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J. Dent, S. Mayfield, G. Ferguson, J. Carroll and P. Burch

SARDI Publication No. F2014/000191-1
SARDI Research Report Series No. 766

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

May 2014

Stock Assessment Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

This is the third report to provide estimates of harvestable biomass of mud cockles (*Katelysia* spp.) across the South Australian commercial fishery. Along with previous estimates of size at maturity, this provides the most robust information to help recommend a total allowable commercial catch to the Minister.

The mud cockle fishery consists of three cockle fishing zones and is based on three species: *Katelysia scalarina* (“greys”), *K. rhytiphora* (“yellows”), and *K. peronii* (“whites”). The current (2013/14) TACCs in Coffin Bay and the West Coast cockle fishing zones are 50.0 t and 18.5 t, respectively which corresponds to a harvest fraction of 6.0% and 2.2%, respectively. The Port River cockle fishing zone was not surveyed as it has been closed since July 2011 due to low mud cockle abundance and recruitment.

Best estimates of harvestable biomass from the Coffin Bay cockle fishing zone were 769.8 t for *K. rhytiphora* (≥38 mm shell length (SL)), 188.6 t for *K. scalarina* (≥30 mm SL) and 0.2 t for *K. peronii* (≥38 mm SL). Collectively this provided a total best estimate of harvestable biomass of 958.6 t. There was an 80% probability that the total harvestable biomass was at least 806.4 t.

The combined best estimate of harvestable biomass (≥30 mm SL) from the West Coast cockle fishing zone in October and November 2013 was 884.7 t, most of which was in Streaky Bay (73%). Following a mortality of mud cockles during December 2013, Streaky Bay was re-surveyed in February 2014. Using estimates based on the February 2014 survey for Streaky Bay and the 2013 survey elsewhere, the best estimate of harvestable biomass for the West Coast cockle fishing zone was 356.9 t for *K. scalarina,* 196.3 t for *K. rhytiphora* and 96.5 t for *K. peronii* which was 26% (total: 649.8 t) lower than the estimate prior to the mortality event. There was an 80% probability that the total harvestable biomass was at least 501.7 t.

The harvest strategy for the mud cockle fishery allows a maximum harvest fraction of 7.5% (at the 80% confidence interval). To maintain the 2012/13 and 2013/14 TACC in the Coffin Bay (50.0 t) and West Coast (18.5 t) cockle fishing zones, the required harvest fraction would be 6.0% and 3.7%, respectively.

Under current exploitation rates the mud cockle fisheries in Coffin Bay and the West Coast are classified as ‘**<u>sustainable’.</u>**

1. INTRODUCTION

1.1 Background

The genus *Katelysia* (Family Veneridae), commonly known as mud cockles or vongole, is a group of commercially important bivalves that represents a major faunal component of shallow estuarine and marine embayments (Roberts 1984). In Australia, the genus is represented by three species – *Katelysia scalarina* (Lamarck 1818) known as “greys”, *K. rhytiphora* (Lamy 1835) known as “yellows” and *K. peronii* (Lamarck 1818) known as “whites” – all of which are broadly distributed around the temperate coastline from Augusta, Western Australia to Port Jackson, New South Wales (Roberts 1984).

Mud cockles have been harvested in South Australia since the early 1960s. Prior to 1985, most of the catch was obtained from the Port River and Kangaroo Island for use as bait. Since then, mud cockles have largely been used for human consumption, particularly in Melbourne. Despite increasing demand, the fishery remained lightly exploited until 1995/96, when the State-wide annual catch exceeded 50 t. From 1996/97, catches increased rapidly to a peak of 375 t in 2005/06. Most of the catch was obtained during this period from the Port River and Coffin Bay. Given the large number of licenses (>600) with access to the resource and the rapid increases in catch, concerns for the sustainability of the fishery were raised which led to implementation of a quota management system across the three cockle fishing zones (Port River, Coffin Bay and West Coast; Figure 1) in October 2008.

The initial total allowable commercial catch (TACC) in 2008/09 was based primarily on catch history and was 100 t for Port River, 70 t for Coffin Bay and 25 t for the West Coast cockle fishing zones. The TACC for all zones combined was 195 t, however of this, 171 t (including the catch used as bait and berley) was landed with a value of AU$1.28M (Knight and Tsolos 2012). In 2009/10, advice from fishers (West Coast and Coffin Bay cockle fishing zones) and survey estimates of biomass (Port River cockle fishing zone) led to reduced TACCs in all three zones. TACCs for the Port River, Coffin Bay and West Coast cockle fishing zones in 2009/10 were 22.6 t, 56.0 t and 15.0 t, respectively (total 93.6 t). The total catch in this fishing season was 99 t (including the catch used as bait and berley) with a value of approximately AU$1.16M (Knight and Tsolos 2012).

Following the first assessment of harvestable biomass across all three cockle fishing zones (Gorman *et al.* 2010), TACCs for 2010/11 were set at 11.3 t for the Port River, 48.1 t for Coffin Bay and 21 t for the West Coast cockle fishing zones (total 80.4 t). The catch in this fishing season was 85 t (including the catch used as bait and berley) with a value of AU$1.20M (Knight and Tsolos 2012). In addition, the minimum legal length (MLL) for all three *Katelysia* species in the Coffin Bay cockle fishing zone was reduced from 38 to 33 mm shell length (SL) through Ministerial exemption. Minimum legal lengths in the Port River and West Coast cockle fishing zones remained at 30 mm SL.

In response to concerns around sustainability, the mud cockle fishery in the Port River was closed from 1 July 2011. The Coffin Bay and West Coast cockle fishing zones remained open for the 2011/12 fishing season with the TACC set at 48.1 t and 18 t, respectively, which corresponded to a harvest fraction of 6.0% and 3.3%, respectively, from the 80% confidence interval of harvestable biomass. Following the second estimate of harvestable biomass in Coffin Bay and the West Coast cockle fishing zones (Dent *et al.* 2012), TACCs for 2012/13 and 2013/14 fishing seasons were increased to 50.0 t and 18.5 t for these zones, respectively. As the Port River cockle fishing zone remains closed, no fishery-independent surveys have been conducted in zone since May 2009, hence there are no estimates of harvestable biomass for this zone. Also in 2012/13, the MLL for *K. scalarina* in the Coffin Bay cockle fishing zone was amended by Ministerial exemption to 30 mm SL to provide access to a larger proportion of the population as few *K. scalarina* reached the legislated MLL and >90% were sexually mature at 30 mm SL. The MLL for other *Katelysia* species in Coffin Bay reverted to the legislated 38 mm SL.

1.2 Objectives

This is the third report on the harvestable biomass of mud cockles in South Australia and follows from Gorman *et al.* (2010) and Dent *et al.* (2012). The objectives of this report are to: (1) provide an estimate of harvestable biomass of mud cockles in the Coffin Bay and West Coast cockle fishing zones; and (2) provide estimates of harvestable biomass at two MLLs for *K. rhytiphora* and *K. peronii* in the Coffin Bay cockle fishing zone in response to an industry proposal to reduce the MLL for *K. rhytiphora* in the Coffin Bay cockle fishing zone. This information will be used in the harvest strategy to establish management arrangements for the 2014/15 and 2015/16 fishing seasons, including TACCs and MLLs.

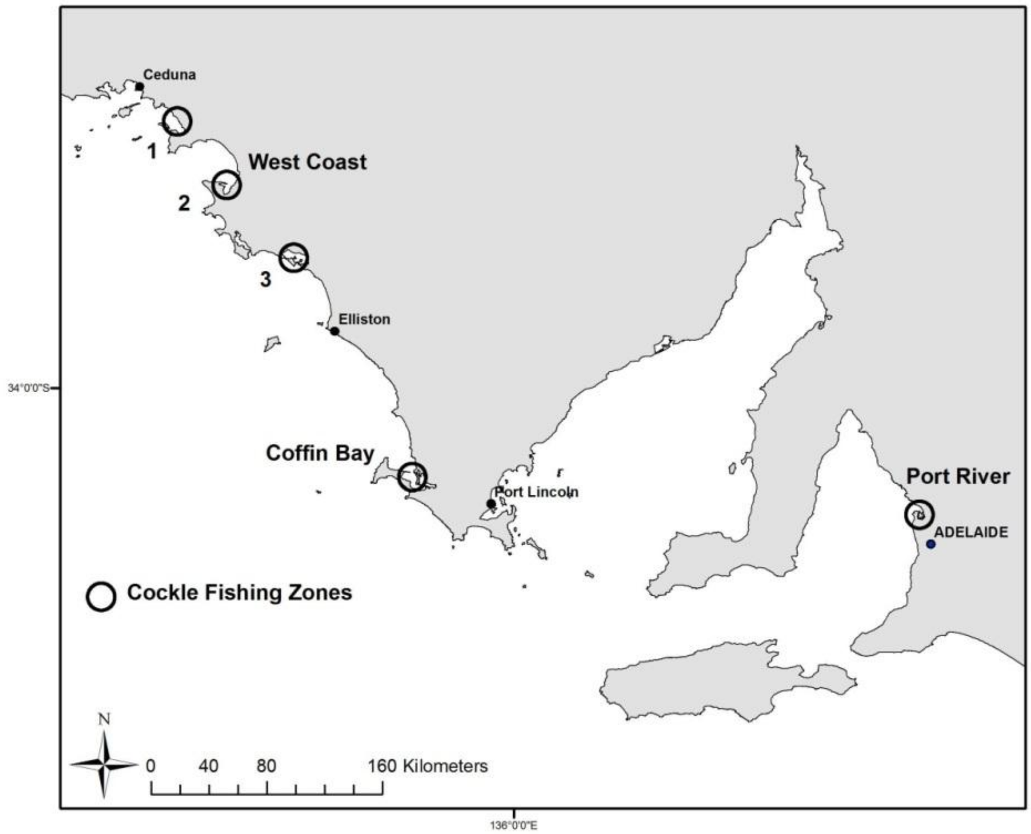

Figure 1. Map showing locations of commercial cockle fishing zones in South Australia: Port River, Coffin Bay and the West Coast. The West Coast zone comprises Smoky Bay (1), Streaky Bay (2) and Venus Bay (3).

2. METHODS

The focus of the study was to provide estimates of the harvestable biomass of mud cockles (i.e. ≥ MLL) in bounded, stratified survey regions within two commercial cockle fishing zones: Coffin Bay and the West Coast. The West Coast cockle fishing zone comprises Smoky Bay, Streaky Bay and Venus Bay.

Surveys of mud cockles were undertaken at Coffin Bay in October 2013 and on the West Coast in October and November 2013. Subsequent to the survey in November 2013, a mortality of mud cockles in Streaky Bay, probably caused by a combination of extreme weather and tidal conditions, was observed by fishers in December 2013. For this reason, a second survey of the resource in Streaky Bay was conducted in February 2014 using the same method as that for the 2013 survey. The second survey provided a reassessment of the harvestable biomass in Streaky Bay which took into account the potential impact that the cockle mortality may have had on the biomass.

2.1 Study sites and survey design

The survey design was consistent with previous assessments of the mud cockle resource in South Australia (Gorman *et al.* 2010; 2011) and integrated commercial-fisher knowledge with fishery-independent research sampling similar to that undertaken for abalone (Mayfield *et al.* 2008b; 2009). Within each cockle fishing zone, fishers identified areas of high and low productivity in the fishing grounds on large-scale aerial photographs. This information was digitized using a Geographic Information System package (ArcGIS v10.1) and used to identify high and low density strata. Maps of mud cockle density strata were generated and returned to fishers for confirmation. Point sampling locations were then distributed systematically within the high and low density strata comprising each survey region. To improve survey precision, sampling intensity was greater in areas with expected high densities of mud cockles (high density strata, sites separated by 30-100 m) than those of expected low densities of mud cockles (low density strata, sites separated by 250-360 m).

The Coffin Bay survey comprised eleven strata while that for the West Coast survey comprised 23 strata: nine in Smoky Bay, three in Streaky Bay and eleven in Venus Bay.

2.2 Survey methodology

The fishery-independent surveys were conducted by survey teams which included a South Australian Research and Development Institute (SARDI) observer and a commercial fisher. Sampling sites were located using global positioning system (GPS). At each sampling site a commercial fisher used a cockle rake (~40 cm in width by ~20 cm in height) with a mesh bag insert (2 cm diagonal mesh size) to collect mud cockles along a transect length of 2 m (i.e. ~0.8 m^2). Samples were sieved through 7 mm square mesh in the base of a plastic crate to remove sand. Live and dead mud cockles were bagged, labelled and frozen for later processing in the laboratory.

In the laboratory, each sample was sorted to remove dead shells and identify mud cockles to species (after Edwards 1999). For the West Coast cockle fishing zone, samples were separated into legal (≥30 mm SL) and sub-legal sized (<30 mm SL) groups. For the Coffin Bay cockle fishing zone, *K. scalarina* were separated into two size classes (<30 mm SL; ≥30 mm SL) while *K. rhytiphora* and *K. peronii* were separated into three size categories (<35 mm SL; ≥35-37.99 mm SL; ≥38 mm SL) to allow an optimal MLL for these two species to be evaluated. Mud cockles in each size category were counted and weighed to the nearest gram. Digital calipers were used to measure all individuals to the nearest 0.1 mm along the longest axis (SL). Due to large sample sizes, *K. scalarina* from the Coffin Bay cockle fishing zone were sub-sampled. These data were used to evaluate changes in population size composition among surveys (Gorman *et al.* 2010; Dent *et al.* 2012).

2.3 Estimates of harvestable biomass

Total harvestable biomass for each survey area was estimated as the weighted-mean biomass density multiplied by the survey area (m^2). Total harvestable biomass for each survey area and stratified total harvestable biomass for each of the survey regions were calculated as the sum of the totals from the strata and survey areas in each region.

A non-parametric, two level bootstrap method (after McGarvey *et al.* 2008) was used to determine confidence intervals around the estimates of legal-sized biomass for each species, in each survey region, using the R 3.0.2 statistical software package. All strata and survey areas within each sampled survey region were included in the analysis. The bootstrap procedure accounted for the random variation at the sampled level of the survey design (i.e. the sampling locations in each survey block). The 200,000 bootstrap iterations of estimated biomass were ranked and the 10%, 20% to 90% quantile confidence intervals extracted. The harvestable biomass values presented in the results and discussion were the 50% quantile from this bootstrap.

Decision tables were formulated based on the nine levels of lower-bound, survey-estimated biomass in the survey sub-region (Mayfield *et al.* 2008b). Each table corresponded to a bootstrap confidence probability from 10% to 90%, to provide a risk assessment framework for determining the TACCs. In the decision tables, the probability percentages (10%, 20%,…,90%) are quantiles used to separate harvestable biomass estimates from a stratified bootstrap. They specify the confidence probability that the actual harvestable mud cockle biomass is greater than or equal to the estimated biomass values. An assumption of this method was that the sampling gear was 100% efficient.

3. RESULTS

3.1 Coffin Bay

A total of 6,474 mud cockles were obtained from the 219 sampling sites in the Coffin Bay cockle fishing zone. The dominant species was *K. scalarina* (n=3,643; ~56%), followed by *K. rhytiphora* (n=2,821; ~44%) and *K. peronii* (n=10; <1%). Legal-sized *K. rhytiphora* (≥38 mm SL) and *K. scalarina* (≥30 mm SL) individuals were observed in seven of the eleven strata. Sub-legal-sized individuals of *K. rhytiphora* and *K. scalarina* were collected from ten and eight of the eleven strata, respectively. Legal-sized (≥38 mm SL) and sub-legal sized (<38 mm SL) *K. peronii* were observed in one of the eleven strata surveyed.

The estimated mean densities for legal-sized and sub-legal sized *K. scalarina* were 3.9±0.7 and 6.5±1.1 mud cockles.m^{-2}, respectively. For legal-sized and sub-legal sized *K. rhytiphora*, the estimated densities were 7.5±1.6 and 15.7 mud cockles.m^{-2}, respectively. The estimated densities of legal-sized (≥38 mm SL) and sub-legal sized (<38 mm SL) *K. peronii* were 0.001±0.001 mud cockles.m^{2} and 0.1 mud cockles.m^{2}, respectively.

For *K. rhytiphora,* the estimated harvestable biomass was 769.8 t based on a MLL of 38 mm SL. Estimated harvestable biomass increased by 159.8 t based on a MLL of 35 mm SL (Table 1). The estimated harvestable biomass was lower at 188.6 t (MLL ≥30 mm SL) for *K. scalarina*. The estimated harvestable biomass of *K. peronii* was low (0.2 t; MLL 38 mm SL; Table 1).

For *K. scalarina,* approximately equal proportions of legal (≥ 30 mm SL) and sub-legal sized individuals were observed in length frequency distributions from 2013 (Figure 2). This contrasted with size structures from 2011 where sub-legal sized *K. scalarina* comprised 63% of the length frequency distribution. For *K. rhytiphora*, the proportion of sub-legal-sized individuals (<38 mm SL; Figure 2) increased slightly between 2009 and 2013.

Table 1. Estimated harvestable biomass (t, whole weight 10–90% confidence intervals) of *K. scalarina, K. rhytiphora and K. peronii* at three alternate minimum legal lengths (MLLs) in the Coffin Bay cockle fishing zone in October 2013.

Coffin Bay MLS 38 mm SL

species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
K. rhytiphora	581.5	643.8	689.9	730.5	769.8	809.7	853.0	905.4	979.8
K. peronii	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.4	0.4

Coffin Bay MLS 35 mm SL

species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
K. rhytiphora	697.7	774.3	831.2	881.1	929.6	978.9	1032.5	1097.2	1189.1
K. peronii	0.0	0.0	0.0	1.0	1.0	1.0	1.0	2.1	2.1

Coffin Bay MLS 30 mm SL

species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
K. scalarina	150.1	162.6	172.0	180.5	188.6	196.9	206.0	217.0	233.1

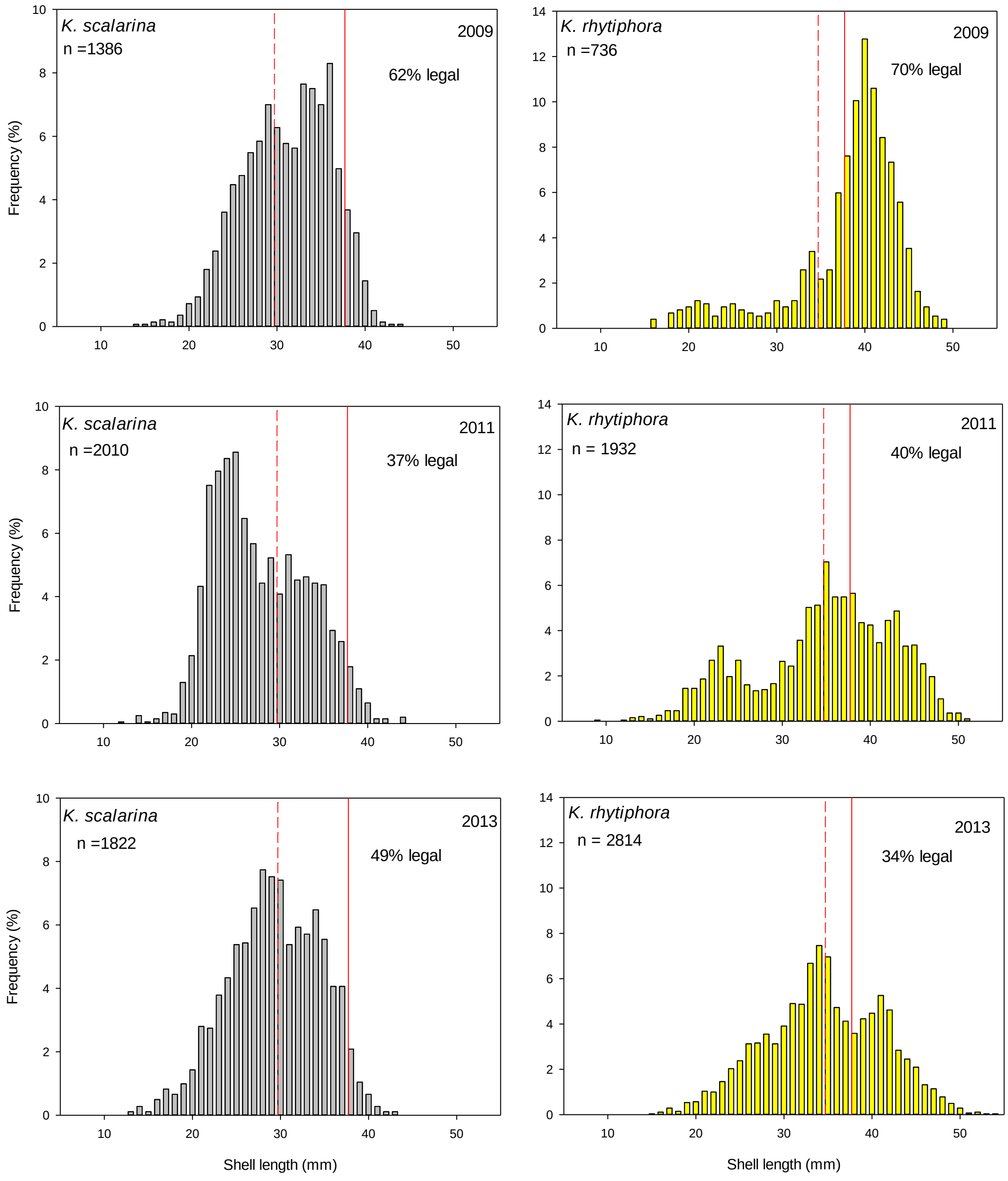

Figure 2. Length-frequency distributions for *K. scalarina* (grey bars) and *K. rhytiphora* (yellow bars) from the Coffin Bay cockle fishing zone in 2009, 2011 and 2013. For *K. scalarina* the solid line indicates the legislated MLL (38 mm SL) and the dashed line indicates the current MLL of 30 mm SL, in place under a Ministerial exemption. For *K. rhytiphora* the solid line indicates the legislated MLL (38 mm SL) and the dashed line indicates a potential alternative MLL of 35 mm SL. Percent legal refers to the proportion of SLs ≥ MLL. Note scales on y-axis vary between species but not among years.

3.2 West Coast

The fishery-independent survey of the West Coast cockle fishing zone was conducted in October and November 2013. Because Streaky Bay was subsequently re-surveyed in February 2014, following a mortality of mud cockles, estimates of biomass for the West Coast are provided using data from the 2014 survey of Streaky Bay and the 2013 survey from Venus Bay and Smoky Bay.

3.2.1 October and November 2013 data

A total of 5,916 mud cockles were collected from 141 sampling sites. Overall, the numerically dominant species was *K. scalarina* (n=3,681; ~62%), followed by *K. peronii* (n=1439; ~24%) and *K. rhytiphora* (n=796; ~14%). Most mud cockles where obtained from Streaky Bay which yielded a total of 2,809 individuals (*K. scalarina*: n=2,332, ~83%; *K. rhytiphora*: n=424, 15%; *K. peronii*: n=53, 19%).

The density estimates of legal-sized *K. scalarina* (≥30 mm SL) at Smoky, Streaky and Venus Bays were 6.3±1.5, 21.8±4.5 and 6.4±1.2 mud cockles.m^{-2} respectively. For *K. rhytiphora*, the density estimates were 1.8±0.4, 11.9±4.0 and 0.7±0.3 mud cockles.m^{-2} in Smoky Bay, Streaky Bay and Venus Bay, respectively. Densities of legal-sized *K. peronii* were 2.0±1.4 and 5.6±2.6 mud cockles.m^{-2} at Streaky Bay and Venus Bay, respectively, while no *K. peronii* were observed at Smoky Bay.

In Streaky Bay, the length frequency distribution of *K. scalarina* was dominated by sub-legal-sized individuals in 2009 and 2013 (Figure 3). Conversely, the sub-legal sized component of length frequency distributions in 2011 was substantially smaller (40%). Temporal patterns in Venus Bay were more consistent with the proportion of legal-sized individuals comprising approximately 50% in each year (Figure 4). The length frequency distribution of *K. scalarina* in Smoky Bay was dominated by legal-sized individuals in all years (Figure 5).

Evaluating temporal changes in the length frequency distributions of *K. rhytiphora* and *K. peronii* in the West Coast cockle fishing zone was impeded by small sample sizes in some years. However, for *K. rhytiphora* there was evidence of an increasing proportion of sub-legal sized individuals in length frequency distributions from 2011 to 2013 at Streaky Bay and Venus Bay, whilst the opposite was observed for *K. peronii* at Venus Bay (Figures 3-5).

The estimate of total harvestable biomass for all species in the West Coast cockle fishing zone was 884.7 t. The majority of the harvestable biomass was located at Streaky Bay which contributed 646.5 t (73%) to the total, whilst Venus Bay and Smoky Bay contributed 142.8 t (16%) and 95.4 t (11%), respectively (Table 2). The majority of the biomass comprised *K. scalarina* (521.3 t, 59%) with smaller contributions from *K. rhytiphora* (258.3 t, 29%) and *K. peronii* (105.1 t, 12%).

3.2.2 February 2014 data

A total of 4,016 mud cockles were collected from Streaky Bay in February 2014 (*K. scalarina,* n=3,669; *K. rhytiphora,* n=297; *K. peronii*, n=50). The mean densities of legal-sized *K. scalarina*, *K. rhytiphora* and *K. peronii were* reduced by 45% (12.1±2.5 mud cockles.m^{-2}), 24% (9.0±2.8 mud cockles.m^{-2}) and 15% (1.7±0.9 mud cockles.m^{-2}), respectively, between December 2013 and February 2014. For *K. scalarina*, mortality was size-specific with larger (>20 mm SL) mud cockles affected to a greater extent than smaller (<20 mm SL) individuals (Figure 3). There was no evidence of size-specific mortality for either *K. rhytiphora* or *K. peronii*.

The estimate of harvestable biomass in Streaky Bay from the survey in February 2014 was 411.6 t (Table 3) which was 36% lower than the estimate of 646.5 t from November 2013. This comprised mostly *K. scalarina* (49%, 202.5 t) with smaller contributions from *K. rhytiphora* (40%, 166.2 t) and *K. peronii* (~10%, 42.9 t).

Amalgamating the February 2014 data for Streaky Bay with the 2013 data for Smoky Bay and Venus Bay, provided a combined estimate of harvestable biomass for the West Coast cockle fishing zone of 649.8 t, which was 26% lower than the estimate based on surveys in all three areas in 2013 (884.7 t). Of the 649.8 t, Streaky Bay contributed 63% (411.6 t) with Venus Bay and Smoky Bay contributing 22% (142.8 t) and 15% (95.4 t), respectively.

Table 2. Estimated harvestable biomass (t, whole weight; 10–90% confidence intervals) of *K. scalarina, K. rhytiphora and K. peronii* (≥30 mm SL) in Smoky Bay, Streaky Bay and Venus Bay which comprise the West Coast survey region in October and November 2013.

Smoky Bay	MLL 30 mm SL								
species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
K. scalarina	51.5	57.9	62.7	66.9	70.9	75.1	79.6	84.9	92.6
K. rhytiphora	17.3	19.7	21.4	23.0	24.4	25.9	27.5	29.4	32.1
K. peronii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Streaky Bay	MLL 30 mm SL								
species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
K. scalarina	275.0	304.5	327.0	347.2	366.9	387.4	409.8	436.7	476.3
K. rhytiphora	136.8	166.6	189.1	209.1	228.2	247.5	269.0	294.9	331.0
K. peronii	10.6	18.7	27.3	44.0	51.4	57.2	67.0	87.4	100.6

Venus Bay	MLL 30 mm SL								
species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
K. scalarina	66.6	72.2	76.3	80.0	83.5	87.0	90.9	95.6	102.1
K. rhytiphora	2.2	3.5	4.2	5.0	5.7	6.5	7.2	8.2	9.3
K. peronii	23.2	31.1	39.4	47.3	53.6	59.8	67.6	78.4	90.7

Table 3. Estimated harvestable biomass (t, whole weight; 10–90% confidence intervals) of *K. scalarina, K. rhytiphora and K. peronii* (≥30 mm SL) at Streaky Bay in the West Coast survey region in February 2014.

Streaky Bay	MLL 30 mm SL								
species	Probability (%) of legal biomass estimate (t)								
	90%	80%	70%	60%	50%	40%	30%	20%	10%
K. scalarina	154.6	170.5	182.4	192.8	202.5	212.6	223.4	236.1	254.5
K. rhytiphora	103.2	124.0	139.4	153.2	166.2	179.5	194.1	211.4	235.9
K. peronii	14.9	22.8	30.1	36.6	42.9	46.1	53.4	61.0	74.5

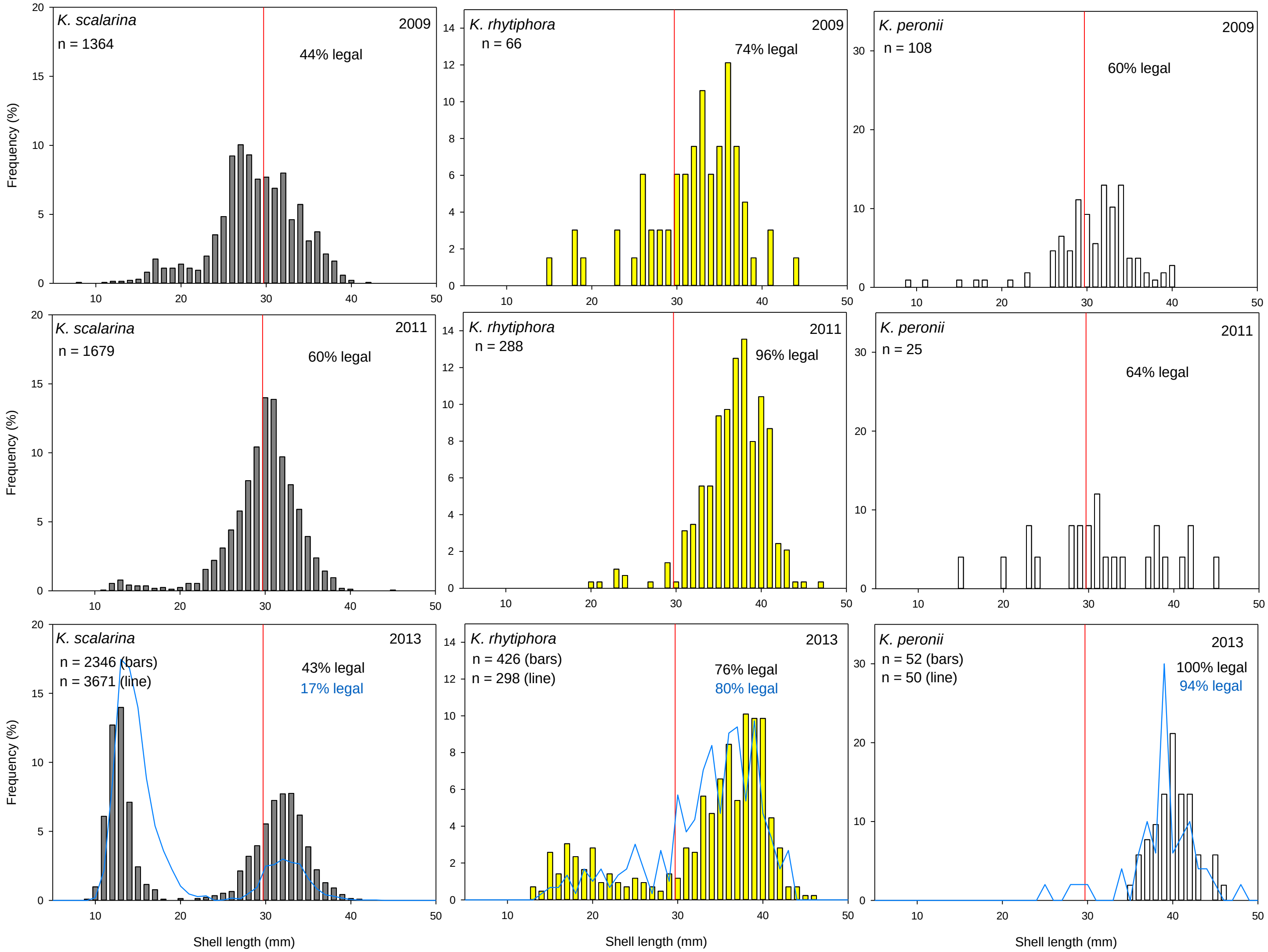

Figure 3. Length-frequency distributions for *K. scalarina*, *K. rhytiphora* and *K. peronii* obtained from Streaky Bay in 2009, 2011, 2013 (bars) and February 2014 (blue line). Solid vertical line indicates the MLL of 30 mm SL. Percent legal refers to the proportion of SLs ≥ MLL. Note scales on y-axis vary between species but not among years.

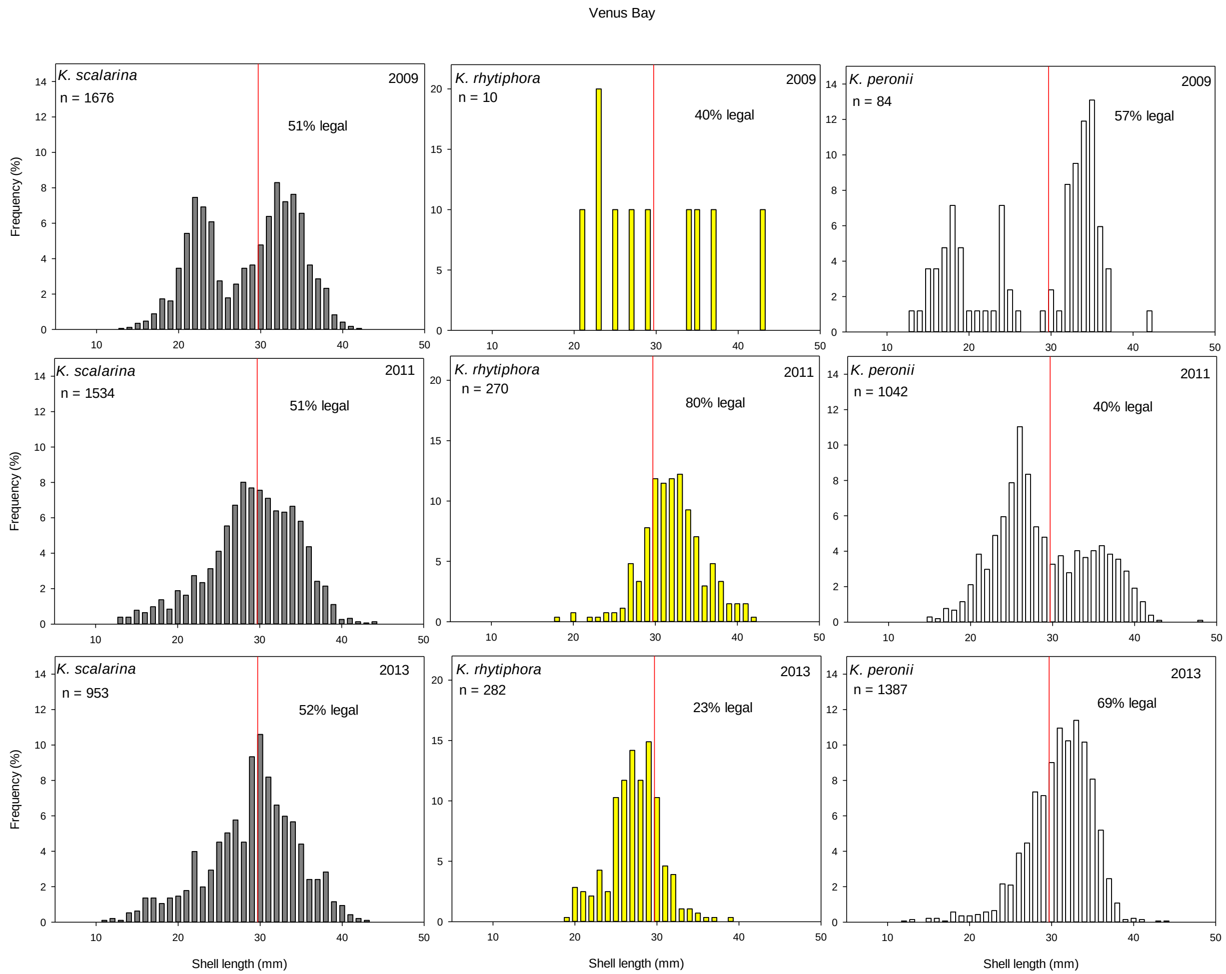

Figure 4. Length-frequency distributions for *K. scalarina*, *K. rhytiphora* and *K. peronii* obtained from Venus Bay in 2009, 2011 and 2013. Solid line indicates the MLL of 30 mm SL. Percent legal refers to the proportion of SLs ≥ MLL. Note scales on y-axis vary between species but not among years.

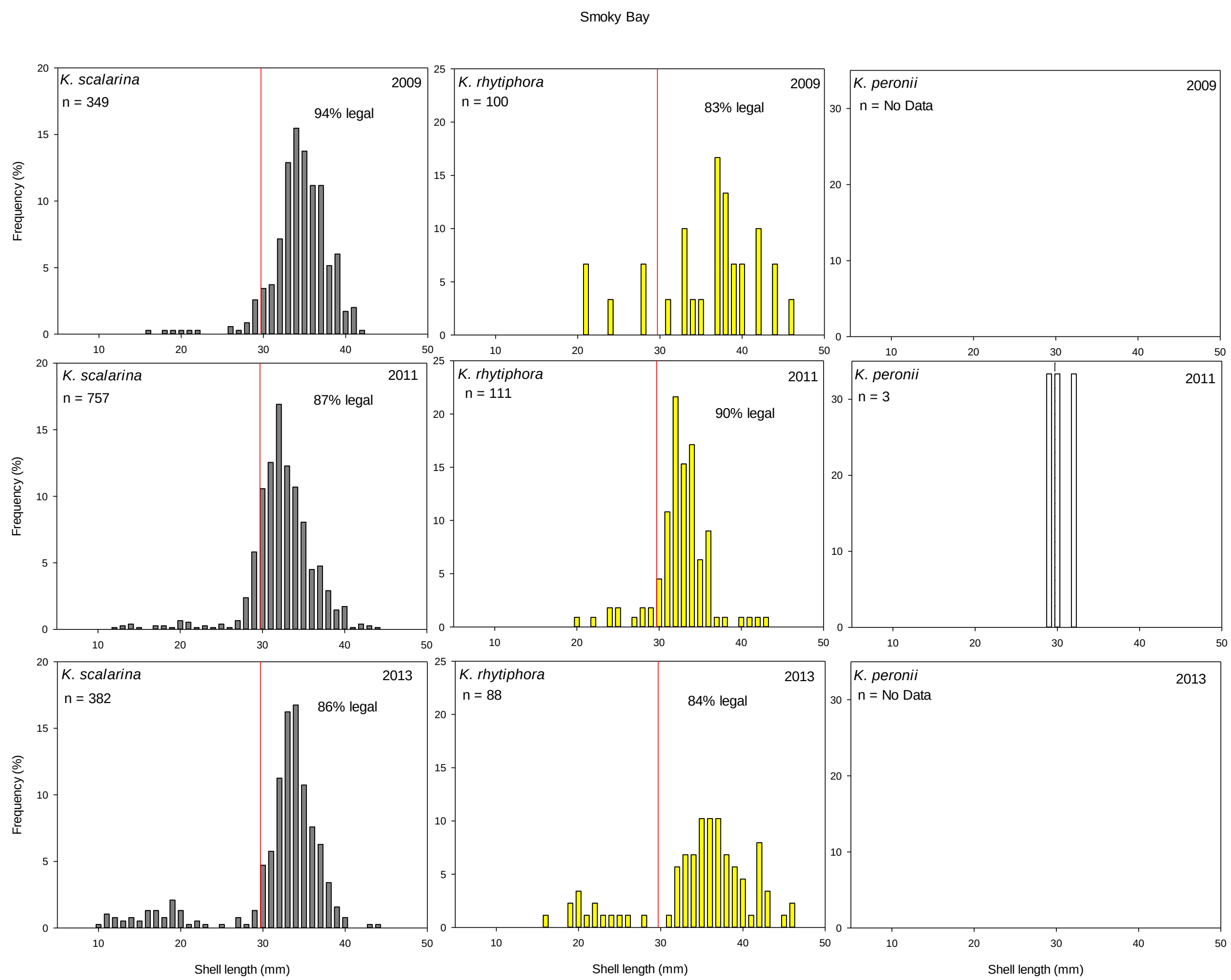

Figure 5. Length-frequency distributions for *K. scalarina*, *K. rhytiphora* and *K. peronii* obtained from Smoky Bay in 2009, 2011 and 2013. Solid line indicates the MLL of 30 mm SL. Percent legal refers to the proportion of SLs ≥ MLL. Note scales on y-axis vary between species but not among years.

4. DISCUSSION

4.1 Harvest strategies for mud cockles

Optimising harvests in multi-species, spatially-complex fisheries is challenging and typically requires information on the composition, distribution, abundance, biomass and biology of the component species (Mangel *et al.* 1996; Haddon *et al.* 2006). This was clearly exhibited by the large reductions in TACCs across the South Australian mud cockle fishery, initially set on the basis of catch history, following surveys in 2009 that provided estimates of harvestable biomass (Gorman *et al.* 2010; 2011). The information presented in this report, which is the third to document the surveys across the fishery, remains the most suitable for informing management decisions relating to TACCs and MLLs (Mayfield *et al.* 2008b; McGarvey *et al.* 2008; Gorman *et al.* 2010; 2011; Dent *et al.* 2012).

The estimates of harvestable biomass and measures of size at maturity (SAM_{50}) obtained in these studies are considered robust information for setting TACCs (Mayfield *et al.* 2008b; McGarvey *et al.* 2008; Mayfield *et al.* 2009) because (1) the precision of the biomass estimates were optimised by targeting survey effort into productive fishing grounds identified by commercial fishers, with less sampling effort in unproductive areas (Ault *et al.* 1999); and (2) measures of SAM_{50} have been obtained from large sample sizes (>3,000 and >700 mud cockles) across the Coffin Bay and West Coast cockle fishing zones, respectively (Gorman *et al.* 2010; Dent *et al.* 2012). When applying this information for determining management arrangements for the fishery, consideration also needs to be made of the risk of population depletion (Ripley and Caswell 2006) in these fisheries. These often occur in cockle fisheries as a result of fluctuating biomass consequent to episodic recruitment (Warner and Chesson 1985; Sakurai *et al.* 1998; Ripley and Caswell 2006). For example, in Coffin Bay, a recruitment pulse observed for *K. scalarina* in 2011 was not observed in either 2009 or 2013.

The TACC is the primary tool used to ensure biological sustainability and is determined as a fraction of the biomass estimate (at the 80% confidence interval), up to a maximum of 7.5% (PIRSA 2013). The TACC is set for a period of two quota years, and is revised annually based on information from fishers as surveys are undertaken biennially. The current harvest fractions are 6.0% and 2.2% for the Coffin Bay and West Coast cockle fishing zones, respectively. The annual TACCs for the mud cockle fishery have been determined from an aggregated estimate of legal-sized biomass for each species. This approach may no longer be appropriate because of declines in the density of *K. scalarina* and the proportion of the harvestable biomass comprising this species in both cockle fishing zones. An effective strategy to overcome this difficulty would be to implement species-specific MLLs and TACCs, but would need to consider required changes to management and compliance arrangements.

4.2 Mud cockle stock status

The current Management Plan (PIRSA 2013) does not identify limit reference points below which the stock would be classified as 'recruitment overfished' under the national stock status framework (Flood *et al.* 2012). Consequently, this assessment uses a 'weight-of-evidence' approach to determine stock status. For both cockle fishing zones, exploitation rates are low (i.e. <7.5%) and there are MLLs in place that should enable mud cockles to reproduce prior to being available for harvest. Given there is no evidence to indicate that the (1) stock is recruitment overfished; or (2) current fishing pressure is likely to result in the stock becoming recruitment overfished, the stock status of mud cockles in the Coffin Bay and West Coast cockle fishing zones has been classified as '**sustainable**'.

4.2.1 Coffin Bay

Changes in the estimates of harvestable biomass among years reflect inter-annual variation in both the area surveyed and density estimates. In Coffin Bay, there have been several changes to the survey design since the first survey in 2009. Specifically, the areas surveyed in 2013/14 differed from previous years in two ways: (1) several survey areas in Coffin Bay that were surveyed in 2010/11 and 2012/13 were excluded from the survey in 2013/14; and (2) the area of the low density strata was reduced. Collectively, these changes were made to exclude areas no longer considered as "commercial grounds" thereby increasing the cost-effectiveness of the biennial survey. As a consequence of these changes, the estimates of density among years provide the best measure of variability in mud cockle abundance.

Applying the current size limits consistently over the three survey years and by using sites which were sampled in all previous surveys allows for comparison of density among years. The densities of legal-sized and sub-legal-sized *K. scalarina* have declined by approximately 50% since surveys began in 2009. In contrast, the density of sub-legal-sized *K. rhytiphora* has more than doubled since 2009, whilst the estimate of legal-sized density has remained relatively stable. These changes in density have resulted in the proportion of the *K. scalarina* contributing to a decline in harvestable biomass from 37% to 20%. These patterns are also evident in the length frequency distributions for both species. For example, there is clear evidence of a recruitment pulse for *K. rhytiphora* in 2013, whereas the recruitment pulse observed for *K. scalarina* in 2011 was not observed in 2009 or 2013. However, the substantial proportion of the *K. scalarina* population below the MLL suggests that there has been recruitment to the harvestable biomass of both species in recent years.

Applying the maximum harvest fraction of 7.5% (80% confidence interval), prescribed in the Management Plan (PIRSA 2013) under the current MLLs, would yield a TACC of 60.5 t (12.2 t of *K. scalarina* ≥ 30 mm SL; 48.3 t of *K. rhytiphora* ≥ 38 mm SL). In the 2012/13 and 2013/14 fishing seasons, the TACC for the Coffin Bay cockle fishing zone was 50 t, which represented a 6.0% harvest fraction from the 80% confidence interval of the biomass estimate. Maintaining the TACC at 50 t would reflect an exploitation rate of 6.2%, which is below the level of 7.5% prescribed in the Management Plan.

The range of TACCs available for Coffin Bay is also dependent on the MLL for each species. The MLL of 30 mm SL for *K. scalarina* that is currently in place appears optimal for this species given estimates of SAM_{50}. However, an appropriate ongoing MLL for *K. rhytiphora* is less clear because fishers have identified concerns over the potential for a high mortality of sub-legal-sized *K. rhytiphora* caused by the grading process which is used to separate sub-legal-sized mud cockles from the retained catch. Fishers contend that a smaller MLL for *K. rhytiphora* would result in fewer mud cockles being returned to the cockle beds following grading. Given the relatively large difference between the MLL and size at maturity for *K. rhytiphora* (6.9 mm), a smaller size limit could be considered. If the MLL for *K. rhytiphora* was decreased to 35 mm SL, application of the maximum (7.5%, 80% confidence interval) harvest fraction permitted under the current management plan would yield a TACC for 2014/15 of 70.3 t (12.2 t of *K. scalarina* ≥ 30 mm SL; 58.1 t of *K. rhytiphora* ≥ 35 mm SL). This TACC is greater (~16%) than that obtained using the same approach but with a 38 mm SL MLL for *K. rhytiphora*.

4.2.2 West Coast

The West Coast cockle fishing zone comprises three areas – Smoky Bay, Streaky Bay and Venus Bay. As in Coffin Bay, changes in the estimates of harvestable biomass among years reflect inter-annual variation in both survey design and density estimates. Consequently, the estimates of density among years provide the best measure of variability in abundance.

Density has varied among years, areas and species, with no obvious consistent trends. For example, density estimates of legal-sized *K. rhytiphora* were high in Smoky Bay in 2009, but have been low in subsequent surveys. In contrast, the estimates of density for this species in Venus Bay show the opposite trend. At Streaky Bay, density estimates of both *K. rhytiphora* and

K. scalarina have declined sequentially since 2009. Overall, these changes have resulted in the proportional contribution of *K. scalarina* to the harvestable biomass reducing from >70% to ~60%. There are also changes in population structure. These include evidence of a substantial recruitment in 2013 of *K. scalarina* in Streaky Bay and *K. rhytiphora* in Venus Bay.

The estimate of harvestable biomass of all species for the West Coast cockle fishing zone from the November and December 2013 surveys was 884.7 t. Following the mortality event of mud cockles in Streaky Bay in December 2013, however, the revised estimate of harvestable biomass in February 2014 was 649.8 t, resulting in a spatial distribution of this harvestable biomass of 63% (411.6 t) in Streaky Bay, 22% (142.8 t) in Venus Bay and 15% (95.4 t) in Smoky Bay. The reduction in the estimate of harvestable biomass was primarily the result of mortality of legal-sized *K. scalarina* in Streaky Bay. The mortality event appears to have been concentrated around the “bushes” and “hummocks” cockle fishing areas which support high densities of mud cockles, predominantly *K. scalarina*. The other two species, *K. rhytiphora* and *K. peronii*, are mostly found in different areas which appear to have been only mildly affected by the mortality event. Whilst histopathology of fresh dead and surviving cockles failed to identify the cause of the mortality event, an extended period of days with air temperatures in excess of 40°C, combined with unusually low tides is considered the most likely cause.

In 2012/13, the TACC for this cockle fishing zone was set at 18.5 t. This reflected an exploitation rate of 2.2% at the 80% confidence interval. This relatively low TACC (and low harvest fraction) was set predominantly because commercial fishers identified that there was inadequate fishing capacity to harvest a larger TACC (Gorman *et al.* 2011), such as that permitted under the Management Plan (i.e. 80/7.5; 37.6 t). For 2014/15, the maximum available TACC permitted for the West Coast cockle fishing zone by the harvest strategy in the Management Plan (7.5% harvest fraction, 80% confidence interval) is 37.6 t. If the TACC in 2014/15 was set at the same level as in 2013/14 (i.e. 18.5 t) this would reflect a harvest fraction of 3.7% (at 80% confidence). Both of these potential TACCs take into account the mortality event of mud cockles in Streaky Bay during summer 2014.

As the mud cockle populations in each of the three West Coast cockle fishing grounds likely comprise separate stocks, the spatial structure of the mud cockle stocks should be formally incorporated into management of the fishery (Taylor and Dizon 1999; Lorenzen *et al.* 2010). Until this occurs catches should be harvested from these areas in approximate proportion to the biomass available for harvest.

4.3 Future research needs

The most important component of future research is to maintain the 2013 sampling design for the West Coast and Coffin Bay fishing zones for the planned 2015, 2017, 2019 and 2021 surveys. This is to ensure that variation in harvestable biomass estimates among surveys accurately reflects changes in population abundance rather than a combination of changes in both abundance and survey design. Notably, mud cockle recruitment is highly variable among years, which requires careful management of adult stocks to maintain adequate spawning biomass.

Using the current method of collecting size frequency information, small mud cockles (up to about 12 mm SL) can be lost through the 7 mm square mesh used to wash the sand from the sample. Obtaining a more representative data on the sub-legal-sized population will require development of an alternative method that would retain mud cockles of approximately 5 mm SL. Development of a new method would need to consider other mud cockle sampling issues such as the efficiency of a rake with a smaller mesh size and reconciliation of historical and future population length frequency distributions.

Given documented spatial variation in the biology of bivalves (Cranfield and Michael 2001) and other benthic marine invertebrates – at both local and regional scales (Saunders and Mayfield 2008) – the lower estimate of SAM_{50} obtained for *K. scalarina* in the West Coast cockle fishing zone (23.2 mm SL; Dent *et al.* 2012), whilst similar to previous estimates (Fowler and Eglinton 2002), was smaller than that obtained from nearby Coffin Bay (26.1 mm SL; Gorman *et al.* 2011). Given the large increase in the proportion of *K. rhytiphora* comprising the harvestable biomass in the West Coast cockle fishing zone between surveys, more robust estimates of SAM_{50} are required for this species, but also for *K. peronii*.

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