

Yelloweye Mullet (*Aldrichetta forsteri*)

Stock Assessment Report 2011/12



J Earl and G J Ferguson

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Cover photograph courtesy of Chris Bice (SARDI Aquatic Sciences).

EXECUTIVE SUMMARY

1. This report is the second assessment of the South Australian Yelloweye Mullet (*Aldrichetta forsteri*) fishery and follows a previous assessment in 2005. It provides a synopsis of information available for this species and reports on: (i) commercial catch and effort data from 1984/84 to 2011/12 for the Lakes and Coorong Fishery (LCF) and the State-wide Marine Scalefish Fishery (MSF); (ii) demographic information, including size and age structures, growth and maturity for the Yelloweye Mullet population in the Murray River estuary and Coorong; and (iii) the performance of the LCF for Yelloweye Mullet in relation to performance indicators and limit reference points identified in the LCF Management Plan.
2. The South Australian Yelloweye Mullet fishery harvested 177 t of Yelloweye Mullet, valued at \$714,000, in 2011/12. The fishery comprises two multi-species sectors: LCF and MSF. The LCF harvested 82% of the State-wide catch in 2011/12.
3. Within the LCF, Yelloweye Mullet is an important species and comprised 48% of the total finfish catch in 2011/12.
4. Annual catches of Yelloweye Mullet by the LCF increased to an historic peak of 346 t in 1989/90 then decreased to a low of 110 t in 2004/05. Catch in 2011/12 was 144 t and was among the lowest on record.
5. The dominant gear type used by the LCF to target Yelloweye Mullet was the small mesh gill net. In 2011/12, targeted catch from small mesh gill nets (>50 mm to ≤64 mm mesh) was 131 t which accounted for 91% of the total catch.
6. In the LCF, targeted effort directed at Yelloweye Mullet was closely related to targeted catch.
7. For the LCF, mean annual catch-per-unit-effort (CPUE) increased from an historic low of 45 kg.fisher day⁻¹ in 1984/85 to a peak of 128 kg.fisher day⁻¹ in 2007/08. In 2011/12, CPUE declined to 91 kg.fisher day⁻¹ and was among the highest on record.
8. For the MSF, CPUE was characterised by high inter-annual variability. It increased to an historic peak of 164 kg.fisher day⁻¹ in 1989/90. Since then, CPUE declined and averaged 102 kg.fisher day⁻¹. In 2011/12, CPUE was 93 kg.fisher day⁻¹.
9. Age structures from commercial catches by the LCF comprised mostly two and three year old fish. Older fish were rare despite the potential for this species to reach 10+ years of age.

10. The legal minimum size for Yelloweye Mullet in South Australia is 210 mm total length (TL), which is approximately 35 mm TL less than the size at maturity (SAM_{50}) for the species.
11. All LCF catch and effort based performance indicators were within the range of limit reference points prescribed in the Management Plan.
12. Available information suggests that the Yelloweye Mullet stock in the Murray River estuary and Coorong is sustainable. Given uncertainty around CPUE which provides the only index of relative abundance, it is important to develop additional indicators based on age/size structures.
13. The most important knowledge gaps for the Yelloweye Mullet fishery and its management include: (i) the need for an extended time series of age structures, including a validated otolith-based ageing protocol; (ii) improved understanding of movement between the Coorong and adjacent marine environments; (iii) ongoing monitoring of discards from small mesh gill nets; and (v) estimation of recreational catches.

1 GENERAL INTRODUCTION

1.1 Overview

This assessment of the Yelloweye Mullet (*Aldrichetta forsteri*) resource in South Australia, builds on a previous fishery assessment report in 2005 (Higham *et al.* 2005) and annual stock status reports (Ferguson 2006; 2008; 2010b; 2011; 2012). The report aims to provide a synopsis of information available for Yelloweye Mullet and an assessment of the current status of the Yelloweye Mullet stock in South Australia. The assessment presented here is based on commercial catch and effort data up to 30 June 2012 for the Lakes and Coorong Fishery (LCF) and the State-wide Marine Scalefish Fishery (MSF), and the results from the most recent South Australian Recreational Fishing Survey 2007/08 (Jones 2009). Demographic information, including size and age structures, growth, and maturity for Yelloweye Mullet in the Murray River estuary and Coorong is also included to inform on population structure.

1.2 Description of the fishery

In Australia, most catches of Yelloweye Mullet are taken from Victoria, South Australia and Western Australia although smaller catches are also taken in Tasmania (Kailola *et al.* 1993). Yelloweye Mullet is regarded as an important species by recreational fishers in these States, as well as New South Wales (Kailola *et al.* 1993). In South Australia, commercial and recreational catches of Yelloweye Mullet are taken in estuaries and nearshore coastal environments across the State. Most LCF commercial catches are taken from the estuary of the Murray River and Coorong (Ferguson 2008).

Commercial Fishery

The fishery for Yelloweye Mullet in South Australia has two main sectors, the LCF and MSF. The Northern Rock Lobster Fishery and Southern Rock Lobster Fishery can also target Yelloweye Mullet, though catches from these sectors are low and are not considered further in this assessment.

Lakes and Coorong Fishery

The LCF is a multi-species, multi-gear fishery that operates in, and adjacent to, the estuary of the Murray River (Figure 1.1), which comprises the Coorong lagoons, Lower Lakes of the Murray River (Lakes Alexandrina and Albert) and Coorong Coastal Waters (Sloan 2005).

Fishers in the LCF use mainly gill nets to target Yelloweye Mullet, *Argyrosomus japonicus*, *Macquaria ambigua*, *Acanthopagrus butcheri*, and *Rhombosolea tapirina*. These fishers also have access to *Donax deltoides* on the ocean beach adjacent to the Coorong lagoons. Yelloweye Mullet is one of the main target species in the LCF.

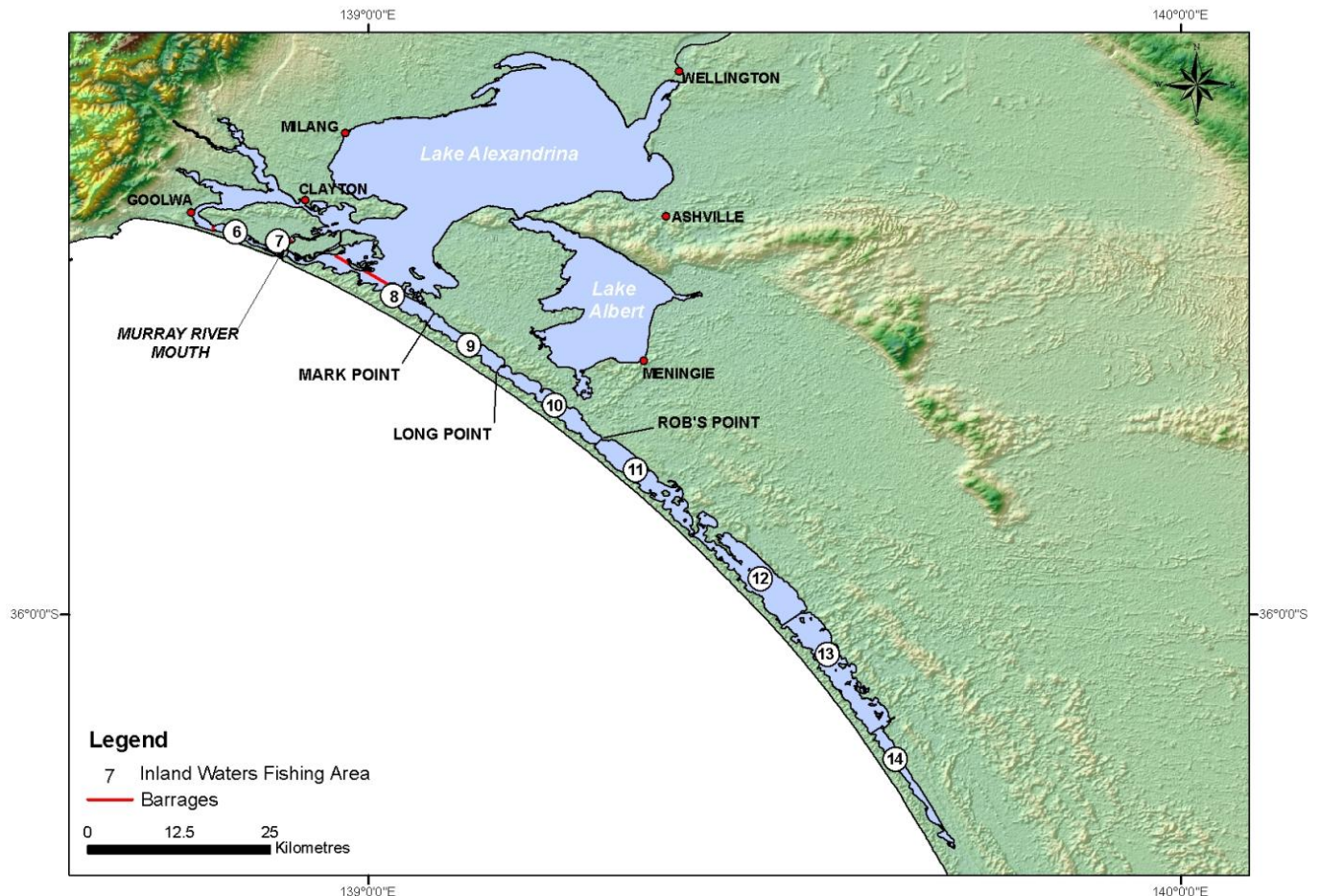


Figure 1.1. Map of the River Murray estuary and Coorong Lagoons showing commercial reporting areas 6-14 of the LCF.

Marine Scalefish Fishery

Similar to the LCF, the MSF is a multi-species, multi-gear fishery. The MSF operates in all coastal waters of South Australia, excluding the Murray River estuary and Coorong (Figure 1.2). Fishers in the MSF use mainly haul nets and gill nets to target Yelloweye Mullet.

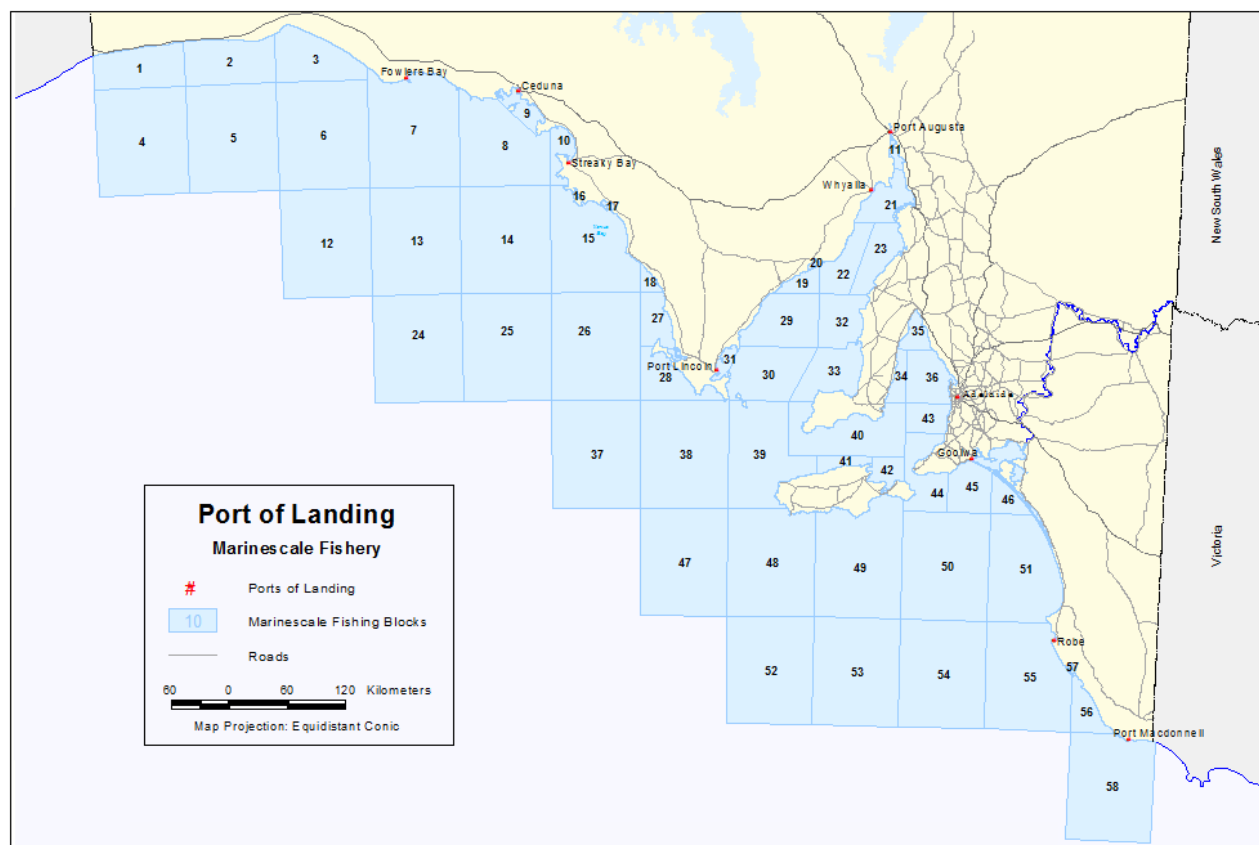


Figure 1.2. Map of South Australia showing the 58 spatial reporting blocks of the MSF.

Recreational Fishery

Recreational fishers harvest Yelloweye Mullet using rod and line in nearshore coastal waters of South Australia, particularly in gulfs, bays and estuaries (Kailola *et al.* 1993). Recreational fishers also target Yelloweye Mullet using registered monofilament nylon nets in the Murray River estuary, Coorong lagoons and Lake George (Pierce 1995). Recreational net fishing is prohibited in all other coastal waters of South Australia.

Traditional Fishery

The Ngarrindjeri population density is likely to have been the largest of any aboriginal group in Australia, with an estimated 3000 people inhabiting the Coorong region in the 1800s, prior to European settlement (Sloan 2005). The Ngarrindjeri people targeted Yelloweye Mullet as well as *Acanthopagrus butcheri*, *Rhombosolea tapirina* and *Argyrosomus japonicus* using traps, nets, spears and modified boomerangs (Jenkin 1979; Olsen and Evans 1991).

1.3 Management of the fishery

Commercial Fishery

Lakes and Coorong Fishery

Management of the LCF is governed by the *Fisheries Management (Lakes and Coorong Fishery) Regulations 2009* and *Fisheries Management (General) Regulations 2007*. The LCF Management Plan (Sloan 2005) provides a strategic policy framework for the management of the fishery and is currently being updated with completion due in 2014 (Ferguson 2012). Table 1.1 provides a timeline of management in the LCF.

The LCF is managed as a limited entry fishery. Currently, there are 36 licences with non-exclusive access within the Lakes and Coorong system and the adjacent beach of the Coorong. Fishing effort is limited through gear entitlements. For example, each licence is endorsed for the type and number of nets that can be used. Owner-operator provisions also apply so that gear must be set and retrieved by the licence holder or a nominated skipper (registered master).

Licence amalgamations were permitted under the Scheme of Management introduced in 1984 to promote economic efficiency by allowing fishers to rationalise individual gear entitlements from within the existing pool of licences. In 1990, following an agreement between PIRSA and the commercial industry, a policy directive was introduced to formalise a set of guidelines on licence amalgamations and transfers. A key element of the policy was the limitation placed on the amount of gear that may be endorsed on an individual licence upon licence transfer or amalgamation. Under the policy, a maximum of two agents may undertake fishing activity pursuant to each licence, following the transfer of a licence. Specific arrangements apply to licence transfers between members of a family. All applications for licence transfer or amalgamation must be considered in accordance with the *Fisheries (Scheme of Management - Lakes and Coorong Fishery) Regulations 1991*. This 'amalgamation scheme' has allowed for limited structural adjustment of the commercial sector by reducing the number of licences and the amount of gear operating in the fishery over time.

The LCF is managed in the context of a number of international legal instruments including the Ramsar Convention and United Nations Convention on the Law of the Sea. In addition, the fishery operates within the boundaries of the Lakes and Coorong National Park, an area recognised primarily for its wetland habitats and importance for a variety of migratory waterbirds.

Catch and effort data for the LCF for Yelloweye Mullet have been recorded since 1984 (Knight *et al.* 2001). Daily catch and effort information is provided to SARDI Aquatic Sciences on a monthly basis and includes; catch (kg), effort (days, fisher days, number of nets) and fishing location (LCF reporting areas) (Figure 1.1). Management arrangements comprise general gear restrictions, spatial and temporal closures and a legal minimum size (LMS) of 210 mm total length (TL).

Marine Scalefish Fishery

Fishers in the MSF have access to Yelloweye Mullet in all South Australian coastal waters except the Murray River estuary and Coorong lagoons. The LMS of 210 mm TL applies to all catches. Catch and effort data for the MSF have been recorded since 1984 (Knight *et al.* 2001). Daily catch (kg) and effort (days, fisher days, number of nets) data for targeted and non-targeted species and location of fishing is provided on a monthly basis to SARDI Aquatic Sciences. Fishing location is reported against MSF reporting blocks (Figure 1.2).

The management of the MSF is governed by the *Fisheries Management (General) Regulations 2007* and *Fisheries Management (Marine Scalefish Fisheries) Regulations 2006*. Management arrangements have evolved since the South Australian Government first introduced a requirement for all commercial fishers to hold a commercial fishing licence in 1906. Major management milestones are listed in Table 1.1.

Recreational fishery

The recreational sector is managed through a combination of input and output controls, aimed at ensuring the total catch is maintained within sustainable limits and to ensure that recreational access to the fishery is equitably distributed between recreational participants. A bag limit of 60 Yelloweye Mullet per fisher per day, and a boat limit of 180 Yelloweye Mullet, applies to this fishery. Management arrangements also comprise general gear restrictions. Netting by recreational fishers is permitted within the Coorong. In 2012, approximately 735 recreational fishers possessed a mesh net that was registered with PIRSA Fisheries and Aquaculture for use in the Lakes and Coorong. An additional 1135 mesh nets were registered for use in Lake George. Recreational mesh nets must be less than 75 m long with 50–64 mm (4 1/4" to 6") mesh size, and the registered net owner must be within 50 m of the net at all times when fishing. Temporal and spatial closures also apply to the use of recreational nets in the Coorong.

Table 1.1. Management milestones for the LCF and MSF species in South Australia.

Date	Milestone
1906	The South Australian Government introduced a requirement for all commercial fishers to hold a commercial fishing licence.
1971	Introduction of fishing licences for all commercial fishing in South Australia.
1972	Licensed commercial fishers required to provide monthly catch data.
1982	<i>South Australian Fisheries Act, 1982.</i>
1984	Scheme of Management (Lakes and Coorong Fishery) Regulations 1984. Scheme of Management (Marine Scalefish Fisheries) Regulations 1984. Scheme of Management (Restricted Marine Scale Fishery) Regulations 1984.
1984-85	The LCF was divided into 16 areas for the purpose of data collection and more detailed fishing location information was collected from operators.
1986	Restrictions on commercial net type, mesh size, net depth and net length. Limit of one registered recreational net per person, with 70 m TL and maximum of 1 m drop.
1990	Guidelines formalised to limit the amount of gear that may be endorsed on an individual licence upon licence transfer or amalgamation.
1991	Fisheries (Scheme of Management—Lakes and Coorong Fishery) Regulations 1991. Fisheries (Scheme of Management—Marine Scalefish Fisheries) Regulations 1991.
1997	Review of the recreational fishery.
2003	Closure of the river fishery.
2004	Amendments to the Scheme of Management to allow an individual to hold more than one licence.
2005	Management Plan for the South Australian Lakes and Coorong Fishery.
2006	Fisheries (Scheme of Management – Lakes and Coorong Fishery) Regulations 2006. Fisheries (Scheme of Management – Marine Scalefish Fishery) Regulations 2006.
2007	<i>The Fisheries Management Act 2007.</i> Fishery Management Committees were discontinued from 31 March 2007.
2009	<i>Fisheries Management (Lakes and Coorong Fishery) Regulations 2009.</i>

Traditional fishery

All of the management measures in place for the recreational sector apply to indigenous fishers when undertaking traditional fishing practices.

1.4 Performance indicators for the commercial fishery

The Management Plan for the LCF (Sloan 2005) identifies four performance indicators (PIs) and their associated limit reference points (RPs) to assess the status of the Yelloweye Mullet fishery. All PIs were derived from catch and effort data for the historical reference period from 1984-85 to 2001-02. Upper and lower RPs for catch and CPUE PIs were estimated from the average of

the three highest and three lowest values during the reference period. Upper and lower trend (rate-of-change) PIs for catch and CPUE were estimated from the highest and lowest slope of the linear relationships for 4-year periods within the reference period (Sloan 2005).

1.5 Previous stock assessments

Commercial Fishery

Lakes and Coorong Fishery

Previous assessment of the status of the LCF for Yelloweye Mullet includes: a fishery assessment (Higham *et al.* 2005) and stock status reports (Pierce and Doonan 1999; Ferguson 2006; 2008; 2010b; 2011; 2012).

In South Australia, catch rates of Yelloweye Mullet have varied among years (Pierce and Doonan 1999; Ferguson 2012). Key points from the assessment by Higham *et al.* (2005) were:

- The LCF harvested 167 t in 2002/03. Small mesh gill nets (SMGN) (>50 mm to ≤64 mm mesh) were the dominant gear accounting for 87% of the total catch. CPUE_{SMGN} was 113 kg/fisher day in 2002/03.
- Assessment of the fishery against PIs in the Draft Management Plan for the LCF indicated that all PIs for 2002/03 were within or above the defined RPs.

Ferguson (2012) provided a stock status assessment of fishery production for Yelloweye Mullet in the LCF. The key outcomes were:

- The LCF harvested 144 t in 2011/12, which decreased 41% from the 2010/11.
- Assessment of the LCF for Yelloweye Mullet indicated that all PIs for 2011/12 were within the range of the RPs defined in the Management Plan (Sloan 2005).

Marine Scalefish Fishery

Fowler *et al.* (2012) provided the most recent assessment of the MSF for Yelloweye Mullet. Key points from this report were:

- The highest annual catch of Yelloweye Mullet in the MSF was 176 t in 1989/90. The MSF harvested 33 t in 2011/12. This decline was related to declining fishing effort, and reflected changes within the fishery rather than declining stock status.

- All PIs for 2011/12 were within or above the RPs defined in the Management Plan for the MSF (Noell *et al.* 2006).

Recreational Fishery

Estimates of recreational catch for Yelloweye Mullet in South Australia are available for two years: 2000/01 and 2007/08. In 2000/01, the estimated harvested catch was 47 t which accounted for 19% of the State-wide catch (Jones and Doonan 2005). The overall release rate in 2000/01 was 34%. The highest catches occurred in the southern Adelaide metropolitan area and Fleurieu Peninsula. Most recreational catches were taken by line, although recreational net fishers in the Coorong may have been under-represented (Jones and Doonan 2005). Catch estimates were also recorded for 'unspecified mullet' and records for this group likely included some catches of Yelloweye Mullet (K. Jones pers. comm.) which would subsequently increase the total recreational catch estimate.

In 2007/08, the estimated catch by the recreational sector declined by approximately 40% since 2000/01 to 28 t. In 2007/08, recreational catches comprised 10% of the combined commercial and recreational catch in South Australia (Jones 2009). In 2007/08, a total of 151,654 ($\pm 52,712$) Yelloweye Mullet were harvested with an overall release rate of 46% (Jones 2009). In this survey, Jones (2009) did not distinguish between mullet species. Catches reported for mullet included *Mugil cephalus*, *Liza argenta* and Yelloweye Mullet. Together these species comprised 10% of the species harvested by the recreational fishers in 2007/08.

1.6 Fisheries Biology

This section provides a summary of the available literature on the fisheries biology of Yelloweye Mullet.

Taxonomy

Fishes of the order Mugiliformes are characterised by a silvery, slender, cigar-shaped adult form and are found in most tropical and temperate coastal and estuarine environments around the world (Gomon *et al.* 2008). Commonly known as mullets, these fishes comprise a single family - Mugilidae, and are represented by about 80 species in 17 genera (Gomon *et al.* 2008). Eight genera and 20 species occur in Australian waters, with four genera represented on the south coast: *Mugil*, *Aldrichetta*, *Liza* and *Myxus*. The only member of *Aldrichetta* in Australian waters is the Yelloweye Mullet (*Aldrichetta forsteri*, Valenciennes 1836).

Geographical distribution and habitat

Yelloweye Mullet are found in bays, estuaries and inshore waters in New Zealand and along the southern coast of Australia, from Kalbarri in Western Australia to Newcastle in New South Wales, and around Tasmania (Gomon *et al.* 2008). Yelloweye Mullet typically occur in schools in brackish and inshore coastal waters over sandy and muddy substrates in depths to 20 m, but can also be found in the lower reaches of freshwater rivers (Kailola *et al.* 1993; Connolly 1994; Gomon *et al.* 2008). Larger fish show a preference for deeper habitats such as channels or 'gutters', whereas juveniles tend to occupy shallow habitats (Platell and Hall 2004; Higham *et al.* 2005).

Yelloweye Mullet are well adapted to the dynamic environmental nature of estuaries and the nearshore coastal environment. They have a wide tolerance of water temperatures e.g. from 14 to 33°C (Chubb *et al.* 1981; Jones *et al.* 1996), and have been recorded in salinities up to 95 ppt in the Coorong, South Australia (D. Short, pers. comm., 2013).

Age and growth

Ages of Yelloweye Mullet have been estimated from whole otoliths, transverse sections (TS) of otoliths, fish scales and modal progression analysis (Thomson 1957a; Harris 1968; Chubb *et al.* 1981; Curtis and Shima 2005; Gaughan *et al.* 2006).

Thomson (1957) estimated ages using scales collected from fish that ranged in size from 13 to 39 cm caudal fork length (CFL) (Table 1.2). Annual periodicity of growth bands in scales was not validated but was inferred from modal progression in size structures, and from a linear relationship between fish length and scale size.

Harris (1968) examined the structure visible in whole otoliths to estimate age of Yelloweye Mullet from the Murray River estuary and Coorong, South Australia. Edge analysis indicated that opaque zones were deposited annually and could be interpreted in terms of fish age. However, the timing of zone formation was not validated for individual age classes. As such, the use of whole otoliths potentially underestimated age for older individuals with thicker otoliths.

Chubb *et al.* (1981) used length-frequency data to examine the progression of cohorts (modes) through time to estimate ages of Yelloweye Mullet (Table 1.2). Age was validated for fish up to 2 years of age (Chubb *et al.* 1981).

Gaughan *et al.* (2006) used otoliths to age Yelloweye Mullet from southern Western Australia. A comparison of the results between whole and TS of otoliths ($n=200$) indicated that whole otoliths underestimated age when 4 or more opaque zones were present. Subsequently, whole otoliths

were used when 3 or less opaque zones were present and TS were used when >3 opaque zones were present. In this study, marginal increment analysis indicated that opaque zones formed annually and were completed by December for at least the first three years. Consistency in the growth of the otoliths and appearance of annual marks suggested that estimates were accurate to 7 years (Gaughan *et al.* 2006) (Table 1.2).

Curtis and Shima (2005) successfully validated the annual periodicity of opaque zone formation in otoliths for several populations of Yelloweye Mullet in New Zealand. Alizarin red S was used to provide a chemical reference mark that was used to interpret the internal structure in TS of otoliths ($n=500$).

Table 1.2. A comparison of size-at-age of Yelloweye Mullet from several populations using four different ageing methods. Estimates by Gaughan *et al.* (2006) represent the upper limit of size-at-age, whereas all other estimates represent intermediate size-at-age. The maximum age recorded for each population is also shown.

Source	Location	Ageing method	Sex	Estimates of size-at-age (mm TL)							Max. age
				1	2	3	4	5	6	7	
Thomson 1957a	W.A.	Scale readings	M	120	209	274	325	365	-	-	5
			F	122	217	293	354	393	423	439	7
	S.E. Aust.	Scale readings	M	51	140	216	276	-	-	-	4
			F	54	148	232	297	341	-	-	5
Harris 1968	S.A.	Whole otoliths	Both	140	210	260	310	-	-	-	4
Chubb <i>et al.</i> 1981	W.A.	Length freq.	Both	161	297	-	-	-	-	-	2
Gaughan <i>et al.</i> 2006	W.A. South	Sectioned otolith	F	142	232	289	325	348	376	381	10
			M	155	233	271	291	301	306	-	6
	W.A. West	Sectioned otolith	F	166	259	310	339	355	364	369	7
			M	175	243	269	279	283	285	285	7
Curtis & Shima 2005	N.Z.	Sectioned otolith	F	-	-	-	-	-	-	-	7
			M	-	-	-	-	-	-	-	7

The maximum age recorded for female and male Yelloweye Mullet is 10 and 7 years, respectively (Thomson 1957a; Curtis and Shima 2005; Gaughan *et al.* 2006) (Table 1.2). The maximum age for Yelloweye Mullet from the Coorong, based on the number of rings visible in whole otoliths, was five years (Harris 1968).

Estimates of intermediate size-at-age of Yelloweye Mullet are highly variable among populations, with females attaining a larger size-at-age than males (Table 1.2). In southern Western Australia, intermediate size of one year old Yelloweye Mullet was 120 mm TL and 122 mm TL for males and females, respectively (Thomson 1957a). Intermediate size of 5 year old males from the same region was 365 mm TL, while females were 393 mm TL at the same age. Gaughan *et al.* (2006) also described differences of size-at-age between male and female Yelloweye Mullet up to 7 years old from Western Australia. One year old males and females from south-eastern Australia were much smaller than their Western Australian counterparts and had an intermediate size of 51 mm TL and 54 mm TL, respectively (Thomson 1957a). Five year old females similarly were much smaller than those in Western Australia and had an intermediate size of 341 mm TL.

Estimates of growth rate for Yelloweye Mullet have used fish scales, length frequency analysis and TS of otoliths (Thomson 1957a; Harris 1968; Chubb *et al.* 1981; Gaughan *et al.* 2006). In each case, Yelloweye Mullet grew rapidly in the first 1-2 years of life, and growth rate declined in subsequent years (Table 1.2). Despite high spatial variability in growth, growth rate during the first two years was similar between sexes, although at larger sizes, females typically grew faster and attained a larger size than males (Table 1.2). Recent work by Gaughan *et al.* (2006) on populations of Yelloweye Mullet in Western Australia used the von Bertalanffy growth function to describe growth. Asymptotic maximum length (L_{∞}) was 20% and 24% higher for females compared to males for populations in the southern and western area, respectively (Table 1.3), despite a slightly higher growth rate for males in the first year of life. In the Coorong, Yelloweye Mullet similarly grew rapidly during the first two years of their life, with growth rate declining after this, although females continued to grow more rapidly than males (Harris 1968).

Table 1.3. Estimates of von Bertalanffy growth parameters for Yelloweye Mullet from two regions in Western Australia (Gaughan *et al.* 2006) ($t_0=0$).

Region	Sex	N	L_{∞} (mm)	K (yr^{-1})
Western	F	406	374.87	0.585
	M	119	285.63	0.953
Southern	F	360	387.43	0.457
	M	85	310.45	0.692

Size at maturity

Several studies have provided estimates of the size at which 50% of the female population of Yelloweye Mullet reach sexual maturity (SAM_{50}) (Thomson 1957b; Harris 1968; Webb 1973b;

Ye *et al.* 2013) (Table 1.4). Ye *et al.* (2013) indicated that female Yelloweye Mullet from the Coorong were sexually mature at 256 mm TL, whilst the smallest mature female was 226 mm TL. This was supported by one previous estimate of 255 mm TL for females from the Coorong population (Harris 1968). Whilst insufficient numbers of fish were collected by Ye *et al.* (2013) to develop an estimate for males, Harris (1968) indicated that 50% of the male population attained sexual maturity at 244 mm TL. Webb (1973b) indicated that male Yelloweye Mullet from a population in New Zealand reached maturity between 200-239 mm TL, whilst males from a population in Western Australia attained maturity between 198-221 mm TL (Thomson 1957b). No LMS regulation exists for commercial and recreational fisheries in Western Australia or New Zealand.

Table 1.4. Size at maturity (SAM_{50} – TL mm) for Yelloweye Mullet populations in Western Australia (WA), South Australia (SA) and New Zealand (NZ).

Source	Location	SAM_{50} (TL mm)	
		Female	Males
Thomson 1957b	WA	198-221	198-221
Harris 1968	SA	255	244
Webb <i>et al.</i> 1968	NZ	220-239	220-239
Ye <i>et al.</i> 2013	SA	256	-

Life cycle: spawning and early life stages

Yelloweye Mullet have been described as “estuarine opportunists” because they regularly utilise estuaries but can also complete their lifecycle when they do not have access to these environments (Potter and Hyndes 1994). Spawning is known to occur across a broad range of habitats including shallow coastal waters, nearshore marine embayments and estuaries (Harris 1968; Webb 1972; Chubb *et al.* 1981; Ye *et al.* 2013). Macroscopic staging, gonadosomatic indices and microscopic analyses for Yelloweye Mullet from the Coorong indicated a protracted reproductive season extending from winter to early-autumn (Harris 1968; Ye *et al.* 2013). Despite the protracted spawning season, the frequency of spawning fish was highest between December and February, e.g. summer months (Ye *et al.* 2013).

The reproductive season for Yelloweye Mullet varies considerably throughout its Australian distribution. The reproductive season in south-eastern Australia and Coorong were similar and occurred over a prolonged period from late winter to early-autumn (Thomson 1957b; Harris 1968; Ye *et al.* 2013). However, for populations in Western Australia it occurred from autumn to spring (Thomson 1957b).

Previous studies on the spawning mode of Yelloweye Mullet conflict, suggesting differences among populations. Several authors have reported that Yelloweye Mullet spawn one batch of moderately large (0.5 mm diameter) pelagic eggs in each reproductive season (Harris 1968; Crossland 1981). However, in New Zealand the presence of two distinct 0+ cohorts within one reproductive season and evidence from the macroscopic staging of females suggested that the species spawns at least twice per year (Webb 1973b). More recently, Ye *et al.* (2013) analysed stained sections of ovarian tissue from mature females from the Coorong population to assess spawning mode. In that study, Yelloweye Mullet were found to spawn multiple batches of eggs throughout the reproductive season (Ye *et al.* 2013). Intra-specific variation in the timing and duration of spawning observed for Yelloweye Mullet is not unusual for mullet species, particularly those that occur across a broad range of latitudes, e.g. *Mugil cephalus* (Thomson 1957b).

The eggs and larvae of Yelloweye Mullet are pelagic and have been found in the surface waters of estuaries and the coastal environment (Pellizzari 2002). Based on otolith microstructure, pre-settlement duration for larvae in the Coorong was 19 to 25 days (Pellizzari 2002). Larvae transformed to juveniles at approximately 12 mm TL and remained near the surface (pelagic) until approximately 30 mm TL (Crossland 1981; Kingsford and Tricklebank 1991; Hickford and Schiel 2003; Smith *et al.* 2008). Newly settled larvae in the Coorong were most abundant during winter and summer, suggesting that there were two dominant cohorts of young-of-the-year (YOY) fish (Pellizzari 2002), and that spawning may have occurred more than once. Size frequency distributions of YOY Yelloweye Mullet from the Coorong (D. Short, unpublished data) indicated that the majority of recruitment in 2010/11 occurred during the winter months.

Diet

The diet of Yelloweye Mullet has been studied extensively throughout its range using gut contents analysis (GCA) (Thomson 1954; Webb 1973b; Potter and Hyndes 1994; Edgar and Shaw 1995; Crinall and Hindell 2004; Platell and Hall 2004; Platell *et al.* 2006) and stable isotope analysis (SIA) (Deegan *et al.* 2010; Giatas 2012). This species is regarded as an opportunistic omnivore that consumes a wide range of food types including algae, small crustaceans, diatoms, molluscs, insect larvae, fish, polychaetes, coelenterates, fish eggs and detritus. Diet has been found to change with size (Webb 1973a; Platell *et al.* 2006; Deegan *et al.* 2010; Giatas 2012). Diet of Yelloweye Mullet has also been found to vary temporally and spatially (Webb 1973a; Potter and Hyndes 1994; Crinall and Hindell 2004; Platell *et al.* 2006; Deegan *et al.* 2010).

Comprehensive studies of the diet for Yelloweye Mullet in the Coorong were conducted by Deegan *et al.* (2010) and Giatas (2012). Both studies used a combination of GCA and SIA and found diet changed with size. During a period of drought, Deegan *et al.* (2008) found that small (<80 mm TL), medium (120-240 mm) and large (>250 mm) Yelloweye Mullet occupied a similar trophic level in the ecosystem (SIA). GCA indicated that large Yelloweye Mullet consumed mainly crustaceans, including crabs and shrimps; medium-sized fish consumed mainly gammaridian amphipods and polychaetes; and small fish fed exclusively on amphipods and capitellids (Deegan *et al.* 2010). Giatas (2012) examined the diet of Yelloweye Mullet during a period of high freshwater inflow to the estuary. In this study, small Yelloweye Mullet (<120 mm) consumed mainly post-larval fish, detritus, amphipods and copepods; and large fish consumed mainly algae, detritus and polychaetes. Ontogenetic differences in diet were attributed to habitat differences and/or changes in feeding and digestive morphology (Giatas 2012).

Deegan *et al.* (2010) and Giatas (2012) also found that the diet of Yelloweye Mullet varied spatially within the Coorong. In each study, the diversity of the dietary items consumed decreased with distance from the mouth of the estuary, e.g. as salinity increased. Spatial differences in diet reflected the environmentally-mediated distribution of prey items in the system (Deegan *et al.* 2010; Giatas 2012).

Dietary composition of Yelloweye Mullet in the Coorong under high flow conditions varied from that during the drought (Deegan *et al.* 2010; Giatas 2012). Differences were mostly due to a higher contribution of amphipods and larval fish during the period of freshwater inflow to the estuary (Giatas 2012). The non-specialised, opportunistic feeding of Yelloweye Mullet from the Coorong is consistent with results in Victoria (Edgar and Shaw 1995; Crinall and Hindell 2004), Western Australia (Potter and Hyndes 1994; Platell *et al.* 2006) and New Zealand (Webb 1973a) and likely contributes to resilience to changes in prey availability, which is an important adaptation for life in estuaries.

Stock structure

The structure of the Yelloweye Mullet stock throughout its distribution is not well understood. It has been suggested that populations in Australia form two discrete stocks, i.e. western and eastern stocks, based on the number of lateral scales and gill rakers (Thomson 1957a; Pellizzari 2001). The western stock comprises Yelloweye Mullet from Western Australia and western South Australia (Smith *et al.* 2008). The eastern stock comprises Yelloweye Mullet from the gulfs of South Australia and eastwards to Victoria, New South Wales and Tasmania. Yelloweye Mullet from New Zealand were most similar to the eastern Australian stock (Smith *et al.* 2008).

Spatial differences in the reproductive biology of the species have also been linked to differences among stocks (Higham *et al.* 2005), however this may vary at finer spatial scales and is more likely due to spatial variation in habitat.

Conclusion

Considerable work has been conducted on Yelloweye Mullet across its distribution. The high degree of spatial variation in the life history of Yelloweye Mullet highlights the importance of understanding the dynamics of critical demographic processes, such as reproduction, growth and recruitment at the local (population) scale.

2 COMMERCIAL FISHERY STATISTICS

2.1 Introduction

The commercial fishery for Yelloweye Mullet in South Australia has two main sectors, the LCF and MSF. This section of the report provides analyses of all fishery-dependent data for Yelloweye Mullet in South Australia from 1 July 1984 to 31 July 2012. It assesses spatial and temporal patterns in commercial catch, effort and catch per unit effort (CPUE). An assessment of the status of the LCF for Yelloweye Mullet against limit reference points prescribed in the Management Plan (Sloan 2005) is presented in Section 4, and the status of the MSF is assessed and presented in a recent stock status report (Fowler *et al.* 2012). Thus, the Discussion provides a traditional weight-of-evidence assessment of the current status of the Yelloweye Mullet stocks in South Australia.

2.2 Methods

Commercial catch and effort data have been collected since 1984 by fishers in the LCF and MSF completing a research logbook for each fishing day. Daily catch and effort data include catch (kg), effort (days, fisher days, number of nets) for targeted and non-targeted species, and fishing location, which is reported against reporting areas (Figure 1.1) and reporting blocks (Figure 1.2) for the LCF and MSF, respectively. These data are submitted to SARDI Aquatic Sciences on a monthly basis and provide a time series that constitutes the most fundamental dataset available for assessing the status of these fisheries.

Fishery statistics are presented at three spatial scales to provide an indication of their contribution to fishery production for Yelloweye Mullet in South Australia. These spatial scales are: (1) the whole of South Australia; (2) areas exploited by the LCF (i.e. Murray River estuary and Coorong); and (3) areas exploited by the MSF (i.e. in all coastal waters of South Australia, excluding the Murray River estuary and Coorong). For each geographic region, data were aggregated into financial years and used to assess (i) inter-annual patterns in total catch by gear type; (ii) intra-annual patterns in total catch; (iii) spatial distribution of catch; and (iv) inter-annual patterns in targeted catch, effort and CPUE. Mean annual CPUE was estimated for each sector by dividing the annual catch by the annual effort in terms of fisher days. For the LCF,

CPUE was also calculated in terms of net days. The number of active LCF licence holders reporting catch of Yelloweye Mullet was also shown to provide an indication of latent effort.

Estimates of the annual value of the South Australian catch of Yelloweye Mullet obtained from the Information Systems and Database Support Program at SARDI Aquatic Sciences are presented from 1984/85 to 2011/12. Fishery production values represent the assessed value of the catch at the point of landing for the quantity of the catch and exclude transport and marketing costs (Knight and Tsohos 2012).

2.3 Results

Total annual State-wide catches

Total annual State-wide catches ranged from 223 t in 1984/85 to an historic peak of 522 t in 1989/90 (Figure 2.1). Annual catches then gradually decreased to 156 t in 2003/04. From 2003/04 to 2006/07 catches were low and averaged 164 t.yr⁻¹. From 2007/08 to 2010/11, catches were similar and ranged between 230 and 271 t.yr⁻¹. In 2011/12, catch declined to 177 t and was among the lowest on record.

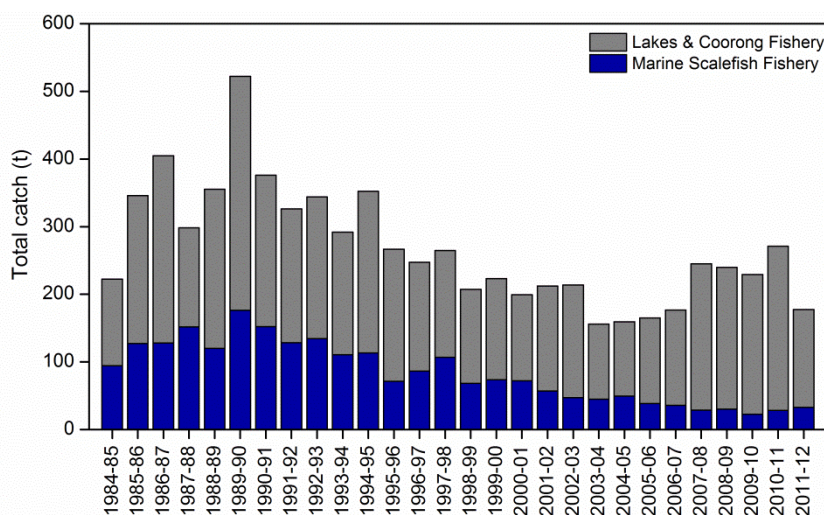


Figure 2.1. State-wide commercial catch of Yelloweye Mullet from 1984/85 to 2011/12, by fishing sector.

The LCF was the main contributor to annual catches of Yelloweye Mullet in South Australia and from 1984/85 to 2004/05 contributed between 49% and 78% of the catch (Figure 2.1). Since then, the contribution from the LCF gradually increased and was 90% in 2009/10, whilst that

from the MSF declined. From 2007/08 to 2010/11, the LCF caught between 87% and 90% of the South Australian catch. In 2011/12, this decreased to 82%.

Lakes and Coorong Fishery

Total annual catches

Annual catches from the LCF increased from 128 t in 1984/85 to an historic peak of 346 t in 1989/90 (Figure 2.2). After this, catches decreased to a minimum of 110 t in 2004/05, subsequently increased to 216 t in 2007/08, and remained $>219 \text{ t.yr}^{-1}$ to 2010/11. In 2011/12, catch decreased to 144 t and was among the lowest on record.

The dominant gear type used to target Yelloweye Mullet was the small mesh gill nets (SMGN) ($>50 \text{ mm}$ to $\leq 64 \text{ mm}$ mesh) which contributed an average of 91% (landed weight, $\pm 6.6\%$ SD) of the annual catch from 1984/85 to 2011/12 (Figure 2.2). Most of the remaining catch was taken using large mesh gill nets (>115 to $\leq 150 \text{ mm}$ mesh). Small contributions ($<1\%$) were also made by other gears including haul nets and ring nets.

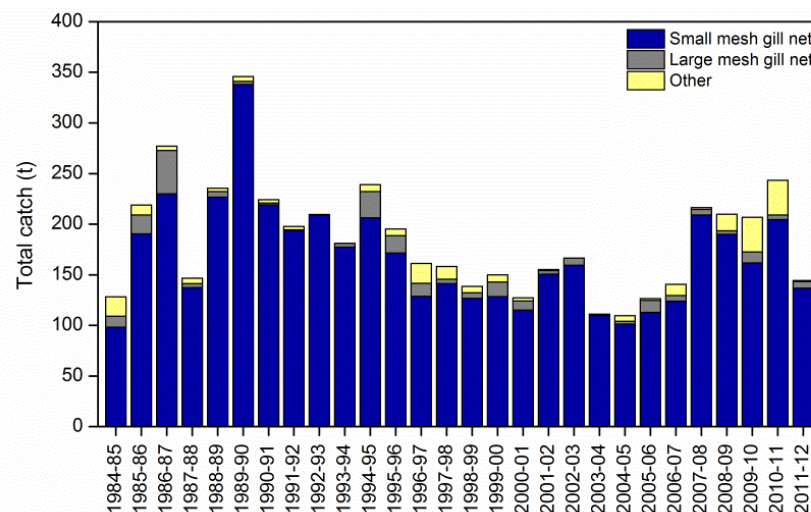


Figure 2.2. Annual catches of Yelloweye Mullet from the LCF from 1984/85 to 2011/12, by gear type.

Intra-annual trends in total catch

Catches of Yelloweye Mullet from the LCF from 1984/85 to 2011/12 were seasonal with on average, 55% of the annual catch taken from November to March (Figure 2.3). Catches were highest in November and January and lowest in June and July.

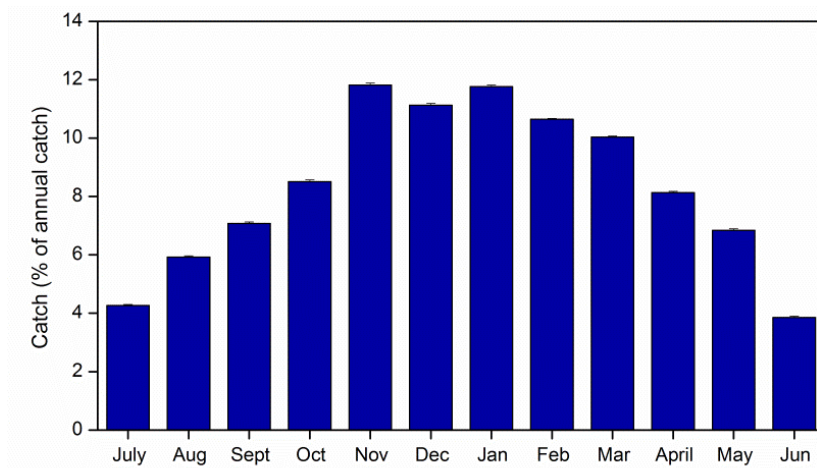


Figure 2.3. Average monthly catches ($\pm$ SE) of Yelloweye Mullet from the LCF from 1984/85 to 2011/12, expressed as a percentage of annual catch.

Spatial distribution of catches

Fishery catch and effort from the Murray River estuary and Coorong is reported against nine commercial reporting areas (Figure 1.1). Area numbers increase from north to south, i.e. Goolwa (Area 6) to Salt Creek (Area 14). Catches from some areas were pooled because catches from some areas in some years were taken by less than five licence holders (Figure 2.4).

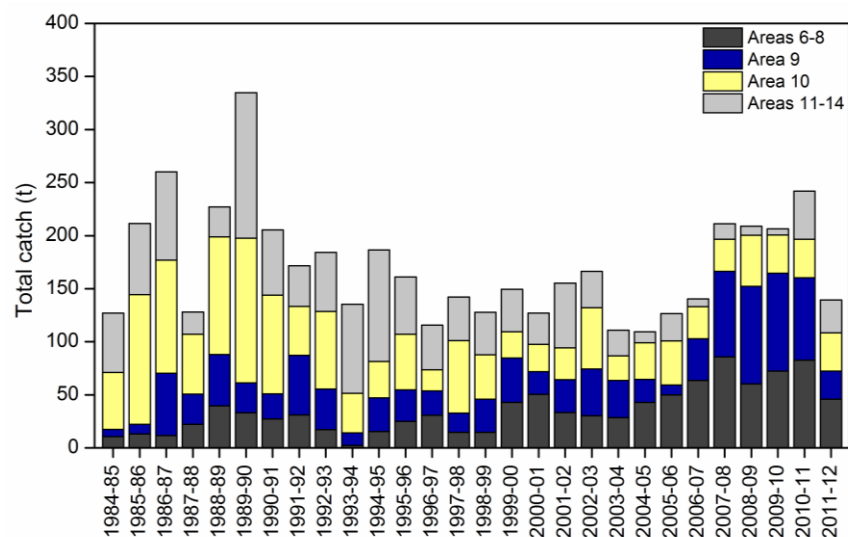


Figure 2.4. Annual catches of Yelloweye Mullet from LCF commercial reporting areas 6 – 14 from 1984/85 to 2011/12.

From 1984/85 to 1998/99, most catches of Yelloweye Mullet were from Area 10 and Areas 11-14, i.e. the North and South Lagoons, with smaller contributions from Areas 6-8 and 9, i.e. the Estuary and upper Coorong (Figure 2.4). From 1998/99 to 2010/11, the contribution from Areas 6-8 and 9, to total annual catch increased, while contributions from southern areas decreased. In 2011/12, the spatial distribution of catches was more evenly distributed among the broad areas with 33% from Areas 6-8 and 26% from Area 10.

Targeted catch, effort and CPUE

Inter-annual trends in targeted catch (i.e. catches from fishing operations that specifically targeted Yelloweye Mullet) from SMGN (Figure 2.5A) generally followed those of total catch (Figure 2.2). From 1984/85 to 2011/12, targeted catch from SMGN ranged from 73% to 99% (mean 88% $\pm$ 1.4). In 2011/12, the targeted catch was 131 t, which comprised 91% of the total catch for the LCF.

Annual targeted effort (SMGN, fisher days) increased from 2,164 fisher days in 1984/85 to an historic peak of 3,828 fisher days in 1989/90 (Figure 2.5B). Targeted effort then remained above 2,806 fisher days until 1994/95, before declining to 898 fisher days in 2003/04. From 2003/04 to 2011/12, targeted effort remained historically low and ranged between 903 and 1,905 fisher days.yr⁻¹. The trend in annual targeted effort in net days was similar to targeted effort in fisher days, e.g. it was highest in the late 1980s and early 1990s, and from then decreased until the mid-2000s (Figure 2.5B). Annual effort in net days was linearly related to effort in fisher days (linear regression, LR: $r^2 = 0.78$, $F_{1,26} = 92.046$, $p < 0.001$).

Mean annual CPUE_{SMGN} (kg.fisher day⁻¹) was characterised by high inter-annual variability from 1984/85 to 1990/91, and ranged from 45 to 88 kg.fisher day⁻¹ (Figure 2.5C). From 1991/92, CPUE_{SMGN} increased to an historic peak of 128 kg.fisher day⁻¹ in 2007/08, before declining to 91 kg.fisher day⁻¹ in 2011/12. Despite the recent decline, CPUE_{SMGN} (kg.fisher day⁻¹) in 2011/12 was among the highest on record. Inter-annual patterns in CPUE_{SMGN} (kg.net day⁻¹) were similar to that of CPUE_{SMGN} (kg.fisher day⁻¹) over the 28-year period since 1984/85 and the two measures of relative abundance were linearly related (LR: $r^2 = 0.52$, $F_{1,26} = 27.82$, $p < 0.001$).

Number of licences reporting catches

Over the last 5 years the number of active LCF licence holders reporting catch of Yelloweye Mullet ranged from 19 in 2007/08 to 26 in 2010/11, i.e. 51% and 70% of the 37 commercial licence holders in 2007/08 and 2010/11, respectively (Table 2.1).

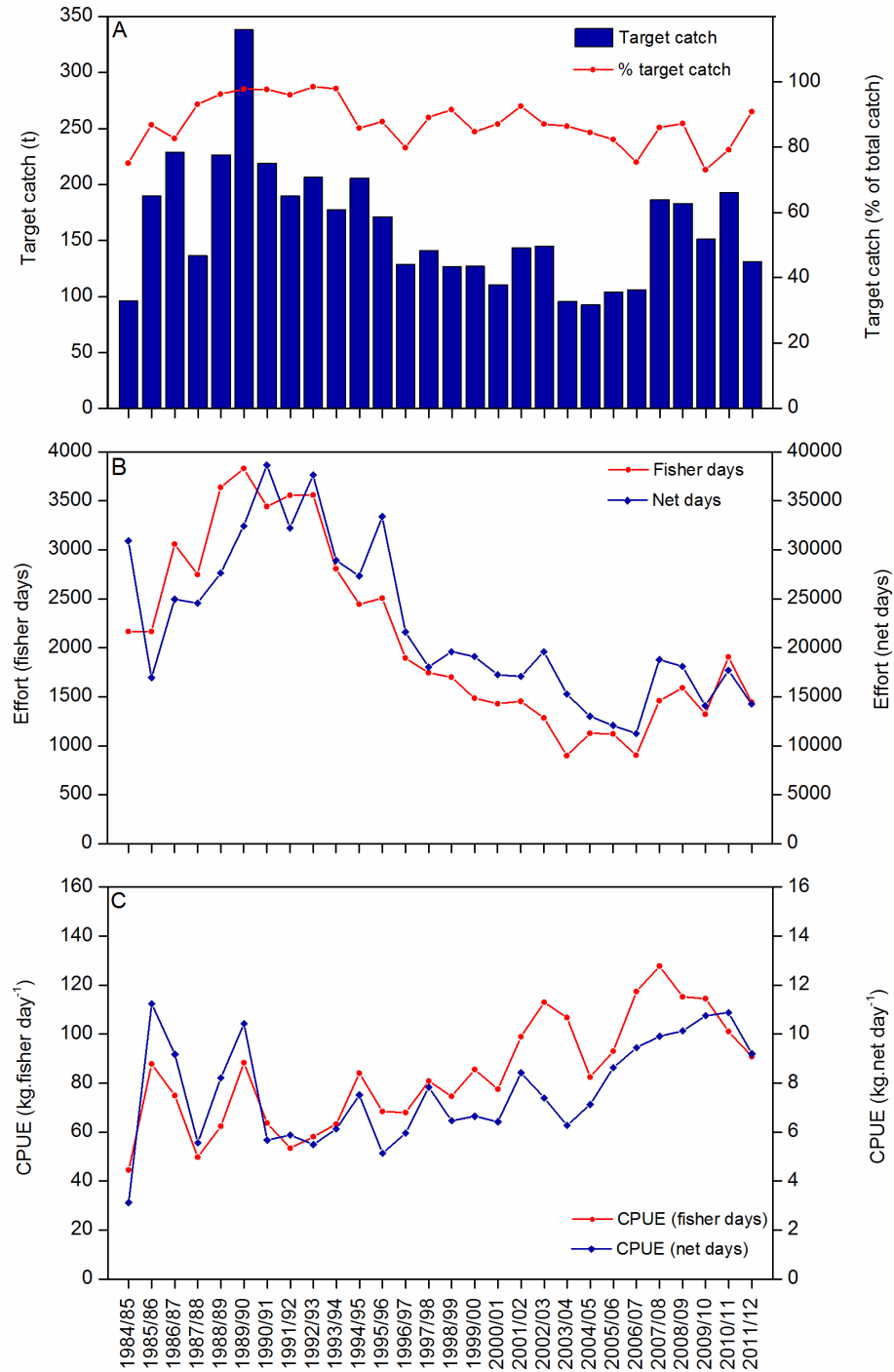


Figure 2.5. Annual targeted catch and effort for small-mesh gill nets for the LCF. (A) Targeted catch is shown in t, and as a percentage of total catch; (B) Comparison of two measures of targeted effort for SMGN, i.e. fisher days, net days; (C) Comparison of two measures of CPUE_{SMGN} based on the two measures of targeted effort.

Table 2.1. The number of Lakes and Coorong commercial licences against which catches of Yelloweye Mullet were reported during the last five years.

Year	No. licences reporting catches of Yelloweye Mullet
2007/08	19
2008/09	20
2009/10	20
2010/11	26
2011/12	20

Marine Scalefish Fishery

Total annual catches

In 1984/85, the total catch from the MSF was 94 t, which then increased to an historic peak of 176 t in 1989/90 (Figure 2.6). From 1989/90, catches declined to an historic low of 23 t in 2009/10. From 2007/08 to 2010/11 annual catches were low and ranged from 23 to 30 t.yr⁻¹. In 2011/12, total catch increased to 33 t but remained among the lowest on record.

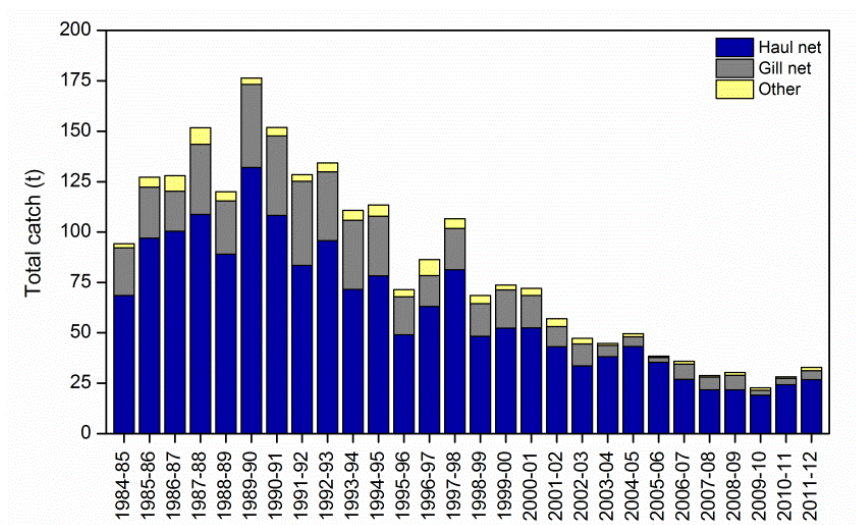


Figure 2.6. Annual catches of Yelloweye Mullet from the MSF from 1984/85 to 2011/12, subdivided by gear type.

The main gear used in the MSF to target Yelloweye Mullet was the haul net (Figure 2.6). From 1984/85 to 2011/12, contributions of catches from haul nets to the total annual catch ranged from 65% to 92%. Gill nets were the second largest contributor, accounting for between 6% and

32% of the annual catch during that period. In 2011/12, haul net catches accounted for 82% of the total catch from the MSF.

Intra-annual patterns in catch

Catches of Yelloweye Mullet by the MSF were seasonal which is similar to LCF. For the period 1984/85 to 2011/12, higher monthly catches were taken in summer (Figure 2.7). On average, 45% of the annual catch was taken from January to April. Catches were highest in March and lowest in August.

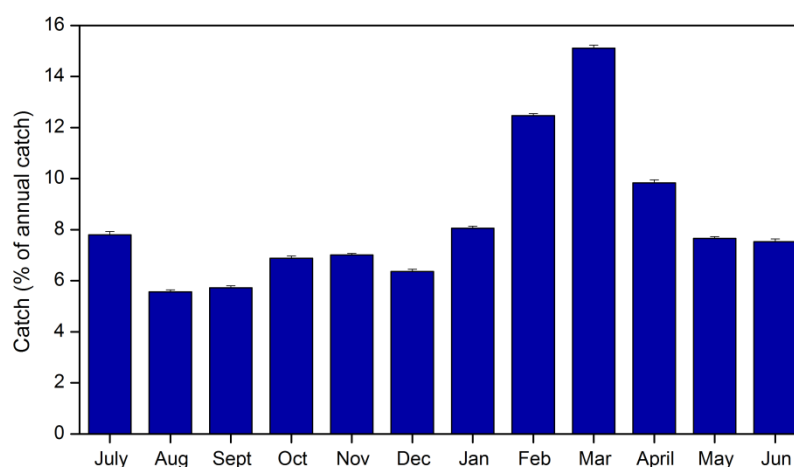


Figure 2.7. Average monthly catches ($\pm$ SE) of Yelloweye Mullet from the MSF from 1984/85 to 2011/12, expressed as a percentage of annual catch.

Spatial distribution of catches

Fishery catch and effort for the MSF was reported against 45 spatial reporting blocks (Figure 1.2). These blocks were grouped into two broad regions because catches from some regions in some years were taken by less than five licence holders. The two broad regions were: (i) Western (blocks 5, 7-11, 15-17, 19-33, 38, 39); and (ii) Eastern (blocks 34-36, 40-46, 48-51, 53, 55-58) (Figure 1.2).

In the 28-year period since 1984/85, total annual catches of Yelloweye Mullet from the MSF were mainly from the Eastern region, i.e. Gulf St. Vincent and the State's south east, with smaller contributions from the Western region, i.e. Spencer Gulf and the State's west coast (Figure 2.8). Over this period, contributions to total annual catches from the Eastern region declined from 124 t in 1989/90 to 9 t in 2010/11, while contributions from the Western region declined from 57 t in 1992/93 to 8 t in 2009/10.

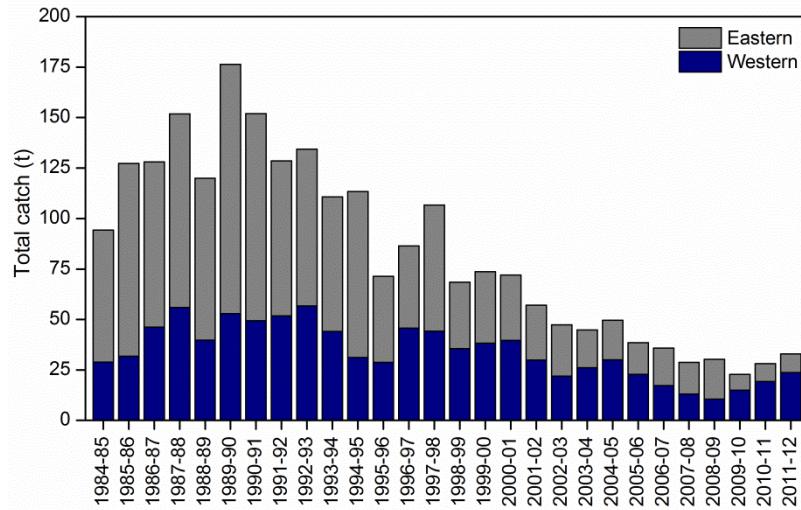


Figure 2.8. Annual catches of Yelloweye Mullet from the MSF from 1984/85 to 2011/12 by region.

Targeted catch, effort and CPUE

For the MSF, inter-annual trends in targeted catches from haul nets were similar to those of total catch (Figure 2.9A and Figure 2.6). Targeted catch peaked at 60 t in 1987/88 and 1989/90. From then, targeted catch declined in most years and was less than 7 t in 2008/09. The contribution of targeted catches to the total annual catch ranged from 14% to 52% in 1998/99 and 2004/05, respectively, but was less than 30% in most years. In 2011/12, targeted catch across all gear types contributed 21% to the total catch of Yelloweye Mullet in the MSF.

Temporal patterns in annual targeted effort (haul nets, fisher days) were generally similar to those for targeted catch, i.e. a peak at 1,015 fisher days in 1987/88, then a decline to 50 fisher days in 2008/09 (Figure 2.9B). In 2011/12, effort targeting Yelloweye Mullet was 75 fisher days.

$CPUE_{HN}$ ($kg.fisher\ day^{-1}$) was characterised by high variability among years (Figure 2.9B). It increased from 53 $kg.fisher\ day^{-1}$ in 1984/85 to an historic peak of 164 $kg.fisher\ day^{-1}$ in 1989/90. From then, $CPUE_{HN}$ declined and averaged 95 $kg.fisher\ day^{-1}$ to 2006/07. It increased to 158 $kg.fisher\ day^{-1}$ in 2010/11 and subsequently declined to 93 $kg.fisher\ day^{-1}$ in 2011/12.

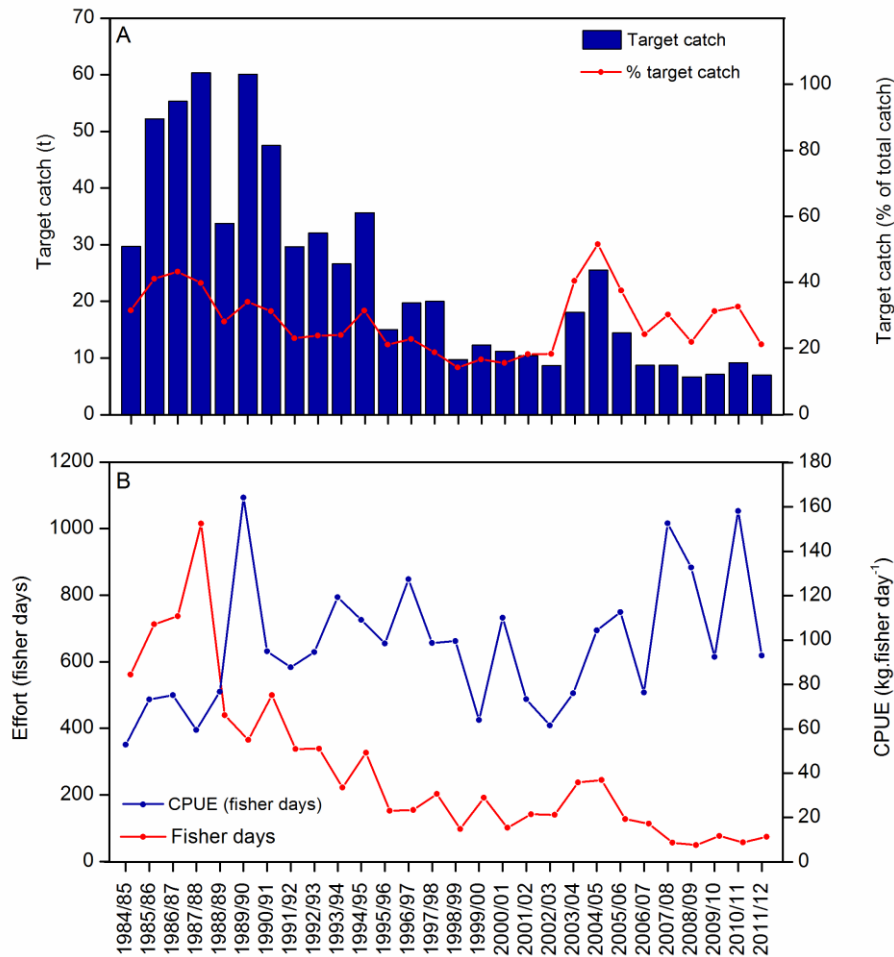


Figure 2.9. Annual targeted catch and effort for hauls nets for the Marine Scalefish Fishery. (A) Targeted catch shown in t, and as a percentage of total catch; (B) targeted effort (fisher days) and CPUE_{HN} (kg.fisher day⁻¹).

Annual value of catches

From 1984/85 to 1986/87, the value of the State-wide commercial catch of Yelloweye Mullet followed the trend of annual catch and increased from \$200,000 to \$507,000 (Figure 2.10). In the following 20-year period, despite a gradual decline in fishery production, the value of the catch remained relatively stable and averaged approximately \$420,000.yr⁻¹. One exception was 1998/99, when it dropped to \$207,000. Value of the catch increased from \$361,000 in 2004/05, to a peak of \$1.1 million in 2010/11 (Figure 2.10). In 2011/12, the value of the catch declined to \$714,000, but remained among the highest on record.

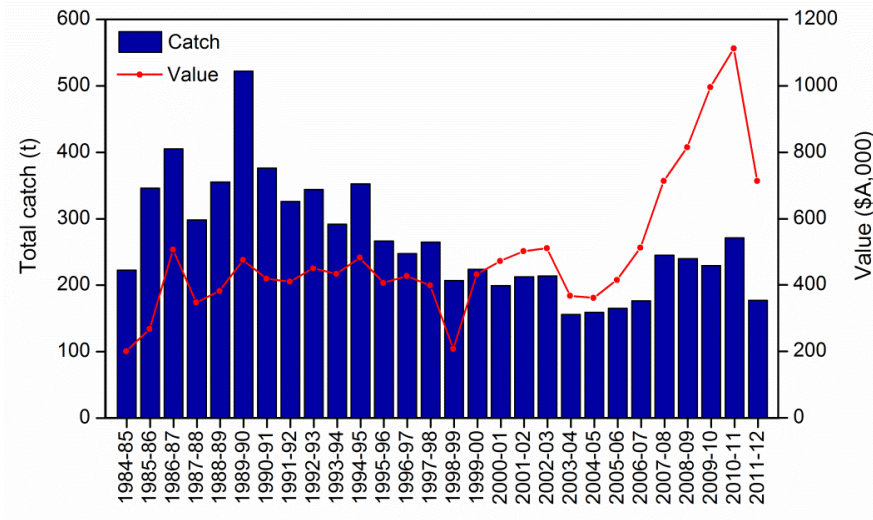


Figure 2.10. Annual catch and value of Yelloweye Mullet from South Australia from 1984/85 to 2010/11.

2.4 Discussion

In 2011/12, total commercial catch of Yelloweye Mullet in South Australia was 177 t and among the lowest on record. This was 94 t less than the previous year, representing an annual decrease of 35%. This decline resulted from a 25% reduction in targeted effort for Yelloweye Mullet by the LCF and historically low targeted effort by the MSF. Nonetheless, the low State-wide catches were the culmination of different trends in each fishery.

Historically the LCF has been the most significant fishery for Yelloweye Mullet in South Australia. Over the 20 years to 2004/05 it contributed, on average, 65% of the State's annual catch, with most of the remaining annual catch taken by the MSF. Since 2004/05, contributions from the LCF increased and in 2009/10 exceeded 90%. This increase was due mostly to an increase in catch by the LCF. However, MSF catches were among the lowest on record. The recent increase in catch by the LCF, i.e. from 2007/08, corresponded to the diversion of targeted fishing effort away from other finfish species (i.e. *Rhombosolea tapirina* and *Argyrosomus japonicus*) toward Yelloweye Mullet during a period of severe drought (Ferguson 2012). Historically high catch rates for Yelloweye Mullet by the LCF during this period suggest an increased relative abundance. However, the spatial contraction of the fishery due to a lack of freshwater flow and subsequent poor environmental conditions in the southern Coorong may have affected CPUE as an indicator of population abundance.

In 2011/12, total annual catch of 144 t was reported for the LCF. This was 90 t less than the previous year. This decrease resulted from a 24% decline in fishing effort and 10% decrease in $CPUE_{SMGN}$. The number of LCF licence holders reporting catches of Yelloweye Mullet in 2011/12 also declined by 23% from the previous year. This reduction in targeted effort for Yelloweye Mullet corresponded to an increase in freshwater flow to the system and a subsequent increase in targeted effort for other finfish species in the Coorong as environmental conditions in the Coorong improved (Ferguson 2012). As such, the decline in effort does not appear to have related to declining population biomass as catch rates remained relatively high.

Total annual catch for the MSF was 33 t in 2011/12 and among the lowest on record. Whilst this estimate was 12% higher than the previous year, it was 82% less than the historic peak in catch of 176 t reported in 1989/90. The decline in catch by the MSF, however, does not appear to have related to declining biomass, as over the past five years, estimates of catch rate were among the highest on record.

In summary, analyses of fishery-dependent catch and effort data for the LCF and MSF provided robust evidence that the Yelloweye Mullet stocks in South Australia were in a strong position at the conclusion of 2011/12.

3 DEMOGRAPHIC INFORMATION

3.1 Introduction

Understanding life history and demographic processes that shape fish populations is fundamental for the effective management of fisheries (King and McFarlane 2003; Fowler *et al.* 2008; Hare *et al.* 2011). This requires information on growth, egg production, recruitment, mortality and knowledge of how each of these processes influences the biomass of the fish population. The rates at which these processes occur are best determined using fish age as a time reference (Campana 2001). The most effective method for providing estimates of fish age is through the interpretation of the structures in their otoliths (Campana 2001), as they often contain distinct growth zones which are formed periodically throughout their life (Fowler 1995; Campana and Thorrold 2001). Nonetheless, it is necessary to validate the timing of formation and interpretation of the structure in otoliths to provide accurate and unbiased estimates of fish age (Campana 2001).

The annual formation of distinct bands in the otoliths of Yelloweye Mullet provides an indication of age for individual fish (Curtis and Shima 2005; Gaughan *et al.* 2006). Despite this, there is a lack of age-based demographic information for exploited populations of Yelloweye Mullet in Australia. The objective of this section is to provide demographic information for the population of Yelloweye Mullet in the Murray River estuary and Coorong, to which future population assessments can be compared. The specific aims were to: (i) provide size/age structures for the Coorong population of Yelloweye Mullet; (ii) provide an estimate of growth rate for the Coorong population and compare growth between sexes; (iii) provide an estimate of size and age at maturity for male and female Yelloweye Mullet; and (iv) determine the sex ratio of the Coorong population.

3.2 Methods

Sample collection

Yelloweye Mullet ($n=1,460$) were collected between August 2012 and May 2013 from the Murray River estuary and Coorong. Monthly samples were available from: (1) gill net catches from commercial fishers (mesh size ranges from 50-57 mm); and (2) multi-panel gill net samples from research sampling which provided a wider size/age range of fish. On each sampling

occasion, fish were randomly sub-sampled (20-30 fish) from gill net catches and stored for processing. In August, September and October 2012, additional samples were available from commercial catches and these fish were measured for TL to the nearest mm, before being returned to the fisher.

Laboratory processing

Each fish was measured to the nearest mm; weighed to the nearest 0.1 g; and their gonads were staged macroscopically to one of five stages of development (Table 3.1). The sagittae, i.e. the largest pair of otoliths, were removed, cleaned, dried and stored. The left otolith from each individual was embedded in polyester resin and a TS section (approximately 400 µm thickness) incorporating the otolith core was made using a low speed diamond saw. The section was mounted on a labelled glass microscope slide using Cyanoacrylate glue. Mounted sections were ground to improve visibility of the internal structure of the otolith, smeared with immersion oil, and examined under transmitted light using a dissecting microscope at x20 magnification. The number of opaque zones surrounding the core of the otolith were counted and interpreted by two trained readers.

Table 3.1. Macroscopic classification of development for ovaries and testes of Yelloweye Mullet. Criteria are from Ye *et al.* (2013).

Sex	Gonad stage	Macroscopic characteristics
Females	1. Immature	Ovaries small and undeveloped, clear or translucent, showing little or no colouration.
	2. Developing	Ovaries small but larger than Stage 1 and often more orange/yellow, no individual oocytes discernible.
	3. Developed	Ovaries larger and turgid, yellow/orange in colour, individual oocytes discernible.
	4. Hydrated	Large ovaries, taking up a large space in gut cavity, with hydrated oocytes easily discernible.
	5. Spent	Ovaries are large, similar in size and colour to Stage 2, however more flaccid with a granular appearance.

Males	1. Immature	Undeveloped testes usually dark in colour.
	2. Developing	Developing testes whereby they are larger and become grey - white in colour but no milt present.
	3. Developed	Developed testes that are large and white in colour and milt is present.

Age and growth

Age determination

Opaque zones in the otoliths of Yelloweye Mullet form annually in populations in New Zealand and Western Australia (Curtis and Shima 2005; Gaughan *et al.* 2006). In this study, ages were estimated from counts of opaque zones in each otolith which were counted along the ventral axis of the sulcal groove. The number of opaque zones within the sectioned otolith, characteristics of the edge of the otolith, date of capture and universal birthdate (1st August) were recorded and used to estimate the age of each fish in months. The universal birthdate of 1st August was used as it aligns with the time of the reproductive season when spawning success was highest (D. Short, unpublished data). Estimates of age in months were calculated using the following formula:

$$Age_m = (N \times 12) + m_c$$

Where, Age_m is the age in months, N is the number of opaque zones, and m_c is the number of months from the nominated birthdate (1st August) to the month of capture.

Each sectioned otolith was assigned a confidence index (CI) to categorise its overall clarity and interpretability. The CI ranged from 1-4, where 1 indicated that the otolith could not be interpreted, and 4 indicated that the otolith structure was clear and unambiguous. All otoliths that were assigned a CI of 1 were excluded from further analysis. Overall, the otolith pairs from 305 fish were examined, of which 17 (6%) were rejected.

Size/age structures

Size and age frequency distributions for Yelloweye Mullet from the Coorong were prepared. The sex ratio of the population was also determined from commercial and fishery-independent samples. A chi-square test for goodness-of-fit was used to assess whether the relative frequency of males and females conformed to a 1:1 ratio.

Growth

Estimates of length-at-age for Yelloweye Mullet were used to describe growth using the von Bertalanffy growth function (VBGF):

$$L_t = L_{\infty} [1 - \exp^{-K(t-t_0)}]$$

Where, L_t is length at age, L_∞ is the theoretical maximum or asymptotic length that fish would reach if they lived indefinitely, K is the rate at which maximum fish size is reached, and t_0 is the theoretical age at zero length. The growth parameters were fitted to the data by minimising the sums of squares using a non-linear curve fitting routine. The parameter t_0 was constrained to zero to provide a better description of early growth, due to the low number of small fish available to the study (Williams *et al.* 2003). Von Bertalanffy growth curves were compared using likelihood ratio tests (Kimura 1980; Haddon 2001). VBGF parameters were compared between males and females. Growth was not compared between areas in the Coorong due to the low numbers of males and females available to the study from the southern Coorong.

Reproduction

To determine the length at which 50% of the sampled population were sexually mature (SAM_{50}), gonad samples were pooled from commercial and multi-panel gill net catches. Fish which had developed gonads (i.e. $\geq$ Stage 2) were deemed sexually mature (Table 3.1). Logistic curves were fitted to describe the proportion of sexually mature individuals (P_m) by TL using the equation:

$$P_m = 1 / (1 + \exp [-r (L - L_m)])$$

Where r is the rate of fish maturity (slope), L is the TL of fish, and L_m is the mean length at which 50% of the sampled population is sexually mature. The Solver routine in MS Excel™ was used to estimate optimal L_m and r values (King 2007).

Age at maturity for males and females was estimated using the VBGF and SAM_{50} .

3.3 Results

Age and growth

Size/age structures

The age structure for Yelloweye Mullet from commercial catches comprised four age classes and was dominated by 3 year old fish (Figure 3.1A). This age class accounted for 62% of the sample, with 1, 2 and 4 year old fish accounting for 1%, 32% and 5%, respectively. This distribution of age classes was similar for males and females.

The size structure from commercial catches comprised a narrow distribution around a mode at 255 mm TL. Males ranged in size from 221 – 277 mm TL and females ranged from 221 – 340 mm TL (Figure 3.1B).

Age/size structures from multi-panel gill nets were wider than those from commercial gill nets. The age structure comprised five age classes from 0+ and was dominated by 2 year old and 3 year old fish which accounted for 48% and 32% of the fish sampled, respectively (Figure 3.1C). Whilst the sex of fish in the 0+ age class could not be determined, males and females were present in all other age classes.

The size structure from fishery-independent samples ranged from 170 to 290 mm TL (Figure 3.1D). A small number of individuals as small as 70 mm TL were also collected. The size distribution comprised a large mode at 260 mm TL which contained mostly male and female fish, and a smaller mode at 190 mm TL consisting mostly of fish whose sex could not be determined.

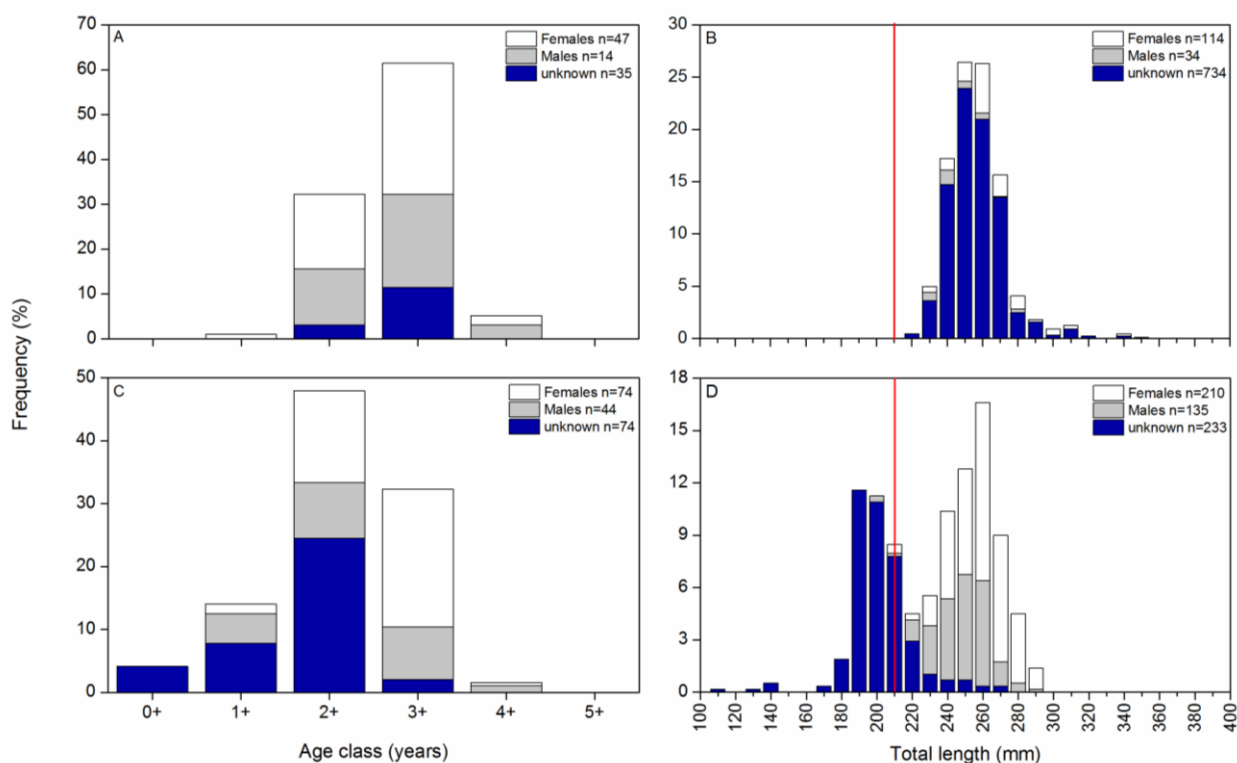


Figure 3.1. Age (left) and size (right) structures for Yelloweye Mullet from the commercial fishery (A and B) and from fishery independent sampling (C and D) in the Murray River estuary and Coorong. Vertical red line indicates LMS of 210 mm TL. Note the different y-axis scales.

Sex ratios differed from 1:1 for samples from commercial gill nets and those from multi-panel gill nets (Table 3.2). Females were three times as numerous as males in samples from commercial gill nets. Samples from multi-panel gill nets also mostly comprised females. Across all gear types, females accounted for 66% of samples.

Table 3.2. Sex ratios of Yelloweye Mullet sourced from commercial catches and fishery-independent sampling.

Gear	n_{females}	n_{males}	$n_{\text{females}}:n_{\text{males}}$	χ^2	p
Commercial gill nets	114	34	3.4:1	29.16	0.000
Multi-panel gill nets	210	135	1.6:1	4.84	0.028
Both	324	169	1.9:1	10.24	0.001

Growth rates

Von Bertalanffy curves were fitted to size-at-age data to describe patterns in growth for males and females (Figure 3.2). There were slight differences in growth between sexes. The asymptotic size of females was significantly higher than for males (L_{∞} , Kimura Likelihood Ratio Test: $P = 0.008$), whilst the growth rate was the same (K , $P = 0.327$) (Table 3.3). On average, males and females grew, to 165 mm TL and 164 mm TL, respectively, in their first 12 months of life. From then, growth rate decreased for each sex. Females grew 65, 26, 11 and 4 mm in their second, third, fourth and fifth year, respectively. Similarly, males grew on average 60, 22, 9, and 3 mm in their second, third, fourth and fifth year, respectively (Figure 3.2).

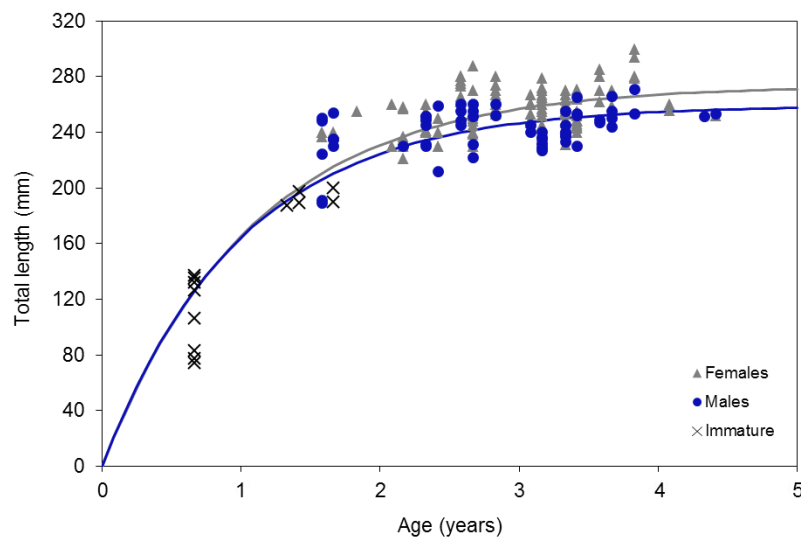


Figure 3.2. VBGF for male and female Yelloweye Mullet from the Coorong population.

Table 3.3. Comparison of von Bertalanffy growth parameters for female and male Yelloweye Mullet including the 95% confidence intervals for each parameter. The parameter t_0 was constrained to zero for both sexes.

Sex	n	L_{∞} (95% CI) (mm)	K (95% CI)
Females	134	273.8 (268-282)	0.077 (0.07-0.09)
Males	71	259.3 (252-268)	0.084 (0.07-0.09)
Males and females	205	269.5 (265-275)	0.079 (0.07-0.09)

Reproduction

For female Yelloweye Mullet, 50% of the population were mature (SAM_{50}) at 242 mm TL (Figure 3.3). The smallest female with developed ovaries was 223 mm TL. For males, SAM_{50} was 248 mm TL and the smallest mature fish was 229 mm TL.

Based on age-at-size estimates according to the VBGF, the estimated age at maturity for males and females was 24 and 28 months, respectively.

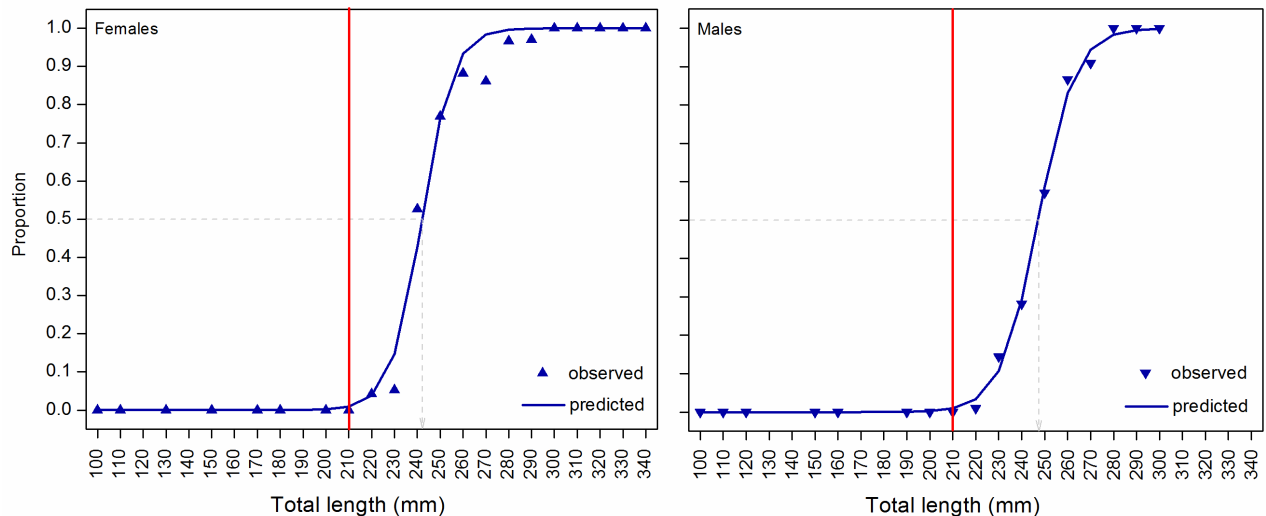


Figure 3.3. Proportion of sexually mature Yelloweye Mullet at size for females (left, $n = 541$) and males (right, $n = 392$) from the Murray River estuary and Coorong. Data points represent observed values. Vertical red line indicates LMS of 210 mm TL.

3.4 Discussion

This study addresses knowledge gaps for Yelloweye Mullet in the Murray River estuary and Coorong in South Australia, and provides information on age, growth and reproduction including

(i) the first otolith-based age structures; (ii) the first otolith-based estimate of growth for males and females; and (iii) estimates of size and age at sexual maturity for males and females.

Age and growth

Size and age information of a fish population may provide insight into processes that contribute to changes in population abundance and biomass. For the population of Yelloweye Mullet in the Murray River estuary and Coorong, age structures were dominated by 2+ and 3+ fish, while older fish were rare. Given the potential of this species to reach 10+ years of age (Gaughan *et al.* 2006), the fishable biomass in the Coorong comprised fish mostly in the youngest age classes. Age structures from this study were consistent with those from a previous study. The dominance of only two young age classes of Yelloweye Mullet in the Coorong observed in this study, was also documented in the 1960s (Harris, 1968). Results from that study indicated that the population consisted mainly of 2+ and 3+ fish, with 4+ and 5+ fish recorded in low numbers.

Possible explanations for the lack of older fish in the age structures include: (i) emigration of older fish from the estuary to the coastal environment; (ii) loss of older/larger fish from fishing; and (iii) bias in the gear used to sample the population, e.g. gill nets. There is a need to better understand patterns of movement of Yelloweye Mullet in the Murray River and Coorong to determine if this explains the low numbers of older individuals in age structures. Fishery-independent sampling for Yelloweye Mullet that uses a small-mesh haul net to sample age/size of this population would provide a useful assessment of population status. Such monitoring, conducted annually, would minimise possible bias associated with sampling gill net catches and enable the compilation of critical demographic information over a longer time series for a broader length range of fish which can be used to monitor the demographic status of the population.

Exploitation can indirectly alter population sex ratios if fishing mortality is higher for one sex due to differences in growth rates that influence an individual's susceptibility to capture (Kendall and Quinn 2013). Female Yelloweye Mullet comprised about 77% of the commercial catch of the LCF. There are several potential hypotheses to account for this sex-related imbalance in the catch. First, females grow to larger sizes which may make them more susceptible to commercial fishing gear. Second, males prefer shallow habitats such as banks and sandbars, whereas females tend to occupy deeper channels, potentially making them more susceptible to gill net sampling (Higham *et al.* 2005; Ye *et al.* 2013).

Higher fishing mortality of one sex compared to the other can affect fishery biology including life history, and local abundance and biomass of populations (Fenberg and Roy 2008). For example, the removal of larger females can impact the number, size and quality of eggs and larvae produced by a population, impacting survivorship and recruitment rates (Berkeley *et al.* 2004). Differences in growth between sexes for Yelloweye Mullet, suggests the sex ratio of the population could potentially change as a result of commercial fishing. Consequently, age structures should be generated for male and female Yelloweye Mullet. A time series of mean annual sex ratios may provide an indicator of population status.

Yelloweye Mullet in the Murray River estuary and Coorong grew rapidly during the first 12 months, after which growth declined. However, asymptotic size (L_{∞}) of females was significantly higher than for males, although the growth rate (K) was the same. Female Yelloweye Mullet typically attain larger sizes and live longer than males (Thomson 1957a; Harris 1968; Chubb *et al.* 1981; Curtis and Shima 2005; Gaughan *et al.* 2006). Differences in growth between sexes may affect catchability in commercial nets and may potentially explain why sex ratios were not 1:1.

Reproduction

Male and female Yelloweye Mullet in the Coorong reached sexual maturity at 248 and 242 mm TL, respectively, which is approximately 16% higher than the LMS. In this study, SAM_{50} for females was lower compared to the estimates by Ye *et al.* (2013) and Harris (1968) of 256 mm TL and 255 mm TL, respectively. SAM_{50} for males observed in this study was similar to the only other estimate for the Coorong population by Harris (1968) of 244 mm TL. The earlier onset of sexual maturity observed in 2012/13 may reflect the higher productivity and enhanced environmental condition of the Coorong during that time, following several years of relatively high freshwater discharge into the system. Increased availability of food resources may reduce the amount of stored energy required for spawning, as it can be easily supplemented throughout the reproductive period (Hüssy *et al.* 2012). In contrast, Ye *et al.* (2013) examined Yelloweye Mullet that were collected during a period of drought, whereby habitat and food availability was significantly lower.

Conclusion and implications for management

This study contributed important demographic information for Yelloweye Mullet in the Murray River estuary and Coorong. The species is characterised by: (i) fast growth, particularly in the

first 12 months; (ii) early maturation; and (iii) truncated age structure, i.e. the fishable biomass is comprised mostly of fish in the youngest age classes.

Estimates of fish age provided in this study assume that the growth zones in otoliths of Yelloweye Mullet are formed annually, as is the case for populations in Western Australia and New Zealand (Curtis and Shima 2005; Gaughan *et al.* 2006). However, given the spatial variation in growth for this species, there is a need to validate the periodicity of otolith zone formation for the Coorong population.

The LMS for Yelloweye Mullet in South Australia is 210 mm TL, which is approximately 85% and 87% of the size at maturity for males and females, respectively. The size structure from LCF commercial catches of Yelloweye Mullet for 2012/13 indicated that catches comprised mainly males and females that were larger than the SAM_{50} . However, a small proportion of the catch was sexually immature. Increased exploitation of Yelloweye Mullet below SAM_{50} would reduce the number of individuals that recruit to the spawning biomass of the population in each year.

4 PERFORMANCE INDICATORS

4.1 Introduction

The Management Plan for the South Australian LCF provides a framework for management (Sloan 2005). Performance indicators (PIs) are based on historical catch and effort data for key species in the LCF. The fishery is assessed by comparing the most recent estimates of these PIs against upper and lower reference points (RPs). The lower RPs represent unacceptable (unsustainable) fishery performance (Sloan 2005). The Management Plan also aims to avoid reaching upper RPs for total catch that result from large effort shifts to a particular species. When RPs are exceeded, management responses are prescribed (Sloan 2005). This section provides an overview of the current status of the LCF for Yelloweye Mullet, based on PIs and associated RPs described in the Management Plan (Sloan 2005). The PIs and associated RPs used to assess the status of the LCF are different to those used for the MSF. The status of the MSF for Yelloweye Mullet is assessed and presented in a recent stock status report (Fowler *et al.* 2012) and is not considered in this report.

4.2 Methods

To assess the status of the LCF for Yelloweye Mullet, there are four PIs: (i) total catch; (ii) mean annual $CPUE_{SMGN}$ ($kg.fisher\ day^{-1}$); (iii) rate of change for total catch; and (iv) rate of change for $CPUE_{SMGN}$ ($kg.fisher\ day^{-1}$). These were assessed against RPs that were defined on the basis of historical catch and effort data for the reference period from 1984/85 to 2001/02 (Sloan 2005). For total annual catch and $CPUE_{SMGN}$, the upper and lower RPs were based on the three highest and three lowest values during the reference period. The four-year rate of change PIs for total catch and $CPUE_{SMGN}$ were determined using the greatest rate of change ($\pm$) over four consecutive years for total catch and $CPUE_{SMGN}$ during the reference period.

4.3 Results

The four PIs for Yelloweye Mullet in 2011/12 are shown in Table 4.1. In 2011/12, all PIs were within the range of the RPs defined in the Management Plan (Sloan 2005). Inter-annual trends for the four PIs from 1984/85 to 2011/12 are shown in Figure 4.1.

Table 4.1. Performance indicators and reference points for Yelloweye Mullet taken using small-mesh gill nets from the LCF in 2011/12.

Performance Indicator	Upper reference point	Lower reference point	2011-12 estimate	Within range of reference points
Total Catch (t)	312	124	144.4	Y
CPUE _{SMGN} (kg.fisher day ⁻¹)	93	47	90.8	Y
4-year total catch trend (t.year ⁻¹)	45	-45	-16.0	Y
4-year CPUE _{SMGN} trend (kg.fisher day ⁻¹)	13	-13	-8.7	Y

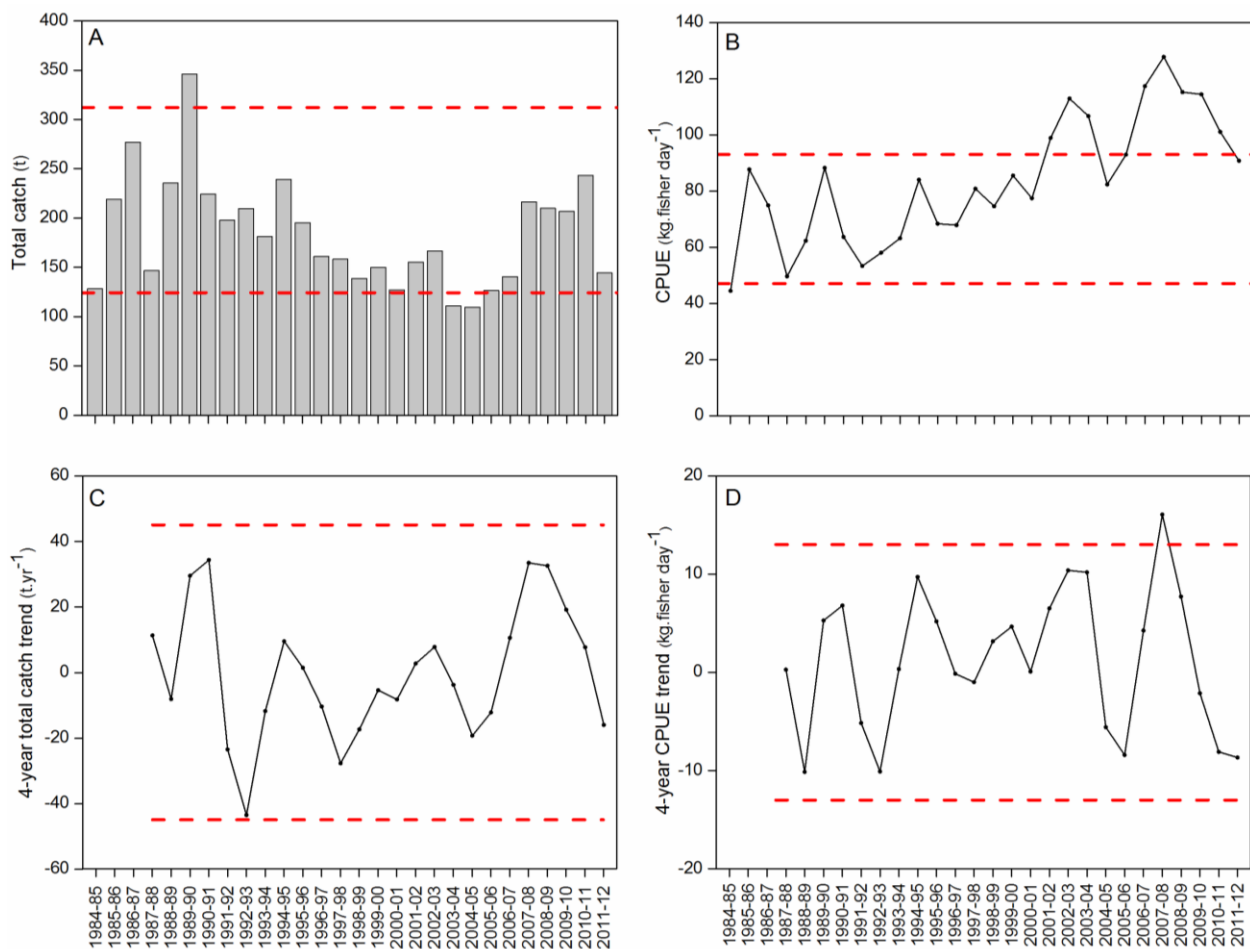


Figure 4.1. Time series of annual PIs and upper and lower limit RPs (red dashed lines) for Yelloweye Mullet taken by the LCF using a small-mesh gill nets from 1984/85 to 2011/12. (A) Total catch (t); (B) CPUE_{SMGN} (kg.fisher day⁻¹); (C) 4-year total catch trend (t.year⁻¹); and (D) 4-year CPUE_{SMGN} trend (kg.fisher day⁻¹).

4.4 Discussion

The PIs for Yelloweye Mullet in the LCF were all within the RPs defined in the Management Plan (Sloan 2005). They are consistent with the assessment of a sustainable stock (Flood *et al.* 2012).

There are concerns around the use of commercial CPUE data as the only available estimate of relative abundance for Yelloweye Mullet in the LCF. The geographic range of Yelloweye Mullet in the Coorong is strongly influenced by salinity, which is primarily driven by the magnitude of freshwater inflows (McNeil *et al.* 2013; Ye *et al.* 2013). During drought, hypersaline conditions in the southern Coorong concentrate Yelloweye Mullet to a reduced area of favourable habitat which may increase their catchability and potentially confound interpretation of CPUE as an indicator of population abundance.

As such, there is a need for additional PIs for Yelloweye Mullet in the LCF. Age structures have the potential to provide a robust PI for Yelloweye Mullet in the LCF. Development of an extended time-series of annual age structures would provide an ongoing indication of population status and structure for Yelloweye Mullet.

5 GENERAL DISCUSSION

This section provides a synopsis of information available for assessing the status of the LCF for Yelloweye Mullet, discusses the level of uncertainty in the assessment for the LCF, assesses the current status of the resource in the Murray River estuary and Coorong, and identifies knowledge gaps and highlights the future research needs for the species in South Australia. The status of the MSF for Yelloweye Mullet is assessed and presented in a recent stock status report (Fowler *et al.* 2012) and is not considered in this report.

5.1 Information available for assessing the status of the fishery

Assessment of the LCF for Yelloweye Mullet is aided by one previous stock assessment (Higham *et al.* 2005), several stock status reports (Ferguson 2006; 2008; 2010b; 2011; 2012), and the Management Plan (Sloan 2005) which describes the current management arrangements, PIs and associated RPs for the fishery.

Daily catch (kg) and effort (net days, fisher days) data are available from the South Australian Inland Waters Catch and Effort Returns from 1984/85 to 2011/12. Annual estimates of relative abundance for Yelloweye Mullet are provided by fishery dependent CPUE_{SMGN} (kg. fisher day⁻¹) for this period. PIs based on catch and CPUE are compared with RPs for the fishery (Sloan 2005).

Several knowledge gaps of the biology of Yelloweye Mullet identified in the previous stock assessment (Higham *et al.* 2005), were addressed in a recent study on flow ecology of fish and fisheries in the Coorong (Ye *et al.* 2013). In that study, several aspects of the biology of Yelloweye Mullet were described including: (i) size structure of the Coorong population; (ii) reproduction; and (iii) size at maturity (Ye *et al.* 2013).

Biological information on demography, growth and maturity are available for several populations of Yelloweye Mullet including the Coorong population and can provide a useful indication of the status of exploited fish populations (Fowler *et al.* 2000). Otolith-based estimates of age from this study (Section 3) provided size/age structures for male and female Yelloweye Mullet from the Coorong population which were consistent with those provided by Harris (1968). Further size/age information is also available for populations in New Zealand (Curtis and Shima 2005) and Western Australia (Gaughan *et al.* 2006). The present study also provided estimates of

mean sex ratio of the Coorong population, as well as otolith-based estimates of growth rates and size and age at sexual maturity for male and female Yelloweye Mullet.

5.2 Uncertainty in the assessment

This assessment relies heavily on commercial catch and effort data. Uncertainty exists around the use of commercial CPUE data as the only available estimate of relative abundance for Yelloweye Mullet in South Australia. This is because spatial contraction of the fishery for Yelloweye Mullet in the Murray River estuary and Coorong particularly in the southern Coorong, may potentially affect CPUE as an indicator of population abundance.

PIs and RPs defined in the Management Plan for the LCF (Sloan 2005) rely on commercial catch and effort data with RPs restricted to a fixed, relatively short time period (Sloan 2005). In addition, catch-trend and CPUE-trend PIs have widely separated upper and lower RPs that do not provide the most informative criteria for assessment of the status of the fishery. Consequently, this assessment would be improved through a review of these PIs and RPs when the management plan is updated in 2014.

Uncertainty also exists around the levels of recreational catches of Yelloweye Mullet in South Australia, as data are only available for 2000/01 and 2007/08 (Jones and Doonan 2005; Jones 2009). This is of particular concern for the Coorong population because recreational fishers can target Yelloweye Mullet using registered gill nets.

Levels of incidental mortality of sub-legal sized Yelloweye Mullet discarded from gill nets in both commercial and recreational sectors operating in the Coorong are poorly understood. For the commercial sector, this will be addressed by monitoring of discards from SMGN. It is planned to incorporate discard information into the Inland Waters Catch and Effort return in 2013-14.

Although this study provided baseline age structure from commercial gill net catches and fishery-independent multi-panel gill net catches it should be noted that these are from an exploited population that has likely also been impacted by environmental changes. Further, the size range of fish collected using these methods may be limited by the mesh sizes of the gill nets. As such, it is possible that larger fish may be underestimated in the size/age structures. Additional fishery-independent sampling using small-mesh haul nets would provide a wider size/age range of fish.

Although Yelloweye Mullet is managed as a single unit stock in South Australia, there is uncertainty around stock structure. Whilst there is evidence of discrete stocks across southern Australia (Thomson 1957a; Pellizzari 2001), the stock structure and extent of population sub-structuring within South Australian waters are poorly understood.

5.3 Current status of the LCF for Yelloweye Mullet

All PIs for 2011/12 were within the range of the RPs described in the Management Plan (Sloan 2005). Total annual catch (144 t) in 2011/12 was 11% above the lower RP and $CPUE_{SMGN}$ (91 kg.fisher day⁻¹) was 4% below the upper RP. The 4-year catch-trend and CPUE-trend PIs from 2008/09 to 2011/12 were both within range of the RPs defined in the Management Plan (Sloan 2005).

The highest total annual catch of Yelloweye Mullet in the LCF was 346 t in 1989/90. From then catch gradually declined and was 110 t in 2004/05, before increasing to >216 t.yr⁻¹ from 2007/08 to 2010/11. In 2011/12, catch declined to 144 t and was among the lowest on record. In contrast, $CPUE_{SMGN}$ gradually increased from 53 kg.fisher day⁻¹ in 1990/91 to an historic peak of 128 kg.fisher day⁻¹ in 2007/08. Despite a decrease in CPUE in the four years since 2007/08, CPUE remained relatively high in 2011/12.

Age structures from commercial catches comprised mostly two and three year old fish, despite the potential of this species to reach 10 years of age (Gaughan *et al.* 2006). As such, the fishable biomass of the Coorong population essentially consisted of fish in the youngest age classes. Whether truncated age structures indicate the impacts of environmental conditions, fishing, or the emigration of larger/older individuals, is not known. The presence of young fish in age structures suggests that recruitment has occurred in recent years. In particular, the presence of small juveniles in the fishery-independent samples suggests that recruitment has occurred in the past 12 months.

The LMS for Yelloweye Mullet in South Australia is 210 mm TL, which is 32 mm TL and 38 mm TL lower than the estimated SAM_{50} for females and males, respectively. While size structures for Yelloweye Mullet from commercial catches indicated that the LCF generally target and capture fish above the SAM_{50} for each sex, a small proportion of the catch comprised sexually immature fish. An increase in the proportion of immature fish harvested by the fishery would reduce the number of fish recruiting to the spawning biomass of the population and

subsequently reduce egg production. This could occur if catches increase and population biomass is reduced. One potential solution is to increase the LMS from 210 mm TL to the SAM₅₀, i.e. 248 mm TL.

Overall, the available information suggests that the Yelloweye Mullet stock in the Murray River estuary and Coorong is sustainable (Flood *et al.* 2012).

5.4 Future research needs

Given the uncertainty around the use of commercial CPUE as the only available estimate of relative abundance for Yelloweye Mullet in the Coorong, there is a need for additional PIs to assess the status of the population. Development of an extended time-series of annual age structures would provide an ongoing indication of population status and should include annual sampling from commercial gill net catches. Issues around possible bias towards smaller/younger fish associated with size selectivity of commercial nets could be addressed with fishery-independent sampling using haul nets. Such sampling may also provide an indication of recruitment of 0+ (<1 year old) fish.

Validation of the periodicity of growth zone formation in otoliths has not been done for Yelloweye Mullet in South Australia and could be achieved by: (i) marginal increment analysis of a range of year classes (~0 to 5 years) from monthly sampling; (ii) oxy-tetracycline marking of captive fish; or (iii) by a mark and release (tagging) study.

Consistency of age estimation for Yelloweye Mullet may be achieved by developing an appropriate otolith-based ageing protocol. Such a protocol would require the development of an otolith reference collection based on sectioned otoliths. The collection would allow for age estimates to be standardised between individual researchers and between years.

Knowledge on the movement of Yelloweye Mullet in South Australia is limited. Understanding movement patterns would inform on demographic processes that may be contributing to changes in population size and structure, and could be achieved by: (i) an acoustic tagging study; (ii) a mark and release (tagging) study; or (iii) an otolith chemistry-based study of the connectivity/exchange between populations.

The extent and mortality of undersized Yelloweye Mullet discarded from commercial and recreational gill net catches is unknown. Ongoing monitoring of discards is needed for SMGN in

the Murray River estuary and Coorong. Baseline discard information is available from a study in 2005 although this occurred during drought (Ferguson 2010a).

Other key knowledge gaps for the LCF for Yelloweye Mullet and its management include: (i) monitoring of discards from commercial and recreational gill net catches; (ii) size/extent of recreational catches; (iii) improved understanding of the impact of targeted fishing on by-catch species; (vi) improved understanding of stock structure in southern Australia; and (v) the development of a recruitment index.

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