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Mulloway (*Argyrosomus japonicus*)

Stock Assessment Report 2013/14

J. Earl and T.M. Ward

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Report to PIRSA Fisheries & Aquaculture

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EXECUTIVE SUMMARY

This report is the third assessment of the South Australian Mulloway (*Argyrosomus japonicus*) fishery and builds on previous assessments in 2003 and 2011. It provides a synopsis of information available for this species and reports on: (i) commercial catch and effort data from 1984/85 to 2013/14 for the Lakes and Coorong Fishery (LCF) and the State-wide Marine Scalefish Fishery (MSF); (ii) population size and age structures; and (iii) performance of the LCF for Mulloway in relation to performance indicators and limit reference points identified in the LCF Management Plan (Sloan 2005).

The South Australian Mulloway fishery comprises two multi-species, multi-gear sectors: LCF and MSF. In 2013/14, the total State-wide commercial catch of Mulloway was 69.1 t, of which 98% was harvested by the LCF.

Annual catches of Mulloway by the LCF increased to an historic peak of 136 t in 2000/01, then decreased and averaged 32.7 $t.yr^{-1}$ from 2004/05 to 2010/11. Total catch by the LCF in 2013/14 was 68 t, which was the second highest catch since 2001/02.

The dominant gear type used by the LCF to target Mulloway was the large mesh gill net (LMGN; >115 to ≤150 mm mesh). In 2013/14, total catch from large mesh gill nets from the Coorong estuary was 60 t which accounted for approximately 88% of the total catch. Most of the remaining catch was taken using swinger nets (6.4 t) from the nearshore marine environment adjacent the Coorong.

For the LCF, mean annual catch per unit effort for large mesh gill nets ($CPUE_{LMGN}$) increased from an historic low of 7 kg.fisher day^{-1} in 1987/88 to a peak of 87 kg.fisher day^{-1} in 2010/11. In 2013/14, $CPUE_{LMGN}$ declined to 52.9 kg.fisher day^{-1} but remained among the highest on record.

Clear spatial differences were evident in age/size structures for Mulloway between the Coorong estuary and adjacent nearshore marine environment from recent years. Catches from the Coorong were dominated by 3 year old (juvenile) fish, while those from the ocean comprised fish between 4 and 18 years of age with 90% of individuals above the age at maturity (5-6 years) for the species in South Australia. The presence of young fish in age structures from estuarine habitats indicates that recruitment has occurred in recent years.

The legal minimum size for Mulloway in the Coorong estuary, i.e. the area that accounts for the majority of the commercial catch of Mulloway in South Australia, is 460 mm total length (TL), which is 54% and 59% of the size at maturity (SAM_{50}) for females and males, respectively.

The legal minimum size for Mulloway in all South Australian coastal waters, except the Coorong estuary, is 750 mm TL which is 88% and 96% of the SAM_{50} for females and males, respectively.

For 2013/14, five of the six performance indicators were within the range of limit reference points prescribed in the Management Plan. The performance indicator for $CPUE_{LMGN}$ was 6.2% above the upper limit reference point.

Using the definitions from the national stock status framework (Flood et al. 2012), the fishery for Mulloway in eastern South Australia is classified as **sustainable**. However, given the uncertainty around the usefulness of CPUE as indicator of population abundance and limited number of samples available for the age/size structures for the adult population, it is important to develop additional indicators that consider the influence of the environment on fishery performance for Mulloway.

The most important research needs for the Mulloway fishery and its management include: (i) independent monitoring of discarding of non-targeted and sub-legal sized individuals from large and small mesh gill nets, particularly under flow conditions when recruits of Mulloway (and other species) are present in the Coorong; (ii) ongoing development of a time series of annual age structures; (iii) improved understanding of the use of the Coorong estuary and marine habitats in eastern South Australia by juvenile Mulloway; and (iv) regular surveys to estimate the recreational harvest of Mulloway in South Australia.

1. GENERAL INTRODUCTION

1.1 Overview

This assessment of the fishery for Mulloway (*Argyrosomus japonicus*) in South Australia, builds on previous fishery assessment reports in 2003 and 2011 (Ferguson and Ward 2003; 2011), a review of the 2011 stock assessment (Smith 2013) and annual stock status reports since 2006 (Ferguson 2006; 2008; 2010c; 2011; 2012a; 2012b). The report provides a synopsis of information available for Mulloway and an assessment of the current status of the Mulloway stock in south-eastern South Australia. The assessment is based on commercial catch and effort data up to 30 June 2014 for the Lakes and Coorong Fishery (LCF) and State-wide Marine Scalefish Fishery (MSF), and results from the most recent South Australian Recreational Fishing Survey 2007/08 (Jones 2009). Information on the size and age characteristics of the Mulloway population exploited by the LCF is also included to inform on population structure.

1.2 Description of the fishery

In Australia, most commercial catches of Mulloway are taken in South Australia and New South Wales, while smaller catches are also taken in Western Australia and Queensland (Kailola et al. 1993; Silberschneider and Gray 2008; Ferguson and Ward 2011). Mulloway is regarded as an 'icon' species by recreational fishers in these States, as well as Victoria (Kailola et al. 1993). In South Australia, most commercial and recreational catches of Mulloway are taken in the State's south-east, primarily from the Coorong estuary, and adjacent nearshore marine environment (Jones and Doonan 2005; Jones 2009; Ferguson and Ward 2011). Recreational fishers also target Mulloway on the State's far west coast (Rogers et al. 2010; 2014) and to a lesser extent northern Gulf St. Vincent, northern Spencer Gulf and along the southern coasts of Yorke Peninsula (Jones and Doonan 2005).

Commercial Fishery

The commercial fishery for Mulloway in South Australia has two main sectors, the LCF and MSF. The Northern Rock Lobster Fishery and Southern Rock Lobster Fishery also have limited access to Mulloway, although catches from these sectors are negligible and are not considered further in this assessment.

Lakes and Coorong Fishery

The LCF is a small scale, multi-species, multi-gear fishery that operates in, and adjacent to, the estuary of the Murray River and Coorong lagoons (hereafter referred to as the Coorong estuary), the lower lakes of the Murray River (Lakes Alexandrina and Albert) and the nearshore marine environment adjacent the Corong (Figure 1.1). Mulloway is a key target species for the LCF. Fishers operating in the Coorong estuary use mainly large-mesh gill nets (115-150 mm mesh) to target Mulloway, along with several other finfish species including Black Bream (*Acanthopagrus butcheri*) and Greenback Flounder (*Rhombosolea tapirina*). Larger Mulloway are also targeted in the nearshore marine environment along Younghusband Peninsula using swinger nets (>150 mm mesh).

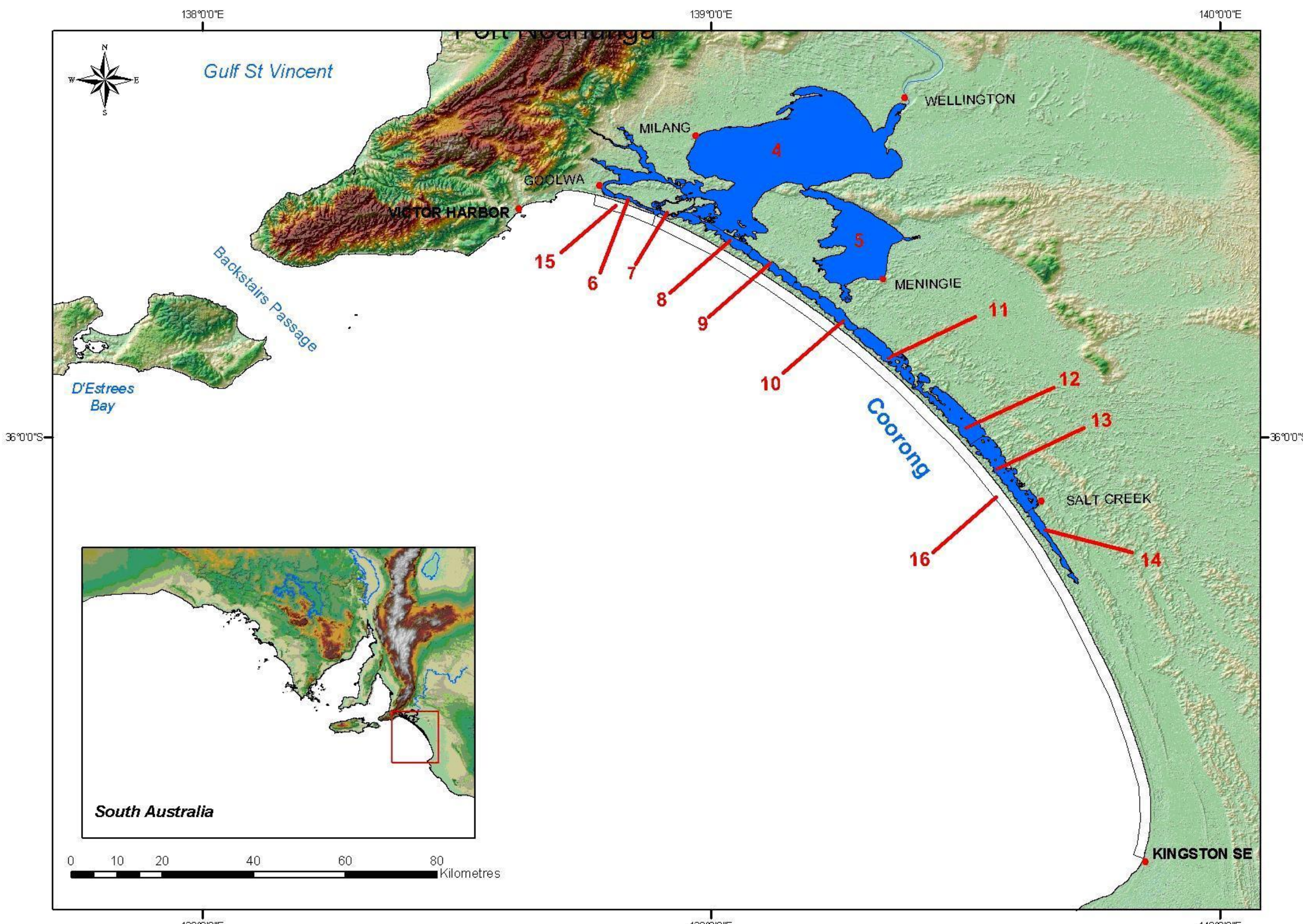

Figure 1.1. Map of the Coorong estuary showing commercial reporting areas 4-16 of the LCF.

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 Coorong estuary (Figure 1.2). Fishers in the MSF use mainly gill nets, haul nets, and rod and lines to target Mulloway.

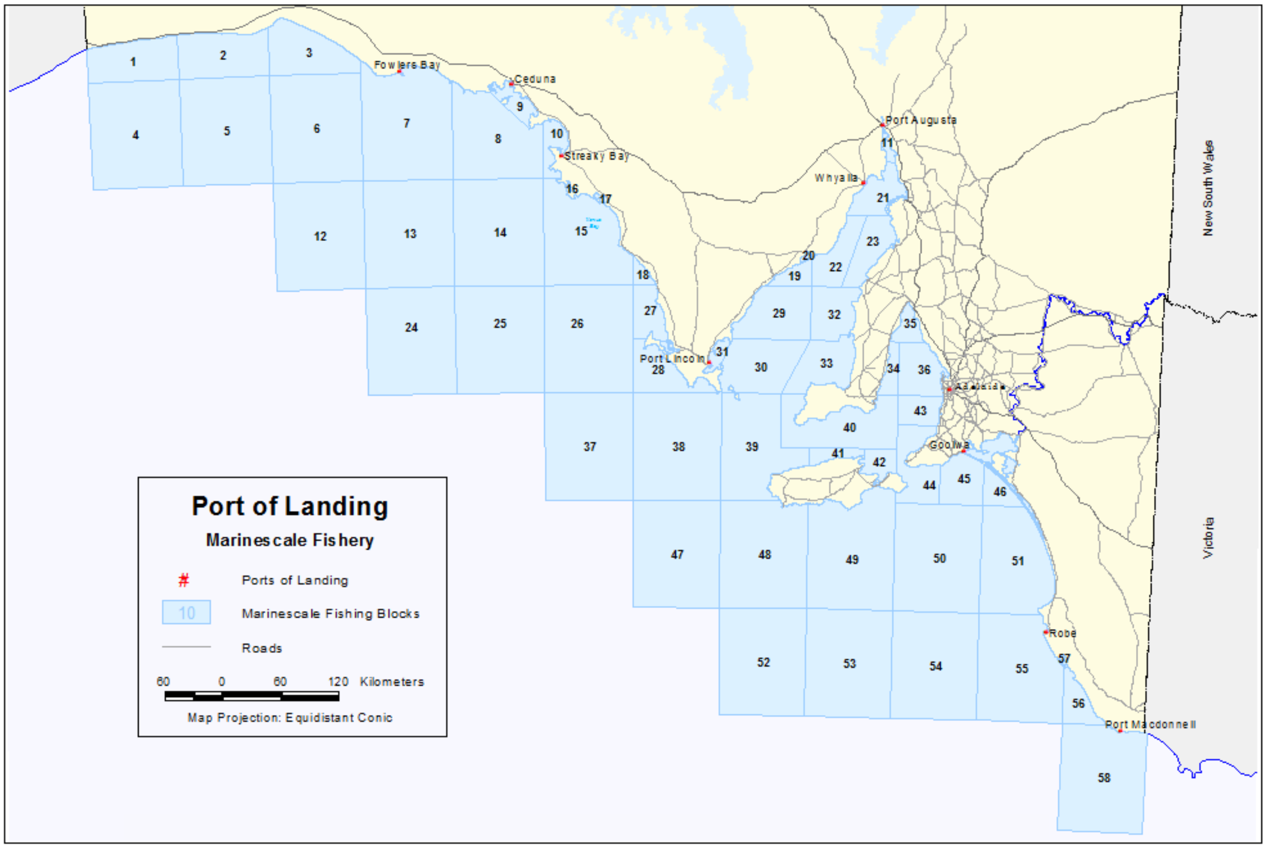

Figure 1.2. Map of southern South Australia showing the 58 spatial reporting blocks of the MSF.

Recreational Fishery

Recreational fishers regard Mulloway as an "icon" species and target them using rod and line in the coastal waters of South Australia, particularly on the State's far west and south-east coasts (Kailola et al. 1993). However, most recreational catches are taken from the Coorong region with smaller catches from the west coast (Jones and Doonan 2005; Jones 2009; Rogers et al. 2010; 2014)

Traditional Fishery

The Ngarrindjeri population density is likely to have been the highest 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 continue to target Mulloway in addition to Black Bream, Greenback Flounder and Yelloweye Mullet using a range of traditional apparatus, including nets, spears and rod and line (Jenkin 1979; Olsen and Evans 1991).

1.3 Management of the fishery

Commercial Fishery

<u>Lakes and Coorong Fishery</u>

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. Table 1.1 provides a timeline of changes to management arrangements for 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 adjacent beach along Younghusband Peninsula. 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. The *Fisheries Management (Lakes and Coorong Fishery) Regulations 2009* provide that a person other than the holder of a Lakes and Coorong Fishery licence cannot be registered as a master of a boat used under that licence, unless the licence holder is already the registered master of another fishery licence.

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.

Table 1.1. Management milestones for the Lakes and Coorong Fishery.

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	*South Australian Fisheries Act, 1982*
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	The Lakes and Coorong Fishery 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 total length 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	*The Fisheries Management Act 2007* Fishery Management Committees were discontinued from 31 March 2007
2009	Pipi quota management arrangements implemented into regulations
2009	*Fisheries Management (Lakes and Coorong Fishery) Regulations 2009*
2013	Amendments to the *Fisheries Management (Lakes and Coorong Fishery) Regulations 2009* to allow licence holders to transfer all entitlements to family members.

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 internationally for its wetland habitats and importance for a variety of migratory waterbirds.

To measure and monitor fishery performance, catch and effort data for the LCF have been recorded since 1st July 1984 (Knight et al. 2001). Daily catch and effort information is provided to SARDI Aquatic Sciences on a monthly basis and includes: catch (kg) and effort (days fished, fisher days, net days) data for targeted and non-targeted species; gear type used; and fishing location in relation to LCF reporting areas (Figure 1.1). Management arrangements for Mulloway comprise general gear restrictions, spatial and temporal closures and a legal minimum size (LMS) of 460 mm TL within the waters of the Coorong estuary, and 750 mm TL in all other State waters.

<u>Marine Scalefish Fishery</u>

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.

Fishers in the MSF have access to Mulloway in all South Australian coastal waters except the Coorong estuary. The LMS of 750 mm TL applies to all catches. Catch and effort data for the MSF have been recorded since 1 July 1984 (Knight et al. 2001). Daily catch (kg) and effort (days fished, fisher days, number of nets) data for targeted and non-targeted species; gear type used; and location of fishing is provided on a monthly basis to SARDI Aquatic Sciences. Fishing location is reported against MSF reporting blocks shown in Figure 1.2.

Recreational fishery

The recreational sector is managed through a combination of input and output controls, aimed at ensuring that the total catch is maintained within sustainable limits and recreational access to the fishery is equitably distributed between recreational participants. The bag and boat limits for Mulloway vary geographically and with fish size. In the Coorong estuary, the daily bag limit is 10 fish for the size range of 460 mm to 750 mm TL and there is no boat limit. For fish >750 mm TL, a bag limit of 2 fish and a boat limit of 6 fish applies for all State waters, including the Coorong estuary. Management arrangements also comprise general gear restrictions (PIRSA 2014).

Recreational fishers can also use registered nylon mesh nets to target finfish within the Coorong. In 2013, approximately 713 recreational fishers possessed a mesh net that was registered with PIRSA Fisheries and Aquaculture for use in the Coorong estuary and Lakes Alexandrina and Albert. An additional 604 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.

Traditional fishery

All of the management measures in place for recreational fishers apply to indigenous fishers when undertaking traditional fishing practices. However, indigenous fishers also have access to Mulloway for traditional, domestic, non-commercial use subject to meeting requirements of the *Native Title Act 1994*.

1.4 Performance indicators for the commercial fishery

The Management Plan for the LCF (Sloan 2005) identifies six performance indicators (PIs) and their associated limit reference points (RPs) to monitor the performance and assess the status of the Mulloway fishery. The PIs are: (i) total catch (LCF and MSF combined); (ii) 4-year total catch trend (LCF and MSF combined); (iii) mean annual CPUE for large mesh gill nets (LCF); (iv) mean annual CPUE trend for large mesh gill nets (LCF); (v) mean annual CPUE for swinger nets (LCF); and (vi) mean annual CPUE trend for swinger nets (LCF). All PIs were derived from catch and effort data for the historical reference period from 1984/85 to 2001/02 (Sloan 2005). Upper and lower limit RPs for catch and CPUE PIs were estimated from the average of the three highest and three lowest values during the reference period, respectively. Upper and lower trend (rate-of-change) PIs for catch and CPUE were estimated from the highest and lowest slope of the relationships for 4-year periods within the reference period (Sloan 2005).

1.5 Previous stock assessments

Commercial Fishery

<u>Lakes and Coorong Fishery</u>

Previous assessments of the status of the LCF for Mulloway include: fishery assessment reports in 2003 and 2011 (Ferguson and Ward 2003; 2011); and stock status reports (Ferguson 2006; 2008; 2010c; 2011; 2012a; 2012b).

The most recent fishery assessment report for Mulloway by Ferguson and Ward (2011) provided information on stock structure in South Australia, size and structure of the Coorong population, commercial catch and effort trends, and examined the relationship between commercial catches and freshwater flows from the Murray River. The key points of the assessment were:

- The LCF harvested 26 t of Mulloway in 2009/10. Large-mesh gill nets (LMGN) were the dominant gear and accounted for 83% of the total catch, while swinger nets (SN) (>150 mm mesh) accounted for 15% of the total catch. In 2009/10, CPUE for LMGN and SN was 39 kg/fisher day^{-1} and 45 kg/fisher day^{-1}, respectively.
- Assessment of the fishery against PIs in the Management Plan indicated that five of six PIs for 2002/03 were within the defined RPs. The total catch PI was below the lower RP.
- In 2010/11, age structures for Mulloway in south-eastern South Australia were truncated because few individuals older than 16 years were represented despite the maximum age of 41 years. Longevity overfishing has likely resulted from the combined impacts of habitat degradation and fishing.
- Mulloway are vulnerable to over-fishing because their life-history is characterised by delayed maturity, high longevity and a requirement for protected juvenile habitat. Mulloway populations rely on one or two strong year classes at irregular intervals to maintain the population.

Ferguson (2012b) provided the most recent assessment of the LCF for Mulloway, based on the analyses of fishery catch and effort data. The key points were:

- The LCF harvested 64 t of Mulloway in 2011/12, which increased 229% from the previous year.
- Assessment of the LCF for Mulloway indicated that five of the six PIs for 2011/12 were within the range of the RPs defined in the Management Plan (Sloan 2005). The CPUE (LMGN) PI was 79% above the upper RP.

<u>Marine Scalefish Fishery</u>

Fowler et al. (2013) provided the most recent assessment of the MSF for Mulloway. Key points from this report were:

- Historically, commercial catches of Mulloway in the MSF have been low. The highest annual catch was 24 t in 1995/96. Since then, catches have progressively declined. In 2012/13, total catch for the MSF was 4.8 t and among the lowest recorded in the fishery.
- The decline in catch since 1995/96 was related to declining fishing effort, and reflected changes within the fishery rather than declining stock status.

- Of the 20 PIs assessed for the MSF for Mulloway in 2012/13, the PI for targeted CPUE (handline/fishing pole) exceeded the upper RP and was the highest on record. All PIs relating to targeted fishing using hauling nets and gill nets were affected by confidentiality agreements.

Recreational Fishery

Estimates of recreational catch for Mulloway in South Australia are available for two years: 2000/01 and 2007/08. In 2000/01, the estimated harvested catch was 90.2 t which accounted for 44% of the State-wide combined commercial and recreational catch (Jones and Doonan 2005). In 2007/08, the estimated catch by the recreational sector declined by approximately 32% since 2000/01 to 61.7 t. In 2007/08, recreational catches contributed 62% of the combined commercial and recreational catch in South Australia (Jones 2009).

On-site, interview-based surveys of recreational fishing near Yalata on the far west coast of South Australia in 2009/10, 2010/11 and 2011/12, indicated significant recreational fishing effort was targeted at spring/summer aggregations of Mulloway (Rogers et al. 2010; 2014). Over the three surveys, a total of 478 Mulloway were landed, of which 75% were returned to the water. Mulloway captured by recreational fishers ranged in size from approximately 250 mm to approximately 1,550 mm TL, and included fish up to 22 years of age (Rogers et al. 2014).

1.6 By-catch issues associated with the commercial fishery for Mulloway

A study of discarding from small and large mesh gill nets used in the Coorong lagoons was conducted in 2005/06 (Ferguson 2010a). Results of this study indicated that: (i) discarded Mulloway contributed significantly to the composition of catches for fishing operations that targeted Yelloweye Mullet, Greenback Flounder and Mulloway; (ii) levels (numbers) of discarding of Mulloway were higher than levels of retained catch; (iii) large mesh gill nets selected Mulloway over a wide range of lengths including individuals above and below the LMS; and (iv) survival of discarded Mulloway was low (<20%). Consequently, discarding of sub-legal sized Mulloway from large mesh gill nets in the Coorong lagoons has the potential to impact on the sustainability of Mulloway stocks (Ferguson 2010a).

1.7 Biology of Mulloway

This section provides an overview of the biology of Mulloway, with particular emphasis on populations in southern Australia. For more detailed information on all biological aspects of

Mulloway in Australia, readers should refer to Silberschneider and Gray (2008), Farmer (2008) and Ferguson et al. (2014).

Taxonomy, distribution and habitat

The Mulloway (*Argyrosomus japonicus;* Temminck and Schlegel 1843) belongs to the order Perciformes, which contains approximately 40% of all bony fish. Among the well-known families of this order that occur in South Australian waters include Sillaginidae (whitings), Sparidae (breams, snappers) and Sciaendiae (croakers, drums) (Gomon et al. 2008). Sciaenidae, of which Mulloway is a member, are mostly coastal fishes that are characterised by a single, long dorsal fin which may be partially or completely sub-divided into two segments (Figure 1.3). Worldwide, there are 70 genera and at least 270 species of sciaenids distributed in fresh, estuarine and coastal marine waters throughout sub-tropical and temperate regions of the Atlantic, Indian and Pacific oceans (Silberschneider and Gray 2008). There are nine genera and twenty species in Australia, with only two species found in temperate waters. One of these species is the Mulloway, which prior to 1985 was classified as *Argyrosomus hololepidotus* (Lacepede, 1802) (Griffiths and Heemstra 1995).

Figure 1.3. Mulloway, *Argyrosomus japonicus* (Temminck and Schlegel, 1843) (Source: Spotfind Network 2014).

Mulloway has an Indo-Pacific distribution where it occurs in coastal waters (< 200 m depth) of southern Africa, India, Pakistan, China, Korea, southern Japan, and southern Australia from North West Cape in Western Australia to the Burnett River in Queensland (excluding Tasmania) (Kailola et al. 1993; Griffiths 1995; Griffiths and Heemstra 1995; Farmer 2008; Silberschneider and Gray 2008). Throughout its distribution, this schooling species is particularly abundant in nearshore coastal environments. Adult Mulloway show a preference for nearshore marine habitats such as surf beaches and inshore reefs, whereas juveniles are most abundant in estuaries and shallow bays and lagoons (Griffiths and Hecht 1995; Griffiths 1996; Ferguson et al. 2008; Silberschneider et al. 2009).

Mulloway possess distinct physiological and morphological characteristics adapted to exploit the dynamic environmental nature of estuaries and nearshore coastal environment. They are a relatively sedentary species (Silberschneider and Gray 2008) that are eurythermal (Harrison and Whitfield 2006) and euryhaline (Fielder and Bardsley 1999; Harrison and Whitfield 2006). In the Coorong estuary, Mulloway have been recorded in water temperatures from 10 to 31 ^{o}C (unpublished data) and salinities up to 62 ppt (Ye et al. 2013).

Reproductive Biology

The estimated size at maturity (SAM_{50}) for male and female Mulloway in south-eastern South Australia is 850 mm TL for females and 778 mm TL for males, which is equivalent to the mean age of approximately 6 years for females and 5 years for males (Ferguson et al. 2014). This is similar in comparison to populations in South Africa (Griffiths 1996) and on the west coast of Western Australia (Farmer 2008). In contrast, populations on the south coast of Western Australia and New South Wales reach sexual maturity at ages of 3-5 years and 2-3 years, respectively (Farmer 2008; Silberschneider and Gray 2008). This suggests that the population in eastern South Australia, South Africa and on the west coast of Western Australia may have a longer juvenile period than those from New South Wales and southern Western Australia.

Our understanding of the reproductive strategy of Mulloway in southern Australia is based primarily on a study undertaken in Western Australia (Farmer 2008). That study determined that Mulloway is a group synchronous spawner with indeterminate fecundity. These results were corroborated by Battaglene (1996), whom monitored the spawning activity of Mulloway in captivity. In eastern South Australia, this species has an extended spawning season from October to January, based on gonadosomatic indices and the presence of mature fish in advanced stages of reproductive development or spent/recovering (Ferguson et al. 2014). No estimates of the fecundity of wild Mulloway have been reported, although Battaglene and Talbot (1994) estimated that hatchery-reared individuals with a total weight of 10 kg could spawn approximately 1 million eggs.

Several authors have hypothesised that Mulloway spawn in nearshore coastal waters in river plumes around mouths of estuaries, near reefs and in surf zones (Hall 1986; Griffiths 1996; Farmer 2008; Ferguson et al. 2014). The formation of aggregations of large Mulloway, with ovaries containing hydrated oocytes, in the lower reaches of the Swan River estuary in southern Western Australia, suggests that spawning may also occur in estuaries (Farmer 2008). Since Mulloway move frequently between estuarine and marine environments (Cowley et al. 2008) and the hydration of oocytes can take up to 24 hours, fish with hydrated oocytes may move from the estuary to the nearshore marine environment prior to spawning. This latter scenario is more likely given the anecdotal evidence of spawning aggregations in coastal waters in New South Wales (Silberschneider and Gray 2008), South Africa (Griffiths and Heemstra 1995) and South Australia (Hall 1986; Ferguson and Ward 2011).

Early life history

Mulloway eggs are pelagic, approximately 0.94 mm in diameter, and hatch after approximately 29 hours at 23 ^{o}C, releasing larvae of 2.3 mm TL (Battaglene and Talbot 1994). Larvae metabolise yolk for 3-4 days and then begin to feed, taking approximately 35 days to reach 15-26 mm TL, when they are capable of settlement as demersal juveniles (Battaglene and Talbot 1994). Eggs have been collected near the surface in nearshore coastal waters off southern Africa (Griffiths 1996) and larvae have been caught in estuarine and coastal waters out to the 200 m depth contour off south-eastern Australia between January and April (Steffe 1991; Gray and Miskiewicz 2000; Smith 2003). In coastal waters of New South Wales, the highest concentrations of larvae was between 20 and 60 m depth, where water temperatures were between 21-23 ^{o}C (Smith 2003). Similarly, in a large coastal embayment in New South Wales, larval Mulloway were most abundant near the substratum (Steffe 1991), suggesting that larval Mulloway may prefer deeper parts of the water column. There is no information on the abundance and distribution of Mulloway eggs and larvae in South Australian waters.

Age and growth

The demography of Mulloway is better understood since a methodology was developed to determine the age of juvenile and adult fish (Farmer et al. 2005; Silberschneider et al. 2009; Ferguson et al. 2014). Sections (transverse and longitudinal) of otoliths of this species display an alternating sequence of opaque and translucent zones (Figure 1.4). Furthermore, results from marginal increment analysis indicated that the incremental structure visible in the sections of otoliths was formed annually, and therefore, can be interpreted in terms of fish age in years.

Numerous studies have provided age and growth information for Mulloway in Australia. Ferguson et al. (2014) sampled fish from the nearshore marine environment adjacent the Coorong in South Australia, between 2000/01 and 2011/12, including fish up to 1400 mm TL and 25 years old (Table 1.2). Silberschneider et al. (2009) described the growth of Mulloway from coastal waters of New South Wales from a relatively large sample of fish, which included individuals ranging in size from 50 to 1690 mm TL, and a maximum age of 24 years. Farmer

(2008) examined the age structure for several populations of Mulloway throughout Western Australia, which comprised mostly fish <15 years old, although individuals to 32 years of age were recorded. In South Africa, Mulloway grow to a maximum size of approximately 1800 mm TL and a maximum age of 42 years (Griffiths and Hecht 1995).

The growth of Mulloway has been well studied in Australia and South Africa (Griffiths and Hecht 1995; Silberschneider and Gray 2005; Farmer 2008; Ferguson et al. 2014). Growth of male and female Mulloway is initially rapid for the first 5-6 years of life, after which the rate of growth declines, with females typically growing faster and attaining a larger size than males.

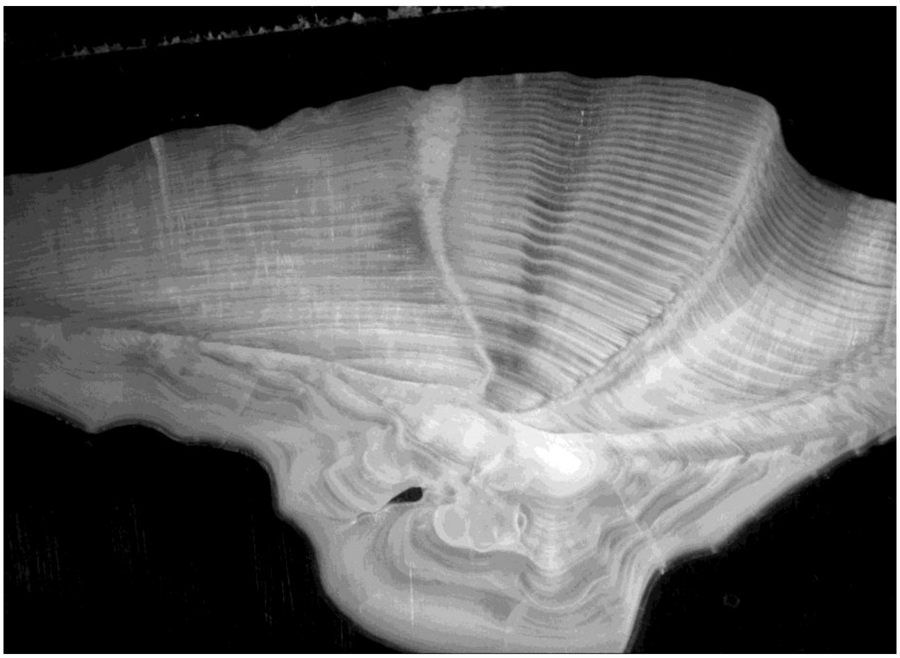

Figure 1.4 Longitudinal section of an otolith from a 25 year old Mulloway captured in the nearshore marine environment adjacent the Coorong in 2000/01, showing the alternating sequence of opaque and translucent zones that were interpreted in terms of age in years (source: G. Ferguson).

Table 1.2. A comparison of size-at-age of Mulloway from several populations in Australia and South Africa. The maximum age recorded for each population is also shown.

Source	Location	Sex	Estimates of size-at-age (mm TL)									Max. age
			1	2	3	4	5	10	15	20	25	
Ferguson et al. 2014	SA East	M	200	370	510	640	740	1080	1230	1300	1330	41[a]
		F	230	390	520	630	740	1080	1250	1340	1390	
Ferguson & Ward 2011	SA West	Both	260	450	610	750	860	1190	1330	1380	1410	20
Silberschneider et al. 2009	NSW	M	260	440	580	700	780	1010	1080	1100	1100	14
		F	280	440	580	700	800	1120	1260	1330	1360	24
Farmer et al. 2005	WA	M	330	510	660	770	860	1090	1160	1180	1190	29
		F	340	530	680	800	890	1140	1210	1230	1240	31
Griffiths & Hecht 1995	South Africa	M	360	500	650	780	890	1220	1330	1360	1370	42[a]
		F	360	510	660	800	910	1280	1410	1450	1470	

[a] unknown sex

Diet

The diet of Mulloway has been studied throughout its geographical range (Marais 1984; Hall 1986; Griffiths 1997a; Taylor et al. 2006; Geddes and Francis 2008). This species is regarded as a benthic carnivore that is capable of feeding throughout the water column (Kailola et al. 1993). The composition of the diet has been found to vary with body size and location. Juvenile Mulloway commonly consume small crustaceans, i.e. mysid shrimp, penaeid prawns and alpheid shrimp, and small-bodied fish (Marais 1984; Hall 1986). The importance of crustaceans in the diet appears to decrease with body size, as the main dietary items for adults are fish and squid; however crabs are important in some areas (Marais 1984; Griffiths 1997). Spatial differences in the diet are likely to relate to the variation in the availability of prey items (Griffiths 1997; Taylor et al. 2006). Conspecific predation has also been detected in several populations in South Africa (Griffiths 1997) and South Australia (Ferguson, unpublished data), with smaller Mulloway found in the stomachs of larger adult fish.

Information on diet for Mulloway in the Coorong estuary is limited. Larger individuals are known to consume mainly fish (i.e. Yelloweye Mullet, hardyheads, Congolli, gobies, Bony Bream and small Mulloway) and crabs (mainly *Paragrapsus gaimardii*), while smaller Mulloway consume polychaetes (mainly Nereididae), small crustaceans (i.e. amphipods, crabs, mysid shrimp) and small-bodied fish (Hall 1986; Geddes and Francis 2008; Ferguson unpublished data; Giatas unpublished data).

Stock structure

Attempts to understand population structure in Australia have included studies based on genetic techniques (Black and Dixon 1992; Archangi 2008; Farmer 2008; Barnes et al. 2014), otolith shape and elemental composition (Ferguson et al. 2011; Barnes et al. 2014), and tag-recapture programs (Thomson 1959; Hall 1984; Griffiths 1996; Griffiths and Attwood 2005). Whilst it has been suggested that a single panmictic population of Mulloway occurs in Australia (Archangi 2008), this has not been supported by other studies which suggest that sub-structuring between populations in New South Wales, South Australia and Western Australia is more likely (Farmer 2008; Silberschneider et al. 2008; Ferguson et al. 2011; Barnes et al. 2014).

Recent research investigating the stock structure of Mulloway across southern Australia and South Africa concluded that four distinct populations occur in Australia based on microsatellite data, with Australian populations differentiated from those in South Africa (Barnes et al. 2014). The Australian populations occurred along the west coast of Australia, far west coast of South Australia, the Coorong region in south-eastern South Australia and New South Wales. These results corroborate the findings of otolith-based studies, which also identified possible sub-structuring of the Mulloway population along the southern coast of Australia (Ferguson et al. 2011; Barnes et al. 2014). Overall, these studies suggest that two biological stocks occur in South Australia (i.e. an eastern stock and a western stock). The eastern stock occupies marine and estuarine waters of the State's south-east including the Coorong estuary and coastal waters along Younghusband Peninsula, while the western stock occurs on the State's far west coast and may have some association with populations in southern Western Australia (Barnes et al. 2014). While there is evidence that fish in the Gulf St. Vincent may form part of the eastern stock, further research is required to confirm biological stock delineation for Mulloway in eastern South Australia (Barnes et al. 2014).

2. COMMERCIAL FISHERY STATISTICS

2.1 Introduction

The assessment of South Australia's fishery for Mulloway relies heavily on fishery-dependent data provided by the LCF and MSF. This section of the report provides analyses of all commercial fishery-dependent data for Mulloway in South Australia from 1 July 1984 (1984/85) to 31 July 2014 (2013/14). 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 Mulloway against limit reference points prescribed in the Management Plan (Sloan 2005) is presented in Section 4, and the status of the MSF is considered in a recent stock status report (Fowler et al. 2013). The Discussion of this section provides a traditional weight-of-evidence assessment of the current status of the Mulloway 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 were presented at three spatial scales to provide an indication of their contribution to fishery production of Mulloway in South Australia. These spatial scales were: (1) the whole of South Australia; (2) areas exploited by the LCF (i.e. the Coorong estuary, and nearshore marine environment along Younghusband Peninsula); and (3) areas exploited by the MSF (i.e. all coastal waters of South Australia, excluding the areas of the LCF). 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. For some years, the presentation of data was limited by constraints of confidentiality (i.e. the data could only be presented for aggregated data from five or more fishers). For the LCF, targeted fishing effort and mean annual CPUE for the dominant gear types (i.e. large mesh gill nets and swinger nets) was also assessed. CPUE was estimated by dividing the annual catch by the annual effort in terms of fisher days and net days. For the MSF, targeted effort and CPUE for specific gear types were not presented due to the low number of licence holders reporting targeted catches in the past decade (see Fowler et al. 2013). The number of active LCF licence holders reporting catch of Mulloway was also shown to provide an indication of latent effort.

2.3 Results

Total annual State-wide catches

Total annual State-wide catches of Mulloway ranged from 26 t in 1987/88 to an historic peak of 145 t in 2000/01 (Figure 2.1). Annual catches decreased to 35 t in 2003/04 and remained low through the 2000s. In 2010/11, total catch declined to 22 t, which was the lowest on record. Annual catch then increased to 108 t in 2012/13, which is the third highest State-wide catch on record. In 2013/14, total catch declined to 69.1 t which is the second highest since 2001/02.

Since 1984/85, the LCF has been the main contributor to annual commercial catches of Mulloway in South Australia (Figure 2.1). From 1984/85 to 1993/94, the LCF landed between 53% and 86% of the State's annual catch, and from 1994/95 to 2001/02 its contribution increased to 96%. In 2013/14, catches from the LCF comprised 98% (68 t) of the total State-wide catch, while the remaining 2% (1.1 t) of the catch was taken by the MSF.

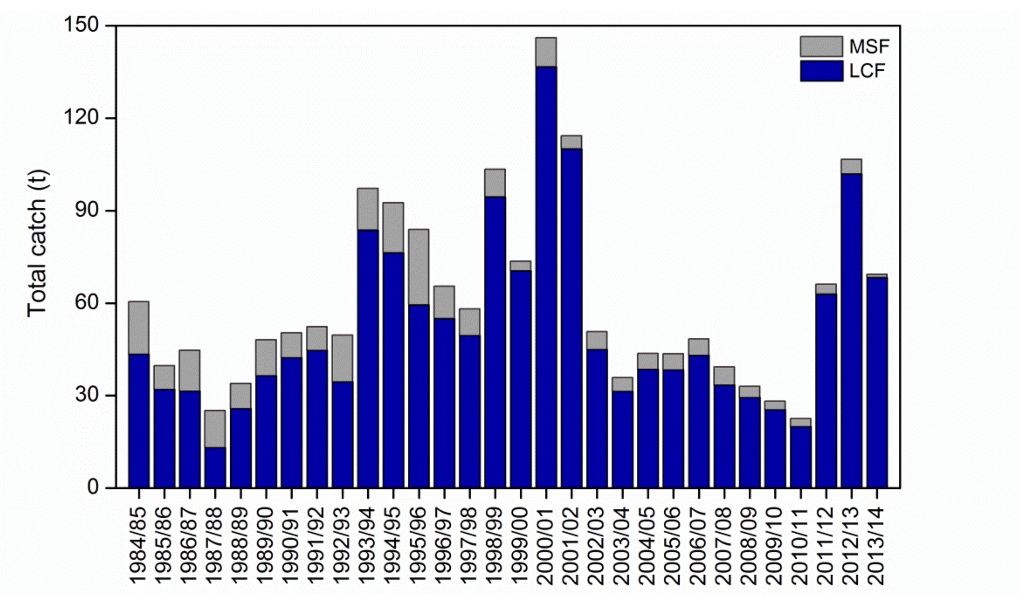

Figure 2.1. State-wide commercial catch of Mulloway from 1984/85 to 2013/14, by fishing sector.

Lakes and Coorong Fishery

Total annual catches

Annual catches from the LCF increased from 14 t in 1987/88 to an historic peak of 136 t in 2000/01 (Figure 2.2). After this, catches declined to 31 t in 2003/04 and remained consistently low and averaged 34 $t.yr^{-1}$ to 2009/10. In 2010/11, catch declined to 19.4 t and was among the lowest on record. From then, annual catches increased to 103 t in 2012/13 and declined to 68 t in 2013/14.

The dominant gear type used to catch Mulloway was the large mesh gill net (115-150 mm mesh) which contributed an average of 81% (landed weight, ±13% SD) of the annual catch from 1984/85 to 2012/13 (Figure 2.2). Most of the remaining catch in each year was taken using swinger nets (>150 mm mesh) with small contributions (approximately 1%) from small mesh gill nets (50 – 64 mm mesh). Other gear types used to capture Mulloway include handlines and haul nets. In 2013/14, catch from large mesh gill nets was 59.6 t which accounted for 87% of the total catch.

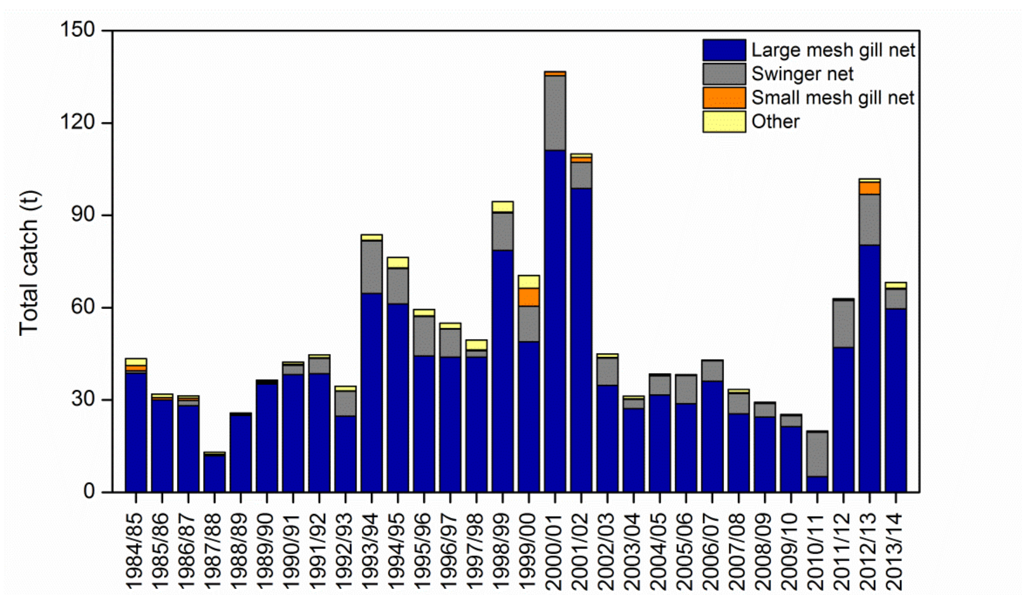

Figure 2.2. Annual catches of Mulloway from the LCF from 1984/85 to 2013/14, by gear type.

Intra-annual trends in total catch

Catches of Mulloway from the LCF from 1984/85 to 2013/14 were seasonal with on average, 68% of the annual catch taken from November to March (Figure 2.3). Catches were highest in December and January and lowest in August.

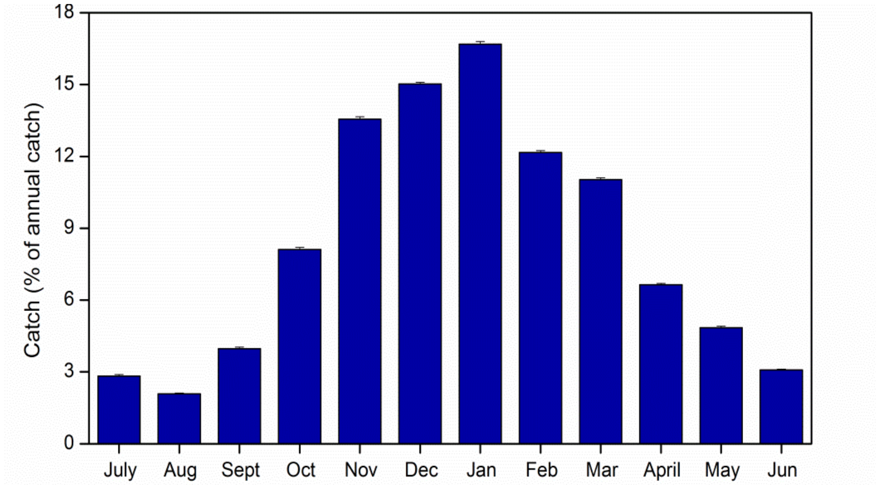

Figure 2.3. Average monthly catches (±SE) of Mulloway from the LCF from 1984/85 to 2013/14, expressed as a percentage of annual catch.

<u>Spatial distribution of catches</u>

Catch and effort data for Mulloway in the LCF is reported against commercial reporting areas across Lakes Alexandrina and Albert (Areas 4 and 5, respectively), the Coorong estuary (Areas 6-14) and adjacent nearshore marine environment (Areas 15-16) (Figure 1.1). For the Coorong estuary, area numbers increase from north to south, i.e. from Goolwa (Area 6) to Salt Creek (Area 14). Catches from individual areas were pooled because catches from some areas in some years were taken by less than five licence holders (Figure 2.4).

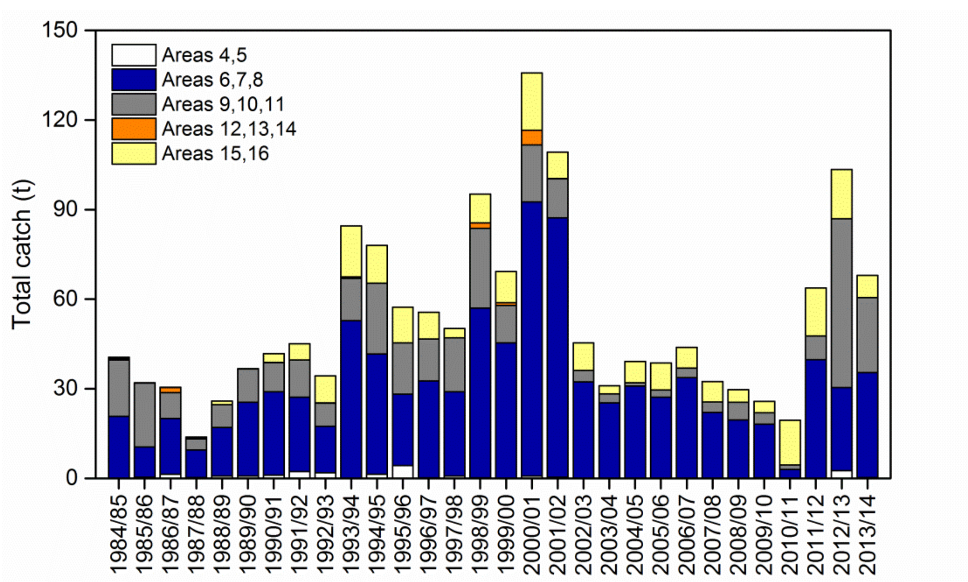

Figure 2.4. Annual catches of Mulloway from commercial reporting areas 4 and 5 (Lakes Alexandrina and Albert, respectively), 6–11 (Coorong estuary), and 15 and 16 (nearshore marine environment) of the LCF from 1984/85 to 2013/14.

From 1984/85 to 1989/90, almost all of the catches of Mulloway were from the Coorong estuary (Figure 2.4). From then, the contribution of annual catches taken from the nearshore marine environment increased to 26% in 1992/93. From 1993/94 to 2012/13, catches was more evenly distributed among these broad areas with 61% taken in Areas 6-8 (i.e. the area of the Coorong estuary between the Goolwa Barrage and Mark Point),19% from Areas 9-11 (i.e. the area of the Coorong estuary between the Mark Point and Parnka Point) and 18% from the marine environment. In 2013/14, 50% of the catch was taken from Areas 6-8, while 37% of the catch was taken from Areas 9-11 (Figure 1.1).

Targeted catch, effort and CPUE – Large-mesh gill nets

Inter-annual trends in targeted catch (i.e. catches from fishing operations that specifically targeted Mulloway) from LMGN (Figure 2.5A) generally followed those of total catch (Figure 2.2). From 1984/85 to 2013/14, the contribution of targeted catch from LMGN to the total catch ranged from 29% to 80% (mean 61% ±15.4). One exception was in 2010/11 when targeted catch from LMGN accounted for just 11% of the total catch. In 2013/14, the targeted catch from LMGN was 46.8 t, which accounted for 69% of the total catch for the LCF.

Annual targeted effort (LMGN, fisher days) increased from 539 fisher days in 1987/88 to an historic peak of 1,977 fisher days in 2000/01 (Figure 2.5B). Effort then steadily declined to an historic low of 107 fisher days in 2010/11, before increasing to 1,057 fisher days in 2012/13. In 2013/14, targeted effort declined to 885 fisher days. The trend in annual targeted effort in net days was similar to targeted effort in fisher days, i.e. it was highest in the late 1990s and early 2000s, and from then decreased until 2010/11 (Figure 2.5B). Annual effort in net days was linearly related to effort in fisher days (linear regression, LR: $r^2 = 0.83$, $F_{1,29} = 140.8$, $p < 0.001$).

Mean annual $CPUE_{LMGN}$ (kg.fisher day^{-1}) was relatively low from 1984/85 to 1989/90, and ranged from 7.4 to 22.9 kg.fisher day^{-1} (Figure 2.5C). $CPUE_{LMGN}$ then increased to a peak of 54 kg.fisher day^{-1} in 1993/94, remained relatively stable until 2010/11, before increasing to an historic high of 87.4 kg.fisher day^{-1} in 2011/12. From then $CPUE_{LMGN}$ declined and in 2013/14 was 52.9 kg.fisher day^{-1}, which is among the highest on record. Inter-annual patterns in $CPUE_{LMGN}$ (kg.net day^{-1}) were similar to that of $CPUE_{LMGN}$ (kg.fisher day^{1}) over the 30-year period since 1984/85 and the two measures of relative abundance were linearly related (LR: $r^2 = 0.87$, $F_{1,29} = 186.6$, $p < 0.001$).

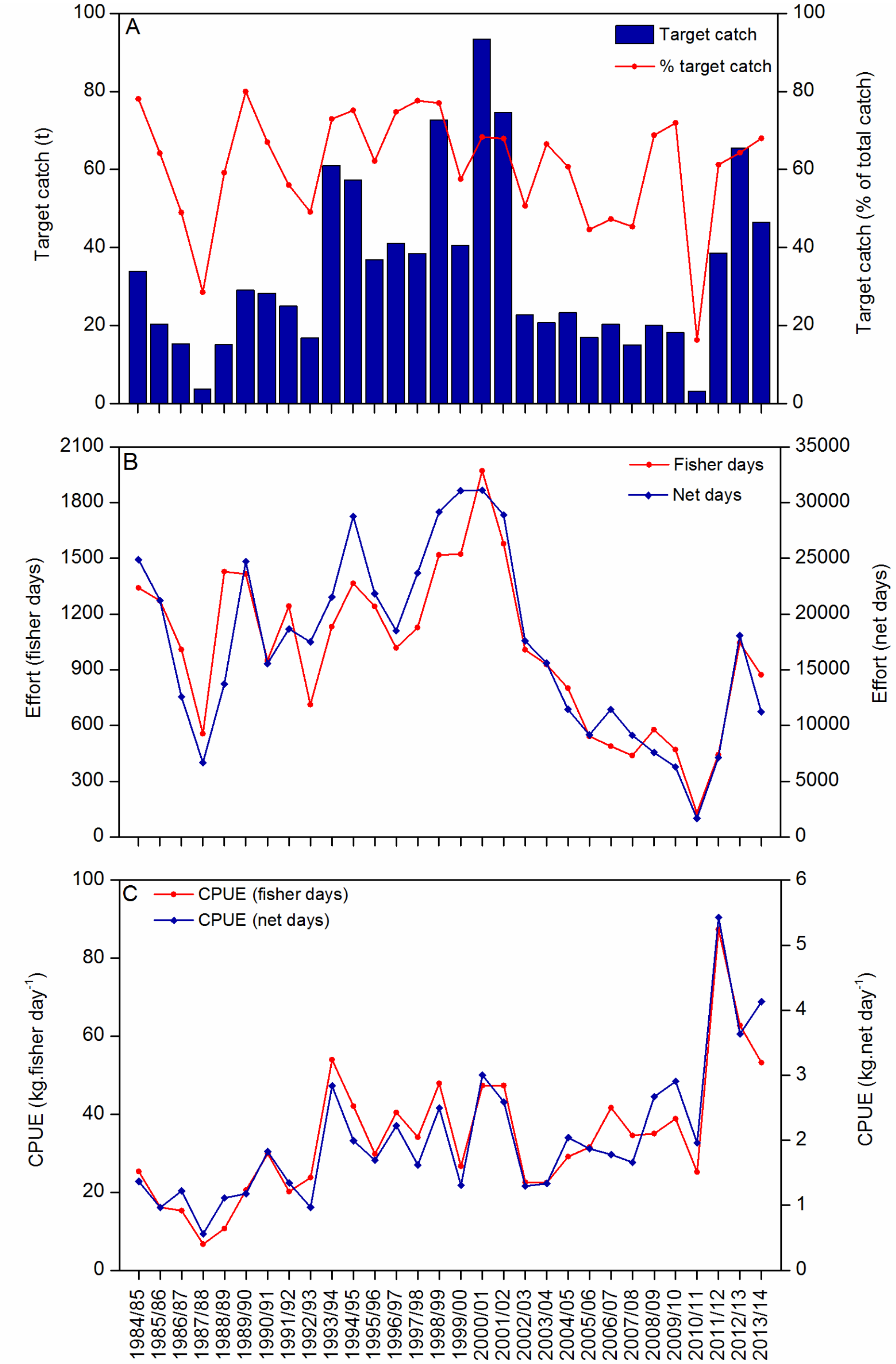

Figure 2.5. Annual targeted catch and effort for large-mesh gill nets for the LCF. (A) Targeted catch is shown in t, and as a percentage of total catch for the LCF; (B) Comparison of two measures of targeted effort for large-mesh gill nets, i.e. fisher days, net days; (C) Comparison of two measures of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

Targeted catch, effort and CPUE – Swinger nets

From 1984/85 to 1989/90, annual catches of Mulloway from swinger nets (SN) were negligible and did not exceed 1.7 t (Figure 2.6A). From that time, catches fluctuated periodically until 2009/10, but were generally higher and ranged from 2.1 t in 1997/98 to 23.8 t in 2000/01. The high catches reported in some years through this period were typically followed by gradual decline in subsequent years. From 2010/11 to 2012/13, annual catches from SNs were relatively high and ranged between 14.4 t and 15.2 t. In 2013/14, the targeted catch declined to 5.5 t, which accounted for 8% of the total catch for the LCF. Overall, since 1984/85, targeted catches from SNs accounted for, on average, approximately 13.7% of the total annual catch of Mulloway for the LCF (Figure 2.6A).

The trend in annual targeted effort for SN (fisher days) was generally similar to that for targeted catch with peaks in 1993/94 (384 fisher days), 2000/01 (522 fisher days) and 2010/11 (336 fisher days) (Figure 2.6B). The trend in annual targeted effort in net days was similar to that for fisher days with both measures of effort linearly related (LR: $r^2 = 0.98$, $F_{1,29} = 1305.04$, $p < 0.001$).

CPUE (kg.fisher day^{-1}) for SN increased from 7.8 kg.fisher day^{-1} in 1987/88 to an historic high of 72.4 kg.fisher day^{-1} in 1998/99 (Figure 2.6C). CPUE then declined to 21.7 kg.fisher day^{-1} in 2003/04 before increasing to 65.3 kg.fisher day^{-1} in 2006/07. In 2013/14, CPUE for SN was 44 kg.fisher day^{-1}.

Number of licences reporting catches

The number of LCF licence holders that reported landing Mulloway from the Coorong estuary was highest in 1984/85 (a total of 36 licences). From then, the number progressively declined to an historic low of 17 licences in 2008/09, i.e. during the recent drought period (Figure 2.7). In 2012/13 and 2013/14, a total of 26 and 23 licence holders landed Mulloway from the estuary, respectively.

For the nearshore marine environment adjacent the Coorong, the number of licences that reported landing Mulloway increased from 1 during the late 1980s to 13 in 1993/94 (Figure 2.7). Since then, between 6 and 13 licence holders reported catches of Mulloway from the ocean beach in each year, including 10 fishers in 2013/14.

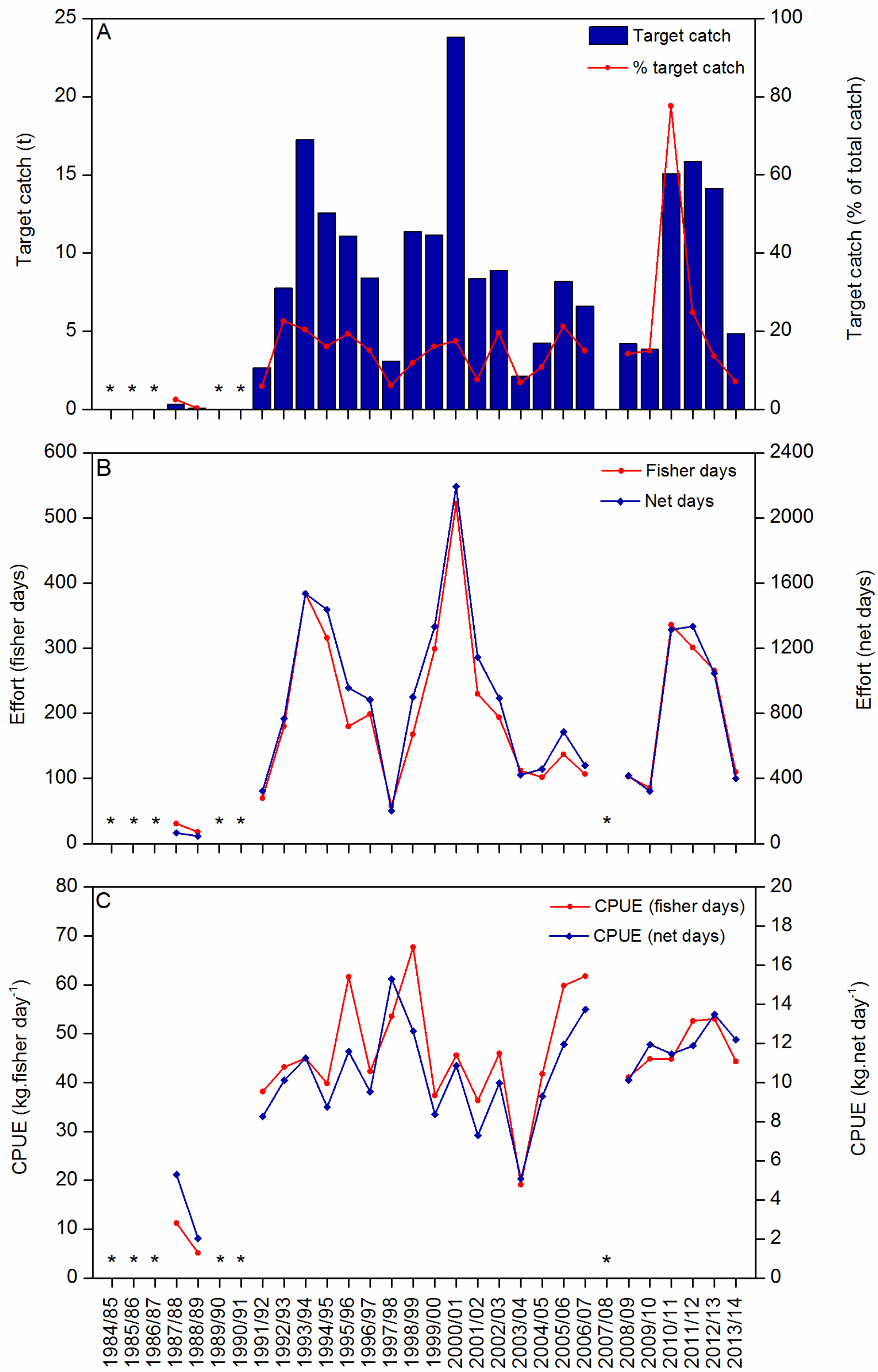

Figure 2.6. Annual targeted catch and effort for swinger nets for the LCF. (A) Targeted catch is shown in t, and as a percentage of total catch for the LCF; (B) Comparison of two measures of targeted effort for swinger nets, i.e. fisher days, net days; (C) Comparison of two measures of CPUE$_{SN}$ based on the two measures of targeted effort. (*) represents confidential data.

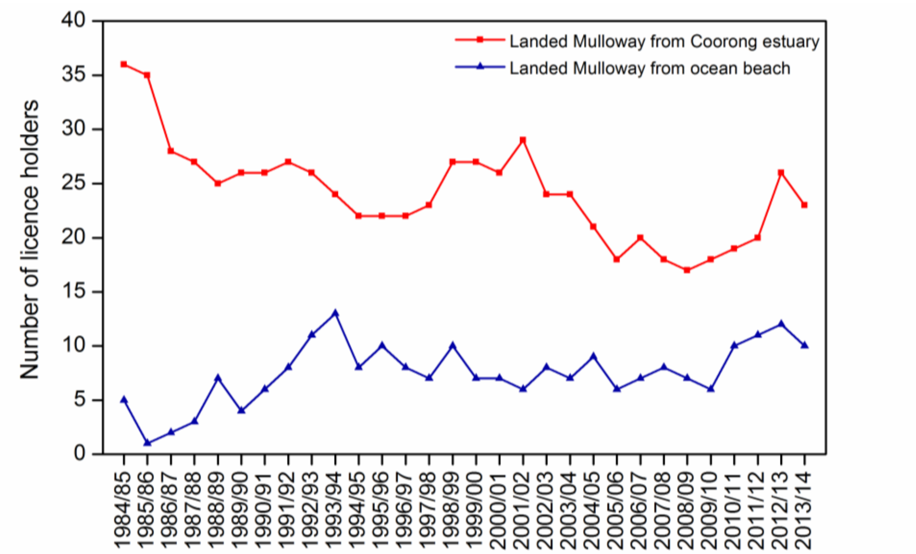

Figure 2.7. The annual number of LCF commercial licences against which catches of Mulloway were reported during from 1984/85 to 2013/14 from the Coorong estuary and nearshore marine environment.

Marine Scalefish Fishery

<u>Total annual catches</u>

In 1984/85, the total catch from the MSF was 17 t, which then decreased and ranged between 7 t and 13 t until 1991/92 (Figure 2.8). From 1992/93, catches increased to an historic peak of 24 t in 1995/96 and then declined to 3 t in 1999/00. From 2001/02 to 2012/13, catches were low and ranged from 3 to 6 t.yr^{-1}. In 2013/14, catch decreased to 1.1 t and was the lowest on record.

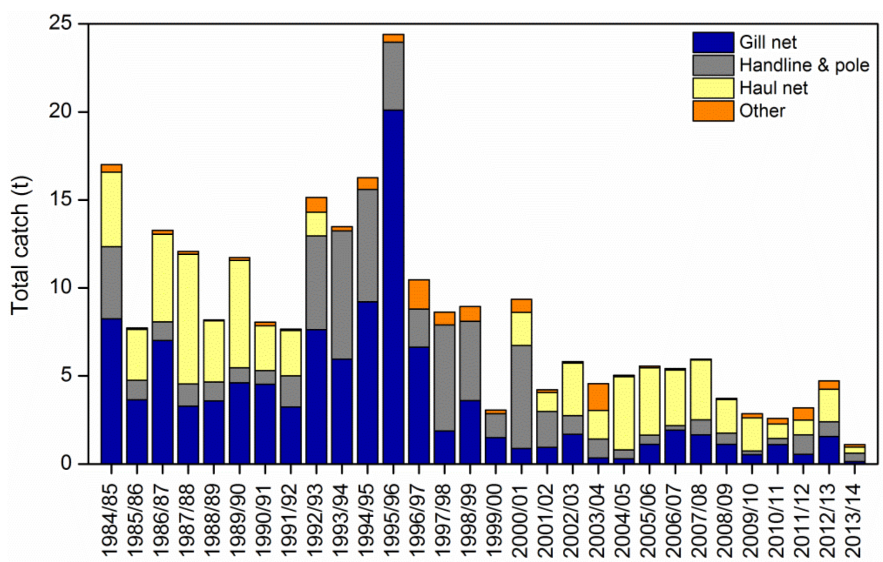

Figure 2.8. Annual catches of Mulloway from the MSF from 1984/85 to 2013/14, subdivided by gear type. Annual haul net catch data from 1993/94 to 1999/00 are not presented, as they are confidential, i.e. they were reported by less than five licence holders.

The main gears used in the MSF to catch Mulloway were gill nets (>150 mm mesh and 50 mm mesh), handlines and fishing poles, and haul nets (Figure 2.8). From 1984/85 to 1996/97, catches from gill nets and haul nets contributed most to the annual total catch. From 1992/93 to 2003/04, contributions of catches from handlines and fishing poles to the total annual catch increased and ranged between 16% and 70%. Since that period, annual catches comprised mostly catches from haul nets. In 2013/14, catches from handlines and fishing poles, and haul nets accounted for 44% and 33% of the total catch from the MSF, respectively.

Intra-annual patterns in catch

Catches of Mulloway by the MSF were seasonal which is similar to LCF. For the period 1984/85 to 2013/14, higher monthly catches were taken in summer (Figure 2.9). On average, 42% of the annual catch was taken from November to February. Catches were highest in December/January and lowest in September.

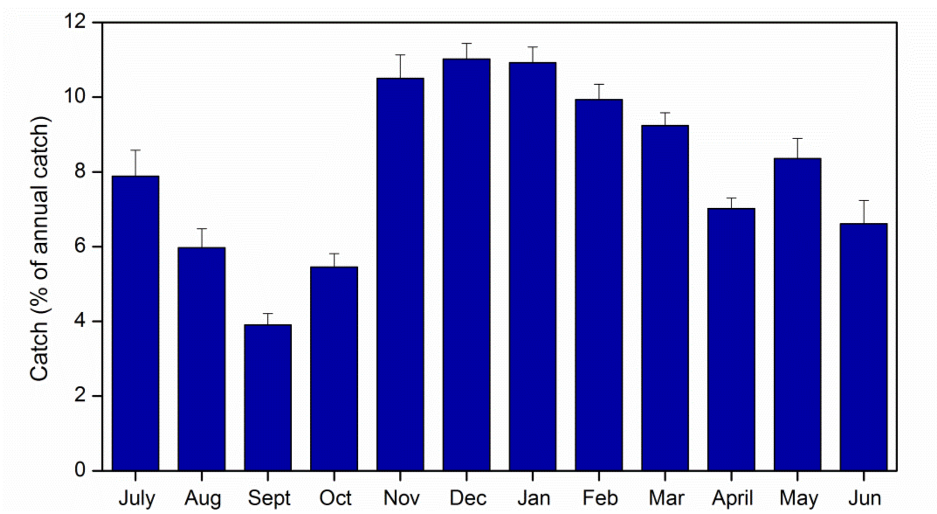

Figure 2.9. Average monthly catches (±SE) of Mulloway from the MSF from 1984/85 to 2013/14, expressed as a percentage of annual catch.

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) Eastern (blocks 34-36, 40-46, 48-51, 53, 55-58); and (ii) Western (blocks 5, 7-11, 15-17, 19-33, 38, 39).

From 1984/85, total annual catches of Mulloway 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 2.10). Over this period, contributions to total annual catches from the Eastern region increased to a peak of 23 t in 1995/96 and then declined to <4 t.yr^{-1} from 2001/02 to 2013/14, while contributions from the Western region declined from a peak of 8 t in 1984/85 to <1 t in several years including 2013/14.

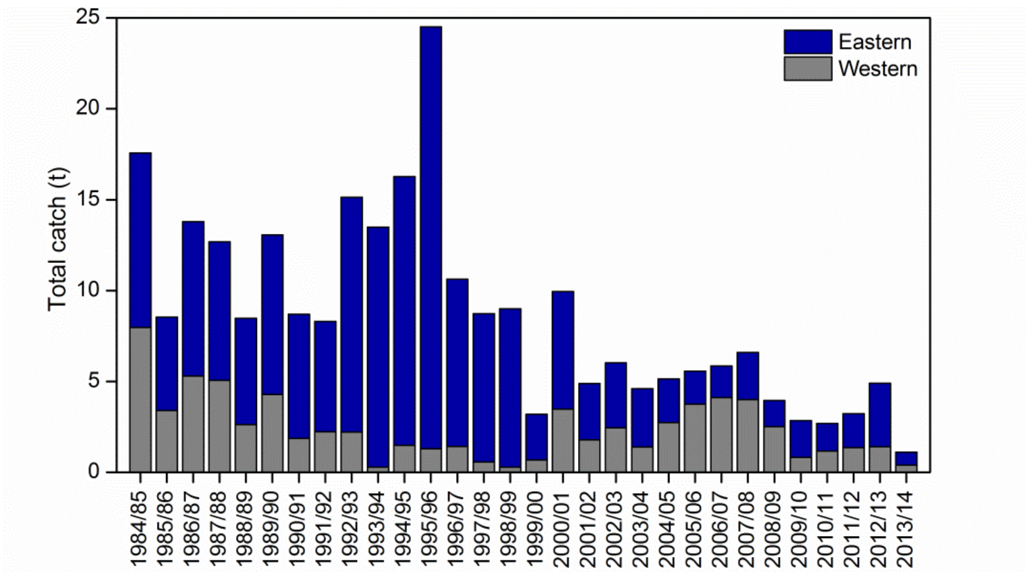

Figure 2.10. Annual catches of Mulloway from the MSF from 1984/85 to 2013/14 by region.

<u>Targeted catch, effort and CPUE</u>

Targeted catch and effort data for each of the dominant gear types used to target Mulloway by the MSF in 2013/14, i.e. gill nets, handlines/poles and haul nets, were confidential for most years because they were reported by less than five fishers. The inter-annual trend in targeted catch for the MSF, from all gear types combined, was similar to that of total catch (Figure 2.11A and Figure 2.8). Targeted catch increased to an historic peak of 9.6 t in 1993/94. From then, it declined and averaged <1 t.yr^{-1} between 2002/03 and 2012/13. In 2013/14 targeted catch was 0.5 t, which is the sixth lowest on record.

The temporal pattern in annual targeted effort (all gears combined) for Mulloway was generally similar to that for targeted catch, i.e. a peak of 565 days in 1993/94, then a decline to 8 days in 2006/07 (Figure 2.11A). In 2013/14, effort targeting Mulloway was 28 fisher days, which is among the lowest on record.

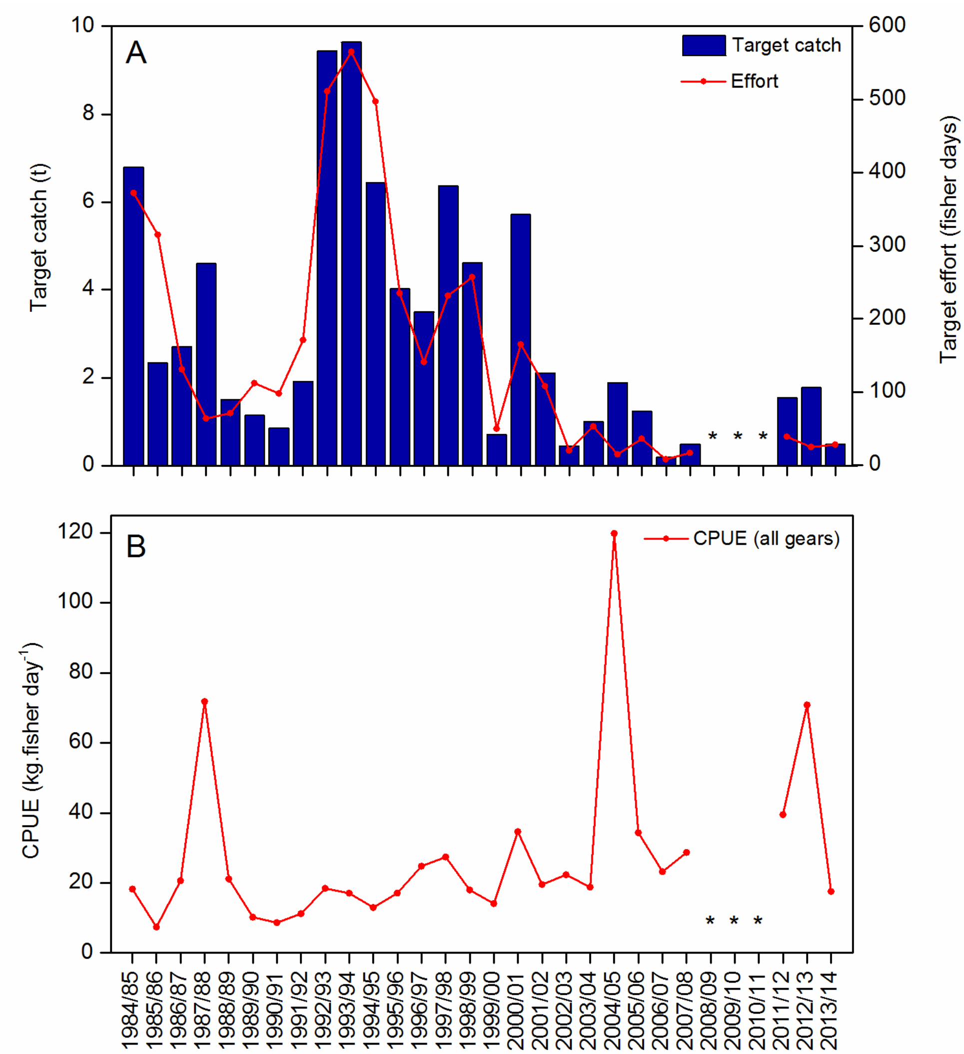

Figure 2.10. Annual targeted catch and effort, combined across all gear types for the MSF. (A) Targeted catch is shown in t, and targeted effort in fisher days; (B) CPUE is based on targeted effort in fisher days and catch in kg. (*) represents confidential data reported by less than five licence holders.

Through the 1990s and early 2000s, CPUE (for all gear types) followed a gradual increasing trend and averaged approximately 19 kg.fisher day^{-1} (Figure 2.11B). CPUE increased sharply to an historic peak of 119 kg.fisher day^{-1}, and then declined and remained highly variable through to 2013/14. For the past three years, mean annual CPUE was 42 kg.fisher day^{-1}, which is 24% higher than the long term (30 year) average for the MSF. However, there is uncertainty around the usefulness of CPUE estimates for the past decade due to the low number of fisher days where Mulloway were the primary target species.

Number of licences reporting catches

Since 1984/85, the annual number of active MSF licence holders reporting catch of Mulloway has steadily declined from a peak of 57 in 1984/85 to an historic low of 14 in 2013/14 (Figure 2.12). On average, approximately 66% of the total number of licences that reported catches of Mulloway in each year did so during fishing operations that were actively targeting other species.

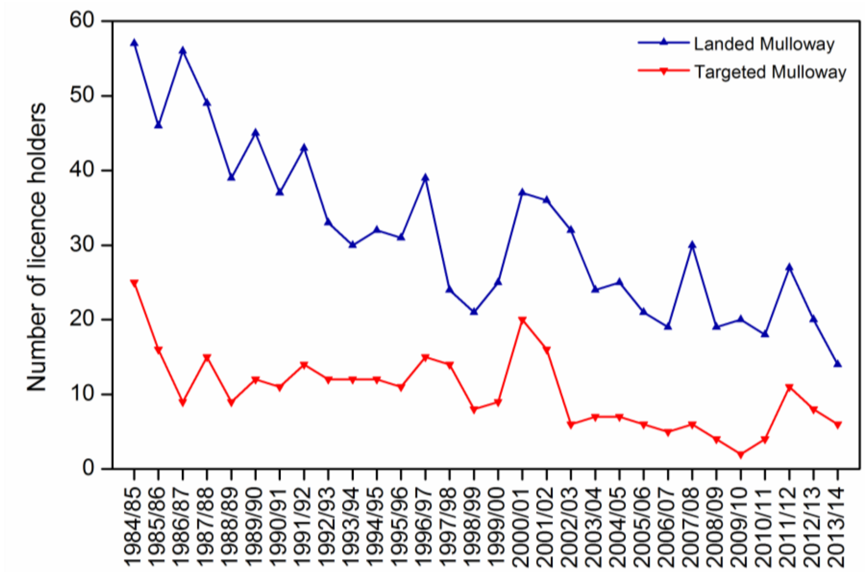

Figure 2.11 The number of MSF commercial licences against which catches of Mulloway and targeted effort for Mulloway were reported from 1984/85 to 2013/14.

2.4 Discussion

In 2013/14, total commercial catch of Mulloway in South Australia was 69.4 t which is the second highest annual catch since 2001/02. This was 37 t lower than the previous year, representing an annual decrease of 35%. This decline related to a 38% decrease in targeted effort (LMGN: net days) for Mulloway by the LCF. Nonetheless, the relatively high State-wide catch (approximately 15% higher than the long term, 30 year, average was the culmination of different trends in the LCF and MSF.

Historically the LCF has been the most significant fishery for Mulloway in South Australia. Over the 14 years to 1997/98 it contributed, on average, 77% of the State's annual catch, with most of the remaining annual catch taken by the MSF. Since 1997/98, contributions from the LCF have increased and from 2011/12 to 2013/14 exceeded 95%. This increase was due mostly to an increase in catch by the LCF. However, recent catches by the MSF are among the lowest on record. The recent increase in catch by the LCF, i.e. since 2011/12, corresponded to the diversion of targeted fishing effort away from other finfish species (i.e. Golden Perch, Redfin Perch, and to a lesser extent Greenback Flounder in 2012/13) toward Mulloway following the recommencement of freshwater inflows to the Coorong estuary in late 2010. Historically high catch rates for Mulloway by the LCF during this period suggest an increased relative abundance. Whilst this is likely, there is uncertainty around the usefulness of CPUE as an indicator of relative abundance in the Coorong estuary because environmentally-mediated changes in the amount of available habitat for Mulloway may affect their catchability and potentially confound interpretation of CPUE as an indicator of population abundance.

In 2013/14, total annual catch of 68.3 t was reported for the LCF. This was 33.6 t less than the previous year. This decrease resulted from a 38% and 59% reduction in fishing effort for LMGN and SN, respectively, and 18% decrease in CPUE for LMGN. The number of LCF licence holders reporting catches of Mulloway in 2013/14 also declined by 14% from the previous year. This reduction in targeted effort for Mulloway corresponded to a decrease in freshwater flow to the system and a subsequent increase in targeted effort for some other finfish species in the Coorong (Earl and Ward, 2014). As such, the decline in effort does not appear to have related to declining population biomass as catch rates were among the highest on record.

Total annual catch for the MSF was 1.1 t in 2013/14, which was the lowest recorded in the fishery. This estimate was 77% lower than the previous year and 96% less than the historic peak in catch of 24.4 t reported in 1995/96. The long term decline in catch for the MSF, likely relates to the long-term reduction in targeted fishing effort, rather than a decline in fishable biomass, as catch rates have followed an increasing trend over the same period. Similarly, the number of MSF licence holders reporting catches of Mulloway has declined by 75% since the mid-1980s. The long term decline in targeted effort likely relates to the relatively low market value of Mulloway taken by the MSF compared other species targeted by the fishery.

In summary, analyses of fishery-dependent catch and effort data for the LCF and MSF provided robust evidence that the Mulloway stock in eastern South Australia was in a strong position at the conclusion of 2013/14.

3. POPULATION SIZE AND AGE STRUCTURE

3.1 Introduction

Effective management of a fishery requires some understanding of the processes that influence the structure and size of the exploited population. As well as helping to understand the dynamics of the population, this may also help to determine the response of the population to fishing and/or changes in the environment. Knowledge of the demographic processes of a fish population is facilitated by obtaining estimates of length and age frequencies that provide information on growth, recruitment, and mortality. 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 incremental structure 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).

For Mulloway in South Australia, growth zones in their otoliths are formed annually and an indicator of age for individual fish (Ferguson et al. 2014). In this study, commercial and recreational catches of Mulloway taken in the Coorong estuary and adjacent marine environment were sub-sampled to develop population size and age structures. Such size and age structures have been developed for a number of years since 2000/01 and provide important information to help determine the stock status (Ferguson and Ward 2011; Ferguson et al. 2014). The specific objective of this section was to describe the population characteristics of the Mulloway exploited by the LCF in terms of annual size and age structures, and determine how these structures compare among years from 2001/02 to 2014/15.

3.2 Methods

Sample collection

Mulloway were collected for 2000/01, 2001/02, 2009/10, 2010/11, 2011/12, 2013/14 and 2014/15, from several sources. Samples were available from commercial catches taken using: (1) large-mesh gill nets (mesh size >115 mm) in the Coorong estuary; (2) swinger nets (mesh size >120 mm) in the nearshore marine environment adjacent the Coorong along Younghusband Peninsula; and (3) rod and line in the surf zone near the Murray Mouth. Catches were accessed at several locations, including the SAFCOL fish market, the fish processing facilities of individual LCF licence holders, and the point of landing. No samples were available from catches taken in the Coorong estuary from 2009/10, 2010/11, 2011/12 and 2014/15.

Additional samples were available from recreational catches taken in the nearshore marine environment adjacent the Coorong along Younghusband Peninsula using rod and line in 2000/01, 2009/10, 2010/11, 2013/14 and 2014/15. Samples were also available from multi-panel gill net (mesh size ranges from 38 – 150 mm) catches from research sampling undertaken in the Coorong in 2013/14, which provided a wider size/age range of fish (Ye et al. 2014).

On each sampling occasion, a two-stage sampling protocol was used to process available catches. First, as many fish as possible from catches were measured for total length (TL) to the nearest mm. Some fish were then processed for the collection of their sagittae, i.e. the largest pair of otoliths (Figure 1.4A), for determination of fish age. The latter fish were measured for TL and their sagittae (hereafter referred to as otoliths) removed via an incision through the ventral ex-occipital region of the skull. Otoliths were cleaned, dried and stored in labelled plastic bags for processing in the laboratory at a later date. As most fish had been gutted by fishers prior to processing, additional biological information, including total weight, sex and reproductive development was not available for most fish.

Ages of several Mulloway from recreational catches taken in the nearshore marine environment adjacent the Coorong along Younghusband Peninsula in 2014/15, were estimated from otolith weights using a linear regression: age = 4.027*(otolith weight) + 0.174 (r^2=0.96; $F_{1,691}$ = 8636.9, P < 0.001) (Ferguson and Ward, 2011).

Laboratory processing of otoliths

In the laboratory, the left otolith from each individual was embedded in polyester resin and a longitudinal section (approximately 500 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 their internal structure, smeared with immersion oil, and examined under reflected light using a dissecting microscope at x5 magnification. The age for individual fish was estimated from counts of opaque zones (Figure 1.4), which for Mulloway populations in South Australia form annually along the ventral axis from the core to the proximal surface of the otolith (Ferguson et al. 2014).

The number of opaque zones within the sectioned otolith, characteristics of the edge of the otolith, date of capture and universal birthdate (1 January) were recorded and used to estimate the age of each fish in years. The universal birthdate of 1 January was estimated from the mid-point of the spawning season (Ferguson et al. 2014).

From 2000/01 to 2011/12, the relative precision of age estimates between multiple readings by two readers was calculated using an index of the average percentage error (APE) for a subset of otoliths. All otoliths were read twice by Dr Greg Ferguson (SARDI) and when counts did not agree, they were re-read by a second reader. If the third reading did not agree with the result from the earlier two readings, the sample was removed from the analysis. In order to ensure that otoliths for 2013/14 and 2014/15 were interpreted consistently between sampling occasions, between readers and between years, otoliths were read by the primary author (J. Earl) who was regularly tested against a random selection of otoliths from a reference collection. The reference collection comprised sections of known-age Mulloway otoliths collected across all sampling years from south-eastern South Australia from 2000/01 to 2011/12.

For each financial year, separate length and age frequency distributions were generated for the nearshore marine environment adjacent the Coorong along Younghusband Peninsula, and the Coorong estuary. Statistical comparison of age structures between years for the estuarine and marine environments was not done due to the small sample sizes in most years.

3.3 Results

Coorong estuary

<u>Age structures</u>

In 2000/01 and 2001/02, age structures from commercial catches taken in the Coorong estuary comprised five young age classes and were dominated by 3 and 4 year old fish (Figure 3.1). Small numbers of 2, 5 and 6 year old fish were also collected in those years. In 2013/14, ages ranged from 2 to 8 years, with 69% of individuals 3 years of age (i.e. 2010/11 year class).

The age structure for fishery-independent samples collected in 2013/14 was dominated by 1 and 2 year old fish (i.e. 2012/13 and 2011/12 year classes, respectively), and included a small number of 3 year old fish (Figure 3.2).

Size structures

The size structures for Mulloway from catches taken in the estuary were similar among years, i.e. they ranged from the LMS of 460 mm TL to 950 mm TL, and were dominated by fish between 500 and 600 mm TL (Figure 3.1). For the fishery-independent samples from 2013/14, sizes ranged from 166 to 538 mm TL, with fish around 300 mm TL dominating the distribution (Figure 3.2).

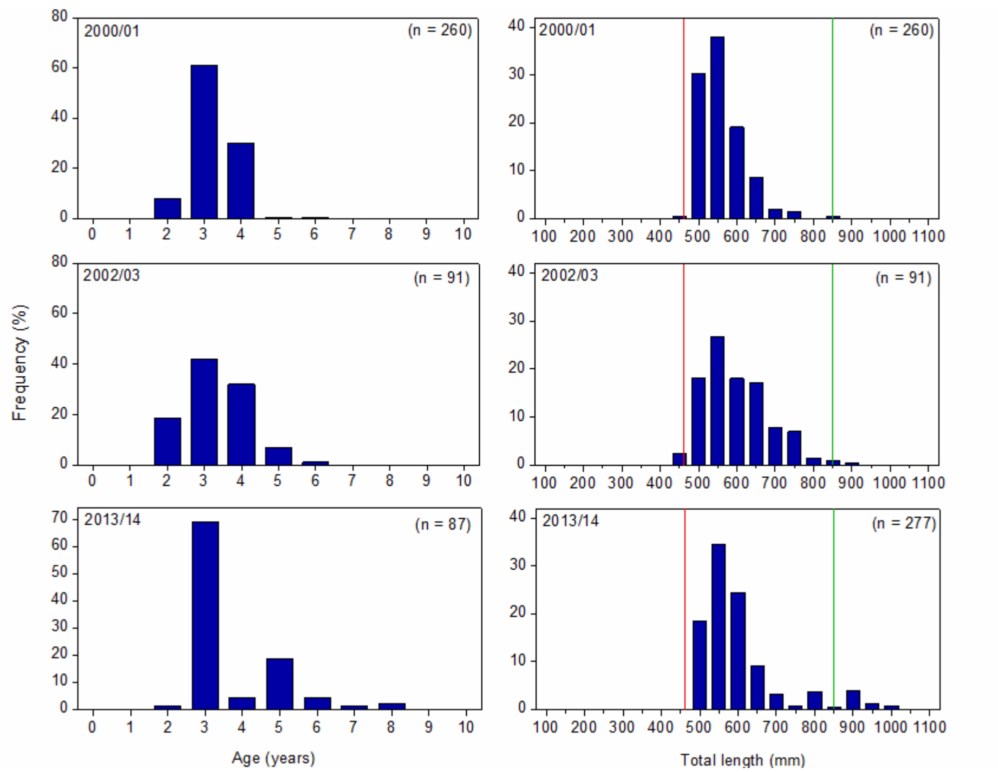

Figure 3.1. Age (left) and size (right) structures for Mulloway from within the Coorong estuary. Age/size structures are for catches taken by commercial LCF fishers using large-mesh gill nets in 2000/01, 2002/03 and 2013/14. Vertical green line indicates size-at-maturity for female Mulloway in eastern South Australia (Ferguson et al. 2014). Vertical red line indicates LMS of 460 mm TL for Mulloway taken within the Coorong estuary.

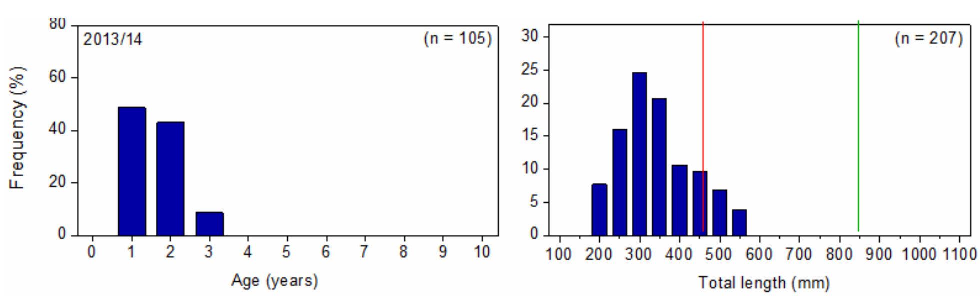

Figure 3.2. Age (left) and size (right) structures for Mulloway from the Coorong estuary. Age/size structures are for catches from fishery-independent research sampling using multi-panel gill nets in 2013/14 (Ye et al. 2014). Vertical green line indicates size-at-maturity for female Mulloway in eastern South Australia (Ferguson et al. 2014). Vertical red line indicates LMS of 460 mm TL for Mulloway taken within the Coorong estuary.

Nearshore marine environment

Age structures

For age structures from the nearshore marine environment adjacent the Coorong in 2000/01, recreational and commercial catches had a similar distribution (Figure 3.3). Ages ranged from 4 to 25 years, with 8 year olds (1992/93 year class) dominating the distribution. Secondary modes occurred at 11 and 6 years. For the commercial sample from 2001/02, ages ranged from 5 to 24 years and the 1992/93 year class persisted as 9 year olds.

In 2009/10, the age structure comprised a similar broad distribution of ages, i.e. from 3 to 25 years, with most individuals aged between 6 and 15 years (Figure 3.3). In 2010/11, approximately 75% of both commercial and recreational catches comprised fish ≤7 years of age and the oldest fish was 15 years old.

In 2011/12, the age distribution from commercial catches was narrower than those for previous years (Figure 3.3). It comprised eight, relatively young age classes and was dominated by 6 year old and 7 year old fish. In 2013/14, the ages of Mulloway sampled from commercial and recreational catches were narrowly distributed around a mode comprising mostly 5 year old, 6 year old and 7 year old fish with no fish >9 years of age present. In 2014/15, the age distribution from recreational catches ranged from 4 to 18 years, with 67% of fish between 7 and 10 years (Figure 3.3). Commercial catches from 2014/15 comprised fish between 5 and 11 years, with 86% of individuals aged between 6 and 9 years. The age structures for 2013/14 and 2014/15 should be interpreted with caution due to the small number of samples and small sample sizes available from the commercial and recreational fishery.

Size structures

The size structure for Mulloway from the marine environment from 2000/01, ranged from 650 mm TL to 1400 mm TL, with modal sizes of 1100 mm TL and 1150 mm TL for commercial net and recreational line catches, respectively (Figure 3.3). The size structure from 2001/02 ranged from 800 mm TL to 1350 mm TL with a dominant mode at 1000 mm TL and a secondary mode at 900 mm TL. For 2011/12 and 2013/14, the lengths of fish sampled were narrowly distributed around a dominant mode of 850 mm TL and 1000 mm TL, respectively, while fish >1050 mm TL were rare. The size distribution for Mulloway for 2014/15 was broader than those for 2011/12 and 2013/14. It comprised fish that ranged from 845 mm TL to 1423 mm TL, with modal sizes of 1000 mm TL and 1100 mm TL for commercial and recreational catches, respectively.

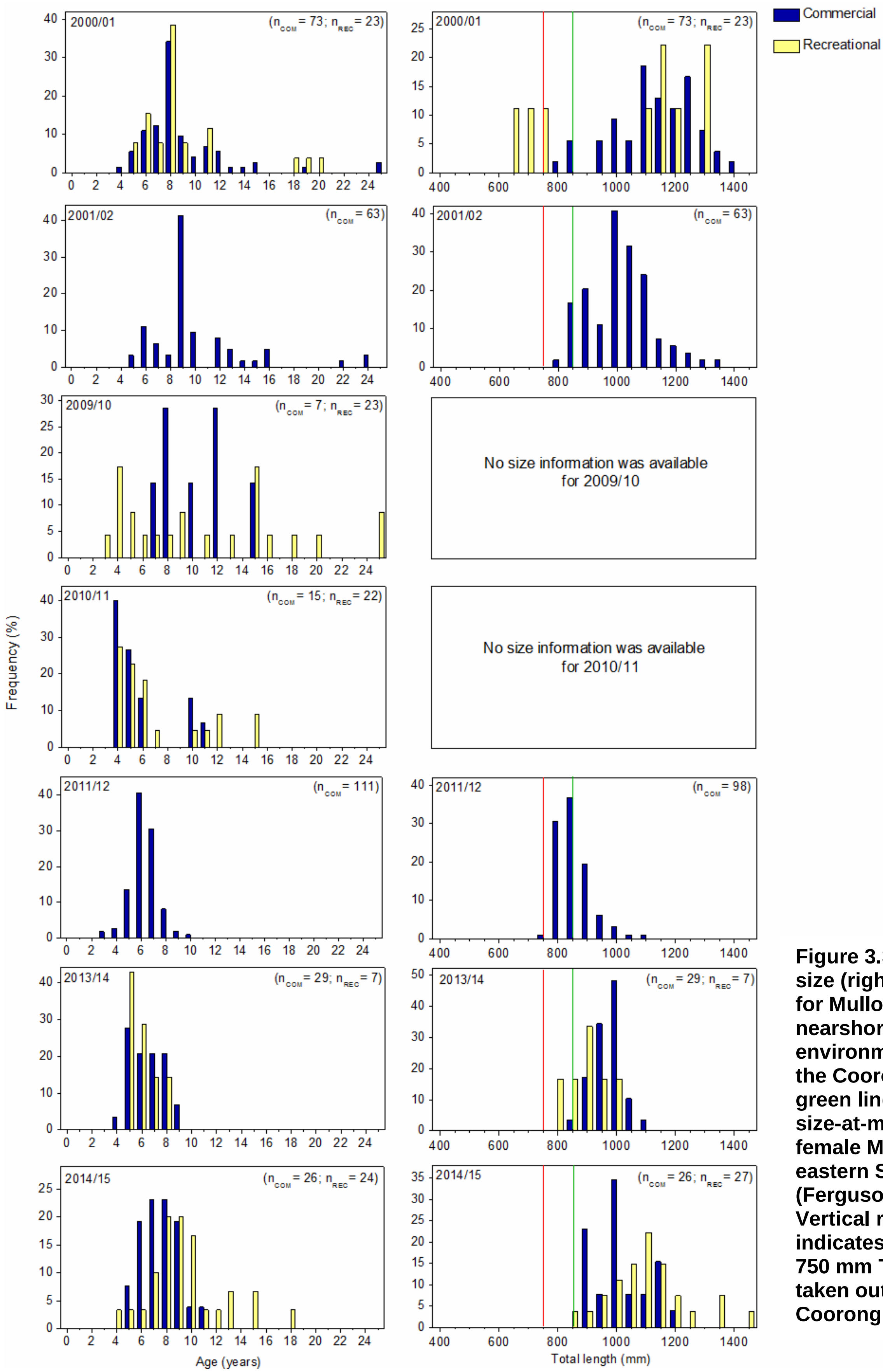

Figure 3.3. Age (left) and size (right) structures for Mulloway from the nearshore marine environment adjacent the Coorong. Vertical green line indicates size-at-maturity for female Mulloway in eastern South Australia (Ferguson et al. 2014). Vertical red line indicates LMS of 750 mm TL for Mulloway taken outside the Coorong estuary.

3.4 Discussion

The size and age characteristics of the Mulloway population in eastern South Australia were examined to inform about population structure and demographic processes likely to account for the observed inter-annual variation in fishery performance. Clear spatial differences were evident for age and size structures between the Coorong estuary and nearshore marine environment adjacent the Coorong. In 2013/14, the Mulloway population in the Coorong estuary comprised mostly individuals <3 years old, while fish >5 years were rare. In contrast, Mulloway from the nearshore marine environment were generally larger and older, with fish up to 18 years old in the age structure for 2014/15. The maximum age in the age structures for the marine environment for 2014/15 was significantly less than the reported maximum age of 41 years for Mulloway in South Australia, but well above the age at maturity (5-6 years) for the species in South Australia (Ferguson et al. 2014).

Coorong estuary

Annual age structures for Mulloway harvested in the Coorong estuary have remained relatively similar since at least the mid-1980s (i.e. dominated by 3 and 4 year old fish) and are consistent with those for Mulloway in other estuaries around Australia (Hall 1986; Silberschneider and Gray 2008; Silberschneider et al. 2009; Ferguson et al. 2014). In 2013/14, ages of individuals sampled from commercial catches taken in the Coorong estuary ranged from 2 to 8 years, with 69% of individuals 3 years of age. The strong cohort of 3 year old fish observed in 2013/14 originated from spawning that occurred 2010/11, i.e. the year of high freshwater discharge to the system (Murray-Darling Basin Authority 2014).

The presence of 1, 2 and 3 year olds in catches from fishery-independent research sampling in 2013/14 suggests that recruitment occurred annually over the past three years. Furthermore, the presence of small juveniles (<200 mm TL) in the estuary in mid-2014 (Ye et al. 2014) suggests that recruitment also occurred in the past 12 months.

Nearshore marine environment

The age structures for the nearshore marine environment adjacent the Coorong estuary from 2000/01 and 2001/02 provide appropriate baseline demographic information for Mulloway in eastern South Australia, to which subsequent population assessments can be compared (Ferguson and Ward 2011). This is because: (i) age structures from recreational line catches and commercial gill net (swinger) catches from the nearshore marine environment are identical;

(ii) the subsequent age structure from commercial nets in 2001/02 was similar with the dominant mode of 8 year olds from 2000/01 persisting as 9 year olds in 2001/02; and (iii) sample sizes >60 were available in each year (Ferguson and Ward 2011).

Since 2001/02, annual size and age information for the adult population in the marine environment adjacent the Coorong estuary has been limited due to the small number of samples and small sample sizes available from commercial and recreational catches in most years. However, the age structures from 2014/15, which were based on moderate sample sizes from commercial (n=26) and recreational (n=24) catches, were similar to the baseline age structures from 2000/01 and 2001/02, i.e. they had a wide range of ages (4 to 18 years) and comprised mostly (90%) individuals above the age at maturity (5-6 years) for the species in South Australia (Ferguson et al. 2014).

Although this study provided age structures for 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 been impacted by environmental changes. Furthermore, the size range of fish collected using these methods is limited by the mesh sizes of the gill nets. Sampling of recreational catches was done to reduce the bias of gear type on the size of fish sampled, however catches from this sector were difficult to access and sample sizes were low. A formal sampling program, which includes additional fishery-independent sampling of recreational catches, is needed for a more robust age structure to support stock assessment.

There is a need to better understand the proportional use of habitat in the Coorong estuary and adjacent nearshore marine habitat by juvenile Mulloway in eastern South Australia to determine if the size/age structures produced from samples collected in the Coorong region are representative of the broader population. There is evidence that Mulloway from the Coorong region may be part of a biological stock that also includes individuals from Gulf St. Vincent and Glenelg River (Victoria) (Barnes et al. 2014). Whilst further research is required to determine delineation of biological stocks in South Australia, future assessments should seek to incorporate demographic information collected from a range of fishery-dependent and fishery-independent sources across this broader spatial scale to monitor the demographic status of the population.

Uncertainty exists around the levels of recreational catches of large Mulloway from marine waters in South Australia (LMS: 750 mm TL) and the influence those catches may be having on the size/age structure of the fished population in South Australia. Recreational fishing surveys estimated that recreational catches of Mulloway accounted for 44% and 62% of the combined commercial and recreational catch in South Australia in 2000/01 and 2007/08, respectively. Future assessments of the size and age characteristics of the eastern South Australian stock should consider a higher number of Mulloway samples (>60 fish) from recreational catches. This may be done through the establishment of a research angler program or sampling of catches at the point of landing.

Conclusion and implications for management

This study contributed important demographic information for Mulloway in the Coorong estuary and adjacent nearshore marine environment. The commercial LCF for Mulloway can currently be described as a 'gauntlet fishery' that targets mainly juveniles, with a much smaller component of the fishery targeting mature adult fish (Smith 2013). As such, the high inter-annual variation in commercial catches of Mulloway for the LCF likely relates to variation in the abundance of juvenile fish in the Coorong estuary.

The current LMS for Mulloway in the Coorong estuary (i.e. the area that accounted for approximately 88% of the total catch in 2013/14) is 460 mm TL, which is approximately 54% and 59% of the size at maturity (SAM_{50}) for females and males, respectively (Ferguson et al. 2014). The size and age structures from commercial catches of Mulloway for 2013/14 (i.e. modal size approximately 550 mm TL and modal age of 3 years, respectively) indicated that the fishable biomass in the Coorong estuary comprised mostly individuals that were less than the SAM_{50}. Increased exploitation of Mulloway below the SAM_{50} may reduce the number of individuals that recruit to the spawning biomass of the population in each year. Similarly, sustained exploitation on mature Mulloway (>750 mm TL) in the marine environment during periods of low recruitment to the adult population (spawning biomass) has the potential to reduce the reproductive capacity of the population.

For long-lived species with delayed maturity such as Mulloway, allowing individuals to spawn at least once is important for sustainable management. However, gauntlet fisheries such as the LCF for Mulloway (Smith 2013), that harvest mainly juveniles, can be sustainable provided an effective management framework is in place to control exploitation, particularly when the fishery reaches a situation that requires a management response. A new management plan is currently being developed for the LCF and will include improved management arrangements for the fishery.

4. PERFORMANCE INDICATORS

4.1 Introduction

The Management Plan for the South Australian LCF provides a framework for management (Sloan 2005). For key finfish species such as Mulloway, performance indicators (PIs) based on historical catch and effort data are used to monitor fishery performance. The fishery is assessed by comparing the most recent estimates of these PIs against upper and lower reference points (RPs). 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. However, it is acknowledged that breaches of the upper RP may also reflect improved fishery performance. When an RP is breached, management responses are prescribed (Sloan 2005). This section provides an overview of the current status of the LCF for Mulloway, based on PIs and associated RPs described in the Management Plan. 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 Mulloway was considered in a recent stock status report (Fowler *et al.* 2013) and is not assessed in this report.

4.2 Methods

To assess the status of the LCF for Mulloway, there are six PIs: (i) total catch (all sectors); (ii) 4-year total catch trend (all sectors); (iii) mean annual CPUE for large mesh gill nets (LCF); (iv) mean annual CPUE trend for large mesh gill nets (LCF); (v) mean annual CPUE for swinger nets (LCF); and (vi) mean annual CPUE trend for swinger nets (LCF). 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, the upper and lower RPs were based on the three highest and three lowest values during the reference period. The trend PIs for total catch and CPUE were determined using the greatest rate of change (±) over four consecutive years for total catch and CPUE during the reference period.

4.3 Results

In 2013/14, five of the six PIs for Mulloway were within the range of the RPs defined in the Management Plan (Sloan 2005) (Table 4.1; Figure 4.1). The PI for $CPUE_{LMGN}$ was 6.2% above the upper RP. All other PIs were well above their associated lower RPs.

Table 4.1. Performance indicators and reference points for the LCF for Mulloway taken using large mesh gill nets ($_{LMGN}$) and swinger nets ($_{SWINGER}$) in 2013/14.

Performance Indicator	Upper reference point	Lower reference point	2013/14 estimate	Within range of reference points
Total catch (t)	118	31	69.1	Y
4-year total catch trend	27	-27	18.3	Y
$CPUE_{LMGN}$ (kg.fisher day^{-1})	49.8	11	52.9	N
4-year $CPUE_{LMGN}$ trend	9.5	-9.5	7.3	Y
$CPUE_{SWINGER}$ (kg.fisher day^{-1})	61	10	44.3	Y
4-year $CPUE_{SWINGER}$ trend	16.1	-16.1	-0.1	Y

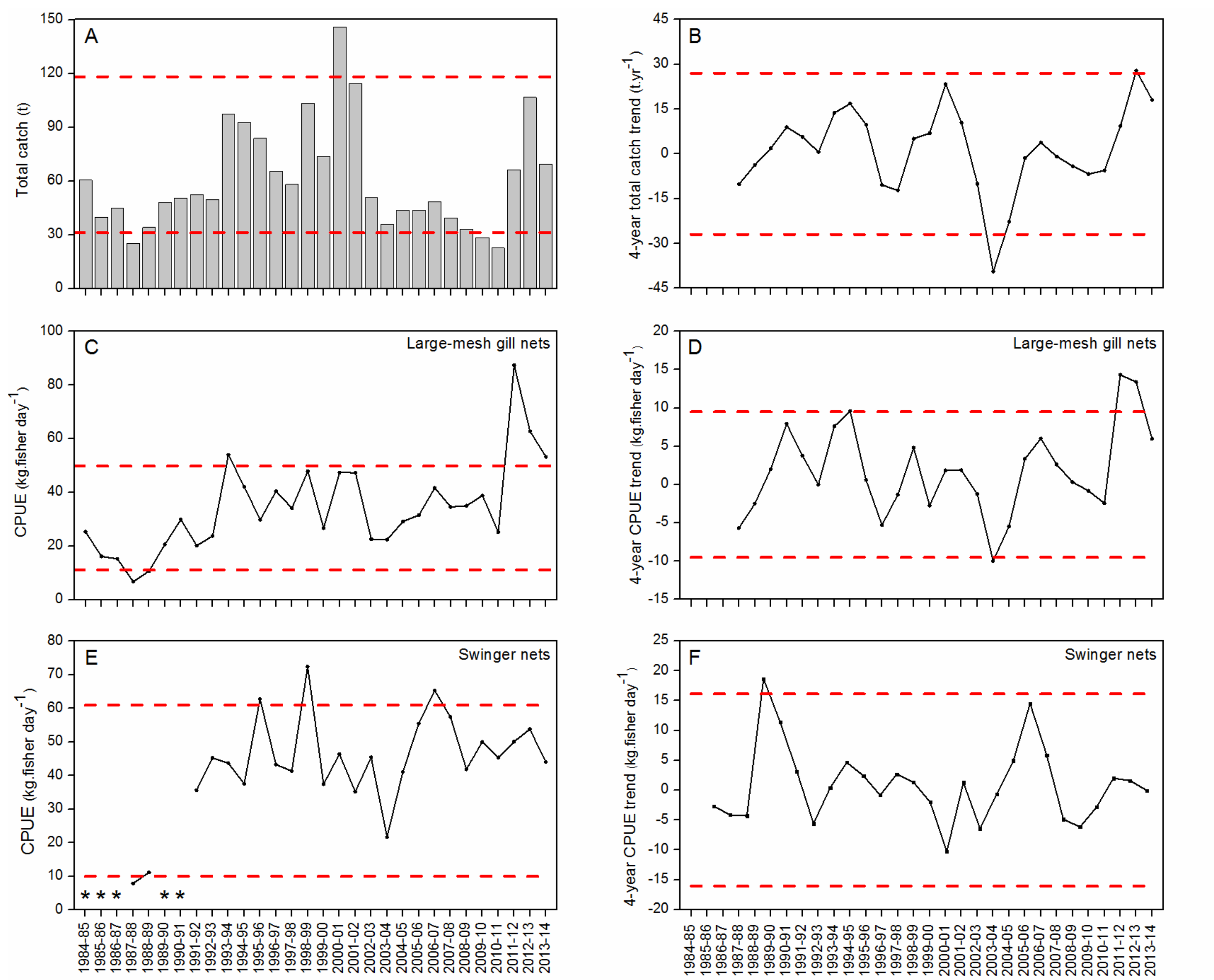

Figure 4.1. Time series of annual PIs and upper and lower limit RPs (red dashed lines) for the LCF for Mulloway from 1984/85 to 2013/14. (A) Total catch; (B) 4-year total catch trend; (C) Mean annual CPUE for large mesh gill nets; (D) 4-year mean annual CPUE trend for large mesh gill nets; (E) Mean annual CPUE for swinger nets; and (F) 4-year mean annual CPUE trend for swinger nets. (*) represents confidential data reported by less than five licence holders.

4.4 Discussion

The recent performance of the LCF for Mulloway was considered by assessing fishery PIs against RPs prescribed in the Management Plan. The PIs showed considerable change in the fishery over recent years. For 2013/14, five of the six fishery PIs were within the range of the upper and lower RPs. The fishery PI for $CPUE_{LMGN}$ was 6.2% above the upper RP, which was related to the catch rate for large-mesh gill nets that was among the highest ever recorded for the fishery. In general, the PIs present a positive view of the status of the stock.

There are concerns around the use of commercial CPUE data as the only available estimate of relative abundance for Mulloway in the LCF due to: (i) differences among individual licence holders in the way that fishing effort is reported; and (ii) environmentally-mediated changes in the amount of available habitat for Mulloway in the Coorong. The geographic range of Mulloway 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 Mulloway to a reduced area of favourable habitat which may increase their catchability and potentially confound interpretation of CPUE as an indicator of population abundance.

A potential approach is to develop a broader suite of environmental and biological indicators to provide a more meaningful assessment of stock status for Mulloway in eastern South Australia. A new management plan for the LCF, which will include a new harvest strategy and management decision-making framework for finfish, is currently being developed. As part of this process, the assessment of the status of the key finfish species, including Mulloway, could be improved through the development of a new suite of PIs that consider the influence of the environment (i.e. salinity, freshwater discharge) on distribution, abundance and fishery performance. Environmental PIs, combined with information on catch, CPUE and population age structure, would support a weight-of-evidence approach to determining stock status for the Mulloway resource in eastern South Australia.

5. GENERAL DISCUSSION

5.1 Information available for assessing the status of the fishery

Information available to assess the Mulloway stock in eastern South Australia included: (i) daily commercial catch and effort data from 1984/85 to 2013/14; (ii) annual estimates of relative abundance for Mulloway based on fishery-dependent CPUE for large-mesh gill nets and swinger nets, i.e. the dominant gear types used to target Mulloway in the LCF; (iii) annual size and age structures for Mulloway from the Coorong estuary and nearshore marine environment adjacent the Coorong from several years between 2000/01 and 2014/15; (iv) limited information on the recruitment of juvenile Mulloway in the Coorong estuary from a fishery-independent research sampling program undertaken in 2013/14 (Ye et al. 2014); and (v) a suite of biological performance indicators and associated limit reference points.

In addition, the assessment is aided by two previous fishery assessment reports (Ferguson and Ward 2003; 2011), several stock status reports (Ferguson 2006; 2008; 2010b; 2011; 2012; 2012b), and the Management Plan (Sloan 2005).

Key knowledge gaps identified in the Management Plan for the LCF (Sloan 2005) were addressed in a PhD study of Mulloway in South Australia (Ferguson 2010b). In that study, several aspects of the biology and ecology of the species were described. These include: (i) the stock structure of Mulloway in South Australia; (ii) growth rates for populations in western and eastern South Australia; (iii) size at maturity for the population in eastern South Australia; and (iv) life-history impacts of flow regulation, drought and fishing on the population associated with the Coorong estuary.

Biological information on demography, growth and maturity are available for several populations of Mulloway 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 the current study (Section 3) provided size/age structures for Mulloway in eastern South Australia which are comparable to those determined for previous years and will contribute to the ongoing development of a time-series that will ultimately improve understanding of impacts of environmental variability and fishing on population health. Additional size/age information is also available for populations in western South Australia (Ferguson and Ward 2011; Rogers et al. 2014), New South Wales (Silberschneider et al. 2009), Western Australia (Farmer 2008) and South Africa (Griffiths and Hecht 1995).

Two recent studies have provided information on stock structure of Mulloway in South Australia. The stock structure of Mulloway across southern Australia was investigated as part of a research project funded by the Southern Fisherman's Association and University of Adelaide (Barnes et al. 2014). Analyses of microsatellite data identified several populations across this broad range including separate populations on the far west coast of South Australia, and in the State's south east. These results corroborate the findings of an otolith-based study, which identified similar population sub-structuring in South Australia (Ferguson et al. 2011). Overall, the findings of these studies suggest that two biological stocks exist in South Australia, i.e. an eastern stock, which includes the Coorong, and a western stock, although uncertainty exists around the extent of the eastern stock (Ferguson et al. 2011; Barnes et al. 2014).

In addition, levels of discarding and discard mortality of Mulloway were estimated in a study of gear interactions with non-target species/sizes in the Coorong (Ferguson 2010a). Information on the abundance, distribution and size/age characteristics of Mulloway in the Coorong estuary is also available from multi-panel gill net sampling undertaken in 2013/14 (Ye et al. 2014).

5.2 Uncertainty in the assessment

This assessment relies heavily on commercial catch and effort data. Uncertainty exists around the use of commercial CPUE as the only estimate of relative abundance for Mulloway in the Coorong estuary. This is because the geographic range of Mulloway 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 cause Mulloway to aggregate into a reduced area of favourable habitat (Ferguson and Ward 2011), which may affect their catchability and potentially confound interpretation of CPUE as an indicator of population abundance.

Uncertainty also exists around each of the performance indicators and associated reference points defined for Mulloway in the Management Plan (Sloan 2005). This is because: (i) uncertainty exists around the usefulness of CPUE as indicator of population abundance; (ii) reference points were determined based on total catch and CPUE data from a fixed, relatively short time period; (iii) catch-trend and CPUE-trend performance indicators have widely separated upper and lower reference points; and (iv) there is limited consideration of the influence of the environment on fishery performance.

Although this study provided age structures for 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 been impacted by environmental changes. Furthermore, the size range of fish collected using these methods is limited by the mesh sizes of the gill nets. Sampling of recreational catches was done to reduce the bias of gear type on the size of fish sampled, however catches from this sector were difficult to access and sample sizes were low. A formal sampling program, which includes additional fishery-independent sampling of recreational catches, is needed for a more robust age structure to support stock assessment.

Uncertainty also exists around the levels of recreational catches of Mulloway 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: (i) recreational catch may be similar or larger than the commercial catch (Jones and Doonan 2005; Jones 2009); and (ii) recreational fishers target spring/summer aggregations (Jones and Doonan 2005; Ferguson et al. 2008). Furthermore, Mulloway are vulnerable to recreational fishers who target aggregations of large Mulloway near the Murray Mouth, as well as along Younghusband Peninsula, particularly during periods of moderate/high river discharge (Anon 2004; Ferguson et al. 2014).

Levels of incidental mortality of sub-legal sized Mulloway discarded by commercial and recreational fishers in the Coorong estuary and marine environment are poorly understood. Available estimates of levels of discarding are available for one year which occurred during the recent drought period, when the amount and quality of available estuarine habitat for Mulloway was at historically low levels. For the commercial sector, this will be addressed by monitoring of discards from small and large mesh gill nets. It is planned to incorporate discard information into the Inland Waters Catch and Effort return in 2014/15, which will be supported by ongoing, validation of discard reporting by fishery-independent observers.

Uncertainty exists around biological delineation of the Mulloway stocks in South Australia. Two biological stocks have been identified i.e. an eastern stock and a western stock (Ferguson et al. 2011; Barnes et al. 2014). While there is evidence that fish in the Gulf St. Vincent may be part of the eastern stock, further research is required to discern the spatial boundaries between the two South Australian stocks, and the extent of the eastern population (Ferguson et al. 2011; Barnes et al. 2014).

5.3 Current status of the LCF for Mulloway

The overall assessment of South Australia's fishery for Mulloway relies heavily on fishery-dependent data from the LCF. The assessment places considerable emphasis on analysing catch, effort and CPUE trends for large mesh gill nets (LMGN) used to target Mulloway (i.e. the gear type that accounts for the majority of the total annual Mulloway catch by the LCF).

The highest total annual catch of Mulloway for the LCF was 136 t in 2000/01. From then, catch declined and averaged 33 $t.yr^{-1}$ until 2010/11. In 2012/13, catch increased to a secondary peak of 103 t, before declining to 68 t in 2013/14, of which 88% was taken from the Coorong estuary using LMGN. Commercial CPUE data for LMGN, which provides an estimate of relative abundance for Mulloway in the Coorong, increased to an historic peak of 87 kg.fisher day^{-1} in 2011/12. Despite a decline in the two years since 2011/12, it remained among the highest on record in 2013/14 (52.9 kg.fisher day^{-1}).

Of the six fishery biological PIs for 2013/14, five were within the range of the RPs described in the Management Plan (Sloan 2005). The CPUE for LMGN (53 kg.fisher day^{-1}) in 2013/14 was 6% above the upper RP, while all other catch and CPUE PIs were within the range of RPs defined in the Management Plan.

The age structure for Mulloway sampled from catches taken in the Coorong estuary (i.e. the area that accounts for approximately 88% of annual commercial catches) in 2013/14 was dominated by three year old fish and consistent with those from 2000/01 and 2002/03. As Mulloway in eastern South Australia attain sexual maturity at approximately 5 years of age (Ferguson et al. 2014), the LCF for Mulloway can currently be described as a gauntlet fishery that harvests mainly juveniles (Smith 2013), with a smaller component of the fishery targeting adults.

Consideration of life history strategies is fundamental to assessments of stock status (King and McFarlane 2003). The life-history of Mulloway is characterised by high longevity (41 yrs) and delayed maturity (5-6 years) (Ferguson et al. 2014). Such a life history (periodic strategist) generally relies on the establishment of one or several strong year classes at irregular intervals to maintain the population (Winemiller and Rose 1992). Thus, a time series of age structures for the adult population based on appropriate sized samples ($n > 60$) collected from multiple fishery sectors on multiple fishing days has the potential to provide important information for monitoring the health and status of the Mulloway stock in eastern South Australia (Ferguson and Ward 2011).

Since 2001/02, annual size and age information for the adult population in the marine environment adjacent the Coorong estuary has been limited due to the small number of samples and small sample sizes available in most years. However, the age structures from 2014/15, which were based on moderate sample sizes from commercial (n=26) and recreational (n=24) catches, were similar to the baseline age structures from 2000/01 and 2001/02, i.e. they had a wide range of ages (4 to 18 years) and comprised mostly (90%) individuals above the age at maturity (5-6 years) for the species in South Australia (Ferguson et al. 2014). Furthermore, the large commercial catches of 3 year old fish in 2013/14 and the presence of small juveniles (1 and 2 year olds) in the fishery-independent samples, indicate that recruitment has occurred over the past three years.

The presence of several relatively strong age classes in the spawning biomass, regular recruitment of juveniles to the fishable biomass in the Coorong estuary over recent years, and recent high annual catches and recent catch rates indicate that the population of Mulloway in eastern South Australia is not recruitment overfished. Using the definitions from the National Status of Key Australian Fish Stocks Report (Flood et al. 2012), the fishery for Mulloway in eastern South Australia is classified as **sustainable**. However, given the uncertainty around the usefulness of CPUE as an indicator of population abundance and the limited sample sizes for the age structure for the adult population from recent years, it is important to develop additional indicators that consider the influence of the environment on fishery performance for Mulloway.

Several lines of evidence indicate that Mulloway in eastern South Australia are vulnerable to recruitment overfishing. Firstly, seasonal aggregations of large adult Mulloway in nearshore marine habitat are targeted by commercial and recreational fishers. Secondly, juvenile Mulloway are targeted in the Coorong estuary by commercial and recreational fishers. Thirdly, catch rates of discarded sub-legal sized, juvenile Mulloway in the Coorong estuary are higher than those for retained Mulloway with survival of discards at net retrieval less than 20% (Ferguson 2010a). Fourth, the recreational catch in 2000/01 and 2007/08 comprised 44% and 62% of the combined State-wide commercial and recreational catch, respectively, with a large proportion of catches from spring/summer aggregations of adult fish near the Murray Mouth and along Younghusband Peninsula (Jones and Doonan 2005; Jones 2009). In addition to the large catches by the recreational sector in those years, a high proportion of fish captured were released (71% in 2000/01 and 85% in 2007/08), but release mortality is unknown (McLeay et al. 2002). The combined effects of harvesting juveniles in estuaries and mature adults in the marine environment, and discarding of sub-legal sized juveniles has been implicated in the decline of Mulloway populations in New South Wales and South Africa (Griffiths 1997b; Silberschneider and Gray 2008), as well as other populations of other sciaenid species (Rowell et al. 2008).

For long-lived species with delayed maturity such as Mulloway, allowing individuals to spawn at least once is important for sustainable management. The LMS of 750 mm TL for Mulloway in marine waters of South Australia is currently approximately 92% of the SAM_{50}, while the LMS of 460 mm TL for Mulloway in the Coorong estuary (i.e. the area that accounts for almost 90% of annual commercial catches) is currently approximately 60% of the size at maturity (SAM_{50}), (Ferguson and Ward 2011). Gauntlet fisheries such as the LCF for Mulloway (Smith 2013), which harvests mainly juveniles, can be sustainable provided an effective management framework is in place to control exploitation when the fishery reaches a situation that requires a management response. The current management framework for the LCF (Sloan 2005) has a number of operational shortfalls that limits the capacity for adaptive management decision-making, including a lack of a *formal* mechanism to control the level of exploitation on key species in response to varying environmental conditions and/or declines in the health of fish stocks. Mulloway in eastern South Australia would benefit from the development of a new management framework that includes: (i) defined management responses to changes in the environment; (ii) a limit reference point that defines an unacceptable risk of commercial fishing; and (iii) a formal mechanism to control the level of exploitation should a limit reference point be approached. A new management plan for the LCF, which will include a new harvest strategy and management decision-making framework for finfish, is currently being developed.

5.4 Future research needs

The most important research needs for the Mulloway fishery and its management include: (i) independent monitoring of discarding of non-target and sub-legal sized individuals from large and small mesh gill nets, particularly under flow conditions when recruits of Mulloway (and other species) are present in the Coorong; and (ii) ongoing development of a time series of annual age structures from the marine environment, based on appropriate sized samples (n > 60) from both the commercial and recreational sectors, as suggested in the review by Smith (2013).

There is a need to better understand the use of the Coorong estuary and adjacent nearshore marine habitat in eastern South Australia by juvenile Mulloway to determine if the size/age structures produced from samples collected in the Coorong region are representative of the broader population.

Regular surveys to estimate the recreational harvest of Mulloway in South Australia (e.g. every 3-5 years) would also assist assessment of stock status, and could be done in conjunction with surveys of other recreational fisheries. On-site, interview-based surveys undertaken during periods of high fishing effort, such as public fishing competitions, would also provide an opportunity to collect important demographic information (size, age, sex, reproduction) for Mulloway in South Australia.

The collaborative Fisheries Research and Development Corporation (FRDC) research project titled '*Developing a management framework and harvest strategies for small-scale multi-species, multi-method, community-based fisheries, using the South Australian Lakes and Coorong Fishery as a case study*' is due for completion in 2015. Key components of the project include a review of the current LCF management framework and development of a new harvest strategy for finfish. This includes development of new PIs that consider the influence of the environment (i.e. freshwater flows, salinity and habitat availability) on distribution, abundance and fishery performance for key species to improve future assessment of stock status for key species including Mulloway.

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