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Assessment of the South Australian Pipi (*Donax deltoides*) Fishery in 2016/17

G J Ferguson and G E Hooper

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SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

August 2017

Fishery Assessment Report for PIRSA Fisheries and Aquaculture

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South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024
Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.pir.sa.gov.au/research

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Author(s): G J Ferguson and G E Hooper

Reviewer(s): M Steer, K Heldt (SARDI) and R Atkins (PIRSA)

Approved by: S Mayfield
Science Leader - Fisheries

Signed: SMayfield

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EXECUTIVE SUMMARY

This is the fourth assessment of the Pipi (Goolwa Cockle) resource on Younghusband Peninsula and builds on the three previous assessment reports (2003, 2006, 2013).

The 2013 stock assessment suggested that the Pipi resource has recovered from a period of over-exploitation prior to 2009/10, based on increasing relative biomass and complexity in size structures from fishery-independent (FI) surveys from 2009/10 onwards. This recovery was likely a result of conservative total allowable commercial catches (TACCs) in place from 2009/10 onwards and the conservative historical minimum legal size.

The second harvest strategy for Pipi was developed in conjunction with the second management plan for the Lakes and Coorong Fishery in 2016/17 and uses two FI biological performance indicators: (i) mean annual relative biomass; and (ii) presence/absence of pre-recruits.

In 2016/17, the estimate of mean annual harvestable biomass was 21.5 kg/4.5 m^2 which was 6% larger than the 2015/16 value and 75% greater than the 2014/15 value. The 2016/17 estimate of 21.5 kg/4.5 m^2 was 95% above the target reference point of 11 kg/4.5 m^2.

From 2007/08 to 2016/17, pre-recruits were present in 8 out of 10 years, with the exceptions being 2008/09 and 2010/11. Pre-recruits were present (52% of size structure) in the size distribution in November 2016.

Although the mean annual harvestable biomass of Pipi was historically high in 2015/16 and 2016/17, large Pipi (>45–50 mm) were poorly represented in size structures compared to earlier years (2007/08–2013/14).

The biomass proxy (FI mean annual harvestable biomass) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e. not recruitment overfished), and fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished. Consequently, under the National Fishery Status Reporting Framework, the status of the Pipi resource in 2016/17 is assessed as **'sustainably fished'** (Flood *et al*. 2014; Stewardson *et al.* 2016).

Future research needs include (i) further development of a time-series of estimates for relative biomass of pre-recruits; (ii) determining whether growth of Pipi is suppressed at high levels of biomass, including (iii) validation of growth and maximum age of Pipi; and (iv) improved understanding of factors that affect recruitment to Younghusband Peninsula.

Keywords: Pipi, *Donax deltoides*, Stock Assessment, Harvest Strategy, Stock Status, South Australia.

1 GENERAL INTRODUCTION

1.1 Overview

This stock assessment of Pipi, *Donax deltoides*, (also known locally as Goolwa cockle) in the Lakes and Coorong Fishery (LCF), South Australia, builds on three previous assessments (Murray-Jones and Johnson 2003; Ferguson and Mayfield 2006; Ferguson 2013), annual stock status reports (Ferguson 2006; 2008; 2010; 2011; 2012; Earl and Ward 2014; Earl 2015; 2016), and advice/presentations given at the annual Total Allowable Commercial Catch (TACC) setting workshops from 2007 to 2011, the Lakes and Coorong Fishery Steering Committee (2012–2015), and the Lakes and Coorong Fishery Management Advisory Committee (2016). The aim of this report is to provide a comprehensive synopsis of information available for the Pipi resource of the LCF and assess the current status of the resource (hereafter referred to as the “Pipi fishery”).

1.2 Description of the fishery

1.2.1 Commercial Fishery

The Pipi fishery in South Australia is located on the ocean beach of Younghusband Peninsula (Figure 1-1). The commercial fishery comprises three sectors: (i) the LCF; (ii) Marine Scalefish Fishery (MSF); and (iii) Southern Rock Lobster Fishery.

1.2.2 Lakes and Coorong Fishery

The spatial extent of the Lakes and Coorong is defined in the *Fisheries Management (Lakes and Coorong Fishery) Regulations 2009* and comprises the waters of the Coorong, Lake Alexandrina, Lake Albert, and coastal waters adjacent to South Australia between the location on Mean High Water Springs closest to 35°31′23.50″ South, 138°46′23.83″ East (Beach Road, Goolwa) and the location on Mean High Water Springs closest to 36°49′34.59″ South, 139°50′55.95″ East (Kingston SE Jetty) (Figure 1-1). The Coorong Coastal Waters is defined as the area from Goolwa Beach Road to Kingston Jetty and extends 3 nm out to sea. Pipi is included under the Order Veneroida as a prescribed species in the multi-species, multi-gear LCF. Currently, 19 licences have endorsements for Pipi which allow harvesting with a rake or net.

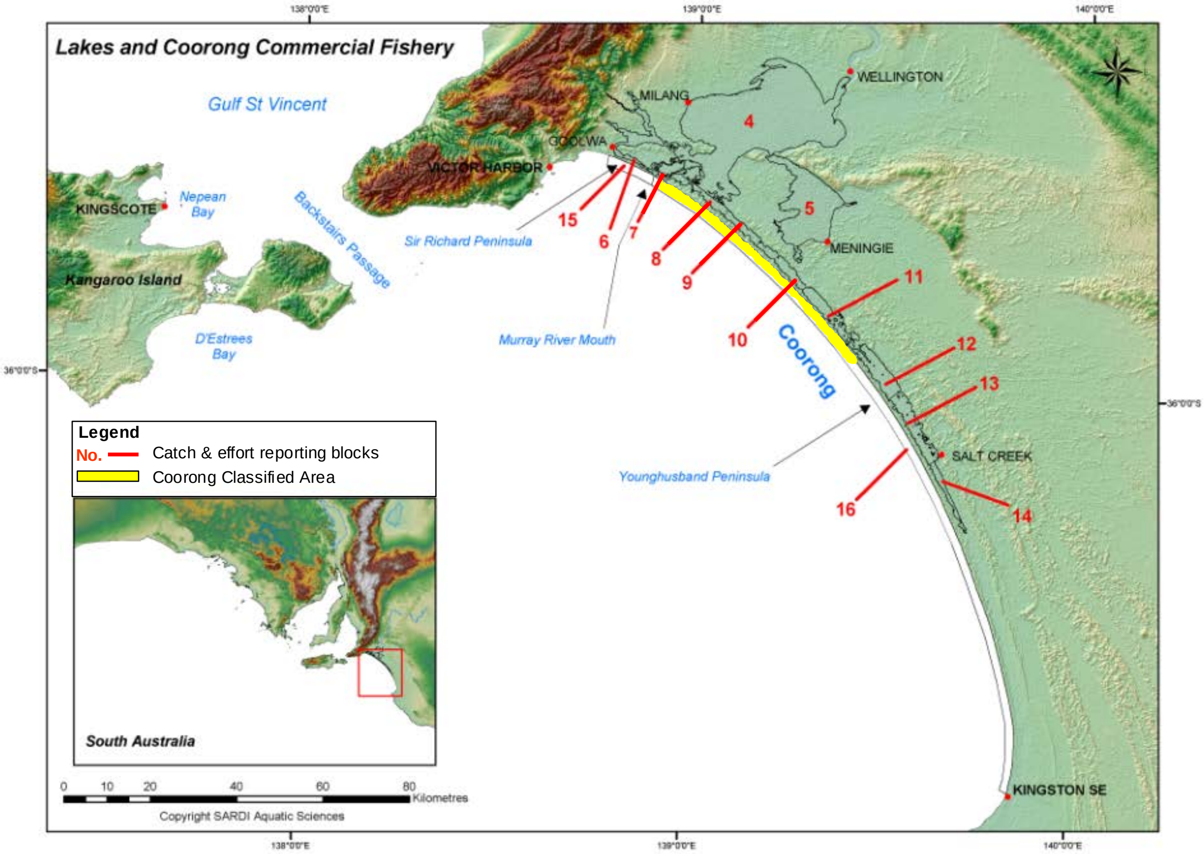

Figure 1-1. Map of the Coorong Coastal waters from Goolwa to Kingston showing the Coorong Classified Area (yellow shading) from which Pipi for human consumption must be taken and catch and effort reporting blocks (numbers in red). The map includes the Murray River mouth and Sir Richard and Younghusband Peninsulas (effort reporting block 16) and an inset map of South Australia highlighting the location of the Coorong.

1.2.3 Marine Scalefish Fishery

The MSF is a multi-species, multi-gear fishery that operates along the entire coast of South Australia. Since 2008/09, this sector has taken Pipi exclusively from Younghusband Peninsula. Prior to 2007/08, catches were also taken from Sir Richard Peninsula and other beaches on the southern Fleurieu peninsula. Currently, two MSF licence holders have quota and endorsements to harvest Pipi for sale. Other MSF licence holders have had access to Pipi for personal bait use only with a maximum of 10 kg per day since July 2005.

1.2.4 Southern Rock Lobster Fishery

The South Australian Rock Lobster Fishery comprises the Northern and Southern Zones. The Northern Zone Rock Lobster Fishery (NZRLF) operates from the Western Australian border to the mouth of the Murray River. The Southern Zone Rock Lobster Fishery (SZRLF) extends from the Murray Mouth to the Victorian border. The NZRLF and SZRLF have access to 10 kg of Pipi per day for personal bait use only. Fourteen NZRLF licence holders have endorsements for cockle devices but there are no SZRLF licence holders with such endorsements.

1.2.5 Recreational Fishery

There is little information on the recreational fishery for Pipi. Anecdotal information suggests that most recreational fishers who harvest Pipi live locally and harvest most of their catch from Sir Richard Peninsula (Goolwa Beach) during summer (Murray-Jones and Johnson 2003; Giri and Hall 2015).

Estimates of recreational catch are available from telephone-based surveys in 2000/01 and 2007/08 and an on-site survey in 2013/14. In 2000/01, the estimated recreational catch was 22.9 tonnes (t), representing 1.8% of the State-wide (i.e. total recreational and commercial catch; Jones and Doonan 2005). In 2007/08, the estimated recreational catch was 5 t, representing 0.8% of the State-wide catch (Jones 2009). In 2013, revised methodology, including an on-site survey specific to the Pipi fishery, estimated the recreational catch to be 33 t, comprising 7% of the State-wide catch (Giri and Hall 2015).

1.3 Economic importance

Pipi catches make the highest contribution to the gross value of production (GVP) among major species in the LCF and in 2013/14 comprised approximately 50% of the value of the fishery (Rippin and Morrison 2015). The value of the Pipi catch has increased more than threefold since 2002/03 which accounts for most of the overall increase in the value of the fishery over the last 12 years (Rippin and Morrison 2015). Despite a reduction in catch between 2007/08 and 2008/09, the value of the Pipi catch increased by 48% as a result of the price doubling (Rippin and Morrison 2015). Prior to 2008/09, the majority of the Pipi catch was sold for bait, and from 2008/09 to 2013/14 a shift towards selling Pipi for human consumption increased market return, resulting in a greater average Pipi price of approximately $9/kg (Rippin and Morrison 2015).

In 2013/14, the overall contribution from the LCF to the gross State production was estimated to be $19.7m with $5.2m generated by fishing directly, $3.0m generated by downstream activities, and $11.5m generated by other sectors (e.g. trade, manufacturing) in the economy (Rippin and Morrison 2015). The total employment attributed to the fishery in 2013/14 was estimated to be 153 full time equivalent (fte) jobs: 40 fte jobs generated by fishing directly, 32 fte jobs in downstream activities, and a further 81 fte jobs generated in other sectors in the economy (Rippin and Morrison 2015).

1.4 Management Plans

1.4.1 Previous Management Plan

Since 1984/85, the Commercial fishery has been managed using a combination of input and output controls including: (i) restrictions on the number of operators and agents; (ii) gear restrictions; (iii) legal minimal length (LML, 35 mm); (iv) combined, spatial and temporal closures; and (v) temporal closures (Table 1-1). From 2007/08 the fishery has been managed under a TACC with individual transferrable quotas. Under current fisheries regulations, the Pipi fishing season is from 1 November to 31 May. Following a program of winter harvest trials conducted as part of a Fisheries Research and Development Corporation (FRDC) funded research project (Ferguson and Ward 2014), exemptions have been allowed for fishers to harvest year round since 2010/11. From July 2013, the quota period was changed to financial years (1 July to 30 June).

Table 1-1. Management milestones for the Lakes and Coorong and Marine Scalefish commercial Fisheries for Pipi in South Australia.

Date	Milestone
1971	Introduction of fishing licences for all commercial fishing in South Australia
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 Scalefish Fishery) Regulations 1984
1984	Spatial information on catches (one area for Pipi)
1984	Catch and effort data reported to Department of Fisheries, SARDI (Aquatic Sciences)
1991	*Fisheries (Scheme of Management—Lakes and Coorong Fishery) Regulations 1991* *Fisheries (Scheme of Management—Marine Scalefish Fisheries) Regulations 1991*
2005	Management Plan for the LCF
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*
2007	Fishery-independent data collection (biomass, size frequency)
2007	Pipi TACC and quota management introduced
2009	Pipi quota management arrangements implemented into regulations
2009	*Fisheries Management (Lakes and Coorong Fishery) Regulations 2009*
2010	Experimental winter fishing – under Ministerial Exemption
2012	First harvest strategy for Pipi
2016	Updated Management Plan for the LCF
2016	Second, revised harvest strategy for Pipi

The first management plan for the LCF described performance indicators that were based on fishery catch and effort data (Sloan 2005): (i) total catch; (ii) 3-year catch trend (i.e. regression slope); (iii) CPUE (kg.day^{-1}); and (iv) 3-year CPUE trend.

The *Fisheries Management Act 2007* provides the framework that supports sustainable resource management in South Australia, and the second management plan for the LCF (hereafter referred to as the 'Management Plan') was developed under this act (PIRSA 2016). The Management Plan addresses the allocation of fishery resources among the commercial, recreational, and indigenous sectors and details the tools for managing the sustainable exploitation of those resources (PIRSA 2016). Key components of the Management Plan are the harvest strategies for finfish and Pipi which assess biological performance indicators against the prescribed biological limit reference points (Sloan *et al*. 2014).

The first harvest strategy for Pipi was implemented in 2012/13, prior to completion of the Management Plan (PIRSA 2016), and based on two fishery-independent (FI) biological performance indicators and one economic performance indicator: (i) primary biological performance indicator – relative biomass of legal-sized Pipi (harvestable biomass, kilograms per 4.5 m^2); (ii) secondary biological performance indicator - presence/absence of pre-recruits in size distributions (Ward *et al.* 2010; Ferguson *et al.* 2015). The objectives of the harvest strategy are to (i) maintain mean annual fishery-independent relative biomass of legal-sized Pipi above the target reference point of 10 kg/4.5 m^2; but (ii) not less than the trigger reference point of 8 kg/4.5 m^2; and (iii) to ensure that mean annual relative biomass does not fall below the limit reference point of 4 kg/4.5 m^2.

The 2012 harvest strategy was ultimately used to recommend the biologically acceptable total commercial catches in 2012/13, 2013/14, 2014/15 and 2015/16 (PIRSA 2012). The economic performance indicator (i.e. fishery gross margin; EconSearch 2012) was then considered within the context of the range of biologically acceptable TACCs. Fishery Gross Margin (FGM) provides a proxy for maximum economic yield (MEY), and changes in TACC, within the range of potential biologically acceptable TACCs, were only considered when FGM increased by greater than 2.5%.

1.4.2 Current Harvest Strategy

In 2016, the second, revised harvest strategy (hereafter referred to as the 'harvest strategy') for Pipi was implemented in the second Management Plan for the LCF and was used to recommend the TACC for 2016/17 (PIRSA 2016). The revised harvest strategy uses the same biological and economic performance indicators as the previous harvest strategy but differs in having more conservative target and limit reference points associated with each of the biological performance indicators (PIRSA 2012; 2016). The objectives of the harvest strategy are to (i) maintain mean annual fishery-independent relative biomass of legal-sized Pipi above the target reference point of 11 kg/4.5 m^2; but (ii) not less than the trigger reference point of 9 kg/4.5 m^2; and (iii) to ensure that mean annual relative biomass does not fall below the limit reference point of 4 kg/4.5 m^2.

1.5 Previous Stock assessments

The assessment of the Pipi fishery in 2003 documented catch and effort data from 1984/85 to 2002/03 and identified: (i) increasing annual catches and effort; (ii) long-term reduction in CPUE; (iii) availability of substantial latent effort; and (iv) the need for improved spatial resolution of catches (Murray-Jones and Johnson 2003).

The assessment in 2006 further recognised that the Pipi resource was in a weakened state and vulnerable to overfishing because (i) CPUE had declined significantly over more than a decade with CPUE in 2004/05, the lowest level since 1999/00; and that (ii) high levels of latent effort in the LCF and MSF had the potential to at least double (Ferguson and Mayfield 2006). In the 2006 assessment, it was noted that there was uncertainty around CPUE as the only available index of relative abundance, thus identifying a strong need for an ongoing monitoring program based on fishery-independent data (e.g. relative abundance, regular size-frequency sampling, recruitment indices) appropriate to the scale of the fishery (Ferguson and Mayfield 2006).

The assessment in 2013 included fishery-independent data collected from 2007/08 to 2012/13 (Ferguson 2013). The 2013 assessment concluded that the Pipi resource was depleted during the mid- to late-2000s but that increasing mean annual relative biomass and increasing complexity of size structures suggested recovery of the resource from 2009/10. This likely resulted from a combination of conservative TACCs in place from that year onwards and recent recruitment and growth of Pipi (Ferguson 2013; Ferguson *et al*. 2015).

PIRSA Fisheries and Aquaculture have adopted the National Fishery Status Reporting Framework (NFSRF) for assessment of fisheries in South Australia (Flood *et al.* 2014; Stewardson et al. 2016). The status of the Pipi resource was assessed as ‘sustainably fished’ under the NFSRF (Flood *et al*. 2014) in 2012/2013 and 2014/15 (Ferguson *et al*. 2014; 2016).

1.6 Fisheries biology of Pipi

1.6.1 Taxonomy, distribution and habitat

Bivalve molluscs of the Family Donacidae (Order Veneroida) are known as surf clams and have a worldwide distribution (King 1976). Of six Donacid species found in Australia, Pipi are the largest and most common large bivalves (>20 mm) living in the surf zone. In Australia, *D. deltoides* occur along the South Australian coast from Eyre Peninsula to Kingston and through Tasmania to Fraser Island in south-eastern Queensland (King 1985; McLachlan *et al*. 1996). The preferred habitat of *D. deltoides* is high energy, dissipative beaches (i.e. surf beaches where blooms of surf diatoms occur; McLachlan and Hesp 1984) and the low tide swash zone where they feed by filtering diatoms from the water column (McLachlan and Hesp 1984; Dakin and Bennett 1987; Saenger and Keyte 1990; Murray-Jones 1999). The Coorong beaches provide high quality habitat for Pipi, and it is likely that the population of Pipi in the Coorong region may represent the largest single stock abundance of this species in Australia (King 1976).

1.6.2 Stock structure

High genetic variation between populations on either side of Bass Strait suggests at least two biological stocks, with the East Australian and South Australian currents acting as key drivers of gene flow on the east and south coasts of Australia, respectively (Miller *et al*. 2013). Results of a study of Pipi from Fraser Island, Queensland, to southern New South Wales (1,200 km), suggested a single biological stock with genetic mixing driven by ocean currents associated with the East Australian Current; however the timescale over which patterns in genetic variation may have occurred was unknown (Murray-Jones and Ayre 1997). Murray Jones and Ayre (1997) suggested that although genetic mixing was observed among populations of *D. deltoides* along the east Australian coast, in any given year most recruits are likely to have been self-seeded or to have come from nearby, adjacent beaches (Murray-Jones and Ayre 1997). Evidence of genetic structuring of Pipi has not been detected for locations west of Bass Strait in South Australia and western Victoria (Miller *et al*. 2013).

The degree of larval mixing is thought to be related to spawning and larval duration (King 1976; Saenger and Keyte 1990; Murray-Jones and Ayre 1997). Results from recent studies suggested that the population of *D. deltoides* on Younghusband Peninsula have a discrete spring spawning season and short larval duration. Developed gonads were present in mature Pipi on Younghusband Peninsula from August to November, with a peak in spawning activity during October (Ferguson 2013). Field observations were supported by a contemporaneous, laboratory-based study which found that synchronous spawning occurred during October (Gluis and Li 2014). This laboratory study also found that the planktonic larval stage of *D. deltoides* was approximately 14 days (Gluis and Li 2014).

1.6.3 Reproduction

For Pipi from Younghusband Peninsula, gonads in most individuals developed oocytes from August to January, with a peak in development from September–November (Ferguson and Mayfield 2006; Ferguson and Ward 2014) and possible synchronous spawning in October (Gluis and Li 2014). Results from Younghusband Peninsula were generally consistent with those from a previous study on nearby Sir Richard Peninsula (<10 km), which found oocytes present in gonads over 6 months from spring to summer (King 1976; 1985). After spawning, the fertilised eggs developed into a planktonic larval phase which has been estimated as lasting approximately 14 days (Gluis and Li 2014) or as long as 6–8 weeks (King 1976; 1985).

For the population of *D. deltoides* on Younghusband Peninsula, the sizes at which 50% (SAM_{50}), and 95% (SAM_{95}) were sexually mature were 28.25 mm (±0.47 se), and 32.48 mm (±0.41 se), respectively (Ferguson and Mayfield 2006). These results were consistent with those from an earlier study of *D. deltoides* from the nearby (<10 km) Sir Richard Peninsula where individuals greater than 36 mm width (13 months old) were sexually mature (King 1976).

1.6.4 Recruitment

Large natural fluctuations in abundance are a feature of surf clam populations worldwide compared to other bivalve species, and this appears to be characteristic of *D. deltoides* in both New South Wales and South Australia (Coe 1955; King 1976; McLachlan *et al*. 1996; Murray-Jones 1999).

In South Australia, recruitment of *D. deltoides* was seasonal with recruits present from April to September with a peak in January (King 1976), compared to New South Wales where recruitment which was found to be continuous (Murray-Jones, 1999). Murray-Jones (1999) found recruits (~5 mm) in 96% of samples collected across all months over five years and suggested that because constant larval supply was not limited, considerable mortality must occur over several months following metamorphosis, resulting in pulses of juveniles surviving to establish a definite year class. In the study of Murray-Jones (1999), despite nearly continuous recruitment, the adult population did not recover within five years (Murray-Jones 1999).

In South Australia, recruitment and ultimately survival of Pipi may be influenced by local currents and coastal outflow. The spring (September–October) seasonality of spawning of Pipi in South Australia has implications for recruitment because the prevailing currents in south-eastern South Australia flow in a north-westerly direction during this period (King 1985). King (1985) suggested that conservation of *D. deltoides* in the south-eastern part of the

Younghusband Peninsula may provide a pool of breeding animals that contribute to recruitment along the beaches to the north-west.

Upwelling along the South Australian coast and outflows from the Murray River have been suggested to promote elevated primary production of phytoplankton, particularly for diatoms (*Asterionella spp.*) but it is not known how these impact on recruitment or survival of *D. deltoides* on the Coorong beaches (McLachlan and Hesp 1984; Lee 2004).

While smaller freshwater flows may potentially benefit *D. deltoides* by providing nutrients, periods of high river discharge may cause widespread mortalities (Clarke 1985; King 1985). In 1984, an estimated 2.5 million, mostly adult, cockles, were found dead on Goolwa Beach, west of the Murray Mouth (Clarke 1985). It was thought that, following flooding from the Murray River, an extended period of low salinity may have resulted in mortality, possibly due to impacts on food sources and starvation of *D. deltoides* (King 1976; Clarke 1985).

The Pipi harvest in South Australia is thought to be based on the two year-classes that exist above the minimum legal size (MLS) of 35 mm shell width (measured across the longest axis) which is reached at approximately 13 months of age (King 1976; 1985). Variation in the recruitment of juveniles into the fishery will likely have only a relatively short lag (1-2 years) before impacting the harvest. Consequently, the relative importance of the contribution of each year class to the harvest is higher than would be the case in longer-lived species (King 1976).

1.6.5 Growth

Estimates of growth were available from modal progression analysis of monthly size-structures. For Pipi from Younghusband Peninsula, the asymptotic maximum size (L_{inf}, Powell-Wetherall plot) of the non-seasonalised von Bertalanffy Growth Function (VBGF) was 59.67 mm with a growth rate (k) of 0.996 y^{-1} (Table 1-2) (Ferguson 2013). Based on a growth rate of 0.996 y^{-1}, the estimated maximum age of *D. deltoides* was 4.52 years (Taylor 1958). Estimates of mean asymptotic size (L_{inf}) and growth rate (k) for *D. deltoides* from Younghusband Peninsula were similar to those from a previous study on the adjacent Sir Richard Peninsula (Table 1-2). The mean asymptotic sizes (L_{inf}) of Pipi from South Australia were smaller than those for Pipi from New South Wales (Table 1-2).

For the seasonalised VBGF, the seasonality coefficient (C) was kept constant for all size classes at 0.62 and indicated low growth rates throughout winter and a lower overall growth rate (k = 0.650). A strong seasonality effect on growth rates was previously reported for *D. deltoides* from Sir Richard Peninsula with Pipi in the 0^+ age class growing approximately 3 and 2 mm per month in summer and winter, respectively (King 1976).

Validation of the growth rates of *D. deltoides* in South Australia and New South Wales using mark and recapture was compromised by low recapture rates (King 1976; Murray-Jones 1999). However, in South Australia, growth increments of the few recaptured individuals (4 recaptures, 1000 tagged, <0.01%), were consistent with modes in size frequency distributions.

Table 1-2. Growth parameters for *Donax deltoides* in South Australia (SA) and New South Wales (NSW). Parameters from the von Bertalanffy growth function (VBGF) are *k*, (intrinsic growth rate) and L_{inf} (asymptotic size). Additional parameters for the seasonalised VBGF are *C* (strength of seasonality) and *WP* (winter point, month in which growth depression is greatest).

State	Location	L_{inf} (mm)	*k* (y^{-1})	*WP*	*C*	Max age (y)	Reference
SA	Younghusband Peninsula	59.67	0.996	-	-	2.96	Ferguson (2013)
SA	Younghusband Peninsula	57.68	0.650	0.24	0.62	4.53	Ferguson (2013)
SA	Sir Richard Peninsula	58	1.26	-	-	3.5	King (1976)
SA	Sir Richard Peninsula	59	0.86	-	-	3.5	King (1985)
NSW	Stockton Beach	75	1.07	-	-	3.8	Murray-Jones (1999)

Check marks, similar to those in bony structures (e.g. otoliths) of finfish species (Fowler and Short 1999; Campana and Thorrold 2001), also occur in the shells of Donacid surf clams and have the potential to provide estimates of age. However, attempts to validate their periodicity have not been successful to date (Laudien *et al*. 2003). Ageing of the mud cockle, *Katelysia scalarina*, by using a layer of acetate to make features in the shell more clearly visible has provided some successful results, and this method has the potential to be applied to Pipi (Riley *et al*. 1993; Fowler and Eglinton 2002; Cantin 2010). There is also potential to validate age check marks in Pipi using shell microchemistry markers (Manetti 2013; Izzo *et al.* 2016).

2 FISHERY STATISTICS

2.1 Introduction

This section of the report provides a synopsis of the fishery-dependent (FD) statistics for Pipi from 1984/85 to 2015/16. Information presented in this section includes: (i) inter-annual patterns in catch, effort, catch-per-unit-effort (CPUE); (ii) a comparison of measures of effort and CPUE available for the fishery; (iii) seasonality of catches; (iv) spatial distribution of catches; (v) destination markets; and (v) discarding.

2.2 Methods

Daily catch records, including catch and effort data, have been provided to the South Australian Research and Development Institute (SARDI) since July 1984. Catch (weight in kg) and effort are presented in financial years to include the historical and current commercial fishing seasons for Pipi (1 November to 31 May).

In order to investigate possible sources of uncertainty around CPUE as an index of relative abundance, annual CPUE (financial years) was estimated from each of three effort units (days, fisher days, hours) with standard error estimated using a ratio estimator (Rice 1995). The first measure of effort (days) was the number of days fished. The second measure (fisher days) was the total number of individuals engaged in fishing, each day, multiplied by the number of days fished. Finally, hours, was defined as the number of hours fished each day.

Additional information on spatial distribution of catches, destination markets, discarding (small pipi <35 mm), and search time has been provided since 1 July, 2008 and was aggregated into financial years. In order to investigate the spatial distribution, catches were aggregated into 10 km sections. Catches comprising aggregates of <5 licences are expressed as proportions to preserve licence holder confidentiality. For example, catches from the MSF have been expressed as a proportion of the 2000/01 catch.

The relationships between three measures of annual effort (independent variables) and annual catch (dependent variable) were investigated using linear regression and analysis of covariance (ANCOVA) (R-Core-Team 2013). Additionally, annual CPUE, estimated from annual catches, and effort, in hours, from 2007/08 to 2015/16 was compared to estimates of FI annual relative biomass using Pearson correlation coefficient.

2.3 Results

2.3.1 State-wide catches

Total annual commercial catches (combined catches from LCF and MSF) of Pipi ranged between 307 t and 457 t from 1984/85 to 1989/90, and then increased steadily to an historical peak of 1,251 t in 2000/01 (Figure 2-1A). Catches exceeded 1,000 $t.yr^{-1}$ from 1999/2000 to 2006/07 then declined steeply to 470 t in 2008/09. From 2009/10, catches were constrained by annual TACCs: 300 t in 2009/10; 330 t in 2010/11; 400 t in 2011/12 and 2012/13; 450 t in 2013/14 and 2014/15; 500 t in 2015/16. In 2015/16, the total annual catch was 492 t.

From 1984/85 to 1991/92, the MSF harvested more than half the total annual State-wide catch. From 1992/93, catches from the MSF contributed a decreasing proportion of the total catch which was <3% of the total catch from 2003/04 onwards (Figure 2-1B).

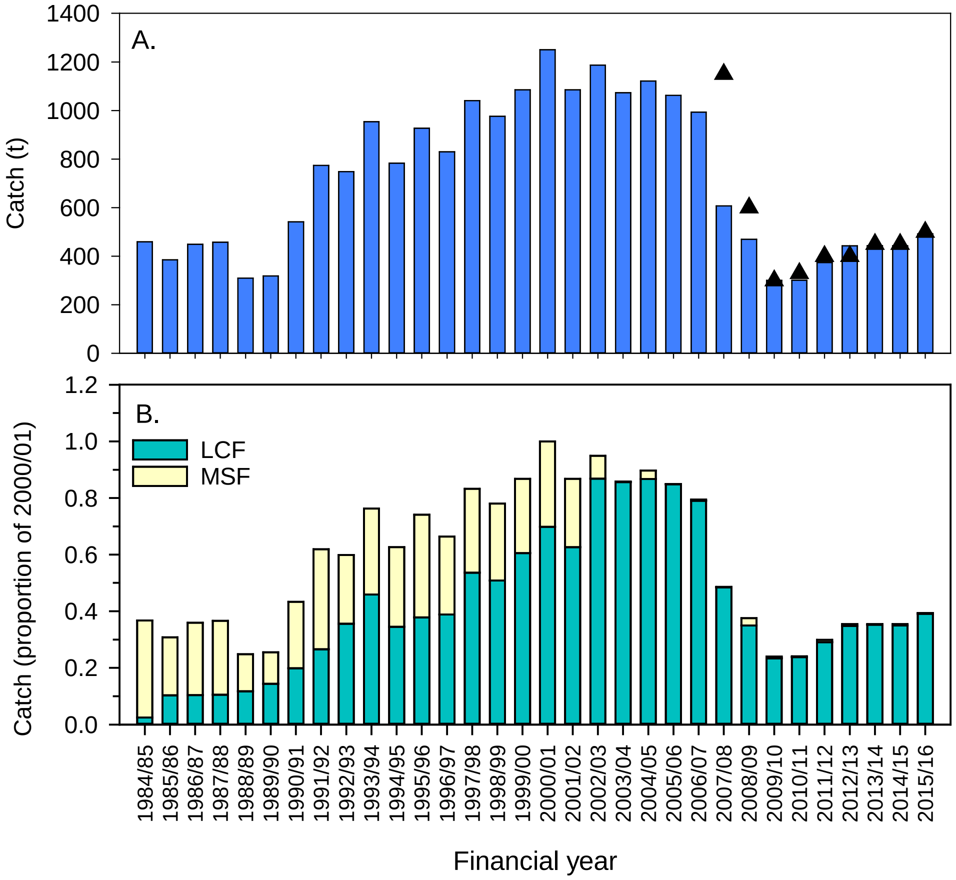

Figure 2-1. For South Australian catches of Pipi from 1984/85 to 2015/16: (A) Total annual catches (bars) and total allowable commercial catch (triangles); NB catches were adjusted for winter fishing (closed season) in 2012/13, and (B) Total annual catches by sector for the Lakes and Coorong (LCF) and Marine Scalefish (MSF) Fisheries. Catches by sector are expressed as a proportion to protect licence holder confidentiality (<5 licences, B).

2.3.2 Lakes and Coorong Fishery

2.3.2.1 Catch

Total annual catch by the LCF increased steadily from 30.7 t in 1984/85 to a maximum of 1,086 t in 2002/03 (Figure 2-2A). From 2002/03 to 2005/06, catches remained stable above 1000 t. From 2006/07, catches declined steeply to 437 t in 2008/09 and were constrained by annual TACCs from 2009/10 onwards. The catch was 292.4 t in 2009/10 and remained below 400 t until 2012/13 when it was 434.9 t. From 2012/13, the annual catch increased to 488.7 t in 2015/16.

2.3.2.2 Effort

$Effort_{dy}$ (effort in days) increased from 60 days in 1984/85 to a historical peak of 1,686 days in 2006/07 then declined to 733 days in 2010/11. From 2010/11, $effort_{dy}$ increased to 1,309 days in 2014/15 and was 1,144 days in 2015/16. For $effort_{fdy}$ (effort in fisher days), the temporal trend was similar to that for $effort_{dy}$. The temporal trend in $effort_{hr}$ (effort in hours), differed to that for $effort_{dy}$ and $effort_{fdy}$. $Effort_{hr}$ increased from 495 hours in 1984/85 to an historic peak of 8,504 hours in 2004/05. From 2004/05, $effort_{hr}$ declined to 1,725 hours in 2010/11. From 2010/11, $effort_{hr}$ increased to 5,137 hours in 2014/15 and was 4,423 hours in 2015/16.

2.3.2.3 Catch per Unit Effort (CPUE)

$CPUE_{dy}$ increased from 547 kg.day^{-1} in 1984/85 to a peak of 877 kg.day^{-1} in 1985/86 then declined to 483 kg.day^{-1} in 1998/99 (Figure 2-2). $CPUE_{dy}$ increased from 1999/2000 to 1,229 kg.day^{-1} in 1992/93 and remained above 1,100 kg.day^{-1} until 1996/97. From 1998/99, $CPUE_{dy}$ declined consistently to 334 kg.day^{-1} in 2008/09. From 2008/09, $CPUE_{dy}$ generally increased to 427 kg.day^{-1} in 2015/16. The temporal trend in $CPUE_{fdy}$ was similar to that for $CPUE_{dy}$ (PCC: r=0.94) (Figure 2-2). The temporal trend in $CPUE_{hr}$, differed to that of $CPUE_{dy}$ and $CPUE_{fdy}$. $CPUE_{hr}$ increased from ~150 kg.hr^{-1} in the early 1980s to a historical peak of 294 kg.hr^{-1} in 1992/93. From 1992/93, $CPUE_{hr}$ declined to 106 kg.hr^{-1} in 2008/09, then increased to 184 kg.hr^{-1} in 2011/12, before declining to 87 kg.hr^{-1} in 2014/15 and was 113 in 2015/16 kg.hr^{-1}.

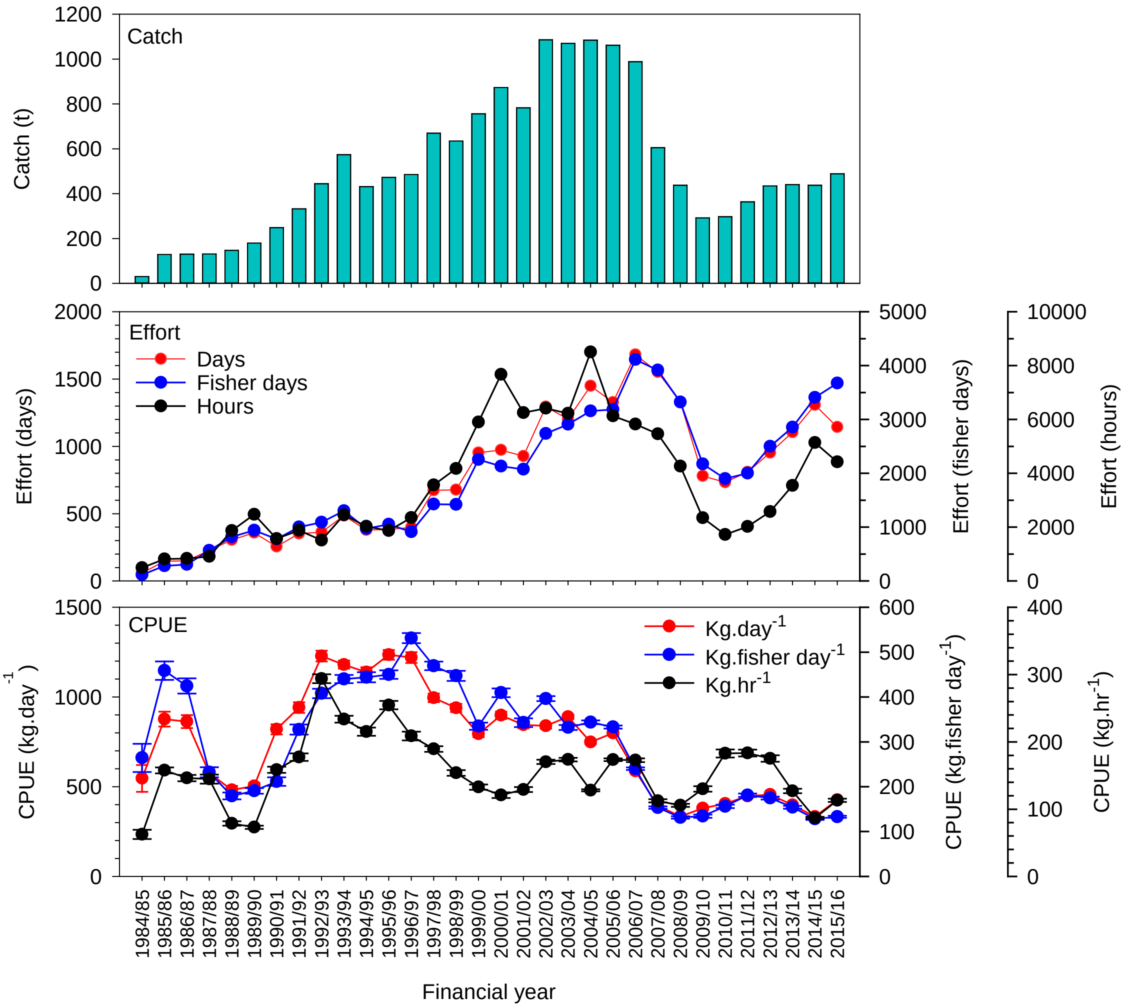

Figure 2-2. Fisheries statistics for the Lakes and Coorong Fishery: Catch, three measures of effort (days, fisher day, and hours) and three measures of CPUE (±se) based on each unit effort.

2.3.2.4 Comparison of effort and catch

Historical measures of annual effort ($effort_{dy}$, $effort_{fdy}$, $effort_{hr}$) and catches were compared to investigate why temporal trends in CPUE based on each measure of effort differed. Distributions of daily $effort_{dy}$ and $effort_{fdy}$ from 1984/85–2015/16 were bimodal while $effort_{hr}$ had a unimodal distribution. From 1984/85–2015/16, the relationship between effort ($effort_{dy}$; $effort_{fdy}$) and annual catch was poorly described by a single linear relationship (R^2=0.56; Table 2-1; Figure 2-3). When two consecutive subsets of this time-series (1984/85–2005/06 and 2006/07–2015/16) were compared: (i) effort was linearly related to catch ($R^2 \geq 0.79$); and (ii) the linear relationships between $effort_{dy,}$/$effort_{fdy}$ and catch differed between the time-series subsets (ANCOVA: p_{slope}<0.005, $p_{intercept}$<0.005). In contrast, annual $effort_{hr}$ was linearly related to annual catch for the entire period (1984/85–2015/16) (R^2=0.80; Table 2-1). For the subsets of this time-period, the relationship between effort$_{hr}$ and catch was similar: 1984/85–2005/06 and 2006/07–2015/16 (ANCOVA: p_{slope}=0.41, $p_{intercept}$=0.09).

Table 2-1. Model coefficients (slope, *b*; intercept, *a*) and fit statistics for the linear relationship between three measures of annual effort (dy, days; fdy, fisher days; hr, hours) and annual catches for three time periods.

LR	Period	*b*	*a*	R^2	*F*	*p*
Effort(d) ~ catch	1984/85–2015/16	0.50	133.56	0.56	$F_{1,30}$ = 37.97	<0.0005***
	1984/85–2005/06	0.71	89.0	0.90	$F_{1,21}$ = 187.20	<0.0005***
	2006/07–2015/16	0.30	94.08	0.79	$F_{1,7}$ = 26.59	0.001**
Effort(fd) ~ catch	1984/85–2015/16	0.18	179.52	0.43	$F_{1,30}$ = 22.57	<0.0005***
	1984/85–2005/06	0.31	76.69	0.87	$F_{1,21}$ = 141.4	<0.0005***
	2006/07–2015/16	0.11	96.51	0.79	$F_{1,7}$ = 25.89	0.001**
Effort(hrs) ~ catch	1984/85–2015/16	0.13	73.91	0.80	$F_{1,30}$ = 117.1	<0.0005***
	1984/85–2005/06	0.13	83.24	0.85	$F_{1,21}$ = 122.9	<0.0005***
	2006/07–2015/16	0.05	217.55	0.71	$F_{1,7}$ = 16.84	0.004**

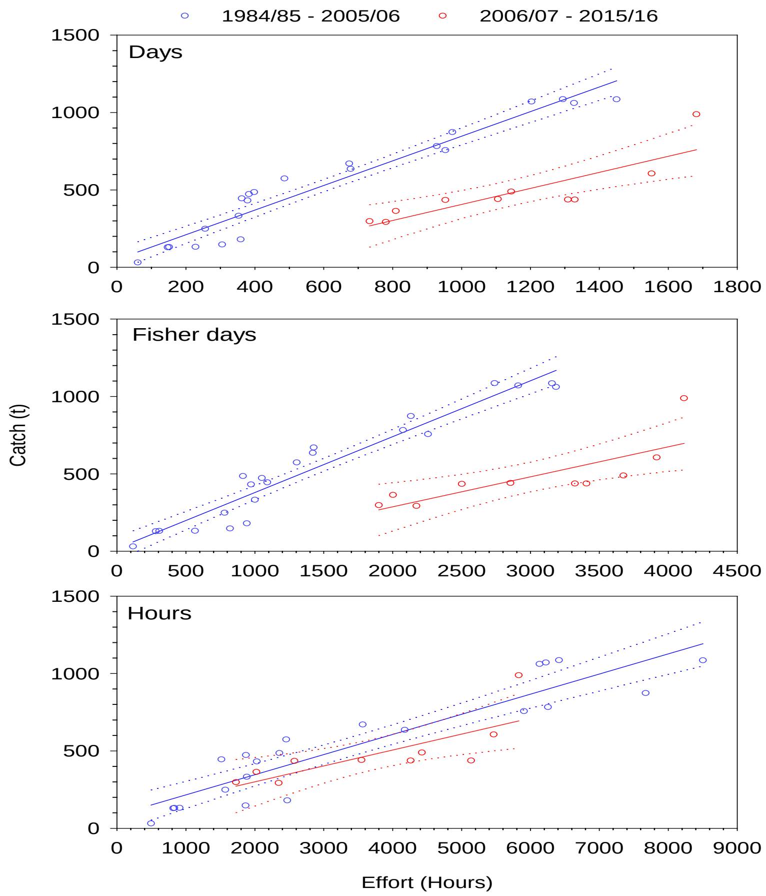

Figure 2-3. The relationship between three measures of annual effort and annual catches for two periods during development of the fishery: 1984/85–2005/06 (blue) and 2006/07–2015/16 (red). Solid line represents regression line for each time-period, dotted lines represent 95% confidence intervals for each regression.

2.3.2.5 Comparison of fishery-dependent and fishery-independent relative biomass

Temporal consistency on the relationship between effort and catch suggested that $CPUE_{hr}$ provided the best FD estimate of relative abundance available to the fishery for Pipi. However, $CPUE_{hr}$ provided a poor predictor of FI estimates of annual relative biomass (LR: $F_{1,7} = 0.2203$, $R^2 = 0.03$, $p>0.5$) (Section 3).

2.3.3 Marine Scalefish Fishery

2.3.3.1 Catch

Total annual catches of Pipi by the MSF sector were relatively constant from 1991/92 to 2001/02, declined substantially to 2003/04, and remained at low levels until 2015/16 (Figure 2-4).

2.3.3.2 Effort

The most reliable measure of effort in the MSF sector is considered to be fisher days because, prior to 2003/04, variable numbers (1–10) of individuals were permitted to fish on each MSF licence on any one day. The two measures of effort show similar temporal patterns (LR: R^2=0.75; $F_{1,30}$=92.22; p<0.005); a long-term increase from 1984/85 to a historical peak in 1999/00, a rapid decline to a historically low level in 2003/04. From 2003/04, effort remained historically low with minor peaks in 2004/05 and 2009/10. Effort in 2015/16 was among the lowest recorded

2.3.3.3 Catch Per Unit Effort (CPUE)

The temporal patterns in CPUE, based on the two measures of effort, showed similar, decreasing trends from 1984/85 to 1989/90; after 1989/90 they showed divergent patterns (Figure 2-4). Mean $CPUE_{dy}$ increased substantially between 1989/90 and 1997/98, whereafter it declined. In 2005/06, mean $CPUE_{dy}$ was at the lowest level on record. In contrast, mean $CPUE_{fdy}$ was generally stable from 1991/92 to 2002/03, and then declined substantially to 2007/08. After 2007/08, $CPUE_{fd}$ increased slightly from 2009/10 to 2011/12. The divergence of the two CPUE measures was due to the variable numbers of individuals (up to 10) that fished on each licence on each day. The relationship between CPUE and stock abundance in the MSF sector is less reliable than that in the LCF sector because effort in hours is not available and because levels of effort in the MSF from 2003/04–2014/15 were historically low.

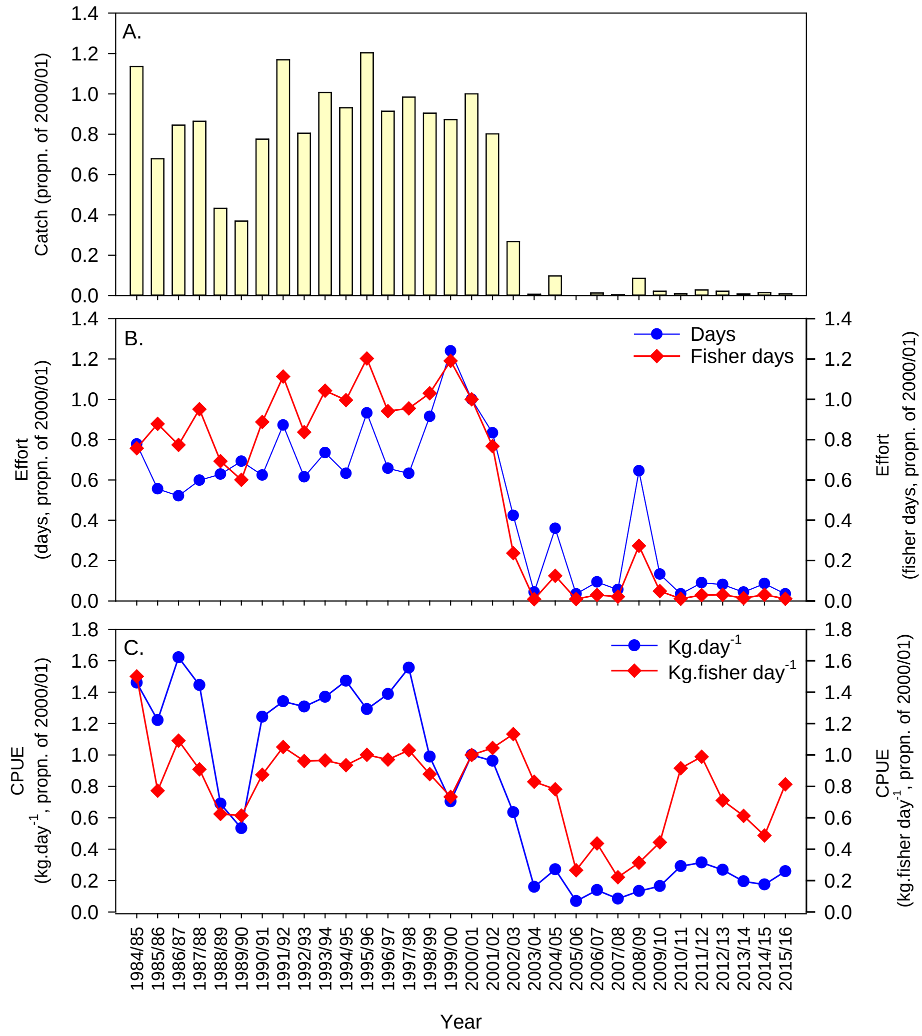

Figure 2-4. Fisheries statistics in the Marine Scalefish Fishery for Pipi (A) catch, (B) two measures of effort and (C) CPUE estimated from two measures of effort. All units expressed as a proportion to protect licence holder confidentiality (<5 licences, B).

2.3.4 Spatial distribution of catch

Catches aggregated by 10 km sections (e.g. 0 to <10 km from the Murray Mouth), starting at the Murray Mouth and moving south-east, are shown in Figure 2-5. The spatial distribution of catches in 2007/08 should be interpreted with caution because this was the first year in which the modified catch and effort logbook was implemented (FRDC 2008/008) and, as a result, there was a high level of erroneous or non-reporting of spatial information (>40%).

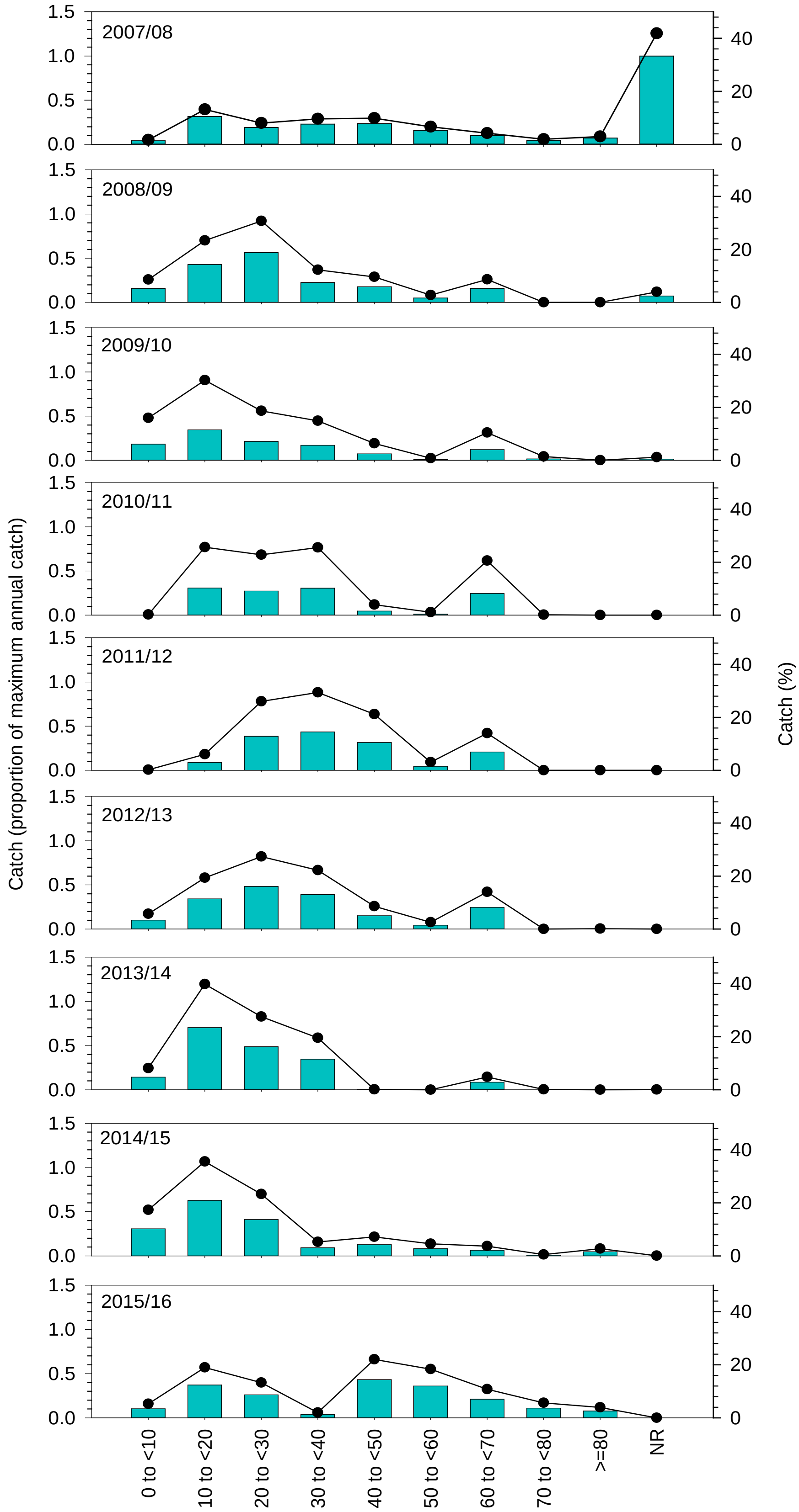

Figure 2-5. Spatial distribution of annual catches (bars) of Pipi across the fishing ground on Younghusband Peninsula from 2007/08 to 2015/16. Black dots and lines show percentage of the annual catch contributed by each 10 km section of the fishing ground.

The spatial distribution of catches varied among years (Figure 2-5). Spatial contraction of the resource appeared to have occurred from 2013/14 to 2014/15 when respectively, 95% and 81% of the annual catch was taken from the north-western two thirds of the main fishing ground (i.e. 0–40 km from the Murray Mouth). In 2015/16, there was little evidence of the spatial contraction observed in the previous year with higher catches from the southern part of the fishing ground (40–60 km) and an apparent expansion of fishing beyond 60 km from the Murray Mouth.

In most years, higher catches were obtained from the north-western part of the main fishing ground (South Australian Seafood Quality Assurance Program, SASQAP, certified area, 2–62 km from the Murray Mouth). Greater than 60% of the annual catch was obtained from the north-western half of the main fishing ground (0–30 km) in 4 of 8 years from 2008/09–2014/15.

2.3.4.1 Seasonality of catches

Prior to 2010/11, the fishery for Pipi was closed from 1 May until 30 September each year. From 2005/06–2009/10, >50% of the annual catch was taken during October–December each year with declining contributions each month thereafter (Figure 2-6). From 2010/11, fishing has occurred throughout the year under Ministerial Exemption. From 2013/14 to 2015/16, 24–27% of catches have been taken during the historical closed period from May to September with approximately half of annual catches taken during December to February (44–50% of annual catch).

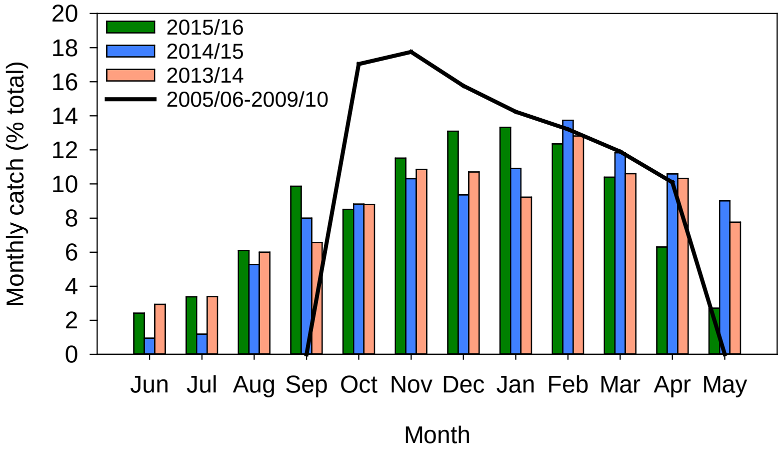

Figure 2-6. Seasonality of catches for three recent years (2013/14 to 2015/16, bars, no temporal closure) compared to combined catches from 2005/06–2009/10 when the winter closure was in place (black line).

2.3.5 Market distribution of catches

The percentage of Pipi suppled to the human consumption market increased from 23% in 2008/09 to greater than 50% from 2013/14 onwards (Figure 2-7). In 2015/16, 62% of the catch was supplied to the human consumption market, the highest value recorded, with any catch not supplied to human consumption markets being supplied to the bait market. Less than 1% of catches were retained for personal use by fishers.

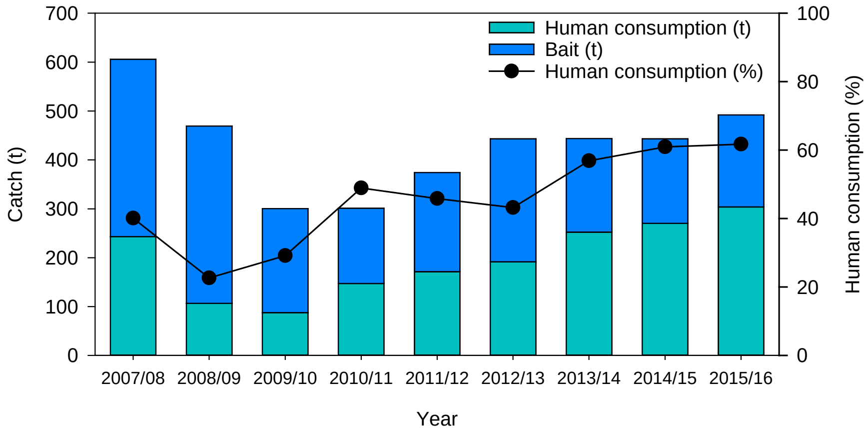

Figure 2-7. Market distribution of Pipi catches from 2007/08 to 2015/16.

2.3.6 Discards

The percentage of licence holders who reported catches of Pipi and also reported discards (i.e. undersized pipi, <35 mm) increased from 44% in 2007/08 to 71% in 2009/10 (Table 2-2). Greater than 60% of licence holders reported discards from 2010/11 to 2014/15, with 71% reporting discards in 2015/16. The percentage of Pipi that were discarded may have been underestimated due to possible non-reporting of discards.

For licences that reported discards, the percentage of discards in the combined catch (discarded catch/(discarded and retained catch)*100) varied among years (Table 2-2). Lowest levels (<10%) of discarding occurred in 2007/08 and from 2010/11–2011/12. The highest levels of discarding occurred in 2009/10 (28%) and 2014/15 (26%).

Table 2-2. Levels of discarded Pipi in commercial catches from 2007/08 to 2015/16.

Financial year	Discards (t)	Discards (% of total catch)	Discards (% of total catch limited to licence holders reporting discards)	% of active licences reporting discards
2007/08	20.7	3.3	4.37	44.4
2008/09	50.8	9.8	12.90	57.9
2009/10	82.9	21.6	28.02	71.4
2010/11	15.5	4.9	6.90	65.0
2011/12	22.9	5.8	7.93	65.0
2012/13	55.1	11.1	16.34	66.7
2013/14	90.8	17.0	23.24	61.5
2014/15	112.1	20.2	26.32	60.0
2015/16	60.8	11.0	14.67	71.4

2.3.7 Search time

Mean daily search time was higher in 2007/08 (mean ±se; 0.94 ±0.05 hours) and 2008/09 (1.43 ±0.05 hours), compared to subsequent years. From 2009/10, mean daily search time remained above 0.4 hours (range 0.52–0.72 hours) with a slight increase from 2013/14 (0.49 ±0.02 hours) to 2015/16 (0.74 ±0.02 hours).

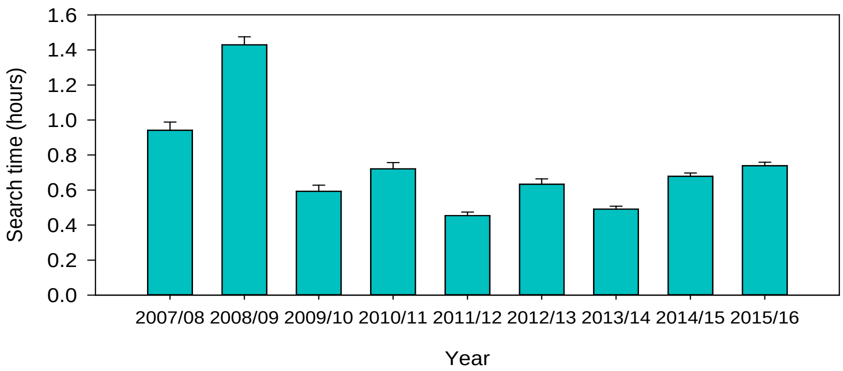

Figure 2-8. Mean daily search time (±se) during Pipi fishing from 2007/08 to 2015/16.

2.4 Discussion

Total annual catches peaked at 1,250 t in 2000/01 and remained above 1,000 t for 6 more years, while $CPUE_{dy,fdy,hr}$ declined steeply. From 2006/07 to 2008/09, catches declined steeply suggesting over-exploitation of the resource (Ferguson and Mayfield 2006; Ferguson 2013). Declining availability of Pipi is supported by high search time in 2007/08 and 2008/09, compared to later years. Conservative TACCs effectively constrained catches from 2009/10.

From 2009/10 to 2012/13, $CPUE_{hr}$ increased, suggesting that the biomass had begun to rebuild; however, this trend was not reflected in $CPUE_{dy,fdy}$.

Simple estimates of commercial CPUE remain a poor predictor of Pipi relative biomass compared to those obtained from FI surveys (Ferguson *et al*. 2015) (Section 3) which is consistent with studies of other species where CPUE was not proportional to abundance over an entire exploitation history or geographic range (Harley *et al*. 2001; Maunder *et al*. 2006). The relationship between annual effort (dy, fdy) and catches differed between two periods in the development of the fishery: 1984/85–2005/06 and 2006/07–2015/16, i.e. from 2006/07 lower catches were obtained from each day of fishing, compared to the preceding period. Anecdotal accounts from fishers and supplementary catch and effort data collected since 2007/08 suggest that the different relationships between these two periods may be due to changes in targeting practices (i.e. fishers increasingly used on-beach size-grading to provide product to the growing human consumption market) (Ferguson and Ward 2014). Changes in targeting are suggested by (i) an increase of 40% to 62% of product supplied to the human consumption market from 2007/08 to 2015/16, and (ii) an overall increase in levels of discarding during this period. Although FD $CPUE_{hr}$ appeared to provide a better measure of relative abundance than $CPUE_{dy}$, or $CPUE_{fdy}$ it was poorly related to FI relative biomass. These results contrast with those from a previous study of Pipi on Younghusband Peninsula which found similar temporal trends for FD CPUE and FI relative biomass from 2007/08–2013/14 (Ferguson *et al.* 2015). The poor relationship between FD CPUE and FI relative biomass observed in this study was likely due to the addition of data from two more years (2014/15, 2015/16), in which there was a strong increase in FI relative biomass but little increase in $CPUE_{hr}$.

While overall catches were consistent with increasing TACCs from 2008/09 to 2015/16, they were spatially variable among years. Spatial contraction of the resource may have occurred from 2012/13 to 2014/15 as suggested by low catches in the south-eastern (40 to <60 km) section of the fishing ground during that period. Conversely, in 2015/16, a higher proportion of the annual catch was taken from this part of the fishing ground suggesting spatial expansion of the resource.

Changes to the SASQAP exclusion zone (Figure 1-1) likely contributed to the spatial re-distribution of catches. Product destined for human consumption markets must originate from within an area determined by SASQAP. For example, there were low catches from the north-western section of the fishing ground in 2010/11, when a section from 0–10 km south-east of the Murray River was closed to commercial fishing. During this period, the SASQAP exclusion zone was extended following detection of high levels of the bacteria *Escherichia coli* associated with flows from the Murray River. The extended exclusion zone included the part of Younghusband Peninsula from 0–30 km south-east of the Murray River in March 2011 but this was reduced to 0–10 km in 2011/12. This restricted access to fishing is reflected in the absence of catches from this north-western section of the fishing ground (0 to <10 km) in 2010/11 and 2011/12. Higher catches from 20 to <40 km in 2010/11 and 2012/13 year suggest that some relocation of fishing effort to the south-east may have occurred.

Uncertainty exists around spatial location of catches from 2007/08 and 2008/09 because of non-reporting of catch location and because significant catches (~14–20% of total) were reported from two areas of Younghusband Peninsula, (i) 0 km i.e. at the Murray River mouth, and (ii) from >60 km south of the Murray River, where it is unlikely that catch was taken because low relative biomass was estimated from FI surveys (Gorman *et al*. 2010). The spatial reporting of catches appears to have improved in recent years given the decrease in non-reported catch locations, however there is potential for further improvement; for example, reporting catches by latitude/longitude. Comparison of spatially resolved catches with FI estimates of relative biomass (Section 3) may provide insight into the fine spatial scale (1–5 km) impacts of fishing on relative biomass and subsequent availability of harvestable sizes.

In addition to spatial resolution of catch and effort reporting, additional sources of uncertainty are: (i) non-reporting of discards; (ii) differences in reporting of effort in fisher days and hours among licence holders (i.e. hours fished with search time included or excluded; number of agents reported); and (iii) the mortality of discards which may be up to 28% of the catch.

Regular catch sampling to obtain data on Pipi sizes for each market would provide useful information on changes in the size classes of Pipi that are targeted by the fishery. This would supplement size structures of Pipi from the FI monitoring program (Section 3).

3 FISHERY-INDEPENDENT SURVEYS OF PIPI

3.1 Introduction

This section provides fishery-independent (FI) estimates of relative biomass and size structures of Pipi at a range of spatial and temporal scales. This allows inter-annual and intra-annual trends in relative biomass and size structures to be examined.

3.2 Methods

3.2.1 Survey design

Fishery-independent surveys were conducted across the entire commercial fishing ground to assess temporal and spatial variability in the distribution and relative abundance of Pipi (Figure 3-1). The survey area is located on Younghusband Peninsula between the mouth of the Murray River to a point 60 km south-east (Figure 3-1).

Surveys were conducted between 2007/08 and 2016/17 with sub-surveys at the beginning (October–November), middle (February–March), and end (May) of the historical commercial fishing season (November–May), but there were several exceptions when sub-surveys were omitted (Section C in pre 2007; mid 2008). For consistency, each sub-survey was conducted over a three day period within the week following the full moon. Each sub-survey was conducted by three teams, with each team responsible for surveying one of three 20 km long sections of the fishing ground. Each team comprised one commercial fisher and one scientific observer.

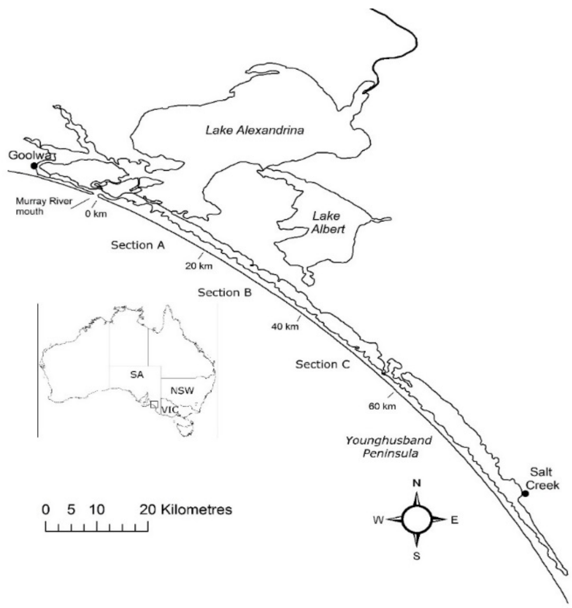

Figure 3-1. Map of the fishing ground for Pipi on Younghusband Peninsula, including the three survey sections: Section A extends south east from the mouth of the Murray River to a distance of 20 km; Section B from 20–40 km; and Section C from 40–60 km. This 60 km section comprises the Coorong Classified Area from which product for human consumption must be caught.

3.2.1.1 Relative biomass

The sampling unit is based on a standard commercial fishing rake (800 × 300 mm frame, 44 mm stretched mesh) which is used to collect Pipi from a 3 m × 1.5 m (4.5 m^2) transect orientated parallel to the shore line. This strategy was used as adult Pipi on Younghusband Peninsula are known to occur in a narrow band located approximately 30–35 m below the mean high water mark within the swash zone (King 1976; SARDI, unpublished data). Samples included the top 15–20 cm of the sediment surface which is greater than the depth to which Pipi typically burrow (James and Fairweather 1995; Lewis *et al*. 2012). To obtain total weight, all legal sized, adult Pipi (>35 mm) from each transect were weighed to the nearest 100 g using calibrated spring scales.

Prior to each sub-survey, fisher effort was standardised by comparing the mean catch weight from each of the three fishers from five randomly-selected locations. For surveys where relative biomass of one fisher differed during pre-survey standardization (4 of 29 sub-surveys) the estimates of relative biomass for the particular fisher and sub-survey were standardised by applying a correction factor:

$$a = b*c/d,$$

where a = corrected relative biomass, b = original relative biomass, c = mean relative biomass of the two equivalent fishers, and d = relative biomass of the less efficient fisher, i.e. for the sub-survey in February 2014, the correction factor for the less efficient fisher was 1.94.

Broad-scale sampling was done at fixed sites selected prior to commencement of surveys in 2007 and located using coordinates (latitude, longitude) stored in hand held GPS units. The sites were located at 2 km intervals, spanning the 60 km fishing ground (Figure 3-1), with each site surveyed twice over two days (n=60 transects). For each year, mean annual relative biomass is the mean weight of adult Pipi (i.e. harvestable biomass) from broad-scale sampling from all sub-surveys (n=180 transects) in a particular year. Annual estimates of relative biomass are presented in financial years which include the November to May fishing season i.e. 2008 refers to the 2008/09 financial year.

In order to investigate intra-annual trends, relative biomass was estimated from each of the sub-surveys (n=60) in each year. To investigate broad-scale spatial variability, the fishing ground was divided into three sections, each of 20 km length (Section A, 0 to <20 km from the mouth of the Murray River; Section B, 20 to <40 km; and Section C, 40 to <60 km). Within each 20 km section were 10 fixed sampling sites, 2 km apart. To investigate spatial trends at a smaller scale relative biomass was also estimated for 10 km long sections (n=9) of the fishing ground in each year.

3.2.1.2 Size Structures

Size-frequency samples were collected by the scientific observer at each of the fixed sites on one day during each sub-survey (i.e. 30 samples). This was done using a commercial fishing rake fitted with fine mesh (10 mm stretched). Samples of Pipi (n=~100) were stored in labelled plastic bags and frozen. In the laboratory, Pipi were measured to the nearest 0.1 mm across the widest axis (width) with digital callipers. Size-frequency distributions were generated for each sub-survey and section (A, B, C) of the fishing ground.

3.3 Results

3.3.1 Inter-annual trends in relative biomass

Estimates of mean annual relative biomass of Pipi were available from 2007/08 to 2016/17. Relative biomass increased from the lowest value (±se) of 4.0 ±0.34 kg/4.5 m^2 in 2008/09 to 10.7 ±0.65 kg/4.5 m^2 in 2009/10 (Figure 3-2). Annual relative biomass remained stable from 2009/10 to 2014/15 (mean 11.4 ±0.28 kg/4.5 m^2; range 9.7–13.2 kg/4.5 m^2). From 2014/15 to 2015/16, annual relative biomass increased to 20.3 ±1.13 kg/4.5 m^2 which was 78% above the 2009/10–2014/15 mean. In 2015/16, annual relative biomass increased to 21.5 ±1.43 kg/4.5 m^2 which was 89% above the 2009/10–2014/15 mean.

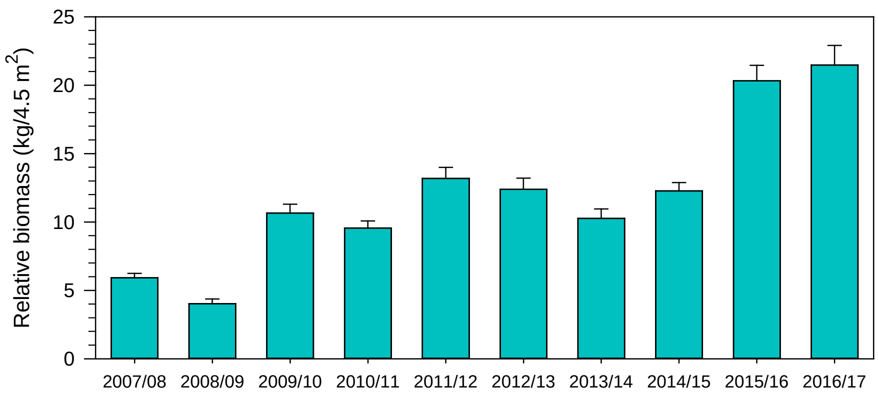

Figure 3-2. Mean (±se) annual relative biomass of Pipi from Younghusband Peninsula from fishery-independent surveys during 2007/08 to 2016/17.

3.3.2 Intra-annual trends in relative biomass

The overall trend among years for relative biomass estimated from pre- (October/November), mid- (February) and post-season (April/May) surveys, was similar to that for mean annual biomass with a general increase from 2007/08 to 2015/16. However, the intra-annual trend in relative biomass varied among years (Figure 3-3).

Relative biomass declined across the fishing season in 2007/08 (70%), 2008/09 (8%), 2012/13 (22%) and 2013/14 (9%). In contrast, relative biomass increased across the fishing season in 2009/10 (48%), 2010/11 (20%), 2011/12 (12%), 2014/15 (68%), 2015/16 (8%) and 2016/17 (>148%). For 2009/10, 2013/14 and 2015/16, relative biomass declined between the pre- and mid-season surveys, with the overall increase occurring between the mid- and post-season surveys.

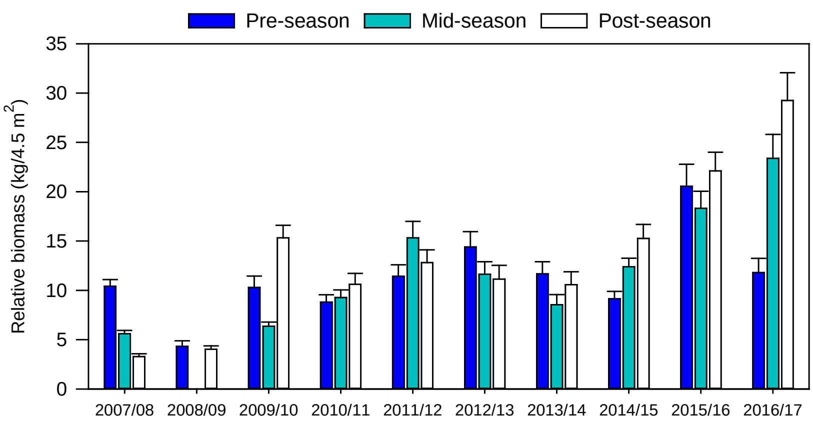

Figure 3-3. Intra-annual trends in mean relative biomass (±se) of Pipi on Younghusband Peninsula from fishery-independent surveys during 2007/08 to 2016/17.

3.3.3 Spatial trends in relative biomass

The distribution of relative biomass across the fishing ground varied among years (Figure 3-4). Years when the highest relative biomass occurred in Section A (north-western fishing ground) were 2007/08, 2012/13, 2014/15 and 2015/16. The lowest relative biomass occurred in Section C (south-eastern fishing ground) in most years. From 2011/12 to 2013/14, the contribution to the total annual biomass from Section C declined consistently suggesting spatial contraction of the resource. Although the total relative biomass was historically high in 2016/17 the contribution from Section C was historically low. The highest recorded relative biomass was in the Section B (central fishing ground) in 2016/17.

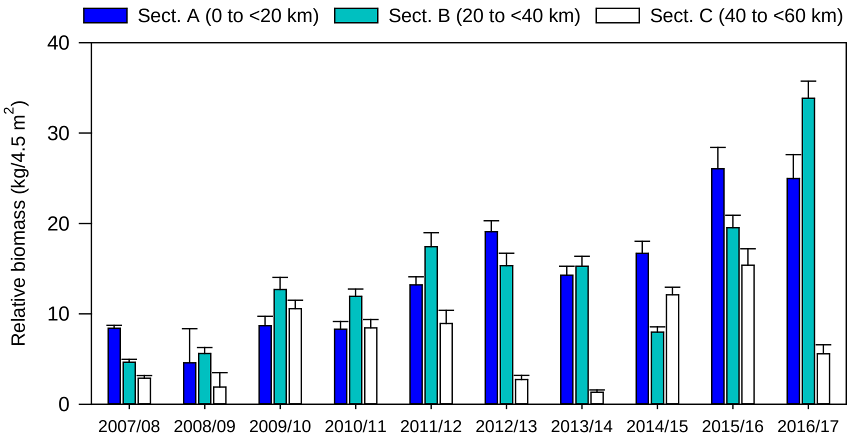

Figure 3-4. Spatial trends in mean (±se) annual relative biomass of Pipi on Younghusband Peninsula from fishery-independent surveys during 2007/08 to 2016/17.

At the finer spatial scale using 10 km sections, annual relative biomass was consistently low across the fishing ground in 2007/08 (<5 kg/4.5m^2) and 2008/09 (<7 kg/4.5m^2), compared to later years (Figure 3-5). While overall relative biomass was stable from 2009/10 to 2014/15, it decreased in the south-eastern part of the fishing ground (50–60 km) throughout this period and was <1 kg/4.5m^2 in 2012/13 and 2013/14. In 2013/14, relative biomass was <3 kg/4.5m^2 over one third (40–60 km) of the fishing ground. The overall higher relative biomass in 2015/16 was associated with higher relative biomass across the extent of the fishing ground including the south-eastern area (40–60 km), with relative biomass >9 kg/4.5m^2 in all 10 km sections. In 2016/17, relative biomass was historically high (>20 kg/4.5m^2) in the north-western and central part of the fishing ground (0–40 km) but was 10 kg/4.5m^2 from 40–50 km and <1 kg/4.5m^2 in the south-eastern most part of the fishing ground.

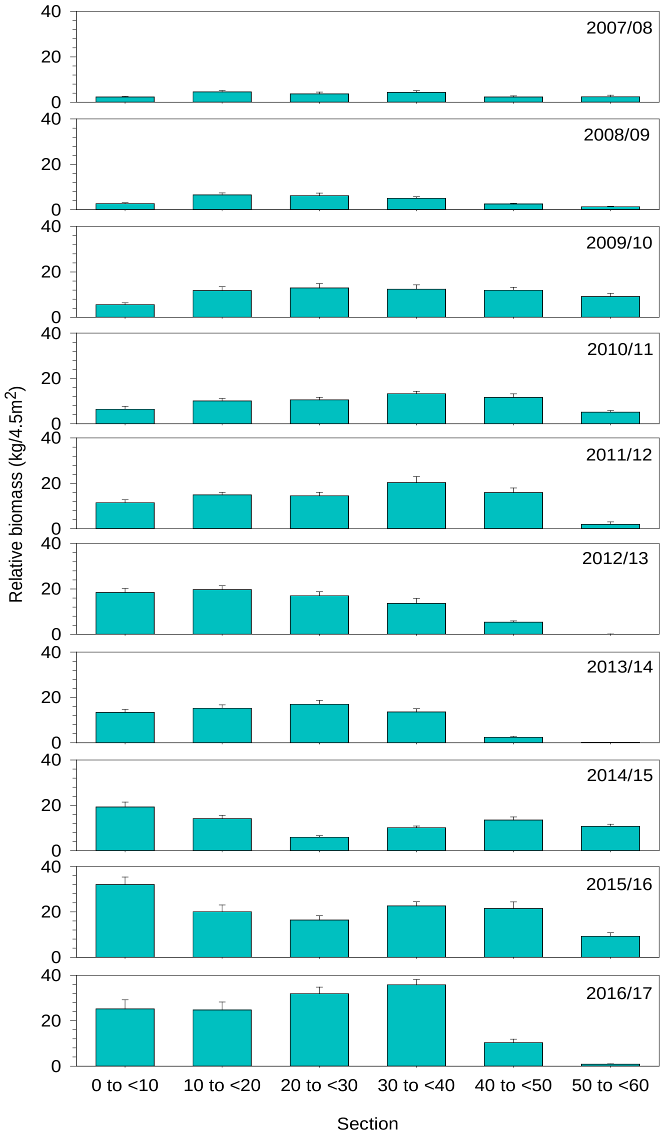

Figure 3-5. Fine-scale spatial trends in mean (±se) annual relative biomass of Pipi on Younghusband Peninsula from fishery-independent surveys during 2007/08 to 2016/17 i.e. 0 to<10 represents the area from the Murray Mouth to a point 10 km south-east of the Murray Mouth.

3.3.4 Population size structures

Size structures of Pipi (research rake, 10 mm mesh) on Younghusband Peninsula ranged from ~10–62 mm shell length with 2–3 modes present and were temporally and spatially variable. When three modes were present, sizes were: (i) small (pre-recruits, 16–35 mm); (ii) recent recruits (35–45 mm); and (iii) large Pipi (>45 mm).

In Section A, during the November–May historical fishing season in 2007/08, two modes were present in size structures (December 2007, February 2008, and April 2008). The largest of these modes occurred at 49 and 53 mm in December 2007 and April 2008, respectively. In

October 2008, prior to the beginning of the 2008/09 fishing season the largest size mode occurred at 54 mm. However, in April 2009 at the end of the fishing season the largest size mode was 17% smaller (45 mm) than at the start of the season. During the following fishing season, the largest mode declined by a further 18% between October 2009 (45 mm) and February 2010 (37 mm). The size of this largest mode increased gradually over the 24 months from April 2010 and was 53 mm in May 2012. In Section A, the large mode at 53 mm present in size structures in May 2012, persisted until November 2012, and then modal size declined by 26% in April 2013 (39 mm). The large mode present in size structures from April 2013 was poorly represented in size structures from November 2014 to April 2016 but was present in May 2017.

The presence of a small mode (16–25 mm) may indicate recruitment (pre-recruits) to research rakes (10 mm). Defined modes of small Pipi, were present in size structures from December 2007 to October 2009 and in November of each year from 2010–2014; i.e. recruitment to the fishing ground occurred in spring in each of these years. In April 2016, a small mode of Pipi (~12 mm) was present across the fishing ground (Sections A, B, C). This small mode of Pipi persisted in November 2016 (~20 mm), with a second, smaller mode of Pipi (~12 mm) present in February 2017.

The timing of recruitment to the fishing ground varies temporally and spatially. In the 2008/09 fishing season, pre-recruits were poorly represented in size structures from November 2008 but were only present in Sections A and B from April of 2009 in. In November 2015, pre-recruits were poorly represented in size structures in Sections A and C but present in Section B. In February 2016, a defined mode of pre-recruits was present in Section A, and in April 2016, this mode of pre-recruits was present across the fishing ground (Sections A, B, C). In February 2017, a mode of pre-recruits that was less defined than in 2016 persisted until May 2017 in Sections A and C but was not present in Section B in either month.

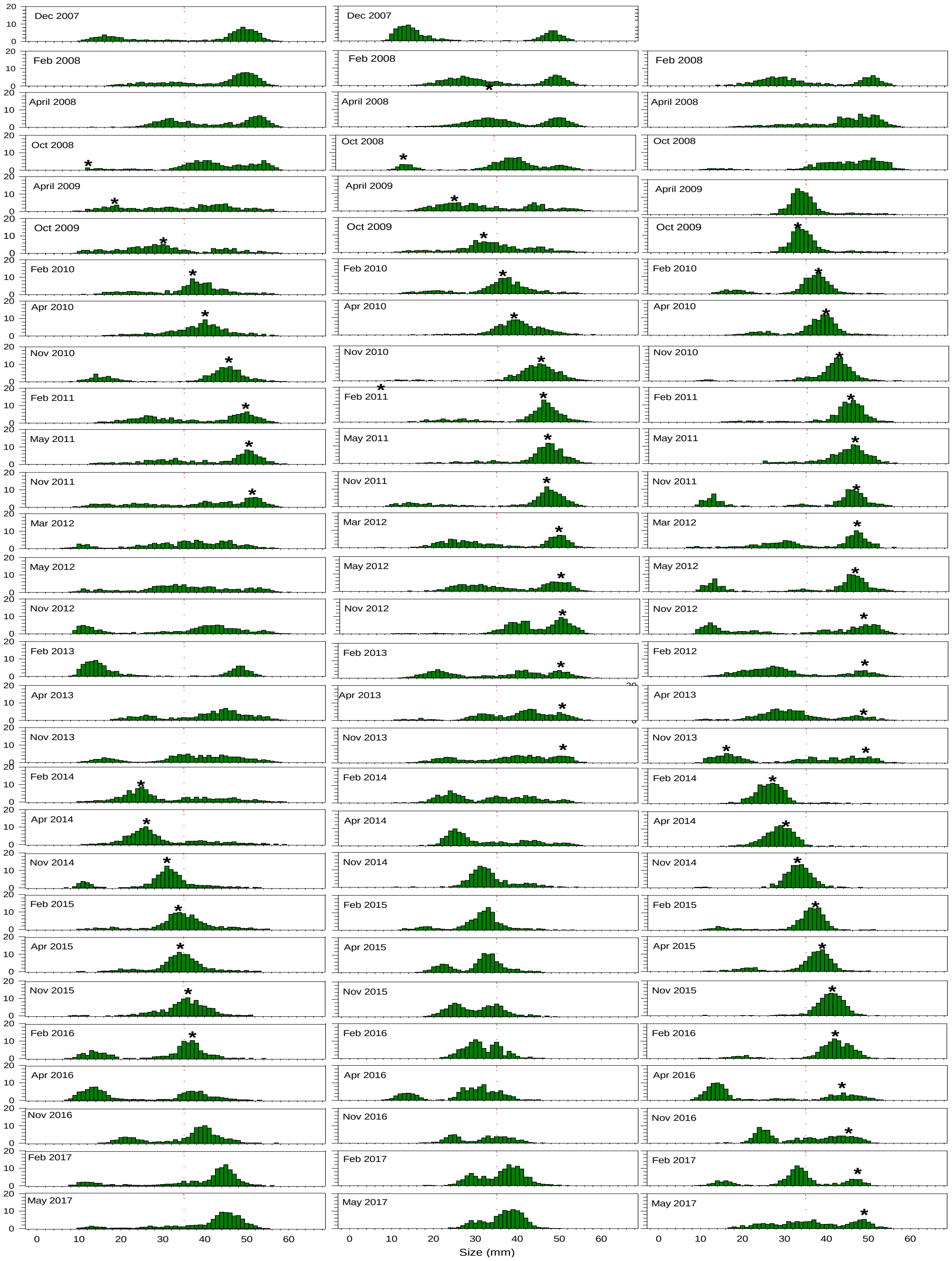

Figure 3-6. Size frequency distributions from three sections of the fishing ground on Younghusband Peninsula: Section A, 0 to <20 (left); Section B, 20 to <40 (centre); and Section C (right), 40 to <60 km from the mouth of the Murray River (right) from 2007/08 to 2016/17. Vertical red, dashed line represents legal minimum size. Possible modal progressions marked with asterisk.

3.4 Discussion

Fishery-independent surveys, which commenced in 2007/08, indicated that mean annual relative biomass (i) was low in 2007/08 and 2008/09; (ii) declined between pre- and post-season surveys in those years; and (iii) that the modal size of larger Pipi in size distributions from 2008 to 2010 was reduced. These results support the assessment of Ferguson and Mayfield (2006) which suggested that the Pipi resource was depleted based on available catch and effort data and declining CPUE throughout each season (Ferguson and Mayfield 2006). From 2009/10, recovery of the Pipi resource was suggested by increasing FI relative biomass and complexity of size structures (Ferguson *et al*. 2015) likely resulting from the combination of (i) a conservative MLS for Pipi, (ii) strong recruitment in 2008/09, (iii) growth of these recruits through 2008/09 and 2009/10, (iv) a voluntary reduction in catches by fishers in 2008/09, and (v) the application of conservative TACCs from 2009/10.

Although stable, mean annual relative biomass of 11.4 kg/4.5 m^2 (range 9.6–12.3 kg/4.5 m^2) occurred over six years from 2009/10 to 2014/15, within any one year, relative biomass varied among sub-surveys and sections (20 km) of the fishing ground. Spatial contraction of the resource appeared to occur from 2011/12 to 2013/14 but low relative biomass in the south-eastern fishing ground was compensated by higher values in the north-western part. During this period, pre-recruits were present in size frequency distributions in four out of five years, and the presence of pre-recruits likely contributed to the stable overall biomass.

The highest values of mean annual relative biomass occurred in 2015/16 and 2016/17. In 2015/16, the exploitation rate, at the TACC of 500 t, may have been sufficiently high for fishing to remove biomass at an equivalent rate to the increases in biomass from recruitment and growth because: (i) growth of Pipi is seasonal with most annual growth occurring during spring-summer (Section 1.6.6); (ii) spring-summer is the period of highest fishery catches (Section 2.3.4.1); (iii) relative biomass was consistent across spring–autumn; (iv) Pipi >40 mm were poorly represented in size frequency distributions in Sections A and B; and (v) the modal size (largest mode <40 mm) in November 2015 had not increased in May 2016. Contrastingly, in 2016/17 when mean annual relative biomass was higher (6%) than in 2015/16, the exploitation rate, at the TACC of 550 t, may have resulted in removal of biomass at a rate lower than biomass contributed by recruitment and growth because: (i) relative biomass increased from November 2016 to May 2017; and (ii) the size of the largest mode in size frequency distributions increased from November 2016 to May 2017.

The Pipi harvest in South Australia is thought to be based on the two year-classes that exist above the minimum legal size (MLS) of 35 mm shell width which is reached at approximately

13–18 months of age (King 1976; 1985). Size structures consistent with the presence of two size/age class above the MLS occurred during several years from 2007/08 to 2014/15, particularly in Section A but did not occur thereafter.

In South Australia, Pipi attained a maximum modal size of ~58 mm in the 1970s when annual catches were historically low (King 1976). In recent years (2015/16 to 2016/17), maximum sizes observed in size structures were smaller (45–50 mm) than those observed during the previous eight years (50–55 mm). This likely reflects (i) the impact of fishing at higher catches (TACCs 500–550 t) compared to the previous years; (ii) depressed growth of Pipi at higher levels of relative biomass (20–21 kg/4.5m^2); or (iii) a combination of both factors.

In 2015/16, most catches were taken from the middle section of the fishing ground which is consistent with the absence of large Pipi in that region. However, uncertainty exists around spatial reporting of catches so these data should be used with caution. Regular sampling of commercial catches would provide useful information on the impact of fishing on available sizes of Pipi. Since markets for Pipi discriminate among sizes, Pipi processors record sizes of the commercial catch. The potential to use processor records exists and can provide ongoing monitoring of the commercial catch.

Recruits were present on the fishing ground in late spring (November) in most years, although exceptions occurred when they were not detected until late summer (2008, 2015). Also, while pre-recruits were present in the north-western part of the fishing ground (Sections A, B) in February 2016, they were poorly represented in Section C until April 2016. Such temporal variability in recruitment of Pipi in South Australia was described by King (1976) who, based on trends in size structures, further suggested that larval settlement may occur more than once during a particular summer. Variability in the month in which pre-recruits are present in size structures, both among years and across the fishing ground, may be due to: (i) timing of spawning; (ii) timing of larval settlement; (iii) the direction of longshore currents during the spawning season (King 1976); and (iv) beach morphology (Thompson and Sánchez De Bock 2009). Although, synchronous spawning of Pipi on Younghusband Peninsula has been suggested (Gluis and Li 2014) the period in which the gonads are developed spans approximately six months (winter-summer). Multiple spawning events during one spring-summer period may contribute to variability in the month in which recruits are detected.

4 PERFORMANCE INDICATORS

4.1 Introduction

The harvest strategy uses two biological performance indicators, and one economic performance indicator, with associated decision rules to recommend a TACC for the following year. The first harvest strategy for Pipi was used to guide the TACC setting process from 2012/13 to 2015/16. In 2015, the second, revised harvest strategy for Pipi was implemented with the second Management Plan for the Lakes and Coorong Fishery and was used to recommend the TACC for 2016/17 (PIRSA 2016). The revised harvest strategy uses the same biological and economic performance indicators as the original harvest strategy but differs in having more conservative target and limit reference points associated with the biological performance indicators (PIRSA 2012; 2016).

Fishery-independent relative biomass has been formally evaluated, gained acceptance by stakeholders (Ward *et al*. 2010; Ferguson *et al*. 2015), and been the primary biological performance indicator in the harvest strategy for Pipi since 2012/13 (PIRSA 2016). A key feature of the method used to estimate relative biomass is strong engagement with Pipi fishers who undertake structured fishing surveys in conjunction with scientific observers.

4.2 Methods

4.2.1 Fishery-independent relative biomass

The collection methods for field data provide estimates of the two biological performance indicators and are described in Section 3, Ward *et al.* (2010) and Ferguson *et al.* (2015). The primary biological performance indicator in the Pipi harvest strategy is the FI estimate of mean annual relative biomass of Pipi (i.e. harvestable biomass). Each annual FI estimate of relative abundance is based on the combined results of three surveys (pre-, mid-, and post-season) which were conducted in October-November, February-March, and April-May of each year. Rakes with standardised mesh (44 mm) are used by fishers to collect Pipi from transects (4.5 m^2) located along 60 km of the Younghusband Peninsula at 2 km intervals from the Murray River mouth. The annual estimate of relative biomass is the mean of all transects from the 3 surveys in that year (n=180).

4.2.2 Presence/absence of pre-recruits

The secondary biological performance indicator is the presence/absence of pre-recruits (<35 mm) in size distributions from October/November of each year. Pipi are collected using a standardised research net (10 mm mesh) from each of the transect locations used for the relative biomass estimates. The size distributions comprise combined samples from all transects located from 0 to 60 km south of the Murray River (n=90).

Pre-recruits are considered to be present in size frequency distributions if they represent at least 30% of the overall size frequency.

4.3 Results

4.3.1 Fishery-independent relative biomass

Estimates of mean annual relative biomass of Pipi are available from 2007/08 to 2016/17 (Figure 4-1). During the development of the second harvest strategy for Pipi, estimates of mean annual relative biomass were available from 2007/08 to 2014/15. The lower limit reference point was set at the lowest mean annual relative biomass of 4.0 kg/4.5 m^2 which occurred in 2008/09. The target reference point of 11 kg/4.5 m^2 was consistent with a period of stable annual relative biomass from 2009/10 to 2014/15 (mean 11.4 ±0.28 kg/4.5 m^2; range 9.7–13.2 kg/4.5 m^2). The trigger reference point of 9 kg/4.5 m^2 was consistent with the lowest annual relative biomass that occurred between 2009/10 and 2014/15, and 18% below the target reference point. From 2014/15 to 2015/16, relative biomass increased by 66% to 20.3 kg/4.5 m^2, which is 78% above the 6-year average from 2009/10–2014/15. In 2016/17, annual relative biomass increased a further 6% to 21.5 kg/4.5 m^2.

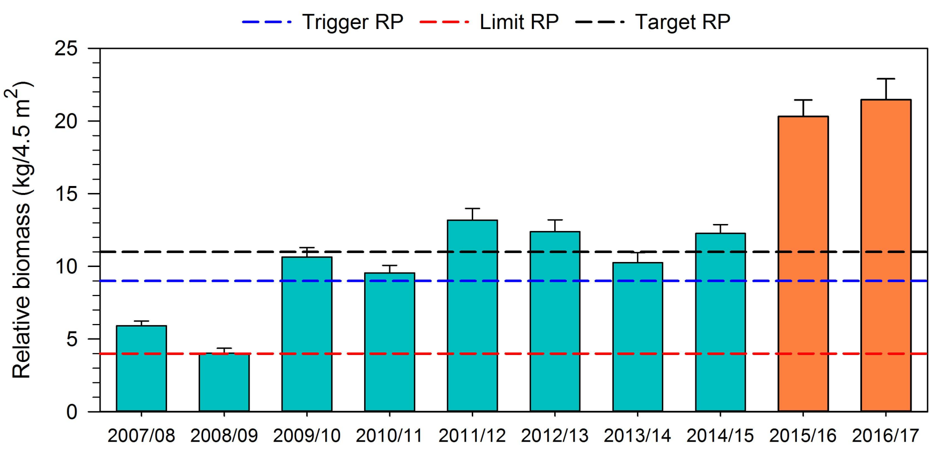

Figure 4-1. Fishery-independent estimates of mean (±se) annual relative biomass of Pipi during development of the harvest strategy (blue) and recent estimates (orange) from 2007/08 to 2016/17. RP = reference point.

Table 4-1. Fishery-independent estimates of mean annual relative biomass.

Year	Relative biomass ($kg/4.5m^2$)	SE
2007/08	5.9	0.3
2008/09	4.0	0.3
2009/10	10.7	0.7
2010/11	9.7	0.5
2011/12	13.2	0.8
2012/13	12.4	0.8
2013/14	10.3	0.7
2014/15	12.3	0.6
2015/16	20.3	1.1
2016/17	21.5	1.4

4.3.2 Presence/absence of pre-recruits

Estimates of the presence/absence of pre-recruits (sub-legal sized Pipi; <35 mm) were available from FI surveys in October–December of each year from 2007 to 2015 (Figure 4-2). A mode of pre-recruits was present in size distributions from pre-season surveys in all years from 2007 to 2016. However, pre-recruits made up a smaller proportion of the size distributions (<30%) in 2008 and 2010. The performance indicator, presence/absence of pre-recruits, was >30% from 2011 to 2016 (i.e. pre-recruits were present). In 2016/17, pre-recruits comprised 52% of size distributions.

4.3.3 TACC for 2016/17 season

From 2012/13 to 2014/15, the annual TACCs for Pipi were recommended under the first harvest strategy for Pipi (PIRSA 2012): 330 t in 2010/11, 400 t in 2011/12 and 2012/13, 450 t in 2013/14 and 2014/15, and 500 t in 2015/16. In 2016/17, a TACC of 550 t was recommended under the revised harvest strategy in the second Management Plan for the LCF (Table 4-2; PIRSA 2013). Under the harvest strategy, the biologically acceptable TACC for 2017/18 is 650 t.

Table 4-1. Pipi harvest strategy decision rule table from the Management Plan (PIRSA 2016).

Relative Biomass ($kg/4.5m^2$)	Maximum biologically sustainable catch*	
	(Pre-recruits absent) Lower TACC range	(Pre-recruits present) Upper TACC range
≥17 to <19	500	650
≥15 to <17	500	600
≥14 to <15	500	550
≥12 to <14	450	500
≥10 to <12	400	450
≥9 to <10	350	400
≥4 to <9	300	350
<4	0	0

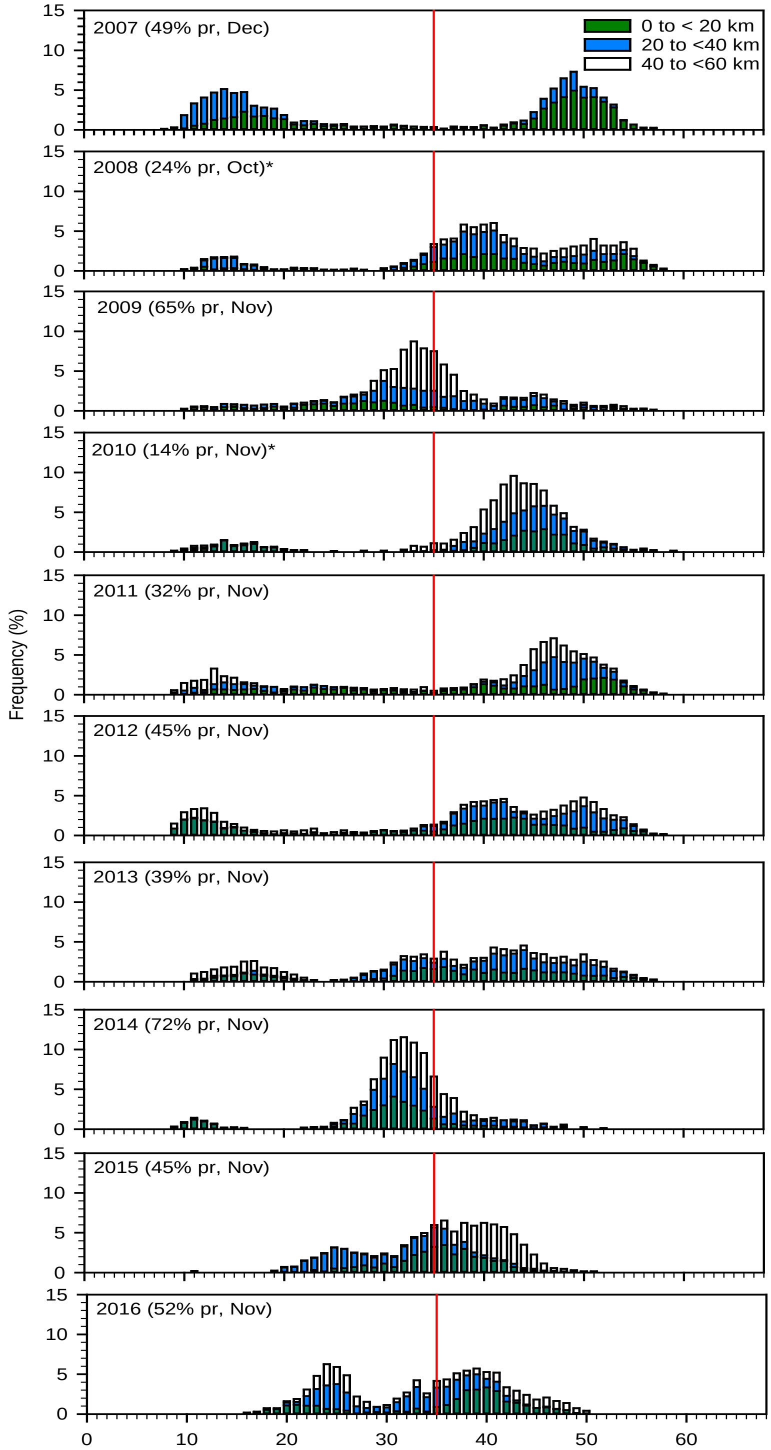

Figure 4-2. Size frequency distributions of Pipi from three sections of Younghusband Peninsula during November (pre-season) surveys from 2007 to 2016. Upper left of each graph shows, year, month of pre-season survey, and percentage of sample below minimum legal size of 35 mm (total samples n = ~1000), represented by vertical red line. *Pre-recruits <30% of total sample.

4.4 Discussion

The reference limits in the harvest strategy for Pipi were set using estimates of relative biomass and pre-recruit presence/absence from 2007/08–2014/15 which included a 2 year period of stock rebuilding and was followed by a period (6 years) of stable relative biomass. Recent, comparatively high levels of mean annual relative biomass underscore the importance of maintaining the current protocol for estimating the two biological performance indicators and continuing to extend the time-series of data/estimates available for the harvest strategy.

The estimates of mean annual relative biomass in 2015/16 and 2016/17 exceeded the highest values in the harvest strategy and were 85% and 95% above the target reference point, respectively. However, it should be noted that the historically high annual relative biomass was associated with a reduction in the maximum size of Pipi observed in size structures in 2015/16 and 2016/17.

Size frequency distributions indicate high inter-annual variability in recruitment to the population of Pipi fishery on Younghusband Peninsula which is also the case for Pipi populations elsewhere (McLachlan *et al*. 1996). Variability in recruitment likely also contributes to variability in the relative harvestable biomass of Pipi. Whilst size frequency distributions provide an indication that recruitment may have occurred, understanding the relative contributions from recruits and pre-recruits is problematic. For example, a high proportion of sub-legal sized Pipi in size frequency distributions may represent recruitment to the fishery or loss of older, larger individuals. Consequently, a time-series of relative abundance of pre-recruits is currently being developed by PIRSA, SARDI, and Pipi fishers for inclusion in a future revision of the harvest strategy.

5 General Discussion

5.1 Current status of the fishery for Pipi

The Pipi resource supporting the Lakes and Coorong Fishery was assessed as depleted in 2006, with 9 prior years of steeply declining relative abundance inferred from FD CPUE (Ferguson and Mayfield 2006). Low relative harvestable biomass in 2007/08 and 2008/09 and the diminished size of the largest mode in size distributions from February 2010 to February 2011 further suggested that the Pipi resource on Younghusband Peninsula was depleted prior to 2009/10 (Ferguson and Mayfield 2006; Ferguson 2010). Due to concerns about the status of the Pipi resource and high levels of latent effort, TACCs were introduced in 2007/08. However, TACCs were considerably higher than the annual catch in 2007/08 and 2008/09 suggesting that the TACCs were too high in those years. The TACCs effectively constrained catches from 2009/10 onwards, and from 2009/10 to 2014/15, annual relative biomass was stable at 11.4 kg/4.5 m^2 per year. High annual relative biomass in 2015/16 and 2016/17 likely reflects consistent recruitment and growth of those recruits into the harvestable population.

The size of the largest mode (~52 mm) in size structures in February 2010 was consistent with the maximum modal size of ~58 mm from an earlier study that measured Pipi when annual catches were historically low (King 1976). However, large Pipi (>45 mm) were not present in size structures in 2014/15 and 2015/16 which was most likely a result of removing larger individuals by fishing. From November 2016 to May 2017, the maximum sizes of Pipi present in size structures increased throughout spring–summer suggesting that recruitment and growth of Pipi contributed more to the harvestable biomass than was removed by fishing in 2016/17. Furthermore, since 2014/15, only one mode of harvestable sized Pipi has occurred in size structures; historically, two modes were present during the early history of the fishery when catches and exploitation rates were low (King 1976) and during 2008/09 and 2012/13 when TACCs were ≤400 t. Poor representation of large Pipi in recent size structures suggests the potential for growth overfishing to be occurring, i.e. Pipi are harvested at an average size that is smaller than the size that would produce the maximum yield per recruit.

The presence of 12–25 mm individuals in size structures from 2011/12 to 2016/17 suggests that consistent recruitment to the fishery has occurred during this period. Additionally, the spatial distribution of small individuals in size structures in November 2016 suggests that recruitment was consistent across the fishing ground in 2016/17.

Application of the harvest strategy for Pipi (mean annual relative biomass 21.5 kg/4.5 m^2; pre-recruits present) indicates that a TACC of 650 t would be biologically acceptable in 2017/18.

PIRSA Fisheries and Aquaculture has adopted the National Fishery Status Reporting Framework (NFSRF) for assessment of fisheries in South Australia (Flood *et al.* 2014; Stewardson *et al.* 2016). The proxy for biomass (FI mean annual relative biomass) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e. not recruitment overfished) and fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished. Consequently, the status of the Pipi resource in 2016/17 is assessed as '**sustainably fished'** (Flood *et al.* 2014; Stewardson *et al*. 2016).

5.2 Information, data gaps and uncertainty in the assessment

This stock assessment of the Pipi resource on Younghusband Peninsula is aided by three previous stock assessments (Murray-Jones and Johnson 2003; Ferguson and Mayfield 2006; Ferguson 2013) and annual stock status reports from 2006 onwards. Also assisting the assessment of the Pipi resource are the Management Plan and harvest strategy for Pipi (PIRSA 2016) and an FRDC project (2008/08) that evaluated potential biological performance indicators for the harvest strategy (Ferguson and Ward 2014).

Although commercial catch and effort data were available from 1984/85 to 2016/17, concerns about changing fisher practices and associated uncertainty around commercial CPUE as an estimate of relative abundance of Pipi have resulted in increased reliance on FI survey data. Assessment of the Pipi resource is primarily informed by annual estimates of relative harvestable biomass and size structures of Pipi from FI surveys during 2007/08 to 2016/17 (Ward *et al*. 2010; Ferguson *et al*. 2015). Since FI surveys are conducted three times per year and transects are located at 2 km intervals, estimates of relative biomass and size frequency distributions provide spatial resolution at a finer scale than fishery catch and effort data.

In addition to evaluating the biological performance indicators during development of the harvest strategy, several key biological knowledge gaps for Pipi on Younghusband Peninsula have been addressed through the FRDC project 2008/008 in collaboration with PIRSA, SARDI, and Pipi fishers including: (i) robust estimates of size at maturity (SAM_{50}, SAM_{95}); (ii) intra-annual trends in gonad development; (iii) intra-annual trends in relative biomass; and (iv) growth of Pipi (Ferguson and Ward 2014).

The Pipi harvest strategy and associated performance indicators, reference points and decision rules have been used to inform the annual TACC since 2012/13. The revised harvest strategy, which includes more conservative reference points, was used to recommend the TACC for the 2016/17 season. For the revised harvest strategy, the reference points for the primary biological performance indicator (FI mean annual relative biomass) were determined from the available time-series (2007/08–2014/15) which included a period of 6 years

(2009/10–2014/15) when mean annual relative biomass was stable at a mean value 11.4 kg/4.5 m^2 per year. In 2015/16 and 2016/17, mean annual relative biomass was respectively, 78% and 89% higher than the mean value for 2009/10–2014/15. Reference points for the primary biological performance indicator may need to be re-evaluated as the time-series of estimates of mean annual relative biomass is extended.

Whilst size structures provide an indication that recruitment may have occurred, understanding the relative contributions from recruits and pre-recruits is problematic because a high proportion of sub-legal sized Pipi in size structures may represent either recruitment to the fishery or loss of older, larger individuals. This will be addressed through a current study to develop an index of relative abundance of pre-recruits.

Currently, levels of discarding of small Pipi are reported in fishery logbooks. However, the sizes of discards are poorly understood because different licence holders may target different size classes. Consequently, the sizes of small Pipi returned to the water after on-beach grading may vary among seasons and licence holders.

Temporal changes in targeting behaviour of fishers and associated changes in fishing practices has resulted in uncertainty around FD CPUE as an index of relative abundance of Pipi. Consequently, CPUE has not been used to inform sustainable management of Pipi in this assessment.

5.3 Future research needs

The most important research need for the Pipi fishery is continued development of the time series of the pre-recruit index. Relative biomass of pre-recruits is estimated using a similar method to that for relative harvestable biomass but differs in that samples are graded for size to separate the pre-recruits. Estimates of relative biomass of pre-recruits are available for 2016 and 2017.

Industry has expressed interest in whether growth of Pipi is supressed at high densities such as those observed in 20165/16 and 2016/17. Recent reduction of the size of the largest mode in size structures may be due to (i) larger individuals being removed by fishing; (ii) depression of the growth rates at high levels of relative biomass; and/or (iii) a combination of both factors. A current FRDC proposal aims to address this issue using digital technology to provide fine-spatial monitoring of the Pipi resource and geo-fencing to allow comparison between fished and unfished areas.

Processes affecting the recruitment of Pipi on Younghusband Peninsula are poorly understood. Because larval duration of Pipi is likely short, understanding recruitment processes could be enhanced by investigating the relationship between spawning seasonality and that of longshore currents on Younghusband Peninsula. Additionally, food and habitat requirements (i.e. beach morphology, slope, moisture content, sand grain size) of early recruits (<5 mm) are poorly known.

Validation of annual growth and the maximum age of Pipi based on shell microstructure has the potential to provide reliable age estimates for bivalves (Arneri *et al.* 1998; Ezgeta-Balić *et al.* 2010; Izzo *et al.* 2016). Validated ages would inform yield per recruit analysis to improve understanding of how growth, natural mortality, and fishing interact to determine the best size at which to start fishing Pipi, and the most appropriate level of fishing mortality (Gayanilo *et al.* 2005; Herrmann *et al.* 2009; 2011).

Other future research needs include: (i) improved spatial reporting of commercial catch and effort and catch size structures, which could be achieved using digital technology; (ii) the potential for maximising production by targeting fishing towards the end of the spring-summer growth season; (iii) better understanding of the seaward distribution of Pipi; (iv) improved understanding of the diet of Pipi on Younghusband Peninsula; and (v) the influence of Murray River outflows and oceanic upwelling on diet, growth and recruitment.

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