Inland Waters & Catchment Ecology

SOUTH AUSTRALIAN RESEARCH & DEVELOPMENT INSTITUTE
PIRSA

Intervention monitoring for black bream (*Acanthopagrus butcheri*) recruitment in the Murray Estuary

Qifeng Ye, Luciana Bucater and David Short

SARDI Publication No. F2015/000685-1
SARDI Research Report Series No. 875

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

October 2015

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

Government of South Australia
Primary Industries and Regions SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Intervention monitoring for black bream (*Acanthopagrus butcheri*) recruitment in the Murray Estuary

Qifeng Ye, Luciana Bucater and David Short

SARDI Publication No. F2015/000685-1
SARDI Research Report Series No. 875

October 2015

This publication may be cited as:
Ye, Q., Bucater, L. and Short, D. (2015). Intervention monitoring for black bream (*Acanthopagrus butcheri*) recruitment in the Murray Estuary. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000685-1. SARDI Research Report Series No. 875. 25pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
www.pir.sa.gov.au/research

Printed in Adelaide: October 2015
SARDI Publication No. F2015/000685-1
SARDI Research Report Series No. 875

Author(s):	Qifeng Ye, Luciana Bucater and David Short
Reviewer(s):	Jason Nicol (SARDI) and Tracie Giersch (MDBA)
Approved by:	Dr Stephen Mayfield Science Leader – Fisheries
Signed:	
Date:	22 October 2015
Distribution:	MDBA, SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library
Circulation:	Public Domain

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

This project was funded by The Living Murray initiative of the Murray-Darling Basin Authority (MDBA). The Living Murray is a joint initiative funded by the New South Wales, Victorian, South Australian, Australian Capital Territory and Commonwealth governments, coordinated by the Murray–Darling Basin Authority. The authors would like to thank Adrienne Rumbelow, Kirsty Wedge and Claire Sims (South Australian Department of Environment, Water and Natural Resources) for support and management of this project. Thanks to SARDI staff Neil Wellman and Tessa Concannon who provided assistance with fieldwork, laboratory analyses or data entry; and George Giatas assisted with graphing. Thanks to Adrienne Rumbelow (DEWNR) who commented on an earlier draft of this report, and to Jason Nicol (SARDI) and Tracie Giersch (MDBA) who formally reviewed and provided comments on this report.

EXECUTIVE SUMMARY

The Lower Lakes, Coorong and Murray Mouth (LLCMM) is the terminal system of Australia's Murray-Darling River, and plays a significant role in providing ecosystem services. It is a Ramsar wetland, one of the six 'icon sites' identified across the Murray-Darling Basin (MDB) as part of The Living Murray Program (MDBC 2006). The unique estuary of the MDB supports a diverse range of fish species, including those with significant commercial and ecological values (e.g. black bream, *Acanthopagrus butcheri*).

During 2014/15, small volumes of environmental water were continuously released through the Boundary Creek Barrage aimed to create a favourable salinity gradient for black bream larval drift and recruitment. SARDI undertook intervention monitoring to assess 1) the presence of salinity stratification (halocline); and 2) recruitment response of black bream in association with the environmental water releases in Boundary Creek. Salinity measurements were conducted at different depths at regular sites along Boundary Creek below the Barrage in November 2014 and March 2015. Sampling of juvenile black bream was conducted using fyke nets in November and December 2014 and March 2015. In addition, a pilot sampling was undertaken to explore black bream larvae in the vicinity of the halocline area using plankton tows and light traps. Salinity and fish sampling were also conducted below the Goolwa Barrage for comparison. Data of black bream juvenile abundances from previous fish condition monitoring in the Coorong by SARDI (2008–2014) provided a baseline to be compared with the current study.

The study detected a halocline with a salinity amplitude favorable for black bream larvae (15–20 psu) in Boundary Creek, following small volumes of constant barrage releases supported by environmental water. Despite no black bream larvae or juveniles being collected during 2014/15, the environmental conditions at Boundary Creek appeared to have facilitated the recruitment of congolli (*Pseudaphritis urvilli)*, a diadromous fish species found in very high abundances (76% of the assemblage). The conditions in the creek also supported a high abundance of sandy sprat (*Hyperlophus vittatus)*, an important small-bodied prey fish that is important in the foodweb in the Coorong. Similarly, sandy sprat and congolli were the most abundant species sampled below Goolwa Barrage. The responses of these ecologically significant species to the barrage releases reinforced the importance of environmental water provision to maintain freshwater flow through the Murray barrages. Whilst Goolwa and Tauwitchere barrages are the primary sites for barrage releases to maintain an open Murray Mouth and improve habitat and ecological health in the Coorong, small volumes of water discharge through Boundary Creek creates 'brackish/estuarine'

conditions and a salinity depth profile (halocline) that would probably benefit the ecological processes and biota in the Murray Estuary. Furthermore, monitoring of ecological responses including fish would provide insights to the key life history and ecological processes supported by Boundary Creek Barrage releases to inform environmental flow management.

1. INTRODUCTION

1.1. Background

The Lower Lakes, Coorong and Murray Mouth (LLCMM) is a large wetland system at the terminus of Australia's largest river system, the Murray-Darling River, and plays a significant role in providing ecosystem services. It has been recognised as a Wetland of International Importance under the Ramsar Convention since 1985 and represents one of the six 'icon sites' identified across the Murray-Darling Basin (MDB) through The Living Murray Program (MDBC 2006). There is a diverse fish community inhabiting the LLCMM region, including key commercial/recreational fisheries species (e.g. black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*), mulloway (A*rgyrosomus japonicas*), golden perch (*Macquaria ambigua ambigua*)) and those of significant conservation and/or ecological values (e.g. smallmouthed hardyhead (*Atherinosoma microstoma*), congolli (*Pseudaphritis urvilli*), Yarra pygmy perch (*Nannoperca obscura*), Murray hardyhead (*Craterocephalus fluviatilis*), Murray cod (*Maccullochella peelii*)). The Coorong and Murray Mouth area is a unique 'estuary', connecting the freshwater and sea. Many estuarine-lagoonal fish species complete their life cycles in the Coorong; whereas others frequently enter the system, using the Coorong as refuge, nursery and feeding ground, as well as a migration pathway at certain life history stages.

Under the Living Murray initiative, the vision for the LLCMM Icon Site, as defined in the Environmental Water Management Plan, is 'a healthier Lower Lakes and Coorong estuarine environment', and the ecological objectives are:

- An open Murray Mouth;
- More frequent estuarine fish spawning and recruitment;
- Enhanced migratory wader bird habitat.

A range of ecological targets were set with appropriate monitoring implemented, including fish monitoring in the Coorong since 2008/09. Fish monitoring undertaken by SARDI from 2006–2014 established valuable data to assess the condition status of key fish populations and inform adaptive management of environmental flow and habitat in this region.

Freshwater flow to the Coorong estuary is pivotal in facilitating a variety of processes, but most importantly with regards to fish, freshwater flow influences the estuarine salinity regime, connectivity between freshwater, estuarine and marine environments, and estuarine productivity by transporting nutrients from upstream. Recruitment of black bream, as an iconic estuarine fish species, is strongly affected by the aforementioned factors. A recent study indicated that freshwater flow had a large influence on the salinity and level of stratification (difference between bottom and surface salinity) in the Gippsland Lakes, Victoria (Williams et al. 2012); this influenced location and extent of environmental conditions suitable for spawning and larval development of black bream. Interestingly, they found that despite the fact that black bream spawning occurred in the lakes and rivers, only locations with a halocline functioned as larval nursery habitat. Other studies indicate 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). Larval fishes retained within the vicinity of the halocline can benefit from faster growth due to high prey availability, and reduced risk of starvation and predation (North and Houde 2003; Islam et al. 2006). Therefore, the halocline forms an important habitat for estuarine spawning fishes and other species with larvae that develop in estuaries. As this 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. This could partially explain variable levels of recruitment success of black bream in the Murray Estuary and Coorong (Ye et al. 2015).

During 2014/15, environmental water was released through the Boundary Creek Barrage. A single bay on the Boundary Creek Barrage was 'cracked' open by inserting a stopper at the bottom of the stop log. This allowed a continuous trickle flow from the barrage, with the intention of creating suitable estuarine conditions downstream of the barrage for black bream recruitment. In response to the Department of Environment, Water and Natural Resources (DEWNR), SARDI undertook intervention monitoring to assess the recruitment response of black bream in association with the environmental water releases in Boundary Creek. Fish condition monitoring by SARDI from 2008–2014 provided baseline data of black bream recruitment in Boundary Creek and below Goolwa Barrage for comparison.

1.2. Objectives

- Assess black bream recruitment in Boundary Creek following environmental flow releases in spring/summer 2014/15 by investigating the following parameters:
    - Presence of a halocline;
    - Abundance of juvenile black bream (i.e. young-of-the-year).

- Provide commentary and interpretation to evaluate the outcomes associated with environmental flow releases through Boundary Creek and management recommendations.

2. BIOLOGY/ECOLOGY

Black bream are an endemic sparid to the estuaries and coasts of southern Australia (Stewart and Grieve 1993; Haddy and Pankhurst 2000; Gommon et al. 2008). They are considered an important commercial and recreational fisheries species (Rowland and Snape 1994; Haddy and Pankhurst 1998; Sarre and Potter 2000) and reputed for their hardiness as they possess a wide environmental tolerance to temperature, salinity and dissolved oxygen concentration (Norriss et al. 2002; Partridge and Jenkins 2002). Even though they have a preference for brackish waters, 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, with salinity approximately 70 psu (Ye et al. 2013).

Black bream are a rare example of a teleost species which can complete their entire life cycle within their natal estuary (Sarre et al. 2000; Burridge et al. 2004). They are multiple batch spawners and spawning often takes place in the upper reaches of the estuarine system, near the interface between fresh and brackish waters (Walker and Neira 2001). Black bream are considered periodic strategists (Winemiller and Rose 1992), slow-growing (k=0.04–0.08), long-lived (29–32 years) with intermediate age of maturity (1.9–4.3 years) (Coutin et al. 1997; Morison et al. 1998; Norriss et al. 2002) and high fecundity (up to 3 million eggs was estimated for a large female) (Butcher 1945; Dunstan 1963).

Given the ecological and commercial importance, black bream have been a key species studied in the Murray Mouth and Coorong over the last decade. Cheshire et al. (2013) found that Coorong black bream spawn in spring, akin to black bream from Victorian estuaries (Coutin et al. 1997; Norriss et al. 2002). Cheshire et al. (2013) detected spawning activity with a peak in gonadosomatic index (GSI) occurring in October and November. However no black bream larvae were found in the Coorong in a larval fish assemblage study during spring 2008, when there was no freshwater releases through the Murray barrages due to the drought (Bucater et al. 2013). Though in this study sampling tows were conducted near the surface without considering halocline location, which may partially explain the absence of black bream larvae in the samples.

Variability of freshwater inflows has been identified as a key factor influencing recruitment success (Sarre and Potter 2000; Nicholson et al. 2008; Jenkins et al. 2010; Williams et al. 2012), with greatest recruitment occurring during years of intermediate river flows and poor recruitment following periods of very low and high flows (Jenkins et al. 2010). Therefore, managing flow releases to estuaries is particularly important for black bream as the majority of individuals from a given population will complete the entire life cycle within a single estuary (Butcher 1945; Sherwood and Blackhouse 1982; Elsdon and Gillanders 2006) individual populations are more dependent on self-recruitment than from adjacent systems (Potter et al. 1996; Partridge and Jenkins 2002; Sakabe et al. 2011). Such life history characteristics and affiliation to estuaries make this species not only highly sensitive to changes in flow but also to overfishing (Ferguson et al. 2013).

3. METHODS

Salinity profiles (longitudinal and depth profile) were measured below Goolwa and Boundary Creek barrages and at various locations to detect the presence of a halocline in November 2014 and March 2015 (Figure 3.1). The timing of sampling was selected to align with the spawning/recruitment season of black bream in the Murray Estuary. Salinity measurements were taken at depths of 0.3, 1, 1.5, 2 and 3 m, wherever possible. Salinity stratification level was quantified by amplitude, which was defined the difference between salinity near the surface (i.e. 0.3 m) and at the greatest depth (i.e. 1–3 m).

Fish sampling was conducted to target early juvenile or young-of-the-year (YOY) black bream below Goolwa and Boundary Creek barrages in November and December 2014, and March 2015 (Figure 3.1). Targeted sampling was conducted using single-wing fyke nets, which were 8.6 m long (3 m lead plus 5.6 m funnel) with a mesh size of 8 mm and a hoop diameter of 0.6 m. Four sets of four fyke nets were set along Boundary Creek, whilst below Goolwa Barrage, two sets of eight fyke nets were set at each side (i.e. Sir Richard Peninsula end and Hindmarsh Island end). Sampling below Goolwa Barrage was conducted to provide a control/comparison for the Boundary Creek intervention monitoring. Available baseline data (2008/09–2013/14) of relative abundances of juvenile (YOY) black bream from relevant sites are also presented for a comparison with 2014/15 data. The relative abundance is defined as number of fish per net.night.

An exploratory larval sampling event was carried out in November 2014 at both Goolwa and Boundary Creek sites, aiming to detect larvae of black bream. Larval sampling was conducted in the vicinity of halocline areas, using plankton tows (day and night) and light traps (over-night). Larval fish samples were preserved in ethanol (90%) and sorted in the SARDI laboratory to identify the presence of black bream.

Figure 3.1 - Map of fish sampling locations for early juvenile and young-of-the-year black bream at Goolwa and Boundary Creek sites.

4. RESULTS

4.1. Water discharge

From 2007 to 2015, water discharge was highly variable at both barrages, varying from no flow from 2007 to early 2010 to a peak of approximately 750 $GL.month^{-1}$ and 40 $GL.month^{-1}$ in March 2011 at Goolwa and Boundary Creek barrages, respectively (Figure 4.1). The difference in barrage operation at the two sites should be noted; Goolwa Barrage was frequently shut during high tide/storm events, but Boundary Creek could be left open through all conditions. Subsequently, there was a sharp decrease in water discharge at Goolwa Barrage, followed by five flow pulses that peaked in August 2011, May and September 2012, October 2013 and August 2014. Whilst at Boundary Creek Barrage, after the substantial decrease, flow remained stable from June 2011 to December 2012 at around 6 $GL.month^{-1}$; between January 2013 and June 2015, flow releases were consistently low (~0.3 $GL.month^{-1}$). Water surface salinity also varied greatly between years (2007–2015), ranging 0.3–20.4 psu at Goolwa Barrage and 0.2–43.5 psu at Boundary Creek Barrage. Salinity, in general, was negatively correlated to water discharge.

During 2014/15, environmental water was released through the Boundary Creek Barrage between September 2014 and June 2015 to maintain a small volume of constant flow; the discharge rate during the fish sampling period averaged 3, 22 and 17 $ML.day^{-1}$ in November 2014, December 2014 and March 2015, respectively (Figure 4.2). Environmental water was also released through Goolwa Barrage, resulting in average flow rates of 519, 482 and 481 $ML.day^{-1}$ for the respective fish sampling periods.

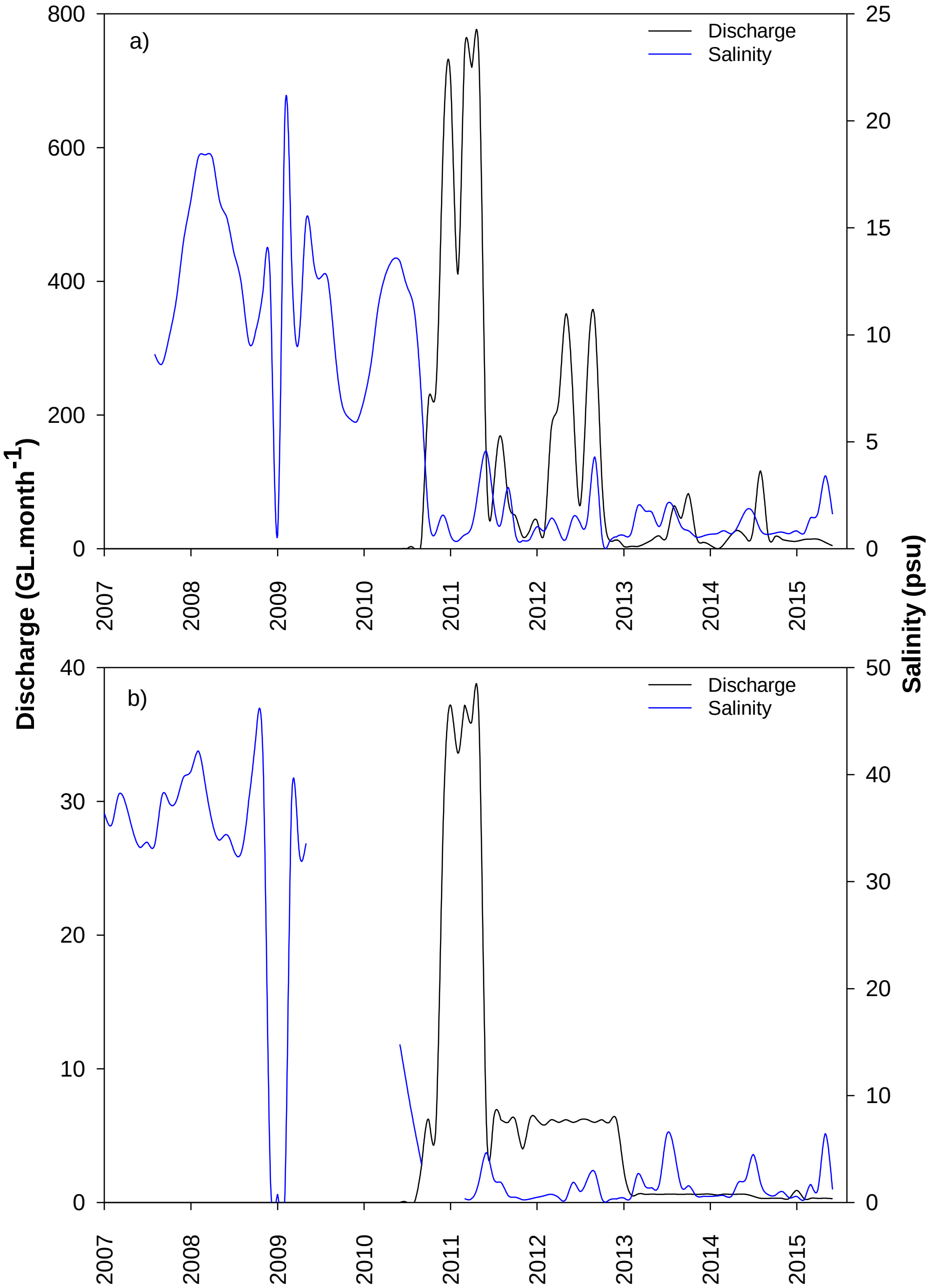


Figure 4.1 – Average monthly water discharge through a) Goolwa Barrage and b) Boundary Creek from January 2007 to June 2015. Flow data based on number of gates opened (source SA Water) and salinity sourced from Water connect website (DEWNR).

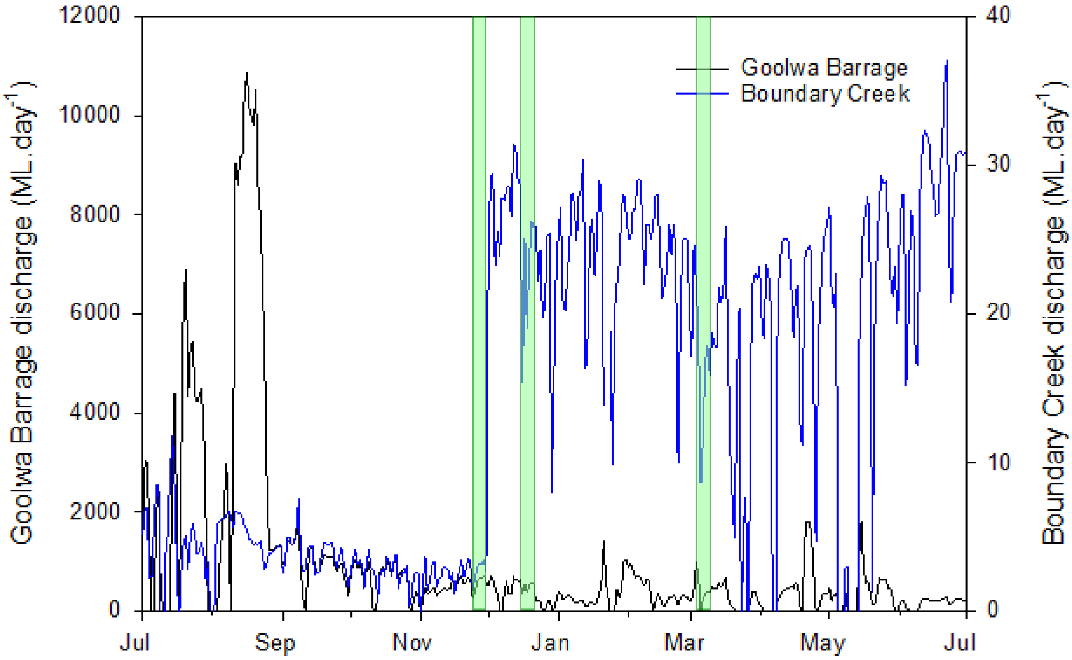


Figure 4.2 - Daily water discharge through a) Goolwa Barrage and b) Boundary Creek Barrage from 1 July 2014 to 31 July 2015. Flow data based on number of gates opened (source SA Water). Green bars indicate fish sampling time.

4.2. Salinity gradient

Salinity measurements taken at various depths (0.3–3 m) at 11–12 locations along Goolwa channel and Boundary Creek during two sampling occasions (November 2014 and March 2015) are presented on Figure 4.3 and Figure 4.4. Generally, salinity varied from approximately 2 to 33 psu and 8 to 36 psu along Goolwa channel and Boundary Creek, respectively. Halocline was detected in both sites and sampling occasions, however, it was most prominent at Goolwa Channel in March 2015 (Figure 4.4). The greatest salinity amplitude, in the Goolwa Channel, was 16.9 psu in November 2014 at Location G7 and 22.9 psu in March 2015 at Location G9; whereas along Boundary Creek, the highest amplitude was 17.8 psu in November 2014 at Location BC6 and 13.3 psu in March 2015 at Location BC3 (Figure 4.5).

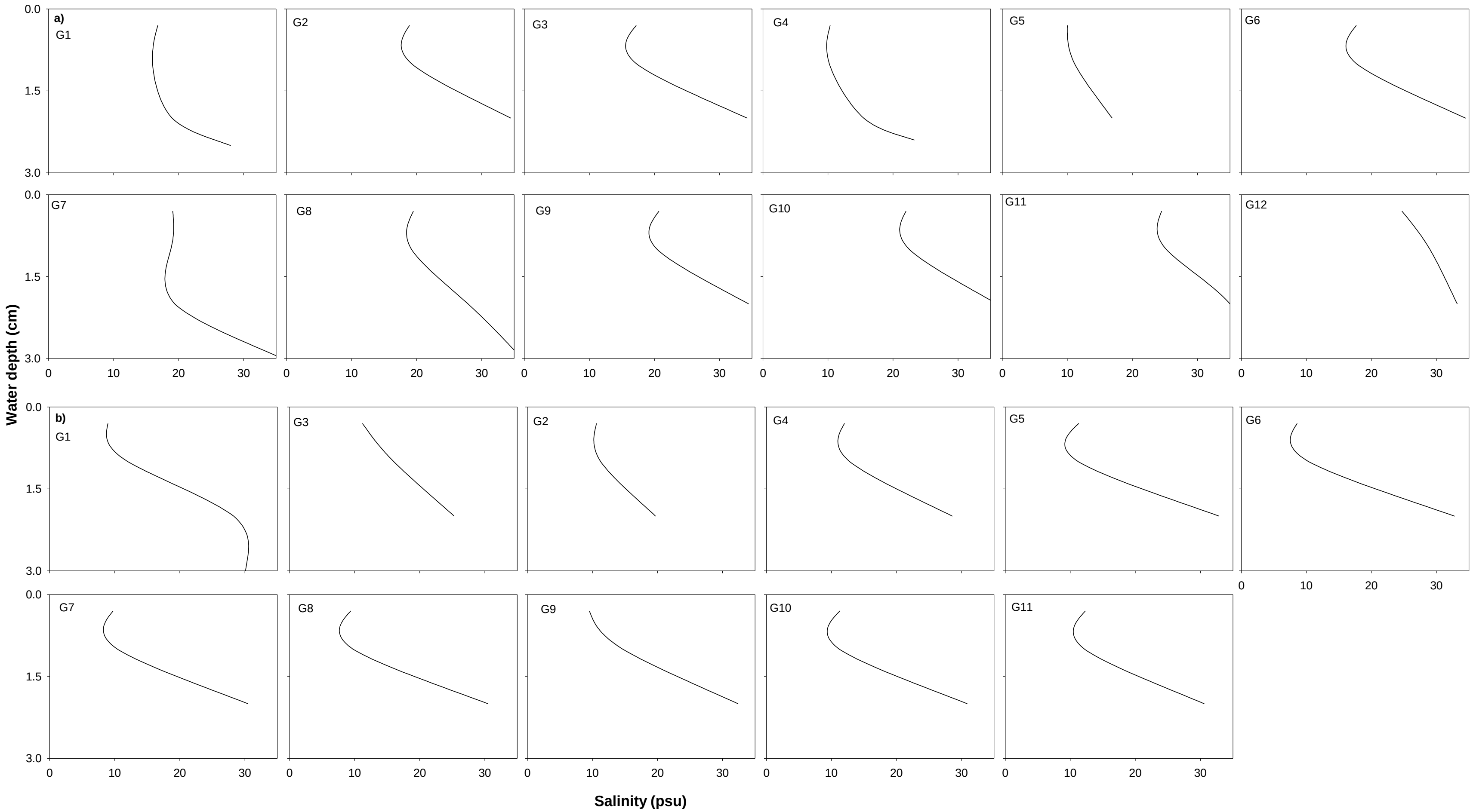


Figure 4.3 - Salinity profile measured at Goolwa channel in November 2014 (a) and March 2015 (b). Measurements taken at a regular distance from just below barrage (G1) and sites downstream (G2–G12).

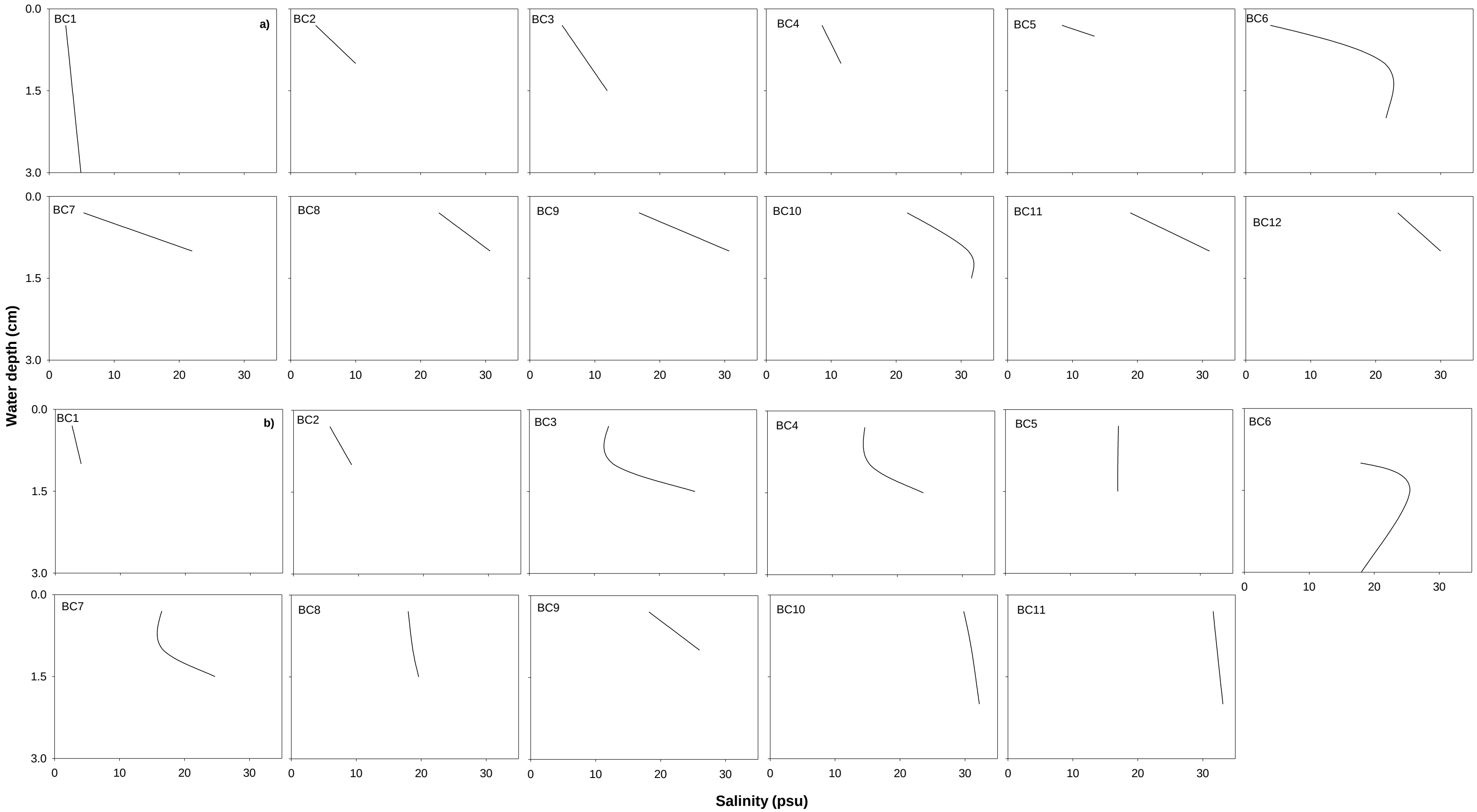


Figure 4.4 - Salinity profile measured at Boundary Creek in November 2014 (a) and March 2015 (b). Measurements taken at a regular distance from just below barrage (BC1) and sites downstream (BC2–BC12).

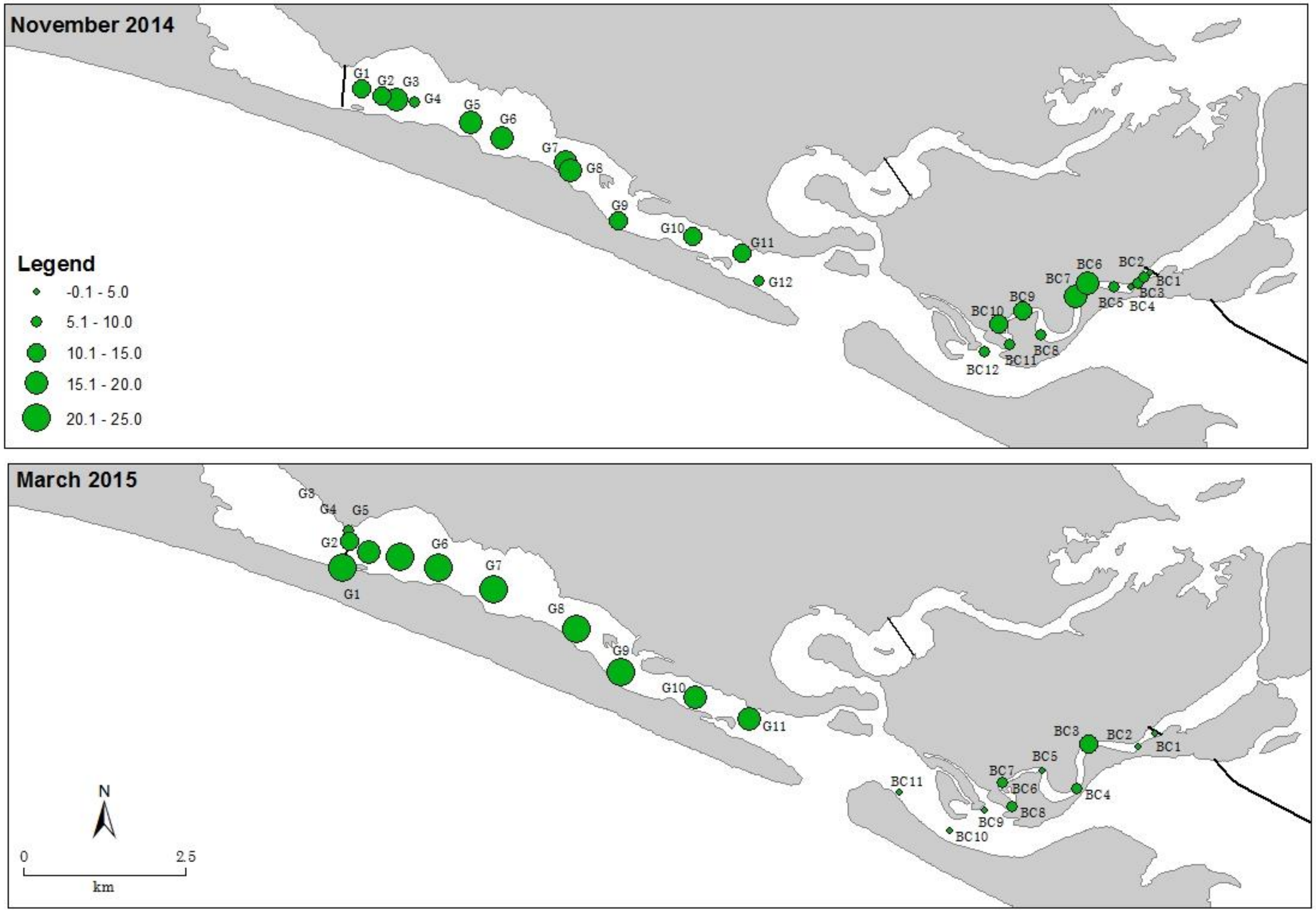


Figure 4.5 - Map of Goolwa channel and Boundary Creek showing the salinity amplitude measured at various locations in November 2014 (top) and March 2015 (bottom). Green bubble size indicates salinity amplitude.

4.3. Catch summary

Overall, a total of 1,119,240 fish representing 22 species were sampled using fyke nets at Goolwa and Boundary Creek in November and December 2014 and March 2015. The total number of fish collected from Boundary Creek was 72% higher than below Goolwa Barrage. There was generally a reduction in fish numbers throughout the sampling months at both sites. The most abundant species sampled in 2014/15 were congolli and sandy sprat, followed by common galaxias, accounting for 61%, 31% and 4% of the overall catches by number (all percentages we presented by fish number in this section), respectively.

At Boundary Creek, congolli was by far the most abundant species (76%), followed by sandy sprat (17%) and common galaxias (5%). Most congolli (99%) were sampled in November and December 2014. Abundances of sandy sprat were also greater in the first two sampling months compared to March 2015; whereas 99% of common galaxias were sampled in December 2015.

In contrast, at Goolwa Barrage, sandy sprat was the most abundant species (57%), followed by congolli (35%). Over the three sampling months, 77% of sandy sprat came from samples in November 2014 whilst 86% of congolli were from samples in November and December 2014.

At both Boundary Creek and Goolwa sites, no black bream juveniles (YOY) were collected on any sampling occasions. The exploratory sampling for larval fish in November 2014 also failed to detect black bream larvae at both sites.

Table 4.1 – Fish species and numbers collected using fyke nets in November 2014 and March 2015 at Goolwa channel and Boundary Creek.

		Goolwa channel				Boundary Creek				Grand Total
Common name	**Scientific name**	**Nov-14**	**Dec-14**	**Mar-15**	**Subtotal**	**Nov-14**	**Dec-14**	**Mar-15**	**Subtotal**	
Black bream	*Acathopagrus butcheri*	0	0	0	0	0	0	0	0	0
Tamar goby	*Afurcagobius tamarensis*	1,300	964	6,408	8,672	720	7,104	404	8,228	16,900
Yellow-eyed mullet	*Aldrichetta forsteri*	4	32	64	100	32	0	84	116	216
Bridled goby	*Arenogobius bifrenatus*	16	448	200	664	32	376	12	420	1,084
Mulloway	*Argyrosoma japonicus*	0	0	8	8	0	0	0	0	8
Western Australian salmon	*Arripis truttaceus*	0	0	0	0	4	0	0	4	4
Smallmouth hardyhead	*Atherinosoma microstoma*	0	7,440	0	7,440	484	16	712	1,212	8,652
Common galaxias	*Galaxias maculatus*	2,088	316	6,968	9,372	88	35,096	636	35,820	45,192
Soldier	*Gymnapistes marmoratus*	4	36	48	88	4	0	0	4	92
Sandy sprat	*Hyperlophus vittatus*	193,768	17,892	39,128	250,788	42,556	63,368	20,048	125,972	376,760
Goldspot mullet	*Liza argentea*	0	0	104	104	0	0	0	0	104
Bony herring	*Nematolosa erebi*	36	0	120	156	48	0	56	104	260
Golden perch	*Macquaria ambigua*	0	4	0	4	0	0	0	0	4
Redfin perch	*Perca fluviatilis*	20	28	160	208	84	40	0	124	332
Flat-headed gudgeon	*Philypnodon grandiceps*	504	3,760	3,872	8,136	736	6,344	328	7,408	15,544
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	8	4	0	12	0	24	0	24	36
Bluespot goby	*Pseudogobius olorum*	20	148	16	184	8	40	340	388	572
Congolli	*Pseudaphritis urvillii*	84,848	48,676	21,664	155,188	375,608	193,200	4,484	573,292	728,480
Australian smelt	*Retropinna semoni*	56	4	88	148	52	0	0	52	200
Greenback flounder	*Rhombosolea tapirina*	8	4	0	12	0	0	0	0	12
Scary's Tasman goby	*Tasmanogobius lasti*	48	32	216	296	16	3,912	564	4,492	4,788
Smooth toadfish	*Tetratenos glaber*	0	4	0	4	0	0	0	0	4
Total		**282,728**	**79,788**	**79,064**	**441,580**	**420,472**	**309,520**	**27,668**	**757,660**	**1,199,240**

4.4. Relative abundance of juvenile Black Bream

Over the past seven years juvenile black bream were more frequently detected below Goolwa Barrage (four out of seven) than in Boundary Creek (one out of seven) (Table 4.2). The only year when juvenile black bream were sampled in Boundary Creek was 2011/12, a year post the 2010/11 flood. No juveniles were detected at either Goolwa or Boundary Creek in 2013/14 or 2014/15, despite the increased targeted effort.

Table 4.2 - Catch per unit effort (CPUE) of juvenile black bream using single-wing fyke nets at Goolwa and Boundary Creek from 2008/09 to 2014/15. (SE = standard error). Note: data collected in March of each year, except for 2014/15 when samples were collected in November and March.

CPUE (fish per net.night)	2008/09		2009/10		2010/11		2011/12		2012/13		2013/14		2014/15	
Regular sites	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Goolwa	5.00	1.89	0.69	0.22	0.00	0.00	0.13	0.13	1.13	0.44	0.0	0.0	0.0	0.0
Boundary Creek	0.00	0.00	0.00	0.00			0.25	0.25	0.00	0.00	0.0	0.0	0.0	0.0
Overall	**2.50**	**0.95**	**0.34**	**0.11**	**0.00**	**0.00**	**0.19**	**0.19**	**0.56**	**0.22**	**0.00**	**0.00**	**0.00**	**0.00**

5. DISCUSSION

As a result of the decadal drought (2001–2010) in the MDB and the impact of river regulation and water extraction, the Murray Estuary and Coorong experienced a drastic reduction of freshwater inflow. There were no barrage releases from 2007/08 to 2009/10. The drought was broken in September 2010 by a major flood; flows in the MDB increased and the Lower Lakes were filled, culminating in increased freshwater discharges through the Murray barrages. At Goolwa and Boundary Creek barrages the discharge rate was highest in 2010/11, followed by a general reduction in 2011/12 and further reductions in the following three years (Appendix I).

Freshwater flow is directly correlated to the level of stratification in estuaries (Jenkins et al. 2010). Studies have found that under certain freshwater flow conditions, there is a linkage between halocline, primary productivity, zooplankton and larval fishes (Cloern et al. 1983; North and Houde 2001; Kimmerer 2002; North et al. 2005). Therefore, larval fishes retained within the halocline proximity may benefit from faster growth and reduce risk of predation (Sirois and Dobson 2000; North and Houde 2003; Islam et al. 2006). For black bream, Williams (2012) found that at the Gippsland Lakes the highest concentration of larvae occurred at sites with a salinity amplitude of 15–20 psu.

In the current study, environmental water delivery with small flow releases (average <25 $ML.day^{-1}$) through the Boundary Creek Barrage led to the formation of a halocline in November 2014, with a salinity amplitude >15 psu at several locations below the barrage for a distance of ~2.5 km. The level of salinity stratification was comparable to that in the Goolwa Channel over a distance of ~6.5 km as a result of larger barrage releases (~520 $ML.day^{-1}$). The halocline conditions during the black bream spawning season in spring and early summer (Cheshire et al. 2013) would have provided potential benefits to larval fish survival and in turn bream recruitment. During March 2015, a halocline remained present at both sites despite a slight reduction in flow release, although the level of stratification was higher in the Goolwa Channel probably due to greater depth and higher volumes of flow discharge.

Although a halocline was present at both Goolwa and Boundary Creek sites, attempts to collect black bream larvae in November 2014 failed with no larvae found at either site. The sampling of early juveniles (YOY) in November/December 2014 and March 2015 also failed to collect any black bream. This may suggest recruitment failure in 2014/15 despite suitable environmental conditions (halocline) being present. The most recent fish condition monitoring report indicated that the black bream population in the Coorong was at a weakened state with a low abundance and truncated aged structure (Ye et al. 2015). The reduced spawning biomass may have explained the decline in recruitment. However, results need to be interpreted with caution given limited sampling effort during the study and the patchiness and high variability in juvenile fish abundance and distribution of black bream across this region (Ye et al. 2015).

Fish condition monitoring in previous years detected higher abundances of juvenile black bream under no flow or small to moderate flow conditions in several years below the Goolwa Barrage and in one year (i.e. 2011/12) in Boundary Creek (Ye et al. 2015). During these years, salinity measurements were only taken at 0.3 m below the water surface, thus no association with salinity stratification could be made for juvenile black bream abundance in the Murray Estuary and Coorong. However, data suggested that juvenile black bream were more regularly collected below the Goolwa Barrage than in Boundary Creek and other sites. This may be related to more regular barrage releases at Goolwa and the morphology (greater depth and length) of the Goolwa Channel, which potentially result in a greater level and extent of salinity stratification, thus improving black bream larval survival.

The current study detected a halocline with a salinity amplitude favorable for black bream larvae (15–20 psu) in Boundary Creek, following small volumes of constant barrage releases supported by environmental water. Despite no black bream larvae or juveniles being collected in 2014/15, the environmental conditions at Boundary Creek appeared to have facilitated the recruitment of congolli, a diadromous fish species found to dominate the samples (76%). The conditions in the creek also supported a high abundance of sandy sprat, a small-bodied marine fish that provide important prey for many piscivorous fish and birds in the region (Giatas and Ye 2015). Similarly, sandy sprat and congolli were the most abundant species sampled below the Goolwa Barrage. The responses of these ecologically significant species to the barrage releases reinforce the importance of environmental water provision to maintain freshwater flow through the Murray barrages. Whilst Goolwa and Tauwitchere barrages are the primary sites for barrage releases to maintain the Murray Mouth opening and improve habitat and ecological health in the Coorong, it is worth noting that only small volumes of water discharge through Boundary Creek could create brackish/estuarine conditions and a halocline that would probably benefit the ecological processes and biota in the Murray Estuary. Such flow releases should continue as a management action. Furthermore, monitoring of ecological responses including the recruitment of black bream and other key fish species would provide insights to key life history and ecological processes supported by Boundary Creek Barrage releases to inform environmental flow management.

REFERENCES

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

Bucater, L. B., Livore, J. P., Noell, C. J. and Ye, Q. (2013). Temporal variation of larval fish assemblages of the Murray Mouth in prolonged drought conditions. Marine and Freshwater Research 64 (10) 932-937.

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

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

Cheshire, K. J. M., Ye Q., Fredberg, J., Short, D. and Earl, J. (2013). Aspects of reproductive biology of five key fish species in the Murray Mouth and Coorong. South Australian Research and Development institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-3. SARDI Research report Series No. 699. 63pp.

Cloern, J. E., Alpine, A. E., Cole, B. E., Wong, E. L. J.; Arthur, J. F and Ball, M. D. (1983). River discharge controls phytoplankton dynamics in the northern San Francisco by estuary. Estuarine, Coastal and Shelf Science 16, 415-426.

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

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

Earl, J., Ye, Q. and Ward, T.M. (in review). Black Bream (*Acanthopagrus butcheri*) Stock Assessment Report 2013/14. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 45pp.

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

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

Giatas, G.C. and Ye, Q. (2015). Diet and trophic characteristics of mulloway (*Argyrosomus japonicus*), congolli (*Pseudaphritis urvillii*) and Australian salmon (*Arripis truttaceus* and *A. trutta*) in the Coorong. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000479-1. SARDI Research Report Series No. 858. 81pp.

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

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

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

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

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

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

McNeil, D. G., Westergaard, S., Cheshire, K. J. M., Noell, C. J. and Ye, Q. (2013). Effects of hypersaline conditions upon six estuarine fish species from the Coorong and Murray Mouth. South Australian Research and Development institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-4. SARDI Research report Series No. 700. 27pp.

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

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

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

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

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

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

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

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

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

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

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

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

Sirois, P. and Dobson, J. J. (2000). Influence of turbidity, food density and parasites on the ingestion and growth of larval rainbow smelt *Osmerus mordax* in an estuarine turbidity maximum. Marine Ecology Progress Series 193, 167-179.

Stewart, P. C. and Grieve, C. (1993). Bream, Acanthopagrus species. In “Australian Fisheries Resources”. (Eds P. J. Kailola, M. J. Williams, P. C. Stewart, R. E. reichelt, A. McNee and C. Grieve.) pp. 311-14. (Bureau of Resource Sciences and Fisheries Research and Development Corporation: Canberra.)

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

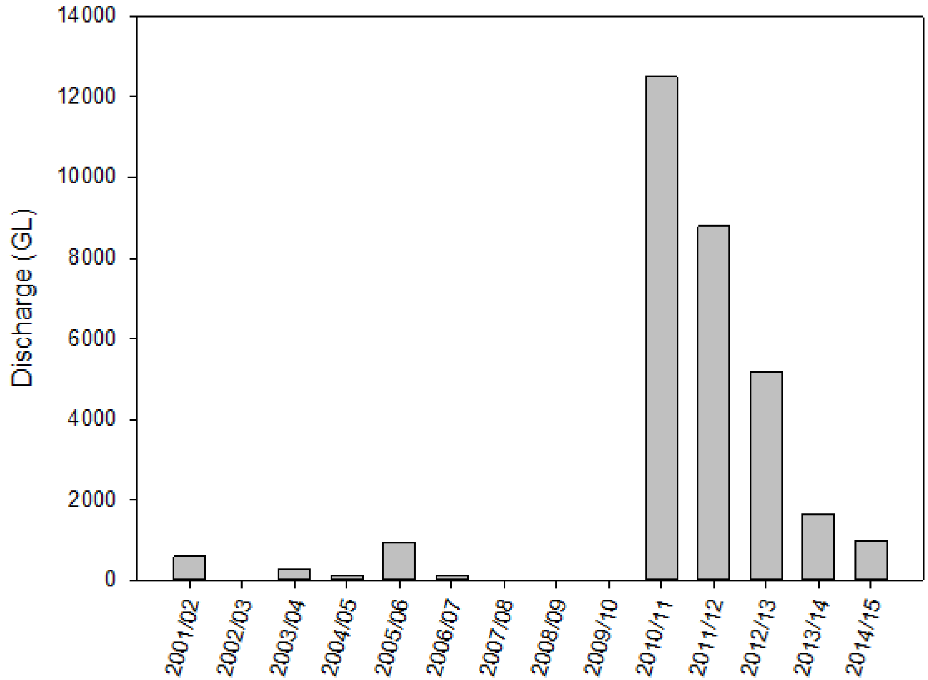
Williams, J., Hindell, J. S., Swearer, S. E. and Jenkins, G. P. (2012). Influence of freshwater flows on the distribution of eggs and larvae of black bream *Acanthopagrus butcheri* within a drought-affected estuary. Journal of Fish Biology, 80, 2281-2301.

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

Ye, Q., Bucater, L. and Short, D. (2013). Coorong fish condition monitoring 2008–2013: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-3. SARDI Research Report Series No. 748. 91pp.

Ye, Q., Bucater, L. and Short, D. (2015). Coorong fish condition monitoring 2008–2014: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-4. SARDI Research Report Series No. 836. 105pp.

APPENDIX



Appendix I – Annual water discharge (gigalitres) through Murray barrages 2001/02 to 2014/15. Flow data based on BIGMOD modelling by MDBA except that 2014/15 data was based on number of gates opened (source SA Water).