reproductive season likely represented a limiting factor for recruitment in the South Lagoon, where salinities were regularly higher than the laboratory determined tolerance (i.e. LC_{50} 108 psu) for this species (Lui 1969). High salinity is known to impact the reproductive performance of other atherinids (e.g. Carpelan 1955; Hedgpeth 1967). Although a previous study in the Coorong did not identify any clear influence of salinity on reproduction of smallmouth hardyhead at a lower salinity range (32–74 psu), it was suggested that salinity may limit food resources (Molsher *et al.* 1994).

Following the flood/high flows in 2010/11 and 2011/12, substantially increased flows from the River Murray 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 in 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. The most distinct increases occurred in the southern North Lagoon and throughout the South Lagoon (from Noonameena to Salt Creek) (Appendix Q).

From 2012/13 to 2014/15, there was a gradual decline in new recruit CPUE from just above the target (>800 fish.UE^{-1}) to 62% and 46% of the target value in the respective three years, corresponding to continuous reductions of freshwater flows to the Coorong. Despite the fact that CPUE in 2014/15 may have been under-estimated due to no small seine net sampling (i.e. only large seine net data from the fish intervention monitoring), the value was unlikely to exceed the target CPUE (>800 fish.UE^{-1}). In 2015/16, the further reduction in river flow led to elevated salinities in the South Lagoon to >100 psu, which could have had a negative impact on recruitment of smallmouth hardyhead. However, the CPUE of new recruits showed an increase in both South and North lagoons, and the mean CPUE (1,003 fish.UE^{-1}) exceeded the ecological target (>800 fish.UE^{-1}). This unexpected result may be due to reduced abundance of predators/competitors caused by further increased salinities, as suggested by the results of fish assemblage monitoring in the Coorong (Ye *et al.* 2015a). In 2016/17, there was a substantial increase in new recruit abundance following high river flows (~6,500 GL y^{-1}) and reduced salinities throughout the Coorong, whereas in 2017/18 new recruit abundance declined with reduced flow. However, further reduced flow in 2018/19 and the generally increased salinities (e.g. by nearly 20 psu to >90 psu at most sites in the South Lagoon) did not lead to a decline but an increase in new recruit abundance, which was again unexpected. Similar to 2015/16, this may be partially explained by the exclusion of fish predators/competitors by elevated salinity. Increased water turbidity and filamentous algae abundance in recent years may have reduced prey accessibility and thus predation efficiency of piscivorous waterbirds in the Coorong, which could be another contributor (Dan Rogers, 2020, pers. comm.). Furthermore, some increases in the presence of *Ruppia* over the last five years in the southern Coorong (Waycott *et al.* 2020) may potentially benefit the reproduction of smallmouth hardyhead. Nevertheless, it was noted that in both 2015/16 and 2018/19, the extent of recruitment of smallmouth hardyhead appeared to be patchy.

Seasonal reduction of salinity by freshwater influence has been suggested as a partial cue to spawning in smallmouth hardyhead (Molsher *et al.* 1994). Also, the timing of the reproductive season of this species may be part of a strategy to take advantage of seasonal peaks in food availability. In the Coorong, smallmouth hardyhead feed mainly on zooplankton/micro-crustaceans, which are most abundant during winter and spring, when salinities are relatively low (Geddes 1987). Freshwater releases provide nutrients and organic matter to the Coorong, along with a direct input of plankton as a food resource (Shiel and Tan 2013; Furst *et al.* 2014). All these would facilitate the growth and recruitment of smallmouth hardyhead. Furthermore, a study undertaken during reduced flow conditions in 2013/14 suggested a potential diet overlap between smallmouth hardyhead, sandy sprat and Tamar River goby in the North Lagoon of the Coorong (Hossain *et al.* 2017). Therefore, flow-induced increases of food resources will benefit these fishes, and probably many other species (Whitfield 1994; Gillanders and Kingsford 2002).

5.4.3. Condition assessment

The population condition of smallmouth hardyhead in the North and South lagoons of the Coorong was highly variable over the last 11 years, ranging from ‘extremely poor’ to ‘very good’. Overall, this short-lived small-bodied estuarine species was highly responsive to freshwater flows, showing a rapid increase in recruitment, abundance and distribution after flood/high flows. This was corroborated by a significant improvement in population condition from ‘extremely poor’ during the drought (2008/09 and 2009/10) to ‘moderate’, ‘very good’ and ‘good’ in the flood (2010/11), high flow (2011/12) and moderate flow (2012/13) years, respectively. During these years, barrage releases were more than 5,000 GL y^{-1}. The ecological objective (F-3) to maintain abundant self-sustaining populations of smallmouth hardyhead in the North and South lagoons of the Coorong was achieved in 2011/12 and 2012/13. The ‘moderate’ condition in 2010/11 was mainly due to a time lag in ecological response in the South Lagoon (i.e. low adult numbers and slow recolonisation into this sub-region given the ‘extremely poor’ antecedent conditions and the furthest distance from the Murray Estuary), although it was a remarkable improvement compared to that during the drought.

From 2013/14 to 2015/16, freshwater flows to the Coorong reduced to less than 2,000 GL y^{-1}, which was below the 1984/85–2015/16 mean discharge (~3,800 GL y^{-1}). By 2015/16, salinities in the South Lagoon increased to >100 psu. Over these low flow years, the smallmouth hardyhead population showed corresponding declines to ‘moderate’ or ‘poor’ conditions in the Coorong. In 2016/17, inflow from the River Murray increased again to ~6,500 GL. This resulted in salinity reductions in the entire Coorong and a significant improvement in the population condition to ‘very good’, meeting the ecological objective (F-3). In the subsequent two years, the population condition reduced to ‘moderate’ associated with much lower inflows. The ecological objective (F-3) was not met in 2018/19.

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 2018/19, a low flow year (377 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 for both new recruits and adults throughout the North and South lagoons; high abundance of new recruits (1,380 $fish.UE^{-1}$) above the ecological target (>800 $fish.UE^{-1}$); 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 last two 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 11 years. For black bream, the population condition ranged from 'extremely poor' to 'poor' in the Coorong in all years except 2017/18 when it improved to 'moderate' due to extensive recruitment of YOY associated with managed barrage flow releases supported by environmental water. In 2018/19, the population condition declined to 'very poor', characterised by:

- A low relative abundance (annual commercial catch of 0.7 t vs the target: ≥8 t);
- A declining 4-year catch trend (vs the target: a positive trend);
- No detection of new recruits (YOY CPUE not meeting the target: >0.77 fish.net $night^{-1}$);
- Decreased distribution (35% commercial catches from the southern Coorong, not meeting the target: >50%); and
- A truncated age structure (only 12% fish >10 years of age vs the target: >20%) although the presence of two strong cohorts with both <5 years (meeting the target).

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 two years. In 2018/19, the population condition was ‘very poor’, characterised by:

- A low relative abundance (annual commercial catch 1.9 t vs the target: >24 t);
- A decreasing 4-year trend in catches (not meeting the target);
- The presence of a recent strong cohort although only ~9% of the fish being 3 years old (not meeting the target: >40% in Year 0–2 and >20% of fish >2 years of age); and
- A low level recruitment (YOY CPUE 0.54 fish.seine net^{-1} vs the target: >1.04 fish.seine net^{-1}) with a contracting distribution (present at 33% sites vs the target: >50% sites); but
- A broad distribution of adults (>99% commercial catches 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 11 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 in 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 seemed 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 11 study years, no significant improvement in the population abundance has been 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 environmental water allocation is critical to improve estuarine fish habitats (salinities, connectivity and productivity), enhance fish recruitment and abundance, and maintain or rebuild 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 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.

The fish monitoring over the last 11 years (2008/09–2018/19) 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, 2017–2019, <1,000 GL y^{-1}) and flood/high flows (2010–2012 and 2016/17, >6,000 GL y^{-1}), which allowed an assessment of biological responses to flow variability and an investigation on population recovery. This report is based on the framework of fish condition assessment in the Coorong using a multiple lines of evidence approach. It facilitated a quantitative assessment of the ecological targets and objectives for the three species and a classification of the population condition for each species in each year. In recent years, there was a reduction in sampling effort (e.g. in 2015/16 and 2018/19 there was no spring/early summer sampling for smallmouth hardyhead) due to funding constraints, which limited our capacity to evaluate some of the ecological targets (e.g. no adult abundance data for smallmouth hardyhead in 2015/16 and 2018/19). Therefore, future monitoring should restore/maintain the sampling regime as recommended in the LLCMM Icon Site 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 2008/09–2018/19. 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**	**2016/17**	**2017/18**	**2018/19**
Regular sampling sites										
Goolwa Barrage sw HI	16	24	24	32	16	24	8	16	4	5
Goolwa Barrage sw SRP	21	24	16	32	24	24	8	16	4	8
Mundoo Barrage			24	40	24	23		16	4	6
Boundary Creek	23	24		8	24	24	4	16	1	7
Additional sampling sites										
Goolwa Barrage fw HI	4									
Goolwa Barrage fw SRP	2	4								
Goolwa Channel HIside				4						
Beacon 19										8
Mundoo Channel in front of house				4						
Boundary Creek Barrage	4						4			
Boundary Creek Pole							4			
Boundary Creek Structure							4			
Swan Point										2
Godfrey's Landing				4						5
Ewe Island									4	5
Ewe Island Causeway		16								
Tauwitchere Barrage		4								
Pelican Pt. YHP Opposite Rumbolow Shack				4						
Cattle Point				8				8	4	8
South Cattle Point								8		
Mark Point			4	12				8	4	8
Mark Point beach								4		
Mark Point deep								4		
Opposite Mark Point YHP				4						
Long Point beach								4		
Long Point			4	4				8	4	8
Long Point corner								4		
Long Point reef								4		
Long Point sand dune								8	4	7
Long Point South								4		
Overall	**70**	**96**	**72**	**156**	**88**	**95**	**32**	**128**	**33**	**77**

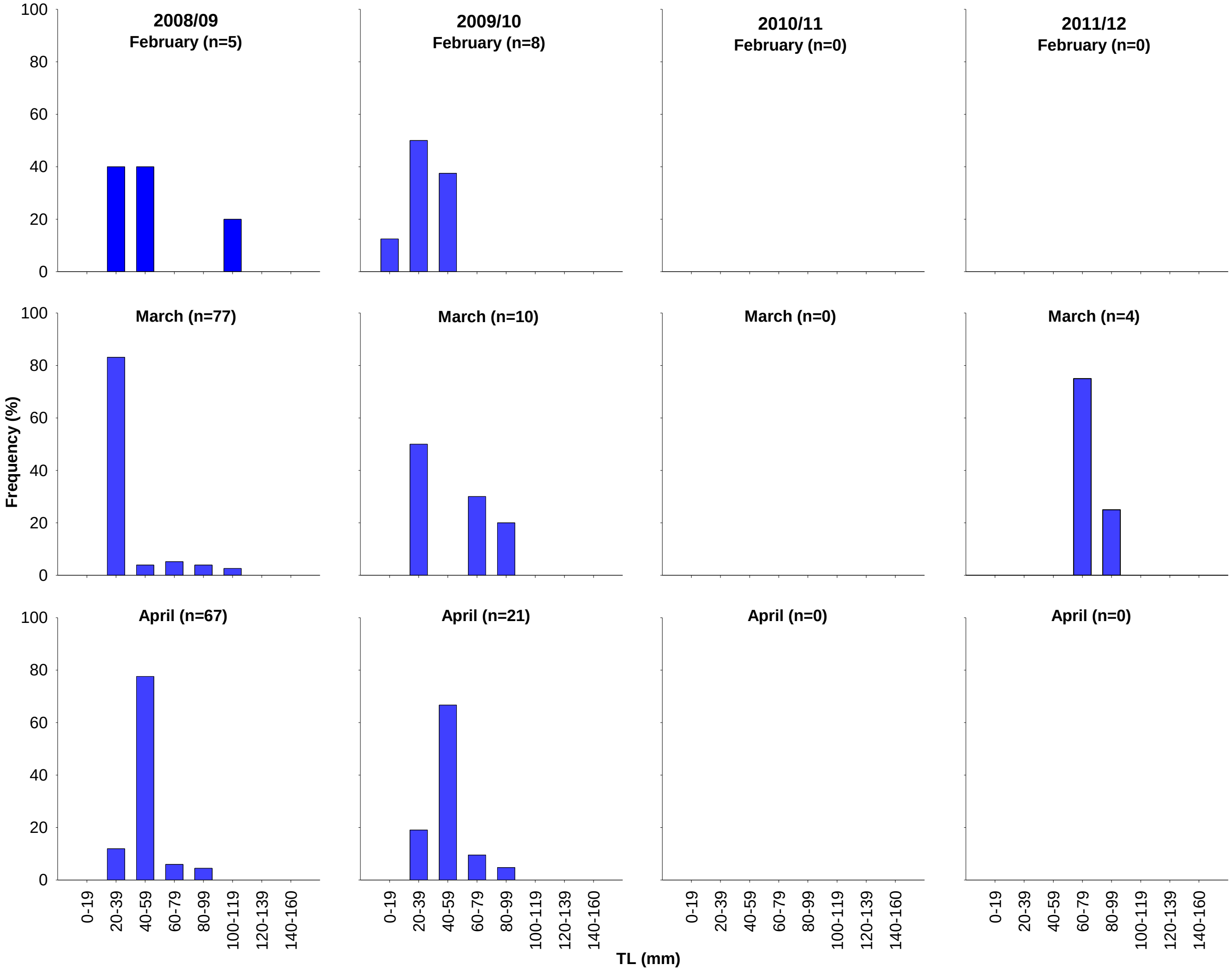
Appendix B. Sampling effort (number of seine net shots) for collecting juvenile greenback flounder using large seine net at the Coorong from 2008/09–2018/19.

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**
Sugars Beach	9	9	9	9	9	9	NS	NS	NS		
Godfrey's Landing	9	9	9	9	9	9	9	6	9	6	3
Mark Point	9	9	9	9	9	9	9	6	9	6	3
Noonameena	9	9	9	9	9	9	9	6	9	6	3
Mt Anderson	NS	NS	3	9	9	9	9	6	9	6	3
Hells Gate	9	9	9	9	9	9	9	6	9	6	3
Villa dei Yumpa	NS	NS	3	9	9	9	9	6	9	6	3
Jack Point	9	9	9	9	9	9	9	6	9	6	3
Salt Creek	9	9	9	9	9	9	9	6	9	6	3
Overall	**63**	**63**	**69**	**81**	**81**	**81**	**72**	**48**	**72**	**48**	**24**

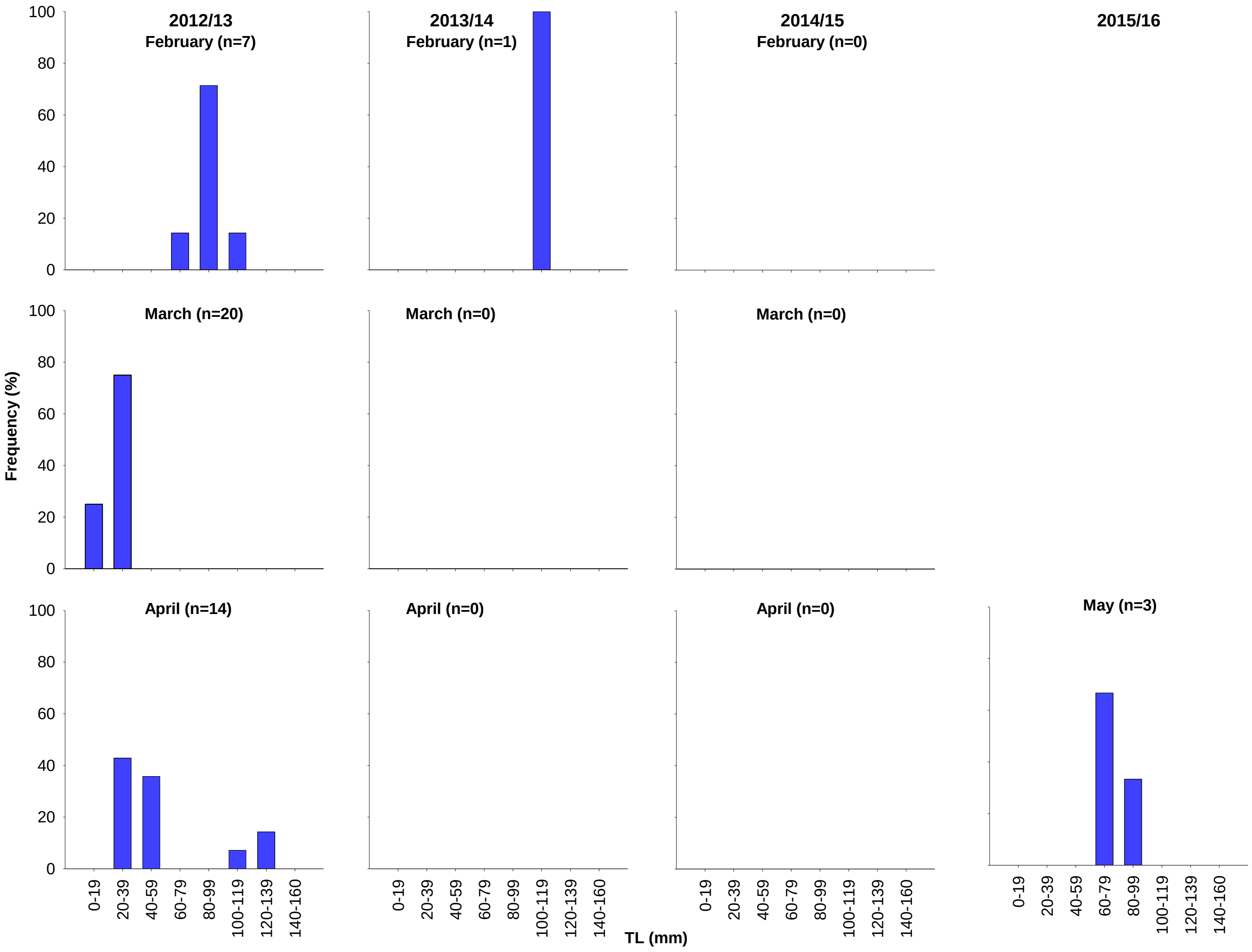
Appendix C. Sampling effort (number of seine net shots) for new recruit and adult smallmouth hardyhead using large and small seine nets in the Coorong from 2008/09–2018/19. NS=no sampling. Note: 2014/15 data are from 'Coorong fish intervention monitoring'; no small seine netting was conducted.

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**
Large seine net											
Mark Point	12	12	12	12	12	12	12	6	9	6	3
Long Point	NS	NS	12	12	12	12	12	6	9	6	3
Noonameena	12	12	12	12	12	12	12	6	9	6	3
Mt Anderson	NS	NS	6	12	12	12	12	6	9	6	3
Hells Gate	12	12	12	12	12	12	12	6	9	6	3
Villa dei Yumpa	NS	NS	6	12	12	12	12	6	9	6	3
Jack Point	12	12	12	12	12	12	12	6	9	6	3
Salt Creek	12	12	12	12	12	12	12	6	9	6	3
Overall	**60**	**60**	**84**	**96**	**96**	**96**	**96**	**48**	**72**	**48**	**24**
Small seine											
Mark Point	3	9	12	12	12	12	NS	6	9	6	3
Long Point	NS	NS	12	12	12	12	NS	6	9	6	3
Noonameena	3	9	12	12	12	12	NS	6	9	6	3
Mt Anderson	NS	NS	6	12	12	12	NS	6	9	6	3
Hells Gate	NS	12	12	12	12	12	NS	6	9	6	3
Villa dei Yumpa	NS	NS	6	12	12	12	NS	6	9	6	3
Jack Point	NS	12	12	12	12	12	NS	6	9	6	3
Salt Creek	NS	12	12	12	12	12	NS	6	9	6	3
Small seine	**6**	**54**	**84**	**96**	**96**	**96**	**NS**	**48**	**72**	**48**	**24**

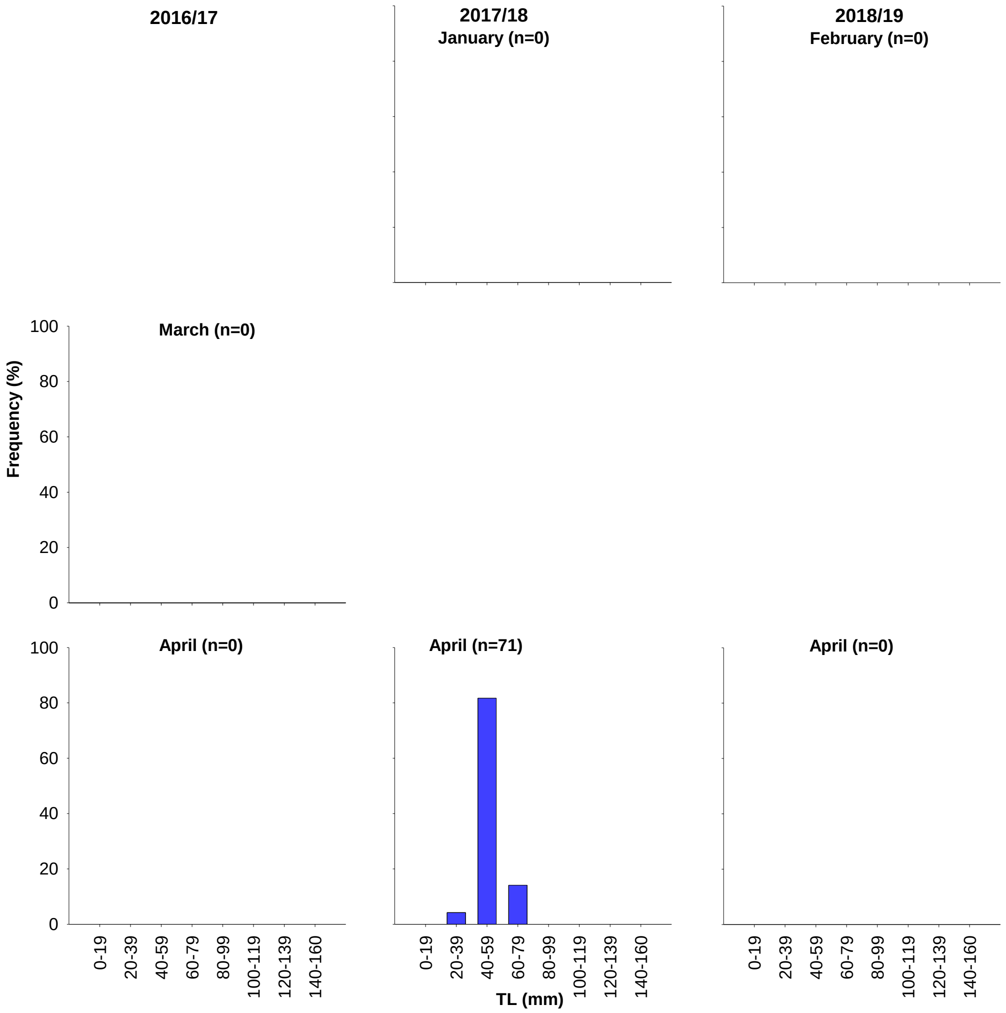
Appendix D. Length frequency distributions of juvenile black bream from fyke net samples in the Coorong during late summer/autumn between 2008/09 and 2011/12.



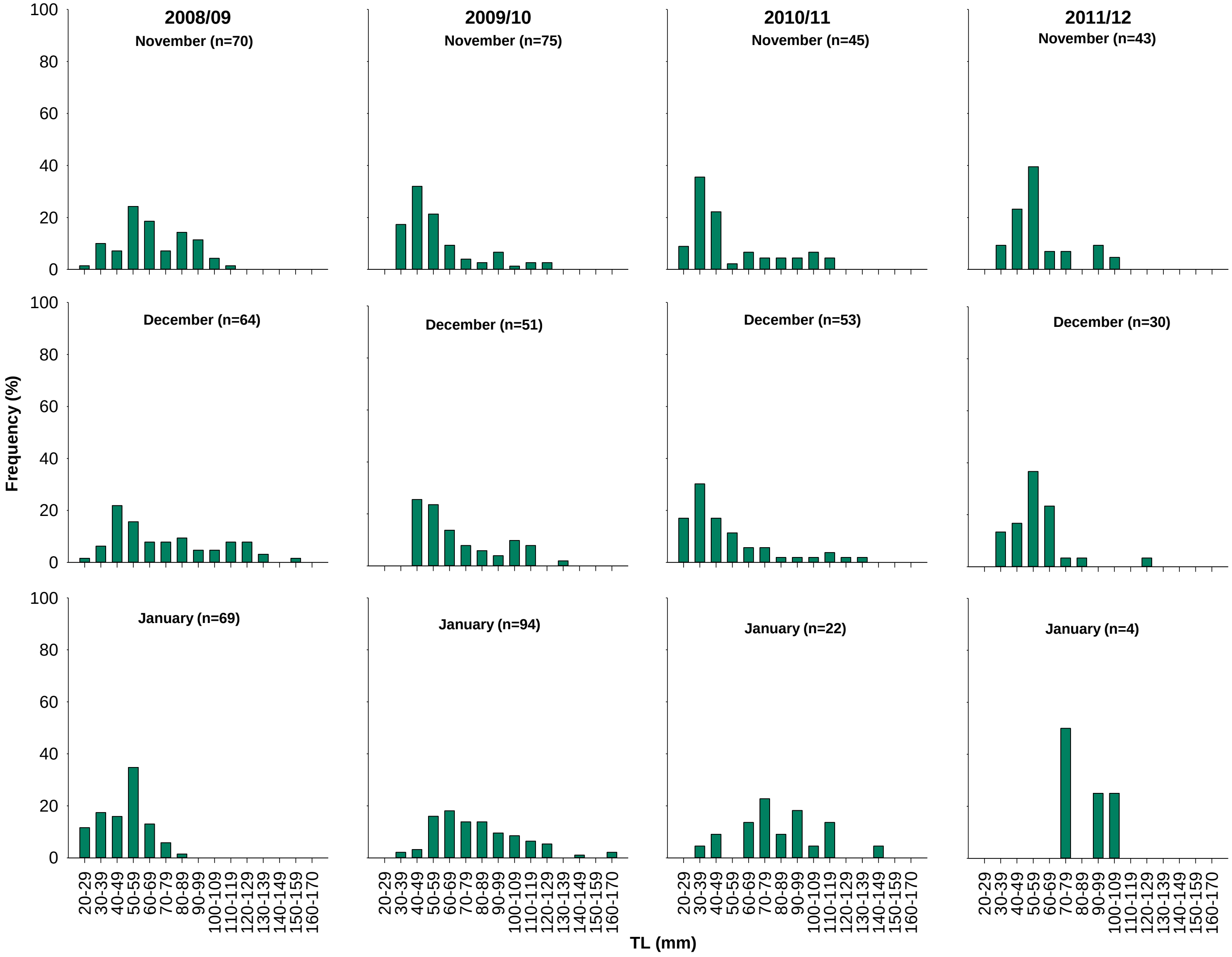
Appendix E. Length frequency distributions of juvenile black bream from fyke net samples in the Coorong late summer/autumn between 2012/13 and 2015/16.



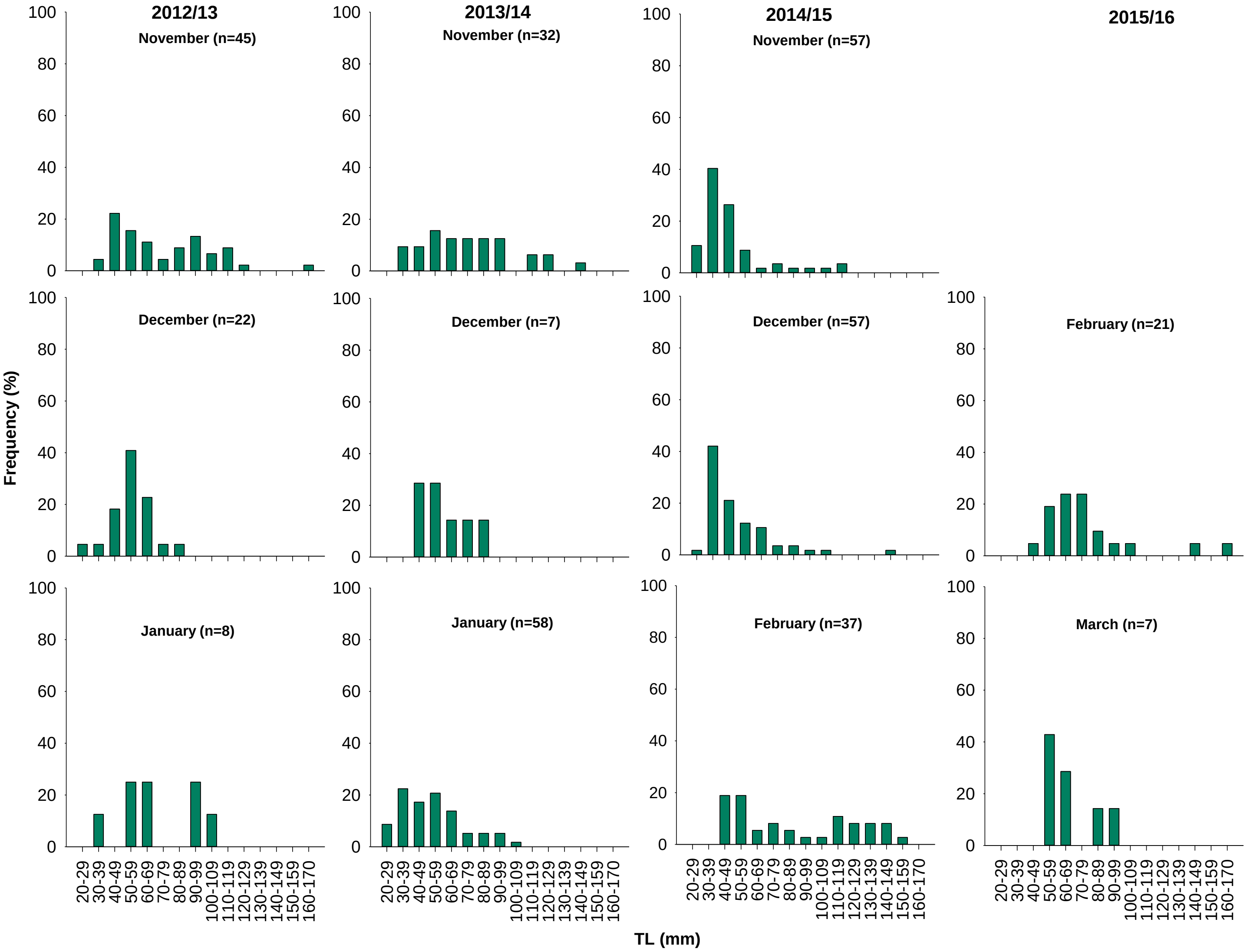
Appendix F. Length frequency distributions of juvenile black bream from fyke net samples in the Coorong late summer/autumn between 2016/17 and 2018/19.



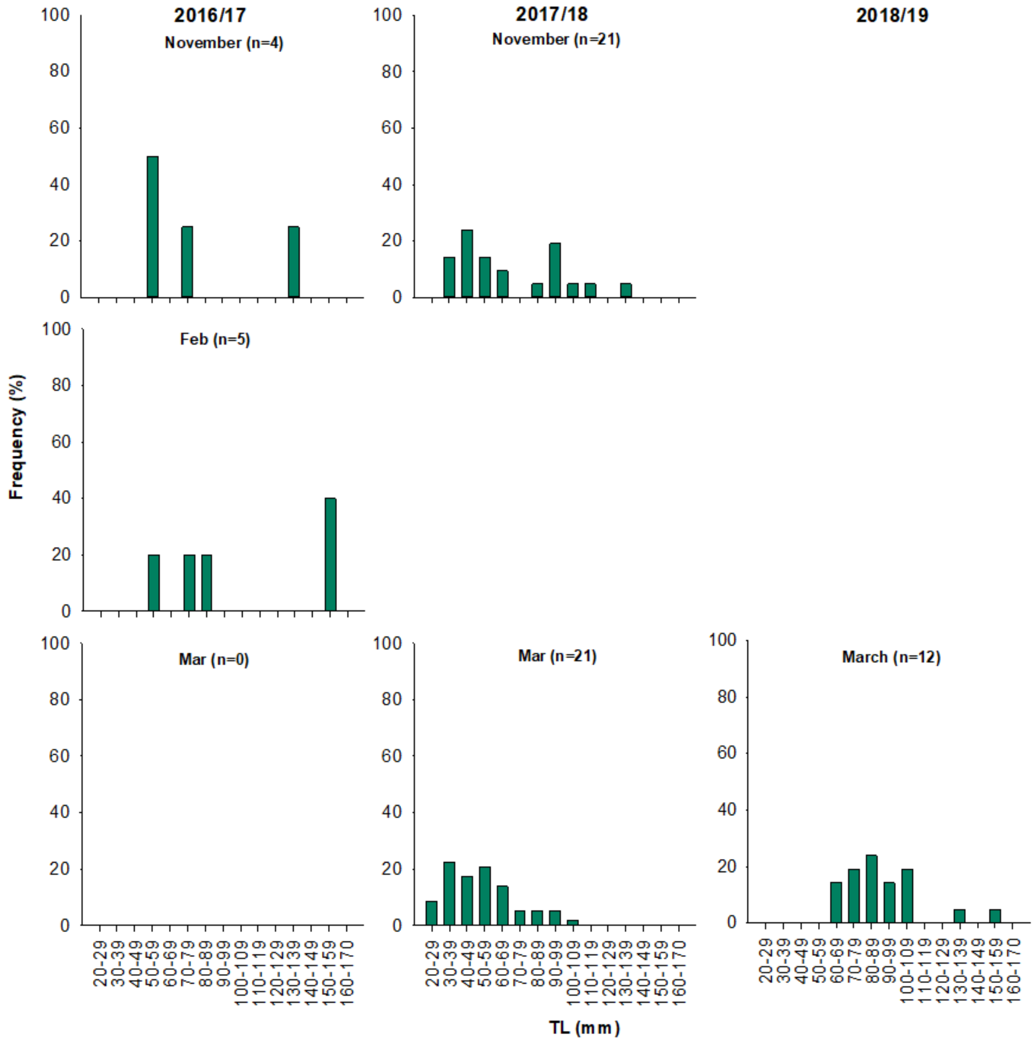
Appendix G. Length frequency distributions of juvenile greenback flounder from seine net samples in the Coorong during late spring/summer between 2008/09 and 2011/12.



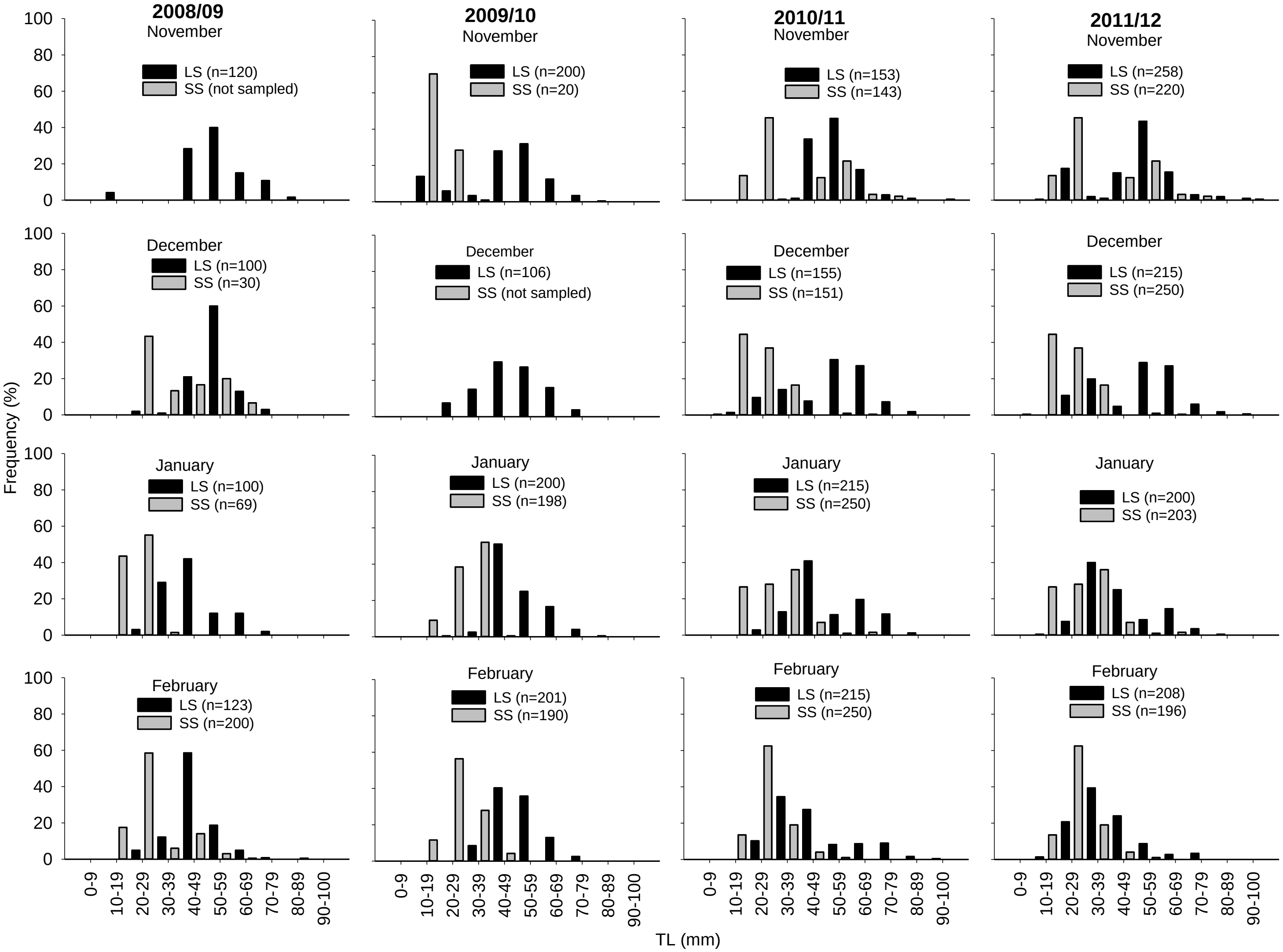
Appendix H. Length frequency distributions of juvenile greenback flounder from large seine net samples in the Coorong during late spring/summer/early autumn between 2012/13 and 2015/16.



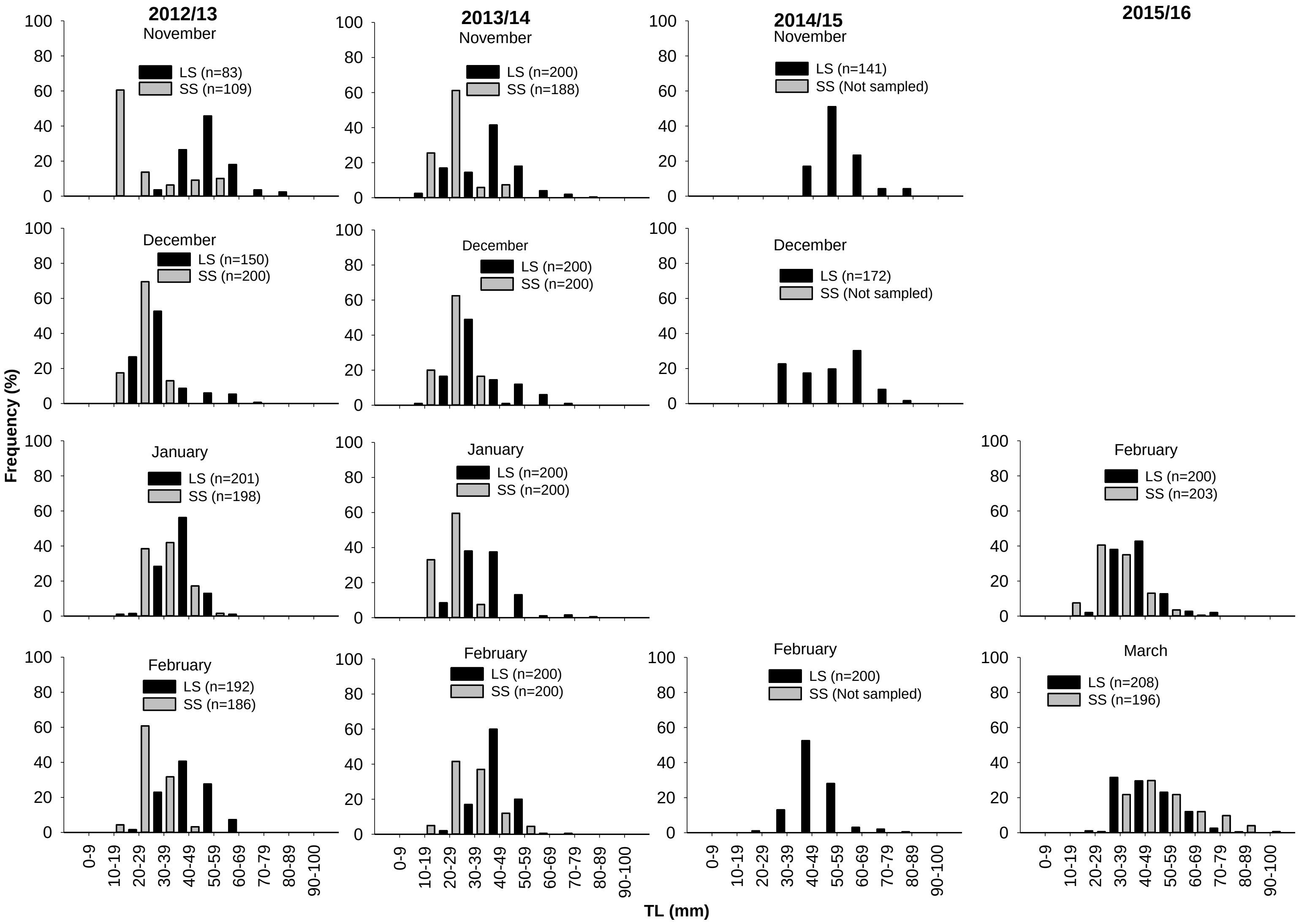
Appendix I. Length frequency distributions of juvenile greenback flounder from large seine net samples in the Coorong during late spring/summer/early autumn between 2016/17 and 2018/19.



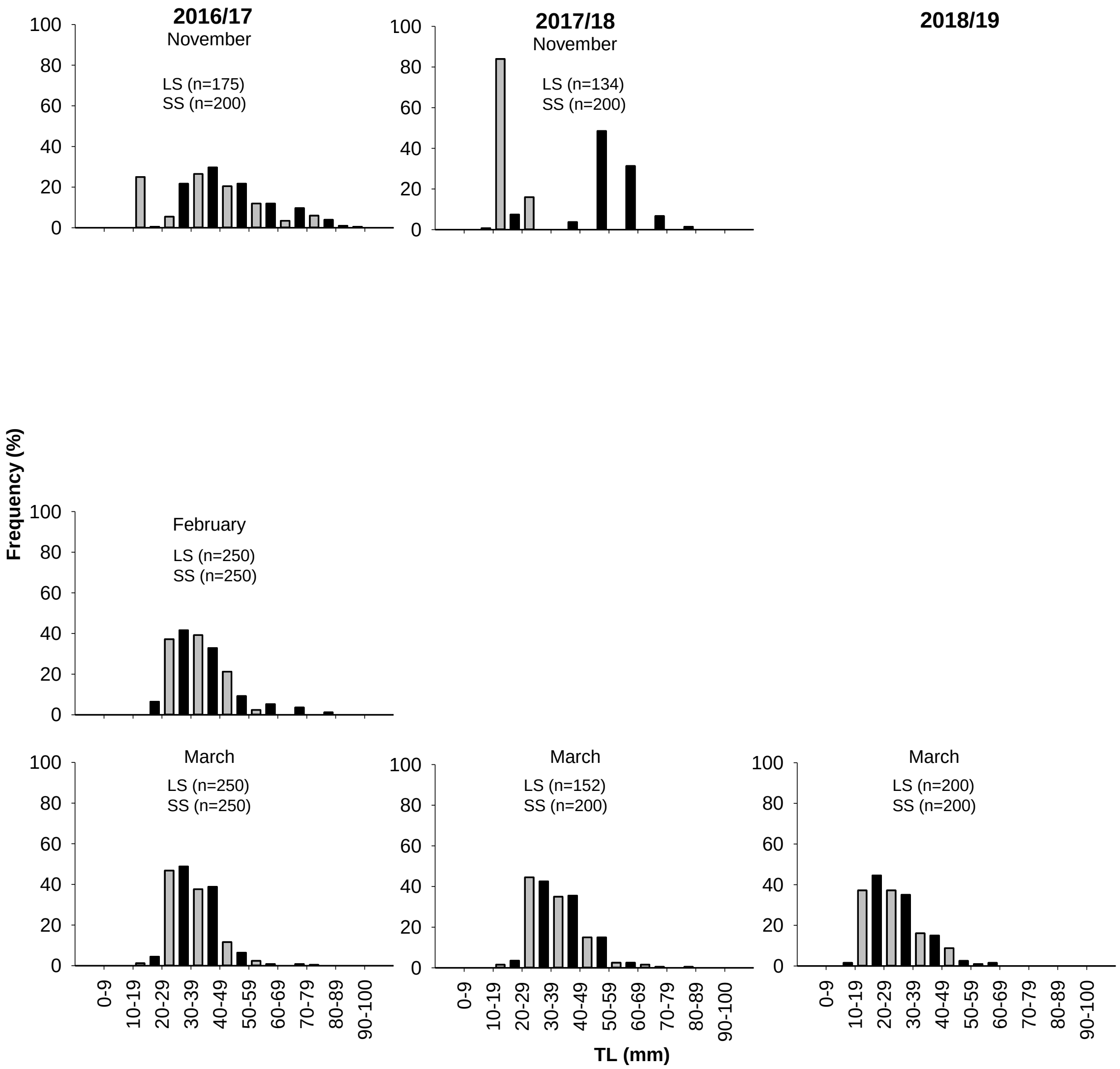
Appendix J. Length frequency distributions of smallmouth hardyhead from large (LS) and small (SS) seine nets in the North Lagoon sites during late spring/summer between 2008/09 and 2011/12.



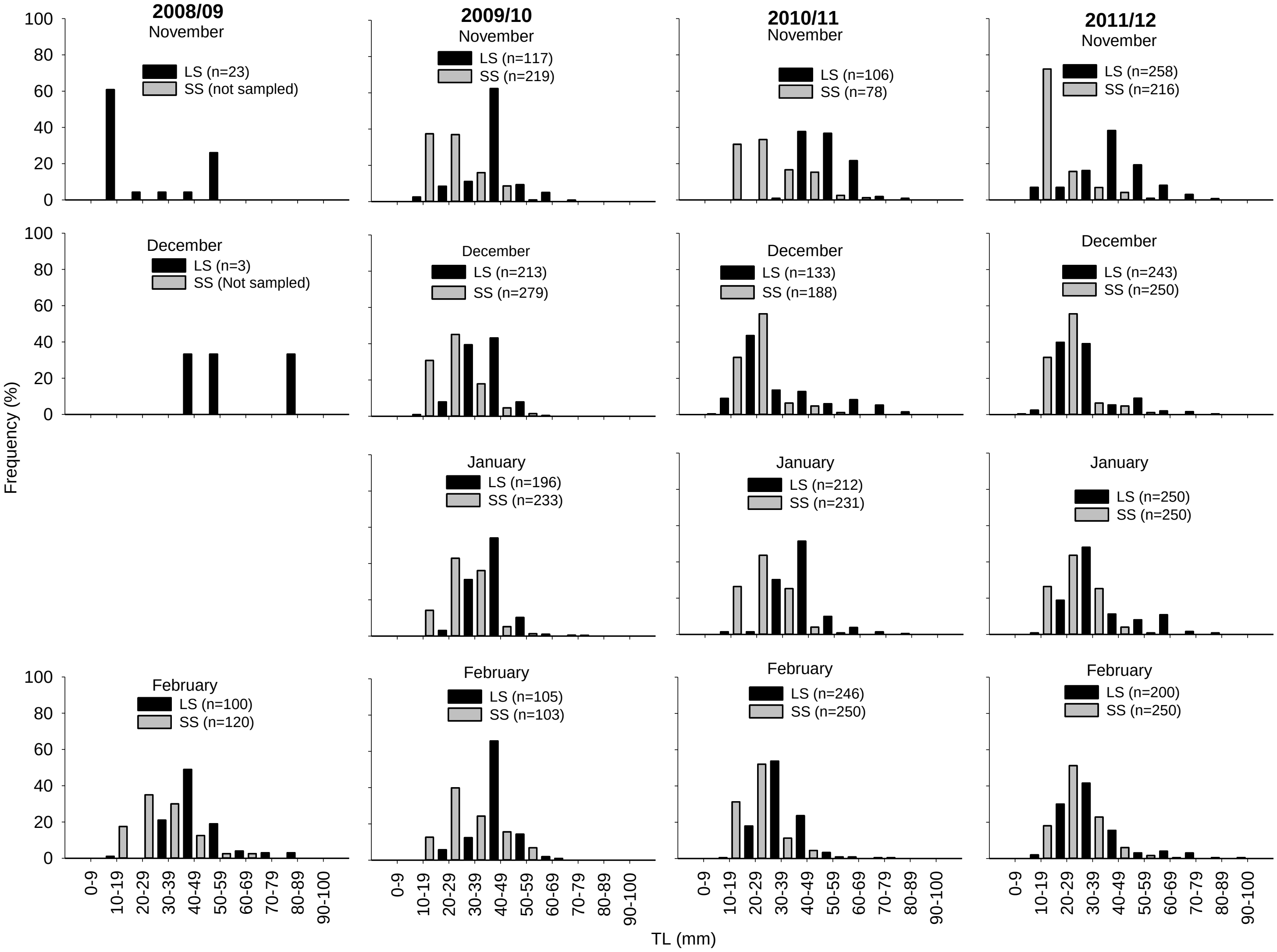
Appendix K. Length frequency distributions of smallmouth hardyhead from large (LS) and small (SS) seine nets in the North Lagoon sites during late spring/summer/early autumn between 2012/13 and 2015/16. Gaps represent months when sampling did not occur.



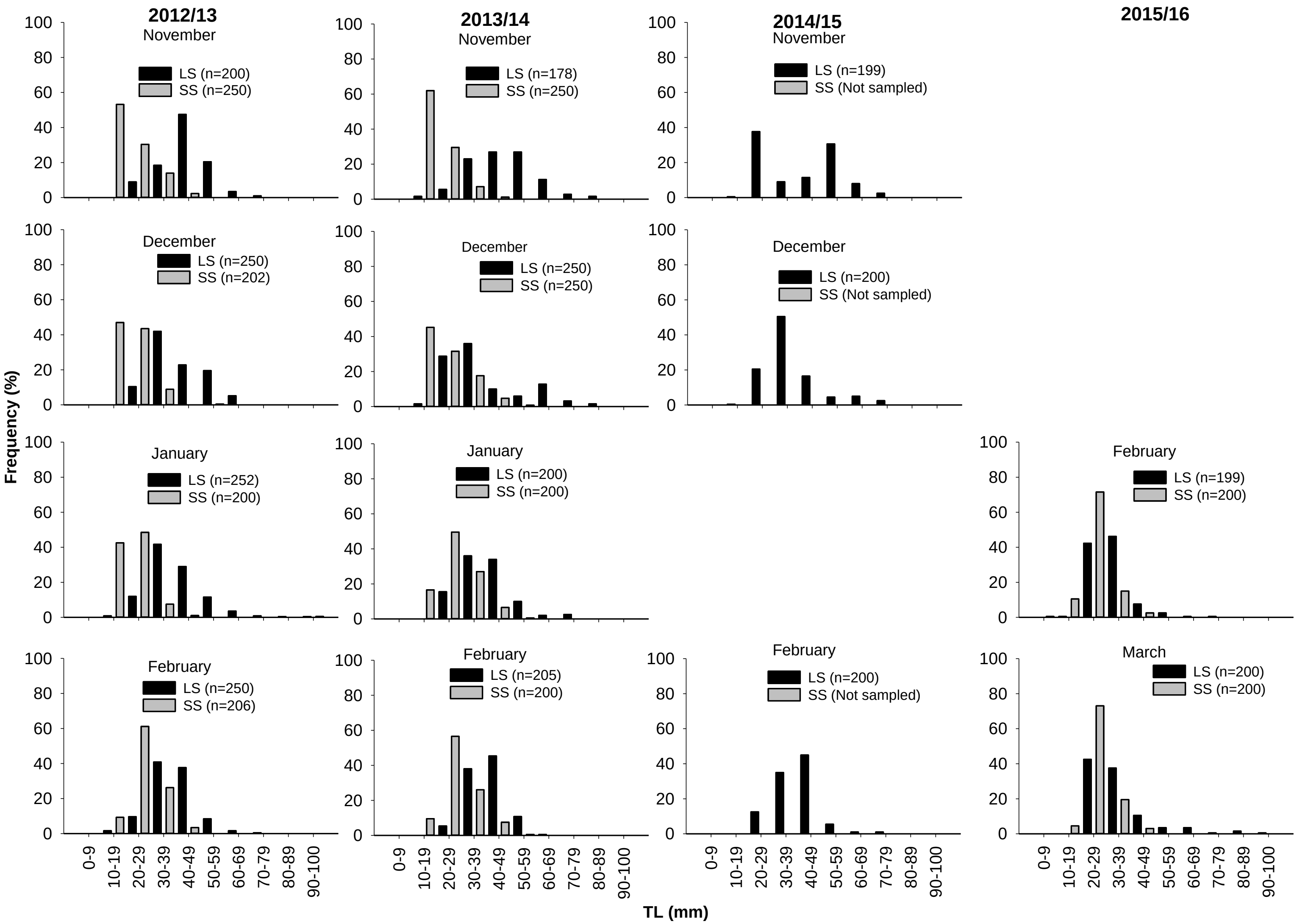
Appendix L. Length frequency distributions of smallmouth hardyhead from large (LS) and small (SS) seine nets in the North Lagoon sites during late spring/summer/early autumn between 2016/17 and 2018/19. Gaps represent months when sampling did not occur.



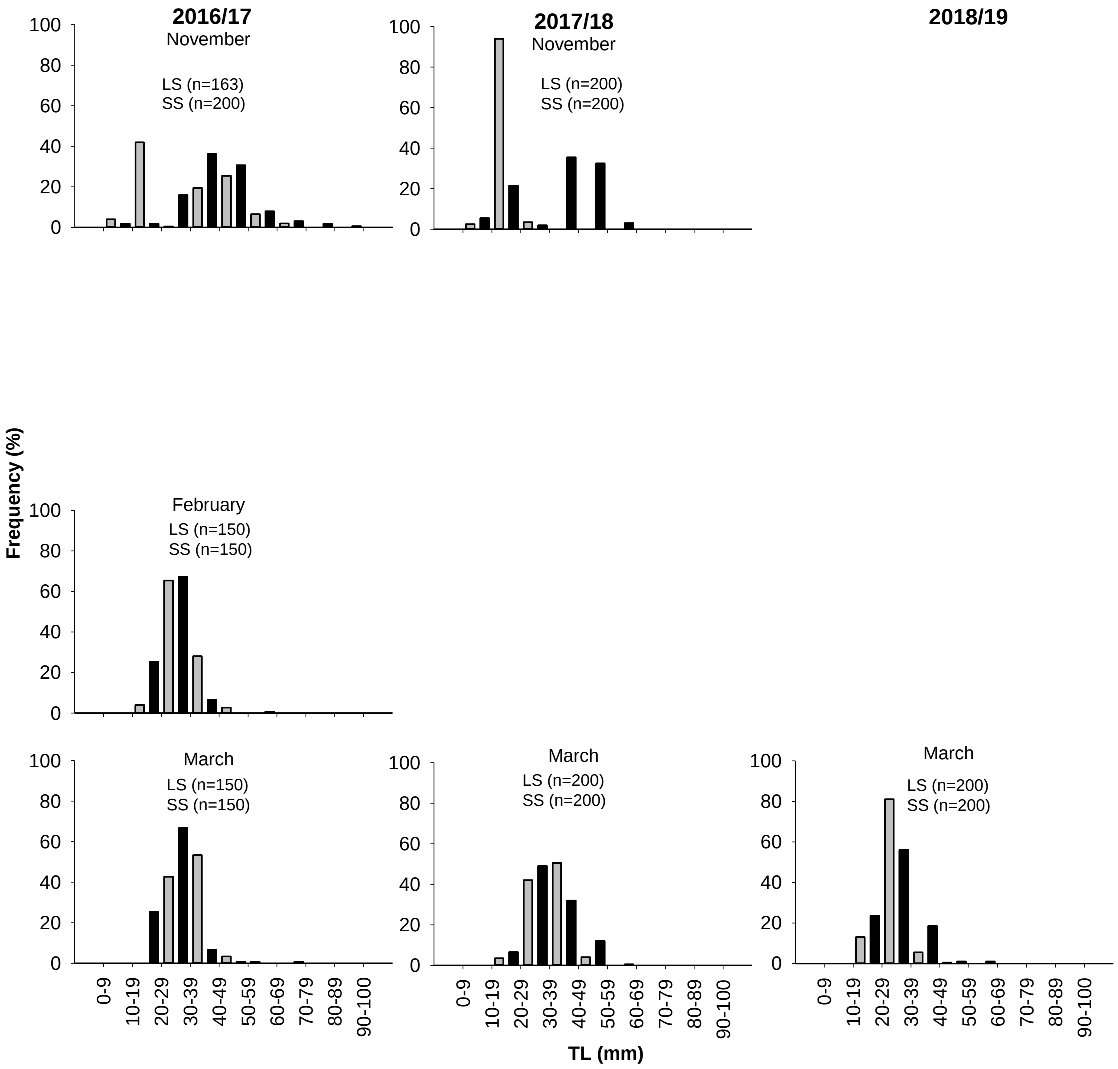
Appendix M. Length frequency distributions of smallmouth hardyhead from large (LS) and small (SS) seine nets in the South Lagoon sites during late spring/summer between 2008/09 and 2011/12. Gaps represent months when sampling did not occur.



Appendix N. Length frequency distributions of smallmouth hardyhead from large (LS) and small (SS) seine nets in the South Lagoon sites during late spring/summer/early autumn between 2012/13 and 2015/16. Gaps represent months when sampling did not occur.



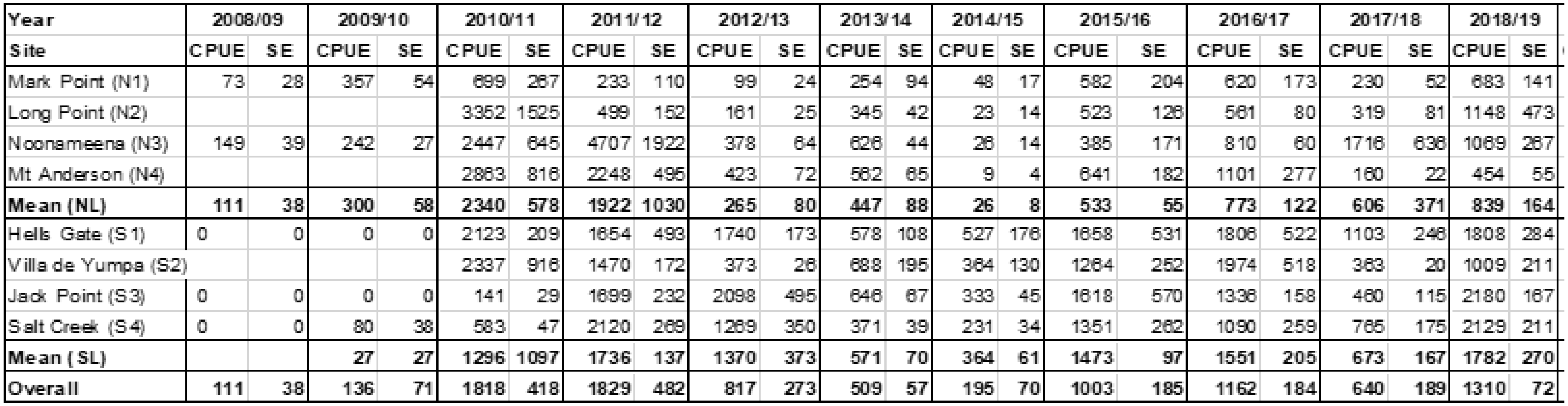
Appendix O. Length frequency distributions of smallmouth hardyhead from large (LS) and small (SS) seine nets in the North Lagoon sites during late spring/summer/early autumn between 2016/17 and 2018/19. Gaps represent months when sampling did not occur.



Appendix P. Mean CPUE (fish.UE^{-1}) of adult smallmouth hardyhead (i.e. ≥40 mm TL) sampled by large and small seine nets in November and December across eight sites in the North Lagoon (NL) and South Lagoon (SL). SE: Standard error. 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 2018/19 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**	
Site	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
Long Point (N2)					152	29	251	78	14	7	22	3	97	36	476	126	93	35	16	6	322	192
Noonameena (N3)	247	59	197	92	254	90	871	567	9	3	223	38	58	37	268	171	126	38	30	28	422	132
Mt Anderson (N4)					0	0	279	103	68	19	59	15	51	21	462	182	27	12	9	5	342	38
Mean (NL)	**124**	**124**	**269**	**72**	**166**	**48**	**408**	**155**	**23**	**16**	**79**	**50**	**53**	**19**	**368**	**58**	**97**	**25**	**14**	**6**	**497**	**137**
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
Villa de Yumpa (S2)					0	0	69	12	98	18	66	31	57	18	84	252	663	131	52	5	115	42
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
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
Mean (SL)	**1**	**0**	**5**	**5**	**25**	**23**	**242**	**104**	**148**	**49**	**50**	**13**	**104**	**31**	**381**	**474**	**225**	**152**	**60**	**7**	**378**	**166**
Overall	**50**	**38**	**110**	**69**	**95**	**39**	**325**	**92**	**85**	**33**	**64**	**24**	**78**	**19**	**375**	**113**	**161**	**75**	**37**	**10**	**438**	**102**

Appendix Q. Mean CPUE (fish.UE^{-1}) of smallmouth hardyhead new recruits (i.e. <40 mm TL) sampled by large and small seine nets in January and February across eight sites in the North Lagoon (NL) and South Lagoon (SL). SE: Standard error. 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 2017/18 and 2018/19 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	
Site	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
Long Point (N2)					3352	1525	499	152	161	25	345	42	23	14	523	126	561	80	319	81	1148	473
Noonameena (N3)	149	39	242	27	2447	645	4707	1922	378	64	626	44	26	14	385	171	810	60	1716	636	1069	267
Mt Anderson (N4)					2863	816	2248	495	423	72	562	65	9	4	641	182	1101	277	160	22	454	55
Mean (NL)	**111**	**38**	**300**	**58**	**2340**	**578**	**1922**	**1030**	**265**	**80**	**447**	**88**	**26**	**8**	**533**	**55**	**773**	**122**	**606**	**371**	**839**	**164**
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
Villa de Yumpa (S2)					2337	916	1470	172	373	26	688	195	364	130	1264	252	1974	518	363	20	1009	211
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
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
Mean (SL)			**27**	**27**	**1296**	**1097**	**1736**	**137**	**1370**	**373**	**571**	**70**	**364**	**61**	**1473**	**97**	**1551**	**205**	**673**	**167**	**1782**	**270**
Overall	**111**	**38**	**136**	**71**	**1818**	**418**	**1829**	**482**	**817**	**273**	**509**	**57**	**195**	**70**	**1003**	**185**	**1162**	**184**	**640**	**189**	**1310**	**72**