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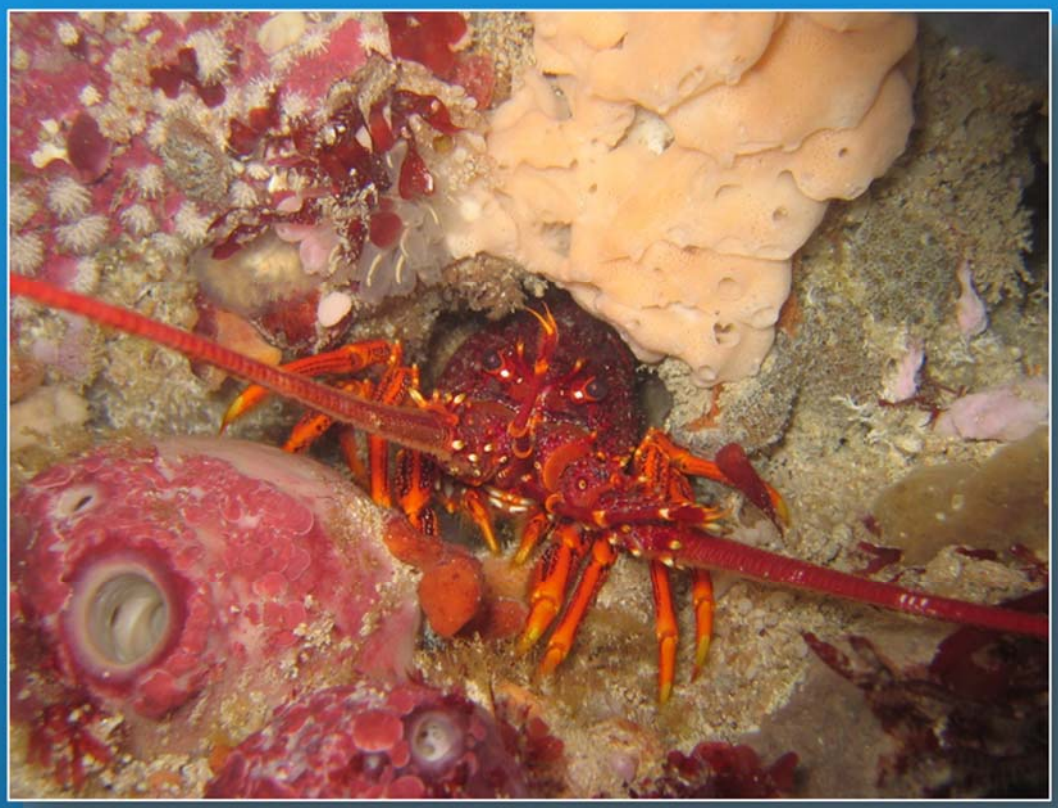
Southern Zone Rock Lobster (*Jasus edwardsii*) Fishery 2014/15



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

SARDI Publication No. F2007/000276-10
SARDI Research Report Series No. 911

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

August 2016

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

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This fishery assessment updates the 2013/14 report for the Southern Zone Rock Lobster Fishery (SZRLF) and is part of SARDI Aquatic Sciences ongoing assessment program for the fishery. The report provides a synopsis of information available and assesses the current status of the resource. The report also identifies both current and future research needs for the fishery.

This report may be cited as:
Linnane, A., McGarvey, R., Feenstra, J. and Hawthorne, P. (2016). Southern Zone Rock Lobster (*Jasus edwardsii*) Fishery 2014/15. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000276-10. SARDI Research Report Series No. 911. 99pp.

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Printed in Adelaide: August 2016

SARDI Publication No. F2007/000276-10
SARDI Research Report Series No. 911

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Date: 29 August 2016

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

Circulation: Public Domain

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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 Kylie Howard, Andrew Hogg, Jay Dent, Damian Matthews, Brian Foureur and Ben Stobart for collecting and collating the data. The report was formally reviewed by Dr. Ben Stobart, Assoc. Prof. Tim Ward, Prof. Gavin Begg (SARDI Aquatic Sciences) and Dr. Annabel Jones (PIRSA Fisheries and Aquaculture) and approved for release by Dr. Stephen Mayfield (SARDI Aquatic Sciences).

EXECUTIVE SUMMARY

This report assesses the current status of the Southern Zone Rock Lobster Fishery (SZRLF) for the 2014/15 fishing season and updates the 2013/14 report. In 2014 (1 October 2014 to 31 May 2015), the Total Allowable Commercial Catch (TACC) was 1,245.7 t. The reported commercial catch was 1,244.4 t and the fifth consecutive season that the TACC was fully taken.

Fishing effort has decreased considerably in recent seasons. In 2014, it was 1,207,123 potlifts, a decrease of 41% from 2009 (2,049,961 potlifts).

The primary biological performance indicator for the SZRLF is catch per unit effort (CPUE; kg of legal sized lobster/potlift). Recent declines in fishing effort have resulted in an increase to CPUE over the last five seasons. In 2014, the CPUE was 1.03 kg/potlift, reflecting a 72% increase from 2009 (0.60 kg/potlift). Current estimates are now at the long-term average.

The logbook derived pre-recruit index (PRI; number of undersized/potlift) is the secondary biological performance indicator. While legal sized catch rates have increased recently, PRI estimates have declined. In 2014, the PRI was 0.92 undersized/potlift which is below the Trigger Reference Point (TRP) of 1.30 undersized/potlift. PRI has been below the TRP in seven of the last eight seasons.

Outputs from the qR and LenMod fishery models agree with recent trends in empirical data sources with both models indicating increases in legal size biomass and egg production over the last five seasons. Current biomass estimates range from 2,400 t to 2,700 t, reflecting exploitation rates that ranged from 47% to 51%.

Four of the last five puerulus settlements have been below the long-term average. Using a five year period from settlement to recruitment, 2015 to 2018 recruitment may be lower than experienced historically.

A catch rate limit reference point (LRP) of 0.50 kg/potlift is the agreed level below which it is considered there may be a significant risk to spawning stock egg production (PIRSA 2013).

In summary, despite current levels of recruitment, recent management decisions have prevented fishery declines. Specifically; (i) TACC levels since 2010 have constrained catch to historically low levels (ii) effort has subsequently been reduced by ~40% and (iii) the CPUE in 2014 was above the LRP. As a result, based on a weight-of-evidence approach, the SZRLF is classified as "**sustainable**".

Key SZRLF statistics for the 2014/15 season are summarised in Table 1.

Table 1. Key SZRLF statistics for the 2014/15 season.

Statistic	**2014/15**
TACC	1,245.7 t
Total commercial catch	1,244.4 t
Total effort	1,207,123 potlifts
Commercial CPUE	1.03 kg/potlift
Pre-recruit index	0.92 undersized/potlift
Biomass estimates	2,400-2,700 t
Exploitation rates	47%-51%
Status	**Sustainable**

1. GENERAL INTRODUCTION

1.1 Overview

This fishery assessment report updates the 2013/14 report for the Southern Zone Rock Lobster Fishery (SZRLF) and is part of the SARDI Aquatic Sciences ongoing assessment program for the fishery. The aims of the report are to provide a comprehensive synopsis of information available for the SZRLF and to assess the current status of the resource in relation to the performance indicators provided in the Management Plan (PIRSA 2013) for the fishery.

The report is divided into seven sections**.** The first section is the General Introduction that: (i) outlines the aims and structure of the report; (ii) describes the environmental characteristics and history of the SZRLF; (iii) outlines the management arrangements including biological performance indicators and reference points; (iv) provides a synopsis of biological and ecological knowledge of the southern rock lobster, *Jasus edwardsii*; and (v) details the data sources from which the current assessment is made.

Section two provides a synopsis of the fishery-dependent statistics for the fishing seasons between 1970/71 and 2014/15. Inter-annual and within-season trends in catch, effort and catch per unit effort (CPUE) of both legal and undersized lobsters at zonal and regional spatial levels are presented. This section also analyses catch rates of important groups such as dead individuals and spawning females as well as reporting on issues such as average number of fishing days per licence and levels of discarded catch due to high-grading within the fishery.

The third section presents fishery-independent data from two sources. The first source is the settlement index, as estimated from the puerulus monitoring program within the zone. It also compares inter-annual variations in the settlement rates of puerulus with lagged estimates of pre-recruit indices and catch rates. The second source provides outputs from the Fishery-Independent Monitoring Survey (FIMS) for the fishery.

The fourth section presents estimates of fisheries indicators obtained from the qR model (McGarvey et al. 1997; McGarvey and Matthews 2001) while the fifth section presents outputs from the length structured model (LenMod) for the fishery.

The sixth section uses information provided in sections two to five to assess the status of the fishery against the biological performance indicators and reference points defined in the SZRLF Management Plan.

Section seven is the General Discussion. It synthesises the information presented, assesses the status of the fishery and identifies future research priorities.

1.2 Description of the fishery

The SZRLF targets the Southern Rock Lobster (*Jasus edwardsii*).

1.2.1 Location and size

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).

1.2.2 Environmental characteristics

1.2.2.1 Geology and Oceanography

The sea-floor in the Southern Zone consists mainly of reefs made of bryozoan or aeolianite limestone. The limestone matrix has eroded to form ledges, crevices, undercuts and holes which provide ideal habitat for lobsters. These reefs are almost continuous, separated by small stretches of sand substrate (Lewis 1981).

The salinity and temperature of the surface water over the continental shelf in the SZRLF varies seasonally, with minimum salinity (35.2 psu) and maximum temperature (18 ºC) during summer and maximum salinity (35.6 psu) and minimum temperature (14 ºC) during winter (Lewis 1981; Middleton and Platov 2003; McClatchie and Ward 2006).

Continental shelf waters are vertically mixed during winter. However, during summer the prevailing south-easterly winds result in an upwelling of sub-surface nutrient-rich, cold water (11-12 ºC) which intrudes onto the continental shelf (Schahinger 1987). Known locally as the Bonney Upwelling (Figure 1-2), this results in an increase in productivity of phytoplankton which may contribute to the high densities of Southern Rock Lobster in the SZRLF (Rochford 1977; Lewis 1981).

1.2.3 Commercial fishery

Southern rock lobster have been fished in South Australian waters since the 1890s, but the commercial fishery did not develop until the late 1940s and early 1950s when overseas markets for frozen tails were first established (Copes 1978; Lewis 1981). Since then, the

industry has seen a gradual change to live export with over 90% of the current commercial catch exported mainly to China, noting much of this product is exported from outside South Australia and therefore not directly reported as exported in South Australian export records.

The majority of commercial vessels fish from Port MacDonnell and Robe (Figure 1-1). Lobsters are caught using pots (Figure 1-3) that are set overnight and hauled at first light. The pots are steel-framed and covered with wire mesh that incorporates a moulded plastic neck. The catch is stored live in holding wells on vessels before being transferred to live holding tanks at the numerous processing factories located in Adelaide and surrounding regional areas.

1.2.4 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 most recent survey of recreational fishers was undertaken on 2013/14 (Giri and Hall 2015). An estimated 102,931 (± 58,763) southern rock lobsters were caught by South Australians residents throughout South Australia with 62,346 (± 39,085) of these harvested and 40,585 (± 25,202) released representing a release rate of 39.4%. These results can be compared with the 2007/08 survey where 106,483 lobsters were caught of which 47,875 were harvested and 58,608 were released (Jones 2009). Using an average weight of 1.2 kg, the recreational harvest in 2013/14 (62,346 lobsters) was estimated at 74.9 t, which was 4.5% of the total harvest weight (1,652 t in 2013/14). Almost two-thirds of the total catch and harvested numbers were taken in the SZRLF.

1.2.5 Illegal catch

The implementation of systems for monitoring the Total Allowable Commercial Catch (TACC), combined with the prior reporting system, has reduced opportunities for the disposal of illegal catches in the commercial SZRLF. It is considered unlikely that illegal fishing is currently a significant source of fishing mortality.

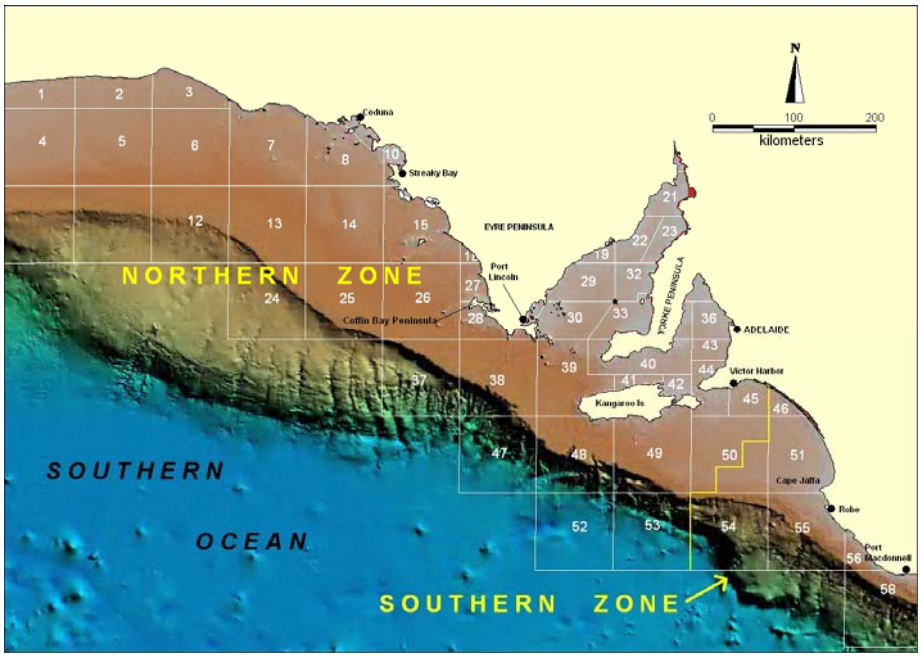

Figure 1-1 Marine Fishing Areas in the Southern and Northern Zones of the South Australian Rock Lobster Fishery.

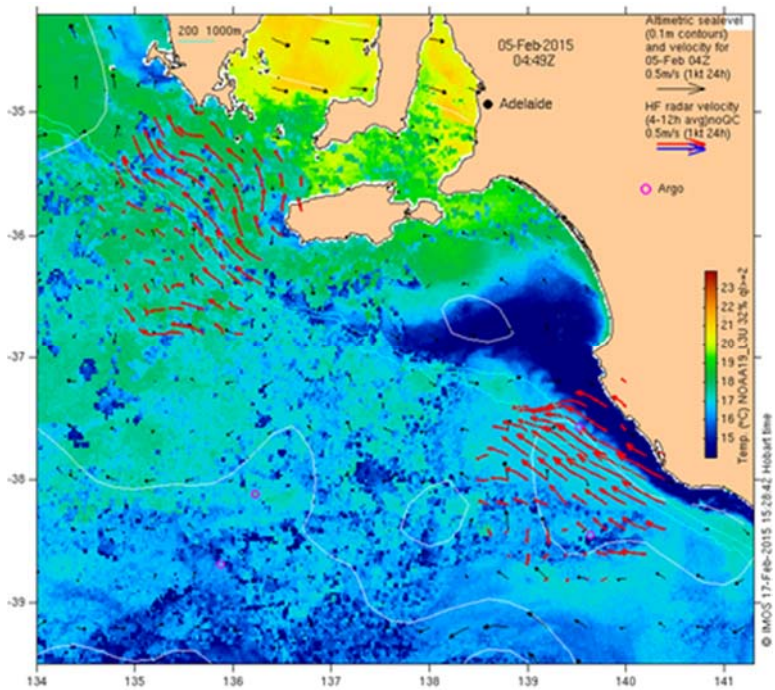

Figure 1-2 Satellite remote sensing image of sea surface temperature showing the extensive cold water Bonney Upwelling system across the SZRLF in February, 2015 (source: CSIRO).

Figure 1-3 The most commonly used pot in the SZRLF.

1.3 Management of the fishery

The commercial SZRLF is a limited entry fishery with a total of 180 licences at the start of the 2014/15 season. The broad statutory framework for the sustainable management of this resource is provided by the *Fisheries Management Act 2007*. General regulations that govern the SZRLF are described in the *Fisheries Management (General) Regulations 2007* and specific regulations are established in the *Fisheries Management (Rock Lobster Fisheries) Regulations 2006*. 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 2007.*

1.3.1 Management milestones

Management arrangements have evolved since the inception of the fishery with the most recent review in 2011. The major management milestones are shown in Table 1-1.

1.3.2 Current management arrangements

Details of management arrangements for the 2014/15 season are provided in Table 1-2. The commercial fishery is managed using a combination of input and output controls. Traditionally, the season extended from October 1st to May 31st. In 2010/11, October was

closed to fishing but was reopened for the 2011/12 season. There is a minimum legal size (MLS) of 98.5 mm carapace length (CL), prohibition on the taking of berried females and several sanctuaries where lobster fishing is prohibited. Fishers may use up to a maximum 100 pots endorsed on their licence at any one time to take lobster.

A TACC was introduced in 1993. It is set annually and divided proportionally between licence holders owning individual transferable quotas (ITQs) units. Each licence holds one quota unit entitlement for each pot entitlement held. If a pot entitlement is transferred, a quota unit must also be transferred at the same time to the same licence, and vice versa. The daily catch of individual vessels is monitored via catch and disposal records and mandatory commercial logbooks. In 2014/15, the SZRLF TACC was 1,245.7 t.

Table 1-1 Major management milestones for the South Australian Southern Zone Rock Lobster Fishery.

Date	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 removed from fishery through marine parks voluntary commercial fisheries catch and effort reduction program
2014	TACC reduced to 1245.7 t

Table 1-2 Management arrangements for the South Australian Southern Zone Rock Lobster Fishery in 2014/15.

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 carapace length (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	Optional or 50 mm mesh size
Monitoring tool	**Requirement**
Catch and effort data	Daily logbook submitted monthly
Catch and Disposal Records	Daily records submitted upon landing (electronic scales currently being implemented to automate this process)
Landing locations	7 designated landing sites
Landing times	Landings permitted during core hours
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.

1.3.3 Biological performance indicators

In 2011, the harvest strategy for the SZRLF (PIRSA 2013) was reviewed with additional amendments implemented in 2015 (McGarvey et al. 2016). The primary goal of the harvest strategy in place for the 2014/15 season is to ensure that the southern rock lobster resource in the SZRLF is harvested within ecologically sustainable limits. To achieve this goal, the fishery is assessed annually. This assessment is undertaken using primary, secondary and additional biological performance indicators.

Primary biological performance indicator

The key biological performance indicator for the SZRLF is commercial catch per unit effort (CPUE) of legal sized rock lobster (kg/potlift). CPUE in lobster fisheries is broadly accepted as being representative of lobster abundance. As a result, it is recognised by industry and managers as a measure of fishery performance that is reliable and well-understood. It is measured using commercial catch and effort data recorded and submitted in mandatory logbook returns.

Within the SZRLF, lobster stocks with estimated commercial CPUE levels greater than 0.50 kg/potlift are considered to be sustainable at pre-determined levels of TACC (PIRSA 2013).

Secondary biological performance indicator

The secondary performance indicator is the pre-recruit index (PRI) in terms of the number of undersized lobster/potlift. PRI provides information on future recruitment to the fishery and is based on logbook data as described in Section 2.3. A trigger reference point (TRP) for PRI of 1.3 undersized/potlift is used as a measure of fishery performance (PIRSA 2013).

Additional performance indicators

Three additional performance measures are used to assess the performance of the fishery. These are: a) puerulus settlement index (PSI); b) exploitable biomass estimates and levels of exploitation; and c) length-frequency data. It is important to note that additional performance indicators do not trigger a specific response in the harvest strategy.

1.4 Biology of Southern Rock Lobster

1.4.1 Distribution

For detailed information on all biological aspects of southern rock lobster *Jasus edwardsii* (Hutton 1875) see Phillips (2013). Southern rock lobster (Figure 1-4) are distributed around southern mainland Australia, Tasmania and New Zealand. In Australia, the northerly limits of distribution are Geraldton in Western Australia and Coffs Harbour in New South Wales. However, the bulk of the population can be found in South Australia, Victoria, and Tasmania where they occur in depths from 1 to 200 m (Brown and Phillips 1994). Southern rock lobster are generally omnivorous, but are primarily carnivores of slow moving benthic invertebrate prey such as spiny urchin, crab and marine snail species (Fielder 1965; Johnston 2003; Hoare 2008).

Figure 1-4 Southern rock lobster, *Jasus edwardsii*, in reef habitat.

1.4.2 Stock structure

Based on morphological and mitochondrial DNA analysis, there is little evidence of population sub-structuring across mainland Australia, Tasmania and New Zealand (Smith et al. 1980; Brasher et al. 1992; 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, point to the likely transport of phyllosoma from south-eastern Australia to New Zealand, providing genetic mixing between the two populations (Booth et al. 1990).

Using a combination of biological and hydrodynamic modelling, Bruce et al. (2007) simulated the planktonic early life history of *J. edwardsii* across its geographical range. In relation to

sources of recruiting pueruli to the Southern Zone, the study predicted that the most significant levels of recruitment occur from within the zone and from westerly regions although some may also come from as far east as south-eastern Tasmania in certain years. Importantly, the study found that the SZRLF had the highest levels of egg production in southern Australia and as a result, was an important source of pueruli for much of the overall south-eastern fishery of Australia.

While rock lobster stocks within South Australia cannot be differentiated based on genetic analyses, the stock is spatially discrete for management purposes based on known biological and ecological differences. As a result, the division of the stock into Northern and Southern Zones reflects known spatial variations in growth (McGarvey et al. 1999a), size of maturity (Linnane et al. 2008; 2009) and habitat (Lewis 1981).

1.4.3 Life history

Southern rock lobster mate from April to July. Fertilisation is external, with the male depositing a spermatophore on the female's sternal plates (MacDiarmid 1988). The eggs are extruded shortly afterwards, where they are immediately fertilised before being brooded over the winter for about 3-4 months (MacDiarmid 1989).

The larvae hatch in early spring and pass through a brief (10-14 days) nauplius phase before entering into a planktonic phyllosoma phase. Phyllosoma have been found down to depths of 310 m and tens to hundreds of kilometres offshore from the New Zealand coast (Booth et al. 1999; 2002; Bradford et al. 2005; Chiswell and Booth 2005). They develop through a series of 11 stages over 12-23 months before metamorphosing into the puerulus stage (Figure 1-5) near the continental shelf break (Booth et al. 1991; Booth and Stewart 1991; Bruce et al. 1999). A short-lived (ca. 3-4 weeks) non-feeding stage, the puerulus actively swims inshore to settle onto benthic reef habitat (Booth et al. 1991; Phillips and McWilliam 2009).

There is substantial geographic variation in larval production which may be due to variations in: (i) size at first maturity, (ii) breeding female abundance and/or (iii) egg production per recruit. Additionally, phyllosoma are thought to drift passively which, coupled with the long offshore larval period, means that oceanographic conditions, particularly currents and eddies, may play an important part in their dispersal (Booth and Stewart 1991; Chiswell and Booth 2005; 2008; Phillips and McWilliam 2009).

Geographic patterns in the abundance of phyllosoma may also be consistent with those in puerulus settlement (Booth 1994). Correlations between levels of settlement and juvenile abundance have been found at two sites in New Zealand (Breen and Booth 1989). In South Australia, it has been suggested that the strength of westerly winds, during late winter and early spring, may play a role in the inter-annual variation in recruitment to the SZRLF (McGarvey and Matthews 2001; Linnane et al. 2010a).

Figure 1-5 Newly settled southern rock lobster puerulus.

1.4.4 Growth and size of maturity

Lobsters grow through a cycle of moulting and thus increase their size incrementally (Musgrove 2000). Male and female moult cycles are out of phase by 6 months, with males undergoing moulting between October and November, and females during April to June (MacDiarmid 1989).

There are substantial variations in growth rates between locations in South Australia (McGarvey et al. 1999a). Growth rates also varies throughout the lives of individuals with the mean annual growth for lobsters at 100 mm carapace length (CL) ranging from 7-20 and 5-15 mm.yr^{-1} for males and females, respectively. Growth rates increase along the South Australian coast from south-east to north-west and are highest in areas of low lobster density and high water temperature. Growth rates also appear to be related to depth of habitat and decline at the rate of 1 mm CL yr^{-1} for each 20 m increase in depth (McGarvey et al.1999a).

Similarly, size of maturity (SOM; the size at which 50% of females reached sexual maturity; i.e. L_{50}) varies spatially within the SZRLF. Linnane et al. (2008) provided SOM estimates from two regions within the fishery i.e. the North Southern Zone (NSZ; MFA 51 and 55) and South Southern Zone (SSZ; MFA 56 and 58). SOM, was higher in the NSZ (104.1 mm CL) compared to SSZ (92.3 mm CL). Approximately 20% of lobsters above the minimum legal size (MLS) in the commercial catch in the NSZ were under the L_{50} estimate. Additionally, SOM may also vary with depth in at least some areas of the SZRLF (Linnane et al. 2009). Data from offshore (>100 m depth) sites revealed a SOM estimate of 68.4 mm CL compared to 103.3 mm CL for inshore (<60 m) females.

1.4.5 Movement

Movement patterns of the southern rock lobster were determined from 14,280 tag-recapture events from across the State between 1993 and 2003 (Linnane et al. 2005). In total, 68% of lobsters were recaptured within 1 km of their release site and 85% within 5 km. The proportion of lobsters moving >1 km ranged from 13% to 51%. Movement rates were noticeably higher at Gleesons Landing lobster sanctuary off the Yorke Peninsula in the Northern Zone Rock Lobster Fishery (NZRLF) where individuals moved distances >100 km to sites located on the north-western coast of Kangaroo Island and the southern end of Eyre Peninsula. In the SZRLF, lobsters moved distances of <20 km from inshore waters to nearby offshore reefs.

1.5 Stock Assessment: Sources of data

SARDI Aquatic Sciences is contracted by PIRSA Fisheries and Aquaculture to: (i) administer a daily logbook program, (ii) collate catch and effort information, (iii) conduct voluntary catch-sampling, puerulus and fishery-independent monitoring programs and (iv) produce annual stock assessment and status reports that assess the status of the SZRLF against the performance indicators defined in the Management Plan.

1.5.1 Catch and effort research logbook

Licence holders complete a compulsory daily logbook which has been amended to accommodate changes in the fishery. For example, in 1998, the logbook was modified to include specific details about giant crab (*Pseudocarcinus gigas*) fishing. In the 2000 fishing season, the logbook was again amended and the recording of undersize, spawning and dead lobster, along with numbers of octopus, became voluntary. Logbook returns are submitted monthly and entered into the South Australian Rock Lobster (SARL) database. Fishery-dependent statistics from logbook data are presented in Section 2 of this report.

Details currently recorded in the daily logbook include:

1. MFA within which the fishing took place;
2. depth in which the pots were set;
3. number of pots set;
4. weight of retained legal sized lobsters - reported at the end of each trip or as a daily estimated weight;
5. landed number of legal sized lobsters;
6. number of undersized lobsters caught;
7. number of dead lobsters caught;
8. number of spawning lobsters caught;
9. weight of octopus caught;
10. number of octopus caught;
11. number of giant crab pots;
12. depth of giant crab pots;
13. landed weight of giant crabs;
14. landed number of giant crabs.

Validation of catch and effort logbook data in the SZRLF can be achieved by comparing them with the catch and disposal records (CDRs) used in the quota management system. Processor records are not used for validation as lobsters may be transported to processors outside of the zone in which the lobsters were landed.

1.5.2 Assessment regions

Previous Management Plans for the SZRLF (e.g. Sloan and Crosthwaite 2007) detailed key biological performance indicators that were assessed at both whole-of-fishery (zonal) and regional levels (Figure 1-6). Currently, the three specific regions are: MFA 55 (Region A), MFA 56 (Region B) and MFA 58 (Region C). The aim of regional assessment is to monitor performance of the fishery at a finer spatial scale. Regional assessment also allows known spatial variations in biological features such as growth rate (McGarvey et al. 1999a) and size of maturity (Linnane et al. 2008; 2009) to be taken into consideration.

1.5.3 Voluntary catch sampling

Since 1991, commercial fishers and SARDI researchers have collaborated in an at-sea voluntary catch sampling program. During the life of this program there were various levels of participation, and changes to the sampling regime. The program started with commercial fishers sampling from several (usually three) pots each day, for the duration of the fishing season. During the 1995 season, sampling was reduced to one week each month over the period of the third quarter of the moon.

In the following season, sampling was done as part of a Fisheries Research and Development Corporation (FRDC) project that aimed to determine the optimal sampling strategy required to produce quantifiable and minimum variances in mean lengths and catch rates (McGarvey et al. 1999b; McGarvey and Pennington 2001). This study demonstrated

that the optimal design should incorporate a high percentage of vessels, with sampling done on as many days as possible from a small fraction of the pots from each vessel. As a result, fishers are now encouraged to participate in the program by recording the number, size and reproductive condition (females only) of both undersized and legal sized lobsters from three pots where the escape gaps are closed. They are supported by research staff that promote the program and demonstrate the methods to new participants.

Results have shown that participation in the program varies among areas and tends to taper off as the season progresses. In recent seasons, with the exception of 2012/13, participation in the program has been <20% (Figure 1-7). Pre-recruit indices and length-frequency data determined from the voluntary catch sampling program are presented in Section 2 of this report. Participation in the program is strongly encouraged to ensure that future decisions for the fishery are based on reliable and robust data.

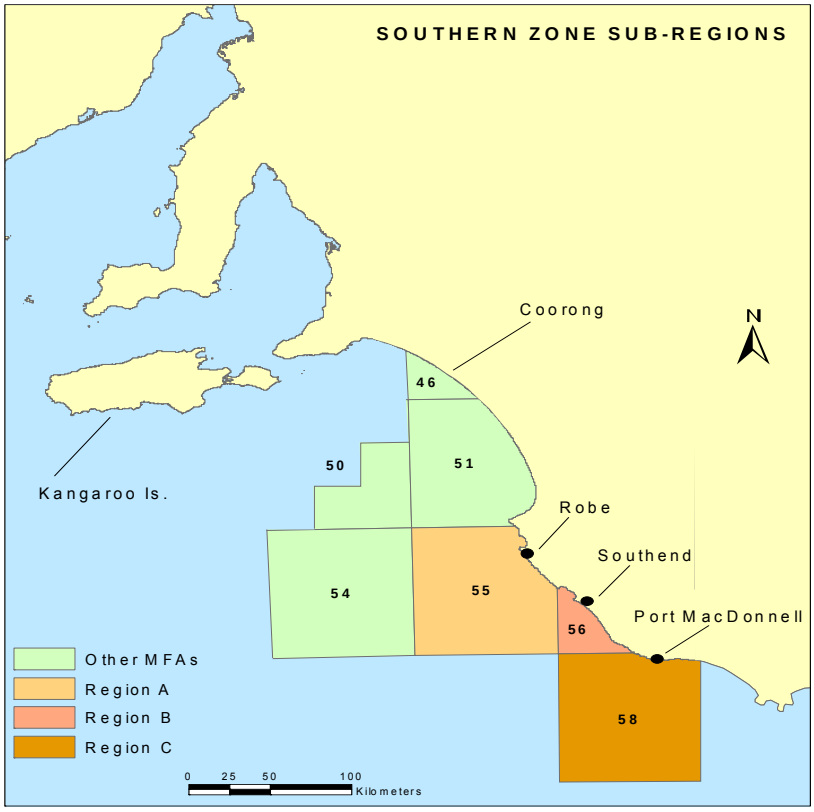

Figure 1-6 Key spatial assessment regions in the SZRLF.

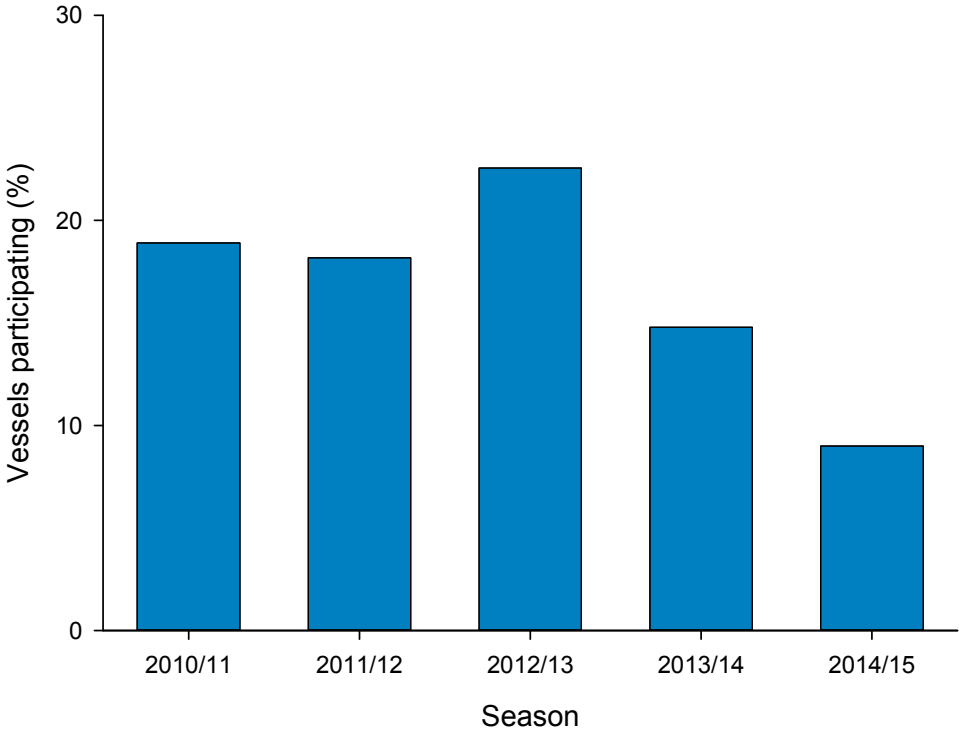

Figure 1-7 Percentage of active vessels participating in the SZRLF catch sampling program from 2010/11 to 2014/15.

1.5.4 Puerulus monitoring program

Puerulus monitoring has been undertaken across south-eastern Australia since the early 1970s (Lewis 1981) but quantified annual indices of settlement were not developed until the 1990s (Kennedy et al. 1991; Prescott et al. 1996). Initially, research was driven by the twin aims of understanding both long-term settlement trends and the biology of early life history. More recently, the focus has changed to examining the use of quantified puerulus settlement indices (PSI) as indicators of future recruitment to the fishable biomass. This largely stems from the success of this relationship in Western Australia where future commercial catches of western rock lobster *Panulirus cygnus* have historically been successfully predicted from settlement indices using a 3 to 4 year time lag (Caputi et al. 1995). Similar relationships have also emerged in specific regions of some *J. edwardsii* fisheries (Gardner et al. 2001; Booth and McKenzie, 2009; Linnane et al. 2013; Linnane et al. 2014a).

The monthly occurrence of puerulus settlement in crevice collectors has been studied in the SZLRF at five main sites since 1990. These sites are located at Blackfellows Caves, Livingstons Beach, Beachport, Cape Jaffa and Kingston, with the collectors set in groups of 10 or 12. 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 (Figure 1-8). The

design has remained unchanged throughout the sampling period. The annual PSI is calculated as the mean monthly settlement on these collectors. This index is then related to an annual pre-recruit index (PRI) and commercial catch rates four and five years, respectively. Results from the puerulus monitoring program are presented in Section 3.1 of this report.

1.5.5 Fishery-Independent Monitoring Survey (FIMS)

A fishery-independent monitoring survey (FIMS) has been undertaken in the SZRLF since 2006/07. The survey design consists of 29 transects, that run from inshore (~10 m depth) to offshore (~120 m depth) grounds (Figure 1-9). Each transect line consists of 10 pots set at predetermined locations that are independent of known fishing effort. Sampling is undertaken during September and January of each season. All lobsters are sexed, measured, staged (females only) and tagged. Results from the survey are presented in Section 3.2 of this report.

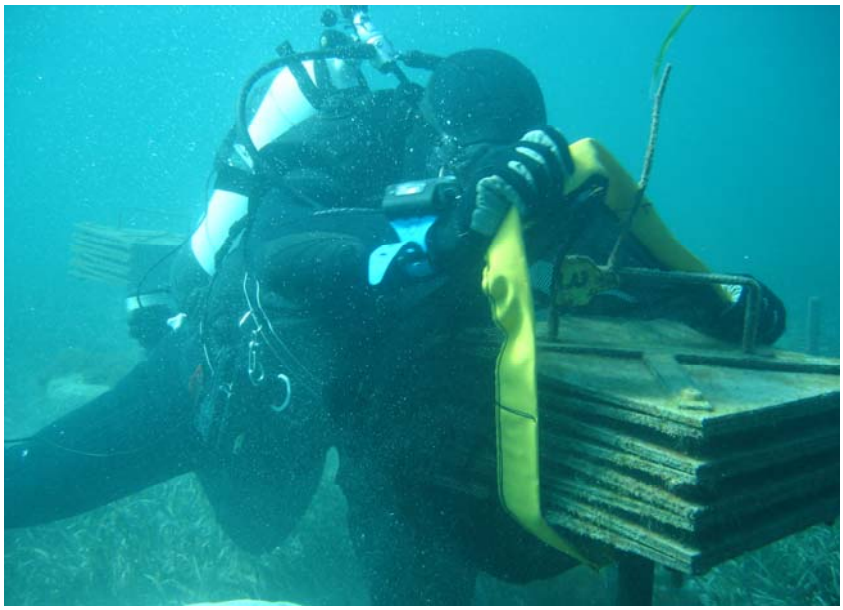

Figure 1-8 Typical puerulus collector deployed in the SZRLF.

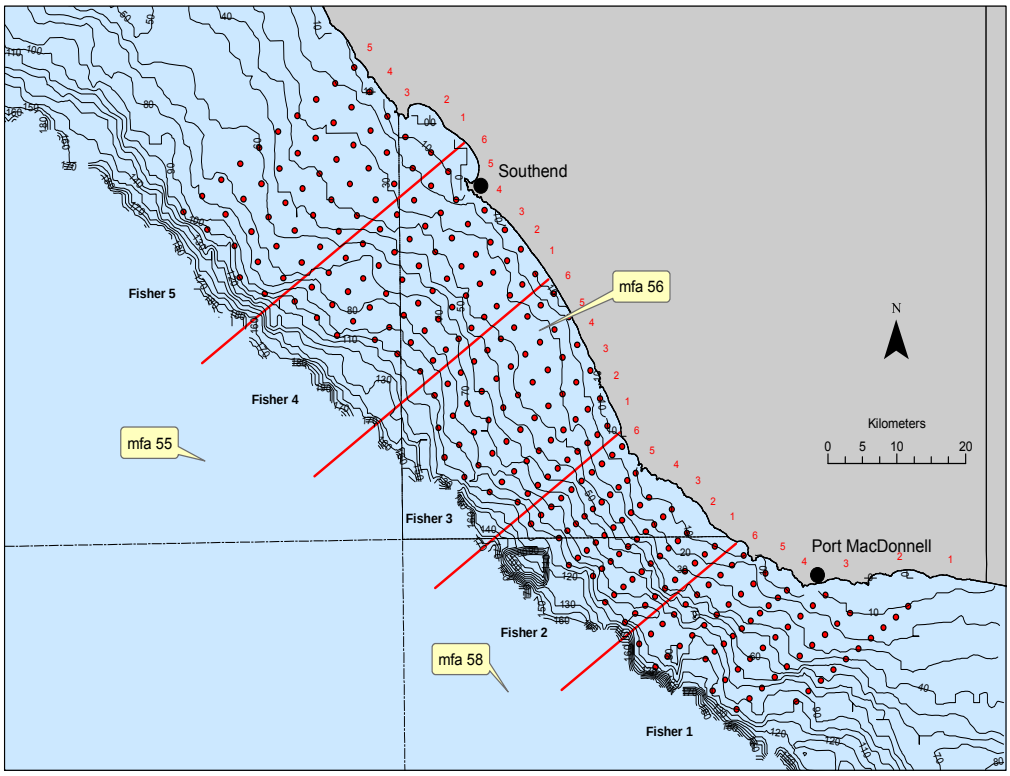

Figure 1-9 Location of Fishery-Independent Monitoring Survey (FIMS) transects in the SZRLF.

2 FISHERY-DEPENDENT DATA

2.1 Introduction

This section of the report summarises and analyses fishery statistics for the SZRLF for the period between 1 January 1970 and 31 May 2015. For ease of reference, figures and text in this section refer to the starting year of each season (e.g. 2014 refers to the 2014/15 fishing season).

The scale of spatial analyses undertaken, with respect to various fishery-dependent data, reflects their importance as performance indicators within the harvest strategy for the SZRLF (PIRSA 2013). For example, both CPUE (primary indicator) and pre-recruit index (secondary indicator) are presented by zone, region and depth. Other indicators (e.g. level of high-grading), not directly linked to the decision-making process of the harvest strategy, are presented at the zonal scale only.

Estimates presented in this section are calculated from daily data that are used to describe the inter-annual and within-season patterns in catch (kg), effort (potlifts), CPUE (kg/potlift) and mean weight (kg/lobster) across both the entire zone, as well as key MFAs (see Section 1.5). Important indices such as PRI (undersized/potlift), spawning females, dead lobsters and octopus catch rates are also provided. Data obtained from the catch sampling program provide the length-frequency distributions of lobsters.

2.2 Catch, effort and CPUE

2.2.1 Zonal trends

2.2.1.1 Catch

Fishing patterns between 1970 and 1983 (Figure 2-1) were highly variable and some discrepancies exist between the published catches for this period and those extracted from the South Australian Rock Lobster (SARL) database. Thus, estimates of absolute catch during this period should be interpreted with some caution. Between 1984 and 1990, catches remained steady at about 1,500 t before increasing to 1,940 t in 1991. In 1993, a TACC of 1,720 t was introduced, but only 1,668 t were harvested (Table 2-1). From 1993 to 1997, the TACC was only fully taken in 1994. The TACC was taken from 1998 through to 2002 with an increase of 50 t to 1,770 t implemented in 2001. In 2003, the TACC was again increased by 130 t to 1,900 t which was largely taken from 2003 to 2006. However, over the next three seasons, from 2007 to 2009, the TACC was not fully landed (Table 2-1). In 2007, a total of

1,849 t was caught (50.4 t below the TACC). In 2008, the TACC was reduced to 1,770 t but only 1,407.3 t was taken, a shortfall of 362.7 t. In 2009, the TACC was again reduced to 1,400 t but only 1,243.3 t were landed, 156.7 t short of the annual quota. In 2010, the TACC was reduced for the third consecutive season to 1,250 t and was fully taken over the next three seasons. In 2014, the TACC was reduced to 1,245.7 t following removal of one fishing licence (and quota units) through the marine parks voluntary commercial fisheries catch/effort reduction program. The total reported logbook catch in 2014 was 1,244.4 t.

2.2.1.2 Effort

As with catch, estimates of effort between 1970 and 1983 should be interpreted with caution (Figure 2-1). A peak of 2,255,333 million potlifts was recorded in 1983. Over the next 19 years, effort declined to the lowest recorded level of 854,091 potlifts in the 2002 season. However, over the next seven seasons, effort continued to rise, peaking at 2,049,961 potlifts in 2009, the highest on record since 1987 (2,130,416). In 2010, there was a considerable reduction in effort with 1,321,824 potlifts required to take the 1,244.1 t catch and since then, estimates have remained below 1.5 million potlifts. Effort in 2014 was 1,207,123 potlifts, representing a decrease of 41% from 2009.

2.2.1.3 Catch per unit effort (CPUE)

CPUE during the 1970s ranged between 0.70 and 0.90 kg/potlift (Figure 2-2). In 1980, the CPUE reached a peak of 1.06 kg/potlift before declining to 0.77 kg/potlift in 1983. CPUE remained steady at around 0.75 kg/potlift from 1983 to 1988 before rising to 0.99 kg/pot lift in 1992 (the year prior to introduction of the TACC).

From 1996 to 2002, CPUE increased substantially reaching 2.10 kg/potlift in 2002, the highest on record. However, over the next seven seasons it decreased annually and in 2009 was 0.60 kg/potlift; the lowest on record. Over the next five seasons, with the exception of 2012, estimates have increased and in 2014 was 1.03 kg/potlift, a 72% increase from 2009. Current estimates reflect the long-term average for the fishery (1.03 kg/potlift).

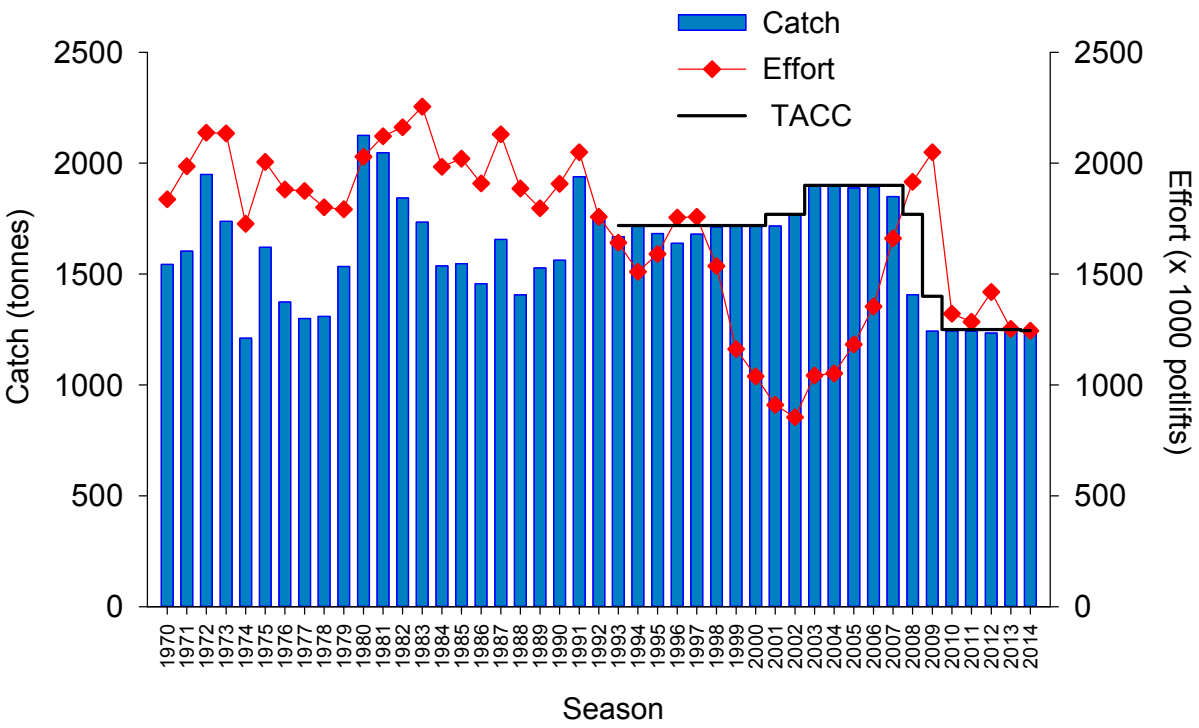

Figure 2-1 Inter-annual trends in catch and effort in the South Australian SZRLF from 1970-2014 inclusive. Solid line represents TACC level.

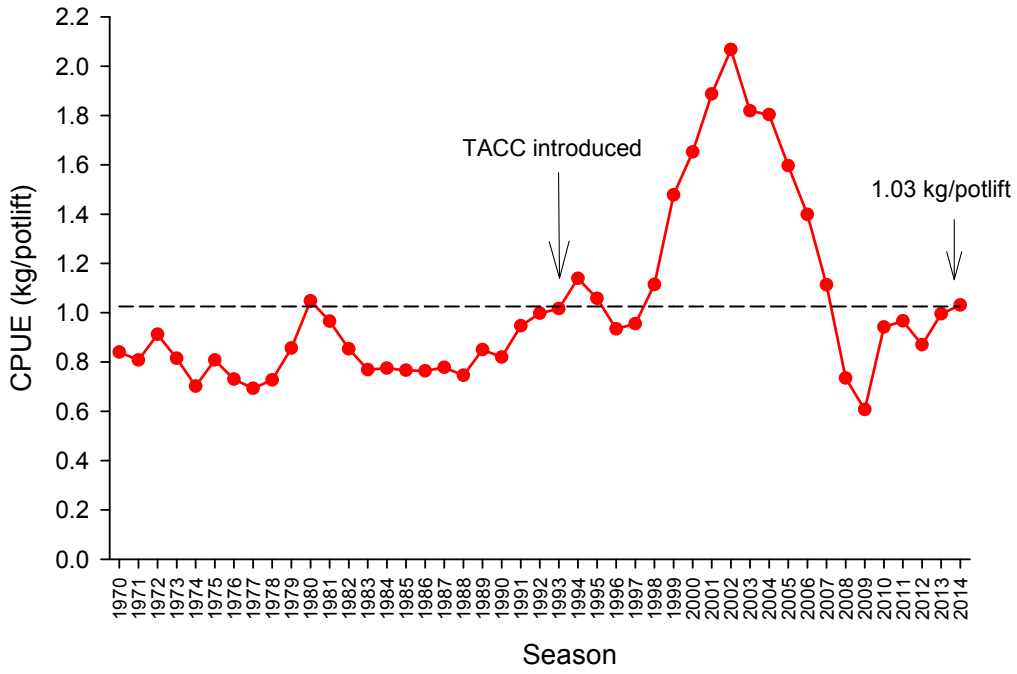

Figure 2-2 Inter-annual trends in catch per unit effort (CPUE) in the South Australian SZRLF from 1970-2014 inclusive. Dashed line represents long-term average.

Table 2-1 Table showing seasons when the TACC was not fully taken within the SZRLF.

Season	TACC (t)	Catch (t)	Shortfall (t)
1993	1720	1668	52 (3%)
1995	1720	1683	37 (2%)
1996	1720	1639	81 (5%)
1997	1720	1680	40 (2%)
2007	1900	1850	50 (3%)
2008	1770	1407	363 (21%)
2009	1400	1243	157 (11%)

2.2.2 Within-season trends

2.2.2.1 Catch

Fishing from 1970 to 1979 was conducted all year round, with most of the catch taken in summer (refer to Linnane et al. (2006) for trends in within–season catch from 1970 to 2002). From 1980 to 1996, the highest catches were usually taken in the first six months of the season before declining in April. More recently, the fishery has recorded high monthly catches from October to January, with the majority of the TACC being taken during this period (Figure 2-3). In 2014, from October to January, 1,030 t (83%) of the 1,244 t total catch were landed. The highest catch was taken in November (286 t), with the lowest catch in May (0.7 t).

2.2.2.2 Effort

Between 1980 and 1996, fishing effort was consistently high from October to March before dropping sharply during April (refer to Linnane et al. (2006) for trends in within–season effort from 1980 to 2002). This likely reflects a seasonal decline in catch rate and the more favourable weather conditions during summer. In 2014, trends in effort reflected those in catch (Figure 2-3). A total of 984,911 potlifts were required to take the 1,030 t catch from October to January. Highest effort was observed in November (281,083 potlifts) with the lowest in May (1,730 potlifts).

2.2.2.3 Catch per unit effort (CPUE)

CPUE within the fishery generally tends to be highest during the first 4-5 months of the season before decreasing thereafter (Figure 2-4). Monthly estimates in 2014 were broadly similar to those in 2013. In 2014, CPUE was highest in January at 1.14 kg/potlift and lowest in May at 0.43 kg/potlift.

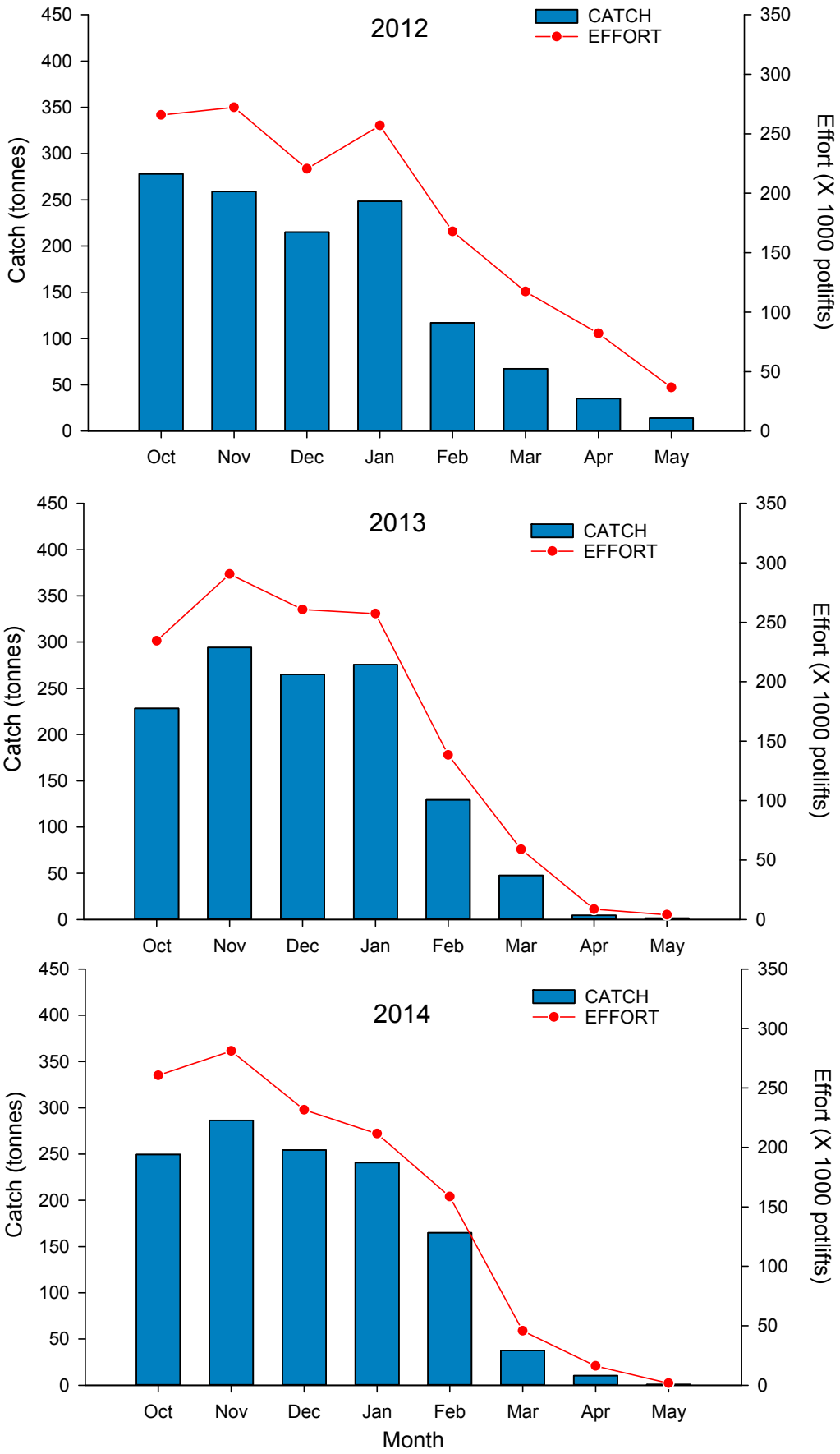

Figure 2-3 Within-season trends in catch and effort in the SZRLF from 2012 to 2014.

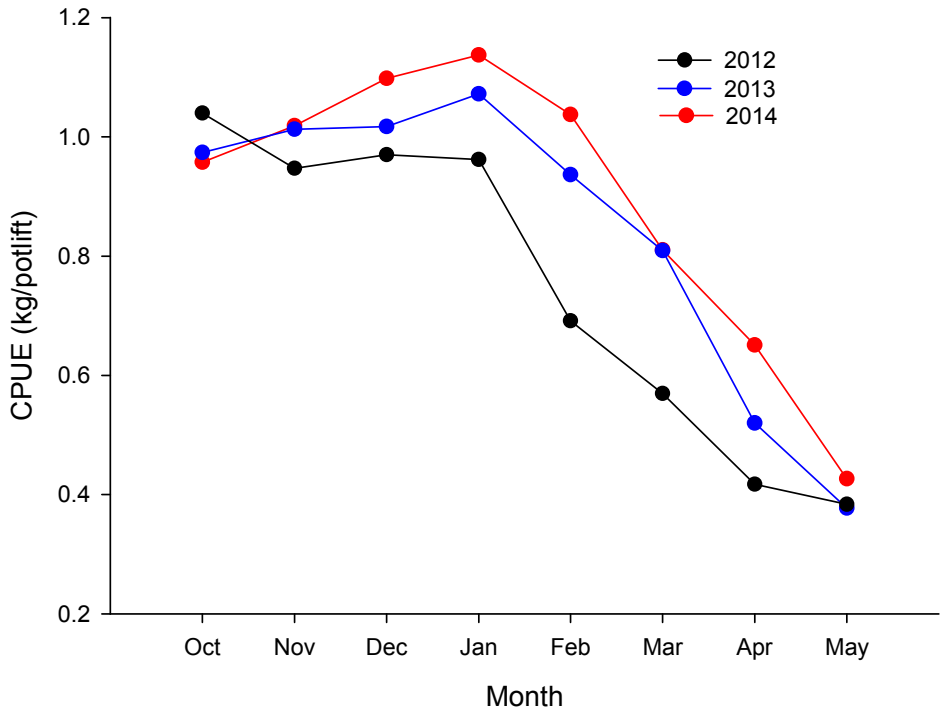

Figure 2-4 Within-season trends in CPUE in the SZRLF from 2012 to 2014.

2.2.3 Regional trends

In 2014, 98% of the catch in the SZRLF was currently taken from MFAs 55, 56 and 58 (Figure 2-5). Historically, MFA 51 was a more important area, but its contribution has decreased in recent seasons.

2.2.3.1 Catch

Historically, catches were highest in MFAs 55 and 56 but more recently these have been surpassed by landings from MFA 58 (Figure 2-6). Historically, the catch in MFA 51 ranged between 200 and 300 t in the 1970s and early 1980s but since 1993 it has been less than 100 t. Data in Section 2.4.2 indicate that lobsters harvested from MFA 51 are generally larger in size and thus have lower market value given the preference for smaller individuals by overseas markets.

In 2014, the catch taken in MFAs 51, 55, 56 and 58 was 25, 412, 384 and 421 t, respectively. Notably, over the last seven seasons, catch has decreased from 580 to 412 t in MFA 55 but increased from 319 to 421 t in MFA 58 over the same period.

2.2.3.2 Effort

Levels of effort have been relatively low over the last five seasons in all regions of the fishery (Figure 2-6). Estimates in 2014 were 24,781, 412,196, 398,222 and 367,262 potlifts in MFAs 51, 55, 56 and 58, respectively.

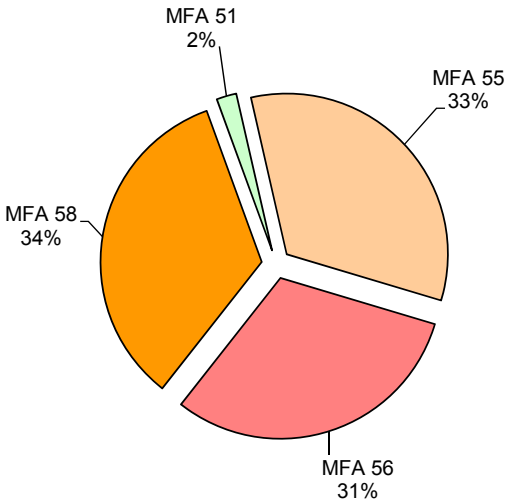

Figure 2-5 Proportion of the total catch (in terms of tonnage landed) taken from MFAs 51, 55, 56 and 58 of the SZRLF in 2014.

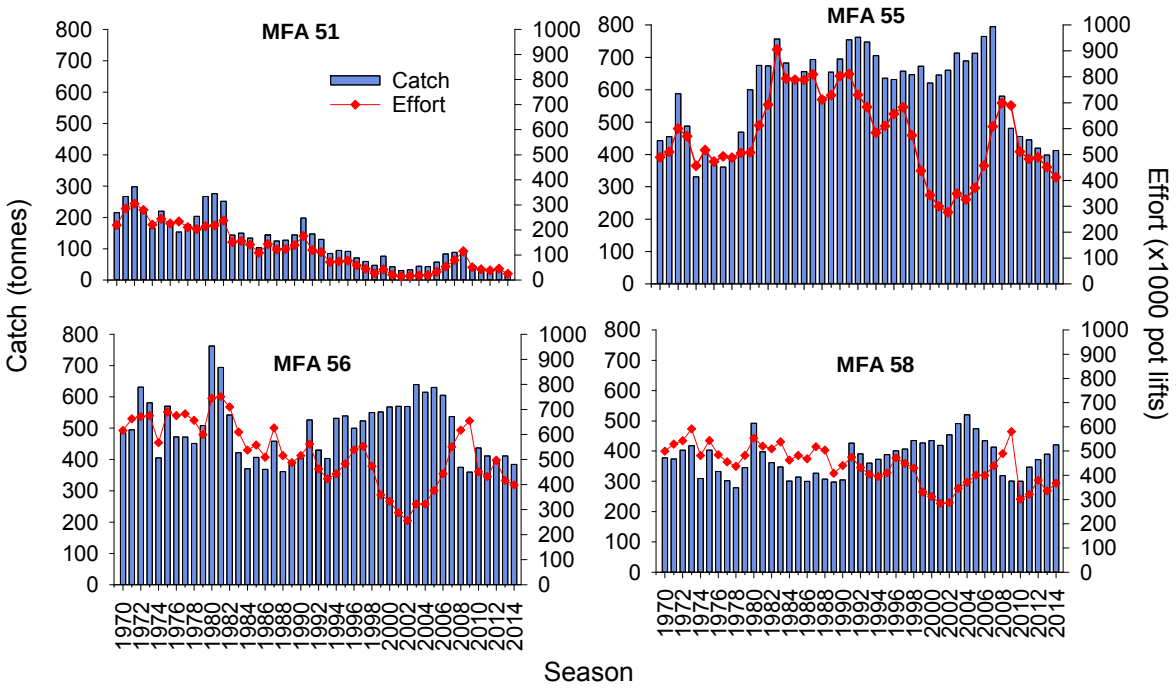

Figure 2-6 Inter-annual trends in catch and effort in the main MFAs of the SZRLF from 1970 to 2014 (note: alternate seasonal ticks on x-axis).

2.2.3.3 CPUE

CPUE in MFAs 51, 55, 56 and 58 increased considerably from 1996 to 2002 peaking at 2.4, 2.3 and 1.6 kg/potlift, respectively (Figure 2-7). However, over the next six seasons it decreased markedly in all areas. For example, in MFA 55 in 2009, CPUE was 0.69 kg/potlift, representing a decrease of 66% from 2003 (2.04 kg/potlift). Similarly, the estimates of 0.54 kg/potlift and 0.51 kg/potlift represented decreases of 73% and 64% since 2003 in MFAs 56 and 58, respectively.

Since 2009, with the exception of MFA 51, CPUE has increased in all major MFAs and in 2014 the estimates were 0.88, 1.00, 0.97 and 1.15 kg/potlift in MFAs 51, 55, 56 and 58, respectively.

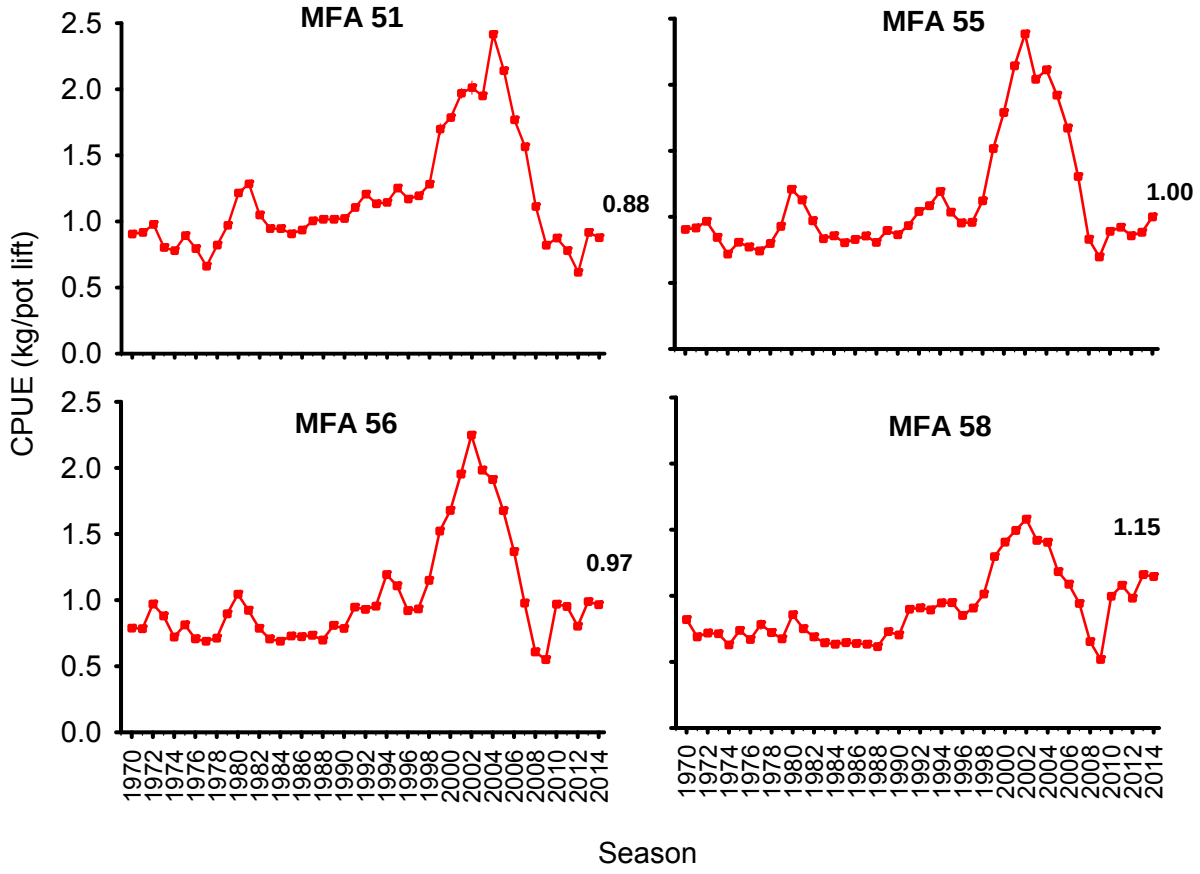

Figure 2-7 Inter-annual trends in CPUE in the main MFAs of the SZRLF from 1970 to 2014 (note: alternate seasonal ticks on x-axis).

2.2.4 Within-season regional trends

2.2.4.1 Catch and Effort

In 2014, within the main MFAs of 55, 56 and 58, most of the catch was taken during the first four months of the season (October-January) before decreasing thereafter (Figure 2-8).

November was the highest catch month in MFAs 51, 55 and 58 (5, 89 and 114 t, respectively), while January (79 t) was highest in MFA 56. May was the lowest catch month for all regions with <1 t landed in each MFA. Overall, within-season trends in effort reflected trends in catch in all regions.

2.2.4.2 CPUE

Regional within-season trends in CPUE (Figure 2-9) broadly reflected those observed zonally (Figure 2-4). In general, CPUE tends to be highest at the start of the season from October to January before decreasing thereafter. In 2014, CPUE was highest in February in MFA 51, in January in MFAs 55 (1.17 kg/potlift), MFA 56 (1.07 kg/potlift), and in December in MFA 58 (1.20 kg/potlift). CPUE was lowest in May across all MFAs with the exception of MFA 58 where April had the lowest observed CPUE.

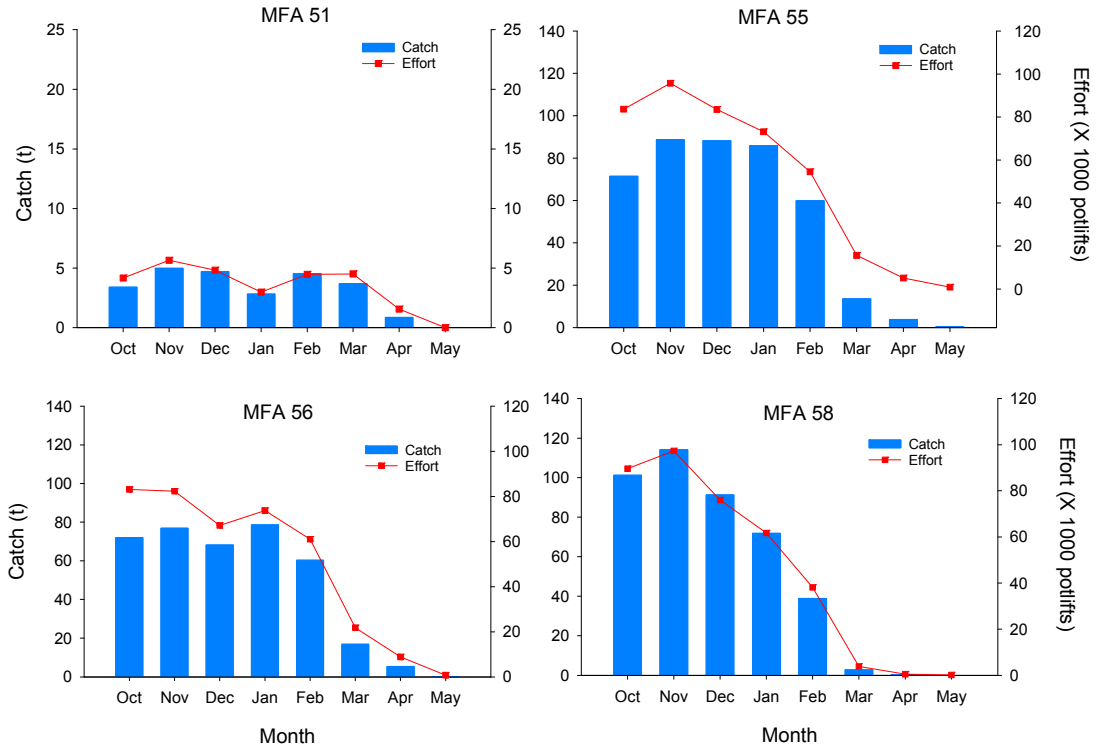

Figure 2-8 Within season trends in catch and effort in the main MFAs of the SZRLF for the 2014 season.

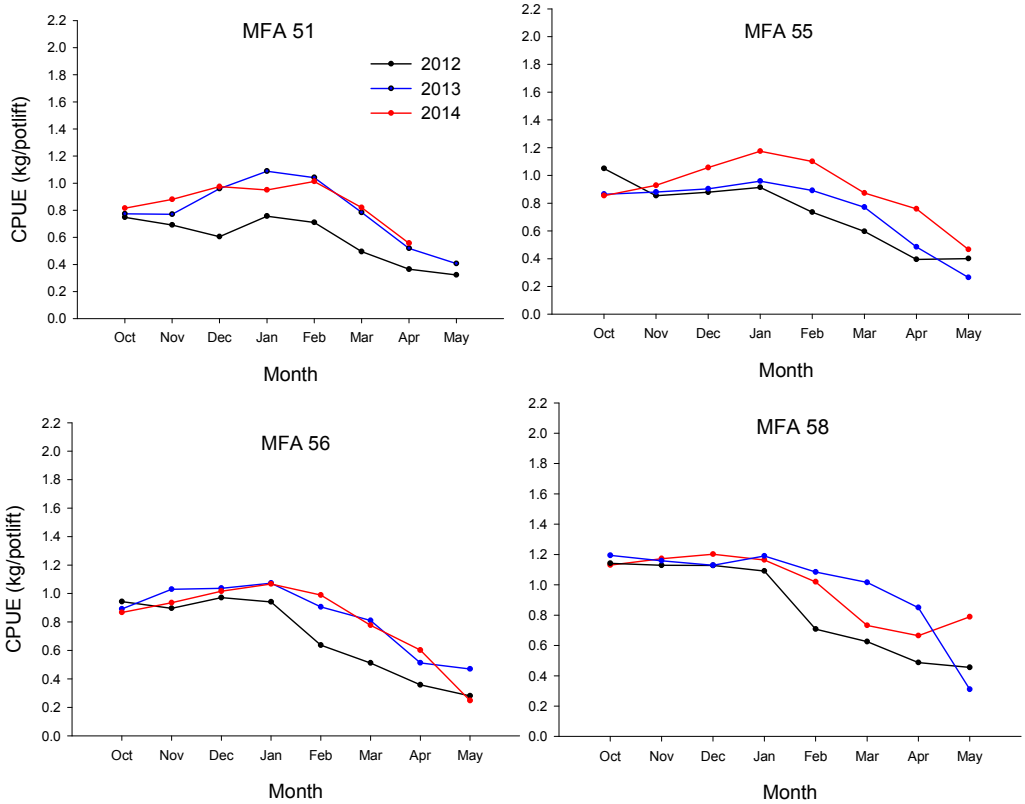

Figure 2-9 Within season trends in CPUE in the main MFAs of the SZRLF from 2012 to 2014.

2.2.5 Trends by depth

2.2.5.1 Zonal catch by depth

Over the last seven fishing seasons, most of the catch has been taken in the inshore grounds (Figure 2-10). For example, since 2008, over 80% of the annual catch has been taken from depths of <60 m. Less than 10% of catch is currently taken in depths >90 m. In 2014, the proportion of catch taken in 0-30 m decreased from 62% to 47%. Catch taken in the 31-60, 61-90 and >90 m depth ranges was 42%, 7% and 4%, respectively.

2.2.5.2 Regional catch by depth

Regional trends in catch by depth broadly reflect those at a zonal level (Figure 2-11). Over the last seven seasons, over 80% of the catch has generally come from <60 m depth in all regions. The reduced proportion of catch taken from 0-30 m depth in 2014 was notable in all MFAs. As with zonal trends, <10% of total catch has been taken offshore in depths >90 m over recent seasons in all regions.

2.2.5.3 Zonal CPUE by depth

In order to assess spatial trends in catch rate by depth, logbook-estimated CPUE from four depth categories of 0-30, 31-60, 61-90 and >90 m were analysed over the period 1970 to 2014 (Figure 2-12). Temporal trends show that inshore CPUE in depths of 0-30 m and 31-60 m is consistently lower than offshore areas of 61-90 m and >90 m. Catch rate increased in all depth ranges from 1997, peaking at about 2.65 kg/potlift in depths >60 m in 2002. This compares to a CPUE of about 1.95 kg/potlift in depths <60 m in the same year. However, from 2003 to 2009, CPUE in all depth ranges decreased. For example, offshore CPUE in depths >90 m dropped from 3.11 kg/potlift in 2004 to 0.92 kg/potlift in 2009, a decrease of 70%. Similarly, inshore CPUE in depths of <30 m decreased from 1.89 kg/potlift in 2002 to 0.61 kg/potlift in 2009, a decrease of 68%. With the exception of 2012, CPUE has generally increased in all depths over the next five seasons with estimates in 2014 of 1.00, 1.00, 1.28 and 1.62 kg/potlift in 0-30, 31-60, 61-90 and >90 m, respectively.

2.2.5.4 *Regional CPUE by depth*

General trends in CPUE by depth are broadly similar across all MFAs (Figure 2-13). Overall, CPUE tends to be lower in shallower areas (0-30 m and 31-60 m) compared to deep water sites (60–90 m and >90 m). It should be highlighted that given the low percentage of overall catch taken from depths >60 m (Figure 2-10) data used to calculate CPUE in the 61-90 m and >90 m depth ranges are limited and should be treated with caution.

In MFA 51, CPUE increased in all depths from 1997 to 2004 before decreasing over the next five seasons. Since 2009, CPUE in the 0-30 m and 31-60 m depth ranges has remained between 0.52 to 0.92 kg/potlift. Catch rates in 61-90 m increased from 0.91 kg/potlift in 2009 to 1.91 kg/potlift in 2011 before decreasing to 0.66 kg/potlift in 2012. Since then CPUE has increased across all depths and in 2014 was approximately 0.90 kg/potlift within the 0-30 m and 31-60 m depth ranges. It is important to highlight that only 2% of catch was taken in MFA 51 in 2014 (Figure 2-5) with no data recorded for 61-90 m during the season. Estimates of CPUE in depths >90 m are not presented due to limited data.

In MFA 55, CPUE increased from 1997 to 2002 in all depth ranges with catch rates higher in depths of 61-90 m and >90 m compared to shallower areas (Figure 2-13). From 2003 to 2009, CPUE decreased in all depth ranges before increasing again over the next five seasons. In 2014, the estimates were 0.95, 0.96, 1.22 and 1.38 kg/potlift in 0-30, 31-60, 61-90 and >90 m, respectively.

Trends in CPUE by depth within MFAs 56 and 58 broadly reflect those in MFA 55 with decreases in catch rate in both MFAs from 2002 to 2009 before subsequent increases over

the next four seasons. In general, catch rates in MFAs 56 and 58 are now consistently higher compared to other regions in the zone. In 2014, with the exception of the 0-30 m and 31-60 m depth range in MFA 56 (0.93 kg/potlift), CPUE was consistently >1 kg/potlift across all depth ranges in both these MFAs.

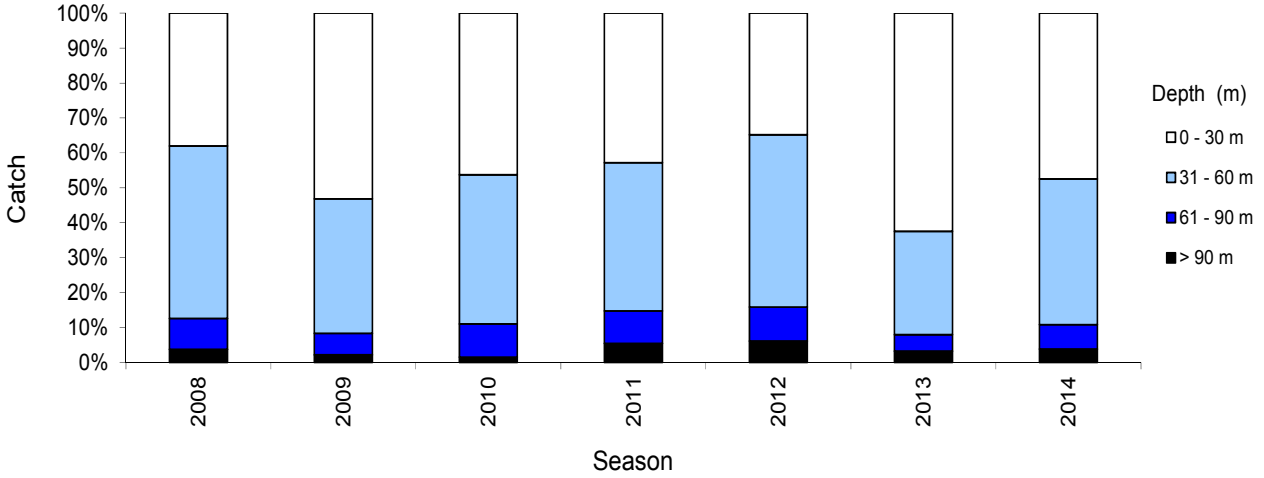

Figure 2-10 Percentage of catch taken from four depth ranges in the SZRLF from 2008 to 2014.

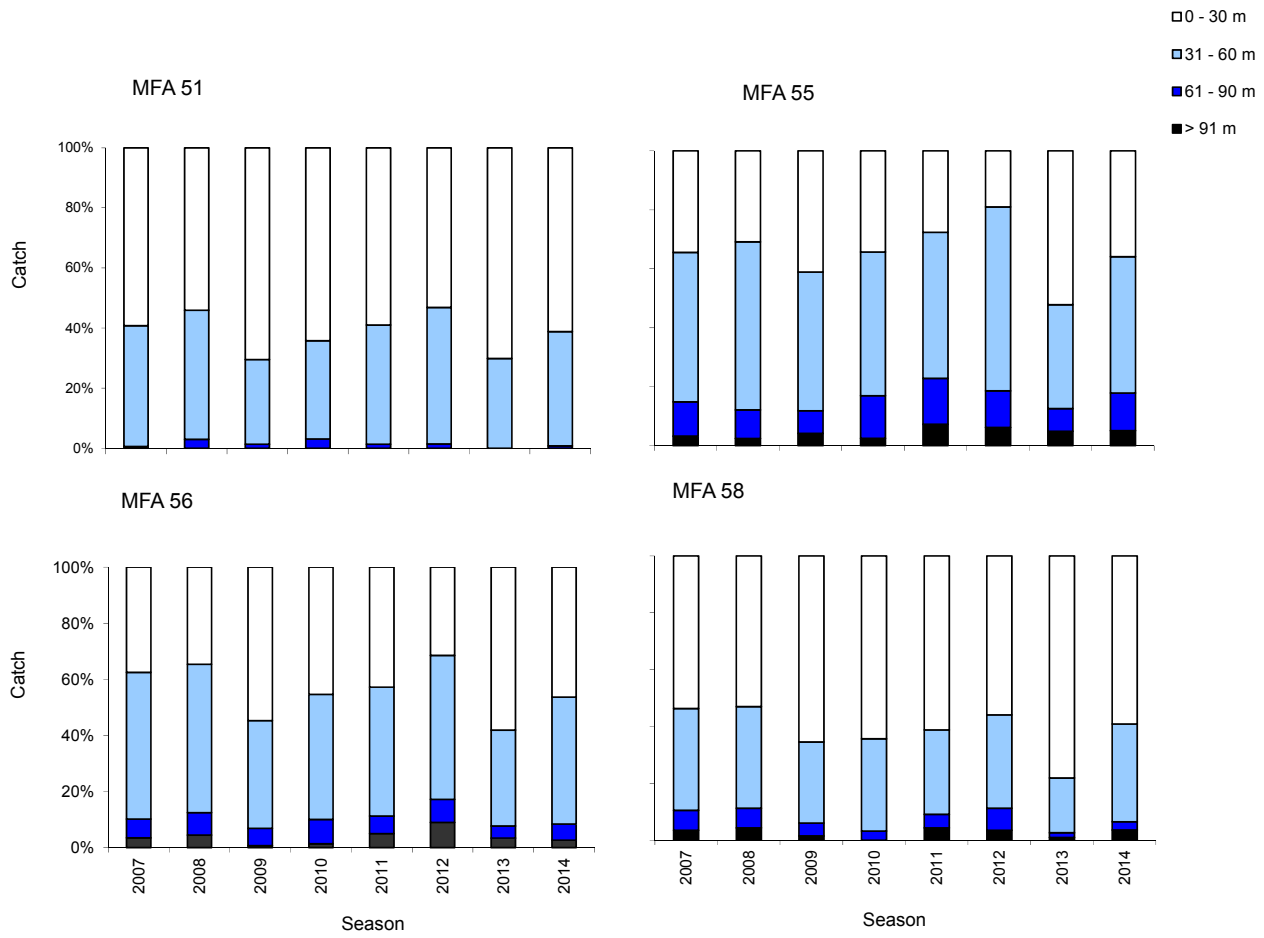

Figure 2-11 Percentage of catch taken from four depth ranges in the four main MFAs of the SZRLF from 2007 to 2014.

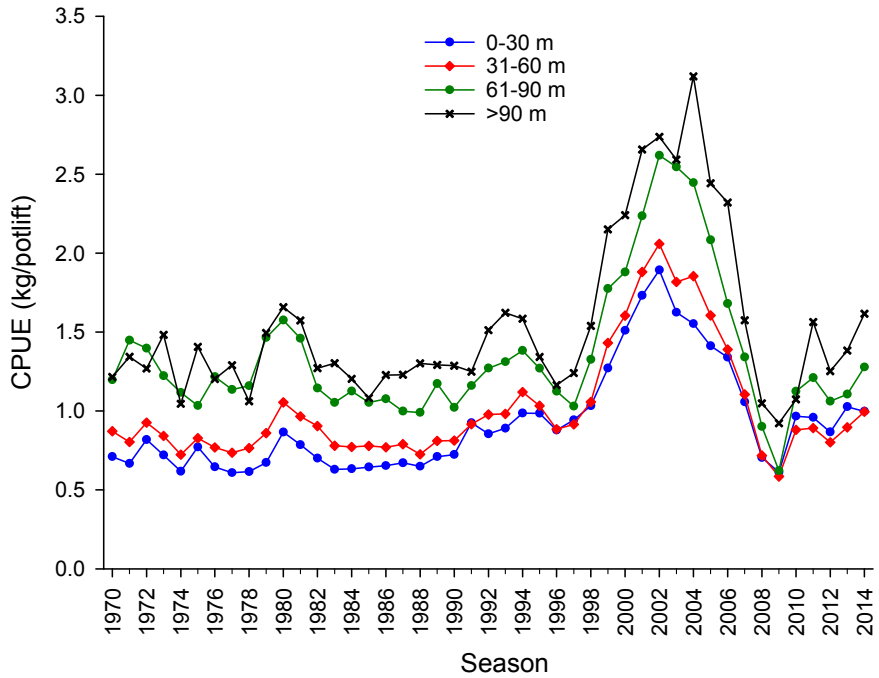

Figure 2-12 CPUE in four depth ranges in the SZRLF from 1970 to 2014.

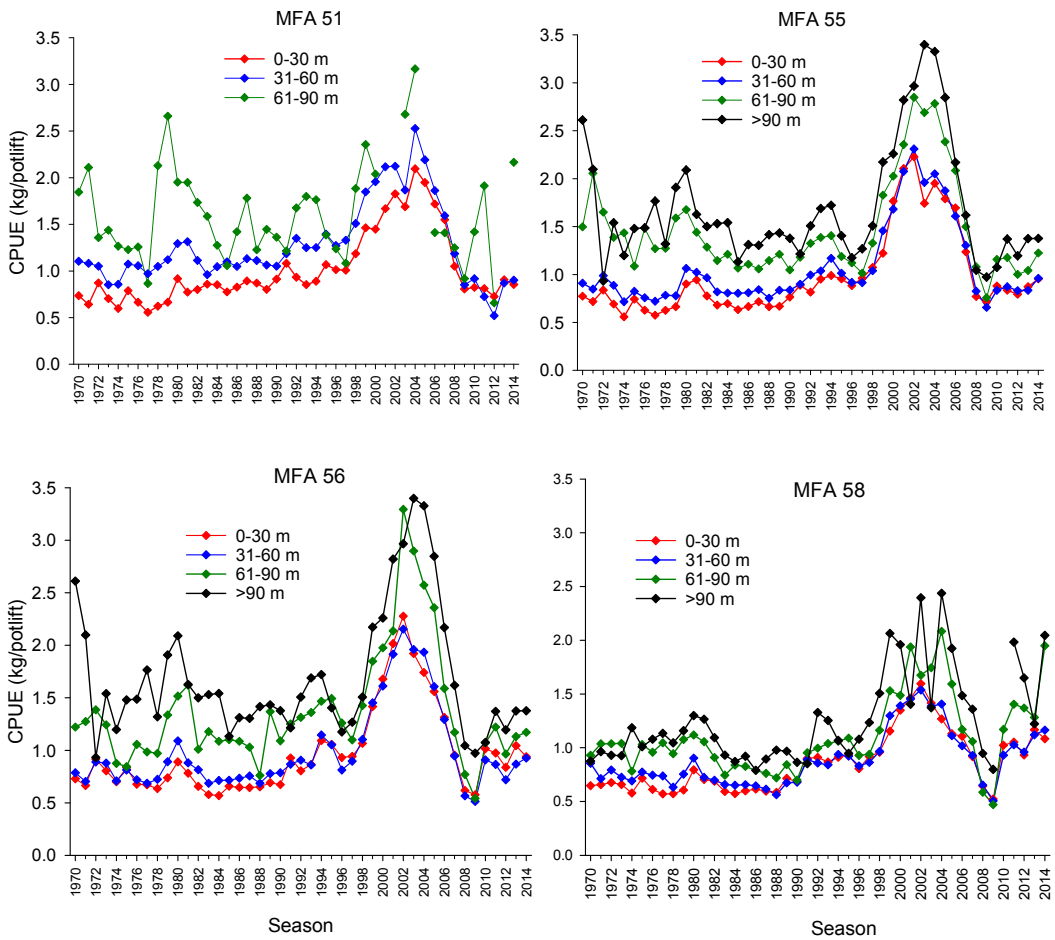

Figure 2-13 CPUE in four depth ranges from 1970 to 2014 across the four main MFAs of the SZRLF.

2.3 Pre-Recruit Index (PRI)

2.3.1 Zonal trends

The harvest strategy for the SZRLF utilises logbook estimated PRI (November-March inclusive) as an indication of future recruitment to the fishery. In the SZRLF, the period between pre-recruits and recruitment into the fishable biomass is estimated to be about one year. With the exception of increases in 2009 and 2010, long-term trends show a general decline in undersized lobster abundance over the last 15 seasons (Figure 2-14). The PRI has decreased from 2.1 undersized/potlift in 1999 to 0.92 undersized/potlift in 2014, a reduction of 56%. The 2014 estimate is the third lowest on record since sampling began.

2.3.2 Regional trends

Levels of PRI in MFAs 51 and 55 are consistently less than that in MFAs 56 and 58 (Figure 2-15) which supports the understanding that PRI increases with latitude between the Coorong and the Victoria/South Australia border. Over the last 16 years the PRI has been relatively constant in both MFAs 51 and 55, generally remaining below 0.5 undersized/potlift. The highest PRI levels are usually observed in MFAs 56 and 58 with trends in these areas highly reflective of zonal estimates. The zonal decline in PRI in 2014 was largely driven by decreases in MFAs 56 and 58 with estimates of 0.99 and 1.95 undersized/potlift, respectively. Estimates for both MFAs are currently at, or close to, the historical lows for these areas.

2.3.3 Within-season trends

Within-season PRI generally tends to be highest at the start of the season from October to January before decreasing thereafter (Figure 2-16). The decline in PRI in 2014 was largely driven by reduced estimates from October through to January. In 2014, the PRI was highest in October at 1.06 undersized/potlift and lowest in April at 0.33 undersized/potlift, noting that PRI estimates in April are not included in the zonal PRI used as the secondary performance indicator in the harvest strategy.

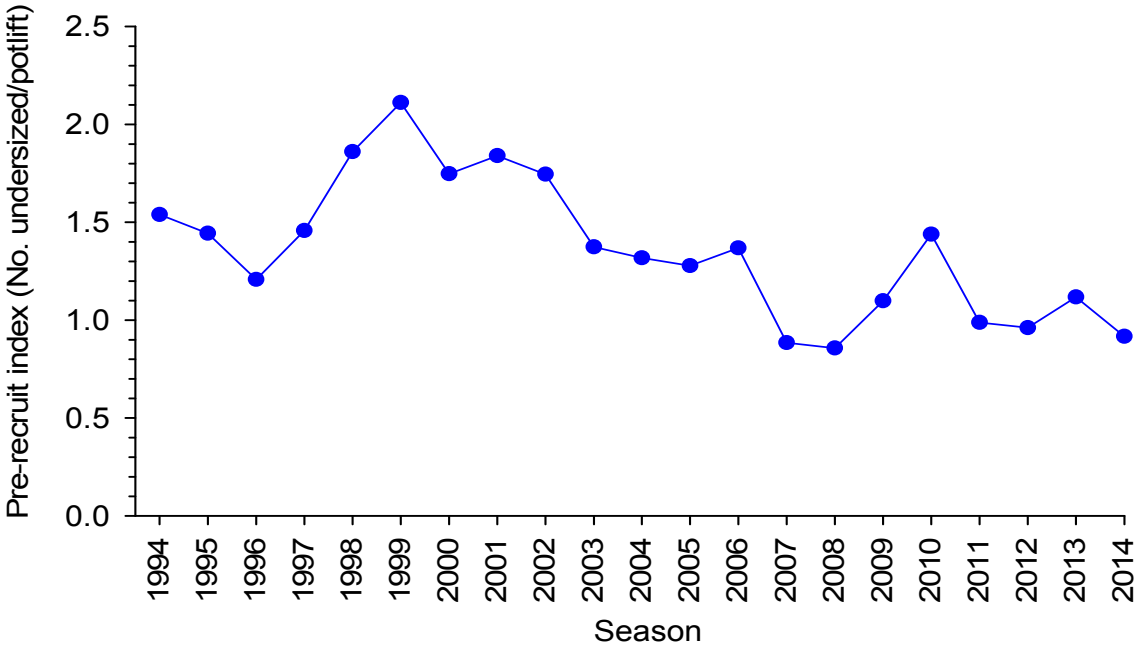

Figure 2-14 Inter-annual trends in PRI in the SZRLF from 1994 to 2014 as estimated from logbook data (November to March inclusive).

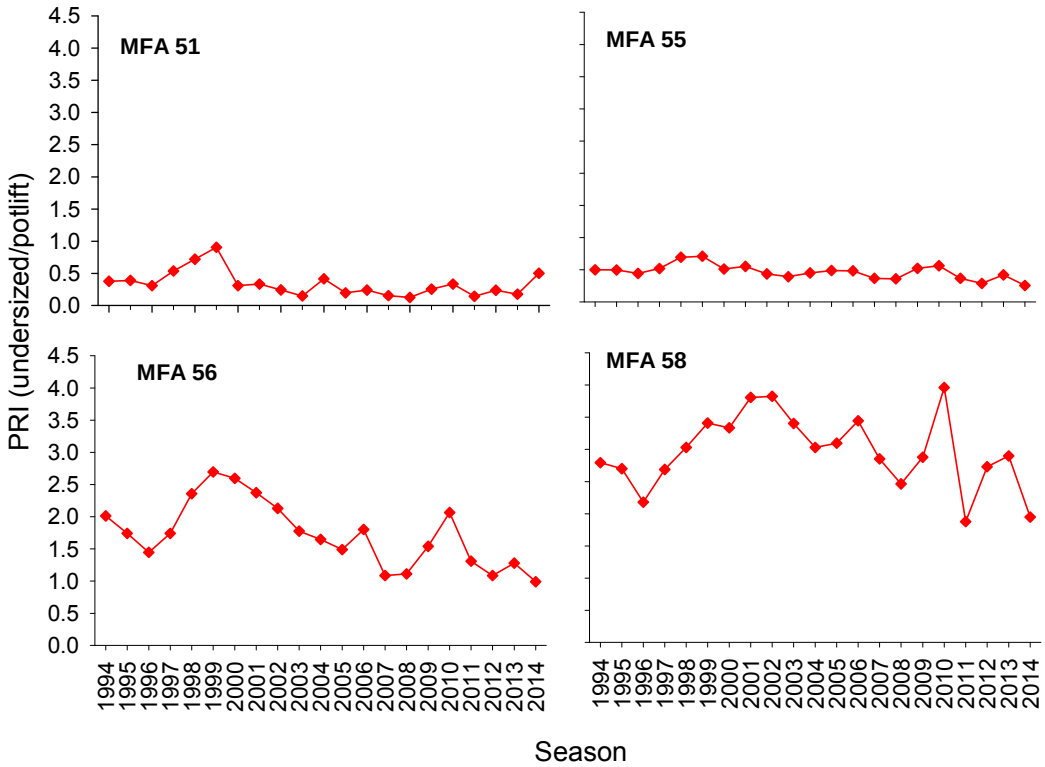

Figure 2-15 Inter-annual trends in PRI from 1994 to 2014 in the main MFAs of the SZRLF as estimated from logbook data (November to March inclusive).

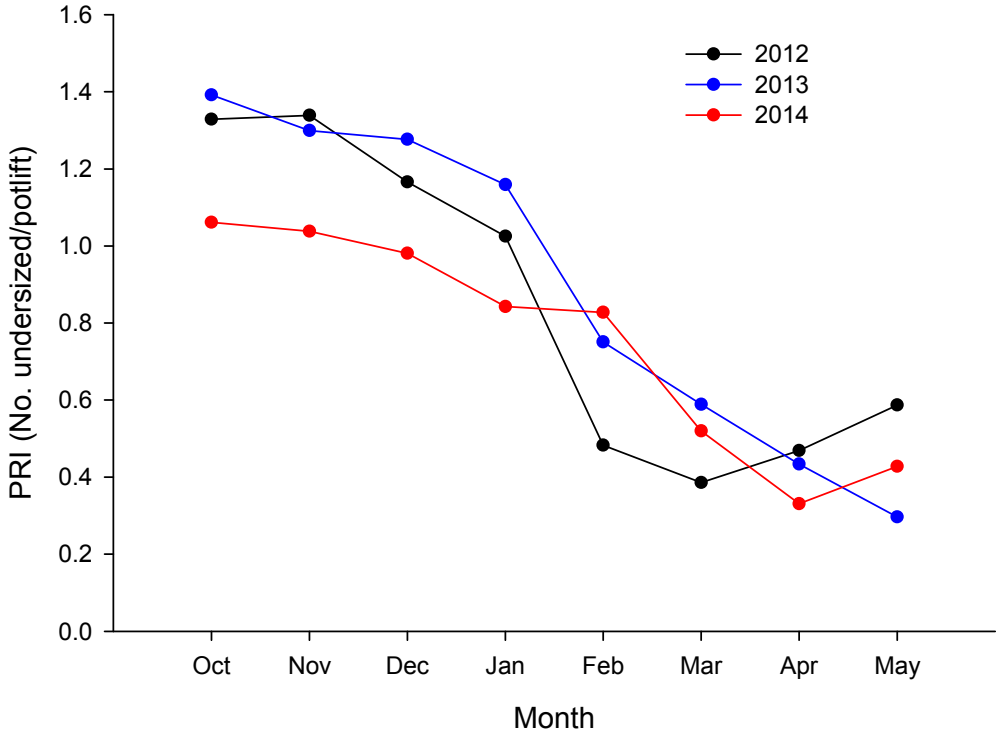

Figure 2-16 Within-season trends in PRI in the SZRLF from 2012 to 2014 as estimated from logbook data.

2.4 Mean weight

2.4.1 Zonal trends

Variations in mean weight of lobsters 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 2-17). From 1982 to 1991, mean weight decreased from 0.88 to 0.79 kg before rising and remaining stable at 0.84 kg in the mid 1990s. Mean weight decreased to 0.76 kg in 1999 before increasing over the next four seasons to reach 0.85 kg in 2003. Over the next six seasons, with the exception of 2006, mean weight remained stable at ~0.84 kg. In 2009 and 2010, mean weight decreased with the 2010 estimate of 0.70 kg being the lowest on record. Over the last four seasons it has increased and in 2014 was 0.83 kg. High-grading (the selection of smaller sized individuals due to higher unit value; Figure 2-32) has the capacity to impact on mean weight estimated from logbook data. However, as seen in Figure 2-32, levels of high-grading appear to have decreased in recent seasons, presumably in response to lower catch rates within the fishery.

2.4.2 Regional trends

Southern rock lobster mean weight decreases with increasing latitude from the mouth of the Murray River (MFA 51) to the Victoria/South Australia border (MFA 58) (Figure 2-18). Up to 1998, the inter-annual trends in mean weight has been variable in MFAs 51 and 55, but have gradually declined in MFAs 56 and 58. From 1998 to 2002/2003, mean weight generally increased across all four MFAs before decreasing over the next 5-6 seasons (with the exception of MFA 51). Over the last four seasons it has increased in all major MFAs and in 2014 was 1.01, 0.94, 0.84 and 0.74 kg in MFAs 51, 55, 56 and 58, respectively.

2.4.3 Within-season trends

Since the 1970s there has been a consistent trend of increasing mean weight as the season progresses (see Linnane et al. 2006). On average, the smallest lobsters are caught in October/November and the largest later in the fishing season. In 2014, mean weight was consistently higher across all months compared to the 2012 and 2013 seasons and was lowest in November at 0.78 kg and highest in May at 1.05 kg (Figure 2-19).

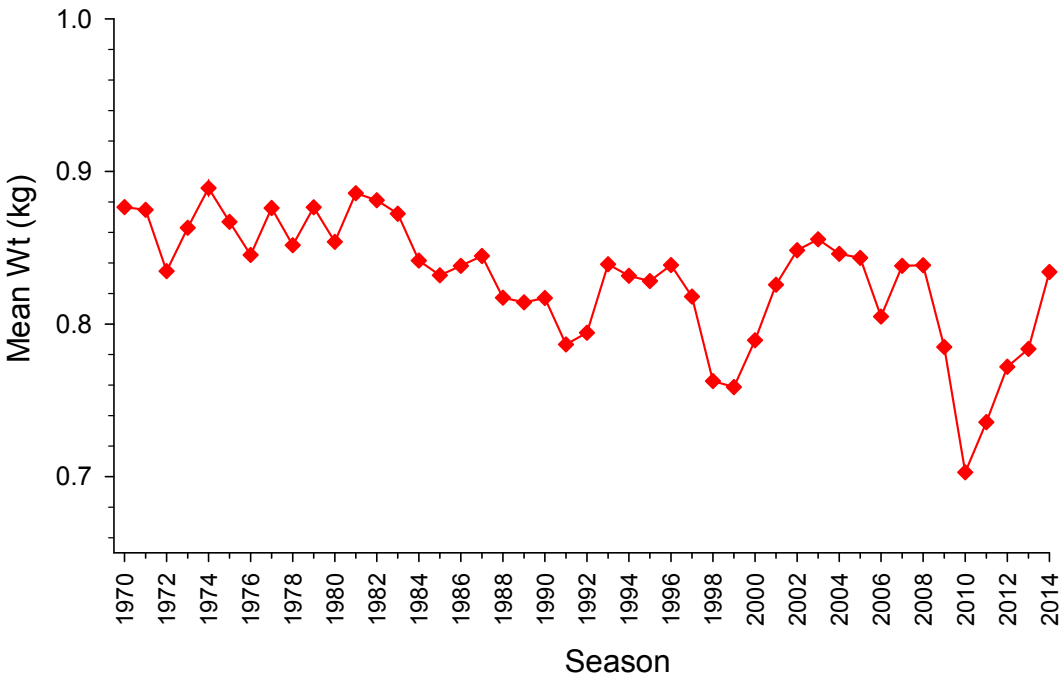

Figure 2-17 Inter-annual trends in the mean weight of lobsters in the SZRLF from 1970 to 2014.

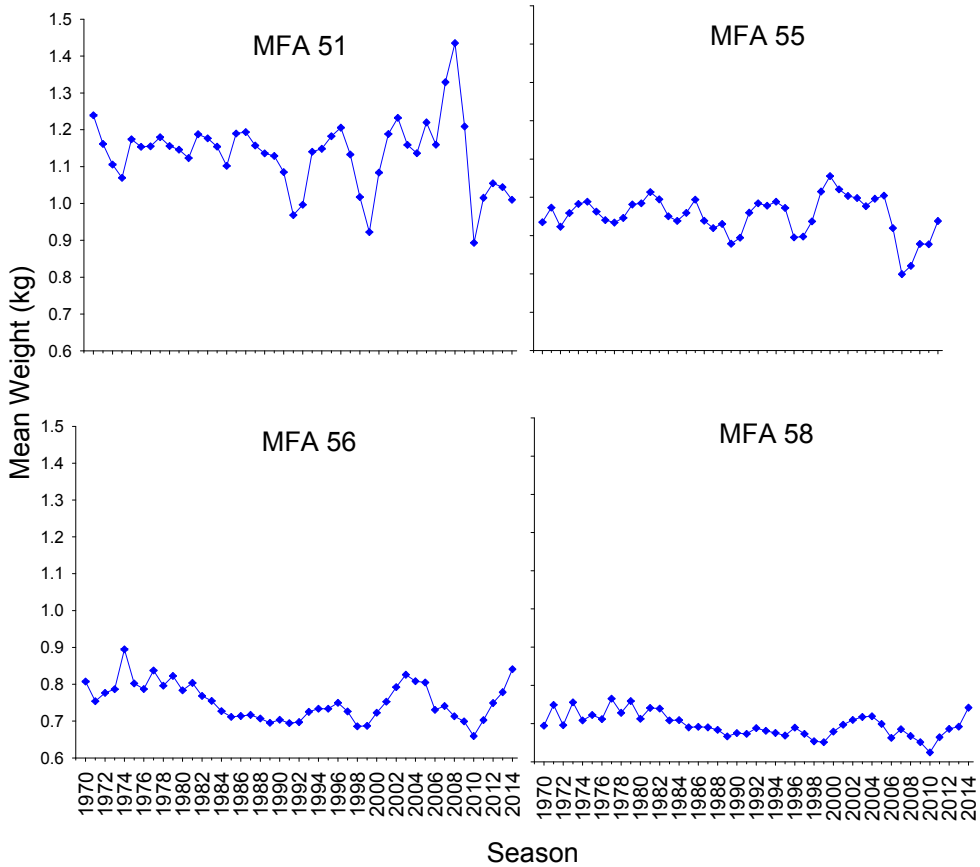

Figure 2-18 Inter-annual trends in the mean weights of lobster for the main MFAs of the SZRLF from 1970 to 2014 (note: alternate seasons on X-axis).

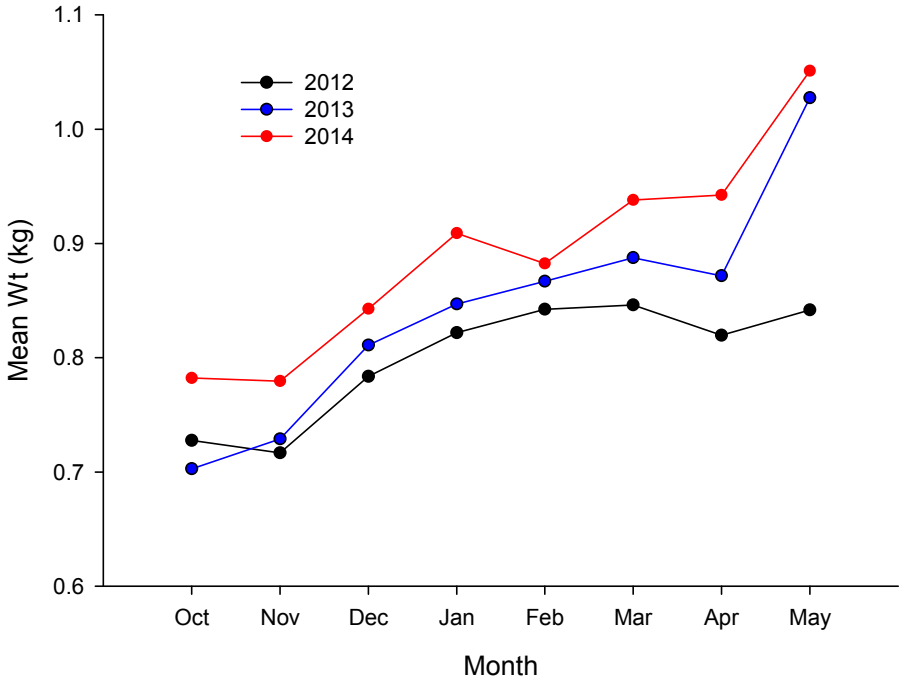

Figure 2-19 Within-season trends in mean weight in the SZRLF from 2012 to 2014.

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2.5 Length-frequency

Since 1991, when the voluntary catch sampling program began, between 5,000 and 30,000 lobsters have been measured annually (see Linnane et al. 2005). As well as providing a comparison of changes in size structure over time, length-frequency data are a critical component of the length-structured model (LenMod; see Section 5).

Male lobsters, which grow faster and reach larger sizes than females (McGarvey et al. 1999a), range between 70 and 200 mm CL. Female lobsters range between 70 and 150 mm CL. In 2014, a total of 6,992 lobsters were measured of which 3,041 were males and 3,951 females. To compare temporal changes in size structure, male and female data were combined and analysed from 2011 to 2014 (Figure 2-20). Broadly, the size structure did not change considerably over this period, however, the percentage of lobsters above the minimum legal size (MLS) has increased from 59% in 2011 to 72% in 2014 reflecting the increase in legal size catch rates over the same period (Figure 2-2).

Length-frequency data from 2014 were presented across MFAs to compare spatial differences in size distributions (Figure 2-21). Spatial differences in mean size (Figure 2-18) were confirmed by the higher frequency of lobsters >120 mm CL in the north (MFA 55 at 33%) compared to the southern region (MFA 58 at 10%). In addition, the frequency of undersized lobsters was highest in MFA 58 at 41%, confirming spatial trends in pre-recruit distributions (Figure 2-15). It is worth noting that lobster catchability from commercial traps can vary by both size and sex depending on environmental or behavioural variability (Miller 1990; Frusher and Hoenig 2001). Current data indicates that lobsters <70 and >150 mm CL are rarely caught, which is consistent with the size-selectivity of trap caught spiny lobsters in other fisheries (e.g. Goňi 2003). As a result, data required to estimate population length-frequency from commercial fishing traps alone, should be treated with some caution.

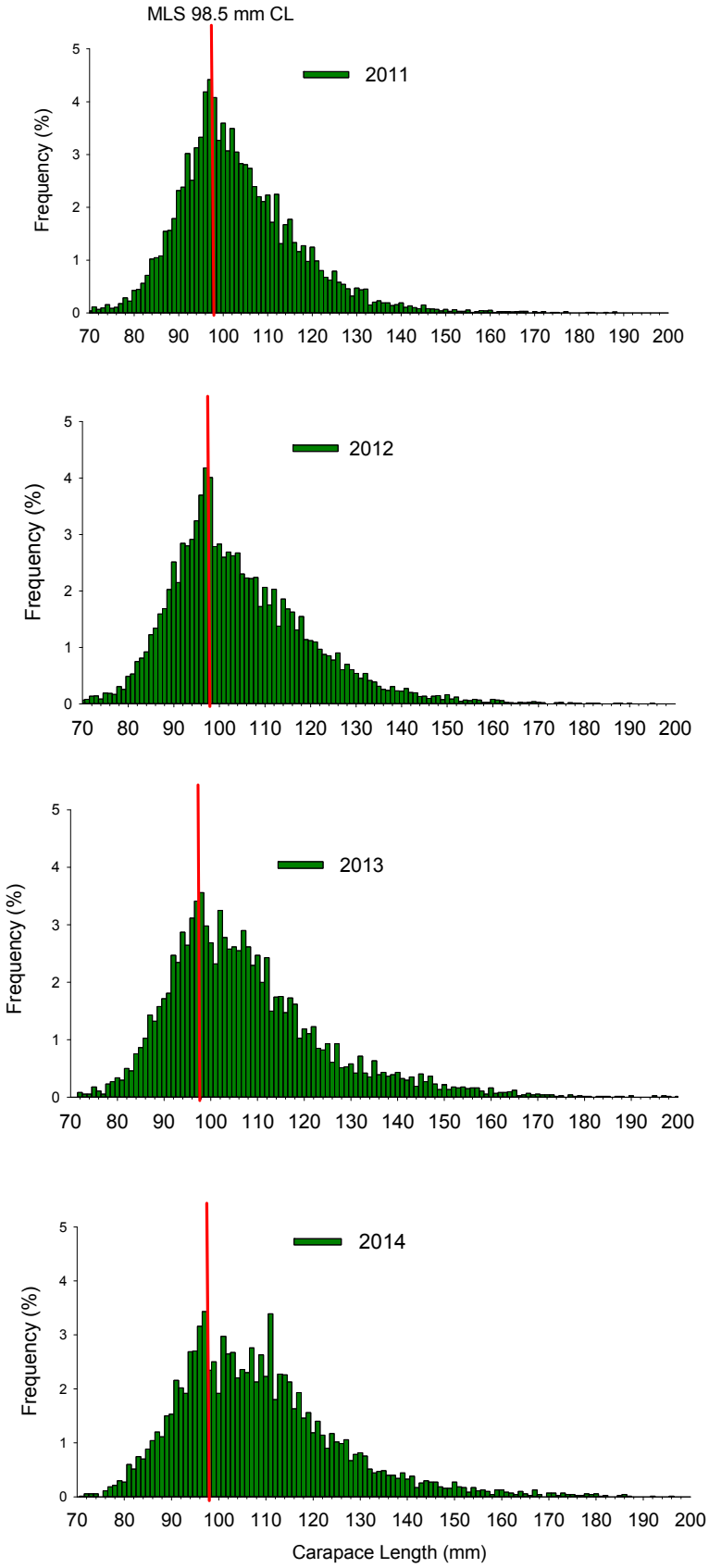

Figure 2-20 Length frequency distributions of male and female lobsters combined in the SZRLF from 2011 to 2014 (MLS = minimum legal size).

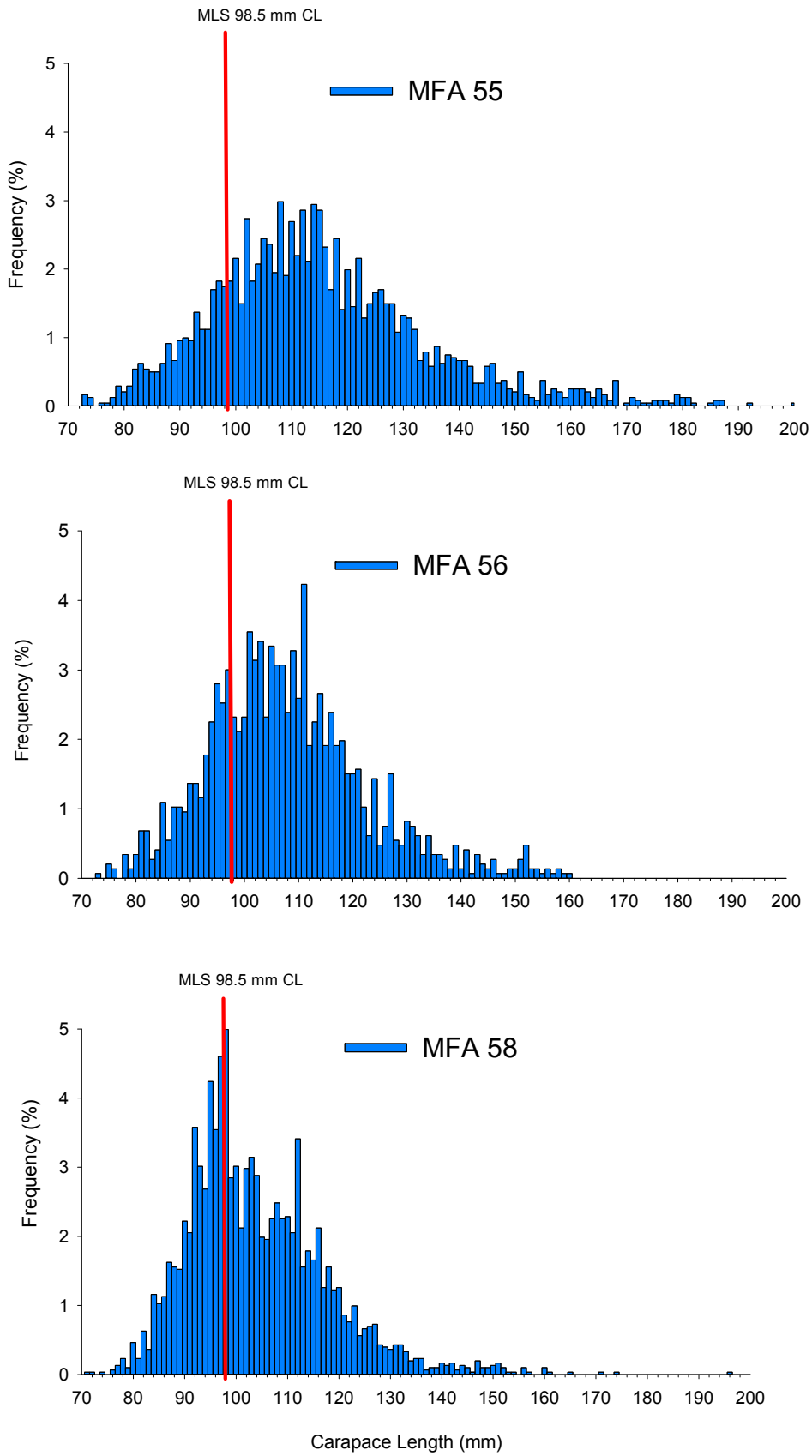

Figure 2-21 A comparison of length frequency distributions (male and female lobsters combined) by MFA in the 2014 season (MFA 51 not included due to limited data).

2.6 Spawning lobsters

2.6.1 Zonal trends

Zonal trends in the CPUE of spawning i.e. ovigerous lobsters (Figure 2-22) broadly reflect those of overall catch rate (Figure 2-2). The number of spawning lobsters/potlift increased from 1991 (0.08 spawners/potlift) to 2002 (0.51 spawners/potlift). Over the next eight seasons, however, the CPUE decreased to 0.05 spawners/potlift in 2010. With the exception of 2013, the index increased over the next four seasons and in 2014 was 0.21 spawners/potlift. It is important to note that as October was closed for the 2010 season, indices for that season are likely to be underestimated since October is commonly the highest catch month for spawning individuals in the fishery.

2.6.2 Regional trends

In general, the catch rate of spawning lobsters increases southward along the coast from the Coorong (MFA 51) to the Victoria/South Australia border (MFA 58) (Figure 2-23). Inter-annual trends indicate that there are considerably higher numbers of spawners caught in MFAs 56 and 58 compared to MFAs 51 and 55. The catch rate of spawning lobsters in MFAs 51 and 55 has varied from 0.07 to 0.32 spawning lobsters/potlift between 1998 and 2004 compared to MFAs 56 and 58 which have rates between 0.45 and 0.76 spawners/potlift over the same period. As with zonal estimates, catch rates from 2003 to 2010 generally decreased in all MFAs before increasing over the next four seasons with the exception of 2013. In 2014, the CPUE of spawning lobsters was 0.04, 0.07, 0.20 and 0.44 spawners/potlift in MFAs 51, 55, 56 and 58, respectively.

2.6.3 Within-season trends

There is a distinct within-season pattern in the number of spawning lobsters/potlift within the SZRLF, which is strongly related to the annual reproductive cycle of the species (Figure 2-24). Hatching commences in early spring and is completed by December/January. As a result, there is a complete absence of spawning lobsters in the commercial catch after December.

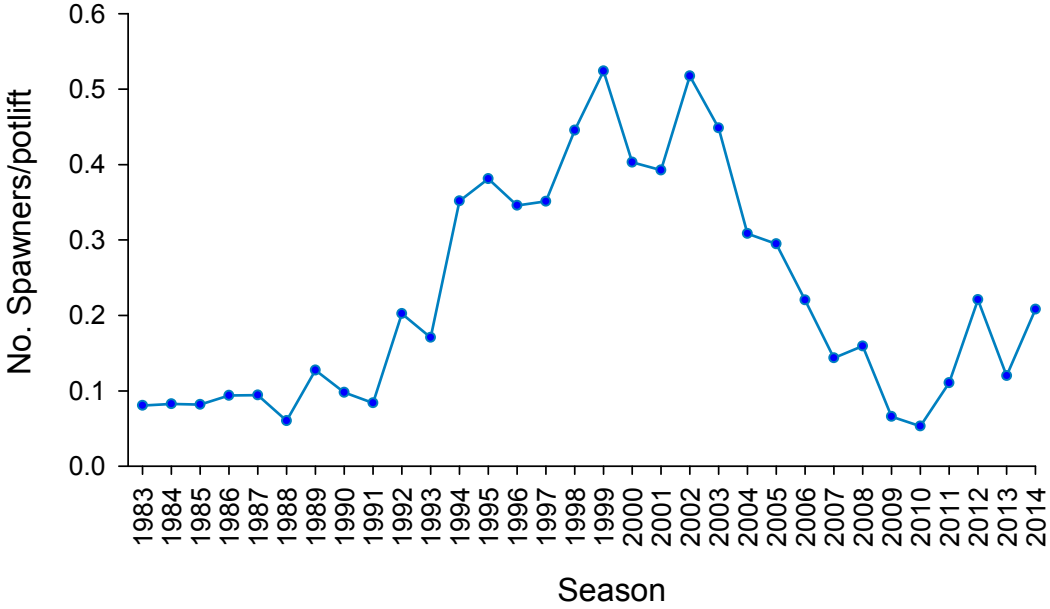

Figure 2-22 Inter-annual trends in the catch rate of spawning lobsters in the SZRLF between 1983 and 2014. October closed during 2010 season.

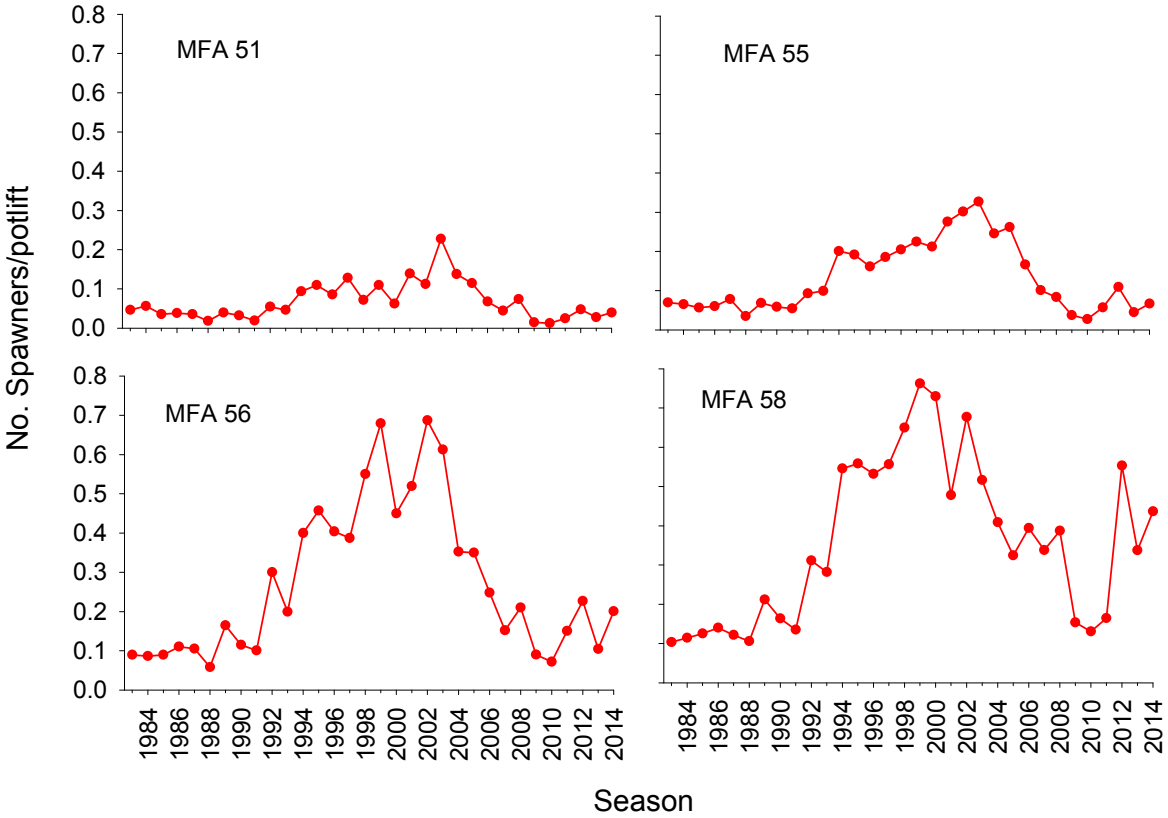

Figure 2-23 Inter-annual trends in the number of spawning lobsters/pot lift for the main MFAs in the SZRLF between 1983 and 2014. Note: October closed during 2010 season.

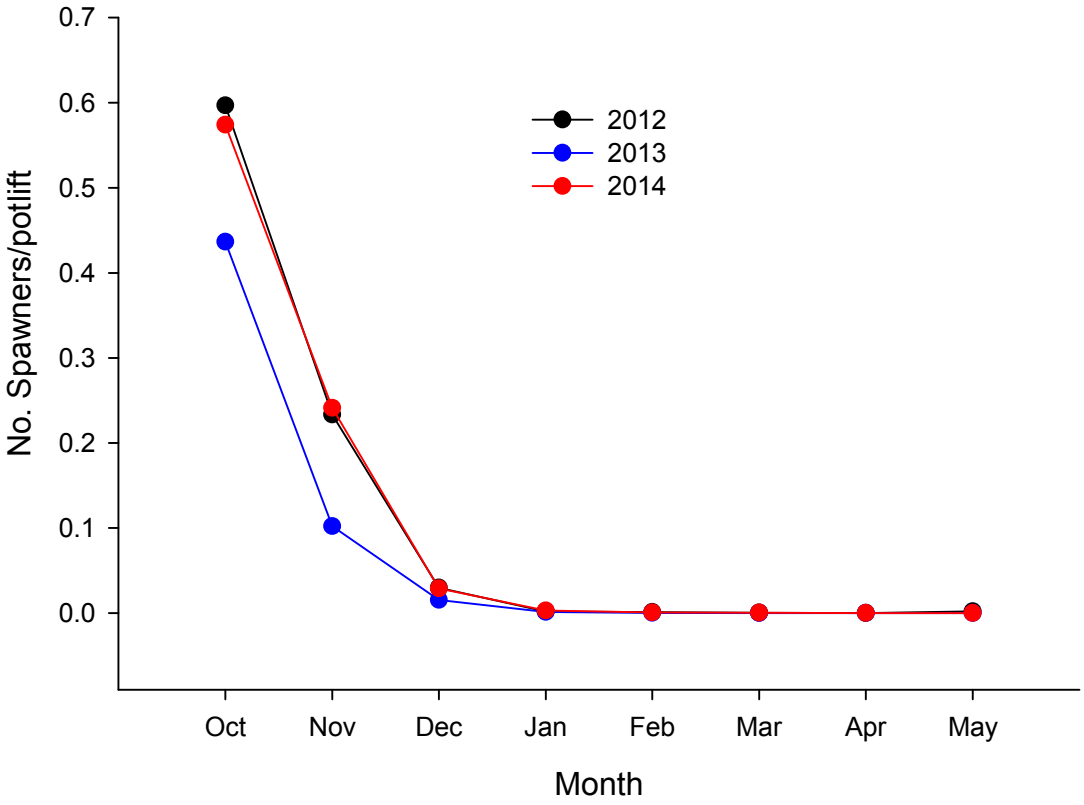

Figure 2-24 Within-season trends in the catch rate of spawning females in the SZRLF from 2012 to 2014.

2.7 Lobster mortalities

2.7.1 Zonal trends

The number of dead lobsters/potlift increased from 1996 (0.13 dead/potlift) to 2004 (0.27 dead/potlift) although the overall numbers were relatively low (<0.3 dead/potlift) (Figure 2-25). With the exception of 2006, the index decreased over the next four seasons and in 2009 was 0.09 dead/potlift, the lowest estimate on record. Since then estimates have remained below 0.18 dead/potlift and in 2014 it was 0.14 dead/potlift.

2.7.2 Regional trends

Regional trends in the catch rate of dead lobsters broadly reflect those observed at the zonal level (Figure 2-26). Overall, catch rates are lower in MFA 51, compared to other regions. As with zonal trends, the CPUE of dead lobsters generally increased from 1996 to 2004 in all regions with the highest number of dead lobsters observed in 2004 in MFA 55 (0.29 dead lobsters/potlift). Over the next five seasons, lobster mortalities generally decreased in all regions with the 2009 estimates the lowest on record (exception of MFA 58). Similar to zonal estimates, regional mortality has generally remained low since 2010 and in 2014 was 0.12, 0.12, 0.14 and 0.15 dead/potlift in MFA 51, 55, 56 and 58, respectively.

2.7.3 Within-season trends

Catch rates of dead lobsters tends to be highest at the start of the season before decreasing thereafter (Figure 2-27). In 2014, the CPUE of dead lobsters was highest in November (0.15 dead lobsters/potlift) and lowest in May (0.06 dead lobsters/potlift). With the exception of May, the catch rate of dead lobsters in 2014 was consistently higher across all months compared to 2013 estimates.

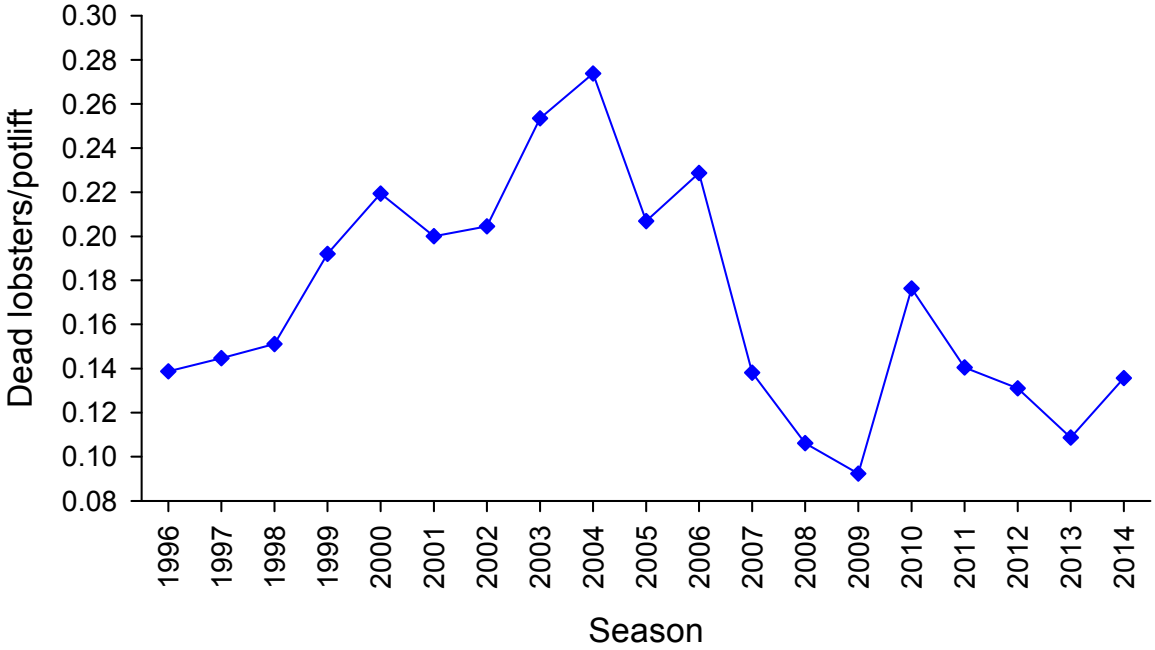

Figure 2-25 Inter-annual trends in the catch rate of dead lobsters in the SZRLF from 1996 to 2014.

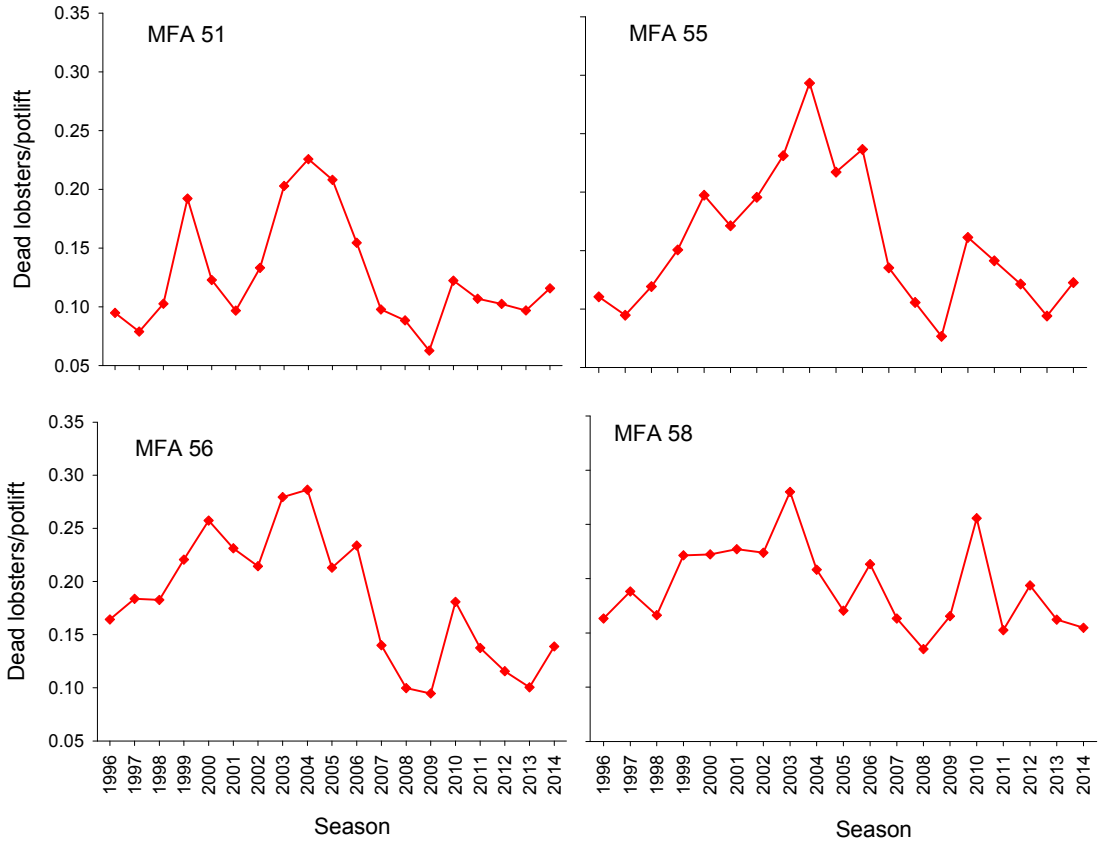

Figure 2-26 Inter-annual trends in the CPUE of dead lobsters for the main MFAs in the SZRLF from 1996 to 2014.

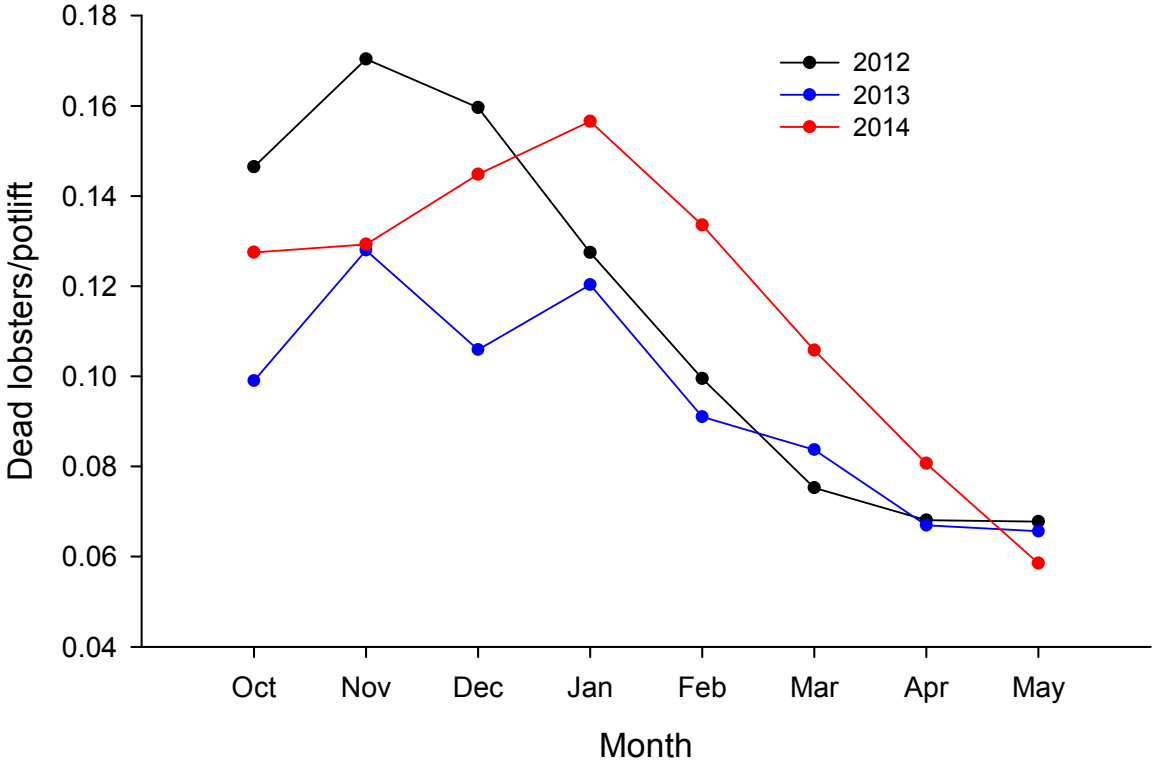

Figure 2-27 Within-season trends in the CPUE of dead lobsters in the SZRLF from 2012 to 2014.

2.8 Octopus catch rates

2.8.1 Zonal trends

Annual catch rates of octopus in the SZRLF have been variable (Figure 2-28). The highest catch rate was observed in 2000 at 0.05 octopus/potlift. Since then there has been a gradual decline in octopus catch rates with the exception of notable peaks in 2003, 2006 and 2010. In 2014, the estimate was 0.02 octopus/potlift, one of the lowest on record. Trends in octopus catch rate reflect those of dead lobsters over the same time series (Figure 2-25) (R^2 = 0.71), since the majority of within pot-lobster mortality is caused by octopus predation (Brock and Ward 2004).

2.8.2 Regional trends

Regional trends in the CPUE of octopus broadly reflect those observed at the zonal level with gradual declines in catch rates since 2000 in all areas (Figure 2-29). In 2014, the estimates were 0.03 octopus/polift in both MFAs 51 and 55 and 0.02 octopus/potlift and 0.01 octopus/potlift in MFAs 56 and 58, respectively.

2.8.3 Within-season trends

Octopus catch rates are generally higher from October to February before decreasing thereafter (Figure 2-30). The trends in catch rate in 2014 showed a general increase from October (0.017 octopus/potlift) to February (0.033 octopus/potlift) before declining to a season low in May (0.013 octopus/potlift). With the exception of November, catch rates were consistently higher across all months compared to 2012 and 2013 estimates.

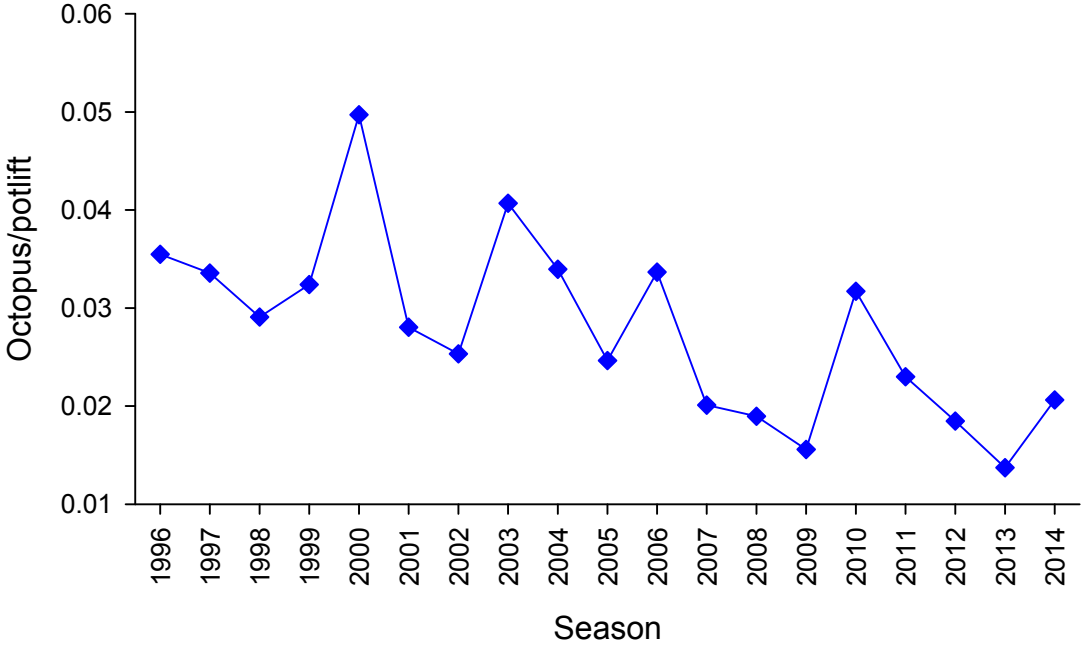

Figure 2-28 Inter-annual trends in catch rates of octopus in the SZRLF from 1996 to 2014.

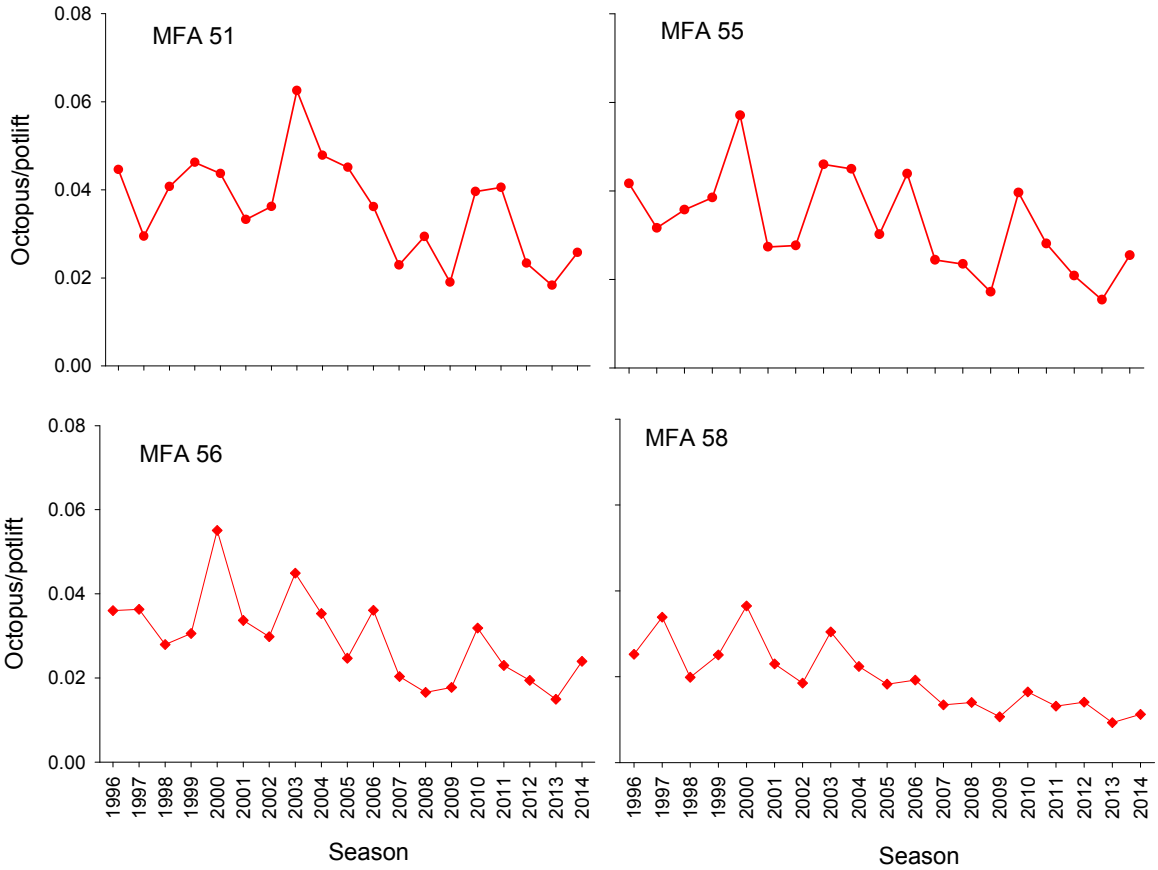

Figure 2-29 Inter-annual trends in the CPUE of octopus for the main MFAs in the SZRLF from 1996 to 2014.

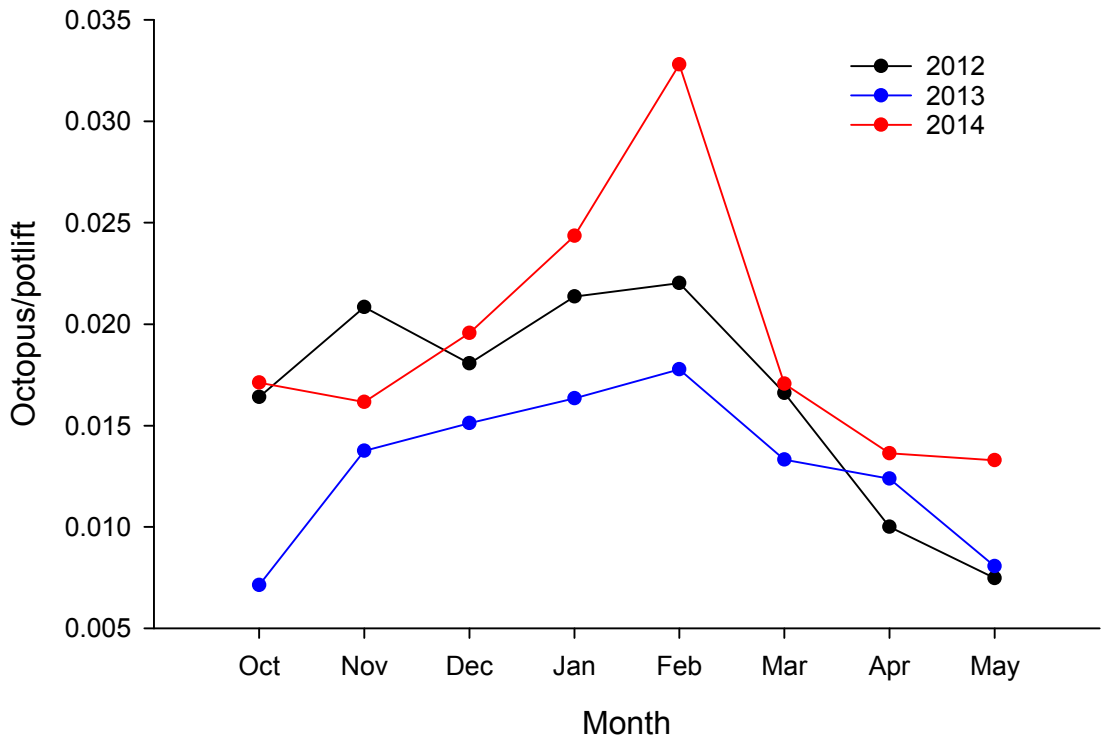

Figure 2-30 Within season trends in the CPUE of octopus in the SZRLF from 2012 to 2014.

2.9 Average days fished

2.9.1 Zonal trends

The average number of days fished each season per licence holder increased from 141 days in 1983 to a peak of 176 days in 1991 (out of a total number of 210 potential fishing days; Figure 2-31). In 1993, the first year of the TACC (1,720 t), the number of days fished/licence was 143. This increased to 153 days in 1997 but decreased over the next 5 seasons to a record low of 79 days in 2002. The TACC was increased from 1,770 to 1,900 t in 2003 with an average of 95 days fished per licence for that season. From 2004 to 2009 the average numbers of days fished increased by 86% from 94 to 175, the highest on record, despite reductions to the TACC from 1,900 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 2014, the TACC was further reduced to 1,245.7 t under the marine park voluntary commercial fisheries catch/effort reduction program, with the average numbers of days fished estimated at 104 days. Overall, this index reflects general trends in effort within the fishery, which over the last decade, increased considerably between 2004 and 2009 before declining thereafter ().

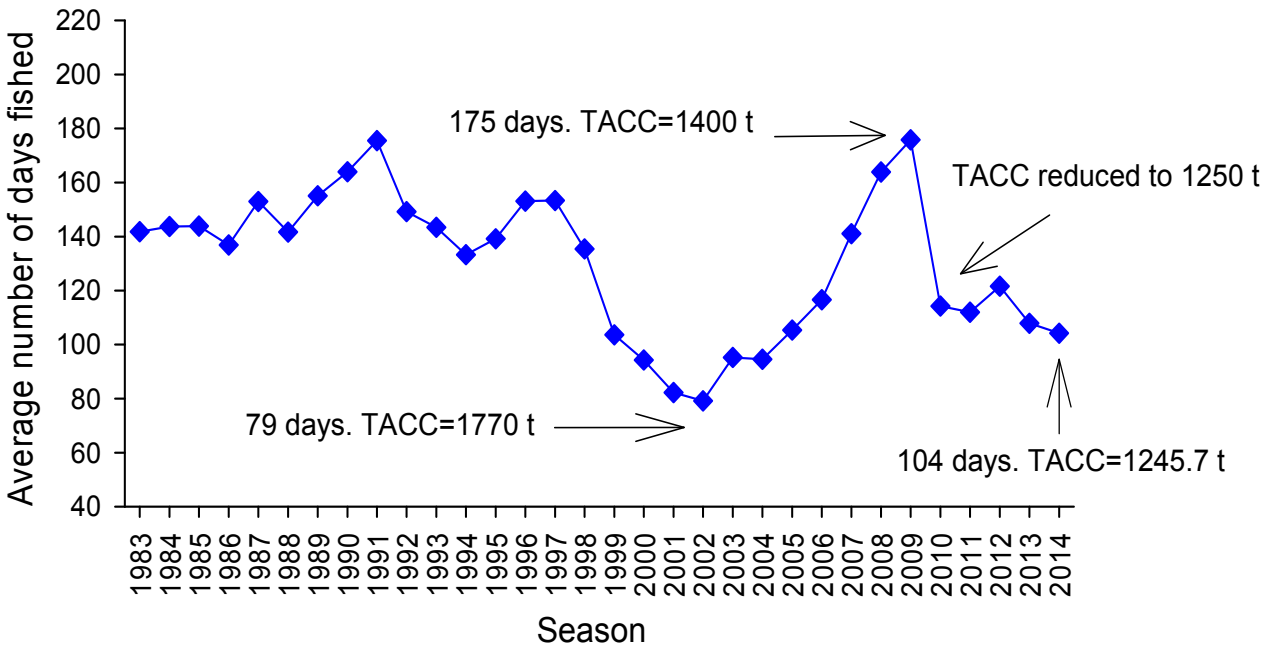

Figure 2-31 Inter-annual trends in the average number of days fished per licence in the SZRLF from 1983 to 2014. TACC = total allowable commercial catch.

2.10 High-grading

2.10.1 Zonal and within-season trends

Between 2003 and 2006, based on voluntary catch returns, the amount of lobsters high-graded (i.e. returned to the water due to low market value) exceeded 100 t annually (Figure 2-32). However, over the next four seasons, levels of high-grading decreased and in 2008 were estimated at 21 t. This decrease is likely to reflect overall declines in legal sized catch rate across the fishery (Figure 2-2). Over the next six seasons estimates remained below 25 t and in 2014, 16.9 t were recorded as discards due to high-grading.

Within-season trends in high-grading are unclear and appear to vary annually (Figure 2-33). In 2014, estimates remained between 0.02 kg/potlift and 0.03 kg/potlift throughout the entire season. 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 only.

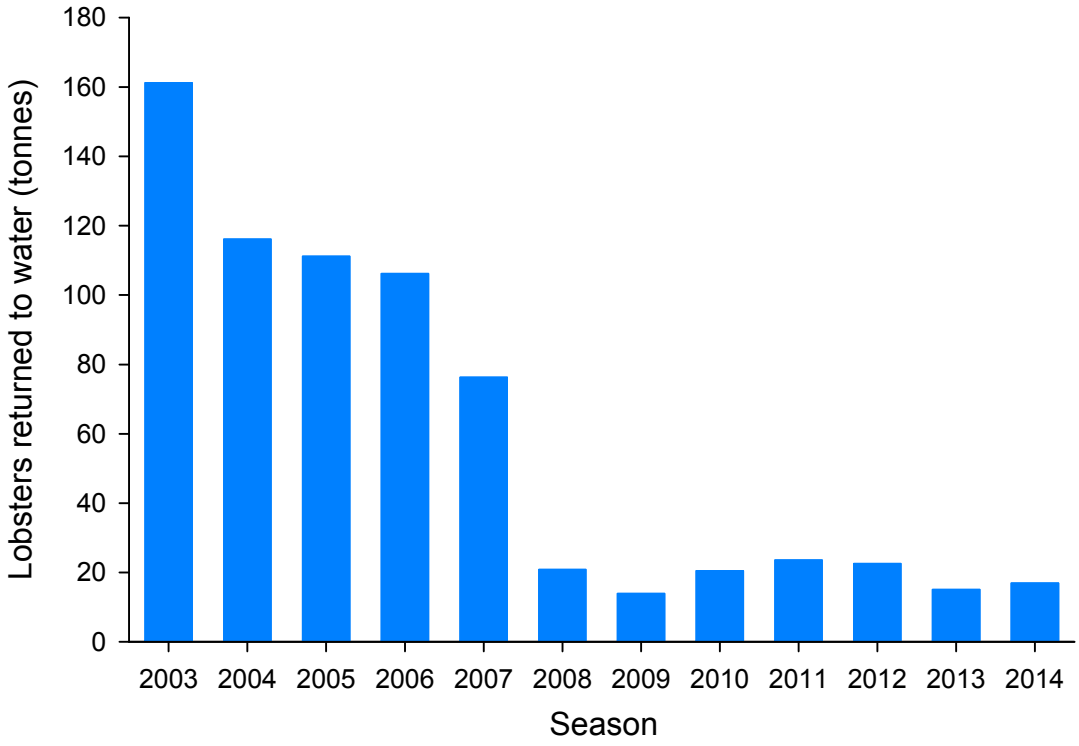

Figure 2-32 Inter-annual trends in high-grading within the SZRLF from 2003 to 2014.

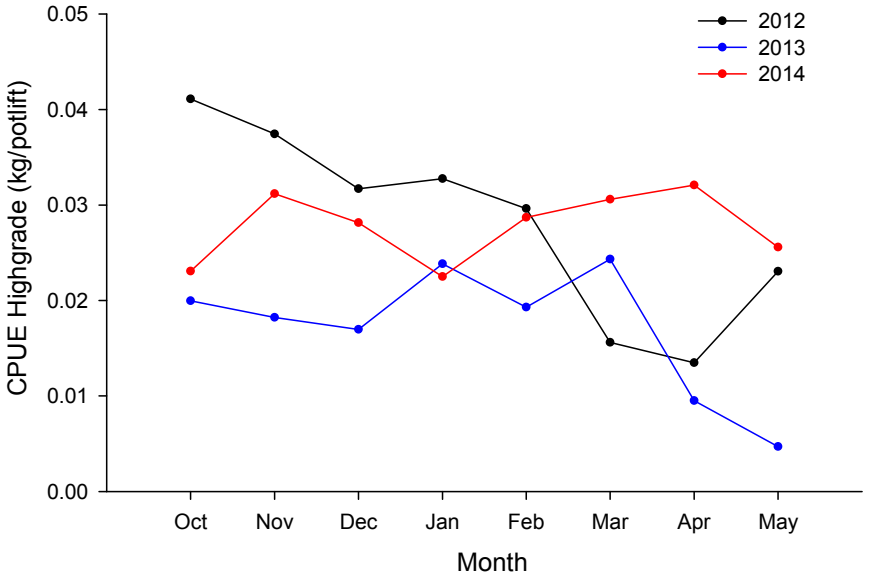

Figure 2-33 Within season trends in high-grading of lobster in the SZRLF from 2012 to 2014.

2.11 Water temperature

Temperature data obtained from a fixed monitoring station at located off Kangaroo Island at 100 m depth showed a gradual decrease in temperature from December to February before increasing thereafter (Figure 2-34). These trends are broadly consistent with previous seasons and reflect cold-water upwelling events from January to March which are synonymous with the region.

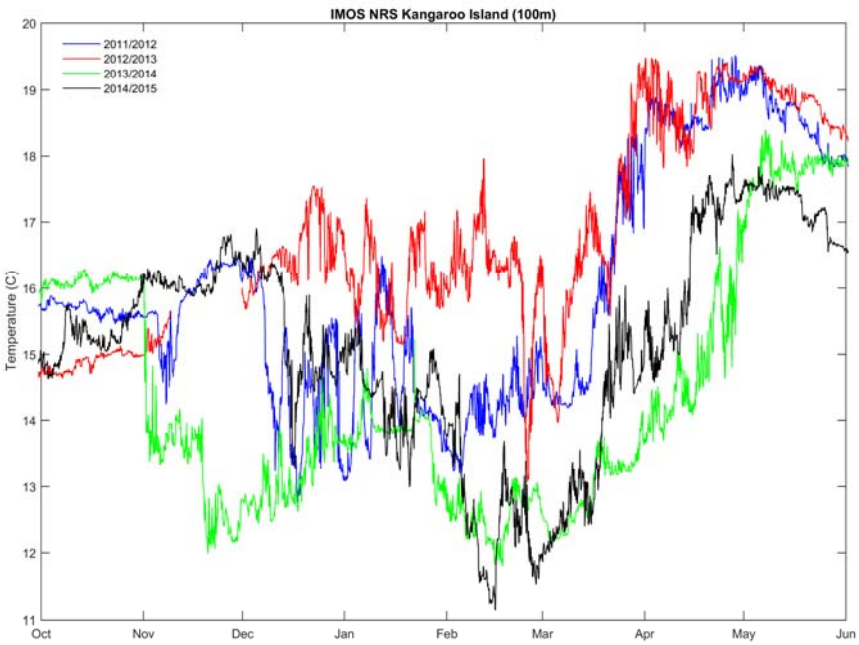

Figure 2-34 Bottom temperature (°C) as recorded in 100 m depth off Kangaroo Island, South Australia during the 2011/12 to 2014/15 rock lobster seasons.

3 FISHERY-INDEPENDENT DATA

3.1 Puerulus settlement index

Puerulus collectors in the SZRLF are located at Blackfellows Caves, Livingstones Bay, Beachport, Cape Jaffa and Kingston. Details of the sampling program are provided in Section 1.5.4. The mean annual Puerulus Settlement Index (PSI) is calculated from the monthly settlement of puerulus on all collectors (Figure 3-1). The period between settlement and undersized (PRI) is about four years, with recruitment occurring into the fishery one year later (i.e. five years after settlement).

Three of the highest PSIs on record were observed from 2005 to 2007 which reflected increases in PRIs in 2009 and 2010 (Figure 2-14) and subsequent increases in catch rate as this recruitment entered into the fishery in 2010 and 2011 (Figure 2-2). However, from 2010 to 2013, PSI estimates were below the long-term average suggesting that reduced levels of recruitment may be experienced in the SZRLF from 2015 to 2018. In 2014, the PSI was 1.74 puerulus/collector which was above the long-term average.

3.1.1 Correlations with PRI and CPUE

PSIs were correlated against both logbook PRI and commercial CPUE data lagged by four and five years, respectively, based on data from 1991 to 2008 (Figure 3-2). Catch rate and PRI data were closely correlated over the entire time series with a one year lag (R^2 = 0.78). More recently, PSI from 2002 to 2009 was strongly correlated (R^2 = 0.80) with subsequent PRIs from 2006 to 2013 and moderately correlated (R^2 = 0.44) with CPUE from 2007 to 2014. Importantly, high PSIs in 2002, 2005 and 2006 were reflected by increases to PRIs in 2006, 2009 and 2010. For correlations between PRIs and model-estimated recruitment from both the qR and LenMod models, see Sections 4 and 5.

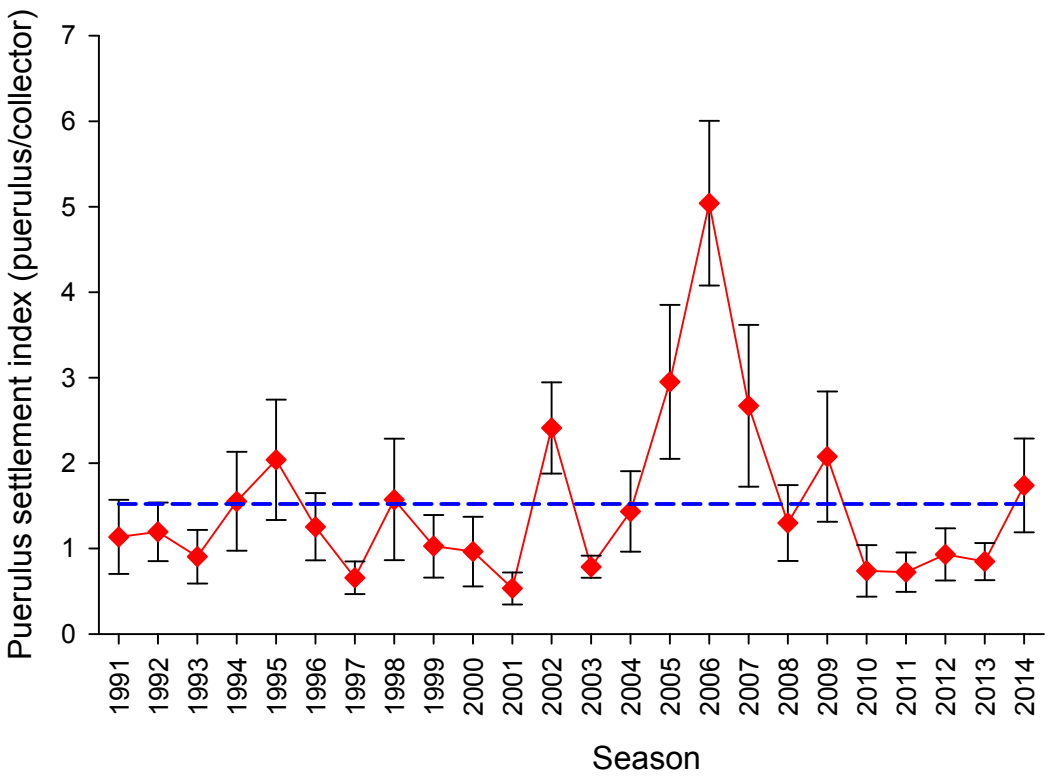

Figure 3-1 PSI (mean ±SE) in the SZRLF from 1991 to 2014. Dashed line represents long-term average.

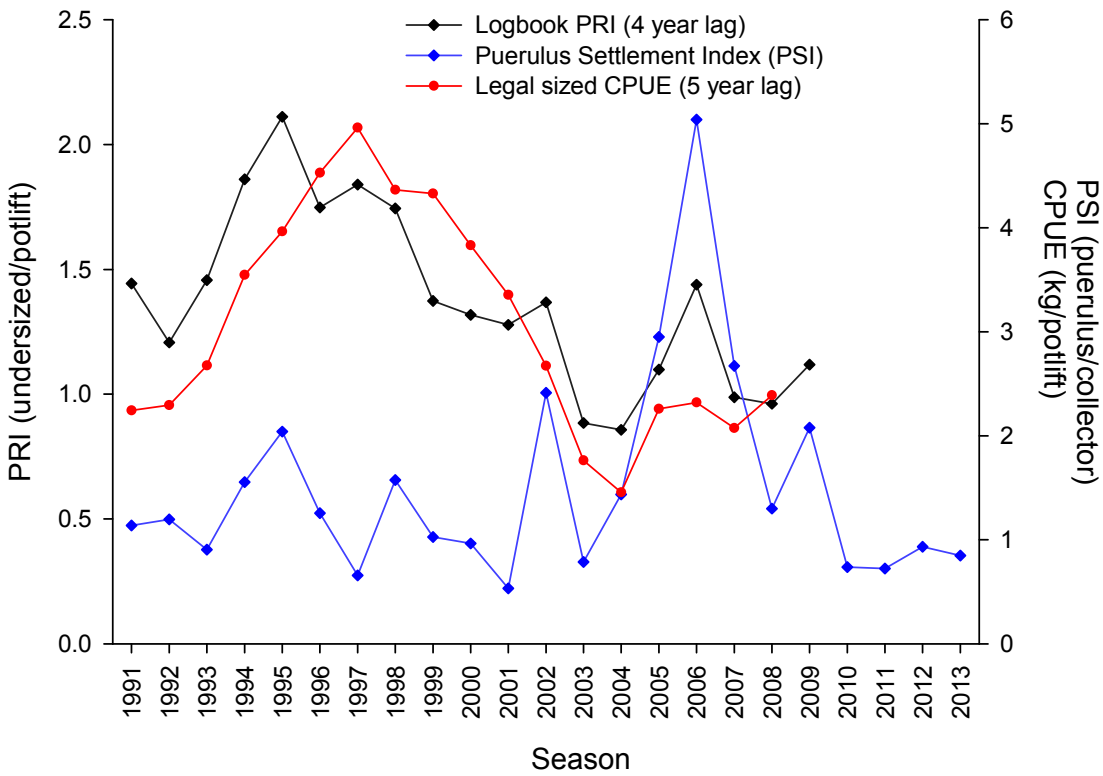

Figure 3-2 Correlations between SZRLF puerulus settlement lagged by four years with logbook PRI and by five years with commercial CPUE.

3.2 Fishery-Independent Monitoring Survey (FIMS)

3.2.1 Legal sized catch rates

Total legal sized CPUE (number/potlift) from fishery-independent surveys in 2014 (September and January surveys combined) was 0.41 individuals/potlift, one of the lowest estimates on record and the fourth consecutive season that this index has decreased (Figure 3-3). In contrast, current fishery-dependent data do not reflect historically low levels. While survey estimates have consistently declined since 2010, fishery-dependent data, with the exception of 2012, has remained relatively constant at between 1.2 to 1.3 individuals/potlift.

3.2.2 Undersized catch rates

Trends in survey derived PRI catch rate broadly reflect those of legal sized individuals (Figure 3-4). In 2014, survey PRI was 0.18 undersized/potlift, the lowest on record and the fifth consecutive season that this estimate has decreased. While fishery-dependent estimates of PRI are also close to historically low levels, estimates have remained relatively constant over the last four seasons at between 0.96 and 1.12 undersized/potlift.

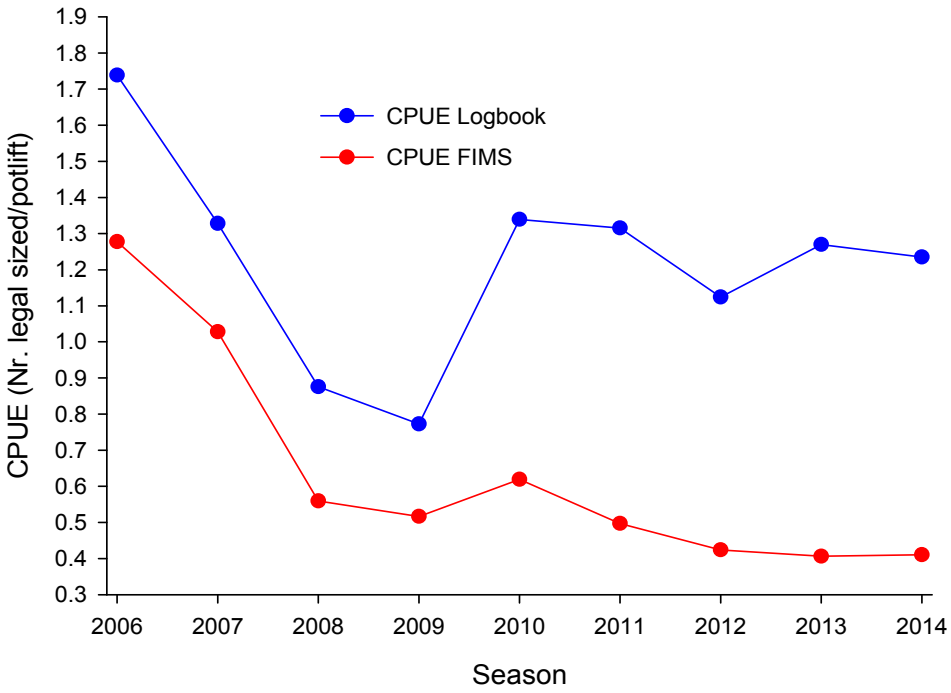

Figure 3-3 Comparison of legal size catch rates (No/potlift) from commercial logbook data and FIMS from 2006 to 2014 fishing seasons.

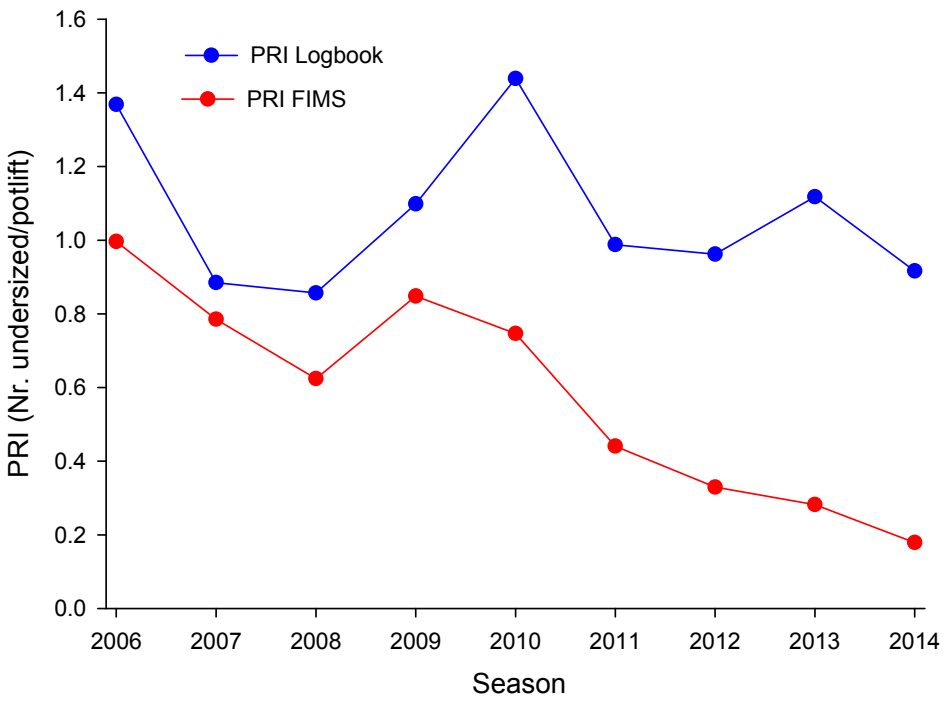

Figure 3-4 Comparison of undersized catch rates (No/potlift) from commercial from logbook data and FIMS from 2006 to 2014 fishing seasons.

4 THE QR MODEL

4.1 Introduction

The qR model (McGarvey et al.1997; McGarvey and Matthews 2001) has been used to generate estimates of performance indicators such as biomass, egg production and exploitation rate for the SZRLF. Outputs from the qR model have been presented in stock assessment reports for the SZRLF since 1997.

A review of the stock assessment research conducted by SARDI Aquatic Sciences (Breen and McKoy 2002) concluded that the qR model was an appropriate tool for assessing exploitation rate and recruitment. The model has been refined over time, most notably during the peer review process for publication of McGarvey and Matthews (2001) and changes to the definition of biomass in 2008. Hence, outputs from the current version of the model differ from those presented in previous stock assessment reports.

This section of the report has two objectives: (i) to generate annual estimates of biomass, egg production, % virgin egg production and exploitation rate for the SZRLF using data from 1983 to the end of the 2014 fishing season; and (ii) to compare estimates of recruitment obtained using the qR model with an independent measure of pre-recruit abundance (based on logbook data).

4.2 Methods

A detailed description of the qR model is provided in McGarvey and Matthews (2001). The qR model fits to annual catch in weight (*Cw*, in kg) and annual catch in number (*Cn*, in numbers of lobsters landed). The model is age-based and effort conditioned with effort (*E*, annual potlifts) taken from logbook data and a Baranov survival model using a Schaefer bilinear catch relationship ($Cn=qEN$) is assumed. The estimation likelihood is written as a modified normal and fitted numerically. Recruitment in each year is estimated as a free parameter. The standard deviation of the two normal likelihood components is specified by a coefficient of variation parameter, assumed to be the same for the two catch data sources, *Cw* and *Cn*.

Stock assessment models using only catch log data normally rely on *CwPUE* as a measure of relative fishable biomass. Adding catches in numbers to the fitted data set provides information about yearly mean size of lobsters in the legal catch, which are normally available only from catch composition sample data. Catch in weight divided by catch in number gives the mean weight of an average 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 data is far more precise than that obtained from length-frequencies, which typically constitute a 0.1% to 1.0% sample fraction. Thus, the qR model is informed by *CwPUE* as a relative index of abundance and by mean weight as a measure of landed body size. McGarvey et al. (2005) demonstrated, using simulated data, that adding catch in number dramatically improves the accuracy and precision of stock assessment estimates. These inputs are also used in LenMod, together with length-sex frequency samples.

The PRI provides a directly measured index of yearly recruitment that is independent of qR model estimates. PRI, therefore, provides a means of validating the time trends in estimated recruitment outputs from the qR model. The annual PRI is based on average undersize CPUE from November to March in each fishing season from commercial logbooks. As with LenMod, the qR model outputs an average level of biomass during each full model year. This differs from previous outputs where start-of-year biomass estimates were reported. Appendix 1 further details the specifications of the qR model including its equations, assumptions and parameters.

4.3 Results

4.3.1 Goodness of Fit

Estimates of catch in numbers and weight from the qR model fit closely to reported total yearly catches of *Cn* and *Cw* obtained from the SZRLF (Figure 4-1 and Figure 4-2).

4.3.2 Biomass

Outputs from the qR model, based on yearly averages, indicate that from 2002 to 2009, estimates of legal sized biomass decreased by 65% from 5,185 to 1,814 t (Figure 4-3). Over the last five seasons, biomass has more gradually increased to 2,665 t in 2014. Despite recent increases, current estimates remain below the long-term average for the fishery (approximately 3,500 t).

4.3.3 Egg Production

Trends in estimated egg production in the SZRLF reflect those of legal sized biomass (Figure 4-4). Egg production estimates decreased by 52% from 679 billion in 2003 to 326 billion in 2009. Over the last five seasons, egg production has increased by 16% to 379 billion in 2014 but remain below the long-term average for the fishery (478 billion). Model

outputs for the 2014 season indicate that egg production currently equates to 9% of virgin levels (Figure 4-5).

4.3.4 Exploitation rate

Exploitation rate increased from 34% in 2002 to 69% in 2009 in response to decreasing biomass over the same period (Figure 4-6). In 2010, exploitation rates decreased considerably and have remained relatively stable over the last four seasons. In 2014, the estimate was 47%.

4.3.5 Estimates of recruitment and correlations with PRI

Estimates from the qR model suggest that recruitment levels increased from 1996 and peaked at 4.0 million lobsters in 1999 (Figure 4-7). Over the next nine seasons the estimate generally decreased and in 2008 was 1.0 million lobsters, the lowest on record. Since then, recruitment levels have been variable with the 2014 estimate at approximately 1.8 million lobsters. Temporal trends in recruitment estimated by qR were strongly correlated (R^2=0.90) with PRI from logbook data over the period 1995-2014 (Figure 4-8). In 2014, both qR model estimated recruitment and logbook reported PRI were at relatively low levels in a historical context.

4.4 Discussion

Details of the qR model, and simulation testing of its performance have been described in a number of peer-reviewed papers (McGarvey et al. 1997; McGarvey and Matthews 2001; McGarvey et al. 2005). Using simulated data from an independent individual-based model yielded close agreement of qR model estimates with ‘true’ fishery indicators of recruitment, biomass, and exploitation rate. Moreover, these simulated data tests found that the model estimates were relatively insensitive to errors in natural mortality rate, and some other common sources of model error. However, qR model estimates were sensitive to assumed weights at age (McGarvey and Matthews 2001; McGarvey et al. 2005).

The qR estimates of biomass reflect the fluctuations in catch rates of legal size lobsters over recent seasons (Figure 2-2). Following significant rebuilding in the fishery, lobster biomass decreased by 65% from 5,185 t in 2002 to 1,814 t in 2009. Similarly, egg production decreased by 52% over the same period. In 2009, the TACC was reduced from 1,770 to 1,400 t; however, evidence now indicates that the rate of biomass decline had been greater than that of catch. As a result, exploitation rate increased over this period and in 2009 was

69% representing an increase of 103% since 2002 (34%) and the highest estimate on record.

qR recruitment estimates indicate that recruitment in the SZRLF trended downward over a ten year period from 1999, in 2008 reaching an estimate of 1.0 million recruits, the lowest on record. These model estimates of recruitment were highly correlated in time with logbook PRI, as well as with LenMod estimates of recruitment. This strongly validates the inference that the SZRLF experienced an extended period of reduced recruitment to the fishable biomass. Combined with higher TACC levels (>1,700 t) at that time, fishery performance over this period was poor. In 2009, the TACC was lowered to 1,250 t. Under the marine park voluntary buyback scheme, the TACC was reduced to 1,245.7 in 2014. There is now evidence to indicate that some biomass rebuilding has occurred subsequent to the TACC reduction in 2009. The 2014 estimate of biomass (2,665 t) reflects a 47% increase from 2009, while egg production has increased by 16%. As a consequence, exploitation rates have decreased to approximately 47%. While some rebuilding has occurred, the biomass levels remain considerably below the long-term average. Low stock abundance is also reflected in current low levels of egg production in a historical context.

Most of the uncertainty in the model estimates lies in the assumed values of input parameters, notably (1) natural mortality, (2) mean weights-at-age, and (3) CPUE as a measure of biomass. Steady-state analysis by McGarvey et al. (1997) showed that catch under-reporting has little effect on the qR estimates of exploitation rate, while yearly estimates of biomass and recruitment are reduced by the proportion of under-reporting. Similarly, McGarvey and Matthews (2001) and McGarvey et al. (2005) showed that model estimates are relatively insensitive to errors in the assumed natural mortality rate, but that these estimates were like any size-based assessment, generally sensitive to the assumed growth inputs of weight-at-age. The impact of differing levels of rising effective effort, and thus of the principal assumed cause of deviation in trends of CPUE and stock biomass, was tested in the Northern Zone fishery where rising effective effort is presumed to be significant (Linnane et al. 2010b). In the Southern Zone, due to the relatively uniform and widespread occurrence of fishable habitat, the impact of rising effective effort is not considered to be large.

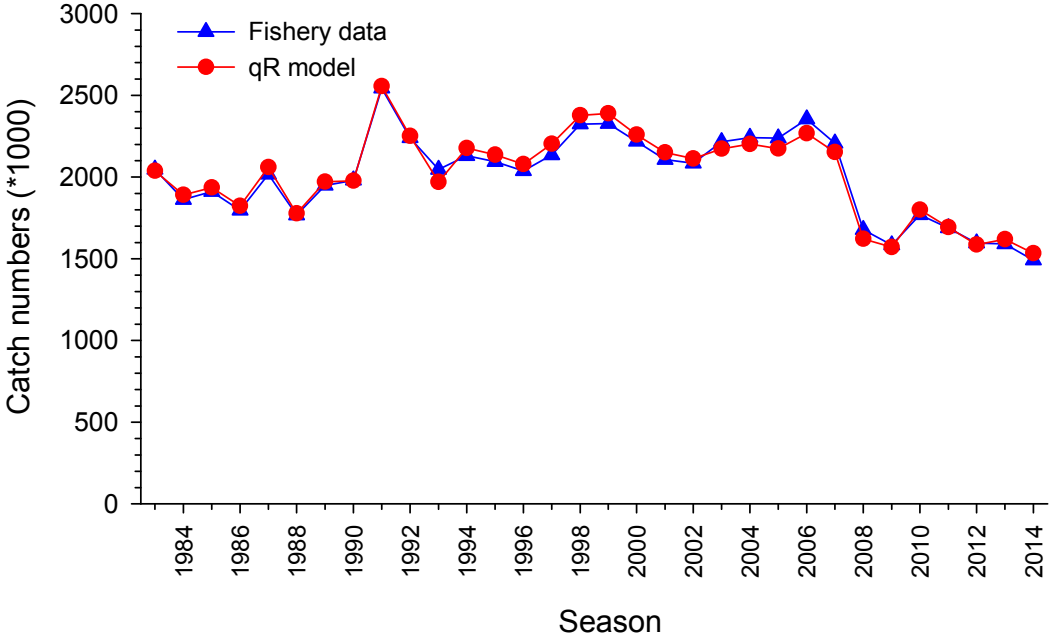

Figure 4-1 Fit of the qR model to catch in numbers (Cn) for the SZRLF, based on annual catch totals from the fishery and estimates provided by the 2014 version of the qR model.

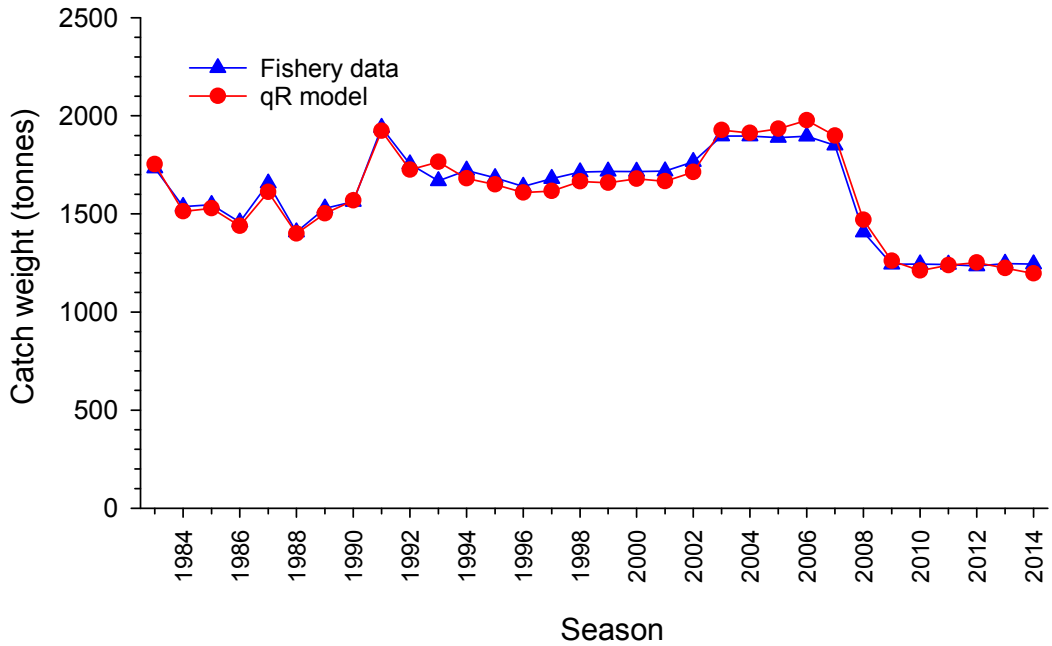

Figure 4-2 Fit of the qR model to catch in weight (Cw) for the SZRLF, based on annual catch totals from the fishery and estimates provided by the 2014 version of the qR model.

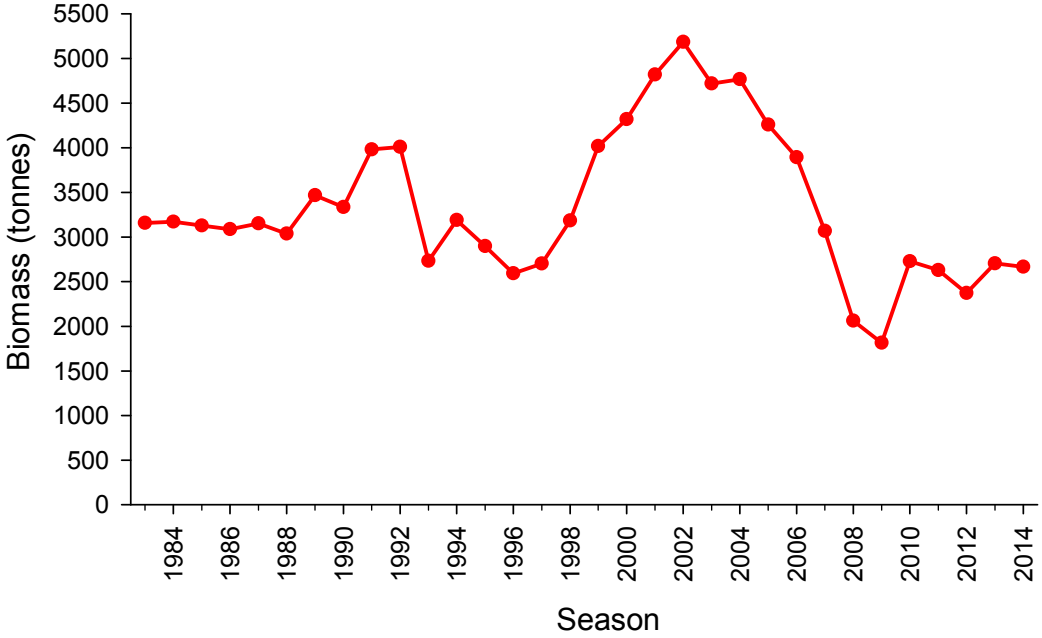

Figure 4-3 Biomass estimates from 1983 to 2014, from the qR model.

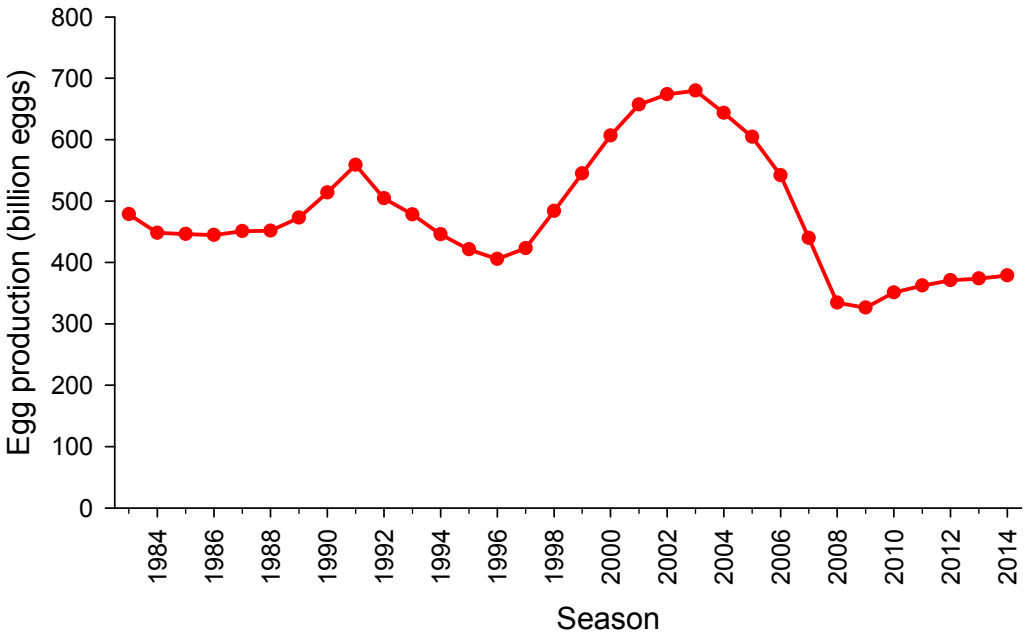

Figure 4-4 Egg production estimates from 1983 to 2014, from the qR model.

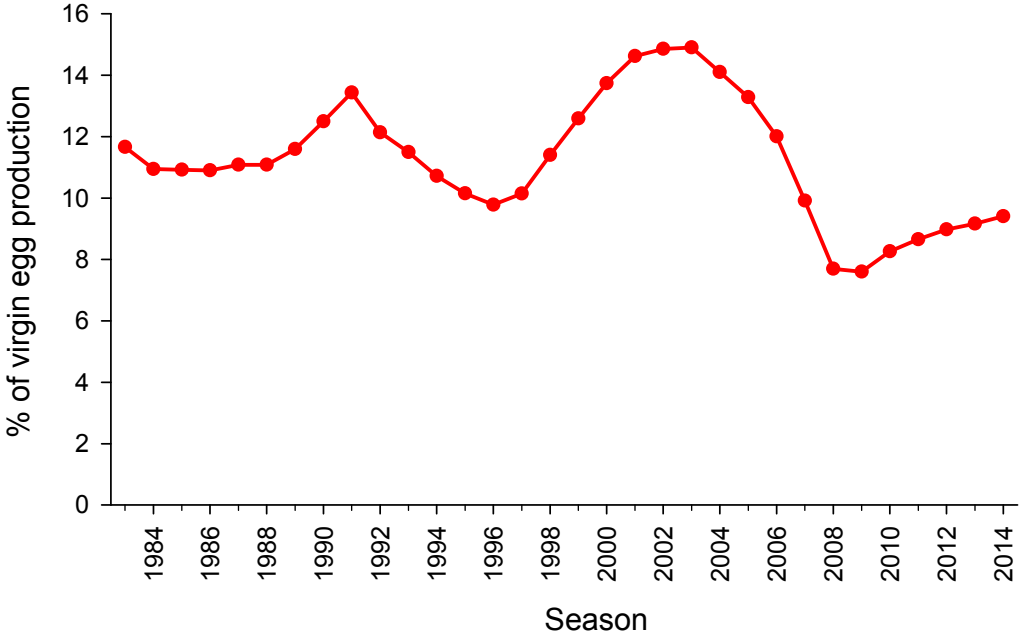

Figure 4-5 Estimates of percent of virgin egg production from 1983 to 2014, from the qR model.

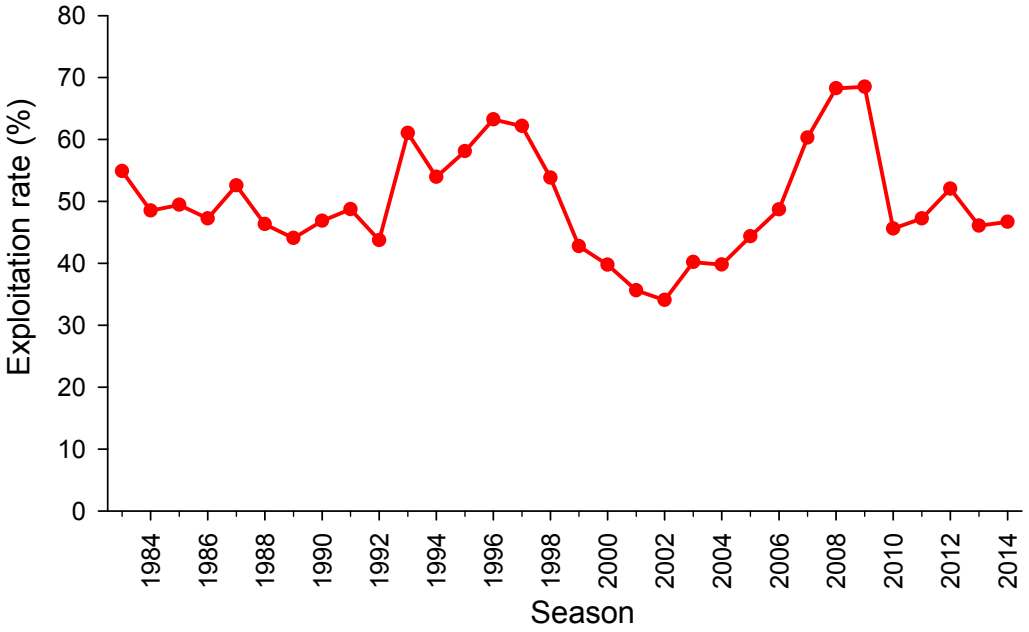

Figure 4-6 Estimates of exploitation rate from 1983 to 2014, from the qR model.

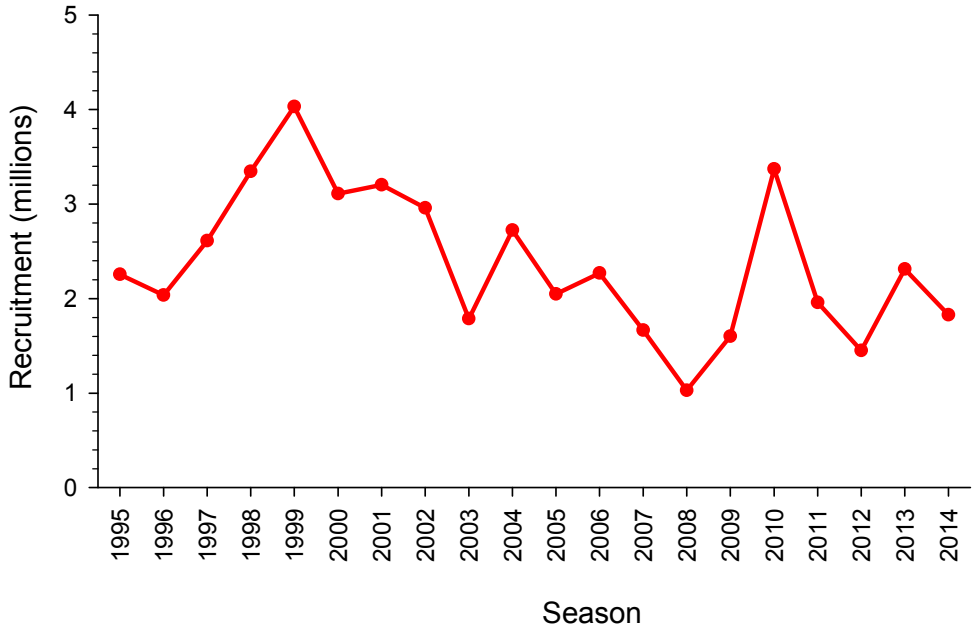

Figure 4-7 Estimates of yearly recruitment from 1995 to 2014, from the qR model.

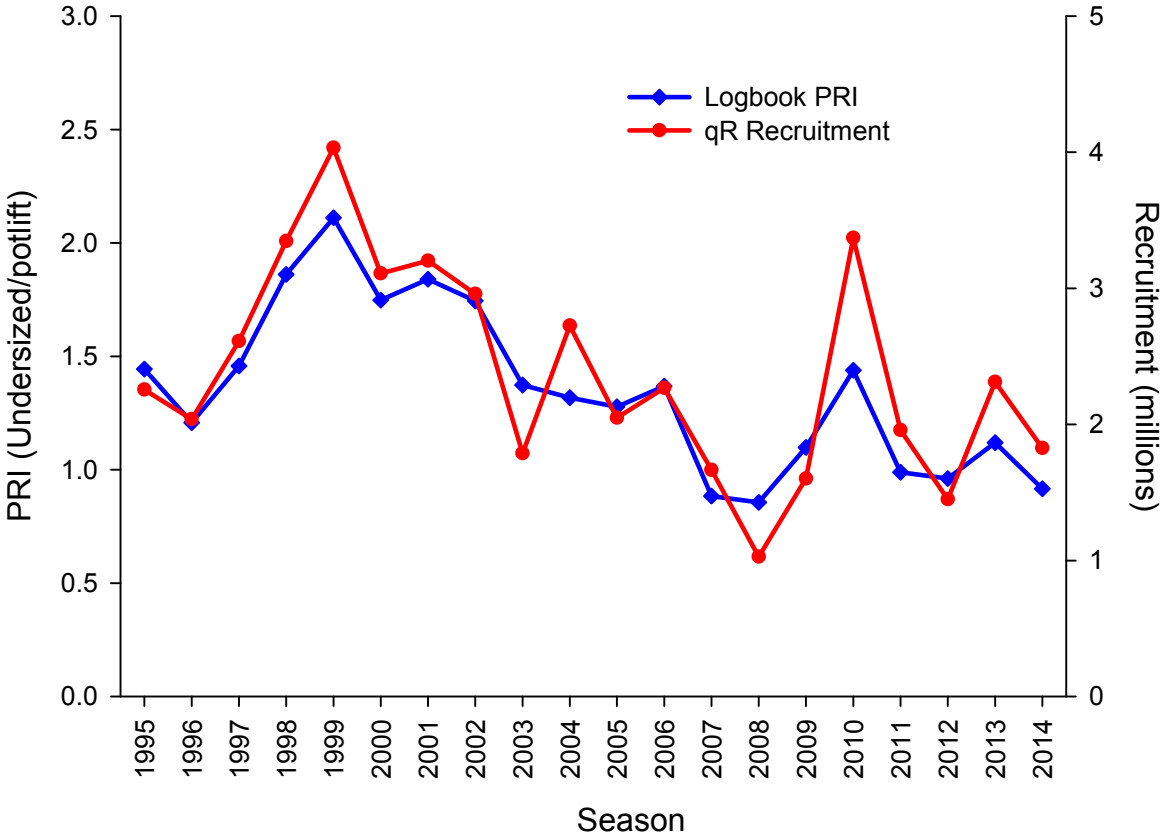

Figure 4-8 Estimates of annual recruitment obtained from the qR model and the pre-recruit index (PRI) as undersized lobster numbers per potlift (Nov-Mar) obtained from logbooks.

5 THE LENGTH STRUCTURED MODEL

5.1 Introduction

This section of the report provides outputs from a length-structured model (LenMod) for the SZRLF. While the qR model provides estimates of biomass, recruitment and exploitation rate based on catch in weight and number, LenMod fits to catch in number and to CPUE, while conditioning on catch in weight. In addition, it also incorporates length-frequency data from catch sampling, in which lobster proportions captured are broken down into size categories of differing carapace length. André Punt (Washington University) first developed the basic LenMod structure in the 1990s (Punt and Kennedy 1997), extending the size-based South African lobster assessment model of Bergh and Johnston (1992), and the size-based New Zealand abalone model of Sainsbury (1982). 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.

5.2 Methods

Earlier versions of the length-structured model, with simulation testing of its performance, have been described in peer-reviewed papers (Hobday and Punt 2001; Punt 2003). The code for the South Australian LenMod was adapted from the Victorian version of the model (Hobday and Punt 2001; Punt 2003). To incorporate the more extensive data set available from the larger South Australian fishery, a number of modifications to the model design have been implemented. These include a monthly, replacing a yearly, time step, which permits (1) accounting for seasonal changes in the fishery, notably of catchability, and of overall catch rate, (2) accounting for mid-summer recruitment to legal size, and (3) acknowledging that the majority of lobster growth in South Australia occurs during moulting periods in late autumn and early summer, rather than once yearly. In addition, the LenMod description of lobster dynamics is improved by (4) incorporating information on sex ratios in recruitment and catch inferred from voluntary catch sampling data, (5) reducing the width of length class bins from 8 mm to 4 mm, and (6) refining the growth matrix estimation.

LenMod infers change and absolute levels of stock abundance principally from three data sources: (1) CPUE (see Section 2.2) with which biomass is assumed to vary in direct proportion, (2) catches in both weight and number, which provide a highly precise (100% sample) measure of mean weight of lobsters in the catch (see Section 2.4), and (3) length-frequency data (see Section 2.5). These data sources are interpreted in combination with the length-transition matrices to yield estimates of mortality rate and absolute biomass. Data

sources (2) and (3) both provide LenMod with information on the sizes of lobsters in the catch.

Growth is modelled using length-transition matrices which specify the proportion of lobsters in each length category that grow into larger length classes during each summer and autumn moulting period. The length-transition matrices were estimated using extensive tag-recovery data. The length-transition estimation method of McGarvey and Feenstra (2001) was applied which permits widely flexible growth curves to be inferred by modelling the parameters predicting mean and variance of tag-recovery growth increments as polynomial functions of (starting) carapace length (CL). Growth matrices were estimated for each combination of sex and moulting season. Knowing that growth rates of female lobsters slow substantially once they reach maturity, the flexible polynomial estimation method (McGarvey and Feenstra 2001) provides a more accurate estimation of female adult growth than growth matrix estimation methods based on a traditional von Bertalanffy model.

Appendix 2 further details the specifications of the length-structured model (LenMod) including its equations, assumptions and parameters.

5.3 Results

5.3.1 Goodness of fit

Estimates of monthly catch in number and catch rate from the LenMod model fitted closely to reported time series *Cn* and CPUE obtained from SZRLF logbook data (Figure 5-1; Figure 5-2), though fits were closer for *Cn*. In addition, with the exception of female lobsters in February, model estimates fitted well to length-frequency data from the commercial catch data as shown in monthly fits from the 2014 season (Figure 5-3).

5.3.2 Biomass

LenMod-generated outputs, based on yearly averages, indicate that over 2002 to 2009, estimates of legal sized biomass decreased by 62% from 4,873 to 1,860 t (Figure 5-4). Between 2009 and 2013, biomass increased 40% to 2,612 t but declined 7% in 2014 to 2,436 t. As with the qR model, LenMod does not take into account the effects of discarded catch due to high-grading. However, as highlighted in Figure 2-32, the 2014 season had low levels (16.9 t) of high-grading.

5.3.3 Egg production

Trends in estimated egg production in the SZRLF increased from 1997 and peaked at 560 billion eggs in 2002 and 2003 (Figure 5-5). Between 2003 and 2009 egg production then decreased and in 2009 was 258 billion eggs, the lowest on record. Between 2009 and 2013, egg production increased 31% to 336 billion eggs, but in 2014 has decreased slightly (4%) to 323 billion eggs. Current egg production estimates are low in a historical context equating to 8% of virgin levels (Figure 5-6).

5.3.4 Exploitation rate

Exploitation rate increased from 36% in 2002 to 70% in 2008 in response to decreasing biomass over the same period (Figure 5-7). Over the next four seasons, exploitation rate decreased and in 2013 was 48%. In 2014, the LenMod estimate increased slightly to 51%.

5.3.5 Estimates of recruitment and correlations with PRI

The recruitment estimates from LenMod increased from 1993, peaking at 4.0 million recruits in 1999 (Figure 5-8). Over the next nine seasons, estimated recruitment generally decreased and in 2008 was 1.4 million, the lowest estimate on record. Over the next two seasons recruitment increased before decreasing again to 1.6 million in 2014, one of the lowest estimates on record. Temporal trends in recruitment estimated by LenMod were well correlated (R^2=0.89) with PRI from logbook data over the period of 1995 to 2014 (Figure 5-9).

5.4 Discussion

Overall, LenMod outputs agree with those from the qR model in terms of the current status of the SZRLF. Specifically, both models estimate that the biomass in the SZRLF decreased considerably from 2002 to 2009 before modest levels of recovery in both biomass and egg production over the next four year period. There is strong evidence from fishery-dependent data to indicate that the decline in fishery status is the result of poor recruitment in recent seasons which correlates with declines in independently derived logbook PRI (undersized/potlift) over the same period. The LenMod and qR models estimate exploitation rates at approximately 47-51% in 2014.

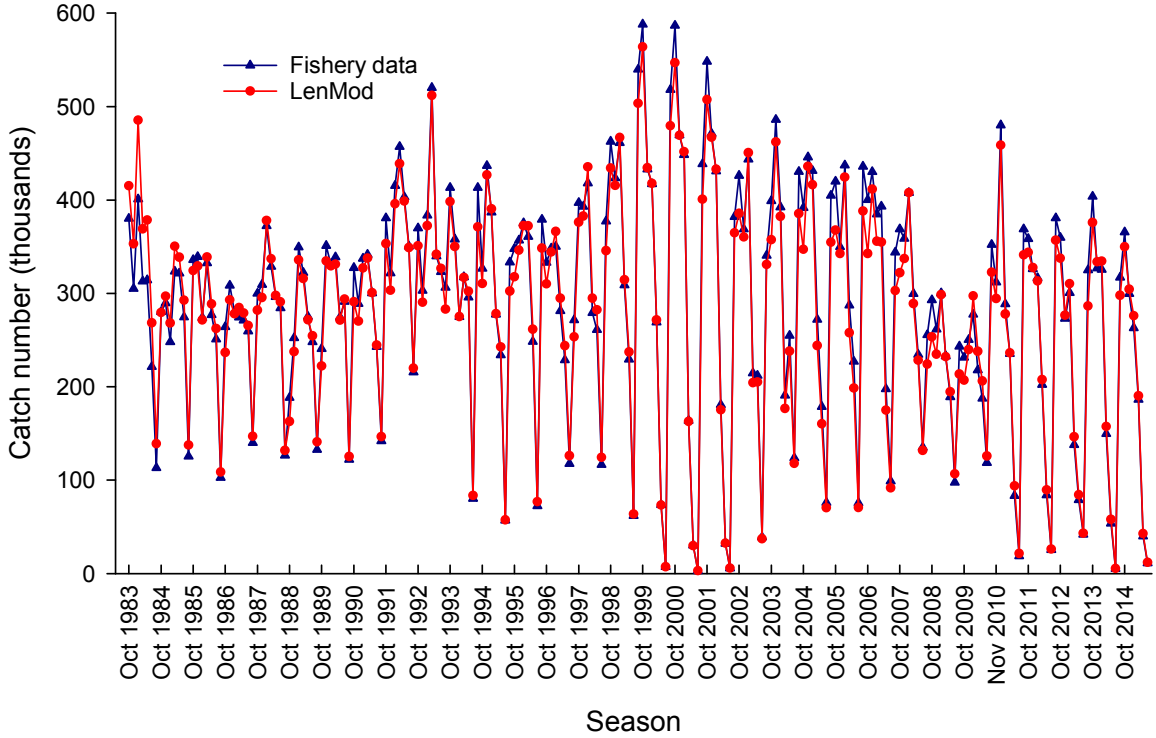

Figure 5-1 Fit of the LenMod model to catch in number (Cn) for the SZRLF, based on annual catch totals from the fishery and estimates provided by the 2014 version of the model (Note: October closed to fishing in 2010).

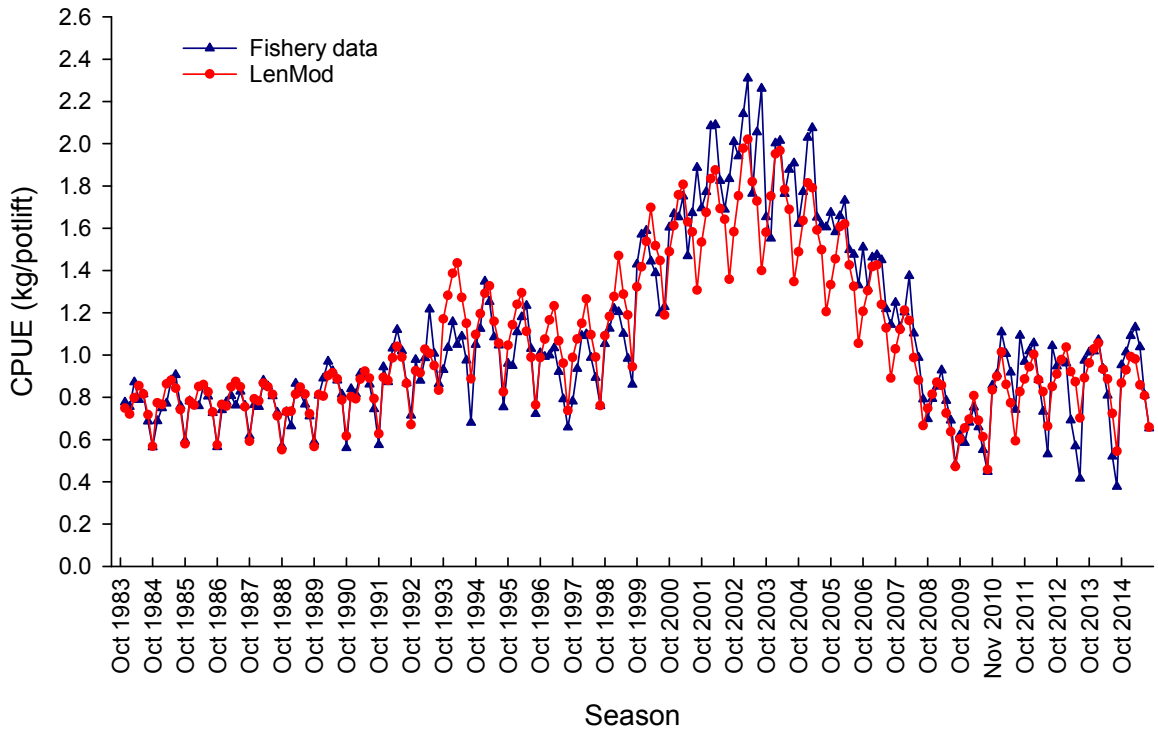

Figure 5-2 Fit of the LenMod model to catch rate for the SZRLF, based on annual estimates from the fishery and those provided by the 2014 version of the model (Note: October closed to fishing in 2010).

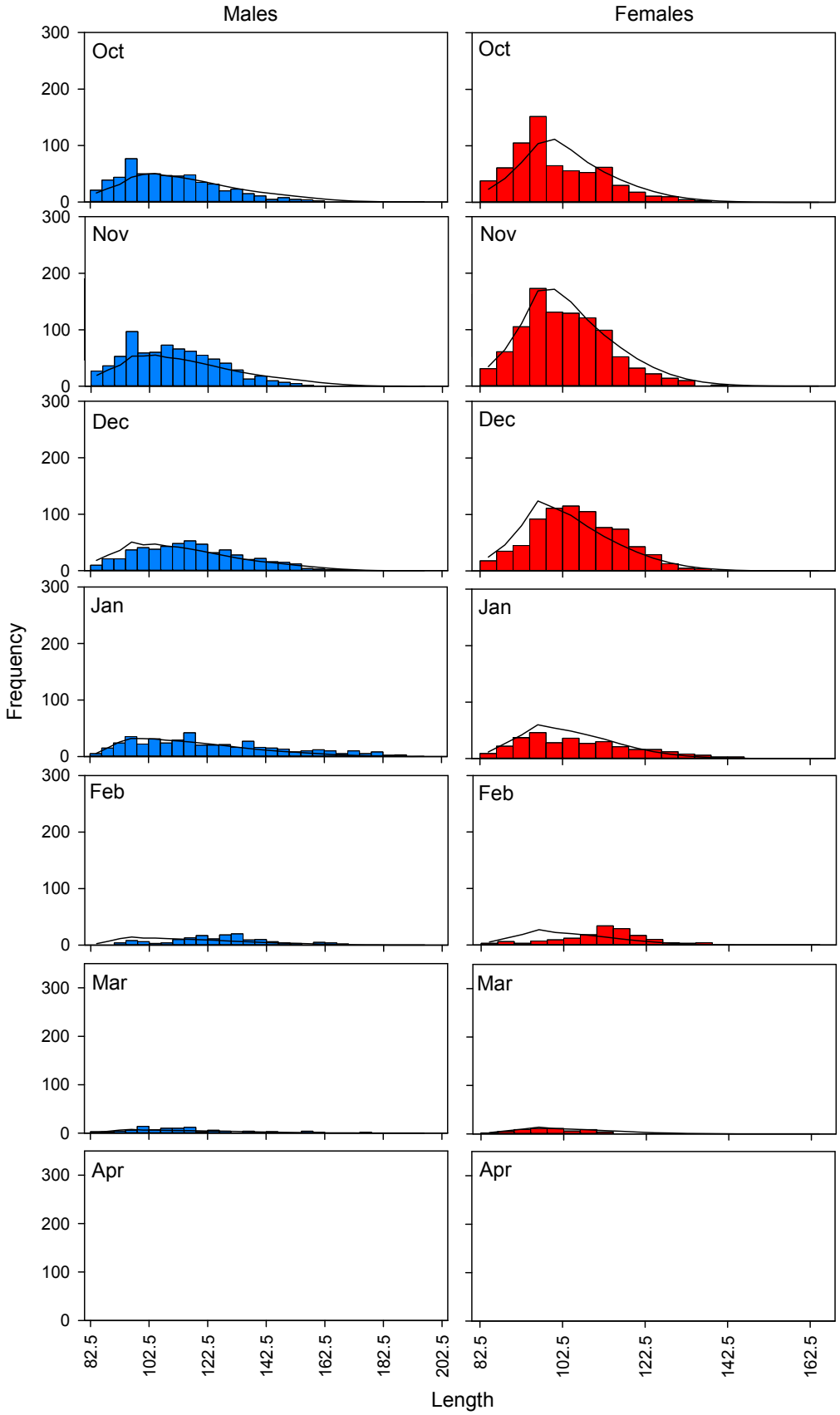

Figure 5-3 Samples of model fit (black line) to commercial length frequency data for both males and females taken during the 2014 season in the SZRLF.

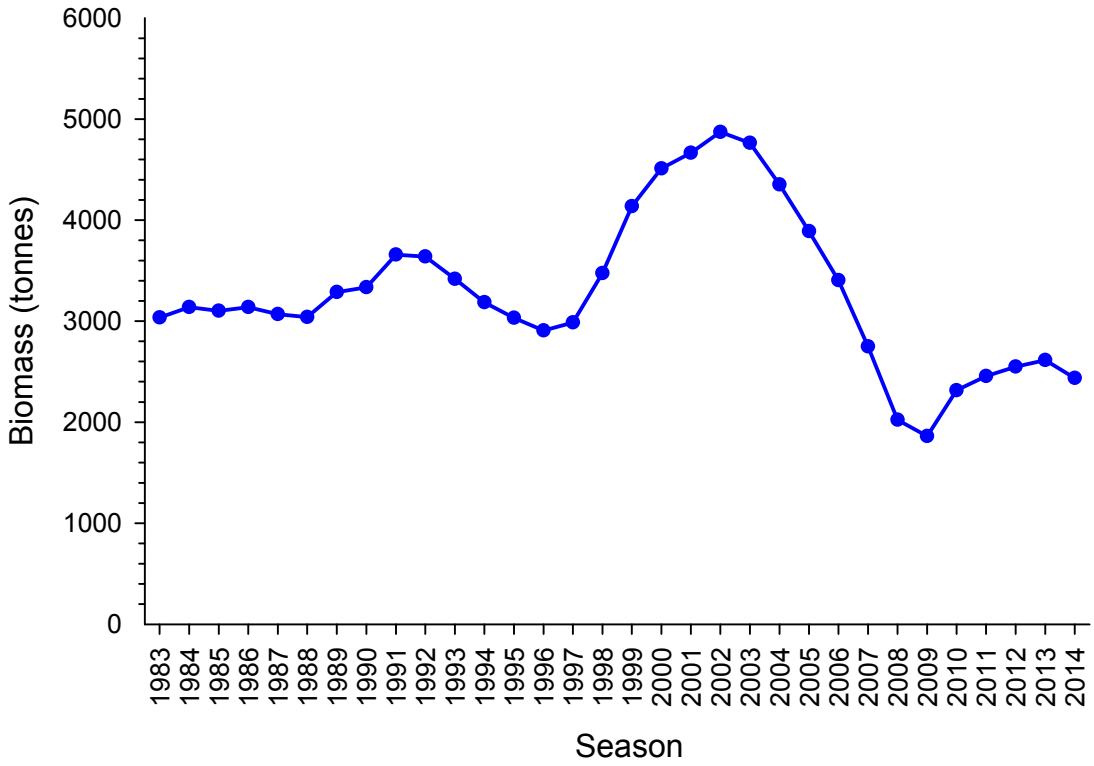

Figure 5-4 Estimates of biomass provided by the 2014 LenMod model.

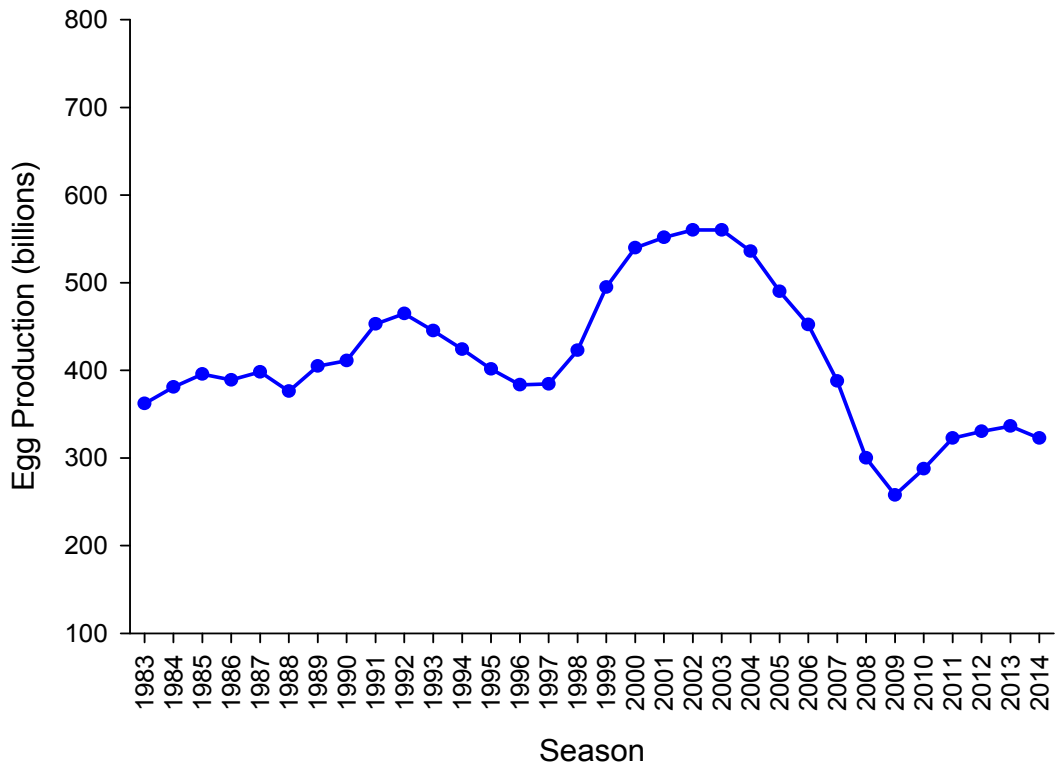

Figure 5-5 Estimates of egg production provided by the 2014 LenMod model.

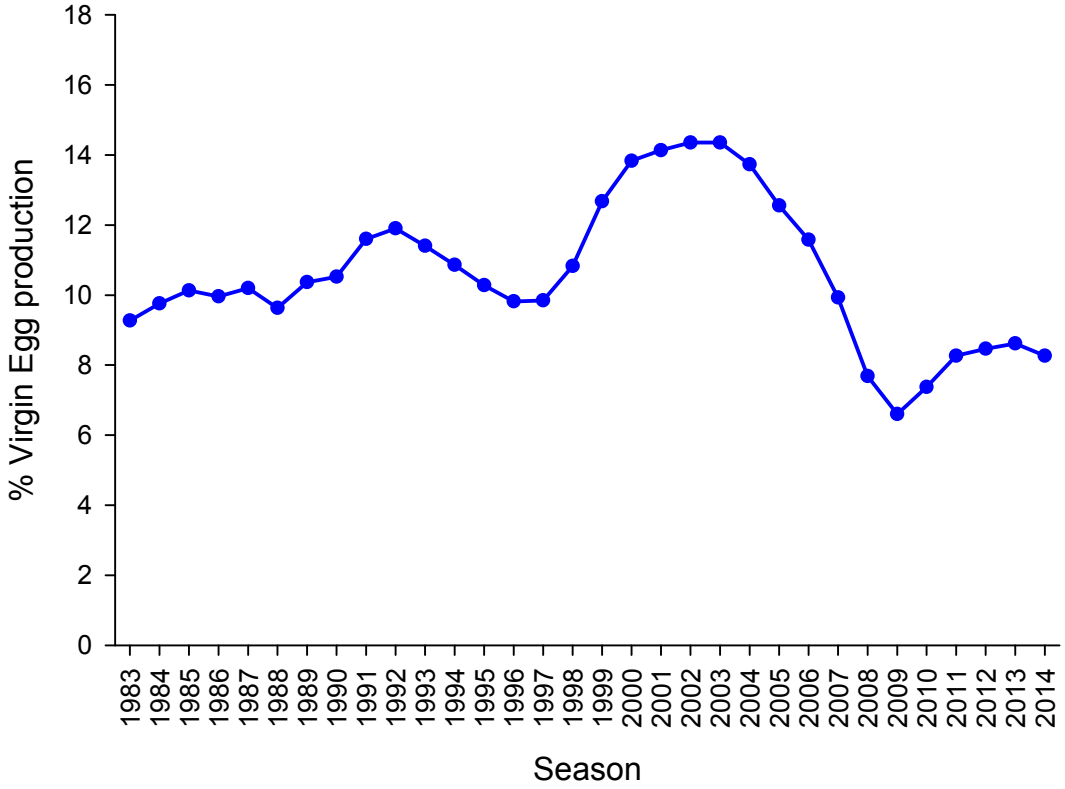

Figure 5-6 Estimates of percent of virgin egg production provided by the 2014 LenMod model.

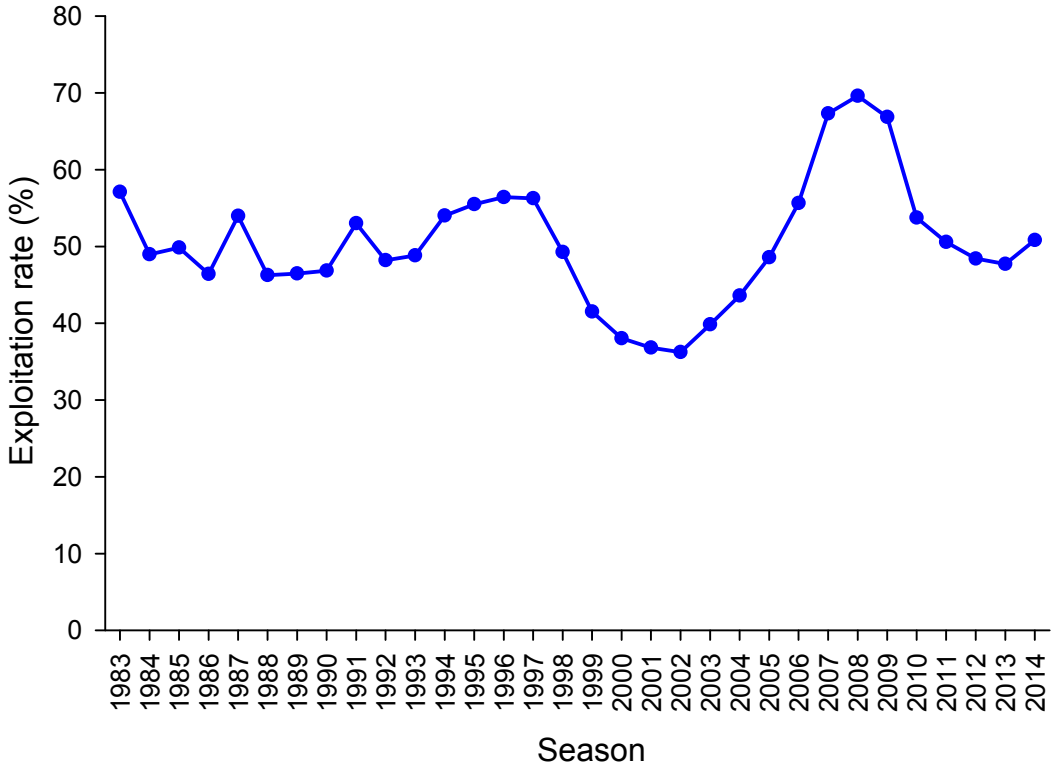

Figure 5-7 Estimates of exploitation rate provided by the 2014 LenMod model.

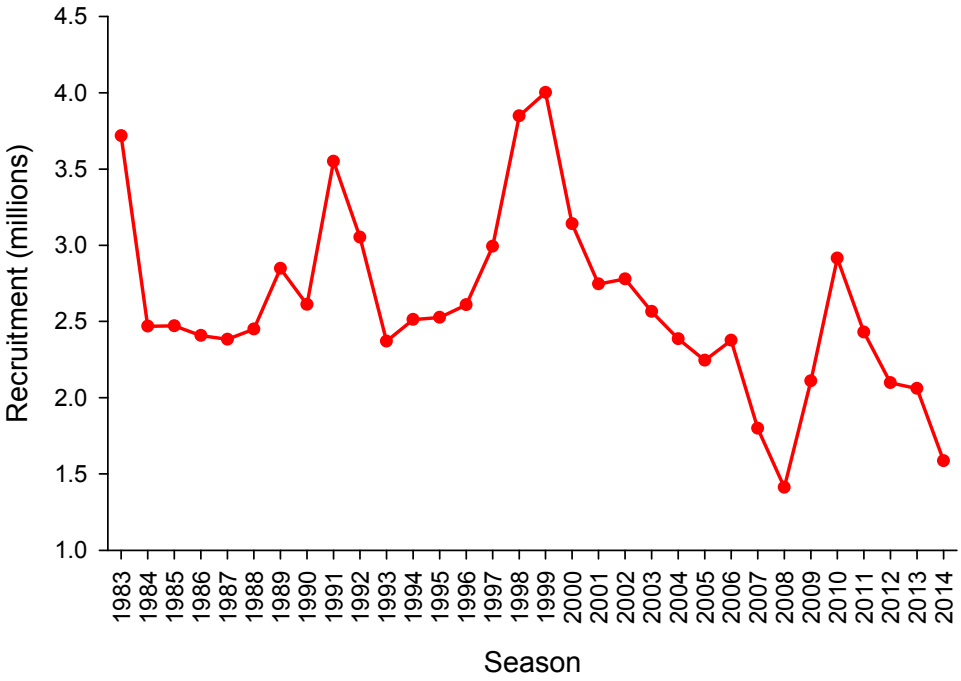

Figure 5-8 Estimates of recruitment obtained from the 2014 LenMod model.

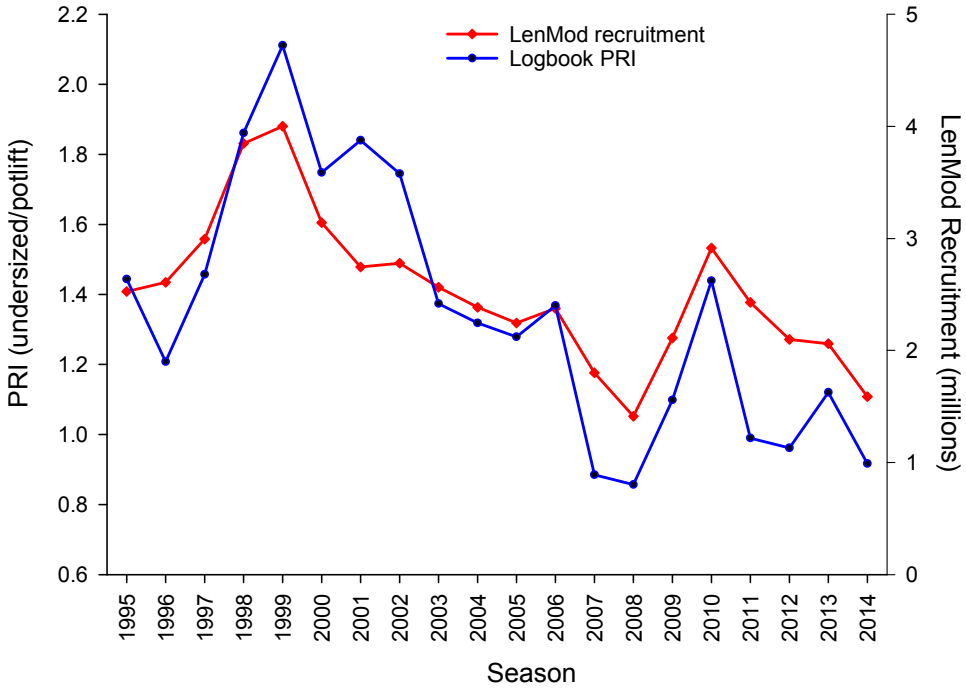

Figure 5-9. Estimates of annual recruitment obtained from the LenMod model and pre-recruit index (PRI) as undersize numbers/potlift (Nov-Mar) obtained from logbook data.

6 PERFORMANCE INDICATORS

The SZRLF Management Plan (PIRSA 2013) harvest strategy details specific reference points for the primary biological performance indicator of CPUE and the secondary indicator of PRI (see Section 1.3.3) that are used to provide a TACC recommendation for the 2015/16 season. In 2015, this strategy was amended with a number of changes implemented in relation to TACCs at specific levels of CPUE (McGarvey et al. 2016) but as this report assesses the fishery for the 2014/15 fishing season, the performance indicators described in the original harvest strategy (PIRSA 2013) will be used here. Specifically, a LRP of 0.50 kg/potlift is the agreed level below which it is considered there may be a significant risk to spawning stock egg production. Consistent with the harvest strategy in the 2013 management plan (PIRSA 2013), the TACC was set at 1245.7 t for the 2014/15 season.

6.1 Primary Indicator: Catch per unit effort (CPUE)

The primary indicator of fishery performance is commercial CPUE derived from logbook data from October to May inclusive with a LRP of 0.50 kg/potlift. In 2014, commercial CPUE was 1.03 kg/potlift which is above the LRP.

6.2 Secondary Indicator: Pre-recruit index (PRI)

The secondary indicator of fishery performance is PRI, derived from logbook data from November to March inclusive, with a trigger reference point (TRP) of 1.3 undersized/potlift. In 2014, the PRI was 0.92 undersized/potlift which is below the TRP. PRI has been below the TRP in seven of the last eight seasons (Figure 6-1).

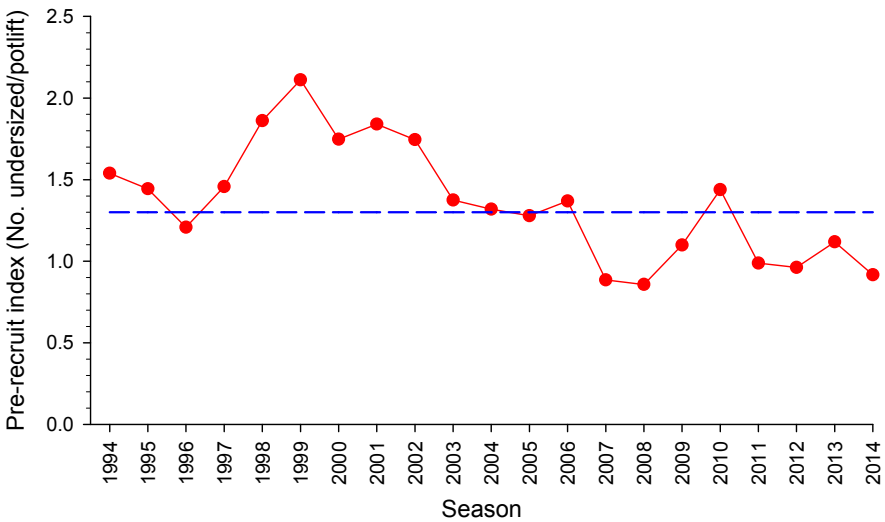

Figure 6-1. Inter-annual trends in pre-recruit index (PRI) in the SZRLF from 1994 to 2014 based on logbook data. Dashed line represents trigger reference point (1.3 undersized/potlift).

7 GENERAL DISCUSSION

7.1 Information available for fishery assessment

Stock assessment of the SZRLF is aided by documentation on the history of previous management arrangements and historical stock assessment reports (e.g. PIRSA 2013; Linnane et al. 2015). Comprehensive catch and effort data have been collected since 1970. Data collected since 1983, however, provide more reliable information on overall catch rate. Voluntary catch sampling data have been collected since 1991 and provide critical information on length-frequency distributions. Fishery stock assessments are also aided by fishery-independent sources of data, namely annual puerulus monitoring and fishery-independent monitoring surveys. The overall stock assessment is further supported by outputs from two independent fishery models specifically developed for the fishery (i.e. the qR and LenMod fishery models).

The primary data source for this fishery in relation to abundance assessment trend, modelling and harvest strategy is commercial catch rate. While generally accepted as an indicator of abundance, there are a number of uncertainties surrounding this. In particular, the index is dependent on when and where vessels target lobsters within the zone and within the season. The principal source of concern in recent years has been inconsistency between fishery-dependent sources and independent surveys.

Fishery-independent monitoring surveys have been undertaken in the SZRLF since 2006, with broadly consistent trends in survey and fishery-dependent logbook estimates of undersized and legal-sized catch rates up to 2010. However, since 2011, diverging trends in relation to fishery performance have been observed between the two sources of data. Specifically, while logbook derived catch rate (number of lobsters/potlift), has increased or remained relatively stable for both legal and undersized lobsters, both indices have declined based on survey data. Notably, unlike fishery-dependent logbook data, current survey catch rates for both legal and undersized in 2014 were the lowest on record in a historical context.

Emerging spatial changes in catch and effort within the SZRLF are an important consideration in relation to observed differences between fishery-independent and fishery-dependent data outputs. While catch and effort has remained relatively stable in MFAs 51 and 56 over the last four to five seasons, there has been a notable decline in MFA 55 and a corresponding increase, over the same time period, in MFA 58. This reflects a shift in fishing effort from north to south in the zone. The driving factor behind this shift is likely to be the observed spatial differences in catch rate between regions. While catch rate has increased in MFA 56 since 2009, the rate of increase has been greater in MFA 58, which is currently

experiencing the highest CPUEs in the fishery at approximately 1.2 kg/potlift. If the observed increase to logbook derived CPUE is being driven by spatial shifts to high catch areas, thereby masking overall declines in lobster abundance as the fishery-independent surveys would suggest, then this factor needs to be given careful consideration from a resource management perspective. Overall, these results highlight the importance of fishery-independent monitoring surveys when assessing lobster stocks under changing fleet dynamics.

From a modelling perspective, commercial catch rate is a primary data input to both models. Model trends in biomass tend to track CPUE. Both models have other sources of data (catch in number, length frequencies, and for LenMod, FIMS) informing biomass trends, but as formulated, commercial catch rate currently dominates. Model biomass trends are therefore strongly influenced by trends in raw commercial catch rate.

The overall implications for the harvest strategy of heightened uncertainty in catch rate as a measure of abundance, are significant. The current strategy uses raw commercial catch rate to set the TACC annually. If true changes in stock abundance are being masked by vessel fleet dynamics, then the harvest strategy decision rules would be inadequately informed. The evidence from FIMS is that raw CPUE may be overestimating trends in stock abundance.

7.2 Current Status of Southern Zone Rock Lobster Fishery

Current catch levels in the SZRLF are low in a historical context. Since 2010, the TACC has been set at 1,250 t (reduced to 1,245.7 t in 2014 as part of the marine park voluntary commercial fisheries catch/effort reduction program) and in 2014 was fully taken for the fifth consecutive season. Over this period, this level of catch has resulted in a considerable improvement in SZRLF status. Catch rates have increased by 72% and are now at the long-term average for the fishery. These increases have been observed across all major MFAs of the SZRLF but are more pronounced in the southern regions, notably MFA 58, which currently has the highest catch rates in the zone. Increased catch rates reflect the reduction in fishing effort in recent seasons, with the 2014 estimate of 1,207,123 potlifts representing a decrease of 41% from 2009.

In combination with reduced effort levels, the recent increases to CPUE reflects the parallel increases in PRI observed in 2009, 2010 and 2013 which subsequently recruited into the fishable biomass. This is supported by length-frequency data, which indicates increases in the frequency of lobsters above the MLS over the last few seasons.

In combination with reduced fishing effort, above average levels of puerulus settlement observed in the SZRLF from 2005 to 2009 may also have contributed to recent increases in CPUE within the fishery. While the relationship between settlement, pre-recruit indices and recruitment in the SZRLF is not explicit in terms of absolute biomass, there are clear signs that relative correlations exist between the indices (Linnane et al. 2013; 2014a). Based on known growth rates in the fishery (McGarvey et al. 1999a), the period between settlement and pre-recruit is ~4 years, with recruitment occurring into the fishery one year later (i.e. 5 years after settlement). As a result, 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, has ultimately resulted in increases to commercial CPUE over the last four seasons.

Overall, outputs from the qR and LenMod fishery models agree with recent trends in empirical data sources. Both models indicate moderate increases in legal size biomass and egg production over the last five seasons following the considerable decreases in these indicators from 2002 to 2009. Importantly, levels of exploitation rates have decreased from the historical high of about 70% in 2009, with current estimates ranging between 47% to 51%.

While recent catch rate, biomass and exploitation rate trends are positive signs, the long-term trends in undersized abundance continue to be a concern within the fishery. The PRI has decreased by 56% since 1999 and the 2014 estimate is one of the lowest on record. The decrease is consistent across all MFAs of the fishery. In particular, estimates in MFA 56 and 58, which are two key indicator regions in terms of undersized abundance, are both at historically low levels. In addition, increases in legal-sized mean weight, an indicator of lower recruitment levels to the fishery, has been observed across the fishery consistently over the last four seasons. Despite these trends, recent levels of catch, which are relatively low in an historical context, are negating, to some extent at least, the impacts of reduced recruitment on the current level of CPUE, which remains at the long-term average.

In summary, despite current levels of recruitment, recent management decisions have prevented fishery declines. Specifically, (i) TACC levels since 2010 have constrained catch to historically low levels; (ii) effort has subsequently been reduced by ~40%; and (iii) the CPUE in 2014 was above the LRP. As a result, based on a weight-of-evidence approach, the SZRLF is classified as "**sustainable**".

7.3 Future research priorities

Given diverging trends of FIMS and CPUE, and the well documented shift of effort southward to higher catch rate and recruitment areas, fleet dynamics may be impacting the reliability of catch rate as an overall zonal measure of abundance. As this is a key indicator used to set TACCs annually based on the harvest strategy, the need to improve CPUE as a measure of abundance has become a priority. Catch rate standardisation provides one tool for improving raw commercial catch rate. As a result, the South Australian Rock Lobster Fisheries Management Advisory Committee Research Sub-committee has identified catch rate standardisation as a key future research priority for the fishery.

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9 APPENDICES

Appendix 1. 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-plus. As data input, it uses yearly totals for commercial lobster catch in both weight and numbers landed, and for effort. Prior values for instantaneous natural mortality rate and a vector for mean weight-at-age are assumed.

Data and fixed parameter inputs

Data and fixed parameter inputs

Annual lobster catch in the South Australian lobster fisheries is reported in commercial landings logbooks by weight (C_t^W) and by numbers (C_t^N). Effort (E_t) is reported as yearly potlifts. A year (t = 1983, …, 1983+n_t-1) refers to a full 8-month fishing season, 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 a =20+ refers to the highest age group including all lobsters of age 20 years or older. The mean weights-at-age $\{w_a;\ a=1, 20+\}$ of harvested lobsters (McGarvey et al. 1999a) 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, as exponential decline in population abundance within each yearly time step. Recruitment in

each year is a freely estimated parameter. Catchability is estimated separately for two time periods, before and after the imposition of quota management.

Model variables are listed in Table 9-1. 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 are assumed to be independent of age. Growth is expressed through the vector of mean weights at age.

Yearly cohort losses due to natural mortality and harvesting are written:

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

where total mortality $Z_t = F_t + M$. Deaths due to harvesting were summed to yield predicted catches by number ($\hat{C}_t^N$) and weight ($\hat{C}_t^W$) in each year of the data 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 ($N_{a,1983}$) was derived assuming a stationary age structure using the first estimated recruitment R_{1983} and a freely estimated F_0:

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

Starting values of parameters were obtained by solving a steady-state version of the qR model for each year independently. For the starting values of parameters that do not vary over time (all except recruitment), time averages of all yearly steady-state qR model estimates were used.

Likelihood function

The negative log likelihood was written:

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

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

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

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

Estimates of free parameters, q, q^{quota}, σ_C, F_0, and yearly recruitment $\left\{R_t; t = 1983, 1983 + n_t - 1\right\}$, were obtained by minimising the negative log-likelihood using the GlobalSearch routine (Loehle Global Optimizer) in Mathematica v. 8.

The output of yearly average biomass over each year was calculated as the age-specific sum of population number times mean weight, with a correction factor ($\left[1 - \exp\left(-Z_t\right)\right] / Z_t$) applied to obtain the negative exponentially integrated mean over the full yearly time period:

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

Similarly, yearly egg production by female lobsters was computed as:

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

where m_a and f_a are previously-estimated vectors of maturity and fecundity versus age (Prescott et al. 1996), and a sex ratio of one-half was assumed.

Table 9–1 Variables of the qR model dynamics.

Model Variable	**Description**
a	subscript for age, 1 to 20+ (the last age group representing ages 20 years and older)
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	number of recruits at start of year t
F_t	fishing mortality in year t
$\hat{C}_t^N$	model numbers of lobsters caught in year t
$\hat{C}_t^W$	model weight of catch in year t
N_t	total population number start of year t
B_t	biomass of lobsters at start of year t
$Eggs_t$	eggs produced by female lobsters in year t

Appendix 2. 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 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 ith 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, giving numbers of lobsters by sex (s), fishing season (y), month (i), and length bin (l) , is $N^s_{y,i,l}$.

The population dynamics model

Basic dynamics

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

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

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

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

$\tilde{H}^{s}_{y,i,l'}$ 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:

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

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:

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

$\tilde{\sigma}_R$ 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}).

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:

$$\tilde{B}_y = \sum_l Q_l\ N^{\text{f}}_{y,i_m,l} \tag{4}$$

where Q_l is the expected number of eggs produced by a mature female in size-class l, and i_m is the time-step in which spawning occurs (month 1).

Catches

$C^{f}_{y,i}$, which is the catch data by fleet *f* during time-step i of year y (equal to the landed catch multiplied by one plus the ratio of numbers landed to discards which die), 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:

$$F^{f}_{y,i} = \frac{C^{f}_{y,i}}{\sum_{l}\sum_{s} \tilde{S}^{s,f}_{y,i,l}(1-\tilde{p}^{s}_{i,l})V^{s}_{i}\,W^{s}_{l}\,\tilde{N}^{s}_{y,i,l}} \tag{5}$$

where and $\tilde{N}^{s}_{y,i,l}$ is the number of animals of sex s in size-class l when the catch during time-step i of year y is removed (halfway through the time-step). Commercial data includes information on spawning lobsters and those brought up dead in the pots, while four surveys (1998, 2001, 2004, and 2007) are used as the basis to estimate catches for the recreational fleet. Vulnerability $\tilde{S}^{s,f}_{y,i,l}$ is the same for commercial and recreational fishers.

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

$$\tilde{H}^{s}_{y,i,l} = \sum_{f} \tilde{S}^{s}_{y,i,l}(1-\tilde{p}^{s}_{i,l})V^{s}_{i}\,F^{f}_{y,i} \tag{6}$$

where:

V^{s}_{i} is the relative vulnerability of males to females during time-step i (V^{s}_{i}=1 for males);

$\tilde{p}^{s}_{i,l}$ 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 of the gear used on animals of sex s in size-class l during time-step i of year *y* given the implications of the legal minimum size as:

$$\tilde{S}^{s}_{y,i,l} = \begin{cases} 0 & \text{if } L^{s}_{l} + \Delta L^{s}_{l} \le \mathrm{LML}_{y} \\ S^{s}_{i,l} & \text{if } L^{s}_{l} \ge \mathrm{LML}_{y} \\ S^{s}_{i,l}(L^{s}_{l} + \Delta L^{s}_{l} - \mathrm{LML}_{y}) / \Delta L^{s}_{l} & \text{otherwise} \end{cases} \tag{7}$$

L_l^s is the lower limit of size-class l for sex s, ΔL_l^s is the width of a size-class l for sex s (4 mm), LML_y is the legal minimum size during year y (allowance is made for vulnerability to differ among years to model future changes to legal minimum sizes), $S_{i,l}^s$ is the vulnerability of the gear used on animals of sex s in size-class l. There were no changes in LML_y over the whole time series.

1.3. 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 and independent catch rates,
b) length-sex frequency data from sampling of commercial potlifts, 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:

$$L_1 = \prod_y \prod_i \frac{1}{I_{y,i}^{\text{Comm}} \sqrt{2\pi}\, \sigma_{q,i}^{\text{Comm}}} \exp\left(-\frac{(\ell\text{n} I_{y,i}^{\text{Comm}} - \ell\text{n}(q_i^{\text{Comm}} B_{y,i}^{e,\text{Comm}}))^2}{2(\sigma_{q,i}^{\text{Comm}})^2} \right) \tag{8.a}$$

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

$$L_1 = \prod_y \prod_i \frac{1}{K_{y,i}^{\text{FIMS}} \sqrt{2\pi}\, \tilde{\tilde{\sigma}}_{q,i}^{\text{FIMS}}} \exp\left(-\frac{(\ell\text{n} K_{y,i}^{\text{FIMS}} - \ell\text{n}(\tilde{\tilde{q}}^{\text{FIMS}} q_i^{\text{Comm}} B_{y,i}^{e,\text{Comm}}))^2}{2(\tilde{\tilde{\sigma}}_{q,i}^{\text{FIMS}})^2} \right) \tag{8.b}$$

where:

q_i^{Comm} is the commercial catchability coefficient;

$\sigma_{q,i}^{\text{Comm}}$ is the standard deviation of the random fluctuations in catchability for log-catch-rate for time-step i for the commercial fleet;

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

$\tilde{\tilde{\sigma}}_{q,i}^{\text{FIMS}}$ is the standard deviation of the random fluctuations in catchability for FIMS during time-step i;

$\tilde{\tilde{q}}^{\text{FIMS}}$ 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 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_i^{Comm}, $\sigma_{q,i}^{\text{Comm}}$, and $\tilde{\tilde{\sigma}}_{q,i}^{\text{FIMS}}$ were

obtained analytically, while the value for $\tilde{q}^{\text{FIMS}}$ 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:

$$B_{y,i}^{e,Comm} = \sum_{s}\sum_{l} V_i^s \, \tilde{S}_{y,i,l}^s \, W_l^s \, (\tilde{N}_{y,i,l}^s - C_{y,i,l}^s / 2) \tag{9}$$

and the catch of animals of sex s in size-class l during time-step i of year y is:

$$C_{y,i,l}^s = W_i^s \, \tilde{N}_{y,i,l}^s \, \tilde{H}_{y,i,l}^s \, . \tag{10}$$

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 potlifts 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:

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

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):

$$L_2 = \prod_{y}\prod_{i}\prod_{l}\prod_{s} \left(\hat{\rho}_{y,i,l}^{s,\text{Comm}}\right)^{\omega \cdot n_{y,i,l}^{s,\text{Comm}}} \tag{11.b}$$

where $n_{y,i,l}^{s,\text{Comm}}$ 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 = 0.125 is a down-weighting constant factor introduced to reduce the influence of this data relative to the catch-effort data sets (acknowledging that 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 predictions given by:

$$S_{y,i,l}^{s} V_i^s (1-\tilde{p}_{i,l}^{s}) \tilde{N}_{y,i,l}^{s} \,. \tag{12a}$$

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

$$S_{y,i,l}^{s} V_i^s \tilde{p}_{i,l}^{s} \tilde{N}_{y,i,l}^{s} \,. \tag{12b}$$

Catch-in-number

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

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

where $\hat{C}_{y,i}^{N} = \sum_s \sum_l V_i^s \tilde{S}_{y,i,l}^{s} (1-\tilde{p}_{i,l}^{s}) \tilde{N}_{y,i,l}^{s} F_{y,i}^{\text{Comm}}$ and σ_N^{Comm} is the standard deviation of the random fluctuations in catch numbers for the commercial fleet, assumed to apply over all time. The spawner discards are also fitted under the assumption that they are lognormally distributed.

Parameter estimation

Table 9–2 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 each fleet is estimated, separately for each sex, by a logistic function of length, and is the same for commercial and recreational fishers. Female vulnerability by time-step is estimated. 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:

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

Table 9–2 Parameters of the length-structured model (LenMod) model and their sources.

Parameter	Description	Value	Sources
ε_y	The settlement residuals for year *y*	Estimated	
$\ell n(\overline{R})$	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 of males to females by time-step	Estimated	
$S^s_{i,l}$	Vulnerability of the gear by sex, size-class and time-step	Estimated as sex-specific logistic functions of length	
$\tilde{p}^s_{i,l}$	Proportion of mature spawning animals by sex, size-class and time-step		Estimated externally
Ω^s_l	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	
$q^{\text{Comm}}_i, \tilde{\tilde{q}}^{\text{FIMS}}$	Catchability for the commercial fleet and FIMS by time-step *i*	Estimated	
$\sigma^{\text{Comm}}_{q,i}, \tilde{\tilde{\sigma}}^{\text{FIMS}}_{q,i}$	Standard deviation of the random fluctuations in catchability for time-step *i* for commercial fleet and FIMS	Estimated	

σ_N^{Comm}	Standard deviation of the random fluctuations in commercial catch in numbers	Estimated