Fisheries

SOUTH AUSTRALIAN RESEARCH & DEVELOPMENT INSTITUTE
PIRSA

Southern Zone Rock Lobster (*Jasus edwardsii*) Fishery Stock Assessment 2018/19

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

SARDI Publication No. F2007/000276-14
SARDI Research Report Series No. 1063

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

July 2020

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

SOUTH AUSTRALIA

Government of South Australia
Primary Industries and Regions SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Southern Zone
Rock Lobster (*Jasus edwardsii*) Fishery
Stock Assessment 2018/19

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

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

SARDI Publication No. F2007/000276-14
SARDI Research Report Series No. 1063

July 2020

This report may be cited as:
Linnane, A., McGarvey, R., Feenstra, J. and Hawthorne, P. (2020). Southern Zone Rock Lobster (*Jasus edwardsii*) Fishery 2018/19. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000276-14. SARDI Research Report Series No. 1063. 68pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5415
http://www.pir.sa.gov.au/research

SARDI Publication No. F2007/000276-14
SARDI Research Report Series No. 1063

Author(s): A. Linnane, R. McGarvey, J. Feenstra and P. Hawthorne

Reviewer(s): B. Stobart and J. Earl (SARDI) and A. Jones (PIRSA)

Approved by: Dr S. Mayfield
Science Leader – Fisheries


Signed:

Date: 1 July 2020

Distribution: PIRSA Fisheries and Aquaculture, Southern Zone Rock Lobster licence holders, SAASC Library, Parliamentary Library, State Library and National Library

Circulation: Public Domain

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Research presented in this report was commissioned by PIRSA Fisheries and Aquaculture using funds obtained from licence fees paid by participants in the Southern Zone Rock Lobster Fishery. SARDI Aquatic Sciences provided substantial in-kind support for the project. We thank Lachlan McLeay, Kylie Odgers, Andrew Hogg, Damian Matthews and Brian Foureur for collecting and collating the data. The report was formally reviewed by Dr Ben Stobart, Dr Jason Earl, and Dr Annabel Jones (PIRSA Fisheries and Aquaculture) and approved for release by Dr Stephen Mayfield (SARDI Aquatic Sciences).

EXECUTIVE SUMMARY

This stock assessment determined the status of South Australia's Southern Zone Rock Lobster Fishery (SZRLF) through analysis of data from several long-term monitoring programs. The performance indicators in the current harvest strategy are not linked to a definition of stock status. Consequently, this assessment used a 'weight of evidence' method to determine stock status using the National Fishery Status Reporting Framework (NFSRF).

Assessment of the SZRLF relies heavily on data from the commercial fishing sector through mandatory catch and effort logbook reporting. Catch per unit effort (CPUE) of legal and undersized (pre-recruit) lobsters are the main indicators of legal and pre-recruit abundance. Fishery independent surveys and fishery model outputs also contribute to the assessment.

In 2018/19, the total allowable commercial catch (TACC) of 1,245.7 t was taken for the ninth consecutive season and effort required to take the catch was the lowest on record (840,572 potlifts). Nominal legal-sized CPUE was 1.48 kg/potlift, reflecting a 54% increase from 2016/17 (0.96 kg/potlift) and the highest catch rate since 2005. Current legal-sized catch rates are now above both the long-term average and the trigger reference point (TRP) for the fishery. Recent increases in CPUE are also reflected in fishery-independent surveys.

The pre-recruit index (PRI) shows a long-term decline since the late 1990s with the 2015/16 estimate the lowest on record (0.74 undersized/potlift). Over the last three seasons, the PRI has increased by 77% to 1.31 undersized/pot and is now above the limit reference point (LRP) of 1.30 undersized/potlift. In the SZRLF, the time taken for pre-recruits to enter the fishable biomass is approximately one year. Fishery-independent surveys also support recent increases in PRI.

Fishery model outputs indicate a current legal-size biomass of approximately 3,800 t reflecting a gradual increase since 2009/10. This translates to an exploitation rate of 33%, which is one of the lowest in the history of the fishery. However, despite recent increases in biomass, egg production in the SZRLF remains low, with the 2018/19 estimate at approximately 11% of unfished levels.

The following lines of evidence were considered in assessing the status of the SZRLF: (i) TACCs since 2010/11 have constrained catch to historically low levels; (ii) the CPUE is above both the long-term average and TRP; (iii) biomass has increased and exploitation rate is low in a historical context; (iv) PRI has increased by 77% over the last three seasons; and (v) fishery-independent surveys support recent increases in CPUE and PRI. Consequently, using a weight-of-evidence approach, under the NFSRF, the SZRLF in 2018/19 is classified as "**sustainable**".

Table 1 Key statistics for the SZRLF.

Statistic	2018/19	2017/18
TACC	1,245.7 t	1,245.7 t
Total commercial catch	1,245.2 t	1,245.7. t
Total effort	840,572 potlifts	1,021,872 potlifts
Commercial CPUE	1.48 kg/potlift	1.22 kg/potlift
Pre-recruit index	1.31 undersized/potlift	1.28 undersized/potlift
Biomass estimate	Approx. 3,800 t	Approx. 3,100 t
Exploitation rate	Approx. 33%	Approx. 40%
Status	**Sustainable**	**Sustainable**

Keywords: Southern Rock Lobster, *Jasus edwardsii*, stock assessment, harvest strategy, total allowable commercial catch.

1 INTRODUCTION

1.1 Overview

Stock assessments for the South Australian Southern Zone Rock Lobster (*Jasus edwardsii*) Fishery (SZRLF) have been produced annually since 1997 (Prescott et al. 1998). The current report presents information on the fishery and biology of the species and provides a current assessment of the status of the SZRLF in relation to the performance indicators provided in the Management Plan for the fishery (PIRSA 2013).

1.2 Description of the fishery

1.2.1 Access

Southern Rock Lobster is a highly valued fishery species across the States of South Australia, Victoria and Tasmania. Within South Australia, the fishery is divided into two zones; Northern and Southern, with an approximate SZRLF value of $98.2 million in 2017/18 (Econsearch 2019). The SZRLF includes all South Australian waters between the mouth of the Murray River and the Victorian border and covers an area of 22,000 km^2 (Figure 1-1). It is divided into seven Marine Fishing Areas (MFAs), but the majority of fishing occurs in four MFAs (51, 55, 56 and 58). There are 180 commercial licences with lobsters caught using steel-framed pots (Figure 1-2) that are set overnight and hauled at first light.

1.2.2 Management arrangements

The SZRLF is managed by the South Australian State Government's Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture Division in accordance with the legislative framework provided within the *Fisheries Management (General) Regulations 2017* while specific regulations are established in the *Fisheries Management (Rock Lobster Fisheries) Regulations 2017*. The policy, objectives and strategies to be employed for the sustainable management of the SZRLF are described in the *Management Plan for the South Australian Commercial Southern Zone Rock Lobster Fishery* (PIRSA 2013). Recreational fishers are regulated under the *Fisheries Management (General) Regulations 2017.*

The commercial SZRLF has undergone considerable management changes over the past 50 years that has seen the fishery restructured and limited through gear restrictions, spatial and temporal closures, size limits and the implementation of a total allowable commercial catch (TACC) in 1993 (Table 1-1). The TACC is set annually and divided proportionally between licence holders owning individual transferable quota (ITQ) units. The daily catch of individual vessels is monitored electronically via catch and disposal records and mandatory commercial logbooks. Details of management arrangements for the 2018/19 season are provided in Table 1-2.

1.2.3 Recreational fishery

There is an important recreational fishery for lobsters in the SZRLF. Recreational fishers are allowed to use drop nets, pots or SCUBA to take lobsters during the same season as commercial fishers. All recreational lobster pots must be registered. The recreational season extends from 1 October to 31 May.

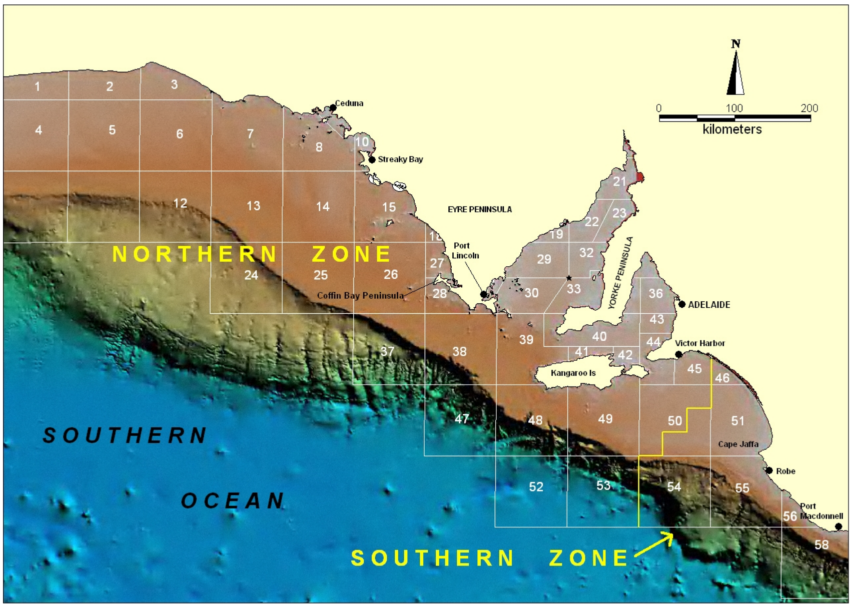

Figure 1-1 Marine Fishing Areas in the Southern and Northern Zones of the South Australian Rock Lobster Fishery.

Figure 1-2 A commercial Southern Rock Lobster fishing pot.

Table 1-1 Major management milestones for the SZRLF.

Year	Management milestone
1958	Closed season for females from 1 June to 31 October and for males from 1 to 31 October
1967	Pot and boat limit introduced, no new boats to operate in the then "South-Eastern Zone"
1968	Limited entry declared, compulsory commercial catch log
1978	June, July, October closed
1980	Winter closure declared. Season from 1 October to 30 April.
1984	15% pot reduction
1987	Buyback of 40 licences (2455 pots)
1993	April closed; TACC implemented for 1993/94 season at 1720 t
1997	Management Plan for the fishery published (Zacharin 1997)
2001	TACC increased by 50 t to 1770 t
2003	TACC increased by 130 t to 1900; May opened on trial basis
2005	May trial completed. Decision to open May permanently
2007	New Management Plan for the SZ fishery published (Sloan and Crosthwaite 2007)
2008	TACC reduced to 1770 t
2009	TACC reduced to 1400 t
2010	TACC reduced to 1250 t. October closed to fishing
2011	New Harvest Strategy developed. October reopened
2013	New Management Plan for the SZ fishery published (PIRSA 2013). One licence surrendered from fishery through marine parks voluntary commercial fisheries catch and effort reduction program
2014	TACC reduced to 1245.7 t to account for voluntary surrender of one licence

Table 1-2 Management arrangements for the SZRLF in 2018/19.

Management tool	Current restriction
Limited entry	180 licences
Total Allowable Commercial Catch	1,245.7 t
Closed season	1 June to 30 September
Total number of pots	11,882
Minimum size limit	98.5 mm CL
Maximum number of pots/licence	100 pots
Minimum number of pots/licence	40 pots
Maximum quota unit holding	Limited by pot holding (100 pots)
Minimum quota unit holding	Limited by minimum pot holding (40 pots)
Spawning females	No retention
Maximum vessel length	None
Maximum vessel power	None
Closed areas	Aquatic Reserves: Margaret Brock Reef, Cape Jaffa and Rivoli Bay
Escape gaps	Two escape gaps or 50 mm mesh size
Catch and effort data	Daily logbook reported electronically
Catch and Disposal Records	Daily records reported electronically
Landing locations	7 designated landing sites
Landing times	Landings permitted during core hours or outside core hours with a prior landing report
Prior landing reports to PIRSA	Outside core hours, 1 hour before landing
Bin tags	All bins must be sealed with a lid and an approved tag prior to lobster being unloaded from the vessel. Tags are sequentially numbered.

1.3 Biology of Southern Rock Lobster

Southern Rock Lobster are distributed around southern mainland Australia, Tasmania and New Zealand. In Australia, the northern limits of distribution are Geraldton in Western Australia and Coffs Harbour in northern New South Wales but the bulk of the population is found in South Australia, Victoria, and Tasmania where they occur to on algal-dominated reef habitat to depths of approximately 200 m.

Detailed reviews on the reproductive biology and life history of *J. edwardsii* are provided in Phillips (2013). In brief, *J. edwardsii* mate from April to July followed by a brooding period of 3-4 months over the Austral winter (June to August) (MacDiarmid 1989). Larvae hatch in early spring and pass through a brief (10-14 days) nauplius period before entering into a planktonic, leaf-like phase called a phyllosoma. These develop through a series of 11 stages over 12-23 months before metamorphosing into the puerulus stage (Booth et al. 1991; Bruce et al. 1999). Puerulus are non-feeding but can actively swim thereby aiding settlement onto suitable reef habitat (Booth et al. 1991; Phillips and McWilliam 2009).

In South Australia, the strength of westerly winds, during late winter and early spring, plays an important role in inter-annual settlement variation (McGarvey and Matthews 2001; Linnane et al. 2010a). After inshore settlement, early juveniles (<20 mm CL) are solitary and normally found in isolated holes and crevices. As they develop, juvenile lobsters become increasingly communal with larger juveniles and sub-adults residing in large aggregations inside rocky dens within structurally complex reef habitat.

Based on morphological and mitochondrial DNA analysis, historical research provided little evidence of population sub-structuring across mainland Australia, Tasmania and New Zealand (Smith et al. 1980; Brasher et al. 1991; Ovenden et al. 1992). The long larval phase and widespread occurrence of larvae across the central and south Tasman Sea, in conjunction with known current flows, pointed to the likely transport of phyllosoma from south-eastern Australia to New Zealand, providing genetic mixing between the two populations (Booth et al. 1990; Bruce et al. 2007). More recent and powerful genetic techniques however have rejected the concept of panmixia and revealed significant population structure in both Tasmanian (Morgan et al. 2013) and New Zealand (Thomas 2012) stocks.

1.4 Research program

SARDI Aquatic Sciences maintains an on-going stock assessment and monitoring program for both the Northern and Southern Zone rock lobster fisheries of South Australia. Outputs from the program are provided to the Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture, through a series of annual status and stock assessment reports.

Dedicated research projects are also undertaken periodically address to addressing key knowledge gaps or improve ongoing stock assessments (McGarvey et al. 2014; Linnane et al. 2016).

1.5 Information sources for assessment

1.5.1 Commercial catch and effort data

All licenced commercial fishers are required to complete a daily logbook of fishing activity. This includes information such as MFA fished, species targeted, species caught, weight of legal–sized catch, number of legal–sized lobsters landed and fishing effort as potlifts. In addition to mandatory details, a number of voluntary fields may also be completed such as number of undersized individuals, lobster mortalities and levels of high-grading. Records are submitted monthly to SARDI Aquatic Sciences where they are entered into the South Australian Rock Lobster (SARL) database. The catch and effort time series used in this assessment extends from 1 October 1970 to 31 May 2019.

1.5.2 Recreational catch and effort data

Four recreational fishing surveys have been carried out in South Australia over the past 15 years. These were primarily telephone/diary surveys in nature and were undertaken in 2000/01 (Henry and Lyle 2003), 2004/05 (Currie et al. 2006), 2007/08 (Jones 2009) and 2013/14 (Giri and Hall 2015).

1.5.3 Voluntary catch sampling

Since 1991, commercial fishers and researchers have collaborated in a voluntary catch sampling program. Fishers contribute by recording data from up to three pots per day while researchers generally record data from all pots during on-board observer trips. The program collects catch and effort data at finer spatial scales to that recorded in commercial logbooks in addition to supplementary data such as sex ratios, reproductive condition of females and bycatch. An important contribution from the program is lobster size data which are used to generate size frequency distributions as well as provide input data for the length-based LenMod fishery model.

1.5.4 Puerulus monitoring program

Rates of puerulus and post-puerulus settlement have been monitored in the SZRLF since 1991/92. This program was initiated based on the settlement-recruitment relationship observed in Western Australia where future commercial catches of *Panulirus cygnus* were predicted from settlement indices using a 3–4 year time lag (Caputi et al. 1995). Though not as explicit, similar relationships are now also evident in specific regions of some *J. edwardsii* fisheries in both Australia and New Zealand (Gardner et al. 2001; Booth and McKenzie 2009; Linnane et al. 2013; 2014).

1.5.5 Fishery-Independent Monitoring Survey

It has long been recognised that fishery-dependent abundance estimates can be influenced by a range of factors associated with fishing behaviour (Thorson et al. 2017). As a result, a fishery-independent monitoring survey (FIMS) has been undertaken in the SZRLF since 2006/07. The primary aim of the FIMS is to determine legal and undersized lobster abundances, as well as size frequency distributions, that are independent of commercial fishing behaviour.

1.5.6 "qR" and "LenMod" stock assessment models

Two computer-based fishery stock assessment models have been developed for the South Australian Rock Lobster Fishery. Each model provides outputs for both the Northern and Southern Zone fisheries that take into account known biological information specific to each region.

The primary data input to the qR model is catch by weight and catch by number. Outputs have been presented in stock assessment reports for the fishery since 1997 (McGarvey et al.1997; McGarvey and Matthews 2001) with a review in 2002 (Breen and McKoy 2002) concluding that the qR model was an appropriate tool for assessing rock lobster stocks. The model has been refined over time, most notably during the peer review process for publication of McGarvey and Matthews (2001) and changes to biomass definitions in 2008.

The basic structure of the second model, LenMod, was developed by André Punt in the 1990s (Punt and Kennedy 1997). Variants of this length-based lobster model are now used for management and quota setting in most *J. edwardsii* fisheries, notably in New Zealand, Victoria and Tasmania. LenMod fits to monthly catch in number and CPUE, while conditioning on catch in weight. In addition, it also incorporates length-frequency data from voluntary catch sampling, where the lobster population is broken down into size categories of differing CL.

The primary outputs from both models are: (i) legal-sized biomass; (ii) egg production; (iii) % unfished egg production; (iv) exploitation rate (fraction of legal-sized biomass); and (v) recruitment. In addition, both models have been extensively used in bio-economic analyses and harvest strategy evaluations (McGarvey et al. 2014; 2015; 2016; 2017).

1.6 Harvest strategy

1.6.1 Management plan

A new Management Plan for the South Australian SZRLF was adopted in October 2013 (PIRSA 2013). A harvest strategy included in this management plan provides a structured framework for decision-making that aims to ensure that the ecologically sustainable development objectives of the *Fisheries Management Act 2007* are achieved. The aim of this harvest strategy is to rebuild the biomass of the resource and increase catch rates. A revised TACC table (Table 1-3) for the harvest strategy decision rules was adopted in 2015. The revised table was used for TACC setting for the fishery from the 2015/16 season.

1.6.2 Performance indicators

The Harvest Control Rule (HCR) uses multiple performance indicators to monitor the performance of the fishery (PIRSA 2013). Details of the HCR and its associated testing are provided in McGarvey et al. (2016). Broadly, the HCR aims to target a constant exploitation rate based on historical fishery performance and uses two fishery-dependent indicators.

The primary indicator is commercial logbook catch per unit effort (CPUE; kg of legal-sized lobster/potlift) based on data from October to May, inclusive. The secondary indicator is a commercial logbook pre-recruit index (PRI; number of undersized lobsters/potlift) based on data from November to March, inclusive. Additional indicators not explicitly used to set a TACC, but which contribute to the overall assessment, include the puerulus settlement index (PSI), length-frequency data and model outputs such as biomass and exploitation rates.

CPUE bands, which equate to target exploitation rates, are specified in Table 1-3. To set a TACC for the upcoming season, the CPUE from the previous season is applied. A Trigger Reference Point (TRP) of 0.60 kg/plotift is used, below which, exploitation rates (and corresponding TACCs) are reduced, while a Limit Reference Point (LRP) of 0.30 kg/potlift reflects the point at which the fishery is closed. TACCs can only be increased if the PRI is above a LRP of 1.3 undersized/potlift. TRPs and LRPs are not applied to additional indicators and are not currently linked to stock status classifications.

Table 1-3 CPUE bands and associated TACCs for the SZRLF harvest control rule.

CPUE (kg/potlift)	TACC (t)
>1.3	1494.8
1.2-1.3	1494.8
1.1-1.2	1320.4
1.0-1.1	1320.4
0.9-1.0	1245.7
0.8-0.9	1245.7
0.7-0.8	946.7
0.6-0.7	896.9
0.55-0.6	812.2
0.5-0.55	638.8
0.45-0.5	480.3
0.4-0.45	336.8
0.35-0.4	209.3
0.3-0.35	97.7
<0.3	0.0

1.7 Stock status classification

The status of the SZRLF was classified using the National Fishery Status Reporting Framework (NFSRF) (Flood et al. 2014) the terminology of which was recently refined and amended (Stewardson et al. 2018) (Table 1-4). It considers whether the current level of fishing pressure is adequately controlled to ensure that the stock abundance is not reduced to a point where the production of juveniles is significantly compromised. The system combines information on both the current stock size and the level of exploitation into a single classification for each stock against defined biological reference points. Each stock is then classified as ‘sustainable’, ‘depleting’, ‘recovering’, ‘depleted’, ‘undefined’ or ‘negligible. PIRSA has adopted this classification system to determine the status of all key South Australian fish stocks.

The performance indicators in the current harvest strategy for the SZRLF are not directly linked to a definition of stock status. Consequently, this assessment used a ‘weight of evidence’ method to determine stock status.

Table 1-4 Stock status terminology (Stewardson et al. 2018).

	Stock status	Description	Potential implications for management of the stock
	Sustainable	Biomass (or proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (recruitment is not impaired) and for which fishing mortality (or proxy) is adequately controlled to avoid the stock becoming recruitment impaired (overfishing is not occurring).	Appropriate management is in place.
	Depleting	Biomass (or proxy) is not yet depleted and recruitment is not yet impaired, but fishing mortality (or proxy) is too high (overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired.	Management is needed to reduce fishing mortality and ensure that the biomass does not become depleted.
	Recovering	Biomass (or proxy) is depleted and recruitment is impaired, but management measures are in place to promote stock recovery, and recovery is occurring.	Appropriate management is in place, and there is evidence that the biomass is recovering.
	Depleted	Biomass (or proxy) has been reduced through catch and/or non-fishing effects, such that recruitment is impaired. Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements.	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect.
	Undefined	Not enough information exists to determine stock status.	Data required to assess stock status are needed.
	Negligible	Catches are so low as to be considered negligible and inadequate information exists to determine stock status.	Assessment will not be conducted unless catches and information increase.

2 METHODS

2.1 Commercial catch and effort statistics

Commercial logbook catch and effort data are compulsorily recorded by licenced fishers in the SZRLF. Detailed analyses of these data are provided for the period between 1 January 1970 and 31 May 2019. For ease of reference, figures and text refer to the starting year of each season (e.g. “2018” refers to the 2018/19 fishing season starting 1 October 2018).

Important commercial data such as catch (tonnes (t)), effort (potlifts), CPUE (kg/potlift), mean weight (kg) and PRI (number of undersized/potlift) were analysed both spatially and temporally. Spatially, data were presented by zone, MFA and in some cases, depth range. Temporally, data were presented by year and month.

In addition to the above, additional data sources recorded in the voluntary component of the logbook are also presented but at a reduced spatial or temporal scale. While these are not directly linked to setting the annual TACC, they are either deemed to contribute to the overall understanding of the fishery or have been specifically requested by stakeholder groups. These include catch rates of: (i) ovigerous (spawning) females and predation mortality as estimated through catch rates of: (ii) dead lobsters and; (iii) octopus. The average numbers of days fished (as a proxy for fishing effort) and estimated levels of fishery high-grading are also analysed.

2.2 Recreational catch and effort data

The specific details of the methodology used in the four recreational surveys considered in this assessment can be found in their respective reports (2000/01: Henry and Lyle 2003; 2004/05: Currie et al. 2006; 2007/08: Jones 2009; 2013/14: Giri and Hall 2015). A detailed description of the telephone-diary design philosophy and method is provided in Henry and Lyle (2003).

2.3 Voluntary catch sampling

Voluntary catch sampling datasheets are completed daily and submitted monthly to SARDI Aquatic Sciences. Fishers and observers count, measure (mm CL), sex and record the reproductive condition of female lobsters (ovigerous or non-ovigerous) from all pots sampled. In addition, all bycatch are identified and counted. The latitude and longitude of each pot sampled is recorded, thereby providing information at a finer-scale spatial resolution than that of commercial logbooks.

2.4 Puerulus monitoring program

Puerulus monitoring sites in the SZRLF are located at Blackfellows Caves, Livingstones Beach, Beachport, Cape Jaffa and Kingston, with the collectors set in groups of 10 or 12 at each site. The collectors are similar in design to those described by Booth and Tarring (1986) and consist of angled wooden slats that mimic natural crevice habitat. The design has remained unchanged throughout the sampling period. Sampling is undertaken monthly, whereby collector heads are detached from a base by a diver, covered with a mesh bag and hauled to the surface for counting.

The annual puerulus settlement index (PSI) is calculated as the mean monthly settlement on all collectors combined. This index is then related to annual pre-recruit and commercial catch rate indices based on previously estimated time lags.

2.5 Fishery-Independent Monitoring Survey (FIMS)

The FIMS design consists of 29 transects, running from inshore (~10 m depth) to offshore (~120 m depth) grounds in the SZRLF (Figure 2-1). Each transect line consists of 10 pots set at predetermined locations that are independent of known fishing effort. Sampling is undertaken in September and January of each season. Lobsters are counted, sexed, measured, staged (females only) and tagged. Data are used to generate legal (number (nr) /potlift) and undersized (nr/potlift) CPUE indices which are compared to those from fishery-dependent logbook sources. FIMS abundance indices were calculated based on systematic confidence interval estimates for clustered populations (McGarvey et al. 2016 and Appendix 2).

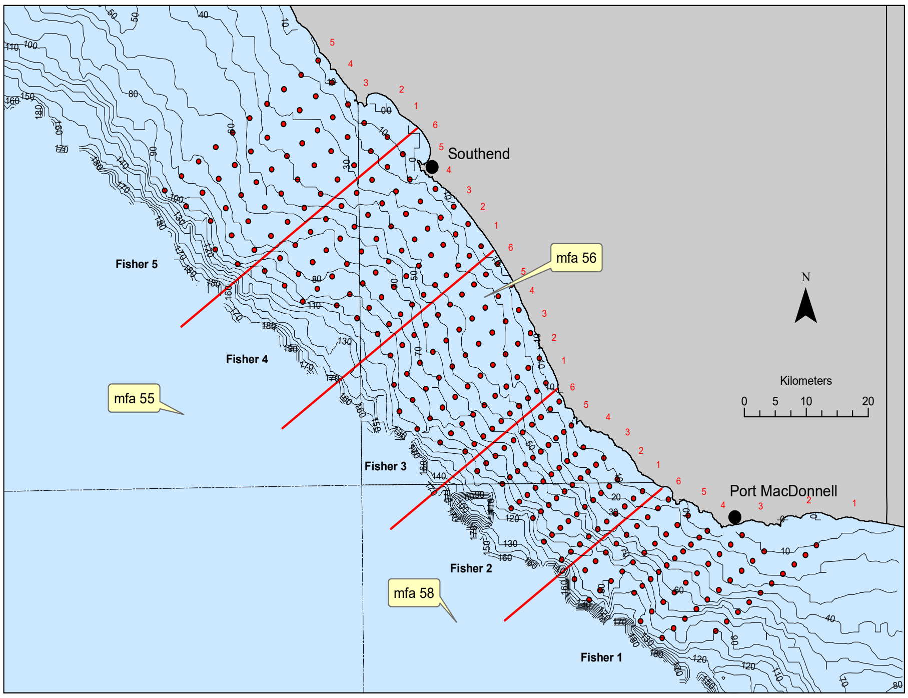

Figure 2-1 Location of Fishery Independent Monitoring Survey (FIMS) transects in the SZRLF. MFA = Marine fishing Area.

2.6 “qR” and “LenMod” stock assessment models

Two models assess the SZRLF. The qR model is yearly and uses the three logbook time series of catch in weight, catch in number, and fishing effort as potlifts. LenMod is monthly, and integrates catch-sampling length-frequencies and FIMS CPUE, in addition to the logbook data used by the qR model. Growth in the two models differs, the qR model using a vector of mean lengths-at-age and LenMod using length-transition matrices. Both models estimate yearly independent recruitment.

A number of changes were introduced to the two models in 2017. In both models, the method of computing unfished egg production (UEP) was modified by adopting 1990–2011 as the reference time period for computing mean unfished recruitment. This reference period is also used in other jurisdictions (e.g. Tasmania) and therefore permits State-wise consistent reporting at the stock level under the Status of Australian Fish Stocks (SAFS) system. Also, this reference time period covers years of both higher-than-average (pre-2002) and lower-than-average (2002+) historical recruitment.

For LenMod, the method of estimating monthly and sex-specific selectivity has been improved to allow separate length selectivity by grouped months through each season.

2.6.1 qR model

The qR model (McGarvey and Matthews 2001) fits to: (i) annual catch in weight and (ii) annual catch in number of lobsters landed. The model is effort conditioned and runs on a yearly time step. It incorporates a Baranov survival model and conditions on effort by assuming that yearly instantaneous fishing mortality rate varies in proportion to yearly reported fishing effort. The likelihood that is maximised numerically to estimate parameters is the sum of the likelihood terms for fitting to catch in weight and number. These are normal, with a shared estimated parameter for the residual error as a likelihood coefficient of variation. Yearly recruitment is estimated for the start of each fishing season. Annual stock biomass is reported as an integrated average over the 12 months of each model year.

Both stock assessment models rely on catch rate as a measure of relative fishable biomass. The addition of catches in number landed to the fitted logbook dataset, unavailable in most fisheries, provides important yearly information about the size of lobsters in the legal catch. Information on mean size in crustacean fisheries is normally available only from length-frequency samples, which can show high sample variation and are subject to additional variation in the specific locations or times during the season when length samples are taken. Catch in weight divided by catch in number gives the yearly mean weight of a landed lobster. Because reported catches in weight and number constitute a 100% sample, the quality of information obtained about changes in mean size from catch-log data is far more precise than that obtained from length frequencies, which typically constitute a 0.1% to 1% sample. Thus, the data informing the qR model provide relative indices of abundance as yearly catch rates (in both weight and number) and yearly mean landed weight. McGarvey et. al. (2005) demonstrated, using independent individual-based simulated data, that adding catch in number dramatically improves the accuracy and precision of stock assessment estimates in species that cannot be aged. Further details of the qR model specifications including its equations, assumptions and parameters are provided in Appendix 3.

2.6.2 LenMod

LenMod is a length-based assessment model running on a monthly time step. Lobster population numbers are broken down and estimated in 4 mm carapace length bins. Catchability is estimated separately for each month. LenMod infers stock dynamics and abundance levels using maximum likelihood by fitting to four data sources, and conditioning on a fifth: (i) nominal monthly CPUE (in weight) to which fishable biomass is assumed to vary in direct proportion (ii) monthly catch in number (iii) length-frequency proportions by length bin fitted by a multinomial likelihood (iv) fishery-independent monitoring survey (FIMS) CPUE; and (v) catch in weight landed from all sources (commercial and recreational). Dead lobsters in pots, and lobsters dying naturally (10% per year) are directly removed from the model population in each time step. Data sources (ii) and (iii) both provide LenMod with information on the size of lobsters in the catch which, interpreted in combination with length-transition matrices, yield estimates of total mortality.

Moulting growth occurring in semi-yearly moulting times is modelled by length-transition matrices that specify the proportion of lobsters in each length class that grow into larger length classes, or remain in that length class, during each summer and autumn moulting season. These length-transition probabilities were estimated using extensive tag-recovery data mainly from the 1990s. The length-transition estimation method of McGarvey and Feenstra (2001) was applied, which infers widely flexible growth curves to be inferred by modelling the parameters predicting mean and variance of observed tag-recovery growth increments as polynomial functions of (starting) CL. Growth matrices were estimated for each combination of sex and moulting season. As growth rates of female lobsters are known to slow substantially once they reach maturity, this flexible polynomial estimation method, which accommodates non-linear growth rate versus starting length, provides a more accurate estimation of female adult growth than a traditional von Bertalanffy model of mean growth increment. Full details of LenMod specifications including its equations, assumptions and parameters are provided in Appendix 4.

2.7 Quality assurance of data

All logbook, catch sampling and fishery-independent survey data are entered and validated according to the quality assurance protocols identified for the SZRLF in the SARDI Information Systems quality assurance and data integrity report (Vainickis 2010). The data are stored in an Oracle database, backed up daily, with access restricted to SARDI Information Systems staff. Extracts from the database are provided to SARDI rock lobster researchers on request. All puerulus data are entered into Excel spreadsheets and stored on a SARDI network drive.

.

3 RESULTS

3.1 Commercial catch and effort statistics

3.1.1 Zone

In 2018, the TACC in the SZRLF was 1,245.7 t and this was taken for the ninth consecutive season (Figure 3-1a; Table 6-1). Current catch levels are low in a historical context and reflect declines in catch and subsequent TACC reductions from 2007 to 2009 (Table 3-1). During this timeframe, the TACC was reduced from 1,900 t to 1,250 t with a further reduction to 1,245.7 t in 2014 due to the removal of one licence as part of the marine parks voluntary commercial fisheries catch and effort reduction program. Catches have been stable since 2014, reflecting the constant TACC level over this period.

Effort required to take the 1,245.2 t catch was 840,572 potlifts in 2018, a decrease of 18% from 2017 (1,021,872 potlifts) (Figure 3-1a; Table 6-1). Since 2009 (2,049,961 potlifts), effort has generally declined in the fishery, with the 2018 estimate the lowest on record.

In 2018, the nominal legal-sized CPUE was 1.48 kg/potlift, reflecting a 54% increase from 2016 (0.96 kg/potlift) and the highest catch rate since 2005 (Figure 3-1b; Table 6-1). Between 2010 and 2016, catch rates remained relatively stable at approximately 1 kg/potlift. The 2018 estimate represents the second time since 2007 that CPUE has been above the long-term average (1.04 kg/potlift) and is the highest estimate since 2005. CPUE also remains above the TRP of 0.60 kg/potlift.

Overall, the zonal estimate of the logbook-based PRI shows a consistent long-term decline between 1999 and 2015 (Figure 3-1c). However, over the last three seasons the PRI has increased and in 2018, was 1.31 undersized/potlift, reflecting an increase of 77% from 2015 (0.74 undersized/potlift) and the highest since 2010. The PRI is now marginally above the LRP of 1.30 undersized/potlift. In the SZRLF, the time taken for pre-recruits to enter the fishable biomass is estimated to be approximately one year.

Legal-sized mean weight has remained relatively stable over time ranging between 0.7 and 0.9 kg (Figure 3-1d). In 2018, the mean weight was 0.85 kg reflecting a marginal increase from 0.83 kg in 2017. Variations in mean weight generally reflect long-term patterns of recruitment, with low mean weights resulting from influxes of small lobsters into the fishable biomass and high mean weights resulting from several consecutive years of low recruitment.

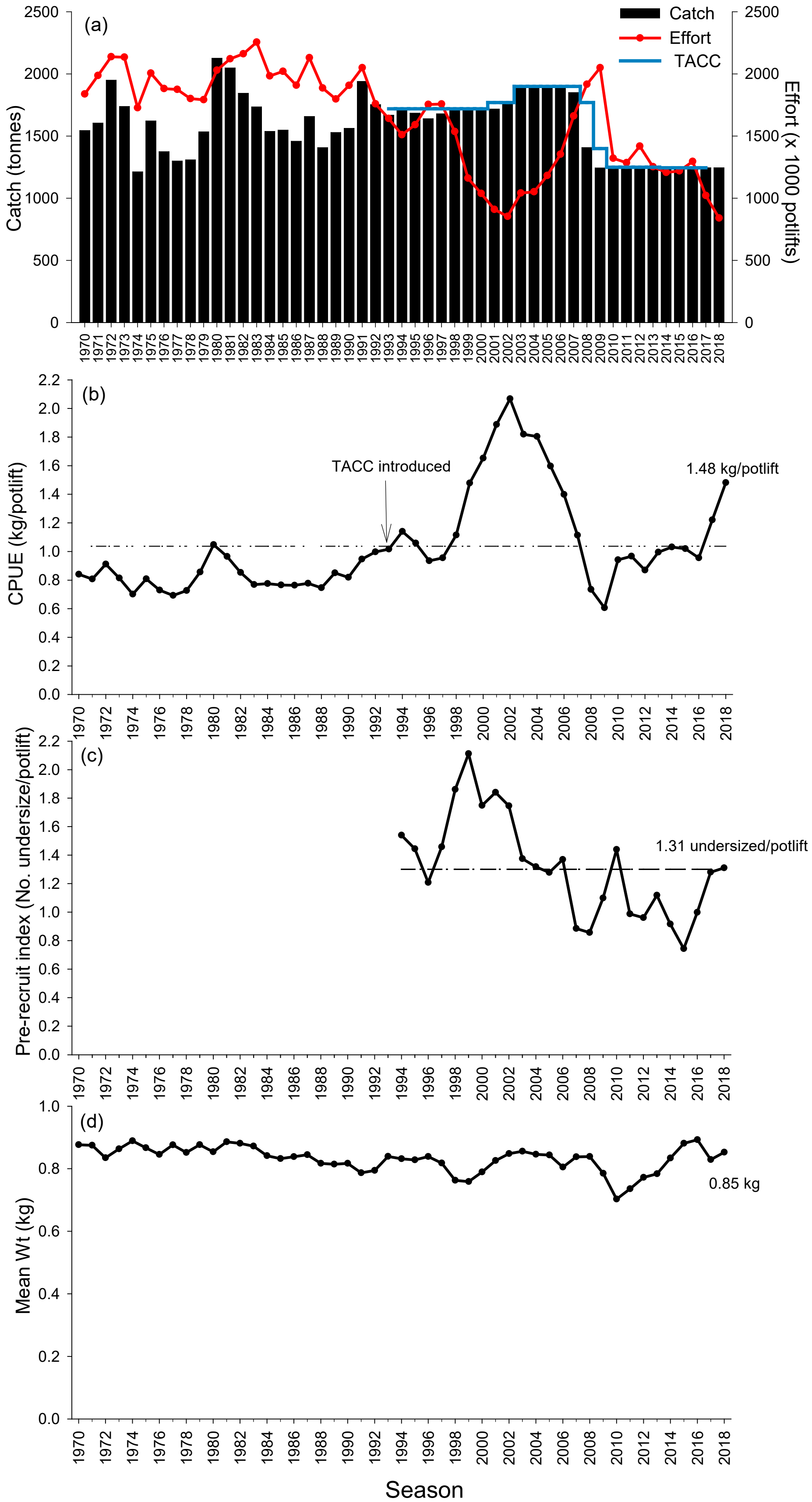

Figure 3-1 Fishery dependent outputs for the SZRLF. (a) Catch and effort including total allowable commercial catch (TACC) limit; (b) catch per unit effort (CPUE) including long-term average (dashed line); (c) pre-recruit index (PRI) including limit reference point (dashed line); and (d) mean weight.

Table 3-1 Chronology of TACC versus landed catch in the SZRLF.

Season	TACC (t)	Landed catch (t)	Shortfall (t)	% TACC taken
1993	1720	1668.6	51.4	97
1994	1720	1721.5	-1.5	100
1995	1720	1683.6	36.4	98
1996	1720	1639.7	80.3	95
1997	1720	1680.0	40.0	98
1998	1720	1713.1	6.9	100
1999	1720	1717.3	2.7	100
2000	1720	1716.3	3.7	100
2001	1770	1717.5	52.5	97
2002	1770	1765.9	4.1	100
2003	1900	1895.9	4.1	100
2004	1900	1896.6	3.4	100
2005	1900	1888.7	11.3	99
2006	1900	1893.9	6.1	100
2007	1900	1849.6	50.4	97
2008	1770	1407.3	362.7	80
2009	1400	1243.3	156.7	89
2010	1250	1244.2	5.8	100
2011	1250	1242.1	7.9	99
2012	1250	1234.4	15.6	99
2013	1250	1246.7	3.3	100
2014	1245.7	1244.4	1.3	100
2015	1245.7	1244.4	1.3	100
2016	1245.7	1237.7	8.0	99
2017	1245.7	1245.7	0	100
2018	1245.7	1245.2	0.5	100

3.1.2 Within-season trends

Within-season commercial catch trends presented here are based on data from 2016 to 2018. Results from earlier seasons are accessed through previously published stock assessment reports (http://pir.sa.gov.au/research/publications/research_reports). In general, within-season trends in catch, effort, CPUE, PRI and mean weight within the SZRLF are consistent through time (Figure 3-2a-d). The highest catches are taken during spring/summer from October to January (Figure 3-2a). In 2018, 1,099 t (88%) of the 1,245.2 t catch was taken during this period with the highest catch taken in October (365 t), and the lowest catch in May (<1 t).

Within-season effort levels are largely consistent with those of catch (Figure 3-2a). In 2018, 745,995 potlifts were recorded between October and January, representing 89% of total effort (840,572 potlifts). Effort was highest in October (253,410 potlifts) before generally declining as the season progressed.

Legal-sized CPUE within the fishery generally tends to increase from October to January before decreasing thereafter (Figure 3-2b). In 2018, monthly catch rates were consistently higher across all months of the fishery compared to 2017 (noting that no catch was taken in May of 2017) and 2016. In 2018, CPUE was highest in January (1.63 kg/potlift) and lowest in May (1.07 kg/potlift).

The monthly catch rate of pre-recruits tends to be highest from October to March (Figure 3-2c). Overall, monthly PRI estimates in 2018 were similar to those in 2017. In 2018, the PRI was highest in March (1.46 undersized/potlift) and lowest in April (0.63 undersized/potlift).

Monthly legal-sized mean weight generally increases as the season progresses with trends broadly similar over the last three seasons (Figure 3-2d). In 2018, mean weight was lowest in November (0.80 kg) and highest in May (1.78 kg). However, care should be taken when interpreting May estimates due to low catch levels.

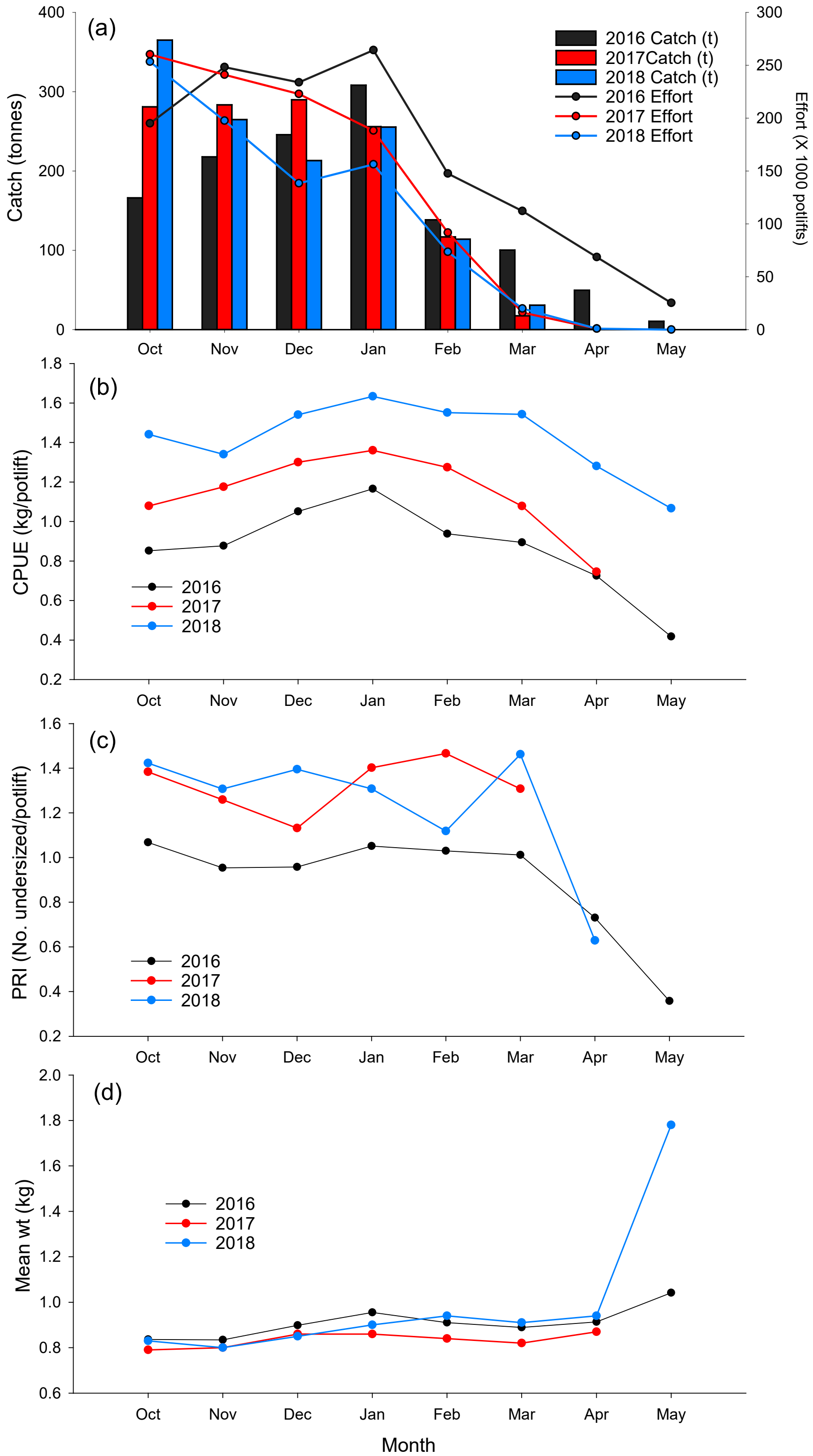

Figure 3-2 Within-season fishery dependent trends in the SZRLF. (a) Catch and effort; (b) catch per unit effort (CPUE); (c) pre-recruit index (PRI); and (d) mean weight.

3.1.3 Spatial trends

3.1.3.1 Marine Fishing Areas (MFAs)

Over 95% of the catch in the SZRLF is taken from MFAs 55, 56 and 58 (Figure 1-1). Historically, MFA 51 was a more important area, but its contribution has decreased in recent seasons. This partially reflects the fact that lobsters harvested from MFA 51 are generally larger in size and have a lower market value given the preference for smaller individuals by overseas markets. In 2018, the catches in MFAs 51, 55, 56 and 58 were 9 t, 447 t, 405 t and 383 t, respectively (Figure 3-3a; Table 6-2). Over the last five seasons, catches have remained relatively stable in all areas.

The zonal decrease in effort in 2018 was observed across all major MFAs. Effort estimates in 2018 in MFAs 51, 55, 56 and 58 were 5,980, 249,107, 265,856, and 319,254 potlifts respectively (Figure 3-3a; Table 6-2). These estimates reflect considerable decreases in effort across all areas, particularly over the last two seasons, with those in MFAs 51 and 55 in 2018 being the lowest on record.

Trends in CPUE are temporally consistent across MFAs (Figure 3-3b;Table 6-2). Following considerable declines between 2002 and 2009, catch rates remained relatively stable between 2010 and 2016. Over the last two seasons, however, catch rates have increased across all major MFAs. In 2018, the estimates in MFAs 51, 55, 56 and 58 were 1.47, 1.80, 1.52 and 1.20 kg/potlift respectively.

Spatial estimates of the logbook-based PRI indicate that the number of undersized/potlift is consistently lower in the northern regions of the SZRLF (i.e. MFAs 51 and 55) compared to the southern regions (i.e. MFA 56 and 58) (Figure 3-3c). Estimates in 2018 in MFAs 51, 55, 56 and 58 were 0.08, 0.34, 1.46 and 1.94 undersized/potlift, respectively.

Rock lobster legal-sized mean weight decreases with increasing latitude from the mouth of the Murray River (MFA 51) to the Victoria/South Australia border (MFA 58) (Figure 3-3d). It is most variable in MFA 51 but generally consistent across other MFAs. In 2018, mean weight increased in all areas with estimates in MFAs 51, 55, 56 and 58, being 1.22, 0.98, 0.83 and 0.76 kg, respectively.

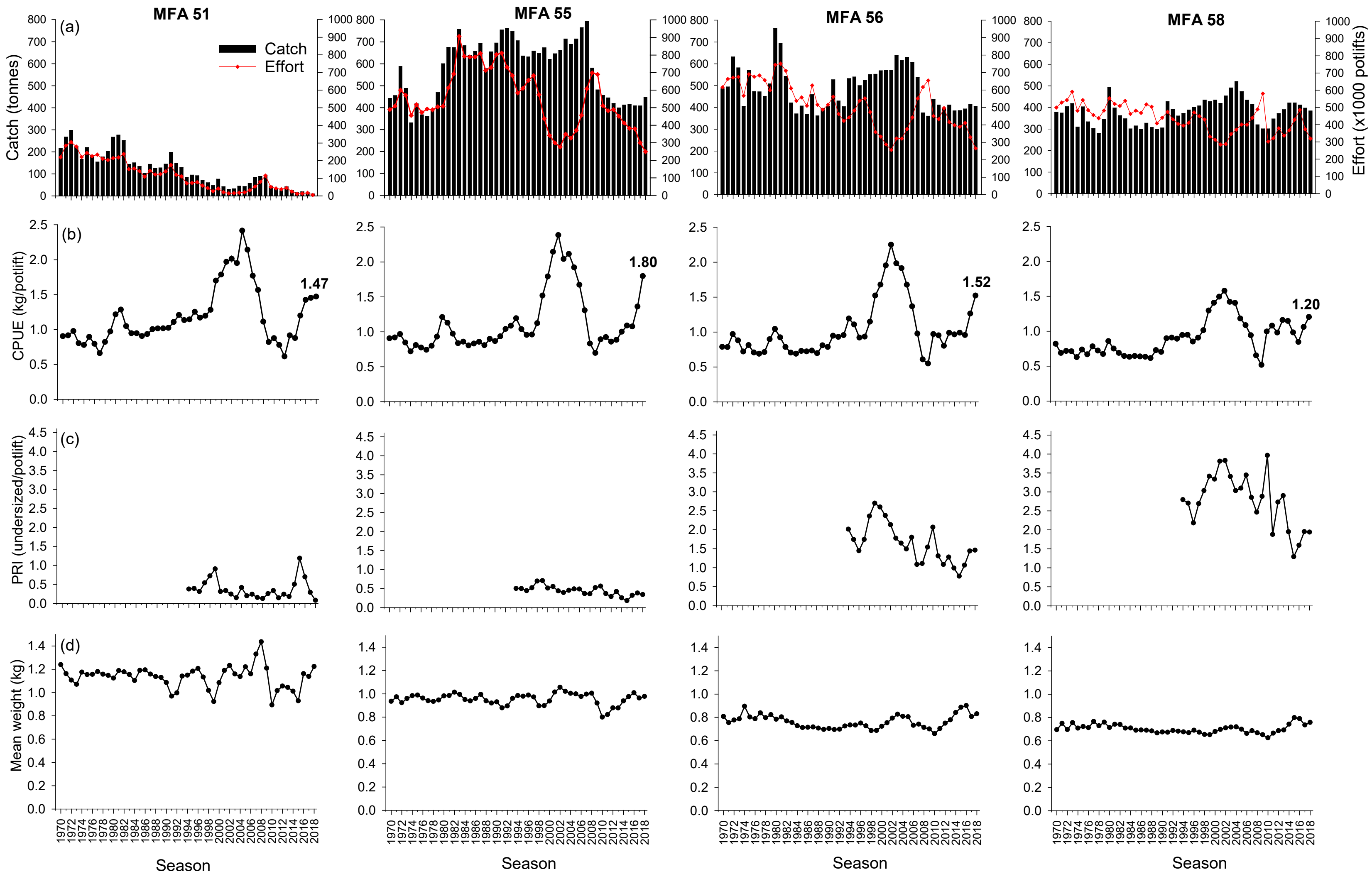

Figure 3-3 Spatial fishery dependent trends in the SZRLF. (a) Catch and effort; (b) catch per unit effort (CPUE); (c) pre-recruit index (PRI); and (d) mean weight.

3.1.3.2 Depth

In order to assess spatial trends by depth, logbook-derived catch from four depth range categories of 0-30, 31-60, 61-90 and >90 m were analysed. Over the last fifteen fishing seasons, over 80% of the annual catch has been taken from depths of <60 m (Figure 3-4). In 2018, 90% of the total catch came from <60 m depth with 32% coming from 0-30 m and 58% from 31-60 m. These trends were also reflected in each of the major MFAs (Figure 3-4).

Despite reflecting the majority of the annual catch, CPUE in depths of 0-30 m and 31-60 m is consistently lower than offshore areas of 61-90 m and >90 m (Figure 3-5). Trends largely reflect those at the zonal level with considerable decreases in all depth ranges from 2002 to 2009 before generally increasing over the last five to eight seasons. In 2018, estimates were 1.35, 1.50, 1.95 and 2.88 kg/potlift in 0-30, 31-60, 61-90 and >90 m, respectively, reflecting increases in all depths compared to 2017.

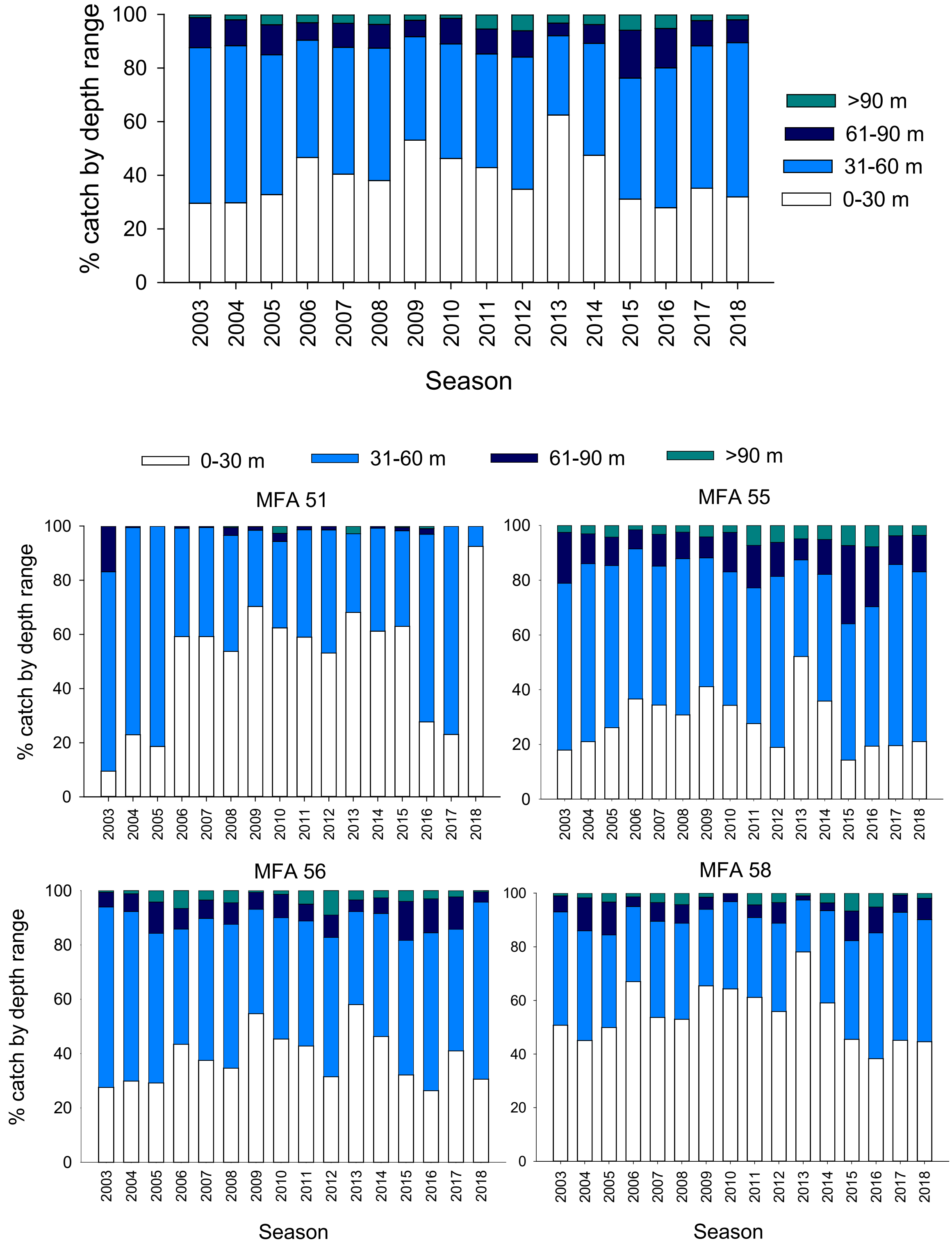

Figure 3-4 Percentage of catch taken from four depth ranges in the SZRLF by zone (top) and across the primary MFAs (bottom) from 2003 to 2018.

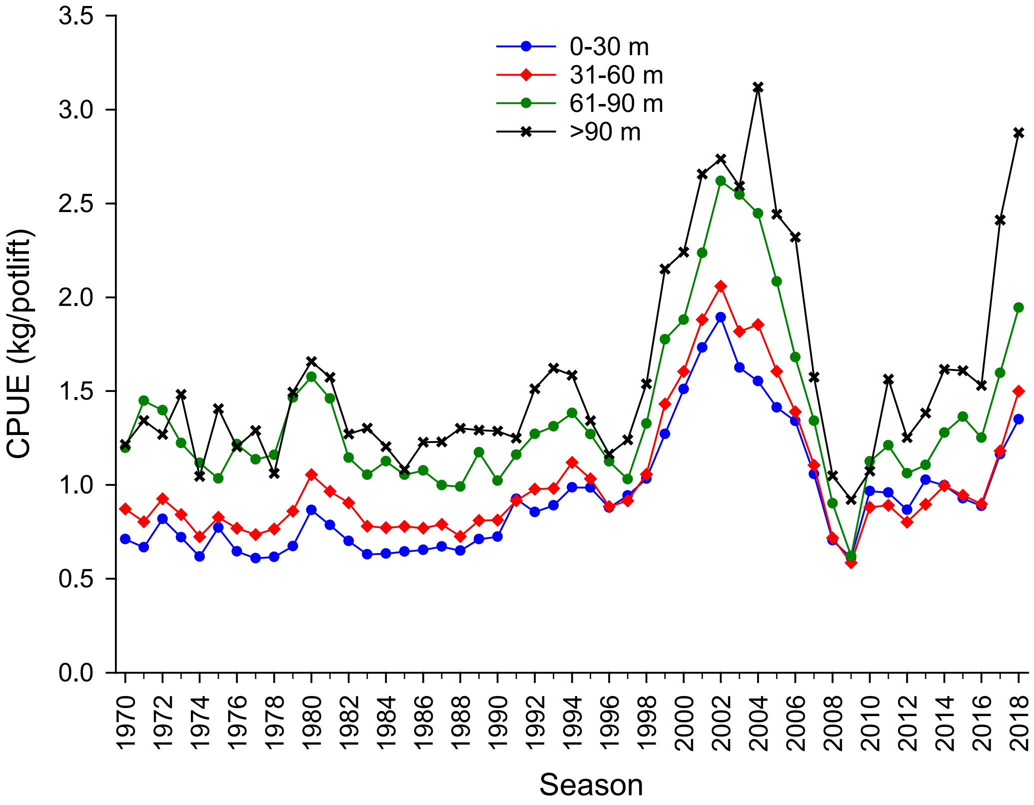

Figure 3-5 CPUE by depth in the SZRLF from 1970 to 2018.

3.1.4 Additional indices

3.1.4.1 Ovigerous (spawning) females

In 2018, the catch rate of ovigerous (spawning) lobsters was 0.46 spawners/potlift, the highest estimate since 2002 (Figure 3-6a). In line with overall declines in legal-sized lobster catch rates (Figure 3-1b), the CPUE of spawners decreased from 2002 to a historical low of 0.05 spawners/potlift in 2010. Since then, the index has been variable, with notable increases over the last two seasons. It is important to note that as October was closed for the 2010 season, the CPUE for spawning lobsters in that season is likely to be underestimated since October is commonly the highest catch month for ovigerous individuals.

3.1.4.2 Predation mortality

The maori octopus (*Pinnoctopus cordiformis*) is the primary predator of Southern Rock Lobster within commercial fishing pots (Brock and Ward 2004). As a result, both the catch rate of octopus and dead lobsters are highly correlated (Figure 3-6b; R^2 = 0.73). The number of dead lobsters/potlift has been variable through time ranging from 0.09 dead/potlift (in 2009) to 0.27 dead/potlift (in 2004) (Figure 3-6b). In 2018, the estimate was 0.16 dead/potlift.

The highest octopus catch rate was observed in 2000 at 0.05 octopus/potlift, with the lowest in 2017 at 0.008 octopus/potlift (Figure 3-6b). In 2018, the estimate was 0.01 octopus/potlift, which is the second lowest on record for the fishery.

3.1.4.3 Average days fished

In 2018, the average number of days fished per licence in the SZRLF was 72, the lowest estimate on record (Figure 3-6c). This index is a proxy for overall fishing effort and largely reflects trends in annual potlifts within the fishery (Figure 3-1a). From 2004 to 2009, the average number of days fished increased by 86% from 94 to 175, the highest on record, despite reductions to the TACC from 1,900 t to 1,400 t over the same period. In 2010, the TACC was reduced to 1,250 t and the average numbers of days fished decreased by 35% to 114 days, the lowest since 2005 (105 days). In 2013, the TACC was further reduced to 1245.7 t under the marine parks voluntary commercial fisheries catch and effort reduction program. The TACC has remained at this level over the last six seasons, during which, the average number of days fished has decreased from 108 days to 72 days.

3.1.4.4 High-grading

In 2018, the estimate of high-grading (i.e. lobsters returned to the water due to low market value) in the SZRLF was 28 t (Figure 3-6d). From 2003 to 2006, based on voluntary catch returns, the amount of lobsters high-graded exceeded 100 t annually. However, since 2008, estimates have not exceeded 30 t. The decrease between 2003 and 2008 is likely to reflect overall declines in legal-sized catch rate across the fishery over this period (Figure 3-1b). It should be highlighted that overall reported values in logbooks are likely to be conservative, since high-grade estimates are recorded on a voluntary basis.

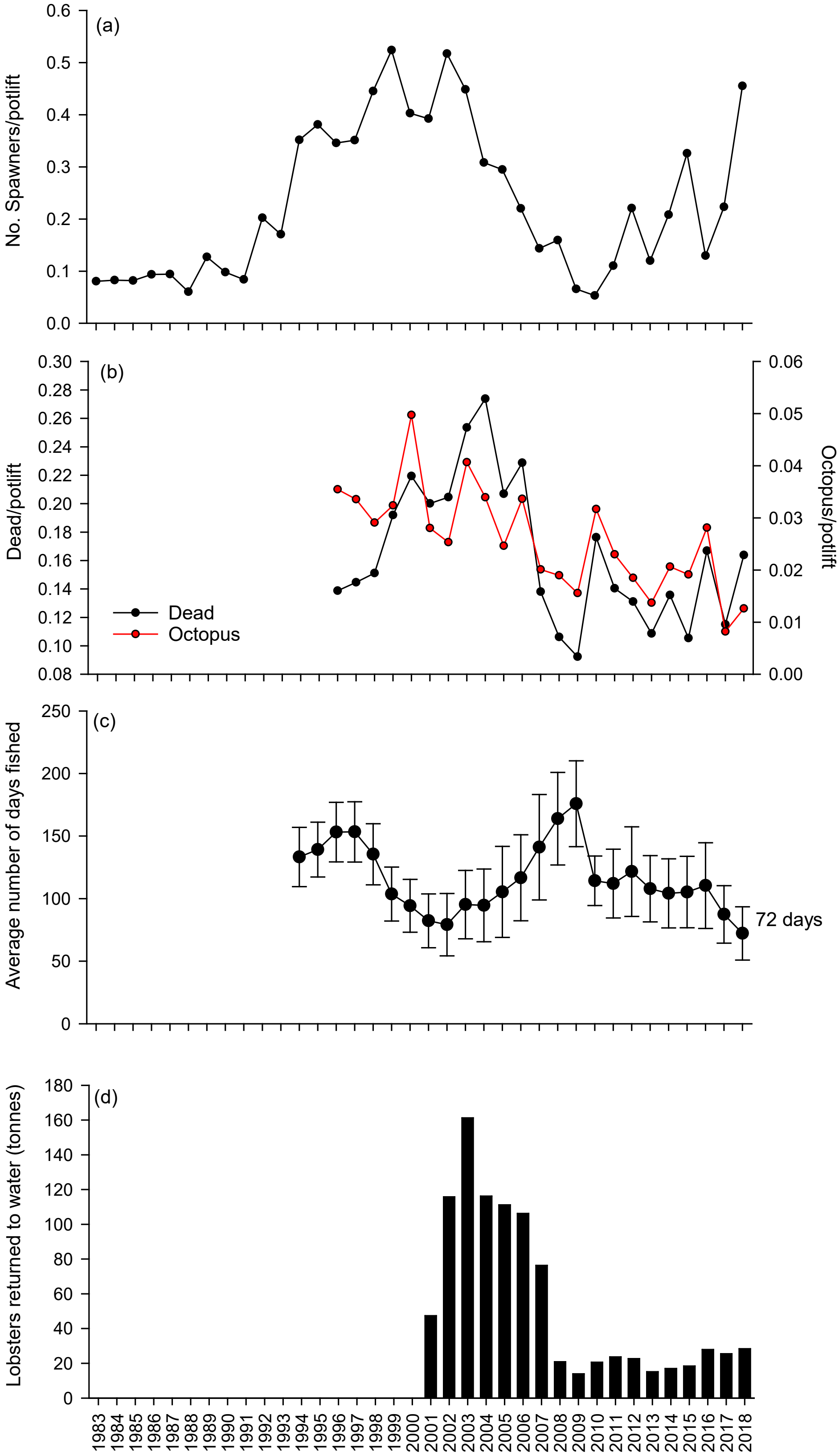

Figure 3-6 Additional fishery dependent indices in the SZRLF. (a) Catch rate of spawning lobsters; (b) predation mortality; (c) average number of days fished (with S.D.); and (d) levels of high-grading.

3.2 Recreational catch and effort

The most recent report on recreational rock lobster fishers was undertaken during the 2013/14 South Australian Recreational Fishing Survey (Giri and Hall 2015). An estimated 102,931 (± 58,763) lobsters were caught by South Australian residents with 62,346 (± 39,085) of these harvested and 40,585 (± 25,202) released representing a release rate of 39.4%. In total, the harvested catch equated to approximately 75 t of which two-thirds were caught in the SZRLF. Pots/nets accounted for 83% of all lobsters caught with dive fishing being the other major capture method.

These results can be compared with 106,483 lobsters caught in 2007/08 with 47,875 harvested (equating to 60 t with approximately 55 t caught in the SZRLF) and 58,608 released representing a release rate of 55% (Jones 2009). Recreational catches are accounted for within LenMod fishery outputs.

3.3 Voluntary catch sampling

Since 1991, up to 26,000 lobsters have been measured annually in the SZRLF as part of the voluntary catch sampling program. The number measured is proportional to the level of participation in the program which has ranged between 9-23% over the last five seasons, with data presented as number of lobsters/100 potlifts. In this report, length frequency data, which are generated from voluntary catch sampling, are presented from 2016-2018. Earlier length frequency distributions can be accessed through previously published stock assessment reports (http://pir.sa.gov.au/research/publications/research_reports).

Male lobsters, which generally grow faster and reach larger sizes than females, range between 70 and 200 mm CL. In contrast, few females are larger than 150 mm CL. In 2018, a total of 10,327 lobsters were sampled with a 45:55 male:female sex ratio. Length-frequency data obtained through the voluntary catch sampling program over the last three seasons (Figure 3-7) support recent trends in commercial catch rates (Figure 3-1c). Notably, the percentage of lobsters measured above the minimum legal size (MLS) of 98.5 mm CL increased from 77% to 92% between 2016 and 2018, reflecting the increase in legal-size catch rate over the same period (Figure 3-1c).

Spatially, larger lobsters are observed in the northern MFAs of the SZLF, as confirmed by logbook estimates of mean weight (Figure 3-3d). In 2018, 34% of all lobsters measured were >120 mm CL in MFA 55, compared to 20% and 9% in MFA 56 and 58, respectively (Figure 3-8). Overall, these data highlight the importance of length-frequency data collated through the voluntary catch sampling program, in providing information on recruitment trends within the fishery.

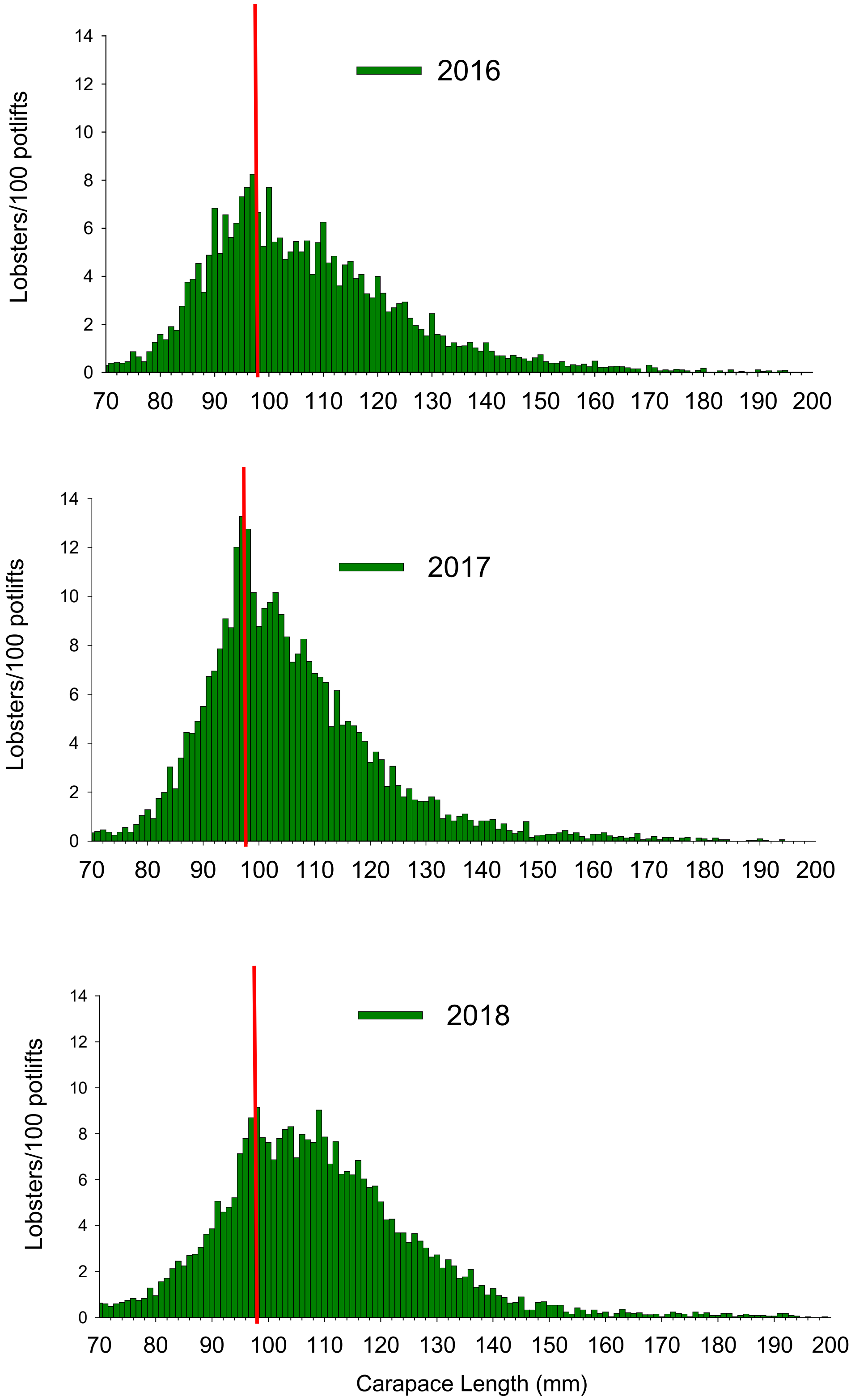

Figure 3-7 Length frequency distributions of male and female lobsters combined in the SZRLF from 2016 to 2018 (red line indicates MLS at 98.5 mm CL).

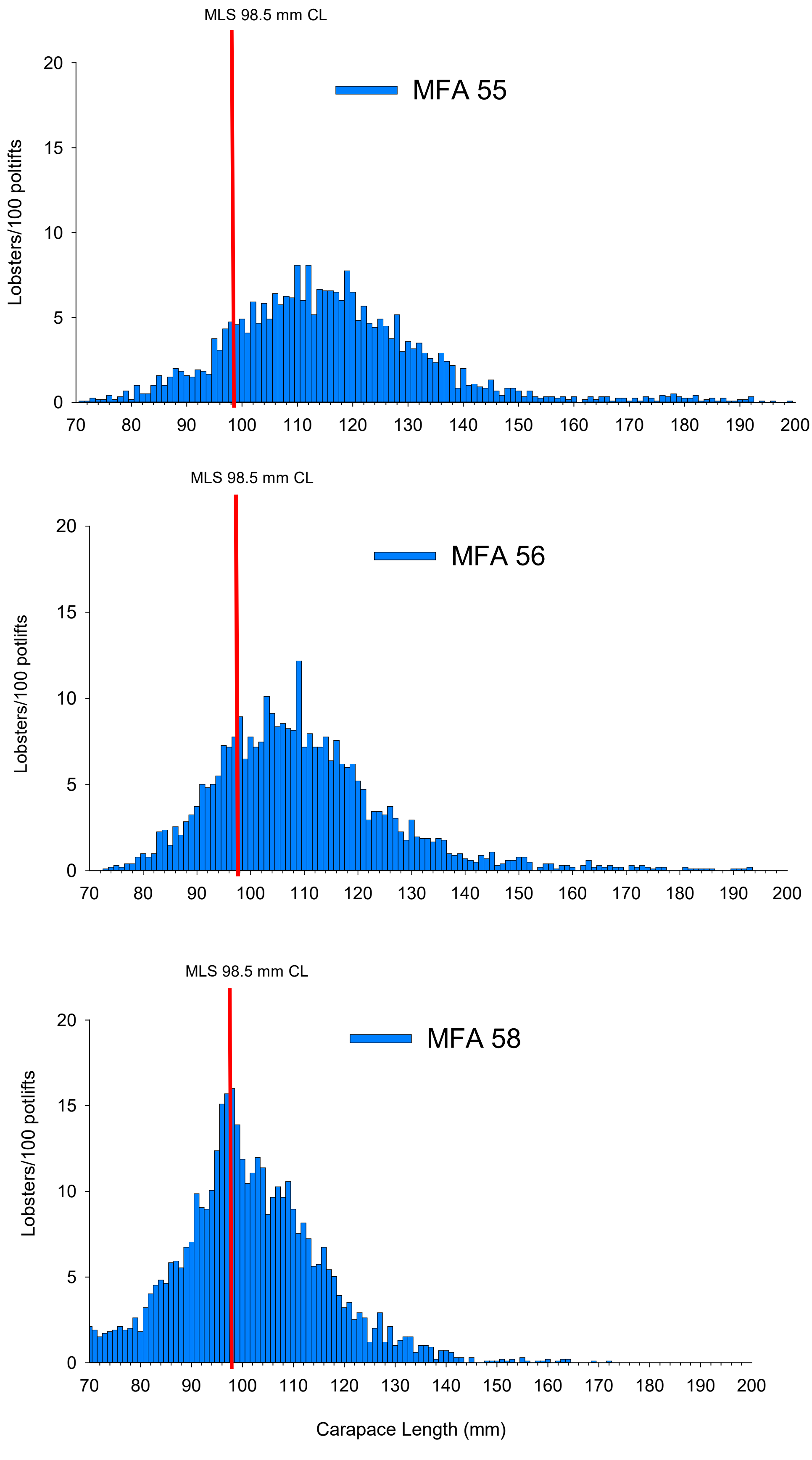

Figure 3-8 A comparison of length frequency distributions (male and female lobsters combined) by MFA in the 2018 season (MFA 51 not included due to limited data. Red line indicates MLS at 98.5 mm CL).

3.4 Puerulus monitoring program

Puerulus settlement indices (PSIs) in the SZRLF have been highly variable over time (Figure 3-9). In 2018, the estimate was 1.44 puerulus/collector, which was close to the long-term average for the fishery. Previous research has indicated that the period between settlement and recruitment to legal size in the SZRLF is approximately five years with undersized numbers correlated after four years (Linnane et al. 2014).

Based on this relationship, PSIs were correlated against both the logbook PRI and commercial CPUE data lagged by four and five years, respectively, using data from 1991 to 2010 (Figure 3-10). CPUE and PRI data were closely correlated over the entire time series with a one year lag (R^2 = 0.75). More recently, the PSIs from 2002 to 2014 were correlated (R^2 = 0.61) with subsequent PRIs from 2006 to 2018, but only showed a weak correlation (R^2 = 0.13) with CPUE from 2007 to 2018.

Three of the highest PSIs on record were observed from 2005 to 2007 which reflected increases in PRIs in 2009 and 2010 (Figure 3-1c) and subsequent increases in catch rate as these recruits entered into the fishery in 2010 and 2011 (Figure 3-1b). However, these relationships are not consistent throughout the time series. For example, increases in CPUE in 2017 and 2018 came from historically low settlements in 2012 and 2013. Recent trends over the last six seasons indicate that recruitment to the fishery will be close to the long-term average in the short-to-medium term.

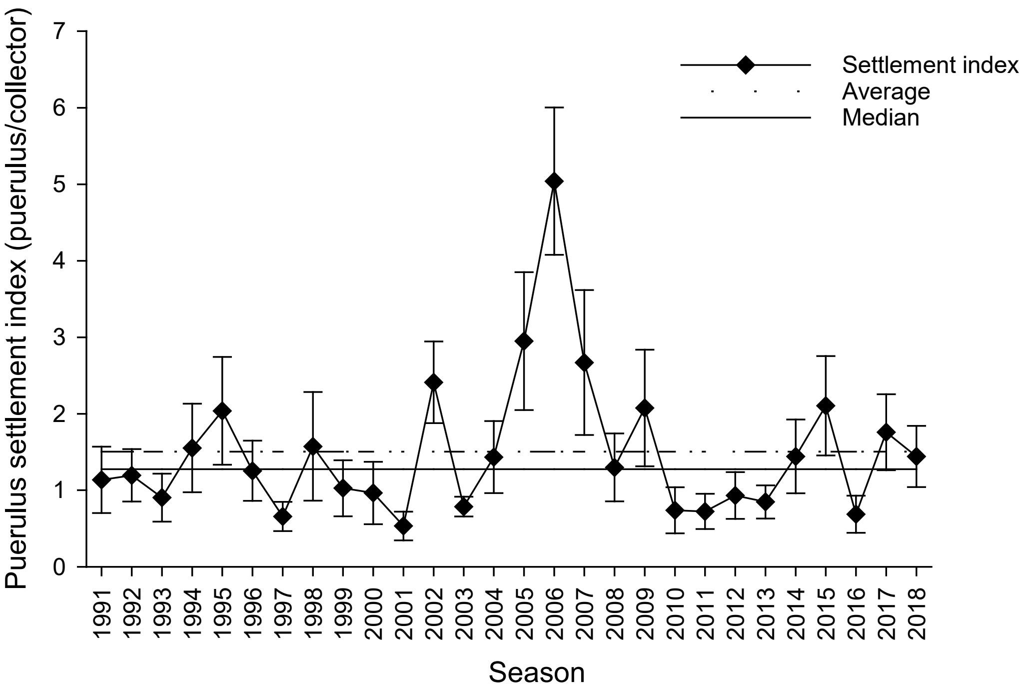

Figure 3-9 Puerulus settlement indices (mean ±SE) in the SZRLF from 1991 to 2018. Dashed and solid black lines represent long-term (1991-2018) average and median estimates respectively.

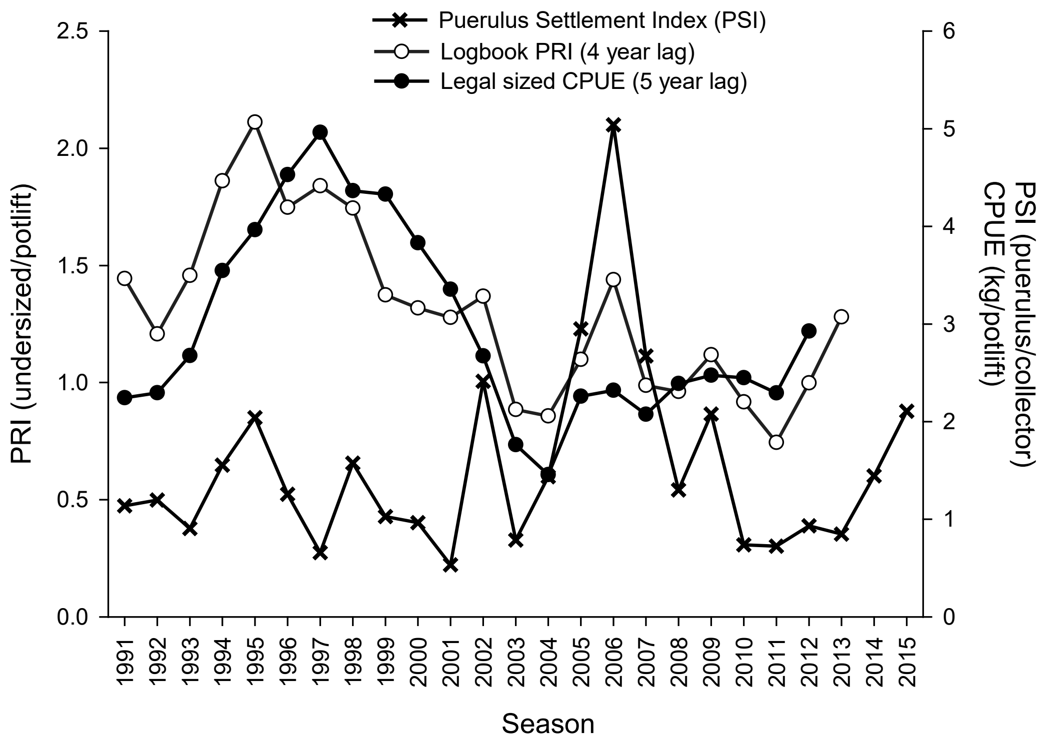

Figure 3-10 Correlations between SZRLF puerulus settlement lagged by four years with logbook PRI and by five years with commercial CPUE.

3.5 Fishery-Independent Monitoring Survey (FIMS)

The latest FIMS for the SZRLF 2019 season was completed in January 2020. Between 2006 and 2015/2016, with the exception of 2015 for legal-size lobsters, the survey catch rates of both legal-size (Figure 3-11) and undersized (Figure 3-12) lobsters generally decreased. From 2016 to 2018, the catch rate of legal-size lobsters increased from 0.46 to 0.96 lobsters/potlift. In 2019, the estimate was 0.83 lobsters/potlift, the fourth highest on record. With the exception of 2018, the catch rate of undersized lobsters also increased from 2015 (0.17 undersized/potlift) to 2019 (0.47 undersized/potlift). The 2019 estimate is the highest estimate since 2010.

Trends in fishery-independent indices were compared against those from the commercial fishery. For legal-sized lobsters, both commercial and survey indices decreased from 2006 to 2009. However, after this period the index trends diverged. In 2010, commercial catch rate increased and remained relatively stable at approximately 1.2-1.4 lobsters/potlift. In contrast, between 2008 and 2016, legal sized survey CPUE remained at historically low levels ranging from 0.43 to 0.74 lobsters/potlift (Figure 3-11). Both indices increased from 2016 to 2018.

Similarly, trends in survey and commercial undersized CPUE were similar between 2006 and 2009 (Figure 3-12). Since then, the rate of decline in undersized abundances in surveys was greater than that observed in commercial catch rate data. Both survey and commercial data showed increases in undersized catch rates between 2015 and 2018.

.

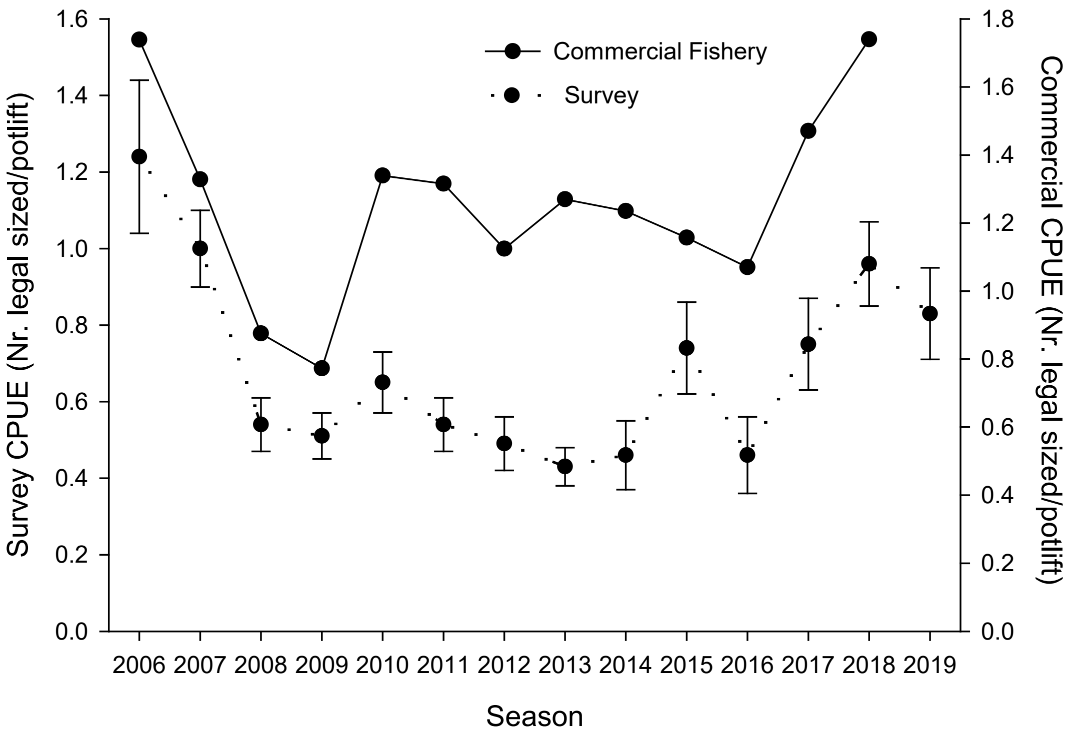

Figure 3-11 Comparison of legal size catch rates (nr/potlift) from commercial logbook data and fishery independent monitoring surveys.

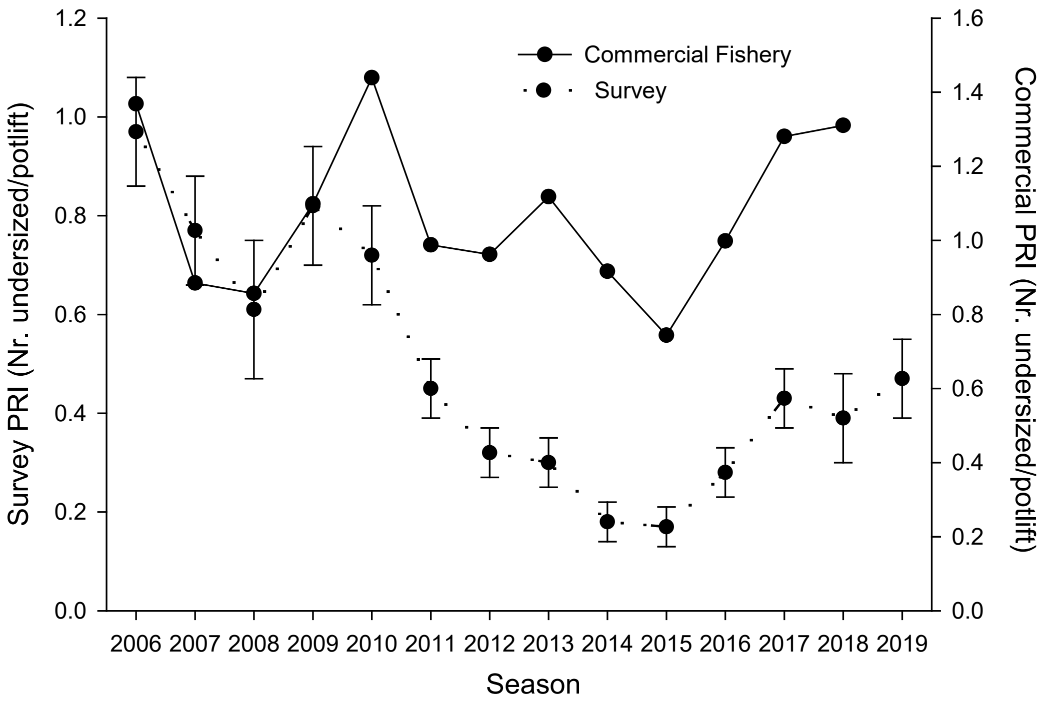

Figure 3-12 Comparison of undersized catch rates (nr/potlift) from commercial logbook data and fishery independent monitoring surveys.

3.6 "qR" and "LenMod" stock assessment models

3.6.1 Model fits

Both the qR and LenMod fishery model show good fits to the available data (Appendix 5). The qR model fitted closely to logbook totals of yearly catch in number (Figure 6-1) and catch in weight (Figure 6-2). For LenMod, model estimates of monthly catch in number and catch rate fitted closely to the reported monthly logbook catch in number (Cn) (Figure 6-3) and catch rate (Figure 6-4). In addition, both male and female model estimates fitted well to length-frequency data from voluntary catch sampling as shown in monthly fits from the 2018 season (Figure 6-5).

3.6.2 Model outputs

The SZRLF qR and LenMod models show close agreement in estimated trends for indicators of performance and status. From 2002 to 2009, estimates of legal-sized biomass decreased by 62%, from approximately 5,000 t to 1,900 t (Figure 3-13a). Since then, biomass has increased, particularly over the past two seasons, and in 2018, the estimate was approximately 3,800 t.

Coincident with declines in lobster biomass, egg production estimates decreased by 52% from approximately 650 billion in 2003 to 310 billion in 2009 (Figure 3-13b). Over the last nine seasons, egg production has trended upward, and in 2018 was estimated at approximately 495 billion. However, despite recent increases, overall egg production estimates are low with current estimates equating to 11% of unfished levels (Figure 3-13c).

Exploitation rate increased from approximately 37% in 2002 to 69% in 2009 (Figure 3-13d) in response to decreasing biomass over the same period (Figure 3-13a). Exploitation rate decreased considerably in 2010 and has continued to gradually decline since. In 2018, after two years of large reductions in exploitation rate reflecting corresponding increases in biomass, the estimate was approximately 33%, which is the lowest on record.

Outputs from the qR model indicate that recruitment to the fishery declined from approximately 4 million individuals in 1999 to 1 million in 2008, a decrease of 75% (Figure 3-13e). Since then, the estimate has been variable and in 2018 was approximately 2.5 million individuals. Temporal trends in recruitment estimated by both models are strongly correlated (R^2=0.88) with PRI from logbook data from 1995-2018 (Figure 3-13e).

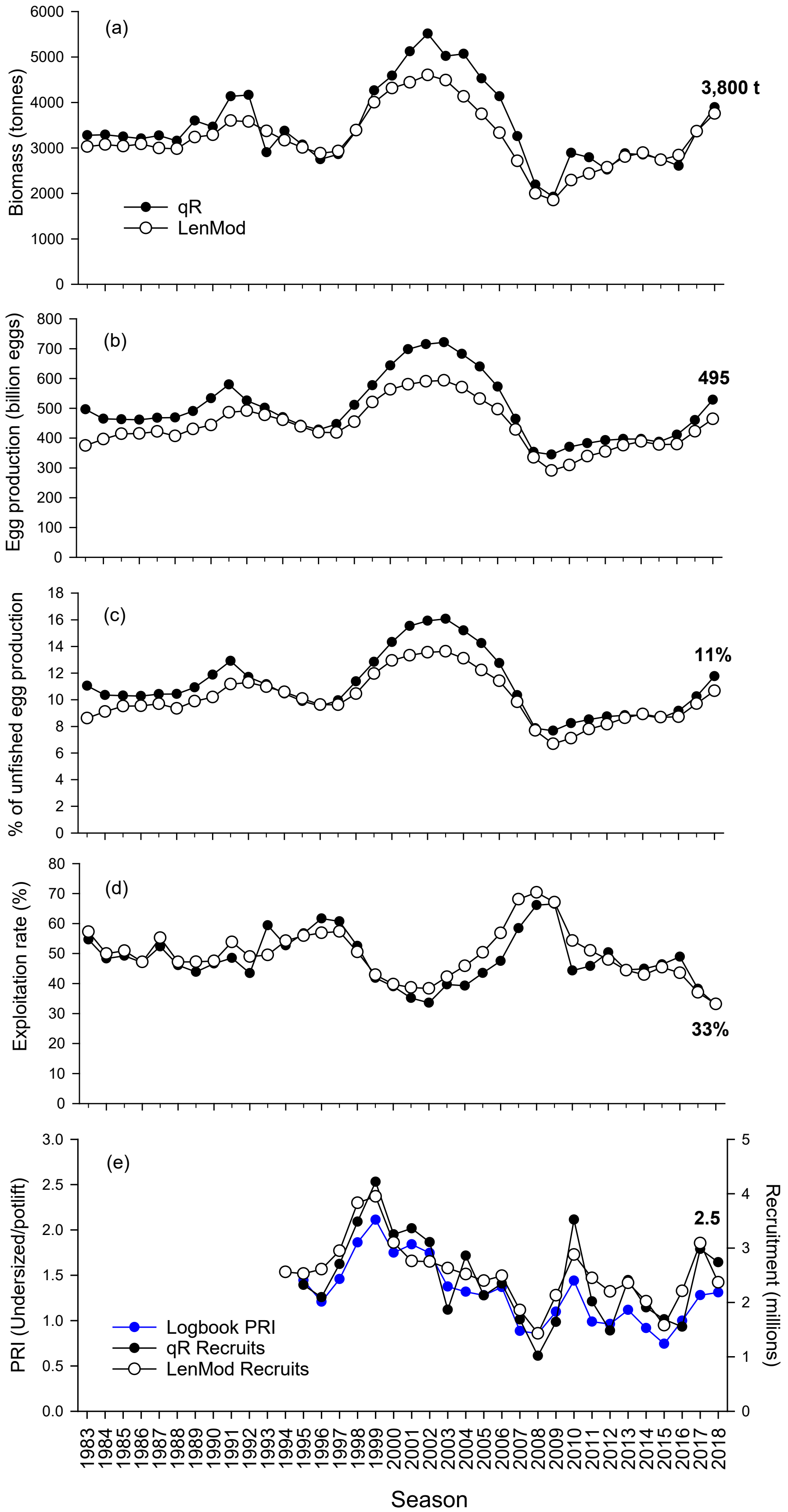

Figure 3-13 Fishery model outputs for the SZRLF. (a) Legal-size biomass; (b) Egg production; (c) % of unfished egg production; (d) Exploitation rate; and (e) Recruitment

4 DISCUSSION

4.1 Information sources used for assessment

This overall assessment of the SZRLF resource relies heavily on commercial fishery-dependent data collected by several long-term monitoring programs. In particular, the assessment places considerable emphasis on assessing catch rate trends of both legal and undersized lobsters. These are supported by outputs from both the qR and LenMod fishery models. A review of these information sources was undertaken in 2017 (Smith 2017) and while concluding that "The monitoring strategies for the South Australian Rock Lobster fishery are generally in line with best practice" it provided a number of recommendations that related specifically to fishery-dependent data and model outputs. These recommendations focused on catch rate standardisation and improvements in model performance.

While not included in the current report, standardised catch rate outputs were presented in Linnane et al. (2018). These outputs were reviewed by the Harvest Strategy Working Group (HSWG), which noted the close agreement between nominal and standardised time-series. The HSWG recommended that periodic catch rate standardisation should be continued, but that nominal catch rate could remain as the primary indicator of lobster abundance.

In terms of model outputs, the review recommended consistency in terms of the recruitment time-series reference period used to estimate %UEP as well as changes to catchability scenarios. The qR and LenMod models have since been modified in response to these recommendations, with details of each model provided in Appendices 3 and 4 of this report. The %UEP recruitment reference time period of 1990-2011 is now also used in both Tasmania and Victoria, permitting consistency with the indicator used to designate national stock status for this species. Both models are now highly consistent in terms of the current status of the SZRLF.

4.2 Stock Status

In 2018, the TACC in the SZRLF was taken for the ninth consecutive season. The current catch level of 1,245.2 t is low in a historical context with effort required to take the TACC having generally decreased since 2010. In 2018, effort was the lowest on record. Reduced levels of catch have resulted in a considerable improvement in SZRLF status. Between 2010 and 2016, catch rates remained relatively stable in the fishery at approximately 1 kg/potlift before increasing to 1.48 kg/potlift in 2018. This estimate is above both the long-term average and TRP for the fishery and the highest on record since 2005. Increased catch rates were spatially consistent, having been observed across all major MFAs of the SZRLF. In addition, legal-size catch rate increases have been observed over recent seasons in fishery-independent surveys.

As well as reduced catch levels, recent increases in catch rate are likely driven by improved recruitment to the fishable biomass, particularly over the last three seasons. After a long-term decline from 1999 to 2015, where undersized abundances decreased by 65%, the PRI increased consecutively over the last three seasons by 77% to 1.31 undersized/potlift, the highest since 2010. Given that the period between PRI and recruitment to the fishery is approximately one year, this has translated to increases in legal-size CPUE. Four additional sources of data support recent recruitment increases: (i) independent model estimates of recruitment are highly correlated with empirical recruitment indices; (ii) length frequency distributions indicate that the percentage of lobsters entering the legal size classes increased in 2018; (iii) lower legal-sized mean weight, an indicator of higher recruitment levels to the fishery, was observed over the last two seasons; and (iv) PRI increases were observed over the last four seasons in fishery-independent surveys.

In the SZRLF, based on tag-recapture studies, the period between puerulus settlement and the PRI is ~4 years, with recruitment into the fishery occurring one year later (i.e. 5 years after settlement) (McGarvey et al. 1999; Linnane et al. 2013; 2014). While correlations between the PRI and CPUE are strong using a one-year lag, consistent correlations between settlement and recruitment are yet to emerge. For example, high levels of settlement observed in 2005, 2006 and 2009 reflected the increase in PRI in 2009, 2010 and 2013 which, combined with reduced catch levels, is likely to have contributed to elevated commercial CPUE over recent seasons. However, these relationships are not consistent over time as highlighted by the fact that the recent increases in CPUE in 2017 and 2018 came from below average settlements in 2012 and 2013.

Outputs from the qR and LenMod fishery models agree closely in relation to the current stock status. Following a considerable decline between 2002 and 2009, legal-sized biomass has gradually increased over the last eight seasons. Given that catch has remained stable over this period, exploitation rate has decreased, with the 2018 estimate of 33% one of the lowest on record. Overall egg production levels has also increased in recent seasons but remain low in 2018 at just 11% of unfished levels.

In 2017, the Management Advisory Committee (MAC) commenced a review of the management plan for the SZRLF. To address low levels of %UEP, testing has focused on increasing egg production in the SZRLF towards a stock improvement target of 20% UEP by 2035. The management plan is currently in the final stages of completion and in 2020, the revised harvest strategy will be used to set a TACC for the 2020/21 season. Importantly, performance indicators in this harvest strategy are linked to a definition of stock status

In summary, the following lines of evidence were considered in assessing the stock status of the SZRLF: (i) TACC levels since 2010/11 have constrained catch to historically low levels; (ii) effort is now the lowest on record; (iii) the CPUE is above both the long-term average and the TRP; (iv) biomass levels have increased and exploitation rates have reduced substantially in recent years; (v) the PRI has increased considerably over the last three seasons and is above the LRP; and (vi) fishery-independent surveys support recent increases in CPUE and PRI. Consequently, using a weight-of-evidence approach, under the NFSRF, the SZRLF in 2018/19 is classified as “**sustainable**”.

4.3 Assessment Uncertainties

This assessment is reliant on fishery-dependent data as an indicator of stock abundance. However, it is widely acknowledged that catch rate estimates, based on fishery-dependent data, can be influenced by factors such as gear selectivity, changes in fishing patterns, fleet efficiency or fleet dynamics over time (Maunder et al. 2006). Two lines of evidence suggest that the catch rate trends detailed in this report are robust indicators of overall lobster abundance. Firstly, trends are highly consistent across large spatial scales. For example, across the four major MFAs of the fishery, catch rate simultaneously increased from the mid-1990s to early 2000s, declined to historical lows from 2002 to 2009, before gradually recovering over the next eight seasons. Similar trends were also observed across a range of depth categories within MFAs. These fishery-wide trends suggest recruitment and subsequent survival in the SZRLF occur consistently across large spatial scales, and that these trends are well reflected in the broad seasonal and spatial coverage (>1 million potlifts annually) used to compute catch rate.

Secondly, a previous stock assessment report (Linnane et al. 2018) highlighted that when nominal catch rate was standardised for factors such as year, month, depth, MFA, mean weight, licence and consumer price index (CPI), the nominal and standardised CPUE time series were closely aligned. While no meaningful difference, and therefore no improvement was observed, the standardisation did not include two factors thought to be important in other lobster fisheries. Specifically, standard catch logs in South Australian lobster fisheries do not record the “vessel” or “skipper”. In the Victorian rock lobster fishery, “vessel” and “skipper” were identified as the two most important factors in legal-size lobster catch rate standardisation (Feenstra et al. 2019).

4.4 Future Work

There is a need to investigate potential changes potential changes in growth rates within the fishery over time. Most growth information in the models is based on the large-scale tag/recapture program undertaken from 1993 to 1996. Quantifying a change in growth rate will require re-launching a substantial tag-recovery program. This has been identified as a high research priority given the importance of accurate growth transition matrices and mean weight-at-age in the estimation of absolute biomass within the two fishery assessment models.

Given observations within other rock lobster fisheries, it is recommended that “vessel” or “skipper” factors are captured and used in future CPUE standardisation analyses.

BIBLIOGRAPHY

Annala, J.H. and Breen, P.A. (1989) Yield- and egg-per-recruit analyses for the New Zealand rock lobster, *Jasus edwardsii*. New Zealand Journal of Marine and Freshwater Research 23: 93-105.

Booth, J.D. and Tarring, S.C. (1986) Settlement of the red rock lobster, *Jasus edwardsii*, near Gisborne, New Zealand. New Zealand Journal of Marine and Freshwater Research, 20: 291–297.

Booth, J.D., Street, R.J. and Smith, P.J. (1990) Systematic status of the rock lobsters *Jasus edwardsii* from New Zealand and *J. novaehollandiae* from Australia. New Zealand Journal of Marine and Freshwater Research 24: 239-49.

Booth, J.D., Carruthers, A.D., Bolt, C.D. and Stewart, R.A. (1991) Measuring the depth of settlement in the red rock lobster, *Jasus edwardsii*. New Zealand Journal of Marine and Freshwater Research 25: 123-32.

Booth, J.D., and McKenzie, A. 2009. Strong relationships between levels of puerulus settlement and recruited stock abundance in the red rock lobster (*Jasus edwardsii*) in New Zealand. Fisheries Research, 95:161-168.

Brasher, D.J., Ovenden, J.R. and White, R.W.G. (1992) Mitochondrial DNA variation and phylogenetic relationships of *Jasus* spp. (Decapoda: Palinuridae). Journal of Zoology 227: 1-16.

Breen, P.A. and McKoy, J.L. (2002) Review of current and past stock assessments for the South Australian Northern Zone Rock Lobster: Report by NIWA to the NZRL FMC Fishery. NIWA, Wellington.

Brock, D.J. and Ward, T.M. (2004). Octopus (*Octopus maorum*) bycatch and lobster (*Jasus edwardsii*) mortality in the South Australian Rock Lobster Fishery. Fisheries Bulletin 102: 430-440.

Bruce, B., Bradford, R., Griffin, D., Gardner, C. and Young, J. (1999) A synthesis of existing data on larval rock lobster distribution in southern Australia. Final report to the Fisheries Research and Development Corporation, Canberra, pp. 1-57, 96/107.

Bruce, B., Griffin, D. and Bradford, R. (2007) Larval transport and recruitment processes of southern rock lobster. FRDC and CSIRO Marine and Atmospheric Research publication Nr. 2002/007. ISBN Nr 1 9210061 01 4.

Caputi, N., Brown, R.S. and Chubb, C.F. (1995) Regional prediction of the western rock lobster, *Panulirus cygnus*, commercial catch in Western Australia. Crustaceana 68:245-256.

Currie, D.R., Sorokin, S.J., and Ward, T.J.M. (2006) Survey of recreational Rock Lobster Fishing in South Australia during 2004/05. South Australia Research and Development Institute Research Report Series No. 123. South Australia Research Development Institute, South Australia. 36 pp.

Department for Environment and Heritage (2009) A technical report on the outer boundaries of South Australia's marine parks network. Department for Environment and Heritage, South Australia.

Econsearch (2019) Economic and Social Indicators for the South Australian Southern Zone Rock Lobster Fishery, 2017/18. A report to PIRSA Fisheries and Aquaculture. Adelaide, 68 pp.

Feenstra, J. McGarvey, R., Linnane, A., Haddon, M., Matthews, J. and Punt, A.E. (2019) Impacts on CPUE from vessel fleet composition changes in an Australian lobster (*Jasus edwardsii*) fishery, New Zealand Journal of Marine and Freshwater Research, DOI: 10.1080/00288330.2018.1556166.

Flood, M., Stobutzki, I., Andrews, J., Ashby, C., Begg, G., Fletcher, R., Gardner, C., Georgeson, L., Hansen, S., Hartmann, K., Hone, P., Horvat, P., Maloney, L., McDonald, B., Moore, A., Roelofs, A., Sainsbury, K., Saunders, T., Smith, T., Stewardson, C., Stewart, J., and Wise, B. (eds) (2014) Status of key Australian fish stocks reports 2014, Fisheries Research and Development Corporation, Canberra.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A. and Sibert, J. (2012) AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software 27:233-249.

Gardner, C., Frusher, S.D., Kennedy, R.B. and Cawthorn, A. (2001) Relationship between settlement of southern rock lobster pueruli, *Jasus edwardsii*, and recruitment to the fishery in Tasmania, Australia. Marine and Freshwater Research 52:1271-5.

Giri, K., and Hall, K. (2015) South Australian Recreational Fishing Survey. Fisheries Victoria Internal Report Series No. 62.

Goldsworthy, S.D., Page, B., Shaughnessy, P.D. and Linnane, A. (2010) Mitigating seal interactions in the SRLF and the gillnet sector SESSF in South Australia. Report to the fisheries research and development institute. Adelaide: South Australian Research and Development Institute (Aquatic Sciences), p.213.

Henry, G.W. and Lyle, J.M. (eds) (2003) The National Recreational and Indigenous Fishing Survey. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra. FRDC Project No. 99/158.

Hobday, D. and Punt, A.E. (2001) Size-structured population modelling and risk assessment of the Victorian southern rock lobster, *Jasus edwardsii*, fishery. Marine and Freshwater Research 52: 1495-1507.

Johnston, S.J. and Bergh, M.O. (1993) Size-based estimates of survivorship for the South African rock lobster *Jasus lalandii*. Fisheries Research 18: 277-304.

Jones, K. (2009) South Australian Recreational fishing Survey. PIRSA Fisheries, Adelaide, 84 pp. South Australian Fisheries Management Series Paper No 54.

Linnane, A., Penny, S. and Ward, T. (2008) Contrasting fecundity, size at maturity and reproductive potential of southern rock lobster *Jasus edwardsii* in two South Australian fishing regions. Journal of the Marine Biological Association of the United Kingdom 88: 583-589.

Linnane, A., Penny, S., Hawthorne, P. and Hoare, M. (2009) Spatial differences in size of maturity and reproductive potential between inshore and offshore fisheries for southern rock lobster (*Jasus edwardsii*) in South Australia. Fisheries Research 96: 238–243.

Linnane, A., James, C., Middleton, J., Hawthorne, P., and Hoare, M. (2010) Impact of wind stress anomalies on the seasonal pattern of southern rock lobster (*Jasus edwardsii*) settlement in South Australia. Fisheries Oceanography 19: 290–300.

Linnane, A. and Walsh, P.H. (2011) Standardising data collection across the southern rock lobster fisheries of South Australia, Victoria and Tasmania. Report to the Fisheries Research and Development Corporation. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2010/000393-1. SARDI Research Report Series No. 447. 101pp.

Linnane, A., McGarvey, R., Hoare, M., and Hawthorne, P. (2013) The importance of conserving recruitment pulses in rock lobster (*Jasus edwardsii*) fisheries where puerulus settlement is low or highly sporadic, Marine Biology Research, 9:1, 97-103.

Linnane, A., McGarvey, R., Gardner, C., Walker, T.I., Matthews, J., Green, B., and Punt, A. (2014) Large-scale patterns in puerulus settlement and links to fishery recruitment in the southern rock lobster (*Jasus edwardsii*) across southeastern Australia. ICES Journal of Marine Science 71, 528–536.

Linnane, A., McGarvey, R., Matthews, J., Feenstra, J., Jones, A. and Toumazos, K. (2016) Informing spatial and temporal management of the South Australian Northern Zone Southern Rock Lobster (*Jasus edwardsii*) fishery. Final Report to the Fisheries Research and Development Corporation. Adelaide, ISBN 978-1-921563-89-8.

Linnane, A., McGarvey, R., Feenstra, J. and Hawthorne, P. (2018). Southern Zone Rock Lobster (Jasus edwardsii) Fishery 2016/17. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000276-12. SARDI Research Report Series No. 988. 81pp.

Linnane, A., McGarvey, R., Feenstra, J. and Hawthorne, P. (2019) Southern Zone Rock Lobster (Jasus edwardsii) Fishery 2017/18. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000276-13. SARDI Research Report Series No. 1023. 72 pp.

MacDiarmid, A.B. (1988) Experimental confirmation of external fertilisation in the southern temperate rock lobster *Jasus edwardsii* (Hutton) (Decapoda: Palinuridae). Journal of Experimental Marine Biology and Ecology 120: 277-85.

MacDiarmid, A.B. (1989) Moulting and reproduction of the spiny lobster *Jasus edwardsii* (Decapoda: Palinurudae) in northern New Zealand. Marine Biology 103: 303-10.

Maunder, M.N., Sibert, J.R., Fonteneau, A., Hampton, J., Kleiber, P. and Harley S.J. (2006) Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science, 63: 1373-1385.

McGarvey, R., Matthews, J.M. and Prescott, J.H. (1997) Estimating lobster recruitment and exploitation rate from landings by weight and numbers, and age-specific weights. Marine and Freshwater Research 48: 1001-08.

McGarvey, R., Ferguson, G.J. and Prescott, J.H. (1999) Spatial variation in mean growth rates of rock lobster, *Jasus edwardsii*, in South Australian waters. Marine and Freshwater Research 50: 333-42.

McGarvey, R. and Feenstra, J.E. (2001) Estimating length-transition probabilities as polynomial functions of pre-moult length. Marine and Freshwater Research 52: 1517-1526.

McGarvey, R. and Matthews, J.M. (2001) Incorporating numbers harvested in dynamic estimation of yearly recruitment: onshore wind in interannual variation of South Australian rock lobster (*Jasus edwardsii*). Journal of the International Council for the Exploration of the Sea 58: 1092-99.

McGarvey, R. and Pennington, M. (2001) Designing and evaluating length-frequency surveys for trap fisheries with application to the southern rock lobster. Canadian Journal of Fisheries and Aquatic Sciences 58: 254-61.

McGarvey, R., Punt, A.E. and Matthews, J.M. (2005) Assessing the information content of catch-in-numbers: A simulation comparison of stock assessment methods based on catch and effort totals. In 'Fisheries Assessment and Management in Data-Limited Situations.' (Eds. G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C.

Shirley, P.D. Spencer, B. Wilson, and D. Woodby). Alaska Sea Grant College Program, University of Alaska, Fairbanks, pp. 635-653.

McGarvey, R., Punt, A.E., Gardner, C., Feenstra, J., Hartman K., Hoshino, E., Burch, P., Paterson, S., Matthews, J., Linnane, A., Rippin, L. and Morison, J. (2014) Bioeconomic decision support tools for Southern Rock Lobster. Report to the Australian Seafood Cooperative Research Centre. Project No. 2009/714.20. 200pp.

McGarvey, R.; Punt, A.E., Matthews, J.M., Feenstra, J.E., Gardner, C., Burch, P., Hartmann, K., Linnane, A. (2015) Comparing size-limit and quota policies to increase economic yield in a lobster fishery. Canadian Journal of Fisheries and Aquatic Sciences 72: 1292-1305.

McGarvey, R., Matthews, J.M., Feenstra, J.E., Punt, A.E. and Linnane, A. (2016) Using bioeconomic modeling to improve a harvest strategy for a quota-based lobster fishery. Fisheries Research 183: 549-558.

McGarvey, R., Linnane, A., Matthews, J.M., and Jones, A. (2017) Decision rules for quota setting to support spatial management in a lobster (Jasus edwardsii) fishery. ICES Journal of Marine Science 74: 588-597. doi:10.1093/icesjms/fsw177.

Morgan, E.M., Green, B.S., Murphy, N.P. and Strugnell, J.M. (2013) Investigation of genetic structure between deep and shallow populations of the southern rock lobster, *Jasus edwardsii* in Tasmania, Australia. PloS one, 8(10), p.e77978.

Ovenden, J.R., Brasher, D.J. and White, R.W.G. (1992) Mitochondrial DNA analyses of red rock lobster, *Jasus edwardsii*, supports an apparent absence of population subdivision throughout Australasia. Marine Biology 112: 319-26.

PIRSA (2013). The South Australian Fisheries Management Series. Paper Nr 63: Management Plan for the South Australian Commercial Southern Zone Rock Lobster Fishery. ISSN 1322-8072.

Phillips, B. (2013) Lobsters: Biology, Management, Aquaculture and fisheries, 2nd Edition. Wiley-Blackwell Publishing Ltd. ISBN: 978-0-470-67113-9.

Phillips, B.F. and McWilliam, P.S. (2009) Spiny lobster development: where does successful metamorphosis to the puerulus occur?: a review. Reviews in Fish Biology and Fisheries 19: 193-215.

Prescott, J., McGarvey, R., Ferguson, G., and Lorkin, M. (1996) Population dynamics of the southern rock lobster in South Australian waters. Final report to the Fisheries Research and Development Corporation 93/086 and 93/087, 1-64.

Prescott, J., McGarvey, R., Jones, A., Peso, A., Ferguson, G., Casement, D., Xiao, Y., and McShane, P. (1998) Southern Zone Rock Lobster. South Australian Fisheries Assessment Series 98/3. SARDI Aquatic Sciences, Adelaide. 22p.

Punt, A.E., and Kennedy, R.B. (1997) Population modelling of Tasmanian rock lobster, *Jasus edwardsii*, resources. Marine and Freshwater Research 48: 967-80.

Punt, A.E. (2003) The performance of a size-structured stock assessment method in the face of spatial heterogeneity in growth. Fisheries Research 65: 391-409.

Sloan, S., and Crosthwaite, K. (2007) Management plan for the South Australian southern zone rock lobster fishery. The South Australian Fishery Management Series. PIRSA Fisheries publication, Adelaide, Australia.

Smith, P.J., McKoy, J.L. and Machin, P.J. (1980) Genetic variation in the rock lobsters *Jasus edwardsii* and *Jasus novaehollandiae*. New Zealand Journal of Marine and Freshwater Research 14: 55-63.

Smith, T. (2017) Review of the Stock Assessment and Monitoring Program for the South Australian Rock Lobster Fishery. A report prepared for the South Australian Rock Lobster Advisory Council Inc. June, 2017.

Stewardson, C., Andrews, J., Ashby, C., Haddon M., Hartmann, K., Hone, P., Horvat, P., Klemke, J., Mayfield, S., Roelofs, A., Sainsbury, K., Saunders, T., Stewart, J., Nicol, S. and Wise, B. (eds) (2018) Status of Australian fish stocks reports 2018, Fisheries Research and Development Corporation, Canberra.

Thomas, L., (2012) Population genetics of the red rock lobster, *Jasus edwardsii*. Thesis submitted to the Victoria University of Wellington in partial fulfilment of the requirements for the degree of Master of Science in Marine Biology. 97 pp.

Thorson, J.T., Fonner, R., Haltuch, M.A., Ono, K., and Winker, H. (2017) Accounting for spatiotemporal variation and fisher targeting when estimating abundance from multispecies fishery data. Canadian Journal of Fisheries and Aquatic Sciences, 74: 1794-1807.

Vainickis, A.A. (2010) SARDI Aquatic Sciences Information Systems Quality Assurance and Data Integrity Report 2010. SARDI Publication No. F2009/000267-2. SARDI research Report Series 497. South Australian Research and Development Institute (Aquatic Sciences) Adelaide.

Zacharin, W. (Ed.) (1997) Management plan for the South Australian northern zone rock lobster fishery. Primary Industries and Resources South Australia, Adelaide, pp. 1-24.

APPENDICES

Appendix 1. SZRLF Catch, Effort and CPUE data

Table 6-1 Catch, Effort and CPUE (commercial and fishery independent survey) for the SZRLF from 1970 to 2018 by zone.

Season	Catch (t)	Effort (000's potlifts)	Commercial CPUE (kg/potlift)	Survey CPUE (Nr/potlift)
1970	1544	1838	0.84	
1971	1604	1987	0.81	
1972	1949	2138	0.91	
1973	1738	2135	0.81	
1974	1212	1727	0.70	
1975	1621	2006	0.81	
1976	1374	1882	0.73	
1977	1300	1875	0.69	
1978	1309	1801	0.73	
1979	1534	1793	0.86	
1980	2126	2029	1.05	
1981	2047	2122	0.96	
1982	1844	2162	0.85	
1983	1734	2255	0.77	
1984	1537	1984	0.77	
1985	1547	2020	0.77	
1986	1458	1909	0.76	
1987	1657	2130	0.78	
1988	1407	1886	0.75	
1989	1528	1798	0.85	
1990	1563	1907	0.82	
1991	1940	2050	0.95	
1992	1754	1759	1.00	
1993	1669	1642	1.02	
1994	1721	1511	1.14	
1995	1684	1591	1.06	
1996	1640	1755	0.93	
1997	1680	1758	0.96	
1998	1713	1537	1.11	
1999	1717	1162	1.48	
2000	1716	1039	1.65	
2001	1717	910	1.89	
2002	1766	854	2.07	
2003	1896	1042	1.82	
2004	1897	1052	1.80	
2005	1889	1183	1.60	
2006	1894	1354	1.40	1.24
2007	1850	1661	1.11	1.00
2008	1407	1916	0.73	0.54
2009	1243	2050	0.61	0.51
2010	1244	1322	0.94	0.65
2011	1242	1285	0.97	0.54
2012	1234	1419	0.87	0.49
2013	1247	1253	1.00	0.43
2014	1244	1207	1.03	0.46
2015	1244	1220	1.02	0.74
2016	1238	1296	0.96	0.46
2017	1246	1022	1.22	0.75
2018	1245	841	1.48	0.96

Table 6-2 Catch, Effort and CPUE for the SZRLF from 1970 to 2018 by MFA.

	MFA 51			MFA 55			MFA 56			MFA 58		
Season	Catch (t)	Effort (000's potlifts)	CPUE (kg/potlift)	Catch (t)	Effort (000's potlifts)	CPUE (kg/potlift)	Catch (t)	Effort (000's potlifts)	CPUE (kg/potlift)	Catch (t)	Effort (000's potlifts)	CPUE (kg/potlift)
1970	215	219	0.91	443	489	0.91	486	616	0.79	377	499	0.82
1971	267	285	0.92	455	510	0.92	494	663	0.78	374	529	0.69
1972	298	305	0.98	588	600	0.97	632	672	0.97	403	543	0.72
1973	224	280	0.80	488	570	0.85	582	676	0.88	418	591	0.71
1974	166	221	0.78	331	456	0.72	405	567	0.72	309	481	0.63
1975	220	244	0.89	418	517	0.81	571	691	0.81	403	543	0.74
1976	184	226	0.80	367	473	0.77	472	676	0.71	333	484	0.67
1977	154	234	0.66	361	493	0.74	471	683	0.69	302	456	0.78
1978	177	211	0.82	390	488	0.80	452	657	0.71	279	437	0.72
1979	203	203	0.97	469	506	0.93	508	599	0.90	345	482	0.67
1980	267	215	1.22	600	508	1.21	763	745	1.04	492	553	0.86
1981	276	218	1.28	675	613	1.13	695	751	0.92	397	520	0.75
1982	252	238	1.05	674	692	0.97	543	710	0.79	362	509	0.69
1983	144	152	0.95	757	906	0.84	421	609	0.71	347	538	0.64
1984	150	156	0.95	683	793	0.86	370	538	0.69	301	463	0.63
1985	134	141	0.91	638	789	0.80	407	558	0.73	314	481	0.65
1986	104	109	0.94	656	788	0.83	368	509	0.72	299	468	0.64
1987	144	143	1.01	693	810	0.86	459	626	0.73	327	518	0.63
1988	125	122	1.02	578	712	0.81	361	516	0.70	307	504	0.61
1989	127	124	1.02	655	729	0.90	396	487	0.81	298	408	0.73
1990	144	139	1.02	695	803	0.87	405	515	0.79	305	440	0.70
1991	198	176	1.11	754	811	0.93	527	562	0.95	426	475	0.90
1992	148	120	1.21	762	730	1.04	429	463	0.93	391	431	0.91
1993	130	112	1.13	747	683	1.09	403	423	0.95	360	404	0.89
1994	85	72	1.14	705	584	1.19	532	443	1.19	372	395	0.94
1995	95	74	1.25	636	610	1.04	540	483	1.11	388	410	0.95
1996	92	78	1.17	632	656	0.95	500	539	0.92	400	471	0.85
1997	71	59	1.20	658	683	0.96	524	553	0.93	407	449	0.91
1998	60	45	1.28	647	574	1.12	550	473	1.15	435	430	1.01
1999	47	27	1.70	673	437	1.52	552	359	1.52	427	330	1.30
2000	76	42	1.79	621	342	1.79	568	333	1.68	435	312	1.41
2001	42	21	1.97	646	300	2.14	570	288	1.95	419	284	1.49
2002	30	15	2.01	661	276	2.38	570	256	2.25	453	287	1.58
2003	33	16	1.95	713	349	2.04	640	322	1.98	491	346	1.42
2004	44	18	2.42	689	326	2.11	615	322	1.91	520	371	1.40
2005	43	20	2.14	713	371	1.92	631	376	1.68	474	401	1.18
2006	57	32	1.77	765	457	1.67	606	443	1.37	434	399	1.09
2007	84	53	1.57	795	608	1.31	538	551	0.98	413	439	0.94
2008	89	80	1.11	580	699	0.83	375	617	0.61	319	489	0.65
2009	95	115	0.82	481	690	0.70	360	655	0.55	301	580	0.52
2010	45	51	0.88	456	511	0.89	437	451	0.97	300	302	1.00
2011	33	43	0.78	445	483	0.92	411	432	0.95	347	321	1.08
2012	23	38	0.62	419	489	0.86	399	497	0.80	372	379	0.98
2013	42	46	0.92	399	451	0.88	411	416	0.99	389	336	1.16
2014	25	25	0.88	412	412	1.00	384	398	0.97	421	367	1.15
2015	14	12	1.20	416	382	1.09	386	389	0.99	421	429	0.98
2016	19	14	1.42	409	380	1.08	393	411	0.96	411	486	0.85
2017	17	17	1.45	408	300	1.36	415	329	1.26	397	374	1.06
2018	9	6	1.47	447	249	1.80	405	265	1.52	383	319	1.20

Appendix 2. Computing confidence intervals for the FIMS indices of abundance

Systematic sampling generally produces more precise estimates than random sampling of natural populations (nearly all) that tend to cluster spatially. However, a universal analytic estimator of confidence interval for systematic samples has not yet been found. In a recent paper (McGarvey et al. 2016), 13 methods for estimating the confidence interval (via the variance of the abundance index estimate) for a systematic sample mean were evaluated. The best performer was v_8 which was adopted here to compute FIMS confidence intervals.

Sampling error variances of the systematic FIMS legal and undersized catch rate were separately estimated for September and January surveys in each year using the v_8 formula:

$$v_8 = \begin{cases} (1-f)(s^2/n)\left[1 + 2/\ln(\hat{\rho}) + 2/(\hat{\rho}^{-1} - 1)\right], & \text{if } \hat{\rho} > 0 \\ (1-f)(s^2/n), & \text{if } \hat{\rho} \le 0 \end{cases}$$

where

$$\hat{\rho} = \frac{1}{s^2 \cdot (n-1)} \sum_{i=1}^{n-1} (x_{i+1} - \overline{x}) \cdot (x_i - \overline{x}),$$

and where n is the number the FIMS pots sampled in each September or January survey, $\{x_i; i = 1, n\}$ denotes the pot-specific measurements of lobster abundance of either legal (nr/potlift) or undersized (nr/potlift) catch rate, $\overline{x}$ is the mean of the index across all potlifts, and $\hat{\rho}$ used in the v_8 formula is the computed estimate of the correlation between neighbouring potlifts along each FIMS transect. The unbiased sample variance s^2 is computed in the usual fashion as $s^2 = \frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \overline{x})^2$.

To combine September and January surveys, the reported yearly index of FIMS abundance for legal and undersized lobsters ($FIMS_y$) is the (unweighted) mean of the computed indices:

$$FIMS_y = \frac{\overline{x}_{spring} + \overline{x}_{summer}}{2}.$$

To compute an overall confidence interval for this FIMS yearly index (either legal and undersize), we computed the combined yearly variance using the standard variance formula for a sum and multiplication by a constant:

$$Var(FIMS_y) = Var\left(\frac{\overline{x}_{spring,y} + \overline{x}_{summer,y}}{2}\right) = \frac{1}{2^2}\left[Var(\overline{x}_{spring,y}) + Var(\overline{x}_{summer,y}) + 2\operatorname{cov}(\overline{x}_{spring,y}, \overline{x}_{summer,y})\right]$$

.

The $\operatorname{cov}(\overline{x}_{spring,y}, \overline{x}_{summer,y})$ was computed using the standard covariance formula over all ($n_{pairs,y}$) paired pot locations that were sampled in both spring and summer FIMS surveys of each year, y:

$$\operatorname{cov}(\overline{x}_{spring,y}, \overline{x}_{summer,y}) = \frac{1}{\left(n_{pairs,y}\right)^2} \sum_{i=1}^{n_{pairs,y}} \left(x_{spring,y,i} - \overline{x}_{spring,y}\right) \cdot \left(x_{summer,y,i} - \overline{x}_{summer,y}\right).$$

The 95% confidence intervals were computed for each year y as

$$CI_{95\%,y} = 1.96 \cdot \sqrt{Var(FIMS_y)}\ .$$

Appendix 3. Specifications of the qR model including equations, assumptions and model parameters

Overview

The qR fishery stock assessment model operates on a yearly time-step. It is an age-based model, with a maximum age of 20+. As data input, it fits to yearly totals for commercial lobster catch in both weight and numbers landed, and conditions on yearly fishing effort. A prior value for instantaneous natural mortality rate is assumed. A vector for mean weight-at-age was estimated from yearly growth increments inferred from tag-recovery data and an assumed length for age-1 lobsters (length of legal recruits).

Data and fixed parameter inputs

Annual lobster catch in the South Australian lobster fisheries is reported in logbooks by weight (C_t^W) and by numbers (C_t^N). Effort (E_t) is reported as yearly pot lifts. The model year (t = 1983, …, 1983+n_t-1) runs from the start of each fishing season (1 October), and n_t = the number of fishing seasons modelled from 1983 to the most recent year. Age is subscripted by a, where a =1 refers to lobsters reaching legal minimum length during or in the winter before a given fishing season, and the plus-group age a =20+ refers to the highest age group including all lobsters of age 20 years and older. The mean weights-at-age $\{w_a;\ a = 1, 20+\}$ of harvested lobsters (McGarvey et al. 1999) are inputs. An instantaneous natural mortality rate of M =0.1 yr^{-1} is widely assumed for this species (e.g. Annala and Breen 1989) and genus (Johnston and Bergh 1993).

The population dynamics model

The qR model is effort-conditioned. A Baranov mortality submodel is assumed, where population number declines exponentially due to mortality within each yearly time step. Recruitment of lobsters to the legal stock in each year is a freely estimated parameter. Catchability is estimated separately for two time periods, before and after the imposition of quota management in 1993.

Model variables are listed in Table 6-3. The array of lobster numbers by age and year, $N_{a,t}$, varies over yearly time due to incoming recruitment, $N_{1,t} = R_t$, occurring at the start of each year t and due to outgoing mortality through each year. Natural and fishing mortality were assumed to be independent of age. Growth is expressed in the vector of mean weights at age.

Yearly cohort losses due to natural mortality and harvesting for ages 1-19 years old are written;

$$N_{a+1,t+1} = N_{a,t} \cdot \exp\left(-Z_t\right) \tag{1a}$$

where total instantaneous mortality rate $Z_t = F_t + M$. For the age 20+ 'plus group', the survival equation is written:

$$N_{20+,t+1} = \left[N_{19,t} + N_{20+,t}\right] \cdot \exp\left(-Z_t\right). \tag{1b}$$

Deaths due to harvesting were summed over age to yield predicted catches by number

($\hat{C}_t^N$) and weight ($\hat{C}_t^W$) for fitting to data in each year of the logbook time series:

$$\hat{C}_t^N = \frac{F_t}{Z_t} \cdot \left\{1 - \exp\left(-Z_t\right)\right\} \cdot \sum_{a=1}^{20+} N_{a,t} \tag{2a}$$

$$\hat{C}_t^W = \frac{F_t}{Z_t} \cdot \left\{1 - \exp\left(-Z_t\right)\right\} \cdot \sum_{a=1}^{20+} w_a N_{a,t} \tag{2b}$$

Fishing mortality is assumed to vary in proportion to reported yearly effort, E_t, related by a catchability coefficient that is different for years before and after quota:

$$F_t = \begin{cases} q \cdot E_t, & \text{for years prior to quota management} \\ q^{\text{Quota}} \cdot E_t, & \text{for years under quota management} \end{cases}. \tag{3}$$

The initial population age vector ($N_{a,1983}$) is estimated assuming a stationary age structure using the first-year estimated recruitment R_{1983} and a freely estimated F_0:

$$\begin{cases} N_{1,1983} = R_{1983} \\ N_{2,1983} = R_{1983} \exp\left[-\left(M + F_0\right)\right] \\ N_{a+1,1983} = N_{a,1983} \exp\left[-\left(M + F_0\right)\right], \quad a = 2,19 \\ N_{20+,1983} = N_{19,1983} \exp\left[-\left(M + F_0\right)\right] / \left\{1 - \exp\left[-\left(M + F_0\right)\right]\right\} \end{cases}.$$

Likelihood function

The negative log likelihood is written:

$$-\log L = n_t \log \sigma_N + \frac{1}{2\cdot{\sigma_N}^2}\sum_{t=1983}^{1983+n_t-1}\left(C_t^N - \hat{C}_t^N\right)^2 + n_t \log \sigma_W + \frac{1}{2\cdot{\sigma_W}^2}\sum_{t=1983}^{1983+n_t-1}\left(C_t^W - \hat{C}_t^W\right)^2 . \quad (4)$$

Variances of the two normal likelihood components of Eq. 4 (for catches in number and in weight) were written in terms of a single estimated coefficient-of-variation parameter (σ_C) and the respective data time series means:

$$\sigma_N = \sigma_C \cdot \overline{C}^N \quad (5a)$$

$$\sigma_W = \sigma_C \cdot \overline{C}^W . \quad (5b)$$

Estimates of free parameters, q, q^{Quota}, σ_C, F_0, and of yearly recruit numbers $\left\{R_t; t = 1983, 1983 + n_t - 1\right\}$, were obtained by minimising the negative log-likelihood using ADMB (Fournier et al. 2012).

The output indicator of yearly biomass was computed as the sum over all ages of population number by age times mean weight at age. For both LenMod and qR models, biomass is reported as a year-average (rather than start-year) quantity. For qR, where population declines Baranov exponentially through each yearly model time step, year-average biomass is computed by analytically integrating over the negative-exponential survival through each 12-month year, giving:

$$B_t = \sum_{a=1}^{20+} w_a N_{a,t}\left[1/Z_t\right]\left[1 - \exp\left(-Z_t\right)\right] . \quad (6)$$

Yearly egg production by female lobsters at the start of each fishing season (in spring) was computed as

$$Eggs_t = \sum_{a=1}^{20+} m_a f_a N_{a,t} / 2 , \quad (7)$$

where m_a and f_a are sampled vectors of maturity and fecundity versus age (Prescott et al. 1996), and a sex ratio of one-half was assumed. The unfished level of egg production (*UEP*) is computed by setting fishing mortality equal to zero and re-running the qR model dynamics for 2* n_t (two times the number of estimated years), taking the final-year value of this unfished equilibrium egg production to be UEP. The reference time period for the constant level of recruitment assumed for all years in this zero-F equilibrium UEP run is the mean of historical estimated recruitment over 1990-2011. The yearly percentage of unfished egg production is computed as $\% UEP_t = Eggs_t / UEP$.

Catchability

The qR catchability parameter estimates are q = 2.7×10^{-7} potlifts^{-1} and q^{Quota} = 4.1×10^{-7} potlifts^{-1} for pre- and post-TACC management (before 1993 and from 1993 onward), respectively.

Table 6-3 Variables of the qR model dynamics and likelihood assessment estimator.

Model Variable	Description
a	subscript for age, 1 to 20+ (the last age group representing ages 20 years and older)
n_t	number of fishing seasons modelled
t	subscript for yearly fishing season, 1983 to 1983+ n_t -1
$N_{a,t}$	number of lobsters of age a , at the start of year t
R_t	estimated number of recruits at start of year t
F_t	instantaneous fishing mortality rate in year t
q	estimated catchability coefficient for pre-quota (pre-1993) years
q^{Quota}	estimated catchability coefficient for years under quota (1993+)
$\hat{C}_t^N$	model numbers of lobsters caught in year t
$\hat{C}_t^W$	model weight of catch in year t
N_t	total population number at start of year t
B_t	biomass of lobsters averaged across year t
$Eggs_t$	eggs produced by female lobsters at start of year t
σ_N	sigma of yearly normal likelihood residuals about model-predicted $\hat{C}_t^N$
σ_W	sigma of yearly normal likelihood residuals for data about model-predicted $\hat{C}_t^W$

σ_C	estimated coefficient of variation relating σ_N and σ_W to data means $\bar{C}^N$ and $\bar{C}^W$
F_0	estimated fishing mortality used to generate the first-year vector of numbers at age
$\hat{C}_t^N$	model number of lobsters caught in year t
$\hat{C}_t^W$	model weight of catch in year t
N_t	total population number at start of year t
B_t	biomass of lobsters averaged across year t
$Eggs_t$	eggs produced by female lobsters at start of year t
UEP	unfished egg production, based on average recruitment 1990-2011
$\%\,UEP_t$	percentage of unfished egg production in year t

Appendix 4. Specifications of the length-structured model (LenMod) including equations, assumptions and model parameters.

Overview

LenMod is a population dynamics model that operates on a fishing season defined over, for the Southern Zone Rock Lobster Fishery, T = 9 time-steps (months), starting with the opening of the fishing season in October (i =1) to May (i =8), with a multi-month June-September (i =9) time step covering each closed winter season. The duration of the i th time-step (i =1,.., T) in units of years is denoted t_i. Lobster size-classes are in 4 mm bins, the lowest length bin defined as 82.5-86.5 mm CL, with 29 bins for males and 21 for females. The model population array, $N^s_{y,i,l}$, is the number of lobsters by length bin (l), sex (s), fishing season (y; hereafter referred to as year), and month (i).

The population dynamics model

Basic dynamics

The equation that specifies $N^s_{y,i,l}$ takes account of natural mortality M (instantaneous yearly rate), fishing mortality, growth, and settlement under the assumption that harvest occurs before growth and settlement:

$$N^s_{y,i+1,l} = \sum_{l'} X^s_{l',l,i}\, N^s_{y,i,l'}\, e^{-Mt_i}\, \{1-\tilde{H}^s_{y,i,l'}\} + \Omega^s_i \Phi^s_l\, R_y \quad (1)$$

where

$X^s_{l',l,i}$ is the fraction of the animals of sex s in size-class l' that grow into size-class l during time-step i;

Ω_i^s is the fraction of the settlement that occurs to sex s during time-step i ($\sum_s \sum_i \Omega_i^s = 1$);

Φ_l^s is the proportion of the settlement of animals of sex s that occurs to size-class l;

$\tilde{H}_{y,i,l'}^s$ is the exploitation rate on animals of sex s in size-class l' at the start of time-step i of year y over all fleets; and

R_y is the settlement of animals during year y:

$$R_y = \overline{R}\ e^{\varepsilon_y - (\sigma_{R,y})^2/2} \tag{2}$$

where $\overline{R}$ is mean settlement, ε_y is the "settlement residual" for year y, $\sigma_{R,y}$ is the standard deviation of the random fluctuations in settlement for year y:

$$\sigma_{R,y}^2 = \begin{cases} \tilde{\sigma}_R^2\, \tilde{\tau}^{(y_{\text{start}} - y)} & \text{if } y \le y_{start} \\ \tilde{\sigma}_R^2 & \text{otherwise} \end{cases} \tag{3}$$

$\tilde{\sigma}_R$ is the extent of variation in settlement for years after y_{start}, and $\tilde{\tau}$ determines the extent to which $\sigma_{R,y}$ changes with time ($\tilde{\tau} < 1$ means that the settlement will be closer to the mean settlement for the years before y_{start}).

$B_y^{AvgTotLeg}$ is the year-average legal-sized biomass during year y, averaging across T months, using mid-month population numbers (after half-month natural survival), where W_l^s is the weight of a lobster of size l and sex s:

$$B_y^{AvgTotLeg} = \frac{1}{T}\sum_{i=1}^{T}\sum_s \sum_{l>=LML} W_l^s\ e^{-Mt_i/2} N_{y,i,l}^s\ . \tag{4}$$

Egg production is given by the following equation for the case in which spawning is assumed to occur at the start of time-step i_m of year y:

$$Eggs_y = \sum_l m_l\, f_l\, N_{y,i_s,l}^{\text{f}} \tag{5}$$

where m_l and f_l are previously estimated vectors of maturity and fecundity versus length for females in size-class l, i_s is the time-step in which spawning occurs (i_s = month 1), and $N^{f}_{y,i_m,l}$ is the total number of females. The unfished level of egg production is computed by setting all estimated parameters to their values (except recruitment) from the stock assessment run, setting catches to zero, and re-running LenMod for 40 years, sufficient to achieve equilibrium. Recruitment for this zero-catch run is set to the average over the years 1990-2011. The % of unfished egg production in each year is computed as the ratio of $Eggs_y$ divided by the final zero-catch equilibrium level of egg production.

Catches

$C^f_{y,i}$ which is the landed catch in weight data by fleet f during time-step i of year y. In addition to landed catch, commercial data includes information on spawning lobsters and those brought up dead in the pots, while five surveys (1998, 2001, 2004, 2007, and 2013) are used as the basis to estimate catches for the recreational fleets. $C^f_{y,i}$ is used in defining the fully-selected exploitation rate for fleet f during time-step i of year y, $F^f_{y,i}$, is calculated as follows:

$$F^f_{y,i} = \frac{(1+d^f_{y,i})C^f_{y,i}}{\sum_l \sum_s \tilde{S}^{s,f}_{y,i,l}(1-\tilde{p}^s_{i,l})V^s_i W^s_l N^s_{y,i,l} e^{-Mt_i/2}} \qquad (6)$$

where

$d^f_{y,i}$ is the ratio of the discarded dead catch to the legal-size catch for fleet f (only for commercials fleets, and is 0 for recreationals);

V^s_i is the relative sex vulnerability, determined separately for each month i, which, if estimated, is either being fixed at a value of 1 for males ($V^{males}_i = 1$) and estimated for females, or fixed at a value of 1 for females ($V^{females}_i = 1$) and estimated for males; or fixed to 1 for both sexes;

$\tilde{p}^s_{i,l}$ is the proportion of mature animals of sex s in length-class l which are returned live during time-step i because they are spawning (0 for males); and

$\tilde{S}^s_{y,i,l}$ is the vulnerability by length for the gear used on animals of sex s in size-class l during time-step i of year y incorporates the legal minimum size as:

$$\tilde{S}^s_{y,i,l} = \begin{cases} 0 & \text{if } L^s_l + \Delta L^s_l \le \text{LML}_y \\ S^s_{y,i,l} & \text{if } L^s_l \ge \text{LML}_y \\ S^s_{y,i,l}(L^s_l + \Delta L^s_l - \text{LML}_y) / \Delta L^s_l & \text{otherwise} \end{cases} \quad (7)$$

where $\tilde{S}^{s,f}_{y,i,l} = \tilde{S}^s_{y,i,l}$ as it is assumed that at any time when recreational fishing takes place the same gear is used as for the commercial fishery. L^s_l is the lower limit of size-class l for sex s, ΔL^s_l is the width of a size-class l for sex s (4 mm), LML_y is the legal minimum size during year y, $S^s_{y,i,l}$ is the vulnerability of the gear used on animals of sex s in size-class l. (There were no changes in LML_y, which is 98.5 mm carapace length, over the whole time series for the Southern Zone Rock Lobster Fishery.)

$F^f_{y,i}$, is used to define $\tilde{H}^s_{y,i,l'}$ as follows:

$$\tilde{H}^s_{y,i,l} = \sum_f \tilde{S}^s_{y,i,l}(1 - \tilde{p}^s_{i,l})V^s_i F^f_{y,i} \quad (8)$$

Catchability

Catchability is estimated separately by month (i) and for two time periods, before (1983-1992) and under (1993+) TACC management. Details on the definition of catchability ($q^{\text{Comm}}_{Q,i}$) are given in this Appendix.

Table 6-4 Catchability estimates from LenMod for the SZRLF.

Month of fishing season (i)	$q^{\text{Comm}}_{Q=0,i}$ **(1983-1992)**	$q^{\text{Comm}}_{Q=1,i}$ **(1993-2018)**
October	2.6 x 10^{-7}	3.4 x 10^{-7}
November	2.6 x 10^{-7}	3.8 x 10^{-7}
December	3.1 x 10^{-7}	4.5 x 10^{-7}
January	4.2 x 10^{-7}	6.5 x 10^{-7}
February	4.5 x 10^{-7}	6.2 x 10^{-7}
March	4.4 x 10^{-7}	6.3 x 10^{-7}
April	4.4 x 10^{-7}	6.0 x 10^{-7}
May	N/A	1.9 x 10^{-6}

Initial conditions

It is impossible to project this model from unexploited equilibrium owing to a lack of historical catch records for the entire period of exploitation. Instead, it is assumed that the population was in equilibrium with respect to the average catch over the first five years for which catches are available in year $y_{start} - 20$. This approach to specifying the initial state of the stock differs from that traditionally adopted for assessments of rock lobster off Tasmania and Victoria (Punt and Kennedy 1997; Hobday and Punt 2001) in that no attempt is made to estimate an initial exploitation rate. The settlements for years $y_{start} - 20$ to $y_{start} - 1$ are treated as estimable so that the model is not in equilibrium at the start of year y_{start}.

The objective function

The objective function summarises the information collected from the fishery and contains contributions from four data sources:

a) Commercial catch rates and independent catch rates,

b) length-sex frequency data from sampling of commercial pot lifts, and

c) commercial catches in number.

Catch-rate data

The contribution of the catch-rate data for the commercial fishery to the likelihood function is given by:

$$L_{1.a} = \prod_y \prod_i \frac{1}{I_{y,i}^{\text{Comm}} \sqrt{2\pi}\, \sigma_{q,Q,i}^{Comb}} \exp\left(-\frac{(\ell n I_{y,i}^{\text{Comm}} - \ell n(q_{Q,i}^{\text{Comm}}\, B_{y,i}^{e,\text{Comm}}))^2}{2(\sigma_{q,Q,i}^{Comb})^2} \right) \qquad (9.a)$$

while the contribution of fishery-independent monitoring survey (FIMS) index data to the likelihood function is given by

$$L_{1.b} = \prod_y \prod_i \frac{1}{K_{y,i}^{\text{FIMS}} \sqrt{2\pi}\, \sigma_{q,Q,i}^{Comb}} \exp\left(-\frac{(\ell n K_{y,i}^{\text{FIMS}} - \ell n(\tilde{\tilde{q}}^{\text{FIMS}} q_{Q,i}^{\text{Comm}}\, B_{y,i}^{e,\text{Comm}}))^2}{2(\sigma_{q,Q,i}^{Comb})^2} \right) \qquad (9.b)$$

where

$q_{Q,i}^{\text{Comm}}$ is the commercial catchability coefficient which varies by time-step (month) i and for each of two periods of years namely before (1983-1992) and after (1993+) inception of TACC (differentiated by index {Q = 0,1}, 0 for years prior to quota, and 1 for years under quota);

$I_{y,i}^{\text{Comm}}$ is the catch-rate index for the commercial fleet for year y and time-step i;

$\sigma_{q,Q,i}^{Comm}$ is the standard deviation of the observation error for the commercial fleet for time-step i and for each of two periods of years indexed by Q for before and after inception of TACC;

$\tilde{\tilde{q}}^{\text{FIMS}}$ is the FIMS catchability coefficient; and

$K_{y,i}^{\text{FIMS}}$ is the FIMS catch-rate index for time-step i of year y.

FIMS catch rates are available since 2005 for the Southern Zone Rock Lobster Fishery for between two or three months surveyed each year, and are derived from sampling pots spaced evenly across transects which span a larger spatial region than that of the concentrated fishing grounds, where catchability by month is assumed to be the same as that for the commercial fishery. The maximum likelihood estimates for $q_{Q,i}^{\text{Comm}}$ and $\sigma_{q,Q,i}^{Comb}$ were obtained analytically, while the value for $\tilde{\tilde{q}}^{\text{FIMS}}$ was estimated as part of the non-linear search procedure.

$B_{y,i}^{e,\text{Comm}}$ is the exploitable biomass available to the commercial fishery (and recreational fishery) during time-step i of year y:

$$B_{y,i}^{e,Comm} = \sum_s \sum_l V_i^s (1-\tilde{p}_{i,l}^s)\tilde{S}_{y,i,l}^s \; W_l^s \; e^{-Mt_i/2} N_{y,i,l}^s (1-\tilde{H}_{y,i,l}^s/2)$$

(10)

Length-frequency data

Length and sex frequency data are available from a sampling program which has been conducted since 1991. This program involves voluntary reporting on the contents of pot lifts by some commercial fishers. The observed fraction, during time-step i of year y by the commercial fishery, of the catch (in number) of animals of sex s in size-class l (including undersize) is denoted $\rho_{y,i,l}^{s,\text{Comm}}$. The model-estimate of this quantity, $\hat{\rho}_{y,i,l}^{s,\text{Comm}}$, takes account of the vulnerability of the gear and the numbers in each size-class and sex:

$$\hat{\rho}_{y,i,l}^{s,\text{Comm}} = \tilde{S}_{y,i,l}^s V_i^s (1-\tilde{p}_{i,l}^s) N_{y,i,l}^s \Big/ \sum_{s'} \sum_{l'} \tilde{S}_{y,i,l'}^{s'} V_i^{s'} (1-\tilde{p}_{i,l'}^{s'}) N_{y,i,l'}^{s'} \quad (11.a)$$

The observed value of $\rho_{y,i,l}^{s,\text{Comm}}$ is assumed to be multinomially distributed, giving the length-sex frequency likelihood function (ignoring multiplicative constants):

$$L_2 = \prod_y \prod_i \prod_l \prod_s \left(\hat{\rho}^{s,\text{Comm}}_{y,i,l}\right)^{n^{s,\text{Comm}}_{y,i,l}\omega} \tag{11.b}$$

where $n^{s,\text{Comm}}_{y,i,l}$ is the observed number of lobsters in the sampling program in time-step i of year y of sex s and size-class l, and ω is a down-weighting constant factor to reduce influence of this data relative to the catch-effort data sets (since catch sampling is not random and selectivity is not stationary). Undersize length-sex frequencies are fit as part of the full length-sex frequency data from the sampling program, with the model catch number predictions being proportional to:

$$S^s_{y,i,l} V^s_i (1-\tilde{p}^s_{i,l}) N^s_{y,i,l} e^{-Mt_i/2} \tag{12.a}$$

The length-sex frequencies for spawners are also assumed to be multinomial samples, except the model catch number predictions being proportional to:

$$S^s_{y,i,l} V^s_i \tilde{p}^s_{i,l} N^s_{y,i,l} e^{-Mt_i/2} \tag{12.b}$$

Catch-in-number

The commercial catches in number, $C^N_{y,i}$, are assumed to be lognormally distributed. The contribution of these data to the likelihood function is therefore given by:

$$L_3 = \prod_f \prod_y \prod_i \frac{1}{C^N_{y,i}\sqrt{2\pi}\sigma_N} \exp\left(-\frac{(\ell\text{n}C^N_{y,i} - \ell\text{n}\hat{C}^{N,\text{Comm}}_{y,i})^2}{2\sigma^2_N}\right) \tag{13}$$

where $\hat{C}^N_{y,i} = \sum_s \sum_l V^s_i \tilde{S}^s_{y,i,l} (1-\tilde{p}^s_{i,l}) N^s_{y,i,l} e^{-Mt_i/2} F^{\text{Comm}}_{y,i}$ and σ^{Comm}_N is the standard deviation of the observation error in catch numbers, assumed to apply over all time. The spawner discards are also fitted under the assumption that they are lognormally distributed.

Parameter estimation

Table 6-5 lists the parameters of the population dynamics model and the objective function, and highlights those parameters assumed to be known exactly and those parameters whose values are estimated by fitting the model to the data. Vulnerability-at-length for specified combinations of months is estimated, separately for each sex, by a logistic function of length. Female spawner fractions are based on auxiliary information.

A constraint is placed on the settlement residuals to stabilise the estimation and prevent confounding with mean recruitment. The following term was included in the objective function:

$$P = 0.5 \sum_{y} (\varepsilon_y)^2 / (\sigma_{R,y}^2). \quad (14)$$

Estimates of all parameters were obtained by minimising the negative log-likelihood using ADMB (Fournier et al. 2012).

Table 6-5 Parameters of the length-structured model (LenMod) and their sources for the Southern Zone Rock Lobster Fishery.

Parameter	Description	Value	Sources
ε_y	The settlement residuals for year y	Estimated	
$\ell n(\bar{R})$	Mean settlement	Estimated	
$\tilde{\sigma}_R$	The extent of variation in settlement for years after y_{start}	0.5	Assumed
$\tilde{\tau}$	The extent to which $\sigma_{R,y}$ changes with time	0.8	Assumed
$X^s_{l',l,i}$	Growth transition matrix	Matrices by sex for months 3 and 8.	Estimated using method of McGarvey and Feenstra (2001).
M	Natural mortality	0.1 yr^{-1}	Conventional assumption
V^s_i	Relative vulnerability by sex by time-step	Fixed at 1 for all months and both sexes.	
$S^s_{y,i,l}$	Vulnerability of the gear by sex, size-class, time-step, and year.	Estimated as logistic functions of length per sex, shared across years, but separately for Oct-Dec, Jan-March, April, and May.	
$\tilde{p}^s_{i,l}$	Proportion of mature spawning animals by sex, size-class and time-step		Estimated externally
Ω^s_i	Fraction of the settlement by time-step and sex	Estimated	
Φ^s_l	Proportion of the settlement of animals by sex and size-class	First six length bins: males = 0.35, 0.2, 0.15, 0.15, 0.1, 0.05; females = 0.45, 0.25, 0.15, 0.1, 0.05, 0	Assumed
Q_l	Egg production as a function of size		Estimated externally
W^s_l	Mass as a function of size and sex	Power function of length	Estimated externally

i_{m}	The time-step in which spawning occurs	1	
$q_{Q,i}^{\text{Comm}}, \tilde{\tilde{q}}^{\text{FIMS}}$	Catchability for the commercial fleet and FIMS by time-step i and for each of two periods of years namely before and after inception of TACC	Estimated	
$\sigma_{q,Q,i}^{Comb}$	Standard deviation of the observation errors for time-step i and for each of two periods of years namely before and after inception of TACC for the commercial fleet, and FIMS surveys combined after TACC inception.	Estimated	
σ_{N}^{Comm}	Standard deviation of the observation error in commercial catch in numbers	Estimated	
ω	Down-weighting factor for length-sex data	0.0125	Assumed

Appendix 5. Model fits

qR model

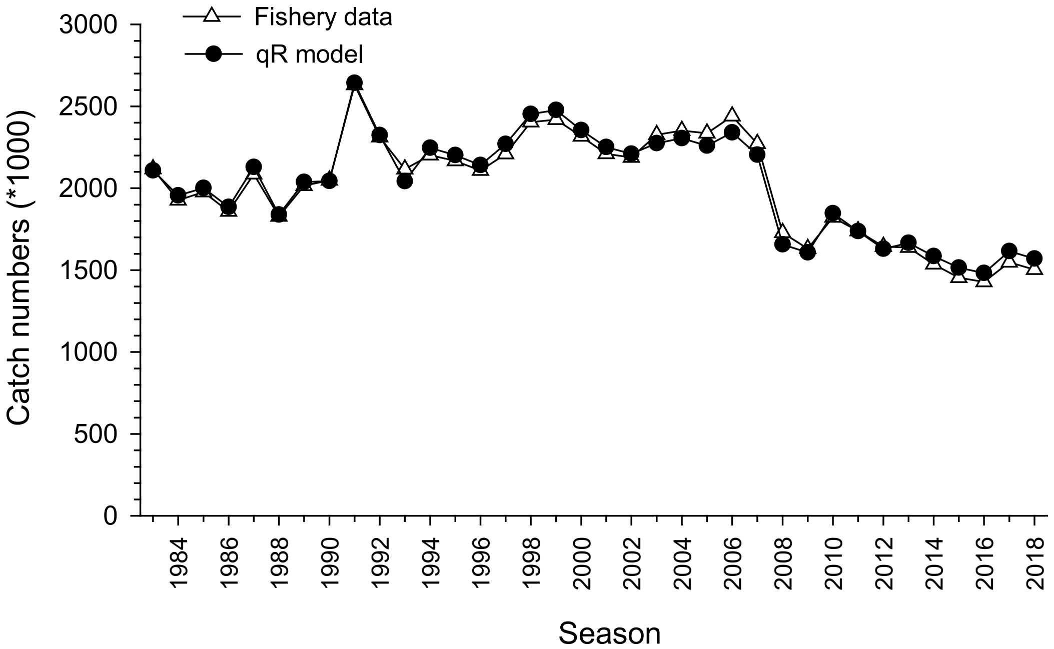

Figure 6-1 Fit of the qR model to catch in number of lobsters landed for the SZRLF, based on annual logbook catch totals from the fishery.

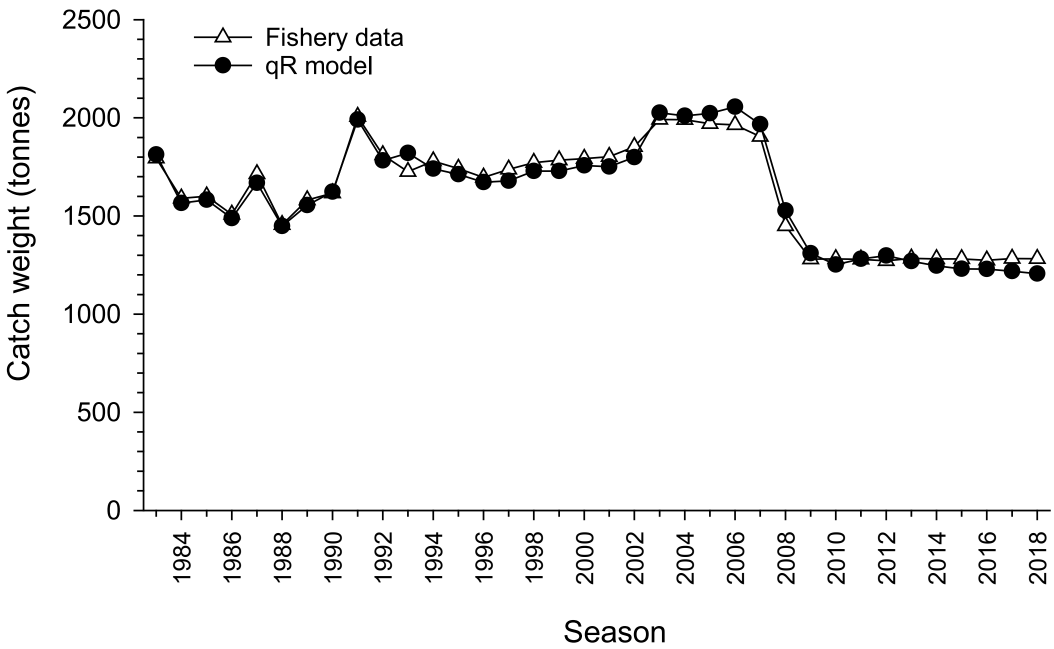

Figure 6-2 Fit of the qR model to catch in weight for the SZRLF, based on annual logbooks catch totals from the fishery.

LenMod

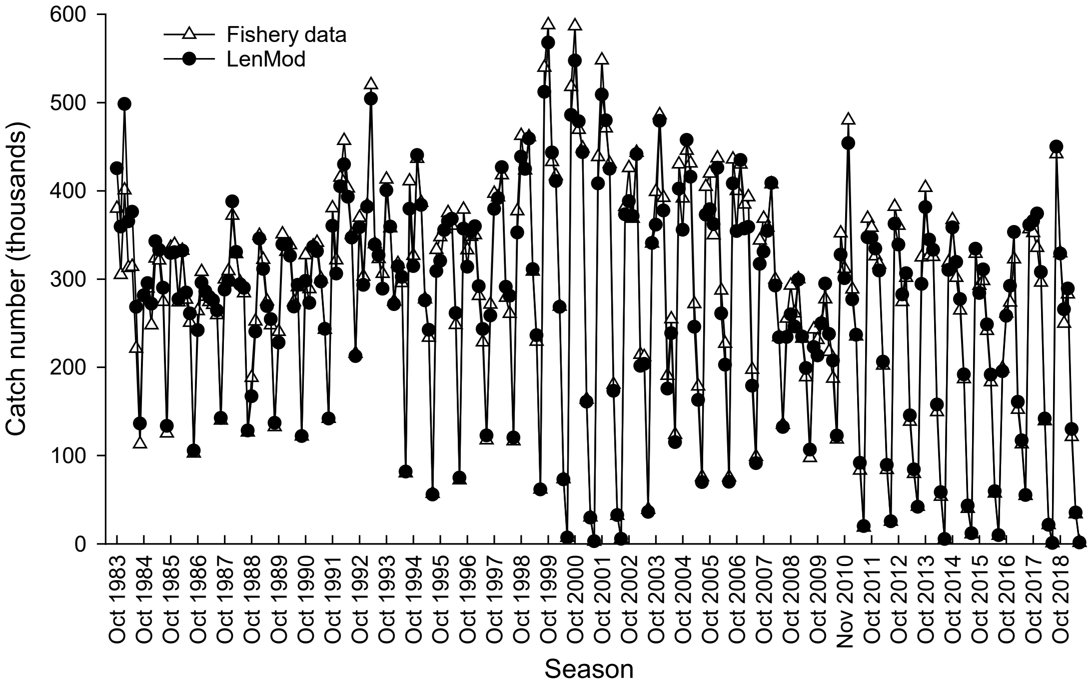

Figure 6-3 Fit of the LenMod model to monthly catch in number (Cn) for the SZRLF, based on logbook catch totals from the fishery. (Note: October closed to fishing in 2010).

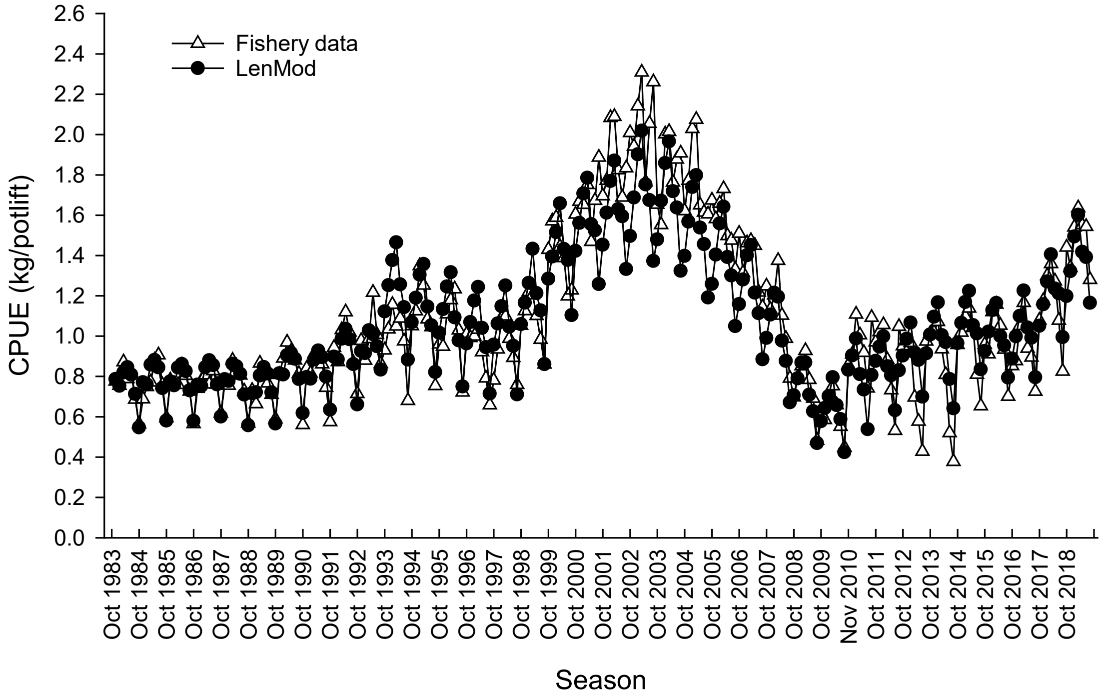

Figure 6-4 Fit of the LenMod model to monthly catch per unit effort (CPUE) for the SZRLF, based on logbook catch totals from the fishery (Note: October closed to fishing in 2010).

Southern Zone Rock Lobster Fishery

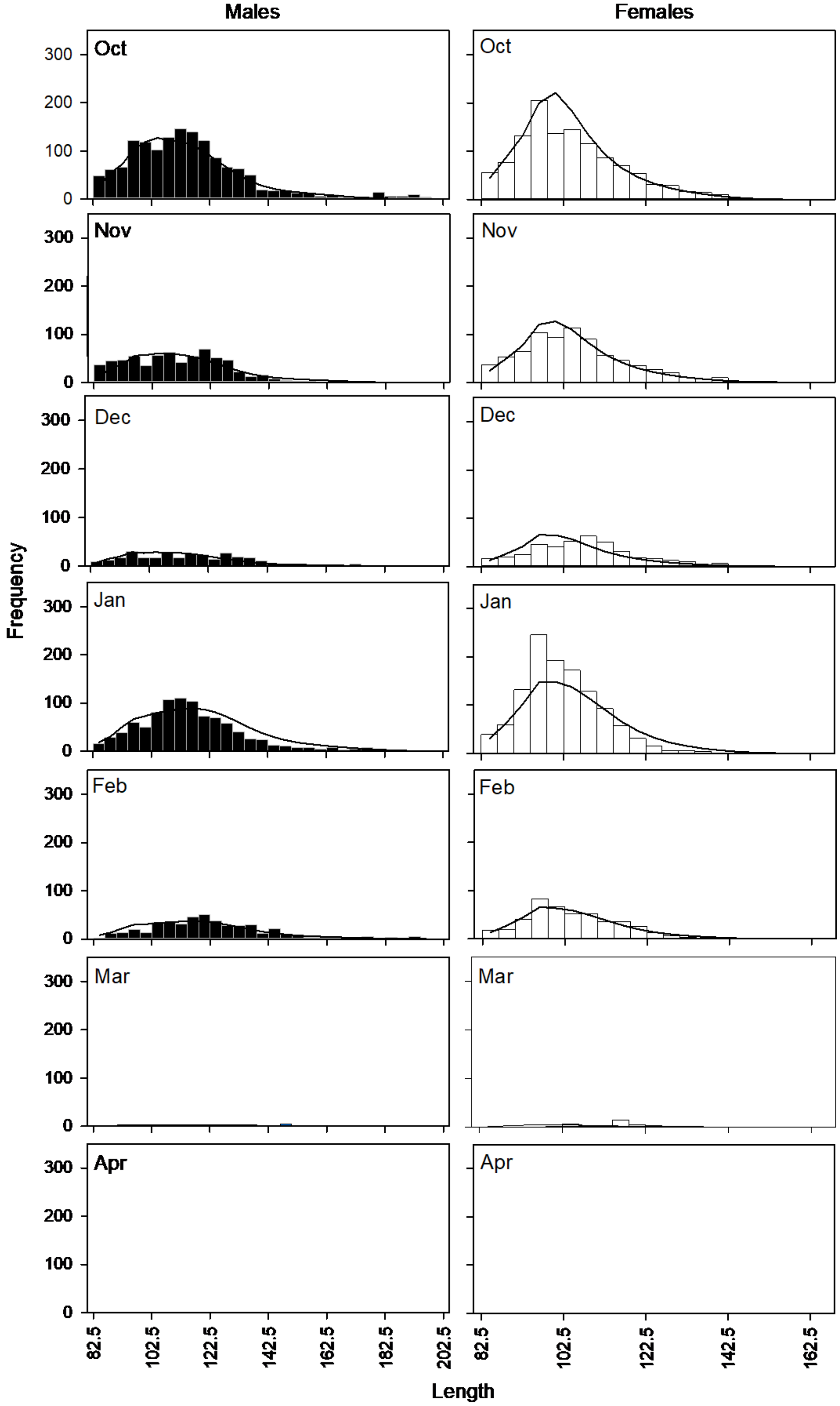

Figure 6-5 Fits of LenMod model (black line) proportions by length bin to commercial length frequency data for both males and females taken during the 2018 season in the SZRLF.