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Rock Lobster Survey of the Western Kangaroo Island Marine Park – Cape Du Couedic (Sanctuary Zone 3)

L. McLeay, R. McGarvey, A. Linnane, J. Feenstra and P. Hawthorne

SARDI Publication No. F2017/000282-1
SARDI Research Report Series No. 962

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

September 2017

Report to the Department of Environment, Water and Natural Resources

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This publication may be cited as:
McLeay, L., McGarvey, R., Linnane, A., Feenstra, J. and Hawthorne, P. (2017). Rock Lobster Survey of the Western Kangaroo Island Marine Park – Cape Du Couedic (Sanctuary Zone 3). Report to the Department of Environment, Water and Natural Resources. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2017/000282-1. SARDI Research Report Series No. 962. 38pp.

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Printed in Adelaide: September 2017

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Date:	28 September 2017
Distribution:	DEWNR, PIRSA Fisheries and Aquaculture, SAASC Library, Parliamentary Library, State Library and National Library
Circulation:	Public Domain

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ACKNOWLEDGEMENTS

Funds for this research were provided by the Department of Environment, Water and Natural Resources (DEWNR). Thanks to Dr Simon Bryars (DEWNR) and staff within DEWNR's Marine Parks Program for background information relating to research and monitoring of South Australia's Marine Parks, and for their review of the report. The Northern Zone Rock Lobster Fishermen's Association coordinated the hire and use of the commercial rock lobster fishing vessel 'Quadrant' and we thank the skipper and crew of the Quadrant for their assistance with the survey. Kylie Howard (SARDI Fisheries - Information Services Group) provided valuable and timely administrative support for data entry and corrections required in the SARL database. The report was formally reviewed by Dr Ben Stobart and Dr Jason Tanner (SARDI Aquatic Sciences) and formally approved for release by Dr Stephen Mayfield (SARDI Aquatic Sciences).

EXECUTIVE SUMMARY

Marine Protected Areas (MPAs) are internationally recognised as a spatial management tool to protect and conserve marine and coastal habitats, species biodiversity and abundance, as well as community, economic, social and cultural heritage values. The Western Kangaroo Island Marine Park (WKIMP) was declared as part of South Australia's Representative System of MPAs in 2009. Sanctuary Zone 3 (SZ-3) of the WKIMP is a no-take area protected from fishing since 1 October 2014 and located within Marine Fishing Area (MFA) 48 of the Northern Zone Rock Lobster Fishery (NZRLF).

As part of DEWNR's Marine Park Monitoring, Evaluation and Reporting Program, and in collaboration with the Northern Zone Rock Lobster Fishermen's Association (NZRLFA), the South Australian Research and Development Institute (SARDI) (Aquatic Sciences) undertook a research project to:

1. survey the relative biomass, relative abundance and size of Southern Rock Lobster (*Jasus edwardsii*) and the abundance of key bycatch species, inside and outside SZ-3 of the WKIMP in February 2017.
2. estimate from historical commercial fishery-dependent data, the relative biomass, relative abundance and size of Southern Rock Lobster, and the abundance of key bycatch species, inside and outside SZ-3 of the WKIMP, and compare the historical data with the 2017 survey results.

Survey estimates of relative biomass (catch per unit effort (CPUE), kg/potlift) and abundance (CPUE, lobsters/potlift) of legal size lobsters (≥ 105 mm carapace length) were 4.4 and 3.5 times higher, respectively, inside SZ-3 compared to outside SZ-3 in 2017. Positive population responses within SZ-3 were indicated by an 81.1% increase in relative biomass, 42.2% increase in relative abundance, and 4.1% and 12.5% increases in the mean size of legal size female and male lobsters, respectively, since 2013, when fishing was last permitted. These results support other research into the effects of marine parks on commercial lobster stocks, and are biologically plausible considering Southern Rock Lobster in SZ-3 have been protected through 3 summers and 2 winters since full implementation of sanctuary zones on 1 October 2014.

Analyses of the historical CPUE data indicate that the relative biomass and abundance inside and outside SZ-3 were similar between the 1994/95 and 2013/14 fishing seasons, prior to marine park implementation, indicating that the lobster population located south of Cape du Couedic was distributed relatively homogenously across rocky reef habitat inside and outside SZ-3 during this period. However, female and male lobsters were significantly larger inside SZ-3 than outside SZ-3 during this time, and there were significantly higher numbers of undersize lobsters recorded outside SZ-3 than inside SZ-3, indicating ontogenetic separation of habitat use among Southern Rock Lobster within the WKIMP.

The key bycatch species identified in the 2017 survey were similar to those reported historically in the NZRLF between 1994/95 and 2015/16. However, the bycatch data should be treated with caution. Rock lobster pots are designed to limit bycatch through their design specifications and therefore are not likely to be the most suitable sampling tool for obtaining measures of species richness, evenness or abundance on temperate reefs.

Keywords: Southern Rock Lobster, *Jasus edwardsii*, marine parks, fishery, bycatch, CPUE, South Australia.

1. INTRODUCTION

Marine Protected Areas (MPAs) are internationally recognised as a spatial management tool to protect and conserve marine and coastal habitats, species biodiversity and abundance, as well as community, economic, social and cultural heritage values. Australia's obligations to protect marine biodiversity and ecosystem integrity are listed internationally under the *Convention on Biological Diversity* (UNEP 1994) and nationally under various policy frameworks such as the *Intergovernmental Agreement on the Environment* (IGAE) (Commonwealth of Australia 1992a); *National Strategy for Ecologically Sustainable Development* (Commonwealth of Australia 1992b); *National Strategy for the Conservation of Australia's Biological Diversity* (Commonwealth of Australia 1996); and *Australia's Oceans Policy* – An Issues Paper (Commonwealth of Australia 1998) (ANZECC 1998).

In 1998, the Commonwealth Government of Australia committed to the expansion of its existing marine reserve system through the establishment of a National Representative System of Marine Protected Areas (NRSMPA). The primary goal of the NRSMPA was "*to establish and manage a comprehensive, adequate and representative system of MPAs to contribute to the long-term ecological viability of marine and estuarine systems, to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels*" (ANZECC 1998).

In South Australia, the commitment to a NRSMPA led to the design of a network of 19 marine parks encompassing locally representative ecosystems and habitats across 8 marine bioregions. Overarching State policies for the network of marine parks include *South Australia's Strategic Plan 2011* (Government of South Australia 2011), the *Living Coast Strategy for South Australia* (DEH 2004a) and the *Blueprint for the South Australian Representative System of Marine Protected Areas* (DEH 2004b). In 2009, the outer boundaries of a network of 19 marine parks was declared in South Australia under the *Marine Parks Act 2007.* In November 2012, the zoning arrangements and management plans were finalised for each park. Two years later the marine parks network was fully implemented on 1 October 2014 when fishing restrictions inside the no-take sanctuary zones came into effect. The parks currently include 26,670 km^2 of State marine waters and 267 km^2 of coastal land and islands.

The Western Kangaroo Island Marine Park (WKIMP) is located in the Eyre Bioregion, between Cape Forbin and Sanderson Bay, Kangaroo Island, and comprises an area of 1,020 km^2 (DEWNR 2012; Bryars *et al.* 2016). The southern and western coasts of the WKIMP are high energy coastal environments exposed to large swells, high winds and seasonal upwelling of nutrient rich water (McClatchie *et al.* 2006; Van Ruth *et al*. 2010; DEWNR 2012). Rocky reefs extend along most of the park's coastline and transition to sandy seafloor habitats in deeper waters (Baker 2004). The WKIMP has three Sanctuary Zones (SZs) (Figure 1). Sanctuary Zones are no-take areas that prohibit the removal or harm of plants, animals and marine products. Sanctuary Zone 3 (SZ-3) of the WKIMP is located to the south of Cape Du Couedic (Figure 1).

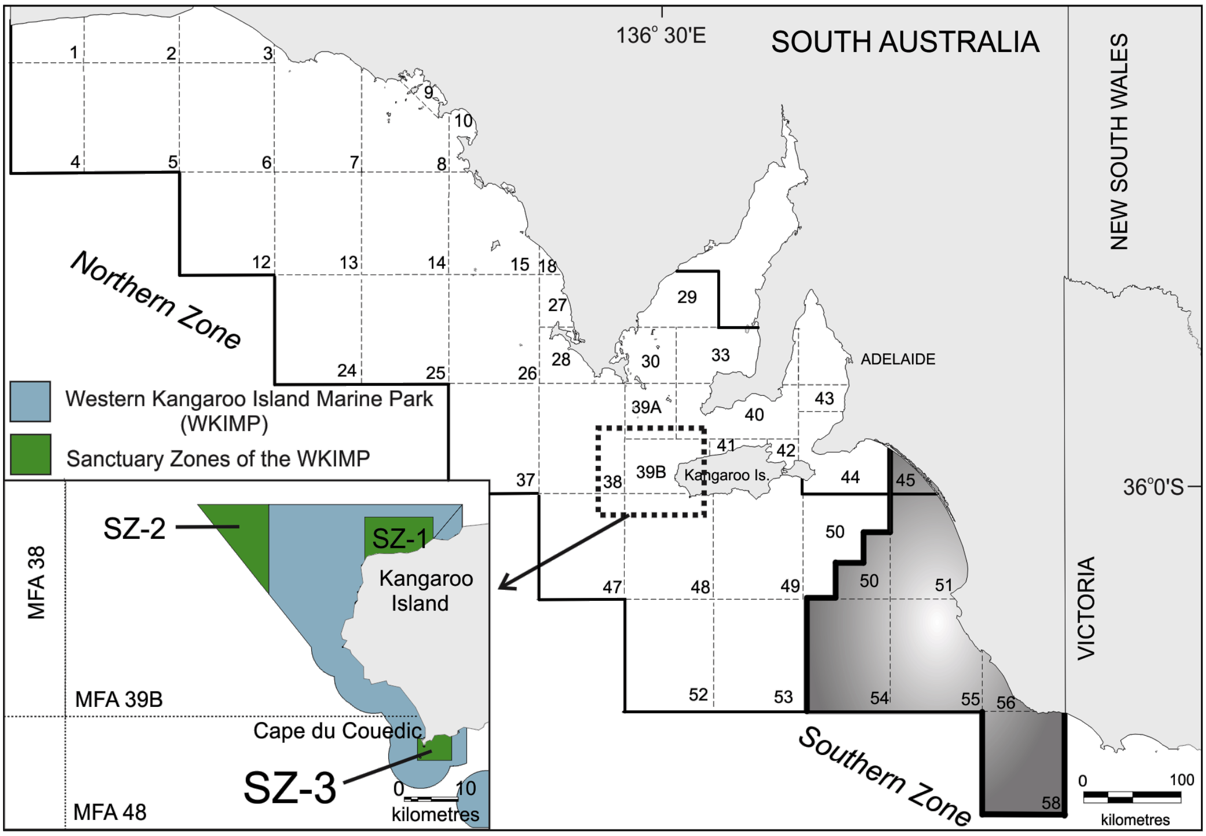

Figure 1. Map showing location of the Northern Zone Rock Lobster Fishery, Marine Fishing Areas and Sanctuary Zone 3 (SZ-3) in the Western Kangaroo Island Marine Park (inset).

Sanctuary Zone 3 of the WKIMP is also located within Marine Fishing Area (MFA) 48 of the Northern Zone Rock Lobster Fishery (NZRLF) (Figure 1). The fishery targets Southern Rock Lobster (*Jasus edwardsii*) that inhabit inshore rocky reefs within continental shelf waters of South Australia between the mouth of the River Murray and the Western Australian border, including Kangaroo Island. Annual catches have ranged between 300 and 1,200 tonnes (t) since 1970. A Total Allowable Commercial Catch (TACC) was introduced in 2003 and is currently set at 360 t. MFA 48 is one of the fishery's top 5 catch MFAs, and produced 11.1% (35.5 t) of the total catch across the Northern Zone in 2014/15 (Linnane *et al.* 2016). The NZRLF has traditionally operated during a fishing season from 1 November through to 31 May, but in the 2015/16 fishing season underwent management changes to allow winter fishing in an 'outer zone' that includes waters offshore. The implementation of sanctuary zones on 1 October 2014 restricted fishing inside sanctuary zones for the whole 2014/15 season and subsequent seasons.

The State's marine park sanctuary zones displaced some commercial fishing, and a voluntary catch and effort reduction program was implemented to ensure that the spatial redistribution of commercial fishing effort did not threaten the sustainability of other areas (PIRSA 2013). Following completion of the program in 2014, a series of meetings between Government and the Northern Zone Rock Lobster Fishermen's Association (NZRLFA) was held to discuss the need for a rock lobster monitoring project relating to SZ-3 in the WKIMP.

Considerable research has been undertaken to understand the conservation benefits of marine parks, and the effects of protecting commercially exploited fish, mollusc and crustacean species within previously fished habitats are well documented (for a review see Gell and Roberts 2003 a, b and Ward *et al.* 2001 and references within). Effects include improvements in habitat resilience, as well as increases in population abundance and biomass and individual body size (Russ and Alcala 1996; Edgar and Barrett 1999; Shears and Babcock 2003; Willis *et al.* 2003; Williamson *et al.* 2004; Barrett *et al*. 2007, 2009; Edgar *et al.* 2009; Ling *et al.* 2009).

The effects of marine park protection on rock (spiny) lobsters are well studied worldwide. The biomass of European spiny lobster (*Palinurus elephas*) from a Mediterranean no take marine reserve more than doubled in the absence of fishing over a 25 year period (Diaz *et al.* 2016). In New Zealand, increases in abundance and mean size of Southern Rock Lobster inside two marine reserves were recorded by Babcock *et al.* (1999) following 13-22 years of protection. Similarly, in New Zealand, Kelly *et al.* (2000) recorded a 9.5% increase in density per year for Southern Rock Lobster inside protected areas, with the size of individual lobsters also increasing 1.14 mm carapace length (CL) per year, and Shears *et al.* (2006) recorded an 11 fold increase in abundance and 25 times higher biomass of Southern Rock Lobster in a no-take marine park following 22 years of protection.

Positive population responses to marine park protection have also been recorded for Southern Rock Lobster in Australia. Following a 10 year period of reserve implementation, Barrett *et al.* (2009) recorded a 250% increase in abundance and 30 mm increase in mean size (CL), relative to fished sites, of Southern Rock Lobster in the Maria Island reserve in Tasmania. Similar increases in Southern Rock Lobster abundance, biomass and individual size have been reported in other studies from Australian waters (Edgar and Barrett 1997; Edgar *et al.* 2009; Young *et al.* 2016).

As part of DEWNR's Marine Park Monitoring, Evaluation and Reporting Program, DEWNR and SARDI Aquatic Sciences, in collaboration with the NZRLFA, developed a project to assess temporal trends in rock lobster abundance and size, and the abundance of key bycatch species, inside and outside SZ-3 before and following its implementation on 1 October 2014.

Specifically, the aims of the study were to:

1. Survey the relative biomass, relative abundance and size of Southern Rock Lobster, and the abundance of key bycatch species, inside and outside SZ-3 of the WKIMP in February 2017.
2. Estimate from historical commercial fishery-dependent data, the relative biomass, relative abundance and size of Southern Rock Lobster, and the abundance of key bycatch species, inside and outside SZ-3 of the WKIMP, and compare the historical data with the 2017 survey results.

2. METHODS

2.1. Marine Park Survey

A survey to measure relative biomass, abundance and size of Southern Rock Lobster, and the abundance of key bycatch species, was undertaken inside and outside SZ-3 of the WKIMP between 20 and 23 February 2017 using the commercial rock lobster fishing vessel ‘Quadrant’. A total of 315 pots were deployed among 16 pre-defined spatial strata; 8 strata located inside and 8 strata located outside SZ-3 (Figure 2). The size, shape and location of strata were designed to enable comparison of survey data with historical data sampled from rock lobster reef habitat inside and outside SZ-3. To further maintain comparison of the survey data with the historical data collected from commercial fishing operations, pots were set and retrieved at locations chosen at the discretion of the Master of the vessel and based on his previous fishing experience (~30 years) in the area. The number of pots deployed per stratum ranged between 15 and 21 (Table 1). Pots were double-baited with blue mackerel (*Scomber australasicus*), set overnight and retrieved the following day. Escape gaps, used to minimise bycatch and undersize lobster catch during normal commercial fishing operations were covered with 1 x 1 cm plastic mesh.

Two SARDI scientists were on-board the vessel throughout the survey to record all data relating to each potlift including: depth, pot location (latitude, longitude), benthic habitat type, bycatch species, lobster size (CL, mm), lobster sex, lobster reproductive state, and lobster moult-state. All lobsters caught during the survey were tagged with intramuscular ‘T-bar’ tags inserted ventrally into the muscle between the tail and carapace. All lobsters were returned to the ocean at the location of capture.

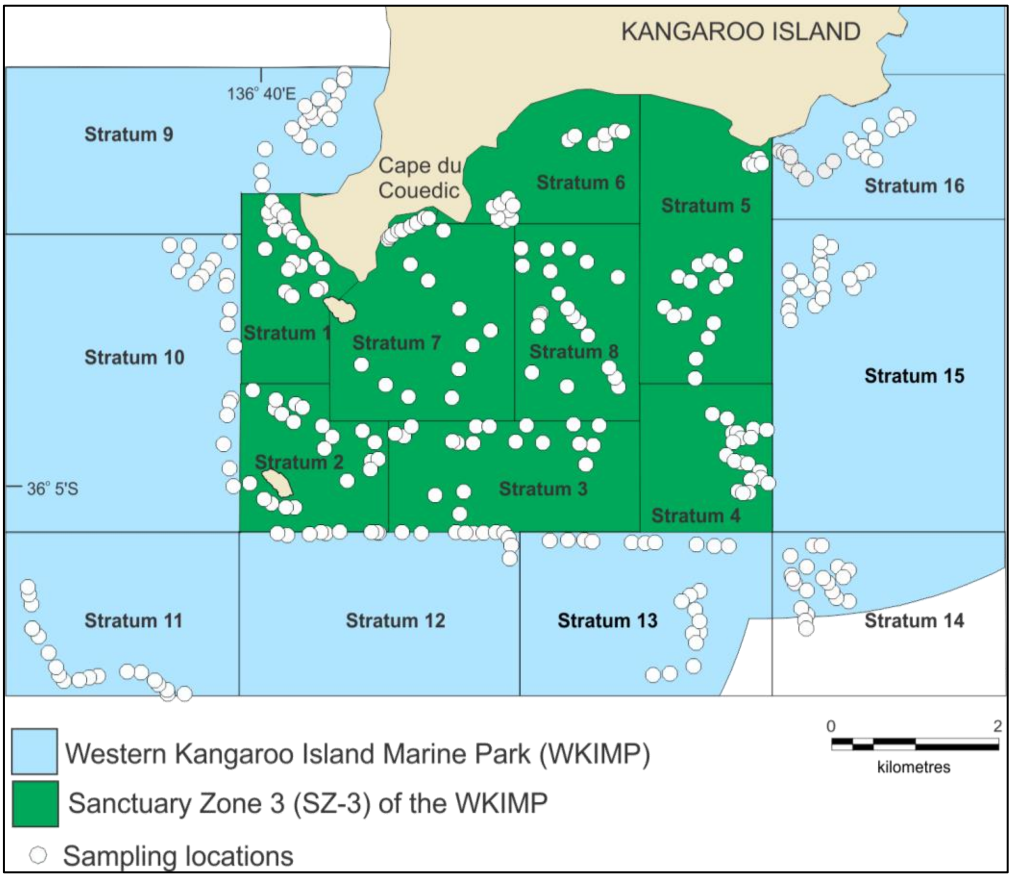

Figure 2. Rock Lobster pot sampling locations within 16 spatial strata inside and outside Sanctuary Zone 3 of the Western Kangaroo Island Marine Park during 2017.

2.2. Marine Park Survey Analyses

Catch per unit effort (CPUE) is commonly used as an indicator of relative biomass and abundance in crustacean fisheries worldwide, and is a primary performance indicator used in stock assessment of the NZRLF. To estimate relative biomass, the weight (kg) of individual male and female lobsters sampled during the survey was first estimated from respective length (CL) - weight (Wt) relationships used in stock assessment of the NZRLF as:

Males: $$Wt\ (kg) = CL^{2.98} \times e^{-14.43}$$

Females: $$Wt\ (kg) = CL^{2.89} \times e^{-13.92}$$

Estimates of relative biomass (CPUE by weight) in each stratum, and inside and outside SZ-3 were then calculated for legal size (CL ≥ 105 mm) lobsters captured and released during the survey as:

$$CPUE_{legalsize} = \frac{\text{Total weight (kg)}}{\text{Total number of potlifts}}$$

Estimates of relative abundance (CPUE by number) in each stratum, and inside and outside SZ-3 were also calculated for legal size (CL ≥ 105 mm) lobsters captured and released during the survey as:

$$CPUE_{legalsize} = \frac{\text{Total number (N)}}{\text{Total number of potlifts}}$$

Similarly, estimates of relative abundance for undersize (CL < 105 mm) lobsters inside and outside SZ-3 were calculated as:

$$CPUE_{undersize} = \frac{\text{Total number (N)}}{\text{Total number of potlifts}}$$

Only alive and non-spawning lobsters were included in calculations of legal size and undersize CPUE. This approach is consistent with the method used to compute CPUE indices in stock assessment of the NZRLF (Linnane *et al.* 2016).

The mean length of male and female lobsters was analysed and compared inside and outside SZ-3. Carapace length data of all lobsters sampled during the survey were grouped into 5 mm bins and analysed to estimate the percentage frequency of female and male lobsters present in each size class inside and outside SZ-3. The total percentage of legal size lobsters (CL ≥ 105 mm) inside and outside SZ-3 was also compared.

The total number of each bycatch species sampled during the survey in each stratum inside and outside SZ-3 was calculated. For the top three bycatch species (by number), relative abundance (CPUE) was then estimated as:

$$CPUE_{\ bycatch\ species} = \frac{\text{Total number}}{\text{Total number of potlifts}} \text{ x } 100$$

$CPUE_{bycatch\ species}$ of the top three bycatch species sampled during the survey was then compared inside and outside SZ-3.

2.3. Historical catch analysis

To provide an overview of historical trends in fishery performance at the MFA and zonal spatial scales, CPUE (by weight and number) of legal-size lobsters within MFA 48 was estimated from commercial daily logbook data that are reported as part of mandatory licence conditions in the NZRLF.

Reporting of catch and effort data at finer spatial resolution is achieved through the voluntary catch sampling program in the NZRLF. Participating fishers voluntarily report catch and effort data from up to three pots per day. Data include the latitude and longitude of each pot location. In addition, SARDI and industry observers routinely undertake trips on board commercial vessels where data from all pots are recorded. Data collected in this program between the 1994/95 and 2015/16 fishing seasons were assigned using GIS (ArcMap 10.3.1) analyses to each of the 16 strata located inside and outside SZ-3 as defined during the marine park survey.

Historical catch rates show a strong seasonal trend (Linnane *et al*. 2016). To enable a standardised comparison with the data collected during the marine park survey in February 2017 (2016/17 fishing season), a General Linear Model with a Gaussian error structure and identity link was applied to obtain a yearly index that corrected (standardised) the time series for the February timing of the 2017 survey. The model had the form:

Index ~ Month + Season:InsideorOutside.

This model produced standardised annual (fishing season: November – May) CPUE estimates for 1994/95 to 2013/14 by applying a February-corrected index to 1) legal size CPUE (kg/potlift); 2) legal size CPUE (N/potlift); and 3) undersize CPUE (N/potlift) estimated both inside and outside SZ-3.

Annual trends in these indices, as well as mean annual rock lobster size (mean CL, mm) and bycatch species composition were then calculated and compared with results of the marine park survey. Differences in legal size and undersize lobster CPUE, and lobster size inside and outside SZ-3 between 1994/95 and 2013/14 were tested using ANOVA, Mann-Whitney U or Kruskal-Wallis tests in SPSS®. Data were tested for assumptions of normality and homoscedasticity using Shapiro-Wilks' test and Levene's test, respectively. Means are reported ± SE.

3. RESULTS

3.1. Marine Park Survey

A total of 315 pots were set and sampled during the survey (Table 1). Depths sampled ranged between 5 m in Stratum 7 to 48 m in Stratum 12. A total of 346 legal size and 79 undersize lobsters were measured, tagged and returned to the sea. Ten dead lobsters were recorded during the survey and no spawning lobsters were sampled.

Estimates of CPUE by weight of legal size lobsters ranged from 0.07 kg/potlift in Stratum 15 located outside SZ-3 to 4.27 kg/potlift in Stratum 1 located inside SZ-3 (Table 1, Figure 3). The CPUE estimate of 2.59 kg/potlift for all legal size lobsters surveyed inside SZ-3 (Strata 1-8) is 4.4 times higher than the estimate of 0.59 kg/potlift measured outside SZ-3 (Strata 9-16) (Table 1, Figure 3).

Estimates of CPUE by number of legal size lobsters ranged from 0.10 lobsters/potlift in Stratum 15 outside SZ-3 to 2.9 lobsters/potlift in Stratum 1 inside SZ-3 (Table 1). The CPUE estimate of 1.73 lobsters/potlift for all legal size lobsters inside SZ-3 (Strata 1-8) is 3.5 times higher than the estimate of 0.49 lobsters/potlift measured outside SZ-3 (Strata 9-16)(Table 1).

Estimates of CPUE of undersize lobsters ranged from 0.00 undersized/potlift in Stratum 11 and 16 to 0.65 undersize/potlift in Stratum 12 (Table 1). Overall, CPUE estimates of undersize lobsters inside (Strata 1-8) and outside (Strata 9-16) SZ-3 were similar at 0.25 and 0.26 undersized/potlift, respectively (Table 1).

Table 1. Summary of number of pots deployed and lobsters sampled within each spatial stratum inside and outside Sanctuary Zone 3 of the Western Kangaroo Island Marine Park in 2017.

			Legal size	Legal size	Undersize	Dead	Legal size relative biomass	Legal size relative abundance	Undersize relative abundance
Stratum	**Inside v Outside SZ-3**	**N pots**	**Number**	**Mean weight (kg)**	**N**	**N**	**CPUE (kg/potlift)**	**CPUE (N/potlift)**	**CPUE (N/potlift)**
1	Inside	20	58	1.5	7	1	4.27	2.90	0.35
2	Inside	21	35	1.5	8	3	2.51	1.67	0.38
3	Inside	19	40	1.5	9	1	3.07	2.11	0.47
4	Inside	20	9	1.1	1	0	0.51	0.45	0.05
5	Inside	20	24	1.6	7	0	1.86	1.20	0.35
6	Inside	15	27	1.7	1	1	2.98	1.80	0.07
7	Inside	20	53	1.5	4	0	3.92	2.65	0.20
8	Inside	20	22	1.5	1	1	1.70	1.10	0.05
9	*Outside*	19	5	0.8	6	1	0.22	0.26	0.32
10	*Outside*	20	10	1.1	4	2	0.56	0.50	0.20
11	*Outside*	20	6	1.4	0	0	0.41	0.30	0.00
12	*Outside*	20	18	1.2	13	0	1.08	0.90	0.65
13	*Outside*	21	23	1.2	9	0	1.35	1.10	0.43
14	*Outside*	20	9	1.2	8	0	0.54	0.45	0.40
15	*Outside*	20	2	0.7	1	0	0.07	0.10	0.05
16	*Outside*	20	5	1.6	0	0	0.40	0.25	0.00
TOTAL		**315**	**346**		**79**	**10**			
Mean wt inside SZ-3				**1.50**					
Mean wt outside SZ-3				**1.20**					
CPUE inside SZ-3							**2.59**	**1.73**	**0.25**
CPUE outside SZ-3							**0.59**	**0.49**	**0.26**

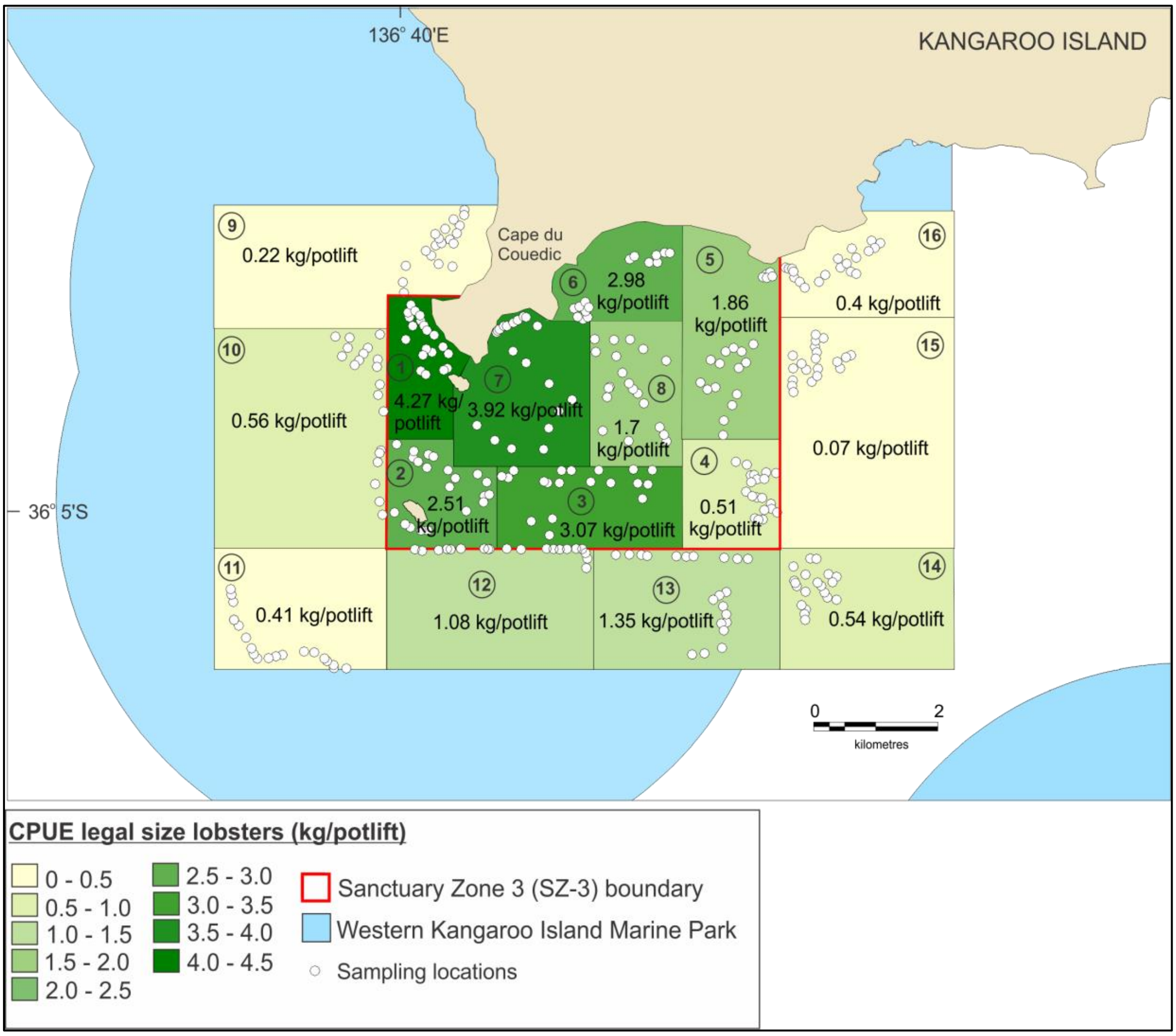

Figure 3. Map showing 2017 (2016/17 fishing season) survey estimates of legal size rock lobster biomass (catch per unit effort (CPUE), kg/potlift) within 16 spatial strata inside and outside SZ-3 of the Western Kangaroo Island Marine Park.

Males and females sampled during the marine park survey were significantly larger in size (CL) inside SZ-3 compared to outside SZ-3 (Females: Mann-Whitney U test -5.413, p<0.001; Males: Mann-Whitney U test -5.480, p<0.001). The mean size of female lobsters sampled inside SZ-3 was 122.5 ± 1.2 mm CL, which was 15.6% larger than female lobsters sampled outside SZ-3 (106.0 ± 2.4 mm CL) (Figure 4). Similarly, the mean size of male lobsters inside SZ-3 (146.3 ± 2.2 mm CL) was 17.4% larger compared to males outside SZ-3 (124.6 ± 3.0 mm CL).

A total of 89.6% of females and 93.5% of males sampled during the survey inside SZ-3 were of legal minimum length (≥ 105 mm CL) (Figure 4). In comparison, a total of 56.8% of females and 84.6% of males outside SZ-3 were of legal minimum length (Figure 4).

The estimates of mean weight (kg) of legal size lobsters sampled inside and outside SZ-3 reflect these results, with legal size lobsters inside SZ-3 being an average of 0.3 kg larger than legal size lobsters found outside SZ-3 (Strata 9-16) (1.50 kg versus 1.20 kg, respectively)(Table 1).

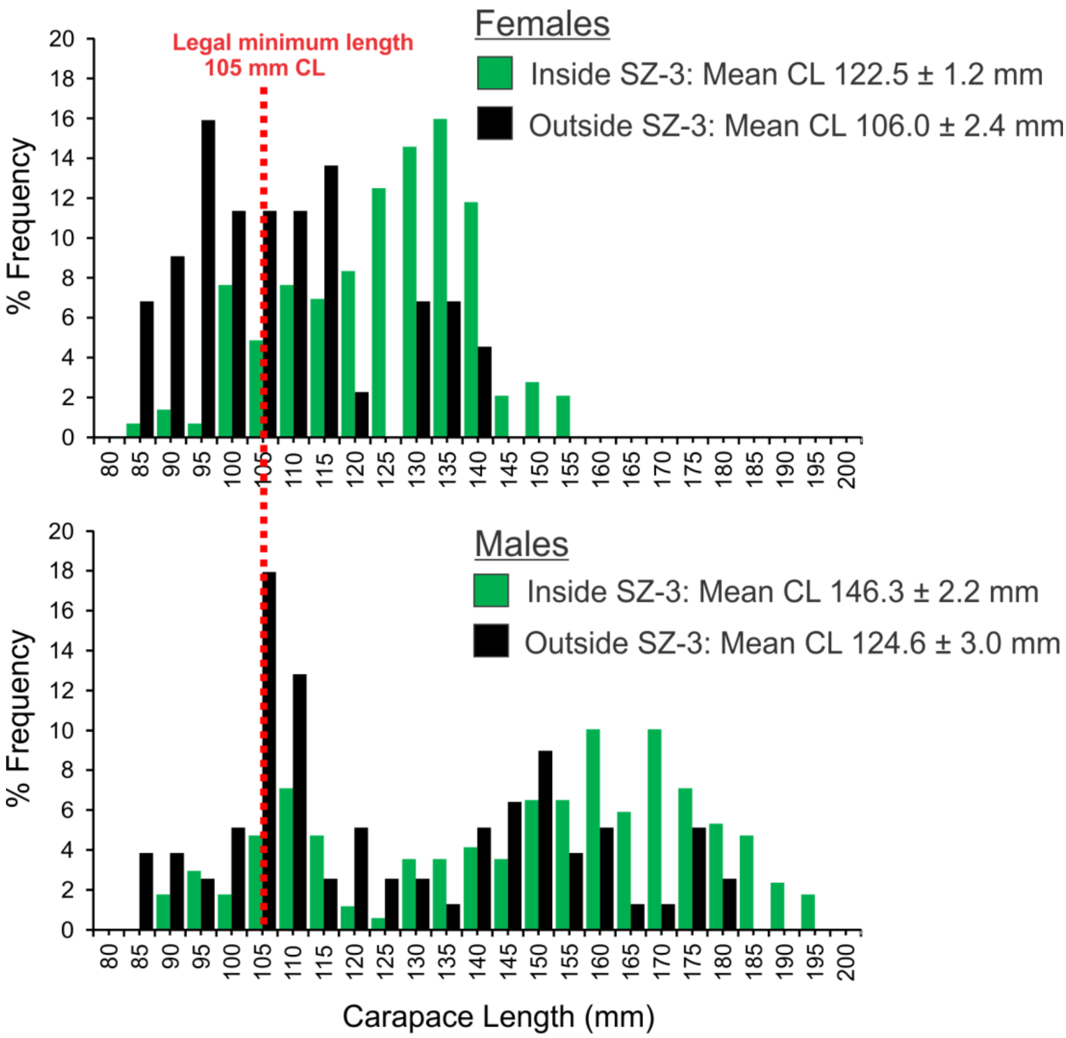

Figure 4. Percentage length (CL) frequency of male and female southern rock lobster sampled inside and outside Sanctuary Zone 3 of the Western Kangaroo Island Marine Park during February 2017.

A total of 126 animals, comprising eight species, were sampled as bycatch during the survey, with 63.5% of bycatch (by number) sampled outside SZ-3 and 36.5% sampled inside SZ-3 (Table 2). Velvet crabs (*Nectocarcinus integrifrons*), horseshoe leatherjackets (*Meuschenia hippocrepis*) and blue throat wrasse (*Notolabrus tetricus*) comprised 90% (by number) of all bycatch sampled. Estimates of CPUE for all three species were higher outside SZ-3 than inside SZ-3, ranging from 7.5 to 28.1 animals per 100 potlifts (Table 2).

Table 2. Summary of all bycatch sampled within each spatial stratum inside and outside Sanctuary Zone 3 of the Western Kangaroo Island Marine Park in February 2017.

Stratum	**Inside v Outside SZ-3**	**N pots**	**Velvet crab (*Nectocarcinus integrifrons*)**	**Horseshoe leatherjacket (*Meuschenia hippocrepis*)**	**Blue-throat wrasse (*Notolabrus tetricus*)**	**Octopus (*Octopus maorum*)**	**Six spine leather jacket (*Meuschenia freycineti*)**	**Silver spot (*Threpterius maculosus*)**	**Hermit Crab (*Paguristes sp.)***	**Wobbegong shark (*Orectolobus ornatus*)**
1	Inside	20	1	4	0	1	0	0	0	0
2	Inside	21	0	0	1	1	0	0	0	1
3	Inside	19	0	2	2	0	0	0	0	0
4	Inside	20	6	2	3	1	1	0	0	0
5	Inside	20	10	0	3	0	0	0	0	0
6	Inside	15	2	0	1	0	0	0	0	0
7	Inside	20	0	1	1	0	0	0	0	0
8	Inside	20	1	0	0	1	0	0	0	0
9	Outside	19	1	0	0	0	0	0	0	0
10	Outside	20	0	0	1	0	0	0	0	0
11	Outside	20	3	10	3	0	0	1	0	0
12	Outside	20	0	1	2	0	0	0	0	0
13	Outside	21	3	2	2	2	0	0	0	0
14	Outside	20	0	3	2	0	0	0	1	0
15	Outside	20	19	1	1	0	1	0	0	0
16	Outside	20	19	0	1	0	0	1	0	0
	TOTAL	**315**	**65**	**26**	**23**	**6**	**2**	**2**	**1**	**1**
CPUE inside (per 100 potlifts)			**12.9**	**5.8**	**7.1**	**0.03**	**0.01**	**0.00**	**0.00**	**0.01**
CPUE outside (per 100 potlifts)			**28.1**	**10.6**	**7.5**	**0.01**	**0.01**	**0.01**	**0.01**	**0.00**

3.2. Temporal trends in the relative biomass, relative abundance and size of rock lobster, and abundance of bycatch species

Temporal trends in legal-size rock lobster biomass in the NZRLF and MFA 48

Since 1994/95, CPUE by weight in the entire NZRLF has been estimated from an average of 550,760 ± 33,132 potlifts per year. CPUE within MFA 48, where SZ-3 of the Western Kangaroo Island Marine Park is located, has been estimated from an average of 46,530 ± 2,564 potlifts per year. Annual trends in CPUE within MFA 48, resemble those across the entire NZRLF and have generally declined since 1998/99 (Figure 5), with a recent peak in 2010/11.

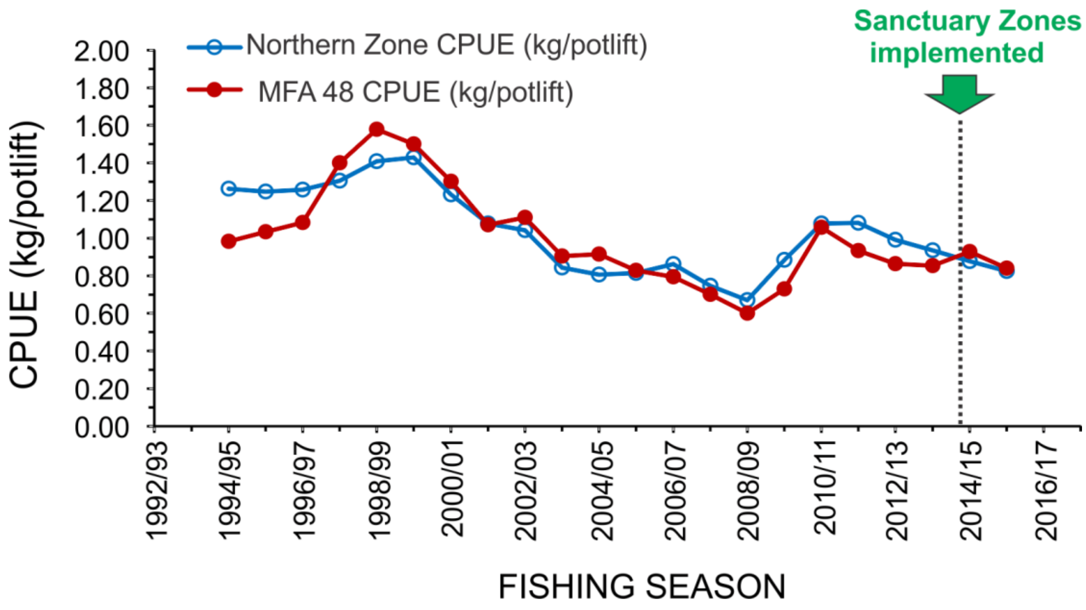

Figure 5. Legal size catch per unit effort (CPUE) by weight in the NZRLF and MFA 48 estimated from commercial fishery logbook data since the 1994/95 fishing season.

Temporal trends in legal-size rock lobster relative biomass and relative abundance inside and outside SZ-3

Annual standardised estimates of CPUE for legal size lobsters from inside and outside SZ-3 (Strata 1-16) between 1994/95 and 2013/14 are estimated from a total of 5,245 potlifts reported through SARDI's voluntary catch sampling program in the NZRLF (1,995 pots inside SZ-3; 3,250 pots outside SZ-3). Effort recorded from the voluntary catch sampling program inside and outside SZ-3 comprised 0.6% of all commercial effort (944,829 potlifts) recorded from commercial logbook data in MFA 48 between 1994/95 and 2013/14, and 37.7% of all effort recorded in the voluntary catch sampling within MFA 48 (N = 13,920 pots).

Estimates of CPUE of legal size lobsters from voluntary catch sampling data inside SZ-3 (Strata 1-8) are calculated from an average of 100 ± 24 potlifts per year between 1994/95 and 2013/14. Estimates of CPUE of legal size lobsters from voluntary catch sampling data outside SZ-3 (Strata 9-16) are calculated from an average of 163 ± 31 potlifts per year between 1994/95 and 2013/14.

Annual trends in legal size rock lobster CPUE by weight (kg/potlift) and number (N/potlift) from voluntary catch sampling resemble the trends in CPUE recorded from commercial logbook data for MFA 48 and the entire NZRLF (Figures 6 and 7 cf. Figure 5). Declines in legal size CPUE by weight and number have been observed both inside and outside SZ-3 since 1998/99 (Figures 6 and 7). No significant difference was detected between annual estimates of standardised legal size CPUE by weight inside and outside SZ-3 between 1994/95 and 2013/14, the period prior to sanctuary zone implementation (ANOVA, df. 1, F=0.139, p=0.711). Similarly, no significant difference was detected between annual estimates of standardised legal size CPUE by number inside and outside SZ-3 between 1994/95 and 2013/14 (ANOVA, df. 1, F=1.143, p=0.292).

The estimate of legal size CPUE by weight measured inside SZ-3 during the marine park survey in February 2017 (2016/17 season: 2.59 kg/potlift) is 81.1% higher than the previous estimate of 1.43 kg/potlift measured inside SZ-3 in 2013/14 and is the highest on record (Figure 6). Similarly, the estimate of legal size CPUE by number measured inside SZ-3 during the marine park survey in February 2017 (2016/17 season: 1.73 lobsters/potlift) is 44.2% higher than the previous estimate of 1.20 lobsters/potlift measured inside SZ-3 in 2013/14 and the second highest on record (Figure 7). In contrast, the estimates of legal size CPUE by weight (0.59 kg/potlift) and number (0.49 lobsters/potlift) outside SZ-3 during the 2017 survey were among the lowest on record (Figures 6 and 7).

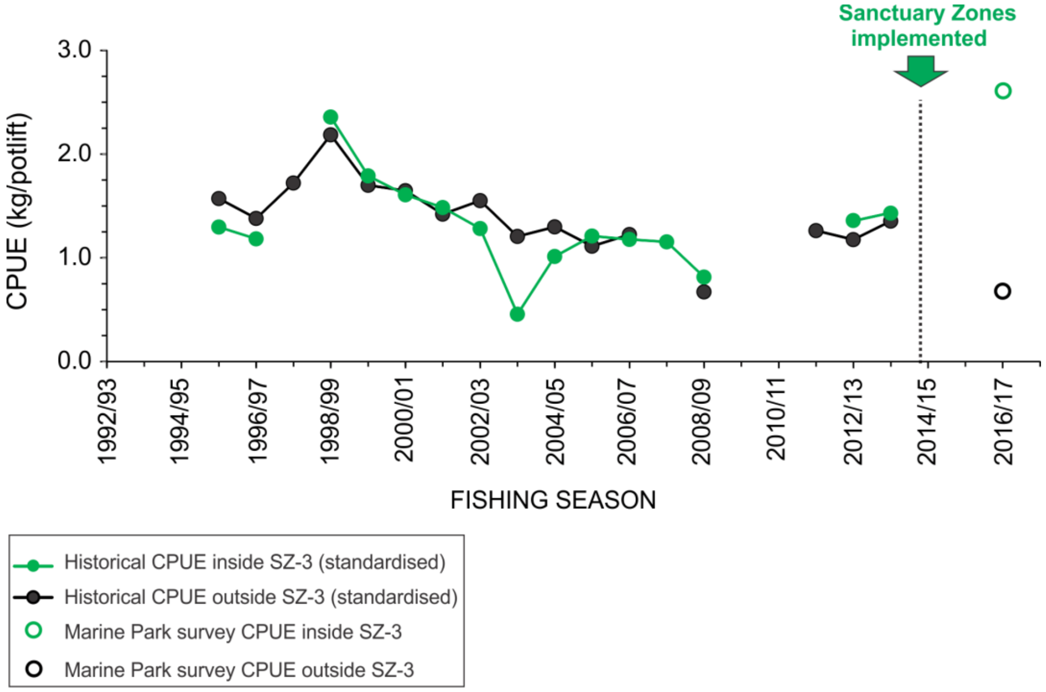

Figure 6. Legal size rock lobster catch per unit effort (CPUE) (kg/potlift) inside and outside SZ-3 between the 1994/95 and 2016/17 fishing seasons. Note, some annual (fishing season) estimates of CPUE could not be presented due to confidentiality requirements that restrict publication of data from <5 fishers. The February 2017 survey data are plotted against the 2016/17 fishing season.

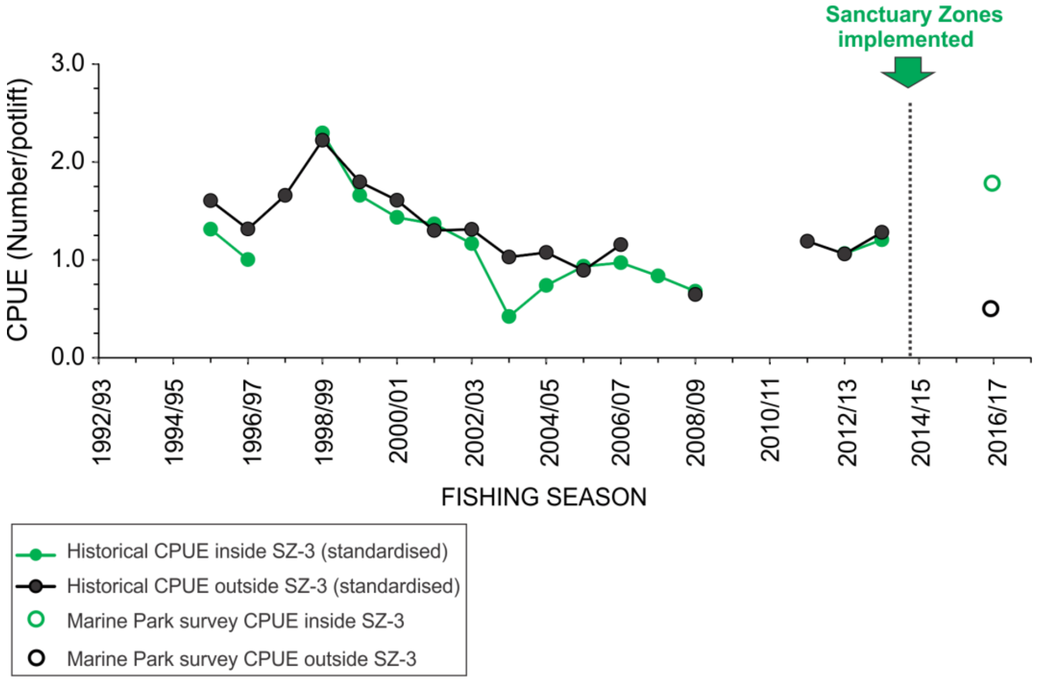

Figure 7. Legal size rock lobster catch per unit effort (CPUE) (N/potlift) inside and outside SZ-3 between the 1994/95 and 2016/17 fishing seasons. Note, some annual (fishing season) estimates of CPUE could not be presented due to confidentiality requirements that restrict publication of data from <5 fishers. The February 2017 survey data are plotted against the 2016/17 fishing season.

Spatial comparison of legal size CPUE (by weight) before and after sanctuary zone implementation supports the temporal trends in legal size CPUE inside and outside SZ-3 shown in Figures 6 and 7. Figure 8 compares the average legal size rock lobster CPUE (by weight) inside and outside SZ-3 for the fishing seasons prior to sanctuary zone implementation (average CPUE:1994/95-2013/14) with estimates of legal size rock lobster CPUE (by weight) inside and outside SZ-3 following sanctuary zone implementation (February survey 2017 - 2016/17 fishing season). Average legal size CPUE (by weight) between 1994/95 and 2013/14 was distributed relatively evenly across the 16 strata prior to sanctuary zone implementation, ranging from 0.67- 1.76 kg/potlift inside SZ-3 to 0.90-2.17 kg/potlift outside SZ-3 (Figure 8). In contrast, the February 2017 survey (2016/17 fishing season) recorded higher legal size CPUE and larger ranges of legal size CPUE inside SZ-3 (0.51-4.27 kg/potlift) compared to outside SZ-3 (0.07-1.35 kg/potlift) (Figure 8).

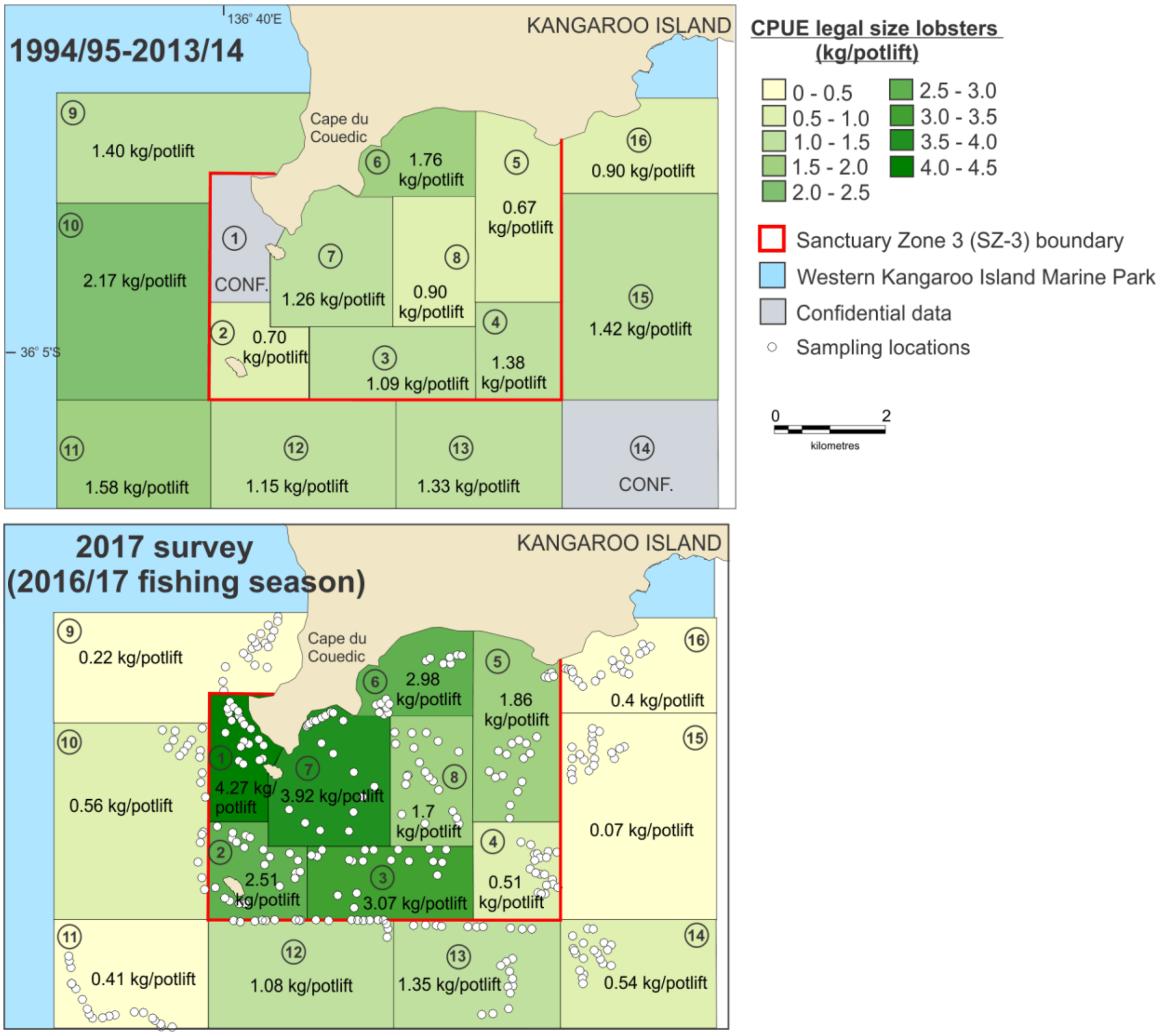

Figure 8. Legal size rock lobster catch per unit effort (CPUE) (kg/potlift) inside and outside SZ-3 prior to sanctuary zone implementation (average: 1994/95 to 2013/14 fishing seasons) and following sanctuary zone implementation (2017 survey). Note, some estimates of CPUE (1994/95-2013/14: Stratum 1 and Stratum 14) could not be presented due to confidentiality requirements relating to data from <5 fishers.

Temporal trends in undersize rock lobster abundance inside and outside SZ-3

Annual estimates of CPUE of undersize lobsters measured from the voluntary catch sampling program have fluctuated inside and outside SZ-3 since 1994/95, with similar declines in CPUE inside and outside SZ-3 observed between 1998/99 and 2003/04 (Figure 9).

Standardised annual estimates of undersize CPUE (N/potlift) inside SZ-3 were significantly lower than estimates of CPUE outside SZ-3 between 1994/95 and 2013/14 (ANOVA, df. 1, F=9.063, p<0.05).

The CPUE estimates of 0.25 to 0.26 undersize per potlift measured during the survey inside and outside SZ-3, respectively, were among the lowest on record (Figure 9).

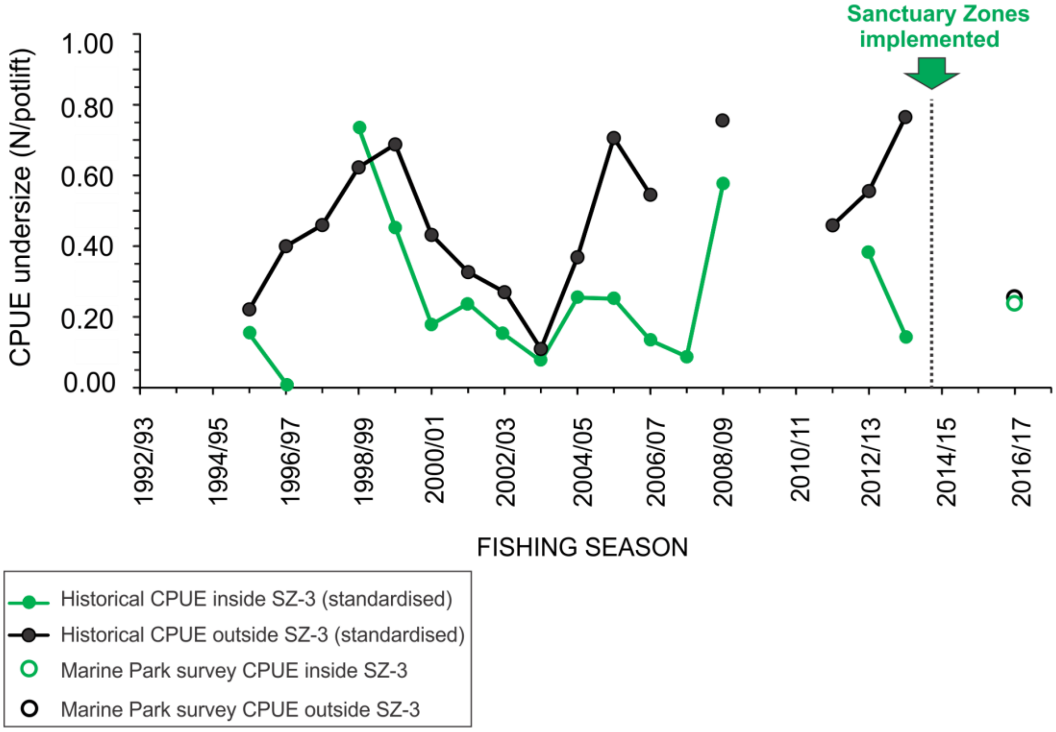

Figure 9. Catch per unit effort (CPUE) (N/potlift) of undersize rock lobster inside and outside SZ-3 between the 1994/95 and 2016/17 fishing seasons. Note, some annual (fishing season) estimates of CPUE could not be presented due to confidentiality requirements that restrict publication of data from <5 fishers. The February 2017 survey data are plotted against the 2016/17 fishing season.

Temporal trends in rock lobster size inside and outside SZ-3

Between 1994/95 and 2013/14, mean annual estimates of female rock lobster size (CL) have ranged from 103.3 to 123.3 mm (CL) inside SZ-3, and from 101.1 to 118.5 mm (CL) outside SZ-3 (Figure 10). Females were significantly larger inside SZ-3 compared to outside SZ-3 (Kruskal-Wallis test 120.3, df 1, p<0.001) over this time. Mean annual estimates of male rock lobster size (CL) ranged from 114.2 to 131.1 mm (CL) inside SZ-3 and from 103.8 to 130.8 mm

(CL) outside SZ-3 over this time (Figure 10). Males were also significantly larger inside SZ-3 compared to outside SZ-3 (Kruskal-Wallis test 85.7, df 1, p<0.001).

The mean size of females recorded inside SZ-3 during the marine park survey (122.5 mm CL, 2016/17 season, Figure 10) was the second largest value on record and 4.1% higher than the mean size recorded in 2013/14 (117.5 mm) when fishing in SZ-3 was permitted. Similarly, the mean CL of 146.4 mm recorded for males inside the SZ-3 during the survey is the largest on record, 11.7% higher than the largest value recorded for males since 1994/95 (131.1 mm in 2005) and 12.5% higher than the mean size recorded in 2013/14 (128.1 mm) before the sanctuary zone was established.

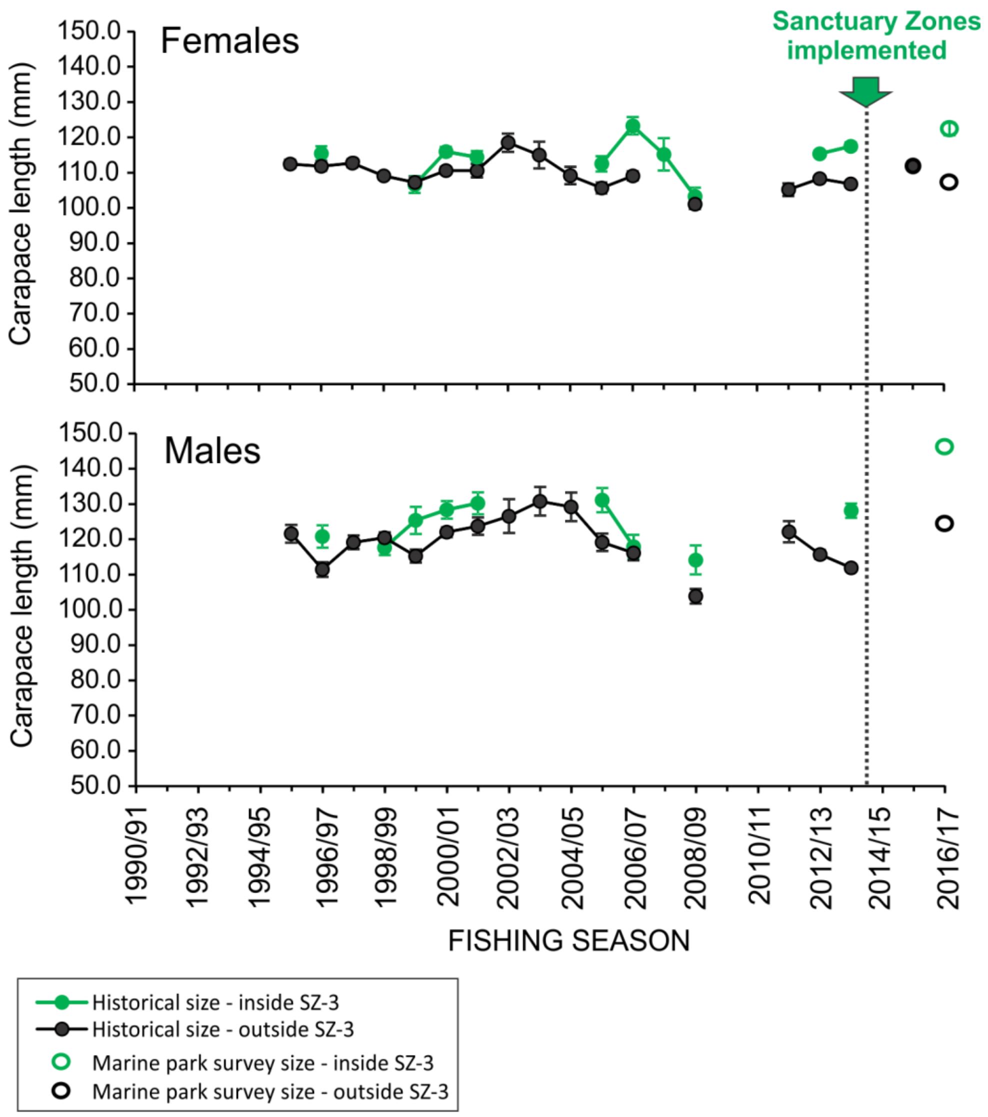

Figure 10. Average size (CL) of female and male rock lobster inside and outside SZ-3 between the 1994/95 and 2016/17 fishing seasons. Note, some annual (fishing season) estimates could not be presented due to confidentiality requirements that restrict publication of data from <5 fishers. Error bars are ± standard error. 2015/16 season data, after establishment of marine parks, are presented (females only) but were not included in statistical analyses. The February 2017 survey data are plotted against the 2016/17 fishing season.

Temporal trends in bycatch inside and outside SZ-3

Between 1994/95 and 2015/16, a total of 709 animals comprising 20 taxa were identified as bycatch from the voluntary catch sampling program inside and outside SZ-3. Not all bycatch was identified to species level. A full summary of the total number of each taxon sampled by fishers inside and outside SZ-3 between 1994/95 and 2015/16 is provided in Appendix 1.

Similar to the results of the marine park survey, velvet crabs (*Nectocarcinus integrifrons*), horseshoe leatherjackets (*Meuschenia hippocrepis*) and blue throat wrasse (*Notolabrus tetricus*) were the top three bycatch taxa reported between 1994/95 and 2015/16. These species, comprised 69.3% (by number) of all bycatch sampled.

Confidentiality requirements that restrict publication of data from <5 fishers preclude presentation of historical annual (fishing season) trends in bycatch CPUE.

4. DISCUSSION

The use of CPUE as an indicator of relative biomass or abundance in crustacean fisheries is common worldwide, and CPUE (by weight) is one of the principal metrics used to develop models of absolute biomass for stock assessment of the NZRLF (Linnane *et al.* 2016). Our study was fortuitous in having fine spatial-scale data recorded from the voluntary catch sampling program in the NZRLF that enabled a 'before' and 'after' comparison of lobster CPUE (weight and number) inside SZ-3. Studies that can analyse long time series of data collected from sites inside and outside a marine park prior to and following its implementation may provide more convincing evidence of the effects of marine park protection than snapshot studies that only compare data from sites inside and outside a marine park in a single point in time. This is because data collected from the same sites over time remove the potential effect of site differences that could potentially be attributed to other ecological factors (e.g. habitat or productivity differences) (Ward *et al*. 2001).

Data collected in the survey conducted in 2017 indicate that the Southern Rock Lobster population within SZ-3 in the WKIMP has increased in the absence of fishing pressure since implementation of sanctuary zones on 1 October 2014. Positive population responses within the sanctuary zone are indicated by an 81.1% increase in relative biomass (CPUE, kg/potlift), 42.2% increase in relative abundance (CPUE, lobsters/potlift), and 4.1% and 12.5% increases in the mean size of female and male lobsters, respectively, since 2013/14, when fishing was last permitted.

These results support the predicted increases in size and abundance of Southern Rock Lobster within South Australia's sanctuary zones (Bailey *et al.* 2012; Bryars 2013) as well as other research of Southern Rock Lobster population responses in marine reserves (MacDiarmid and Breen 1993; Edgar and Barrett 1997; Babcock *et al.* 1999; Kelly *et al.* 2000; Shears *et al.* 2006; Pande *et al.* 2008; Barrett *et al.* 2009; Edgar *et al.* 2009; Freeman *et al.* 2012; Young *et al.* 2016). A review of these studies indicates that the rates at which lobster populations respond to protection vary according to the time-period over which protection is measured, site differences in environmental conditions (e.g. habitat or oceanographic conditions) and competitive interactions (Freeman *et al.* 2012).

The response of lobster populations within SZ-3 appears to be rapid but such rates of response are biologically plausible considering Southern Rock Lobster in SZ-3 have been protected through 3 summers and 2 winters since sanctuary zones were implemented on 1 October 2014, and are supported by the findings of Shears *et al*. (2006), Barrett *et al.* (2009), and Edgar *et al.* (2009). The growth schedules of Southern Rock Lobster vary according to size and sex, with larger (>120 mm) males generally moulting once or twice yearly and larger females (>120 mm) moulting once between April and June (MacDiarmid 1989; Prescott 1997). Smaller (<90 mm CL) males and females may moult up to twice a year (Prescott 1997).

Consequently, depending on their size prior to protection by sanctuary zones in 2014, lobsters have moulted at least two to four times before being measured in the February 2017 survey.

This period of growth is represented in the 4.1% and 12.5% increases in mean size of female and male lobsters, respectively, since size was last estimated in 2013/14, with the relatively lower percentage increase in size attained by females relative to males during this time explained by the reductions in female growth rate that occur upon maturity (Aiken and Waddy 1980; McKoy and Esterman 1981). The increases in size recorded are also supported in the mean annual growth rates recorded for legal-size lobsters in MFA 48 by McGarvey *et al.* (1999). Consequently, the increases in legal-size lobster population biomass (CPUE, kg/potlift) observed in SZ-3 in the February 2017 survey, likely represent: 1) the growth of undersize lobsters into legal-size, and 2) an overall increase in the mean size of all lobsters within SZ-3 since sanctuary zone implementation.

Historical estimates of legal size rock lobster CPUE by weight (kg/potlift) and number (N/potlift) inside and outside SZ-3 between 1994/95 and 2013/14 were derived from the voluntary catch sampling program in the NZRLF and represent 0.6% of the total effort recorded from MFA 48 between 1994/95 and 2013/14, and 37.7% (14.3% inside SZ-3 (Strata 1-8); 23.3% outside SZ-3 (Strata 9-16)) of all effort recorded in the voluntary catch sampling within MFA 48. Although representing a small percentage (0.6%) of total commercial effort within MFA 48, trends in annual estimates of legal size CPUE (by weight and number) inside and outside SZ-3 resemble those recorded from commercial logbook data for MFA 48 and the entire NZRLF, indicating that the reduced sample size used to calculate legal size CPUE inside and outside SZ-3 from the voluntary catch sampling data was adequate.

No significant difference was detected in our study between annual estimates of standardised legal size CPUE (by weight and number) inside and outside SZ-3 between 1994/95 and 2013/14, indicating that the relative biomass and abundance of legal size rock lobster inside and outside SZ-3 have been similar in the period prior to marine park implementation. These results support the research of Kosturjak *et al.* (2015) that compared CPUE (by weight) inside and outside South Australia's sanctuary zones at broader spatial scales and indicate that the lobster population located south of Cape du Couedic was distributed relatively homogenously across rocky reef habitat inside and outside SZ-3 during this period.

The estimates of relative biomass (0.59 kg/potlift) and relative abundance (0.49 lobsters/potlift) of legal size lobster outside SZ-3 from the survey in 2017 were among the lowest on record. The pot sampling locations from which these CPUE estimates were derived were located within 3.4 km of the SZ-3 boundary. Although CPUE across MFA 48 has generally declined since 1998/99, it is possible that the low CPUE recorded outside SZ-3 during the survey also reflects the occurrence of edge effects relating to fishing that has occurred on or near the SZ-3 boundary since sanctuary zone implementation. Fishers readily try to capitalise on 'spillover' of animals from protected areas by ‘fishing the line’ and several studies have recorded increased fishing effort near to the boundaries of areas closed to fishing (Murawski *et al.* 2000; Kelly *et al.* 2001; Bohnsack and Ault 2002). Fishing the line was also reflected in the 2017 survey where the master of the vessel, in replicating normal fishing behaviour, fished along the boundary of SZ-3 (Strata 10, 12 and 13, Figure 3). Current rates of spillover from SZ-3 are unquantified. Future data acquired from lobsters tagged during the survey and recaptured in commercial fishing operations or future surveys may provide some information on rates of movement from inside or outside SZ-3.

Female and male lobsters were significantly larger inside SZ-3 than outside SZ-3 in all years between 1994/95 and 2013/14, and there were significantly higher numbers of undersize lobsters recorded outside SZ-3 than inside SZ-3. These data suggest ontogenetic separation of habitat use among Southern Rock Lobster. The reasons for the observed size-related patterns of spatial separation are unclear without more information on the habitat characteristics within the WKIMP, however ontogenetic differences in habitat use have been reported previously for Southern Rock Lobster and attributed to 1) changes in social behaviour, mediated by chemical cues that enhance aggregation of large lobsters; 2) differential mortality of lobsters among habitats that creates patches of survivors of different sizes; and 3) differences in the spatial distribution of habitat (e.g. rock crevices) that favour different size lobsters (MacDiarmid 1991, 1994; Butler *et al.* 1999 and references within). As part of their ongoing monitoring program, DEWNR is collating information relating to benthic habitat characteristics within the WKIMP. These data may help clarify the reasons behind ontogenetic separation of Southern Rock Lobster in the WKIMP in the future.

The bycatch data recorded during commercial fishing operations between 1994/95 and 2015/16 and in the survey in 2016/17 should be treated with caution. Rock lobster pots are designed to limit bycatch through their design specifications and therefore are not likely to be a suitable sampling tool to obtain measures of species richness, evenness or abundance on temperate reefs. Smaller individuals or species are able to escape from pots through the neck of the pot or the sides of the pot that are covered by 50 mm mesh. Ongoing monitoring of bycatch sampled in fishery-independent surveys at consistent sampling locations inside and outside SZ-3 may help elucidate any trends in abundance of key bycatch species sampled by rock lobster pots, however, other techniques such as Baited Remote Underwater Videos (BRUVs) may be more suitable to estimate trends in species richness, evenness or abundance.

In summary, the increases in mean size, abundance and biomass recorded for Southern Rock Lobster within SZ-3 of the WKIMP support the findings for other marine park studies worldwide and indicate that the rock lobster population biomass within SZ-3 has increased in the absence of fishing since sanctuary zones were implemented in South Australia on 1 October 2014. The initial response of the Southern Rock Lobster population inside SZ-3 has been rapid, and future research may determine if rates of population increase inside SZ-3 remain on the same trajectory, stabilise or decline in response to density-dependent effects, or whether SZ-3 is contributing to spillover of juveniles or adults to outside fishable areas, and enhancing total rates of larval export, settlement and recruitment within the NZRLF.

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APPENDICES

Appendix 1. Summary of bycatch sampled in SARDI's voluntary catch sampling program inside and outside SZ-3 between 1994/95 and 2015/16.

Stratum	inside v outside SZ-3	Velvet crab (*Nectocarcinus integrifrons*)	Horseshoe leatherjacket (*Meuschenia hippocrepis*)	Blue-throat wrasse (*Notolabrus tetricus*)	Octopus (*Octopus maorum*)	Leather jacket (unid Monacanthiodae)	Wrasse (unid Labridae)	Whelk (*Pleuroploca australasia*)	Hermit Crab (*Paguristes sp.*)	Barber Perch (*Caesioperca rasor*)	Wobbegong (*Orectolobus ornatus*	Ocean Jacket (*Nelusetta ayraudi*)	Brown striped leather jacket (*Meuschenia australis*	Red snapper (*Centroberyx gerradi*)	Slimy cod (*Pseudophycis barbata*)	Ling (*Genypterus blacodes*)	Gummy shark (*Mustelus antarcticus*)	Port Jackson shark (*Heterodontus portusjacksoni*)	Cuttlefish (*Sepia apama*)	Conger eel (*Conger verreauxi*)	Snapper (*Chrysophrys auratus*)
1	inside	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	inside	0	3	6	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	inside	6	7	12	6	1	3	3	1	0	0	1	0	0	0	0	0	0	0	0	0
4	inside	20	11	11	6	9	1	1	0	0	3	0	0	0	0	0	1	0	0	0	0
5	inside	28	3	5	4	2	1	0	0	1	0	0	1	2	0	0	0	0	0	0	0
6	inside	2	0	4	2	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
7	inside	6	4	8	6	2	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0
8	inside	7	1	4	5		0	0	0	3	0	0	1	0	0	0	0	1	0	0	0
9	outside	17	5	4	11	1	2	0	3	0	0	0	0	1	0	0	1	0	0	0	0
10	outside	5	13	6	4	2	3	0	2	1	0	0	1	0	0	0	0	0	0	0	0
11	outside	4	33	13	4	20	3	1	2	0	0	3	0	0	2	0	0	0	0	0	1
12	outside	6	3	4	0	3	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0
13	outside	36	61	38	12	8	2	1	4	2	1	0	0	0	0	3	0	1	0	0	0
14	outside	5	7	4	5	4	0	2	0	0	0	0	0	0	1	0	1	0	0	1	0
15	outside	41	19	6	6	2	0	2	2	0	0	1	1	0	1	0	0	0	0	0	0
16	outside	8	0	3	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Total inside		70	30	50	34	15	5	5	1	6	4	1	2	2	0	0	1	1	1	0	0
Total outside		122	141	78	43	40	11	9	13	3	1	4	2	2	4	3	2	1	0	1	1
Total		**192**	**171**	**128**	**77**	**55**	**16**	**14**	**14**	**9**	**5**	**5**	**4**	**4**	**4**	**3**	**3**	**2**	**1**	**1**	**1**