Informing spatial and temporal management of the South Australian Northern Zone Southern Rock Lobster (*Jasus edwardsii*) Fishery

Final Report to the Fisheries Research and Development Corporation

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Abbreviations

AUD – Australian Dollars
CL – Carapace length
CPUE – Catch Per Unit Effort
CRC – Co-operative Research Centre
FRDC – Fisheries Research and Development Corporation
ICES – International Council for the Exploration of the Sea
ITQ – Individual Transferable Quota
LenMod – Length-based stock assessment model
MFA – Marine Fishing Areas
MLS – Minimum Legal Size
NIWA – National Institute of Water and Atmospheric Research
NZRLF – Northern Zone Rock Lobster Fishery
OZ – Outer Zone
PIRSA – Primary Industries and Regions South Australia
qR model – Lobster model estimating catchability (q) and recruitment (R)
RLFMAC – Rock Lobster Fishery Management Advisory Committee
RSC – Research Sub-Committee
SARL – South Australian Rock Lobster
SARDI – South Australian Research and Development Institute
TACC – Total Allowable Commercial Catch

Executive Summary

The Northern Zone Rock Lobster Fishery (NZRLF) of South Australia is extensive, covering approximately 207,000 km^2. The fishery has been managed as a single spatial unit using both input and output controls which includes a total allowable commercial catch (TACC) of 323 t in 2014/15. Temporally, a closed season extends from 1 June to 31 October each year. Despite its size, the majority of the annual TACC is taken within inshore grounds (<60 m depth) in the eastern region of the fishery. This trend is largely driven by overseas market demands for lobsters of a particular size and colour, specific to shallow-water areas. The confined nature of fishing behaviour under the TACC system has led to concerns within the industry of localised spatial depletion and the subsequent need for an adaptive management response. In addition to being spatially confined, fishing in the NZRLF is temporally restricted by the current fishing season, with the majority of the catch taken from November to March each year.

In order to inform possible changes to temporal and spatial management options, this project was developed in response to the following needs: (i) information on the catch composition in the NZRLF during the current closed season, from June to October, and (ii) spatial biomass estimates within the NZRLF to ensure that harvest strategies set annual TACCs based on sustainable and economically optimal levels of exploitation rate. Further to the identified needs, the objectives of this project were to: (i) provide a detailed breakdown of catch composition in each of four specific regions in the NZRLF from dedicated surveys undertaken from June to October; and (ii) generate spatial estimates of Rock Lobster biomass in the fishery using historical catch and effort data.

In 2014, a winter fishing survey was successfully completed with 104 out of a possible 120 days sampled (87%) and 3.6 t of lobsters landed. The overall survey catch rate was 0.49 kg/potlift. This estimate was approximately 50% below that of the normal fishing season but this could be expected given that: (i) overall lobster catchability decreases during winter, and (ii) only males were retained during the survey and therefore the kg/potlift estimate was lower than the normal fishing season estimates when both sexes are allowed to be taken. The highest catch rate was observed in August (0.68 kg/potlift) within the western part of the fishery. These estimates were driven by mean weight which was consistently higher across all survey months in western areas. High mean weights were further confirmed by length frequency data which showed that larger lobsters (predominantly males) above 150 mm carapace length were more prevalent in the west compared to all other areas. These results are likely to reflect the known spatial variation in lobster growth across South Australia.

Previous within-season trends have shown that during the normal fishing season, the highest levels of undersized lobster catch occurs from November to March but declines considerably thereafter. The results from the current survey were positive in that undersized catch rates remained low from June to October.

During the survey period, the sex ratio of individuals was primarily skewed towards males, especially during June, July and August. Egg bearing females first appeared in the catch in June, with levels peaking in September. However, given the overall reduction in catchability of females during most of the survey period, the contribution of ovigerous individuals to the total catch was low, ranging from 2% to 26%. These levels are comparable to those recorded in October in the Southern Zone Rock Lobster Fishery when the fishing season starts in that zone.

A total of 29 by-catch species were identified in the survey but with the exception of four groups (Leatherjackets, Bluethroat Wrasse, Hermit Crabs and Port Jackson Shark), overall by-catch catch rates were negligible (<1 individual/100 pots). Leatherjacket and Bluethroat Wrasse are the dominant commercial Rock Lobster by-catch species across South Australia. The results indicated that the catch rate of these species was lowest during winter before increasing during spring and summer. The primary by-product species in the fishery are Giant Crab and Maori Octopus. Only a single Giant Crab was landed during the survey, while the catch rates of Octopus (that are known predators of Rock Lobster) during the survey were considerably lower when compared to months during the regular fishing season. The survey results confirmed low levels of dead lobsters which tend to be highest during spring and summer.

Based on extensive consultation with industry stakeholders, estimates of biomass were generated for three spatial sub-regions; West Coast, Deep Water and Inner Region using the South Australian qR lobster fishery model. Two-thirds of the biomass was estimated to lie in the Inner Region, with 28% and 6%, respectively, in the West Coast and Deep Water. However, the Inner Region comprised 93% of the average yearly catch since 2009, with 5% and 1.5% of landings coming from the West Coast and Deep Water. Accordingly, exploitation rates were much lower in the West Coast and Deep Water with only 3% and 4% of the lobster stock biomass in those sub-regions harvested annually since 2009, compared with 32% in the Inner Region. Thus, a principal outcome of this project was to quantify low levels of exploitation in the outer regions of the NZRLF.

Growth rates of lobsters varied spatially by sub-region. Deep Water lobsters grow more slowly than Inner Region or West Coast counterparts, implying a lower stock productivity below 80 m depth. The mean weight of lobsters during the current 7-month fishing season was similar in the Inner and Deep Water regions, but was higher in West Coast waters, consistent with the larger lobsters harvested in this area during the winter fishing survey.

The outcomes of this project have been directly applied to the management of the NZRLF. Spatial management of the TACC in this fishery was recommended by the South Australian

Rock Lobster Fishery Management Advisory Committee (RLFMAC). The boundary line separating the Inner and Outer Regions has been accepted, with the Outer Region combining West Coast and Deep Water areas. An amended NZRLF harvest strategy was implemented into the management arrangements in 2015 based on Inner and Outer regions, with a new schedule of TACCs underpinned by spatial biomass and exploitation rate estimates generated from this project. TACCs were computed to target 21% and 10% exploitation rates in the Inner and Outer Regions, respectively.

At the request of the RLFMAC, to further investigate the option of a 12-month fishing season, in 2015, a second commercial fishing survey was undertaken based on a maximum of 175 fishing days (35 days for each of five months June to October inclusive). While results of this survey are not presented in this report, the findings in terms of catch composition, were in close agreement with those observed during the 2014 surveys.

It is envisaged that optimal economic benefit of these revised NZRLF management arrangements will accrue from the combination of winter fishing and spatial management. Specifically, the predominantly larger fish taken from the Outer Region are anticipated to attract a higher price by fishers in winter thereby improving overall economic return in this important commercial fishery.

Keywords

Southern Rock Lobster, Northern Zone Rock Lobster Fishery, temporal management, spatial management, crustacean fishery, lobster biomass, exploitation rates, catch composition.

1 Introduction

Southern Rock Lobster *Jasus edwardsii* (Hutton 1875) are distributed around the southern mainland of Australia, Tasmania and New Zealand (Phillips 2013). They are primarily found on limestone reef systems or isolated granite formations that provide ideal Rock Lobster habitat in the form of protective crevices or ledges. In south-eastern Australia, the resource supports important regional fisheries across the States of South Australia, Victoria and Tasmania. The total annual catch across all States ranges from 3,500-4,000 t with an estimated gross commercial value of ~AUD$200 million (Skirtun et al. 2013). Fishing methods have not changed markedly over time and generally consist of baited pots that are set individually, left overnight and hauled at first light.

The South Australian fishery is divided into two management zones; Northern and Southern, which are further sub-divided into Marine Fishing Areas (MFAs) for statistical purposes. The Northern Zone Rock Lobster Fishery (NZRLF) is extensive, covering all South Australian marine waters between the mouth of the Murray River and the Western Australian border, an area of approximately 207,000 km^2. From a stock assessment perspective, MFAs are grouped into four regions (Figure 1) that acknowledge key biological differences among areas. However, despite monitoring catch by both region and MFA, the NZRLF is currently managed as a single spatial unit using both input and output controls (PIRSA 2014). The season extends from 1 November to 31 May of the following year. There is a minimum legal size (MLS) of 105 mm carapace length (CL), prohibition on the taking of ovigerous females and several sanctuaries where lobster fishing is prohibited. In 2003, a Total Allowable Commercial Catch (TACC) was introduced. The TACC is set annually and divided proportionally between licence holders as individual transferable quotas (ITQs). Each licence holds one quota unit entitlement for each pot entitlement held. The daily catch of licensed operations is monitored through mandatory commercial logbooks and quota monitoring catch and disposal records. In the 2014/15 season, the TACC was 323 t.

This project primarily stems from concerns in recent seasons over changes in fishing behaviour within the NZRLF under the ITQ system. Specifically, these centre on the spatial contraction of the fleet and potential for localised depletion as a result. Evidence from catch monitoring of *J. edwardsii* fisheries suggest that fleet dynamics have indeed changed over time with a number of recent studies across south-eastern Australia indicating that the majority of the annual Rock Lobster catch is now taken within discrete depth ranges of the fishery (Chandrapavan et al. 2009; Linnane and Crosthwaite 2009; Chandrapavan et al. 2011). The factors driving these trends appear to be primarily economic, underpinned by unique market demands for Southern Rock Lobster. Approximately 90% of the annual catch is exported live, mainly to China, where consumers favour small (<1 kg), “red”-coloured lobsters that are primarily found inshore as opposed to larger “speckled” or “white” lobsters that are synonymous with offshore grounds. As a result, since quotas began to effectively constrain catch in the NZRLF after considerable TACC reductions in 2009, higher prices for inshore lobsters have driven effort into shallow water grounds, evidenced by the fact that approximately 80% of the annual TACC across south-eastern Australia is taken at <60 m depth (Linnane and Crosthwaite 2009). In addition to being spatially confined, fishing in the NZRLF is currently temporally restricted by the fishing season, with the majority of the catch taken from November to March each year (Linnane et al. 2014).

This project was an industry-led initiative that aimed to explore alternative fishery management arrangements at both spatial and temporal scales. It was developed through consultation with the South Australian Northern Zone Rock Lobster Fishermen’s Association and the South Australian Rock Lobster Management Advisory Committee (RLMAC) Research Sub-Committee (RSC). The work aimed to build on an earlier Fisheries Research and Development Corporation (FRDC) project (2011/072) *Assessing the feasibility of spatial management in the South Australian Northern Zone Rock Lobster (Jasus edwardsii) fishery* (Linnane and McGarvey 2014) and connects to the recently completed Seafood Co-operative Research Centre (CRC) Project (2009/714.20) *Bioeconomic decision support tools for Southern Rock Lobster* (McGarvey et al. 2014).

Broadly, the project aimed to inform management decision-making by generating data specific to temporal and spatial fishing aspects in the NZRLF. From a spatial perspective, a number of management options are currently being considered that aim to utilise Rock Lobster stocks in both western and offshore regions of the Northern Zone at higher levels of exploitation. Fundamental to any spatial management option is the need to generate spatial estimates of biomass to ensure that any increase in catch from peripheral regions is sustainable from a management perspective. Currently, estimates of biomass in the fishery are across the entire zone. This project aimed to generate spatial biomass estimates in operational areas of the Northern Zone based on historical logbook catch returns using the qR Rock Lobster fishery model which had been specifically developed for this fishery.

From a temporal viewpoint, the commercial industry wished to examine the possibility of an extended fishing season to enhance profitability by providing product during a period of low supply and higher prices. Currently, there are no available fishery or biological data from the Northern Zone during the closed season from June to October. In particular, there is a need to attain information on the proportion of ovigerous (spawning females) in the catch during this period. Through a number of dedicated surveys, this project aimed to provide a detailed catch breakdown in each fishery region during the current closed season.

2 Need

1) In order to inform decision-making on temporal management arrangements, there is a need to attain data on catch composition during the closed season from June to October. This is required across the whole extent of the fishery.

2) In order to inform decision-making on spatial management arrangements, there is a need to generate spatial biomass estimates to ensure that current harvest strategies set annual TACCs based on sustainable and economically optimal levels of exploitation rate.

3 Objectives

Based on the above needs, the objectives of this project were to:

1) Provide a detailed breakdown of catch composition from dedicated surveys undertaken in the NZRLF from June to October.

2) Provide spatial estimates of Rock Lobster biomass in the NZRLF based on historical catch and effort data.

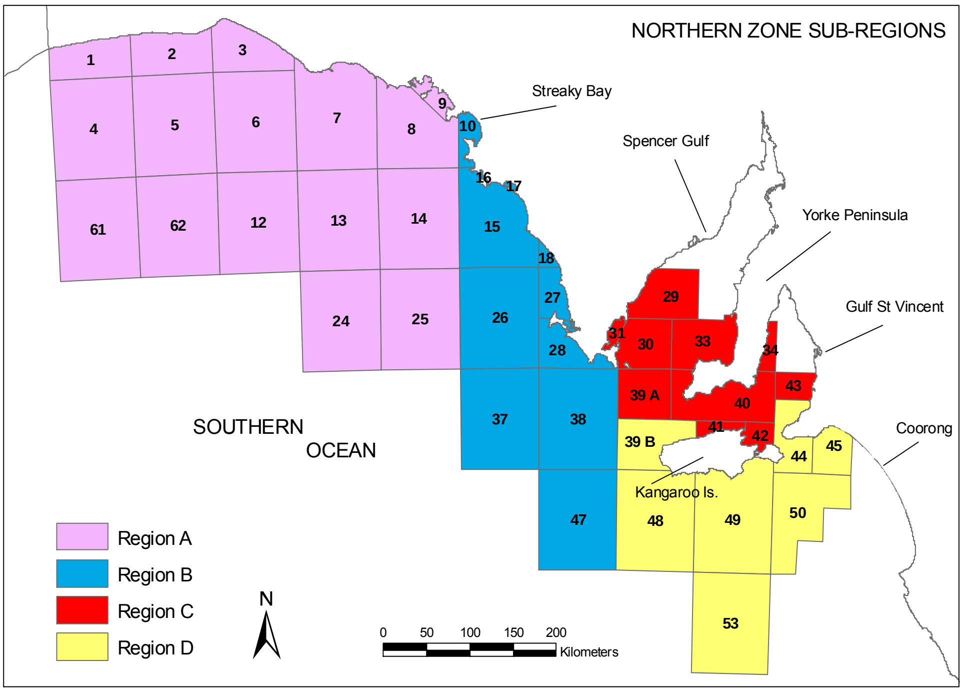


Figure 1. Key spatial management regions of the NZRLF.

4 Methods

4.1 Temporal component

4.1.1 Surveys

Catch composition and commercial fishery-dependent catch data during the closed season were attained through dedicated surveys using commercial vessels with independent South Australian Research and Development Institute (SARDI) Aquatic Sciences observers on-board for all trips. Sampling was undertaken for six days in each of four NZRLF regions (Figure 1) from June to October (a total of 120 sampling days). The time of sampling, as well as the vessels involved, was decided and arranged by the South Australian Northern Zone Rock Lobster Fishermen's Association in collaboration with PIRSA Fisheries and Aquaculture and SARDI Aquatic Sciences.

4.1.2 Data collection

Catch composition data collection followed the protocols currently used in the NZRLF commercial catch sampling program. This involved independent on-board observers recording the number, size and sex of all lobsters, in all pots, during each fishing day. The reproductive condition of females (ovigerous or non-ovigerous) was also detailed, as well as the number and species of all by-product and by-catch landed. By-product is defined as non-targeted catch that is commercially valuable and therefore retained by fishers.

Commercial fishery-dependent catch data were recorded by vessel skippers within mandatory commercial logbooks. This included the MFA and depth within which the fishing took place, number of pots set, weight of retained legal size lobsters (>105 mm CL) reported at the end of each trip or as a daily estimated weight and landed number of legal size lobsters. For the purpose of this study, only legal size males were permitted to be retained in the catch and therefore all catch rate estimates are based on kg/potlift of males only. Once collated, all data were entered into the South Australian Rock Lobster (SARL) database which is maintained by SARDI.

4.1.3 Data analyse

Catch and effort data from both logbooks and the catch sampling program were used to estimate a range of temporal and spatial fishery indices including legal sized catch rate (kg/potlift), pre-recruit indices (undersized/potlift), and mean weight (kg). Size data from catch sampling were used to generate length frequency distributions, while sex data allowed for sex ratios and percentage of females in various stages of reproductive condition to be determined.

4.2 Spatial component

There were three components to providing spatial estimates of biomass in the NZRLF: (i) a summary analysis of historical catch and effort data in each of the agreed sub-regions within the Northern Zone (Figure 2). These data are critical inputs to the qR stock assessment model (McGarvey et al. 1997; McGarvey and Matthews 2001); and (ii) estimation of lobster growth. This is based on the qR model using weights-at-age information as input information about growth in each of the sub-regions; and (iii) qR model fits and spatial estimates of biomass.

4.2.1 Spatial sub-regions

Through a series of meetings held between the South Australian Northern Zone Rock Lobster Fishermen's Association, PIRSA Fisheries and Aquaculture and SARDI Aquatic Sciences during September to December 2014, three sub-zonal regions were developed for the NZRLF, (i.e. Inner, West Coast and Deep Water Regions; Figure 2).

Specific details of the boundaries associated with these sub-regions are as follows. Records from potlifts set at depth >80 m were all assigned to Deep Water. Records where depth was <80 m were assigned either to the West Coast if fishing occurred in MFA Blocks 1-9, 12-14, 24, 25, 61 and 62, or to the Inner Region if fishing occurred in MFA Blocks east of block 14. Where records of catch fell exactly on the 80 m boundary, yearly totals of catch weight, catch number and effort were divided in half and allocated in equal parts to either the Inner Region and Deep Water, or to the West Coast and Deep Water, according to its MFA block.

As the 80 m depth contour did not pass uniformly through MFAs 49 and 50, these regions were handled differently from an analytical perspective. This involved a new boundary line separating the Inner from the Deep Water sub-region by a straight east-west latitude line at 36° 20' S. As the straight line did not strictly follow a depth contour, and so depth alone could not identify the spatial location of each catch log record, mean weight of landed lobsters (computed as daily catch in weight divided by catch in number) was adopted as an additional criterion for allocating records to Inner or Deep Water sub-regions in these two MFAs. Based on fishing industry advice and the knowledge that mean weight increases with depth in the NZRLF (Linnane et al. 2014), catch was then allocated between Inner and Deep Water sub-regions in these two MFAs as follows. For MFA 49; (i) catch records from depth ≥80 m were included in the Deep Water sub-region, (ii) records from 60-80 m that had a mean lobster weight >1.3 kg were included in the Deep Water sub-region, (iii) records from 60-80 m that had a mean lobster weight <1.3 kg were included in the Inner sub-region, and (iv) records from <60 m were included in the Inner sub-region. For MFA 50, (i) all records of mean weight >1.3 kg were included in the Deep Water sub-region, and (ii) all other catch records were included in the Inner sub-region.

4.2.2 Historical catch and effort data

Mandatory logbooks have been in place in the NZRLF since 1970. Based on these fishery-dependent data, spatial estimates of catch (t), effort (number of potlifts), catch per unit effort (CPUE) (kg/potlift) and mean weight (kg) by MFA and depth range were generated from the 1970 to 2013 fishing seasons for each sub-region.

4.2.3 Lobster growth

Growth data were attained from a tagging study undertaken across South Australia between 1993 and 1996 in which over 61,000 lobsters were tagged and 16,000 recaptured (Linnane et al. 2005). Tag recovery data provided two sources of information for inferring the rates of growth as functions of CL: (i) the time-at-large of each recaptured lobster, and (ii) the change in CL. Parameters describing growth rate from tagging data (time-at-large and lengths at release and recapture) were estimated using GROTAG, a program following methods described in Francis (1988).

4.2.3.1 Tagging data

The tag-recapture records were filtered to remove records with unassigned sex. Only one tag-recapture event per animal was used for the GROTAG analysis, so for lobsters recaptured multiple times, the initial tagging event and the most recent recapture were used to obtain the longest time-at-large. To avoid bias that might have resulted from giving greater weighting to tagged lobsters that were recaptured multiple times, each recaptured lobster in the data set was only used once. As the growth model explicitly accounts for slowing of growth as the asymptotic length is approached, this approach is reasonable.

Tagging and recapture events were assigned to one of three depth-based sub-regions as follows. Recaptures were assigned to the West Coast when reported depth was <80 m for MFA Blocks 1-9, 12-14, 24-25 and 61-62. Similarly, recaptures were assigned to the Inner sub-region for depth <80 m and MFA Blocks east of MFA 14 (see Figure 2). All recaptures with depth ≥80 m were assigned to the Deep Water sub-region. Once all tag and recapture events were allocated to a sub-region, only those that were tagged and recaptured in the same sub-region were used in the GROTAG analysis.

After discussions with industry, MFA Block 50 was treated slightly differently to other areas with recaptures from depths <60 m assigned to the Inner sub-region and recaptures from depths ≥80 m being assigned to the Deep Water sub-region. All recaptures from depths ≥60 m and <80 m were excluded.

4.2.3.2 Growth rate estimation model: GROTAG

Growth rate parameters were estimated for both females and males in each of the three sub-regions. GROTAG is a maximum likelihood estimator, based on a transformed version of the Von Bertalanffy model which assumes that average growth increment declines linearly with CL. The model produces two yearly growth rate parameters, applicable for any two selected lobster body lengths (α and β). These yearly growth rates, gα and gβ, each quantify the estimated yearly mean increases in lobster CL starting from the selected CL's of α and β. In this study, we chose α = 100 mm for both females and males, β = 120 mm for females, and β = 140 mm for males. The increasing spread of observed growth increments about the mean with time was modelled as a power function of mean growth increment.

To overcome the large residuals that were common for the short time-at-large, only tag-recapture records where the time from tag release to recapture was >0.25 years were used. Allowing seasonality parameters to vary had minimal impact on the growth estimates and as a result, seasonality was not included in this growth analysis.

4.2.3.3 Weights-at-age

To estimate yearly biomass using the qR model, a vector of mean weights-at-age of lobsters in the landed catch was required. In this instance, "*age*" refers specifically to the number of years within the legal size population. For example, age =1 (new recruits), refers to lobsters that have, in that year, grown to a size greater than the MLS. Given estimates of the rates of yearly lobster growth, from any given starting length, weights at age can be computed using two additional inputs, the sex ratio in the catch and the weight-length relationship.

Lengths-at-age were computed for males and females separately using the growth rate estimates, gα and gβ with a cubic power function which was then used to convert the lengths-at-age to weights-at-age. The resulting male and female weights-at-age were then combined using the average proportion of females in the catch (0.482) to estimate overall average weights-at-age in the catch.

4.2.4 qR model and spatial estimates of biomass

The qR model was used to estimate biomass by sub-region. This model is routinely used for stock assessment in both the northern and southern South Australian Rock Lobster fishing zones, along with the more comprehensive and detailed LenMod fishery model. In addition to the total removals by fishing, commercial logbook data provide two quantities that convey important information about changing composition and abundance of the lobster stock i.e. yearly catch total in weight (Cw) divided by yearly catch total in number of lobsters landed (Cn) gives the mean weight of landed lobsters (Cw/Cn), thus providing a measure of lobster size. Logbook derived CPUE (kg/potlift), provides information about the time trend in stock biomass. As commercial logbooks report yearly totals, there is no sampling error and are therefore regarded as 100% samples.

The qR model has been shown to provide reliable estimates when data inputs and assumptions are met. Tests of the qR model using simulated input data (where true levels of biomass and recruitment are known, being generated from a computer model based simulation of the fishery) show that the qR model, using these catch and effort time series, can give accurate estimates of biomass, recruitment and exploitation rate (McGarvey et al. 2005).

4.2.4.1 qR model overview

Details of the qR model including associated assumptions and equations are provided in Appendix 1. Broadly, the qR model is an age-based model that fits to catch weight and catch number using a maximum likelihood statistical method (McGarvey et al. 1997; McGarvey and Matthews 2001). It conditions on effort and uses Baranov depletion dynamics. In estimating sub-zonal biomass, the qR model used the following data inputs: (i) catch in weight (by sub-region and year); (ii) catch in numbers of lobsters landed (by sub-region and year); (iii) fishing effort (potlifts by sub-region and year); (iv) tag-recoveries, by sub-region, used to estimate growth; and (v) natural mortality rate (M = 0.1).

The estimated parameters are: (i) catchability; (ii) the average proportion of the stock captured by a single potlift; and (iii) yearly recruitment numbers. The likelihood function is normal for both Cw and Cn, with a single freely estimated likelihood coefficient of variation parameter used in both of these normal likelihood components. Reported biomass is the (analytically integrated) average across each year (rather than start-of-year biomass). Yearly trends in biomass are inferred primarily from CPUE. Mortality, and thus the absolute level of sub-zonal biomass, is indirectly inferred from the mean weight of landed lobsters (Cw/Cn) in combination with weights-at-age.

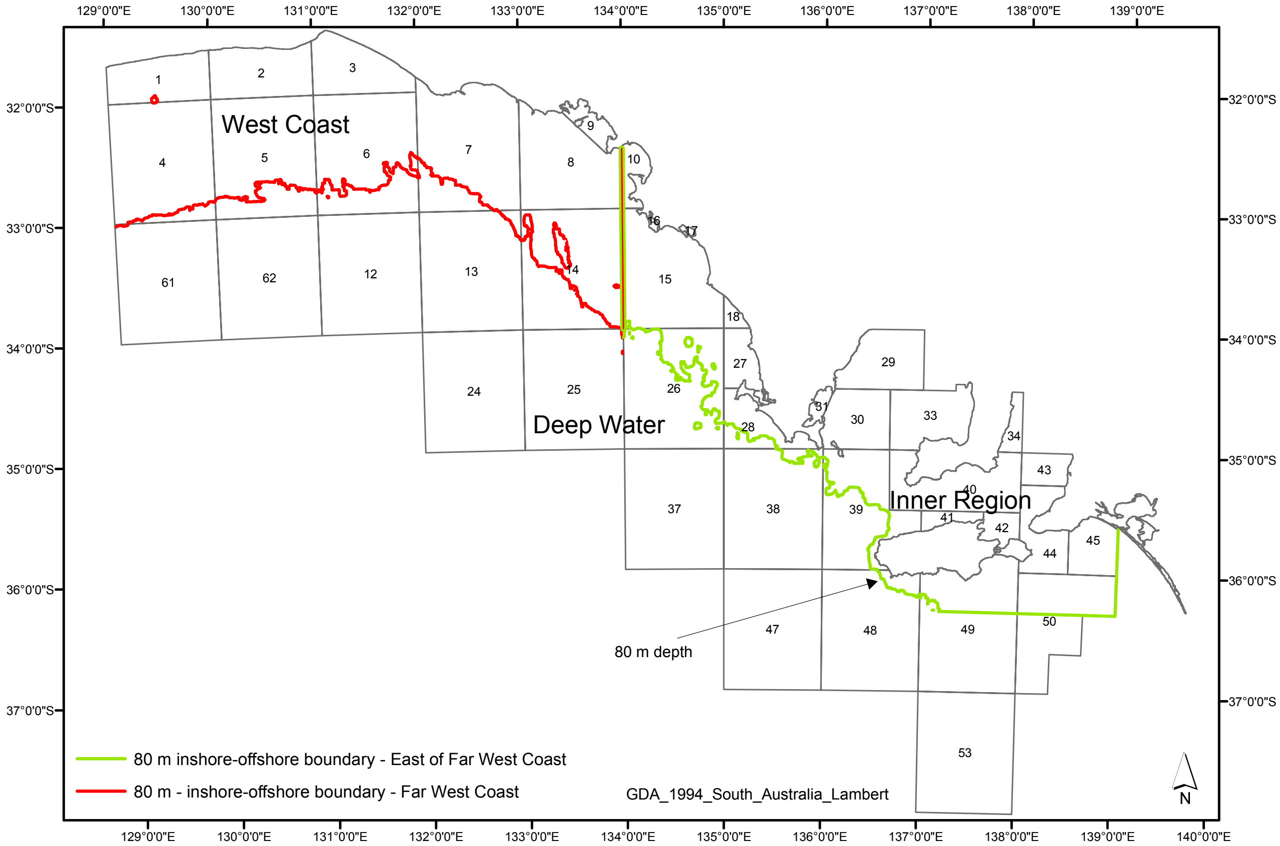


Figure 2. Map showing the three spatial sub-regions of the Northern Zone Rock Lobster Fishery.

5 Results

5.1 Temporal component

5.1.1 Surveys

Out of a possible 120 days available, 104 days (87%) were sampled during the study (Table 1). The shortfall occurred primarily in June due to inclement weather conditions. The regions where no sampling was undertaken for this month were B and D (Figure 1). In total, 3.6 t of male lobsters were landed from a fishing effort of 7,572 potlifts.

Table 1. Number of days sampled and primary catch statistics for temporal surveys undertaken in the NZRLF from June to October 2014 inclusive.

	Days Sampled	Catch (kg)	Effort (potlifts)	Number of lobsters	CPUE (kg/potlift)	Mean Wt (kg)
June	9	178	457	77	0.39	2.31
July	24	821	2080	445	0.39	1.85
August	24	1128	1687	600	0.67	1.88
Sept	23	702	1531	414	0.46	1.70
Oct	24	792	1817	621	0.44	1.28

5.1.2 Fishery statistics

5.1.2.1 Catch and effort

Total temporal trends in catch and effort from June to October are provided in Figure 3. All catch and effort data presented in this section are for males only. Of the 3.6 t landed, the highest catch of 1.1 t was taken in August. Of the remaining months, catch ranged between 700 to 800 kg, with the exception of June where only 178 kg were landed due to adverse weather conditions. Trends in effort generally reflected those of catch.

Regional temporal trends in catch and effort showed that the majority of catch (1.6 t) was taken in Region A (Figure 4). Regions B and C both contributed 0.5 t, while 1 t was taken in Region D. The highest observed catch was in August in Region A when 0.56 t were landed.

5.1.2.2 Catch per unit effort

Monthly catch rates attained during the temporal surveys were compared against those from the regular commercial fishing season from November to May of 2013/14 (Figure 5). Overall, the survey catch rate of 0.49 kg/potlift was considerably lower than the commercial season estimate of 0.94 kg/potlift, which was to be expected given that only legal sized males were permitted to be taken. The highest survey catch rate of 0.67 kg/potlift was observed in August, while the remaining months ranged between approximately 0.4 and 0.5 kg/potlift.

Regional estimates provided some clear trends in terms of spatial variability with monthly catch rate consistently higher in Region A across the entire survey period (Figure 6). Overall Region A catch rate was 0.76 kg/polift, compared to between 0.3 and 0.4 kg/potlift in other areas. The highest catch rate of 1.34 kg/potlift was observed in Region A in August.

5.1.2.3 Mean weight

Mean weights during the temporal surveys were compared against those from the commercial fishing season from November to May of 2013/14 (Figure 7). At 1.70 kg, survey mean weight was considerably higher than the regular season estimate of 1.10 kg, which is likely to reflect that only males were taken during the surveys. The highest survey mean weight was observed in June at 2.31 kg, after which mean weight decreased to 1.31 kg in October.

Higher catch rates in Region A were driven by consistently higher mean weights within this region (Figure 8). Overall, survey Region A mean weight was 2.27 kg, compared to between 1.2 and 1.5 kg in other regions. Highest monthly mean weight was observed in Region A from June through to August at 2.5 kg, before decreasing to 1.8 kg in October.

5.1.2.4 Length frequencies

Regional survey length frequency data confirmed observed differences in mean weight (Figure 9). Lobsters sampled in Region A (males and females combined) were considerably larger than those from other areas. Specifically, 55% of all lobsters measured in Region A were >150 mm CL, while only 14% to 27% of individuals attained this size in other areas. In Regions B to D, lobsters in the 105 to 145 mm CL size classes dominated the samples. Undersized lobsters below the MLS of 105 mm CL were almost entirely absent from the samples as escape gaps were required to be open as part of the regulatory permit for this study.

5.1.2.5 Pre-recruit indices

Total pre-recruit indices during the temporal surveys were compared against those from the commercial fishing season from November to May of 2013/14 (Figure 10). At 0.02 undersized/potllift, survey pre-recruit abundances were considerably lower than the regular season estimate of 0.15 undersized/potlift. The highest survey pre-recruit index was observed in October at 0.04 undersized/potlift.

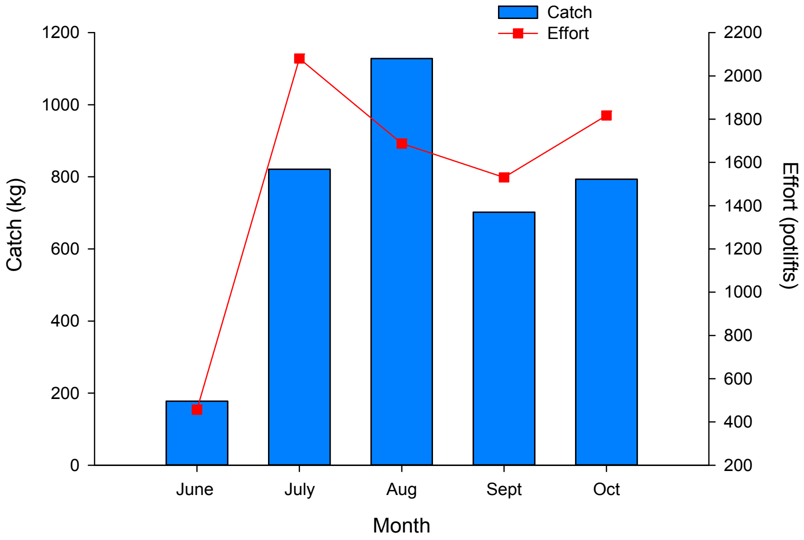


Figure 3. Total temporal trends in catch and effort from June to October 2014 in the NZRLF.

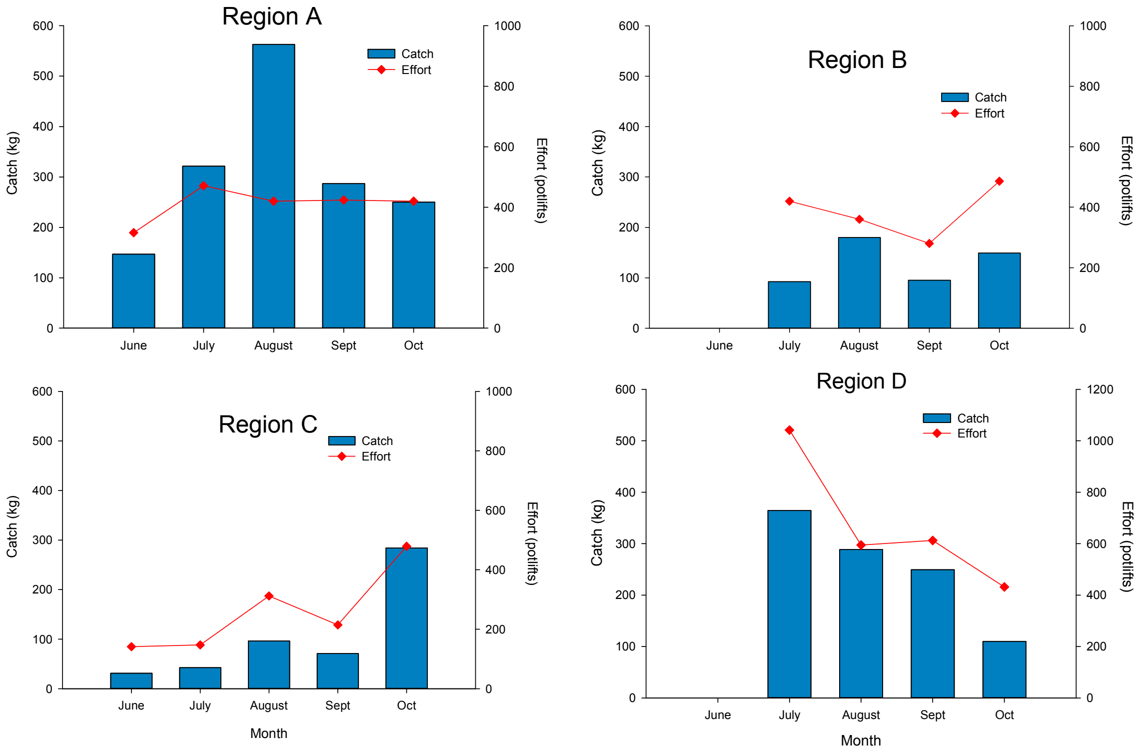


Figure 4. Regional temporal trends in catch and effort from June to October 2014 in the NZRLF.

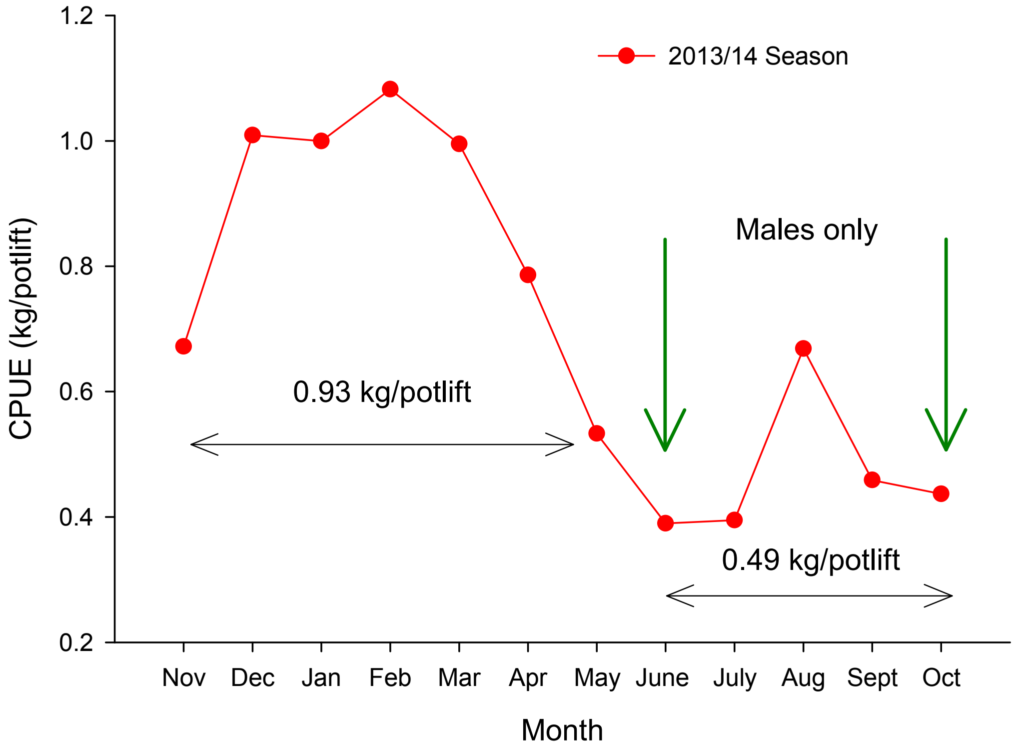


Figure 5. Total temporal trends in catch rate in the NZRLF in 2013/14, comparing data from regular fishing season (November-May) with surveys (June to October).

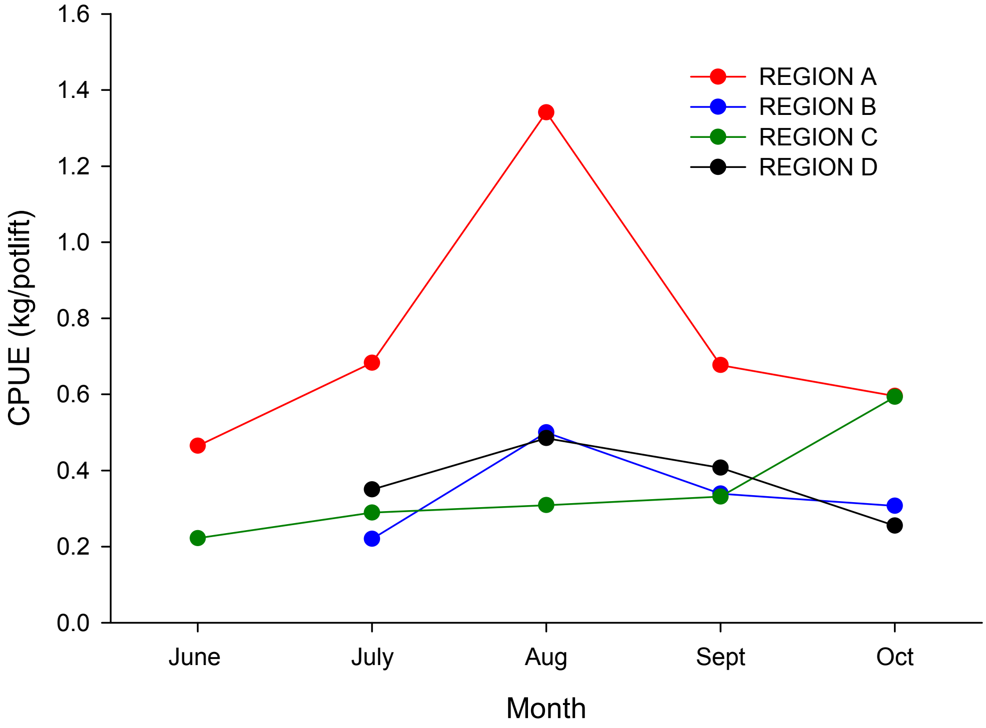


Figure 6. Regional temporal trends in catch rate from June to October 2014 inclusive in the NZRLF.

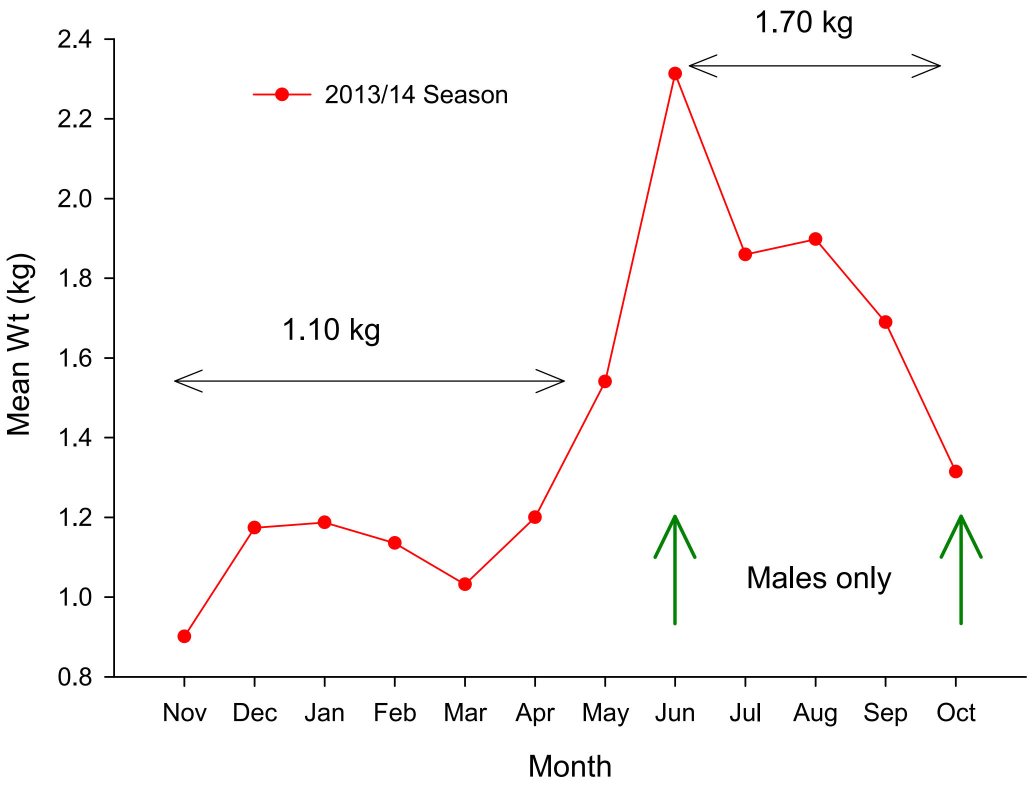


Figure 7. Total temporal trends in mean weight in the NZRLF in 2013/14, comparing data from regular fishing season (November-May) with surveys (June to October).

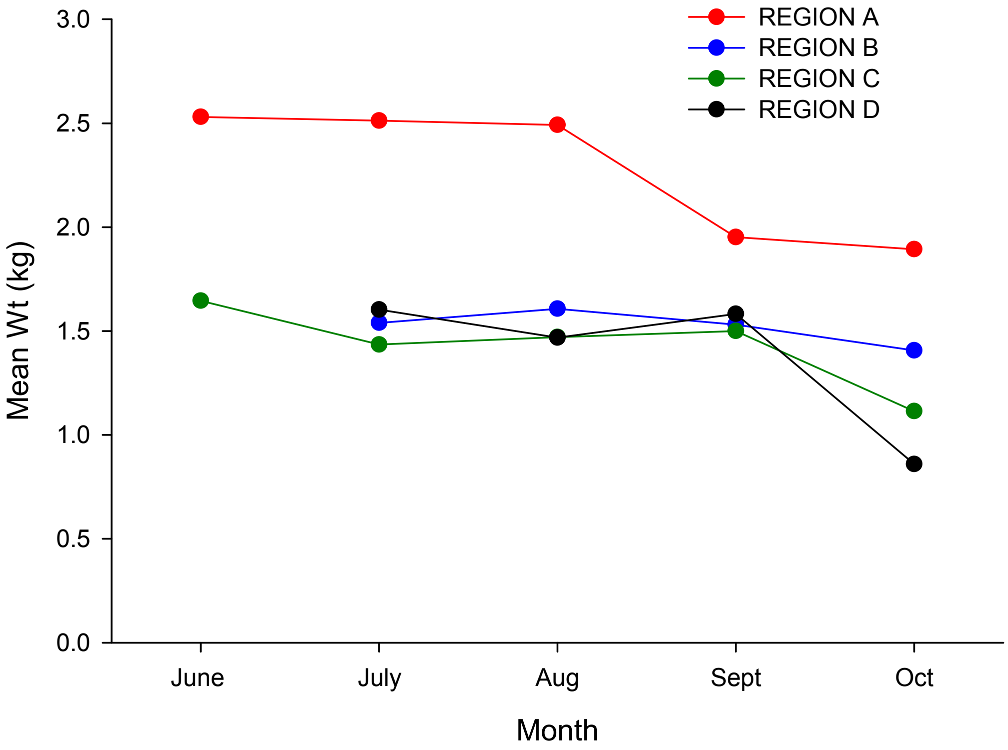


Figure 8. Regional temporal trends in mean weight from June to October 2014 inclusive in the NZRLF.

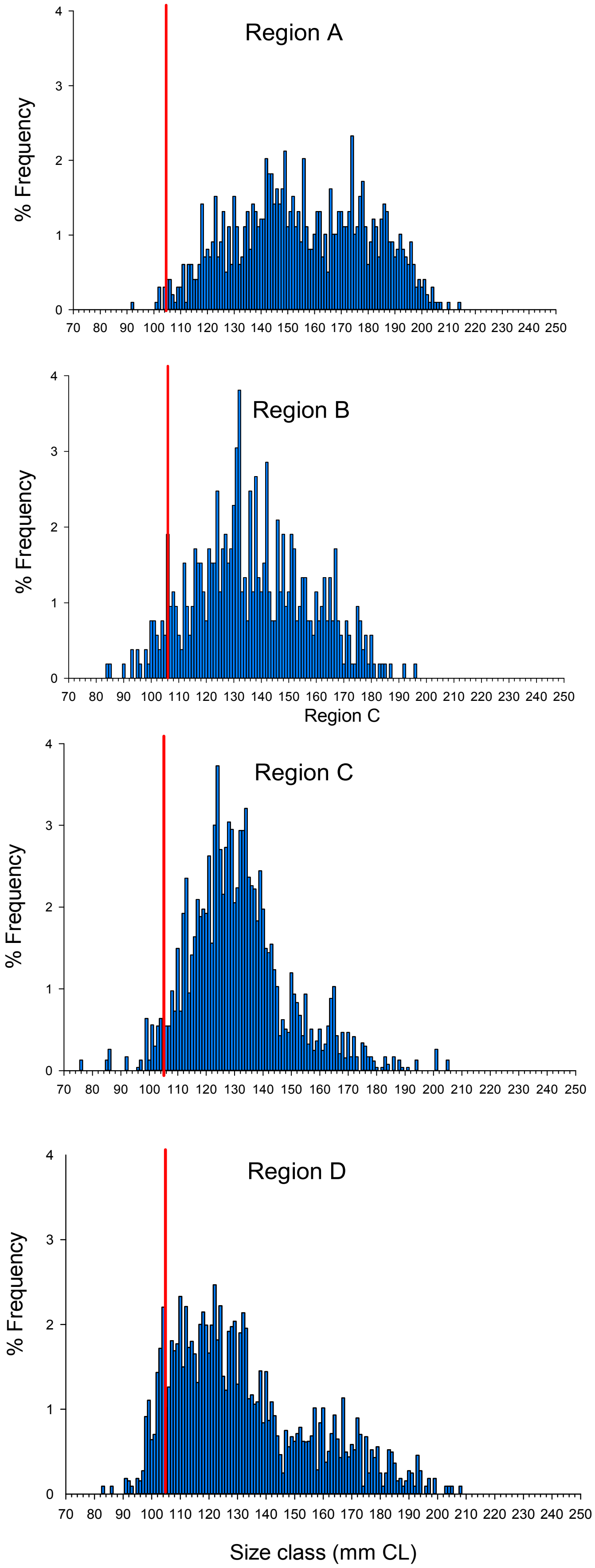


Figure 9. Regional combined length frequency data from June to October 2014 inclusive in the NZRLF. Red lines indicate MLS of 105 mm CL.

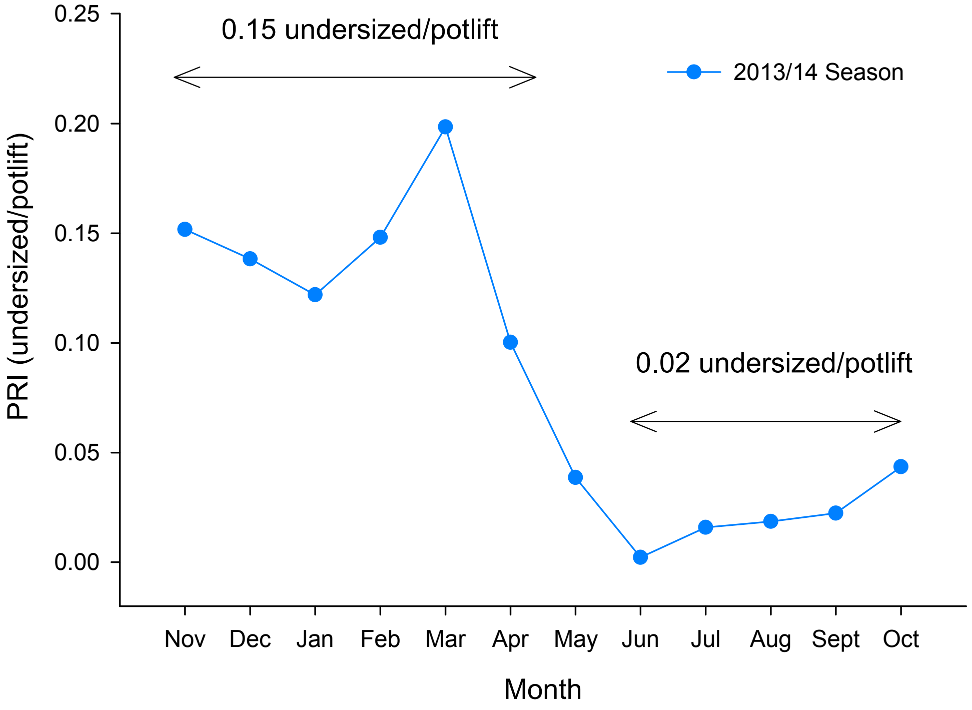


Figure 10. Total temporal trends in pre-recruit index in the NZRLF in 2013/14, comparing data from regular fishing season (November-May) with surveys (June to October).

5.1.3 Catch composition

5.1.3.1 Sex ratios

Changes in sex ratios during the temporal surveys were compared against those from the regular 2013/14 commercial fishing season based on catch sampling data (Figure 11). From November to April, the percentage of females in the catch ranged from 45-55%. However, in June, the start of the temporal survey, the percentage decreased to 18% before steadily increasing to 44% in October. These results indicate that the catchability of females in winter is considerably lower than in other seasons and that males are more likely to dominate catches during this period.

5.1.3.2 Reproductive condition of females

The proportion of females in various stages of reproductive condition was examined based on catch sampling data (Figure 12). Egg-bearing females were firstly observed in the catch in July but at low levels (2%). Over the next three months this increased considerably with the contribution of egg-bearing females to the total catch being 18%, 26% and 17% in August, September and October, respectively. Regionally, with the exception of Region B (October at 27%), September had the highest proportion of egg-bearing females compared to other months of the survey (Figure 13).

5.1.3.3 By-catch species

A total of 29 by-catch species were recorded during the temporal surveys (Table 2). Leatherjacket species (*Meuschenia* and *Nelusetta* spp) dominated in terms of catch rate, followed by Hermit Crab (*Trizopagurus strigimanus*), Port Jackson Shark (*Heterodontus portusjacksoni*) and Bluethroat Wrasse (*Notolabrus tetricus*). By-catch compositions of the four most abundant species during the survey months were compared against those during the regular 2013/14 season (Figure 14) with results indicating that by-catch composition was broadly similar across both periods. The only exception was Port Jackson Sharks, which appeared to be more prevalent from June to October, while velvet crabs were less abundant.

Zonal catch rates of the two most common by-catch species in the fishery i.e. Leatherjacket species and Bluethroat Wrasse, were compared from the regular season of November to April and the survey period of June to October, 2013/14 (Figure 15). The trends in catch rate of both species were consistent through time, being lowest from April to August and generally highest from September to December.

5.1.3.4 By-product species

The two most commonly caught by-product species in the NZRLF are Giant Crab (*Pseudocarcinus gigas*) and Maori Octopus (*Pinnoctopus cordiformis*). A single Giant Crab was landed in July, while octopi were observed across all months (Table 2). The catch rates of octopi during the survey months were compared against those of the regular 2013/14 season (Figure 16). Catch rates were considerably lower from June to October with the highest indices observed in March and April.

Almost all of the within-pot mortalities observed in the NZRLF are due to predation by the Maori Octopus (Brock and Ward 2004). The survey catch rate of octopus was 0.001 octopus/potlift (June to October), compared to 0.003 octopus/potlift during the regular 2013/14 season (November to May). Based on the reduced levels of octopi catch during the surveys, overall catch rates of dead lobsters from June to October (0.01 dead/potlift) were considerably lower than those observed in the regular fishing season (0.04 dead/potlift) (Figure 16). In 2013/14, the highest levels of within-pot mortality were observed in March and April, consistent with trends in octopi CPUE.

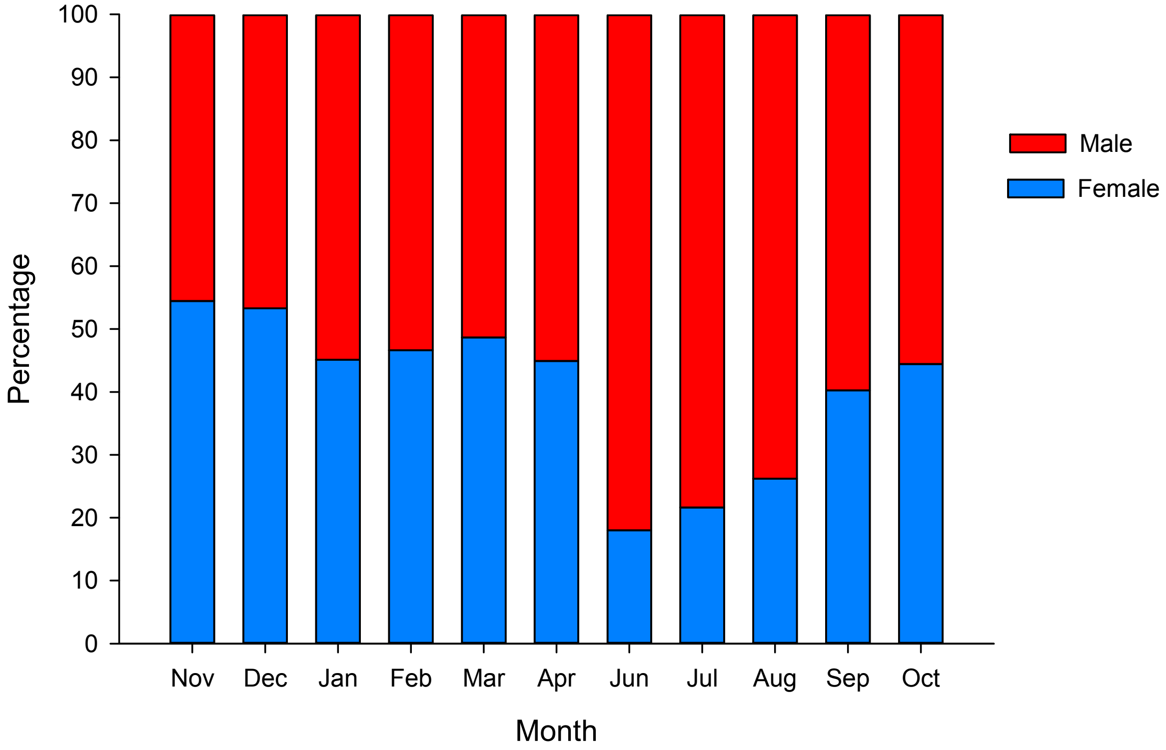


Figure 11. Zonal temporal trends in sex ratios in the NZRLF in 2013/14, comparing data from regular fishing season (November-April) with surveys (June to October). Data from May are excluded due to limited sampling.

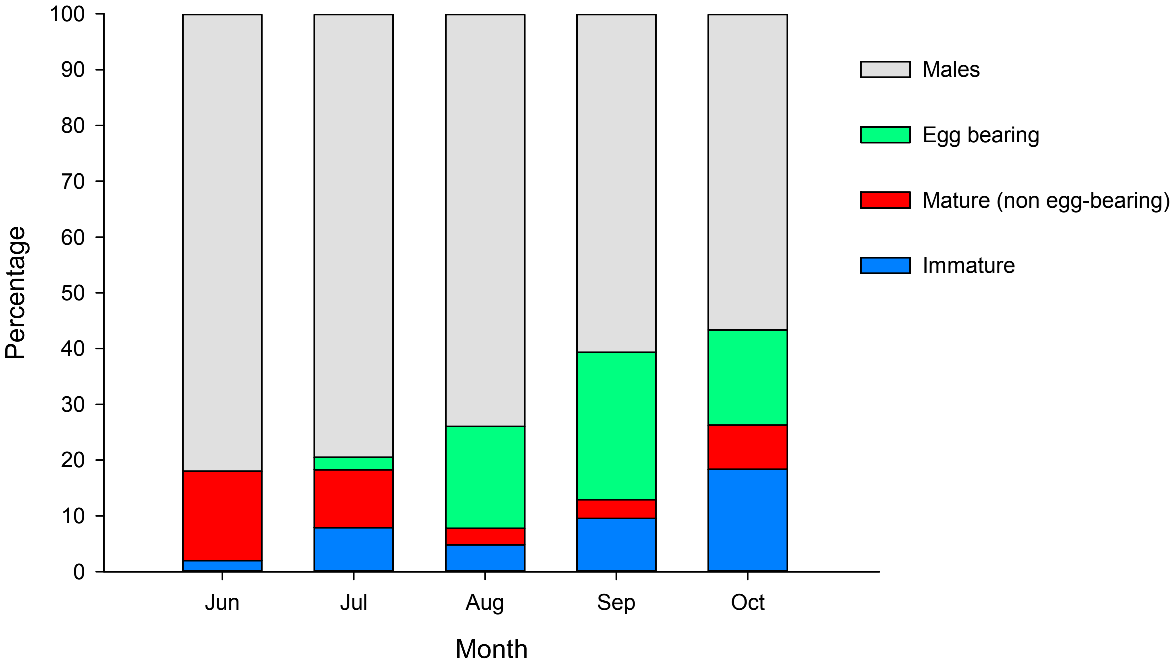


Figure 12. The proportion of male and female lobsters (in various stages of reproductive condition) from June to October 2014 in the NZRLF.

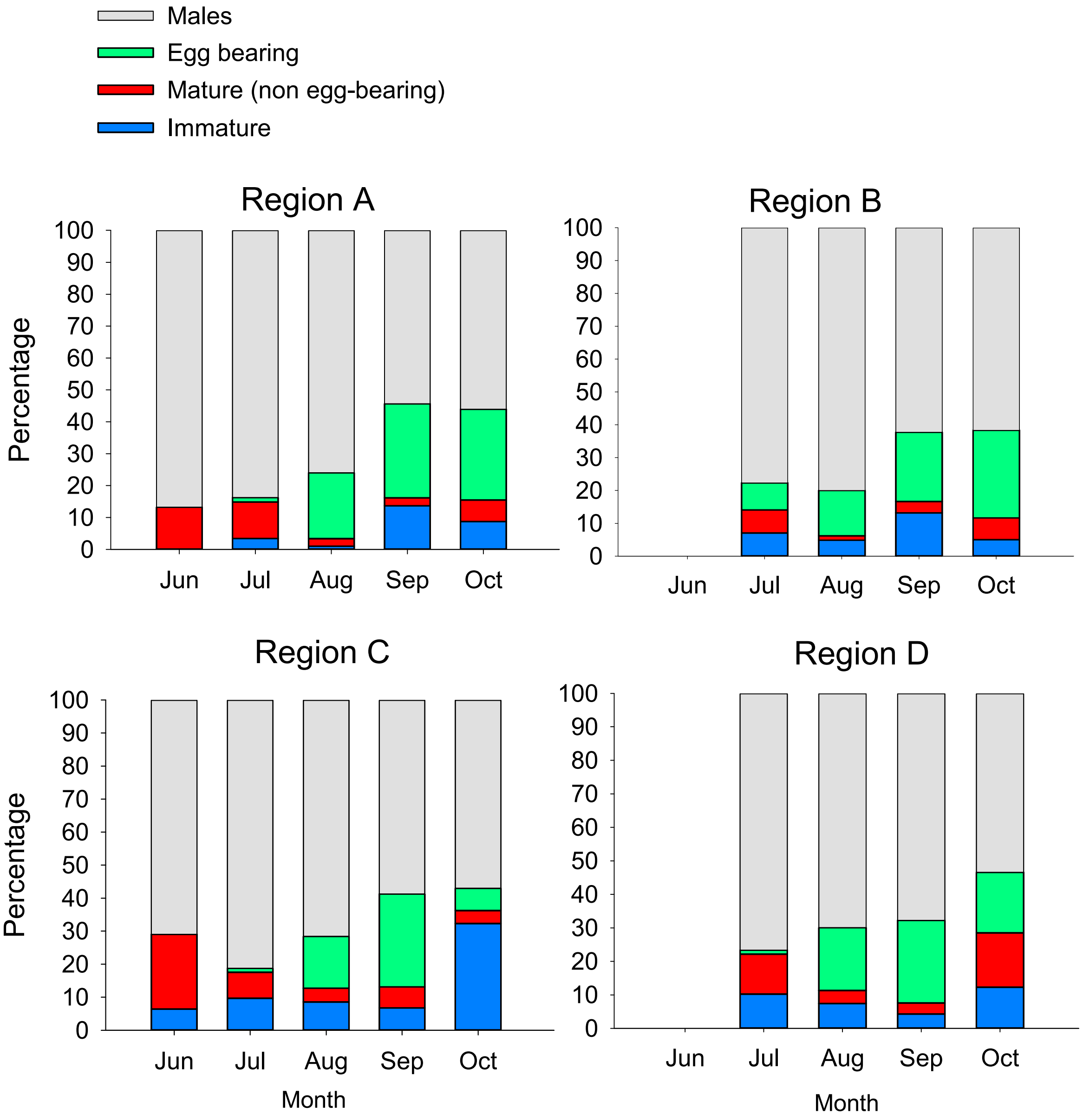


Figure 13. Regional estimates of the proportion of male and female lobsters (in various stages of reproductive condition) from June to October 2014 in the NZRLF.

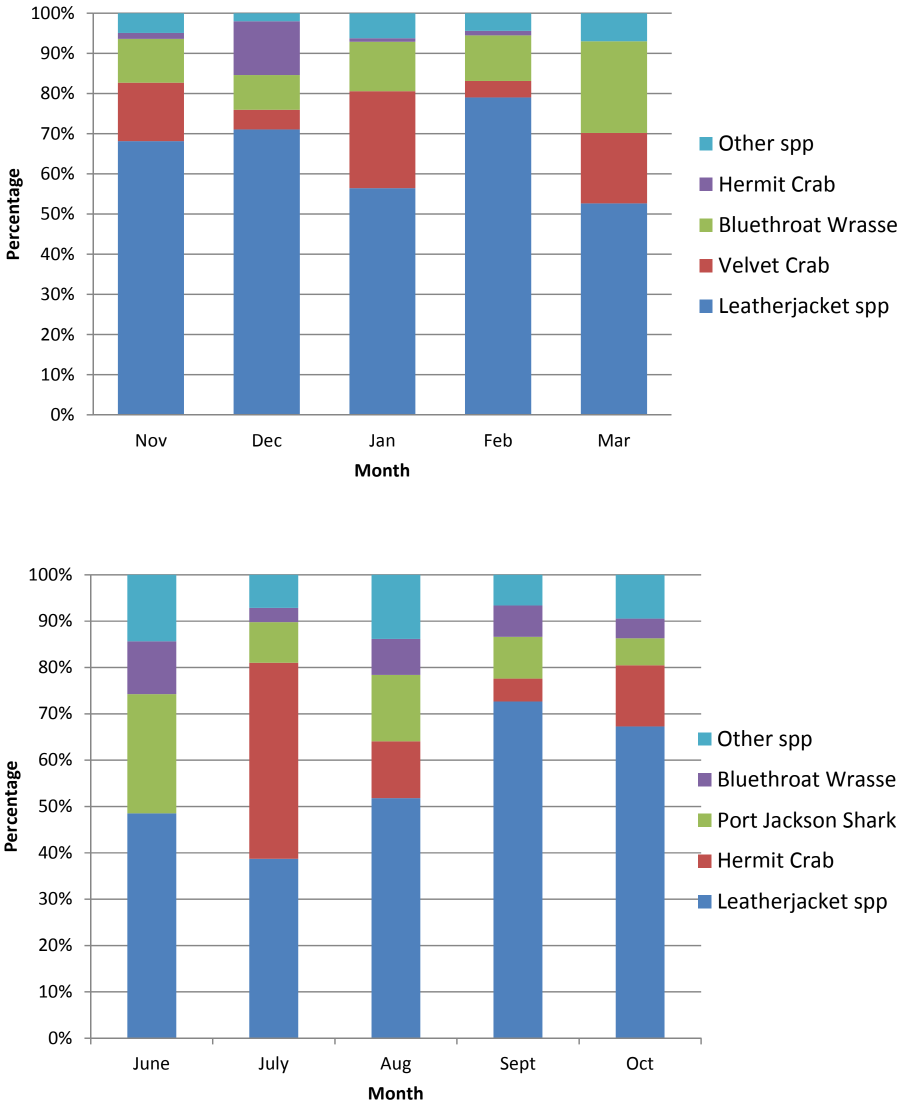


Figure 14. Percentage composition of the four most abundant by-catch species during the regular 2013/14 season (top) compared to the survey period from June to October (bottom) in the NZRLF.

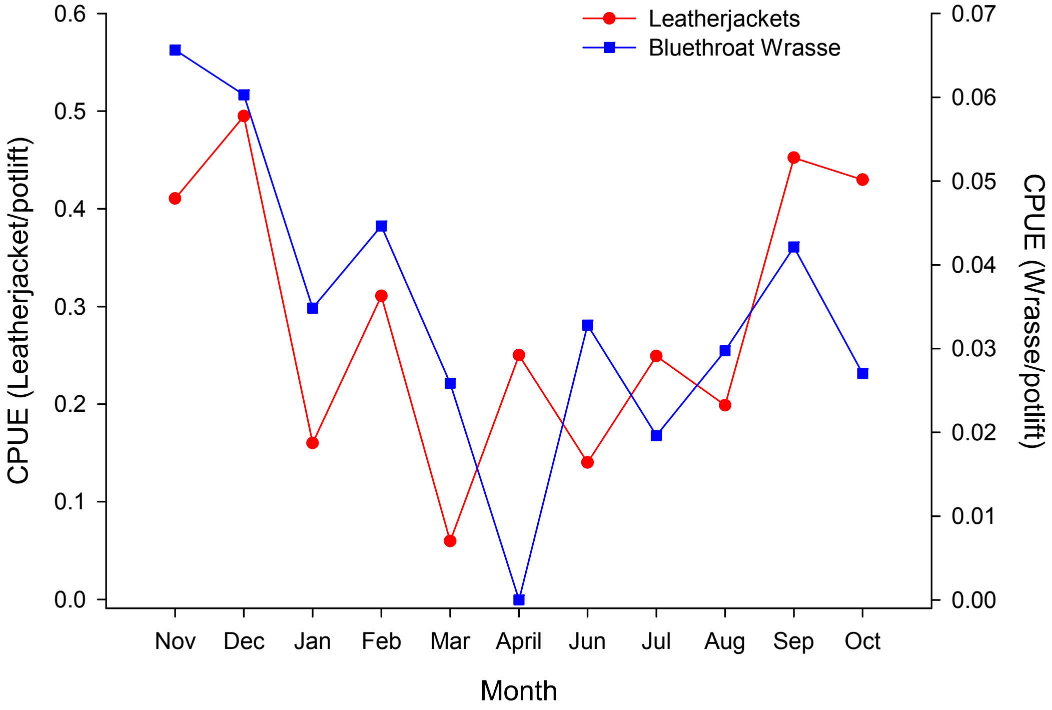


Figure 15. Temporal trends in catch rate of Leatherjackets and Bluethroat Wrasse by-catch species in the NZRLF in 2013/14, comparing data from regular fishing season (November-April) with surveys (June to October). Data from May are excluded due to limited sampling.

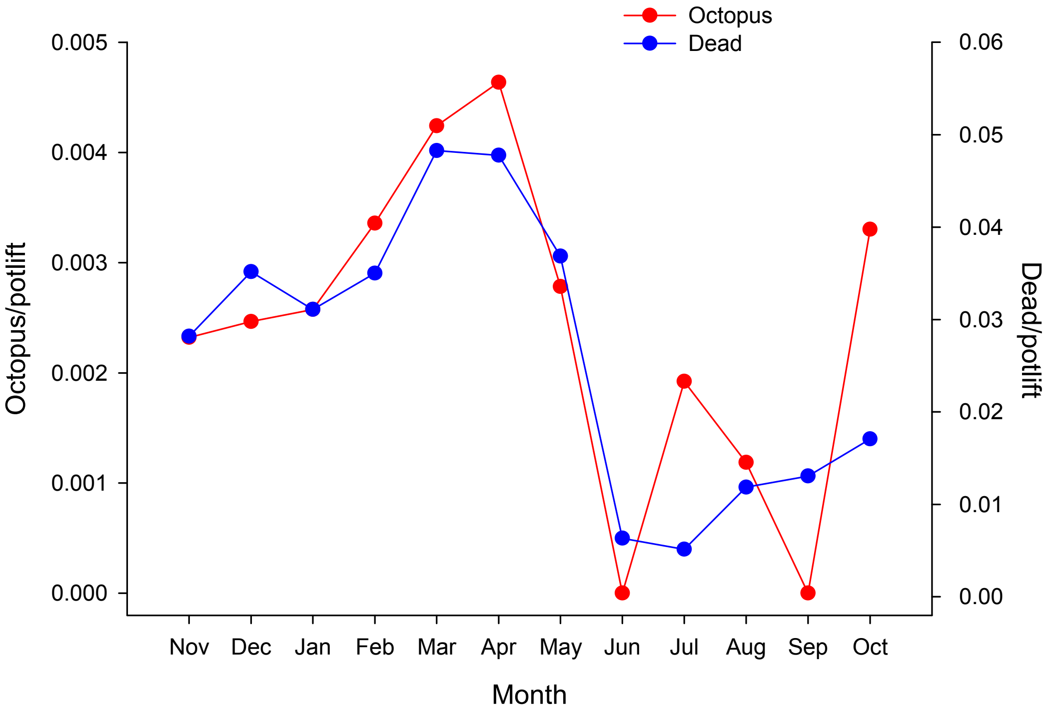


Figure 16. Temporal trends in catch rate of Octopus and dead lobster in the NZRLF in 2013/14, comparing data from regular fishing season (November-April) with surveys (June to October).

Table 2. Catch by number and catch rate estimates of by-catch species from June to October 2014 in the NZRLF. Asterisks indicate by-product species.

Species	June	July	Aug	Sept	Oct	Total	#/potlift
Leatherjacket *(Meuschenia* and *Nelusetta* spp)	64	470	321	687	780	2322	0.3184
Hermit Crab (*Trizopagurus strigimanus*)		514	76	47	153	790	0.1083
Port Jackson Shark (*Heterodontus portusjacksoni*)	34	107	89	85	68	383	0.0525
Bluethroat Wrasse (*Notolabrus tetricus*)	15	37	48	64	49	213	0.0292
Velvet Crab (*Nectocarcinus tuberculosis*)	7	4	26	6	21	64	0.0088
Barber Perch (*Caesioperca rasor*)	1	23	16	2	12	54	0.0074
Snapper (*Pagrus auratus*)		5	7	15	11	38	0.0052
Whelk (*Pleuroploca australasia*)		8	7	9	14	38	0.0052
*Octopus (*Pinnoctopus cordiformis)*	1	7	7	3	15	33	0.0045
Slimy Cod (*Pseudophcyis spp and Lotella rhacinus*)	2	6	7	7	9	31	0.0043
Sea Perch (*Helicolenus percoides*)		10	1	6		17	0.0023
Wobbygong (*Orectolobus ornatus*)	1	3	1	8	6	19	0.0026
Wrasse (*Pseudolabrus* spp)	5	2	4		2	13	0.0018
Red Snapper (*Centroberyx* spp)		1		1	11	13	0.0018
Pink Ling (*Genypterus tigeranus*)		8			3	11	0.0015
Gummy Shark (*Mustelus antarcticus*)	2	3	2		1	8	0.0011
Nannygai (*Centroberyx affinis*)			4			4	0.0005
Star Fish (Unknown spp)				3	1	4	0.0005
Conger Eel (*Conger verreauxi*)		2	1			3	0.0004
Jackass Morwong (*Nemadactylus macropterus*)		2			1	3	0.0004
Morwong (*Nemadactylus* spp)				1	2	3	0.0004
Knife Jaw (*Oplegnathus woodwardi*)			1		1	2	0.0003
Cuttle Fish (*Sepia apama*)		1				1	0.0001
Grouper (*Achoerodus gouldii*)				1		1	0.0001
Harlequin Fish (*Othox dentex*)			1			1	0.0001
*Giant Crab (*Pseudocarcinus gigas*)		1				1	0.0001
School Shark (*Galeorhinus galeus*)		1				1	0.0001
Magpie Perch (*Cheilodactylus nigripes*)				1		1	0.0001
Mullet (*Mugil cephalus)*			1			1	0.0001

5.2 Spatial component

5.2.1 Spatial sub-regions: historical catch and effort data

In this section, we present a summary analysis of the catch and effort data from the NZRLF based on the spatial sub-regions detailed in Section 4.2.1. Specifically, we present historical catch, effort, catch per unit effort and mean weight data by sub-region from 1983 to 2013. Along with mean weights-at-age, these data are critical input to the qR model in order to estimate absolute levels of biomass.

5.2.1.1 Catch in weight

Catch in weight followed a similar general trend in all three sub-regions from 1983 to 2013 (Figure 17) with coefficients of yearly catch weight between each of the three sub-regions highly correlated (Table 3). Catches rose from the mid 1980s to the early 1990s, and varied, with some evidence of decadal cyclicity, through the 1990s. In 2003, a TACC was introduced at 625 t but did not constrain catch until 2009, when catch levels were reduced to 310 t. Since 2009, overall catch levels in each sub-region have been at historically low levels.

As proportions of the total catch, averaged over all years since 1983, the Deep Water and West Coast sub-regions constituted about 6% and 8% of the catch, respectively (Table 4). However, since 2009, when the TACC became binding, this has been reduced to 1.5% and 4%, respectively. Accordingly, averaged over all years since 1983, the Inner Region sub-region contributed 86% of all catch, and since 2009, this has increased to 94%.

5.2.1.2 Fishing effort

Trends in fishing effort broadly reflect those of catch (Figure 18) with significant correlations between all sub-regions (Table 5). Within the Inner Region, effort remained between 500,000 and 750,000 potlifts from 1983 to 2009, despite the introduction of a TACC in 2003. After 2009, when the TACC became binding, effort decreased considerably in all sub-regions.

After 2009, the proportion of effort by sub-region shifted more towards the Inner Region (Table 6). Overall, 95% of the NZRLF potlifts were set in the Inner Region averaging from 2009 to 2013 compared with 89% averaging over all years. Since 2009, the West Coast sub-region comprised of only 3.4% of potlifts, while the Deep Water contributed only 1.2%.

5.2.1.3 Catch per unit effort (CPUE)

In lobster fisheries, notably for *Jasus edwardsii* in Australia and New Zealand, catch per unit effort (CPUE) is accepted as a relatively reliable index of stock abundance, making it an important indicator for management decision making, stock assessment and model inference. Temporal trends in catch rate were consistently higher in the Deep Water and West Coast sub-regions compared to the Inner sub-region (Figure 19). Catch rates in all sub-regions declined from the late 1990's through to 2008 before increasing over the next three seasons. More recently, CPUE has again declined across the zone.

Temporal trends in CPUE among the three sub-regions were strongly correlated (Table 7). The Inner sub-region with West Coast and Deep Water and the lower, but still strong, correlation of West Coast and Deep Water are highly significant, implying that common factors are driving changes in stock abundance in all three sub-regions.

5.2.1.4 Mean weight

Variations in mean weight of lobsters generally reflect long-term patterns of recruitment, with low mean weights resulting from influxes of smaller lobsters into the fishable biomass and high mean weights resulting from several consecutive years of low recruitment.

Distinctive trends in mean weight were observed across sub-regions (Figure 20). Firstly, mean weight was consistently higher in the West Coast compared to the other sub-regions. Within the West Coast, legal sized lobsters have historically weighed between approximately 1.4 and 1.8 kg while those in the Deep Water and Inner sub-regions consistently range between 0.9 and 1.2 kg. In addition to having similar absolute levels, the trends in mean weight between the Inner and Deep Water sub-regions are identical, providing further evidence to suggest that both these sub-regions are influenced by common recruitment patterns.

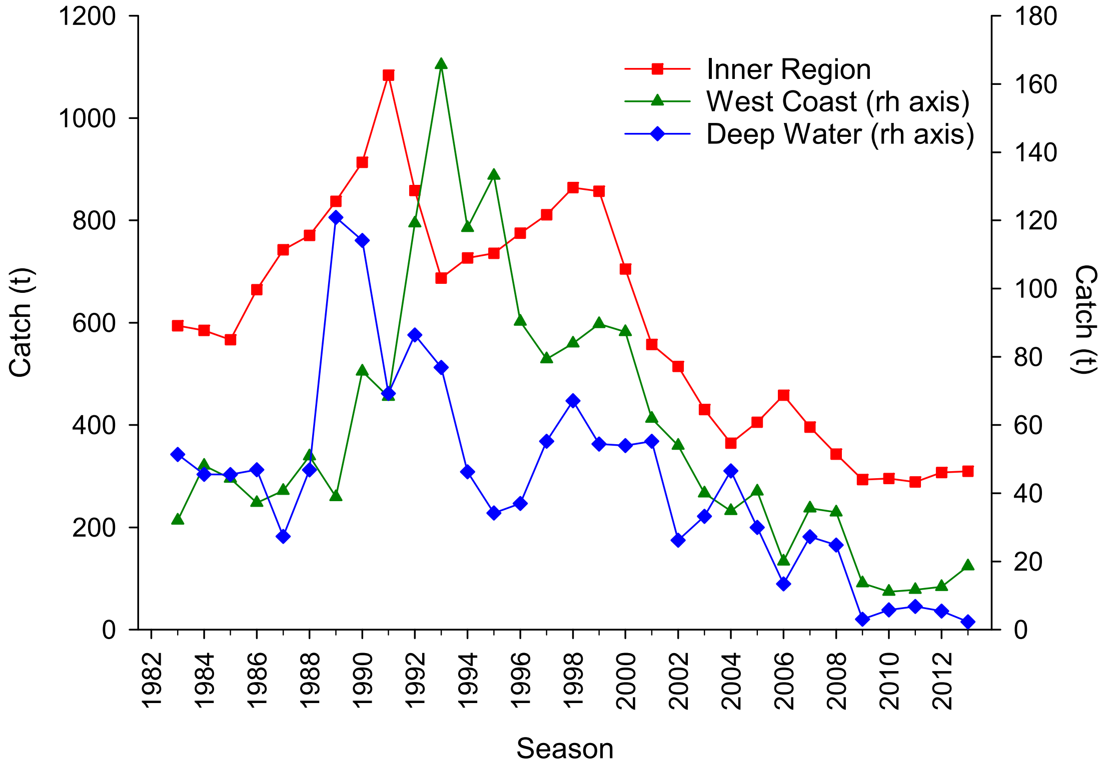
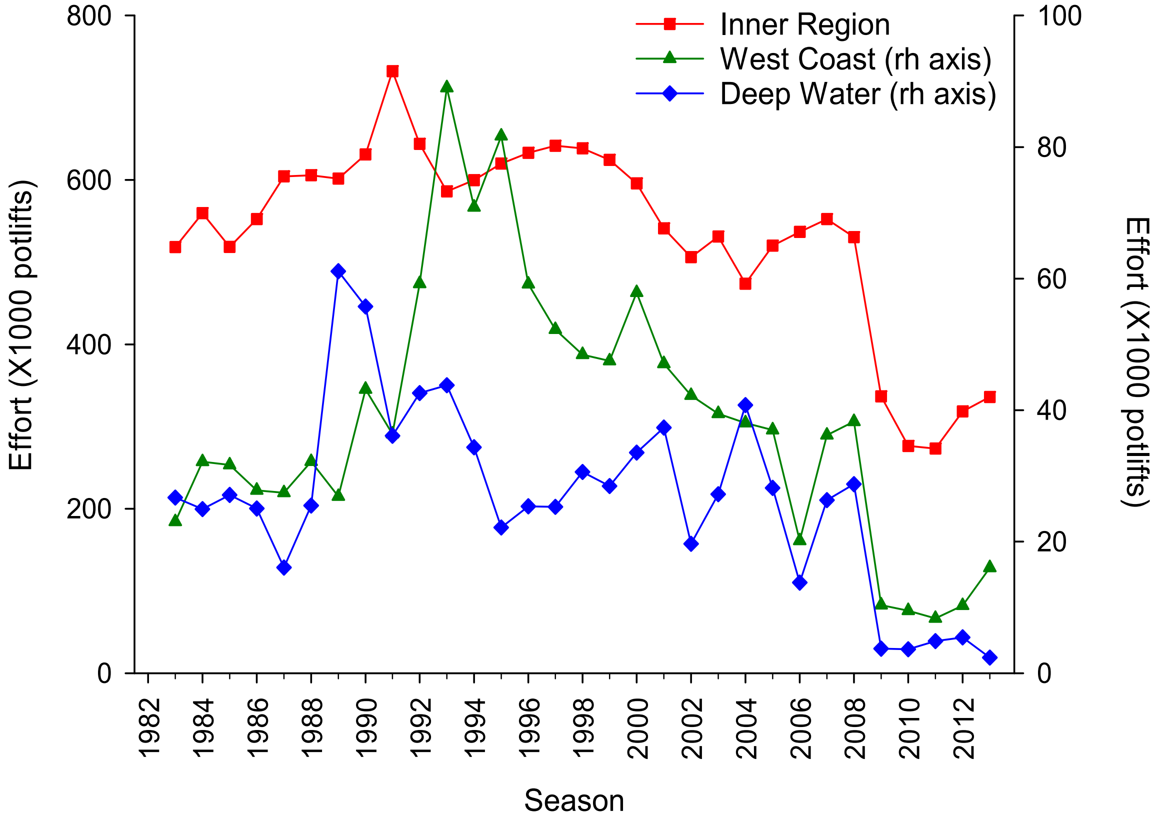


Figure 17. Trends in catch by weight (t) in the NZRLF sub-regions from 1983 to 2013 (rh = right



hand).

Figure 18. Trends in effort in the NZRLF sub-regions from 1983 to 2013 (rh = right hand).

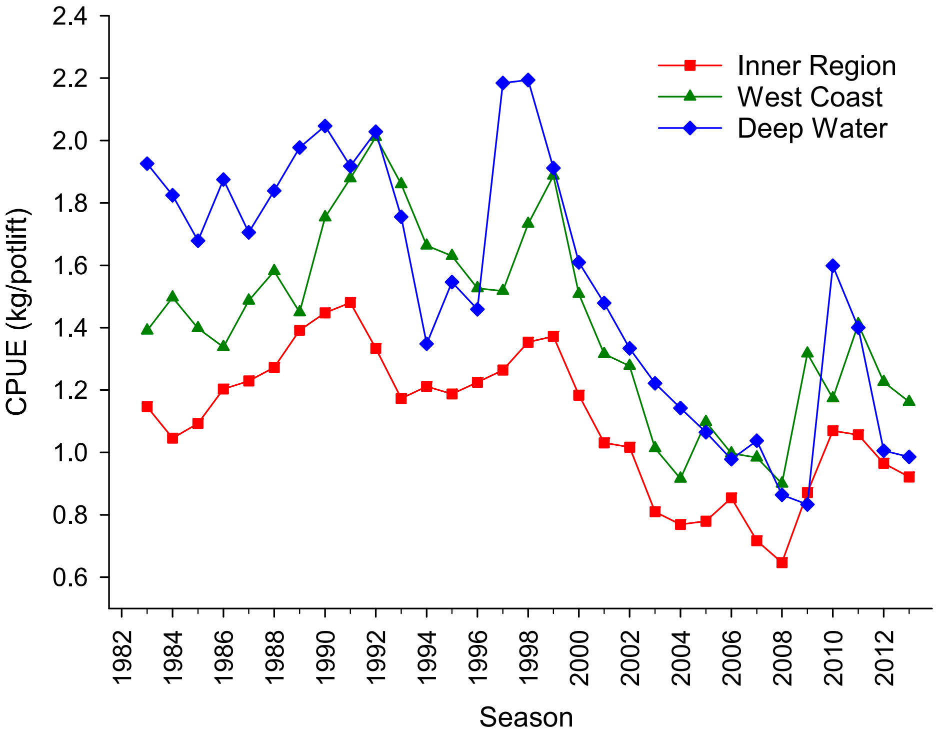


Figure 19. Trends in catch rate in the NZRLF sub-regions from 1983 to 2013.

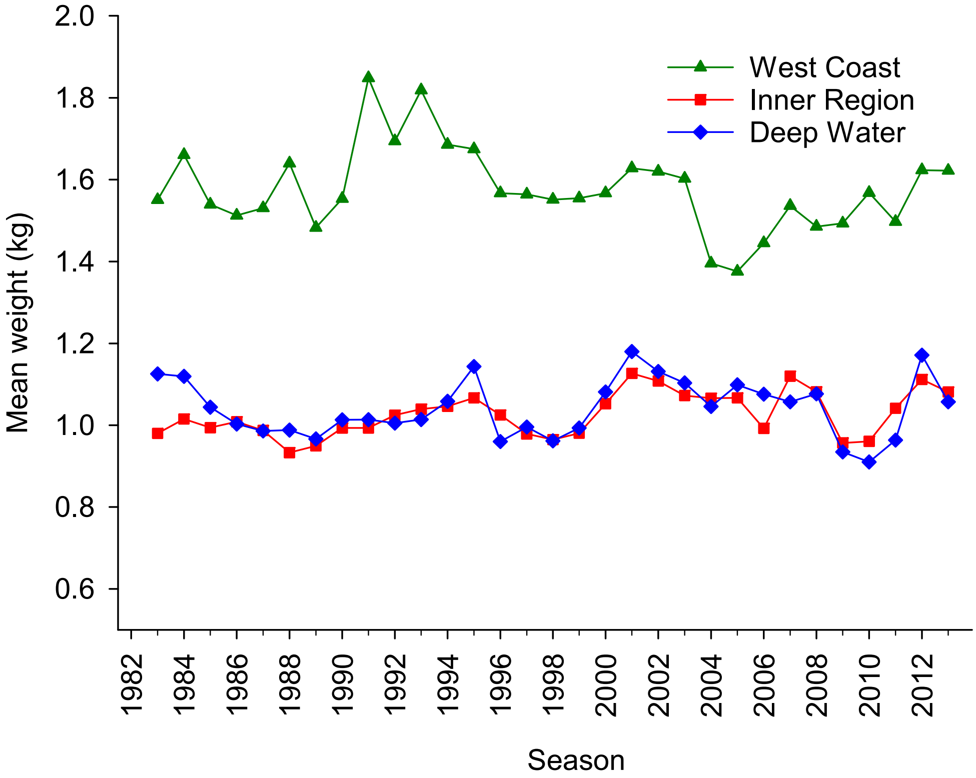


Figure 20. Trends in mean weight in the NZRLF sub-regions from 1983 to 2013.

Table 3. Correlations of catch weight between the three sub-regions. Asterisks indicate significance level of correlation (<0.05*, <0.01**, <0.001***).

	Inner Region	West Coast	Deep Water
Inner Region	1		
West Coast	0.65***	1	
Deep Water	0.77***	0.53**	1

Table 4. Percentages of catch in the NZRLF sub-regions by year.

Year	Inner Region	West Coast	Deep Water
1983	88%	5%	8%
1984	86%	7%	7%
1985	86%	7%	7%
1986	89%	5%	6%
1987	92%	5%	3%
1988	89%	6%	5%
1989	84%	4%	12%
1990	83%	7%	10%
1991	89%	6%	6%
1992	81%	11%	8%
1993	74%	18%	8%
1994	82%	13%	5%
1995	81%	15%	4%
1996	86%	10%	4%
1997	86%	8%	6%
1998	85%	8%	7%
1999	86%	9%	5%
2000	83%	10%	6%
2001	83%	9%	8%
2002	87%	9%	4%
2003	85%	8%	7%
2004	82%	8%	10%
2005	85%	9%	6%
2006	93%	4%	3%
2007	86%	8%	6%
2008	85%	9%	6%
2009	95%	4%	1%
2010	95%	4%	2%
2011	94%	4%	2%
2012	94%	4%	2%
2013	94%	6%	1%
Avg 1983+	86%	8%	6%
Avg 2009+	94.2%	4.3%	1.5%

Table 5. Correlations of effort between the three sub-regions. Asterisks indicate significance level of correlation (<0.05*, <0.01**, <0.001***).

	Inner Region	West Coast	Deep Water
Inner Region	1		
West Coast	0.67***	1	
Deep Water	0.70***	0.55**	1

Table 6. Percentages of effort in the NZRLF sub-regions by year.

Year	Inner Region	West Coast	Deep Water
1983	91%	4%	5%
1984	91%	5%	4%
1985	90%	5%	5%
1986	91%	5%	4%
1987	93%	4%	2%
1988	91%	5%	4%
1989	87%	4%	9%
1990	86%	6%	8%
1991	91%	5%	4%
1992	86%	8%	6%
1993	82%	12%	6%
1994	85%	10%	5%
1995	86%	11%	3%
1996	88%	8%	4%
1997	89%	7%	4%
1998	89%	7%	4%
1999	89%	7%	4%
2000	87%	8%	5%
2001	87%	8%	6%
2002	89%	7%	3%
2003	89%	7%	5%
2004	86%	7%	7%
2005	89%	6%	5%
2006	94%	4%	2%
2007	90%	6%	4%
2008	89%	6%	5%
2009	96%	3%	1%
2010	95%	3%	1%
2011	95%	3%	2%
2012	95%	3%	2%
2013	95%	5%	1%
Avg 1983+	89.1%	6.4%	4.4%
Avg 2009+	95.4%	3.4%	1.2%

Table 7. Correlations of CPUE between the three sub-regions. Asterisks indicate significance level of correlation (<0.05*, <0.01**, <0.001***).

	Inner Region	West Coast	Deep Water
Inner Region	1		
West Coast	0.89***	1	
Deep Water	0.87***	0.76***	1

5.2.2 Lobster growth

For estimating yearly biomass in each sub-region, the qR model uses weights-at-age as input information about growth. Mortality, and thus the absolute biomass available for harvesting, is inferred from the mean weight of landed lobsters in combination with weights-at-age. By using mean weight of landed lobsters as an input, the qR model represents a method of size-based stock assessment inference. In this chapter, lobster growth, and from that, mean weights-at-age are presented for each of the three sub-regions: Inner Region, West Coast and Deep Water.

5.2.2.1 Growth rate estimation model: GROTAG

Yearly growth rates (mm CL yr^{-1}) were estimated for two carapace lengths, α (100 mm CL for both females and males) and β (120 mm CL females, 140 mm CL males). A summary of mean growth parameter estimates of lobsters by sex from the GROTAG estimation model for the three sub-regions are provided in Table 8.

Sample sizes were large for the main Inner Region sub-region with 2406 female and 1471 male recaptures reported, thereby satisfying all the criteria for inclusion. However, sample sizes for the two outer sub-regions were small. West Coast recaptures numbered 13 for females and 15 for males, while the Deep Water had 63 female and 43 male recaptures. These outer sub-region sample sizes are marginal as input to infer growth rates, particularly for the West Coast. However, the pattern of the residuals, and the overall estimates were satisfactory and as a result, were deemed usable for this analysis. Nonetheless, it should be noted that the uncertainty associated with these sub-region growth estimates will be carried into the biomass estimates for these two outlying areas.

The GROTAG estimates of yearly average growth by sub-region are given in Table 8 and the estimated linear rates of growth versus CL for all lengths are plotted in Figure 21. Estimated average yearly CL increases in the Inner Region were 10 mm for a female of 100 mm and 6 mm for the larger females of 120 mm, reaching an estimated L_∞ of 151 mm CL.

West Coast females grew faster at 12.25 and 8.49 mm CL per year for the same two starting lengths. Deep Water females grew more slowly than either of the other two sub-regions averaging approximately 5 mm CL per year for 100 mm CL females and 2 mm CL per year for females of 120 mm CL (Figure 21). There was less spatial variation in growth of males with Inner and West Coast sub-regions having almost identical rates, but as with females, male lobster growth was slowest in Deep Water (Figure 21). Overall, male growth rates were about twice that of females, with estimates from the slowest growth sub-region for males (Deep Water) showing faster growth than the fastest growing sub-region for females (West Coast) (Table 8).

Table 8. Summary of mean growth parameters for females (top) and males (bottom) as generated by the GROTAG estimation model.

Sub-region	n	g_{100} (±95% CB)	g_{120} (±95% CB)	K	L_∞
Inner Region	2406	10.14 (10.07, 10.20)	6.18 (6.15, 6.23)	0.22	151.23
West Coast	13	12.25 (11.71, 12.59)	8.49 (8.26, 8.84)	0.21	165.16
Deep Water	63	4.89 (4.26, 5.66)	2.06 (1.42, 2.96)	0.15	134.55

Sub-region	n	g_{100} (±95% CB)	g_{140} (±95% CB)	K	L_∞
Inner Region	1471	19.08 (18.78, 19.37)	11.51 (11.22, 11.88)	0.21	200.89
West Coast	15	19.59 (16.49, 23.51)	11.59 (9.66, 13.42)	0.22	197.87
Deep Water	43	13.75 (11.87, 15.98)	7.54 (6.37, 9.18)	0.17	188.49

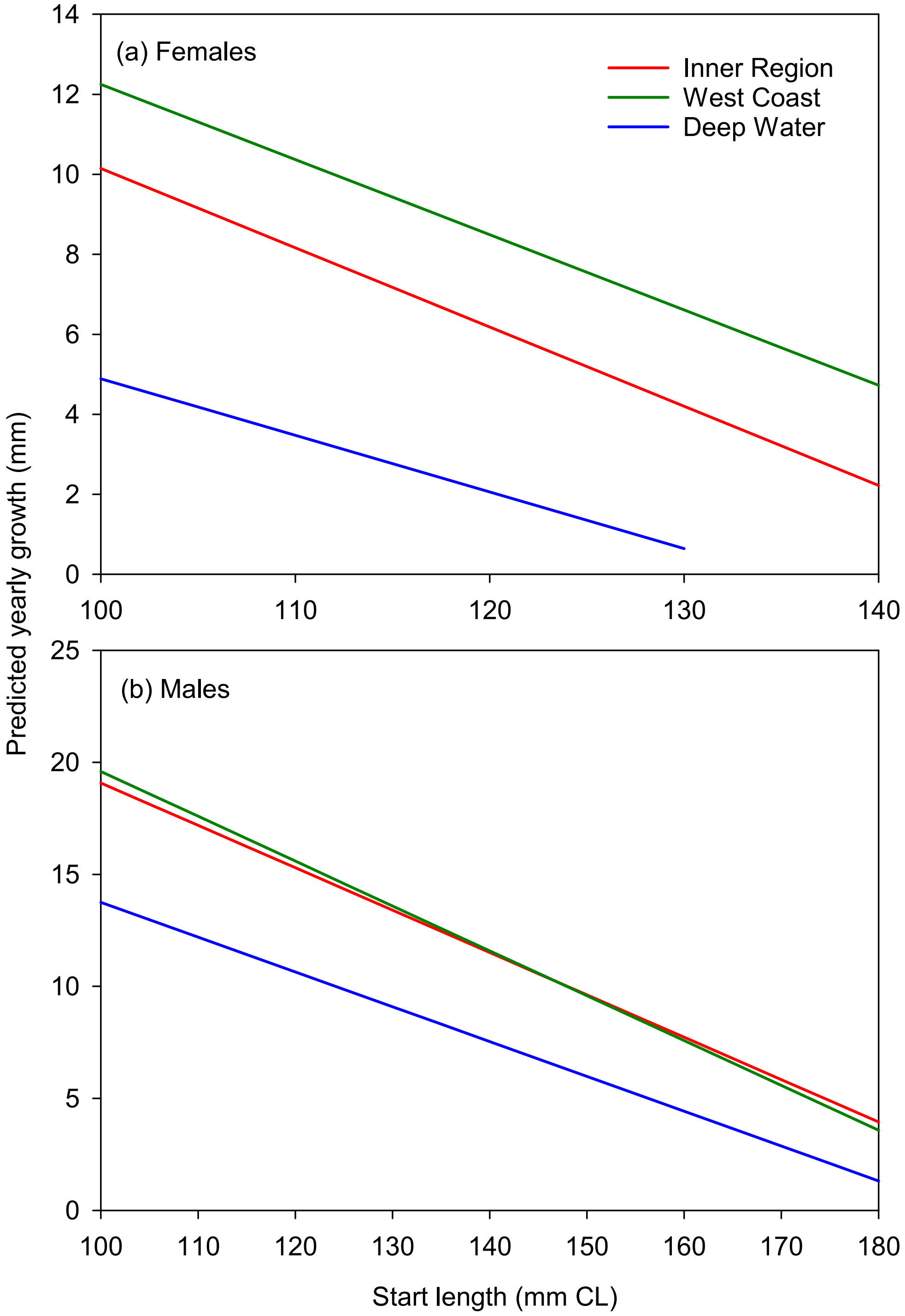


Figure 21. Estimated yearly growth of lobsters from given starting lengths for each sub-region in the NZRLF.

5.2.2.2 Weights-at-age

Mean weights-at-age, used by the qR model to estimate biomass, were generated for each sub-region for males and females combined (Table 9). Growth curves (using mean lengths-at-age) were then inferred from known growth rates of both males and females (Figure 22). The plots shown assume that lobsters at the starting age of 4 years were exactly 100 mm CL in size. Overall, as would be expected based on known growth rate by sub-region, mean length-at-age was lowest for both female and male lobsters in the Deep Water sub-region compared to other areas in the NZRLF.

Table 9. Weights-at-age, males and females combined, for each sub-region in the NZRLF.

Age class subscript	Inner Region	West Coast	Deep Water
1	0.583	0.583	0.583
2	0.838	0.864	0.738
3	1.097	1.149	0.894
4	1.344	1.421	1.044
5	1.570	1.668	1.187
6	1.772	1.888	1.318
7	1.948	2.078	1.438
8	2.099	2.239	1.545
9	2.227	2.375	1.640
10	2.335	2.488	1.724
11	2.425	2.582	1.797
12	2.499	2.658	1.861
13	2.560	2.721	1.917
14	2.610	2.773	1.965
15	2.651	2.814	2.006
16	2.685	2.848	2.041
17	2.713	2.875	2.071
18	2.735	2.897	2.097
19	2.753	2.915	2.119
20	2.768	2.930	2.138

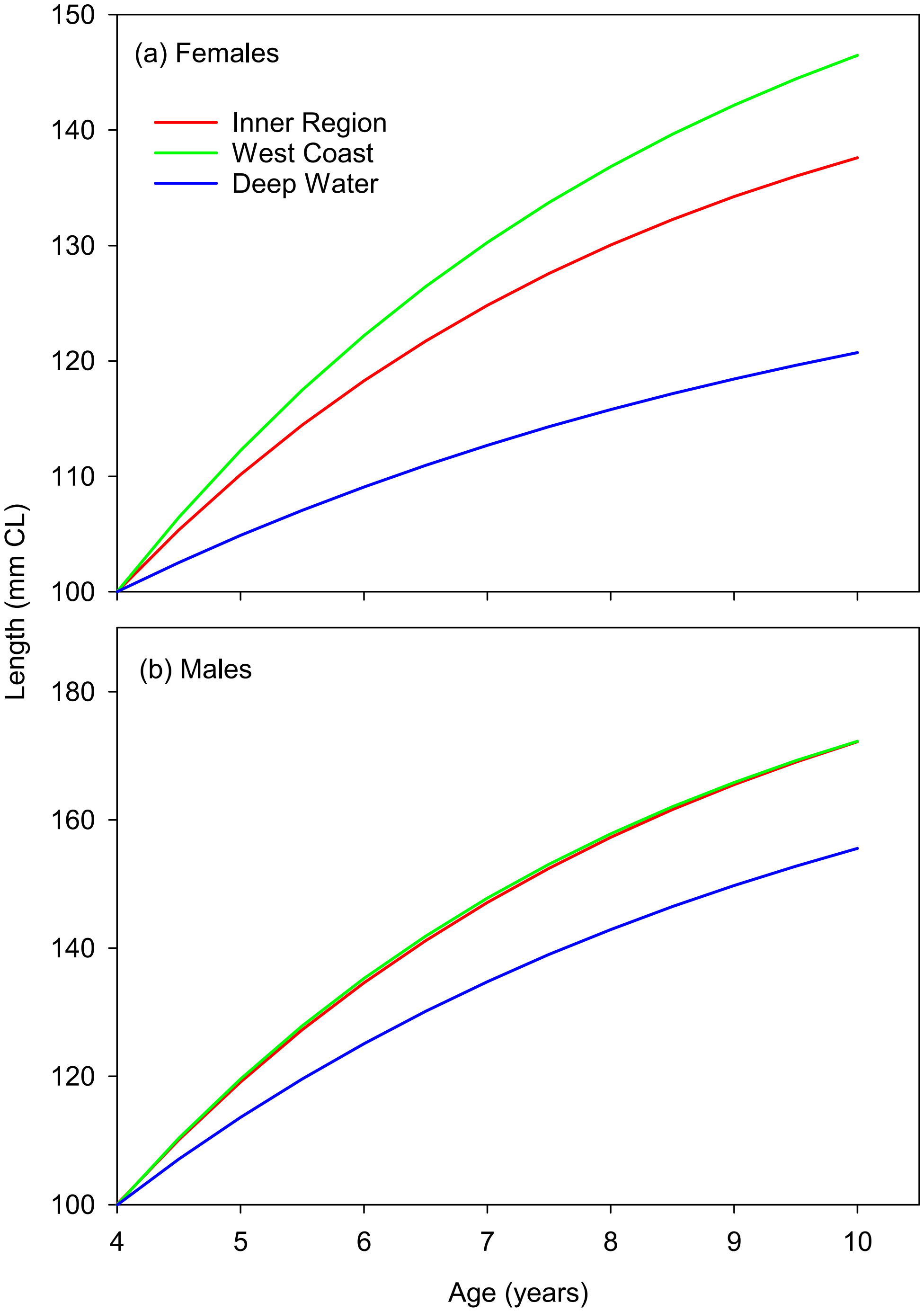


Figure 22. Growth curves of length versus age for female and male lobsters for each sub-region in the NZRLF.

5.2.3 Spatial estimates of biomass

5.2.3.1 Model fits to data

Estimates of catch in numbers and weight from the qR model fitted closely to reported total catches in each of the three sub-regions of the NZRLF (Figure 23 - Figure 25).

5.2.3.2 Correlations in recruitment among sub-regions

The yearly variation in qR-model estimated recruitment showed significant correlations among all three sub-regions with moderately stronger correlations between the Inner Region and the two outer sub-regions (Table 10). These outcomes reflect similar correlations among yearly effort, catch, and most strongly, CPUE (see Table 7), derived from commercial data as shown in the Section 5.2 of this report.

5.2.3.3 Biomass estimates by sub-region

The qR estimates of yearly biomass for each of the three sub-regions are shown in Figure 26. Overall, the Inner Region was estimated to contain about twice the biomass of the other two sub-regions combined. Despite this, there was some degree of synchronicity between sub-regions over time with biomass generally decreasing from the early 1990s to 2008 before showing some signs of recovery as TACCs became binding thereafter.

Numerical biomass estimates for the years 2000-13 are tabulated for each of the three sub-regions and the whole of the NZRLF in Table 11. Summarising these estimates as percentages of biomass by sub-region shows them to be relatively consistent as a proportion of the NZRLF total over time, with two thirds of the biomass being in the Inner Region, approximately 26-27% in the West Coast, and 5-6% in Deep Water (Table 12).

Yearly estimates of exploitation rate within each sub-region were generated from qR spatial estimates of biomass (Table 13). Exploitation rate was highest in the Inner Region compared to the West Coast and Deep Water. Since 2009, exploitation rates have decreased considerably across all sub-regions with the zonal average over this period estimated at 15%, compared to 25% over the entire time series since 1983.

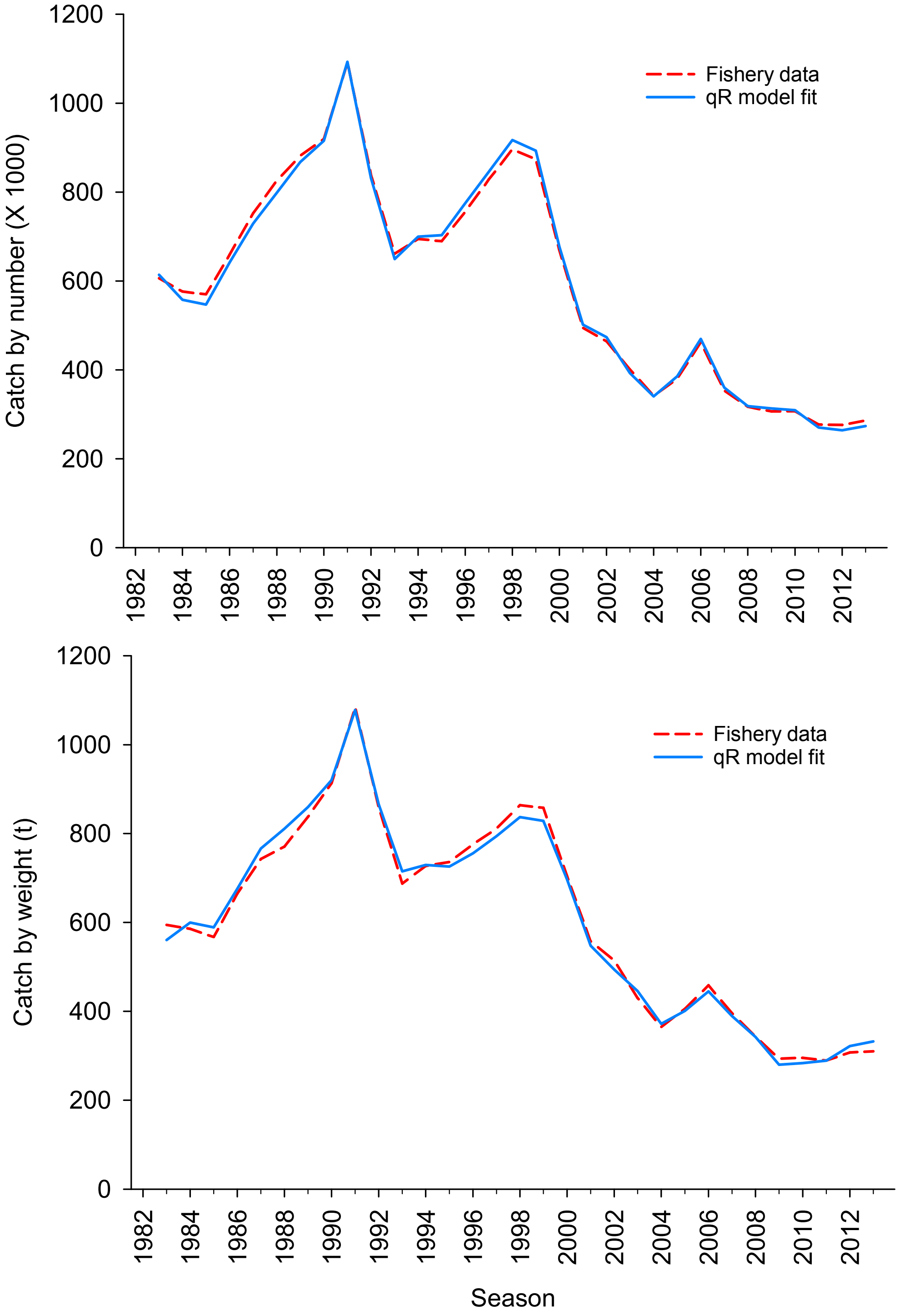


Figure 23. Fit of the qR model to catch in numbers (top) and catch by weight (bottom) for the Inner Region sub-region of the NZRLF.

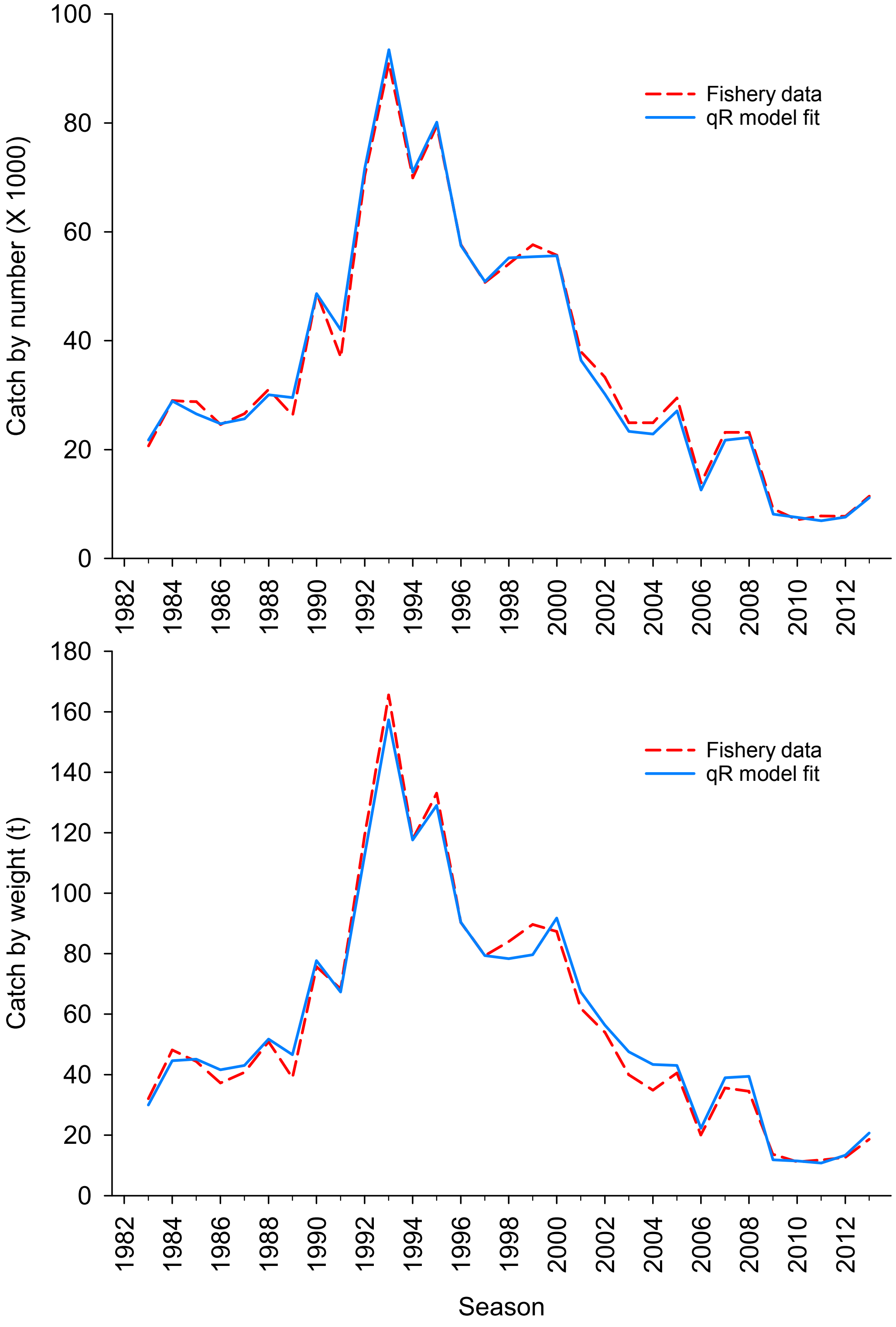


Figure 24. Fit of the qR model to catch in numbers (top) and catch by weight (bottom) for the West Coast sub-region of the NZRLF.

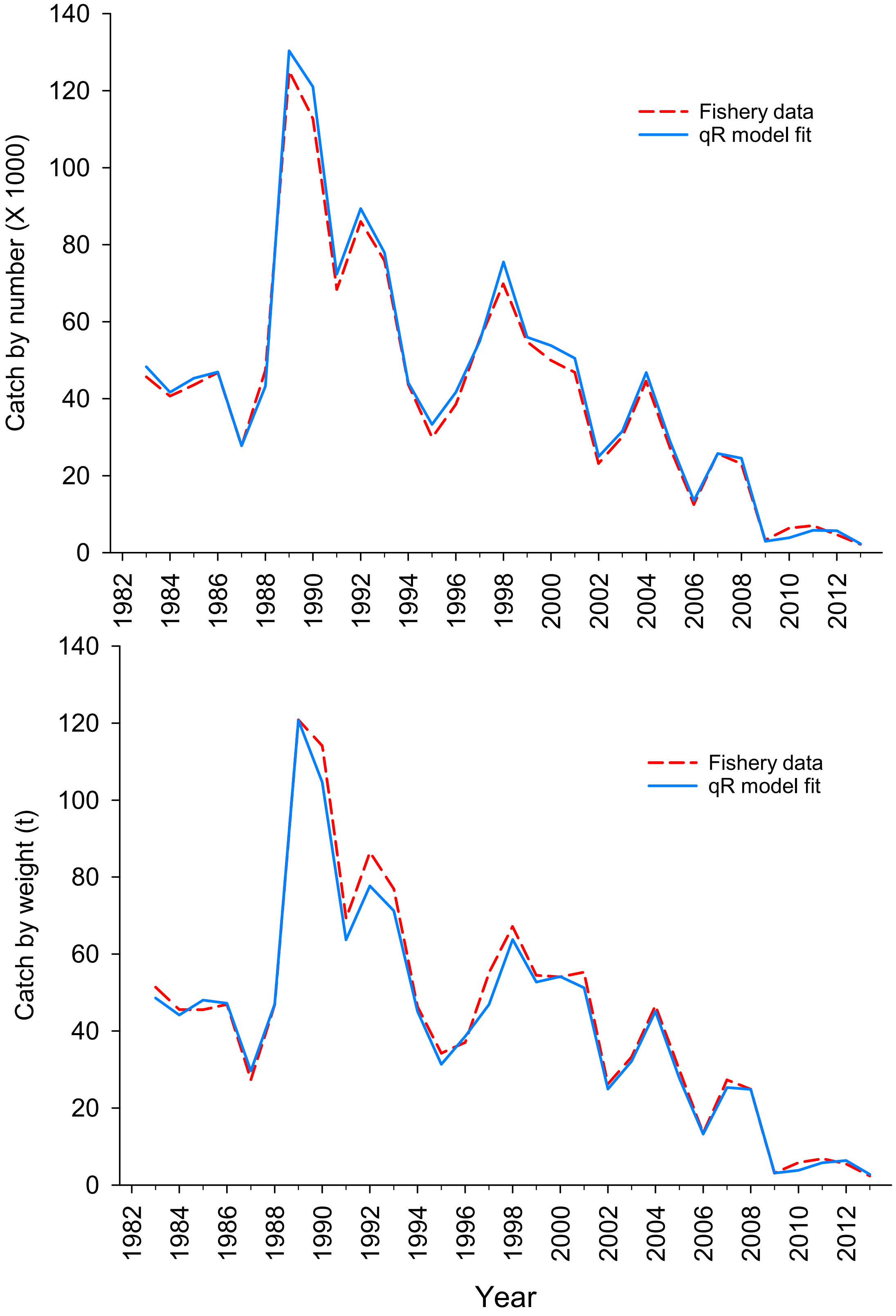


Figure 25. Fit of the qR model to catch in numbers (top) and catch by weight (bottom) for the Deep Water sub-region of the NZRLF.

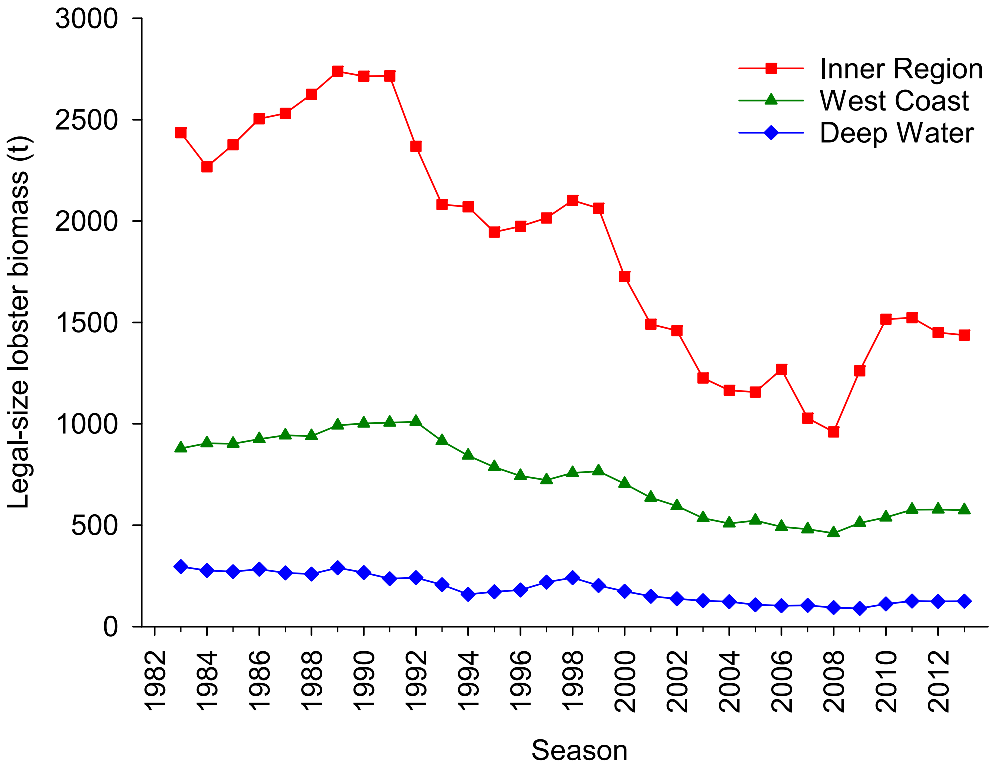


Figure 26. Estimates of legal sized biomass for each sub-region in the NZRLF.

Table 10. Correlations of yearly recruitment, computed from the qR model, between the three sub-regions. Asterisks indicate significance level of correlation (<0.05*, <0.01**, <0.001***).

	Inner Region	**West Coast**	**Deep Water**
Inner Region	1		
West Coast	0.75***	1	
Deep Water	0.65***	0.62***	1

Table 11. Regional qR estimates of biomass (t) shown for years 2000-2013. Averages are also given for the five most recent years from 2009-2013 (“Average 2009+”) and across all estimated years from 1983-2013 (“Average 1983+”).

Year	**Inner Region**	**West Coast**	**Deep Water**	**Whole NZ**
2000	1727	704	174	2605
2001	1491	636	149	2276
2002	1461	594	137	2192
2003	1225	535	128	1888
2004	1165	508	123	1796
2005	1156	523	107	1786
2006	1268	491	103	1862
2007	1027	479	104	1611
2008	960	460	93	1513
2009	1261	511	89	1861
2010	1516	538	111	2166
2011	1524	576	126	2226
2012	1451	577	124	2152
2013	1438	574	125	2136
Average 2009 +	1438	555	115	2108
Average 1983 +	1878	733	186	2797

Table 12. Regional qR biomass percentage estimates shown for years 2000-2013. Averages are also given for the five most recent years (2009-2013) and across all estimated years (1983-2013).

Year	Inner Region	West Coast	Deep Water
2000	66%	27%	7%
2001	66%	28%	7%
2002	67%	27%	6%
2003	65%	28%	7%
2004	65%	28%	7%
2005	65%	29%	6%
2006	68%	26%	6%
2007	64%	30%	6%
2008	63%	30%	6%
2009	68%	27%	5%
2010	70%	25%	5%
2011	68%	26%	6%
2012	67%	27%	6%
2013	67%	27%	6%
Average 2009 +	68.2%	26.4%	5.4%
Average 1983 +	67%	27%	6.5%

Table 13. Regional qR exploitation rate estimates shown for years 2000-2013. Averages are also given for the five most recent years (2009-2013) and across all estimated years (1983-2013).

Year	Inner Region	West Coast	Deep Water	Whole NZ
2000	41%	12%	31%	32%
2001	37%	10%	37%	30%
2002	35%	9%	19%	27%
2003	35%	7%	26%	27%
2004	31%	7%	38%	25%
2005	35%	8%	28%	27%
2006	36%	4%	13%	26%
2007	39%	7%	26%	28%
2008	36%	7%	27%	27%
2009	23%	3%	3%	17%
2010	19%	2%	5%	14%
2011	19%	2%	5%	14%
2012	21%	2%	4%	15%
2013	22%	3%	2%	15%
Average 2009+	20.9%	2.4%	4.1%	15.1%
Average 1983+	32%	8%	23%	25%

6 Discussion

This project has improved the understanding of the temporal and spatial characteristics of commercial Rock Lobster fishing in the Northern Zone of South Australia. From a temporal perspective, the study has provided an insight into the targeted and non-targeted catch composition during periods of the year not currently fished under existing management arrangements. Additionally, this study provided preliminary estimates of commercial catch rates during the current closed season. Spatially, the study has described the changes to fishing fleet dynamics as a result of catch restrictions under the TACC system. In addition, based on historical tagging data, the project has provided regional estimates of lobster growth which were utilised to generate spatially explicit levels of biomass and exploitation rates. Overall, it is envisaged that the outputs from this project will underpin future discussions in relation to alternative temporal and spatial management options for the NZRLF.

6.1 Temporal component

6.1.1 Fishery statistics

This study has provided preliminary insight into commercial catch rates during what is currently, the closed season in the fishery. It is important to highlight however, that as the catch statistics generated were survey based, they may not be truly reflective of normal commercial fishing operations. Overall, the catch rates during the surveys were approximately half that observed during the normal fishing season. This might be expected, given that the surveys only allowed the landing of legal sized males, whereas both sexes can be taken during all months of the open season. In addition, overall lobster catchability is known to decrease during the winter period (Ziegler et al. 2004).

The highest survey catch and catch rate was observed in August within Region A, the western part of the fishery. These estimates were driven by mean weight which was consistently higher across all survey months in this area. High mean weights were further confirmed by length frequency data which showed that larger lobsters above 150 mm CL were far more prevalent in Region A compared to all other areas. These results are likely to reflect the known spatial variation in lobster growth across South Australia, with some of the highest rates observed in the western areas of the Northern Zone based on previous tagging studies (McGarvey et al. 1999). In addition, males are known to attain an overall larger size than females, which would further influence mean weight estimates given that survey landings were male only.

The catch rate of undersized lobsters has been minimised in the fishery since the mandatory introduction of escape gaps in 2003 (Linnane et al. 2011). Previous within season trends have shown that during the normal fishing season, levels of undersized catch are highest from November to March, but decline considerably thereafter (Linnane et al. 2014). The results from the current survey were positive in that catch rates of undersized lobsters remained low from June to October. Overall, this suggests that the catchability of undersized lobsters is lowest during winter and spring, before increasing over the summer.

6.1.2 Catch composition

During the survey period, the sex ratio of individuals was primarily skewed towards males, especially during June, July and August. The reduction in catchability of females during this period is most likely linked to temporal trends in the reproductive cycle of *J. edwardsii*. In South Australian waters, moulting, and subsequent mating of females occurs from April to July with external brooding of eggs through winter (Prescott et al. 1996). During the moulting period, feeding and therefore overall catchability, is known to decrease in females (Ziegler et al. 2004), thereby, skewing monthly sex ratios towards males. By September, when the majority of moulting has occurred, feeding resumes and the catchability of females increases as observed by a return to an approximate 1:1 ratio in the catch.

Egg bearing females first began to appear in the catch in July, with levels peaking in September. However, given the overall reduction in catchability of females during most of the survey period, the contribution of ovigerous individuals to the total catch was low, ranging from 2% to 26%. The levels observed during October (17%) were consistent with those recorded in recent seasons in the Southern Zone fishery of South Australia (9% to 17%) which is currently open to fishing during this month.

6.1.3 By-catch and by-product species

A total of 29 by-catch species were identified in the survey, but with the exception of four groups, overall by-catch rates were negligible (<1 individual/100 pots). Leatherjackets, Bluethroat Wrasse, Hermit Crabs and Port Jackson Shark were the dominant groups identified, all of which are closely associated with temperate reef habitat favoured by Southern Rock Lobster (Shepherd and Edgar 2013). The results are consistent with a major by-catch study previously undertaken in the fishery (Brock et al. 2007), which identified Leatherjacket and Bluethroat Wrasse as the dominant commercial Rock Lobster by-catch species across South Australia. Given that both of these groups are typically the highest by-catch group in terms of catch by number, the catch rate of Leatherjackets and wrasse during the survey were specifically compared against those of the normal fishing season. The results indicated that the catch rate of these species were lowest during winter before increasing during spring and summer. The overall low levels of by-catch are likely to reflect the mandatory introduction of escape gaps into the fishery in 2003 which has subsequently been shown to have reduced by-catch levels of finfish species by >50% (Linnane et al. 2011).

The primary by-product species in the fishery are Giant Crab and Maori Octopus. Only a single Giant Crab was landed during the survey which is likely to reflect the fact that the majority of fishing during the temporal survey of the four regions was inshore (<60 m) whereas Giant Crab are predominately landed in depths ranging from 200 m to 400 m (Gardner et al. 2009). The catch rates of Maori Octopus during the survey was considerably lower during the survey period compared to months of the regular season. Given that the majority of within-pot mortalities are caused by octopus predation (Brock and Ward 2004), this is a positive result for the fishery. The survey results confirmed low levels of dead lobsters which tend to be highest during spring and summer.

6.2 Spatial component

6.2.1 Spatial sub-regions: historical catch and effort data

The long-term analyses of historical catch and effort data by sub-region provided an insight into the spatial dynamics of the NZRLF fleet, particularly after the introduction of the quota system. A TACC was first introduced into the NZRLF in 2003 at 625 t. However, from 2003 to 2008, the TACC was never fully taken. In 2003, only 503 t of the 625 t quota was landed. In 2004, the TACC was reduced to 520 t of which only 446 t was taken. Over the next three seasons, the TACC was retained at 520 t but with only 476 t, 491 t and 459 t taken in 2005, 2006 and 2007, respectively. In 2008, the TACC was reduced to 470 t, but only 403 t were taken. Therefore, 2008 represented the sixth successive season in which the TACC had not been landed within the fishery. As effort levels within each sub-region remained high, despite a declining catch trend, this translated into poor fishery performance, as reflected by the long-term decrease in catch rates across all sub-regions from 1999 to 2008.

In 2009, the TACC was reduced from 470 t to 310 t. This represented the first time that a TACC had been set at a level below the previous year's total reported catch (402.7 t in 2008). As a result of a constraining TACC, effort levels reduced considerably within each sub-region. In addition, the percentage of the total catch decreased from 9% to 4% and 6% to 1% in the West Coast and Deep Water sub-regions, respectively. When quota became constraining from 2009 onwards, the focus within the fishery shifted to maximising economic return for the limited catch available. As a result, the observed spatial contraction of the fleet into the Inner sub-region was driven by: (i) higher costs, especially in relation to fuel, of fishing the West Coast and Deep Water sub-regions; and (ii) the fact that a higher unit price is paid by overseas markets for smaller (<1 kg) lobsters of red colouration (Chandrapavan et al. 2009) which are captured in greater abundance in the Inner Region.

Overall trends in catch, effort and CPUE were strongly correlated across all sub-regions with more year to year variation occurring in the Deep Water sub-region. This result suggests that the processes driving recruitment in the NZRLF occur across large spatial scales. Catch rates decreased to a historical low in all sub-regions in 2008, before increasing over the next three seasons. This rebound was in part permitted by the constraining TACC that reduced effort from 500,000 - 600,000 potlifts to around 300,000 potlifts between 2008 and 2009. In addition, a recruitment pulse from relatively high puerulus settlement in 2005 and 2006 (Linnane et al. 2013), also assisted the recovery, with the settled larvae reaching the legal stock between 2009 and 2011. Since 2011, catch rates have again trended downward in all three sub-regions.

Two outcomes were evident in the yearly plots of landed lobster mean weight by sub-region. Firstly, the mean weight of lobsters from the West Coast sub-region was much larger compared to other sub-regions. Secondly, the Deep Water and Inner sub-regions have almost identical absolute levels of average mean weight. In addition, the temporal trend in mean weight from these two sub-regions was very similar. This similarity was unexpected given that growth rates of lobsters in South Australia decrease with depth (McGarvey et al. 1999). One possible explanation is that the, on average, lower level of exploitation in the Deep Water sub-region, which presumably ensures longer survival times in the legal stock, approximately balances the slower growth rates, thus resulting in lobsters having a similar mean weight at time of landing. The similar time trend in mean weight, as with CPUE, also adds support to the evidence of similarity across sub-regions in relation to yearly recruitment variation.

6.2.2 Lobster growth

Growth rates of lobsters varied spatially by sub-region with Deep Water individuals growing considerably slower than Inner Region or West Coast counterparts. This result confirms the findings from a previous study by McGarvey et al. (1999) which showed that growth rates were found to decrease with each 20-m increase in depth by 1.6 mm CL yr^{-1} for females and 1.8 mm CL yr^{-1} for males. McGarvey et al. (1999) also identified specific MFAs around the Yorke Peninsula (Figure 1) and in the West Coast sub-region, which exhibited some of the highest growth rates within South Australia.

The factors impacting on lobster growth are likely to be numerous. Water temperature appears to be one driving factor with some of the lowest growth in South Australia observed in the south-eastern regions (McGarvey et al. 1999) where the influence of the local cold-water Bonney upwelling is greatest (McClatchie et al. 2006). Similarly, lower growth rates in southern Tasmania can be attributed to lower annual water temperatures compared to more northerly sites (Gardner et al. 2006). Environmental causes are not always evident however with growth rates higher in some regions of New Zealand despite decreasing latitude (Annala et al. 1980), thus indicating that growth in *J. edwardsii* is regulated by factors in addition to temperature. Suggested influences include density dependence (Beyers and Goosen 1987; MacDiarmid 1989), food availability (Melville-Smith et al. 1995), habitat type (Howard 1980), fishing pressure (Lizarraga-Cubedo et al. 2003) and social interactions through antagonistic behaviour with conspecifics (Thomas et al. 2003).

6.2.3 Spatial estimates of biomass

While yearly trends in biomass were broadly similar across sub-regions, absolute levels differed. Specifically, biomass levels within the Inner Region sub-region were considerably higher than the West Coast and Deep Water. Exploitation rates, however, were much lower in the West Coast and Deep Water compared to the Inner Region.

Much of the analyses undertaken focused on 5-year averages of data from 2009 to 2013 when the TACC firstly constrained catch and when effort was greatly reduced (300,000-350,000 potlifts) as compared to the previous period of input controlled management or when the TACC was non-constraining (500,000-700,000 potlifts). This was undertaken primarily because the spatial management regime that these results will inform are expected to proceed under a regime of quota constraint more similar to the 2009 to 2013 period.

These 5-year averages provide guidance for the principal Northern Zone spatial management questions that this project was undertaken to address. The principal outcome is that exploitation levels in the West Coast and Deep Water sub-regions are currently low. As a result, the estimated levels of 2-3% in the West Coast, and 4% in the Deep Water, suggest that these populations could support an increased take of lobsters compared to that previously experienced over the most recent 5-year period.

However, one line of evidence suggests that an increase in exploitation rate to levels currently seen in the Inner Region (>20%) would not be sustainable for the remaining sub-regions. From 2009 onward, despite large reductions in levels of effort and exploitation rate, CPUE and biomass estimates in the West Coast and Deep Water did not increase at rates observed in the Inner Region. In fact, within the West Coast sub-region, these measures of abundance rose more slowly over the last five years. Evidence of a slow recovery, despite much lower levels of exploitation, suggests that the productivity of the West Coast and Deep Water sub-regions is not as high as the Inner Region. Specifically, recruitment levels in the West Coast and Deep Water sub-regions are likely to be lower than the Inner Region. As a result, this study recommends that levels of exploitation rate in the West Coast and Deep Water sub-regions should be maintained at levels lower than the Inner Region to ensure sustainability in these areas.

Another point of consideration, particularly in the West Coast sub-region, relates to sources and sinks of puerulus larvae in the fishery. 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 NZRLF, the study predicted that the most significant levels of recruitment occur from the western regions of the zone. As a result, explicit levels of exploitation rate within the West Coast sub-region requires careful consideration, given the risk implications to potential recruitment overfishing across the broader fishery.

Finally, it should be highlighted that since the last year of data used in the analyses was from the 2013/14 season, recently introduced marine park sanctuaries in the NZRLF are not accounted for in any of the spatial biomass estimates presented in this report. No-take areas only became active in the NZRLF in October 2014.

7 Conclusion

The two objectives of this study were to: 1) provide a detailed breakdown of catch composition from dedicated surveys undertaken in the NZRLF from June to October 2014, and 2) provide spatial estimates of Rock Lobster biomass in the NZRLF based on historical catch and effort data. Both of these objectives were achieved.

The major findings of the temporal component of the project were:

i) The winter fishing survey was successfully completed with 104 out of a possible 120 days sampled (87%) and 3.6 t of male lobsters landed.

ii) The survey catch rate was ~0.50 kg/potlift and was highest in August (0.68 kg/potlift).

iii) The mean weight of survey fish was 1.70 kg (males only), considerably higher than in the regular season at 1.10 kg (males and females combined).

iv) Predation levels during the survey were low compared to the regular season.

v) The survey catch rate of undersized lobsters was also considerably lower than the regular season.

vi) The proportion of females in the total catch increased from 18% in June to 44% in October. The contribution of egg-bearing females to the total catch was 18%, 26% and 17% in August, September and October, respectively.

vii) A total of 29 by-catch species were recorded during the survey but catch rate estimates were negligible for most species. By-catch was dominated by Leatherjacket species at catch rates comparable to the regular months of the fishing season.

Spatially, the primary findings of the biomass estimation were:

i) Overall trends in catch, effort and CPUE were strongly correlated across the Inner Region, West Coast and Deep Water sub-regions with more year to year variation occurring in the Deep Water area. This result suggests that the processes driving recruitment in the NZRLF occur across large spatial scales.

ii) Growth rates of lobsters varied spatially by sub-region with Deep Water individuals growing considerably slower than Inner Region or West Coast counterparts.

iii) While overall trends in biomass were broadly similar across sub-regions, absolute levels differed. Two-thirds of the biomass lies within the Inner Region sub-region, with approximately 28% and 6% in the West Coast and Deep Water areas respectively.

iv) Average exploitation rates have decreased considerably across all sub-regions in the NZRLF since TACCs first began to constrain catch levels in 2009. Current exploitation rates in the West Coast and Deep Water sub-regions are less than 5%.

8 Implications

Temporally, the results from the winter fishing survey suggest a number of implications for the fishery. Firstly, if some proportion of the total catch is taken in winter rather than summer, this may result in a higher proportion of male fish being harvested, due to the low catchability of females observed during the survey. Overall, this should have positive implications for egg production, with more females remaining in the population. Other positive impacts could be reduced levels of by-catch and undersized lobster mortality, as survey results showed lower catch rates of these individuals during winter. In addition, within-pot predation is lower in winter and thus a shift of fishing effort to this period could see reduced levels of lobster mortality in the fishery.

In contrast, if egg bearing females handled during winter months have reduced reproductive success, the implications for the fishery could be negative. This aspect could be reduced by ensuring that a code-of-practice in relation to the handling and release of females is developed and adhered to within the fishery. However, as shown in this study, female catchabilty is considerably reduced in winter meaning that the overall number of females being handled will be lower than in other times of the year.

Economically, it is understood that while the market generally demands smaller lobsters during the regular season, prices for larger lobster in winter attract a higher average price due to low overall supply. As larger fish that make up a greater proportion of the catch from the Northern Zone, winter fishing is anticipated to positively impact on the economic performance of the fishery by providing fishers with the flexibility to harvest fish when prices are optimised.

With respect to spatial management, given the currently low levels of exploitation rate in the West Coast, and Deep Water sub-regions, the implications are that these populations could support an increased take of lobsters compared to that previously experienced in recent seasons. However, as previous research indicates that these areas may be important contributors to Southern Rock Lobster fish stocks in more eastern jurisdictions, increased levels of harvest require careful consideration in this regard.

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9 Recommendations

The following recommendations have been developed from this project.

Temporally, following consideration of advice from the RSC, the RLFMAC agreed to recommend investigation of winter fishing be continued in 2015, noting the need for adequate monitoring requirements for vessels and that the fishery develop a code of conduct for the handling of egg-bearing females. The RLFMAC further agreed that the effectiveness of these arrangements be closely monitored throughout the winter fishing period.

As a result, a second winter fishing survey began in the NZRLF in June 2015. It was agreed that fishing would be for a maximum of 175 fishing days (35 fishing days for June to October) including a minimum of ten fishing days (over two fishing trips) in each calendar month. Both males and females can be landed during this survey with fishing allowed in the Outer Zone (see below) only. Broadly, the Outer Zone incorporates both the West Coast, and Deep Water sub-regions (Figure 27).

From a spatial perspective, following consideration of advice from the RSC, the RLFMAC agreed to recommend an option for amending the NZRLF harvest strategy (PIRSA 2014) based on CPUE levels and associated TACCs detailed in Table 14. This is based on Inner and Outer Zones (Figure 27) which were agreed upon based on the spatial analyses undertaken in this project.

Table 14. TACC levels (t) for recommending TACC in the Northern Zone Rock Lobster Fishery. Note that all CPUE levels relate to commercial catch rate at or above the lower CPUE in each range, and up to the upper figure.

CPUE (kg/potlift)	Inner TACC	Outer TACC	Total TACC
<0.5	0t	0t	0t
0.5-0.55	43t	13t	56t
0.55-0.6	93t	27t	120t
0.6-0.65	150t	43t	193t
0.65-0.7	170t	46t	216t
0.7-0.8	215t	50t	265t
0.8-1.0*	300t	60t	360t
>1.0	300t	80t	380t

* When TACC is recommended based on a CPUE range of 0.8-1.0kg/potlift, if CPUE is less than 0.9kg/potlift for two consecutive years, TACC will drop to that corresponding to the next lowest CPUE range level (0.7-0.8 kg/ pot lift). TACC will not return to a level corresponding to a CPUE range of 0.8-1.0 kg/potlift until catch rates are equal to or greater than 0.9 kg/ pot lift for two consecutive years. 2015/16 will the first year that this rule would be considered to be taken into account.

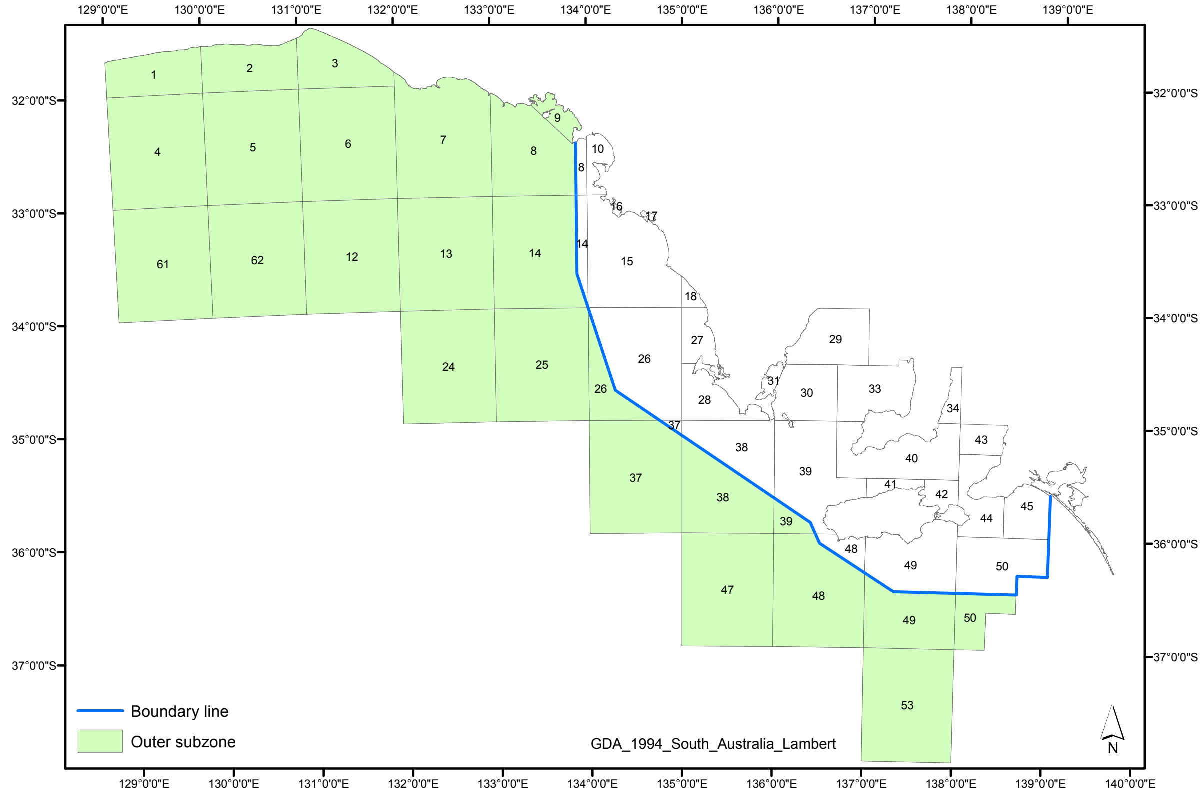

Figure 27. Newly proposed spatial boundaries for the NZRLF.

10 Extension and Adoption

Throughout the project, all stakeholders were kept updated through a specifically designed extension and communication strategy. This involved two dedicated workshops with industry members and PIRSA Fisheries and Aquaculture managers, held on 26 November 2014 and 18 February 2015. In addition to workshops, throughout the project a number of informal meetings were held with members of the NZRLF Fishermen's Association executive committee where work progress was detailed. The final project outcomes were presented to industry stakeholders at two dedicated meetings held at West Beach and Port Lincoln on 8 and 9 April 2015, respectively. Media extension included contributions to the *Port Lincoln Times* and *Southern Rock Lobster Newsletter*, as well as PIRSA Fisheries and Aquaculture media communications.

On 21 April 2015, the South Australian Rock Lobster Fishery Management Advisory Committee (RLFMAC), Research Sub Committee (RSC) convened to consider the implications of the project outcomes.

Based on the temporal research findings, the RSC concluded that:

"…..*there is no scientific reason that winter fishing could not be considered by the RLFMAC. Furthermore, it is recommended that the RLFMAC consider that there are strong monitoring requirements on the fishery for those that undertake winter fishing and a fishery code of conduct arrangement for the handling of berried females be developed and that the effectiveness of these arrangements are monitored*."

Based on the spatial research findings the RSC concluded that:

"*The RSC finds that there is scope for fishing in the Outer Zone (OZ – which is the West Coast and Deep Water sub-regions combined), given the present low levels of fishing mortality in these regions. However, past exploitation levels did result in a decline in abundance in the two outlying subregions, especially in the Deep Water meaning that the OZ may be less productive than the inner zone and has lower biomass levels. However, it was agreed that the two outlying regions could sustain at least moderately higher catches*."

Based on these recommendations, the RLFMAC recommended amendments to the NZRLF harvest strategy which incorporated regional TACCs for Inner and Outer Regions of the fishery based on estimates of biomass derived from this project. An amended NZRLF harvest strategy was implemented into management arrangements in 2015 based on Inner and Outer regions, with a new schedule of TACCs underpinned by spatial biomass and exploitation rate estimates generated from this project. TACCs were computed to target 21% and 10% exploitation rates in the Inner and Outer Regions respectively. In addition, the RLFMAC also recommended a further winter fishing trial to gain additional biological and catch information. In 2015, a second fishing survey in the annual fishing closure was undertaken in the NZRLF in waters >80 m depth only. Overall, the results broadly confirmed those observed in 2014 surveys with (i) low levels of undersized, dead and by-catch catch rates, (ii) a predominately male dominated catch and (iii) the percentage of egg-bearing females highest in September but comparable to October levels in the Southern Zone.

Consideration of alternative temporal management of the NZRLF, namely changes to the closed fishing period, will be formally considered by the RLFMAC in 2015/16 following consideration of the information from this research project and the 2015 winter research fishing trial.

11 Project materials developed

A presentation titled "*Adaptive management response to a spatially confined rock Lobster (Jasus edwardsii) fishery in South Australia*" (Linnane, McGarvey, Matthews and Jones) was given at the International Council for the Exploration of the Sea (ICES) *Symposium on Targets and Limits for Long-term Fisheries Management* held in Athens, Greece from 27-30 October, 2015.

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13 Appendices

Appendix 1. Intellectual Property

No intellectual property has been identified. The report and resulting manuscripts are intended for wide dissemination and distribution.

Appendix 2. Staff

Adrian Linnane – Principal Investigator (SARDI)
Richard McGarvey – Co-investigator (SARDI)
Annabel Jones – Co-investigator (PIRSA)
Janet Matthews – Co-investigator (SARDI)
John Feenstra – Co-investigator (SARDI)
Kyriakos Toumazos - Co-investigator (Executive Officer NZRLF)
Kylie Howard – Fisheries information services (SARDI)
Lachlan McLeay – Technical support (SARDI)
Peter Hawthorne – Technical support (SARDI)
Andrew Hogg – Technical support (SARDI)
Owen Burnell – Technical support (SARDI)
Leonardo Mantilla – Technical support (SARDI)
Matthew Hoare – Technical support (SARDI)
Alex Dobrovolskis – Technical support (SARDI)
Lorenzo Andreacchio – Technical support (SARDI)
Andrew Hogg – Technical support (SARDI)
Douglas Graske – Technical support (SARDI)
Michael Drew – Technical support (SARDI)
Members of the Northern Zone Rock Lobster Fisherman’s Association.

Appendix 3. qR Model Specifications

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 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

Annual lobster catch in the South Australian lobster fisheries is reported in logbooks by weight (C_t^W) and by numbers (C_t^N). Effort (E_t) is reported as yearly pot lifts. A year (t = 1983, …, 1983+ n_t -1) refers to a full 7-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. In the Northern Zone qR model, as in LenMod, a 3% yearly increase in effective effort from 1984 to 2000 is assumed based on discussions with industry and managers, modelled as a rising catchability in these pre-quota years.

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 were assumed constant across age. Growth is expressed in 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.

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

Likelihood function

The negative log likelihood was written:

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

Variances of these two normal 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:

$$\sigma_N = \sigma_C \cdot \bar{C}^N \tag{5a}$$

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

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

The output of yearly biomass in each year was calculated as the sum over all ages of population number by age times mean weight at age:

$$B_t = \sum_{a=1}^{20+} w_a N_{a,t} . \qquad \text{(6)}$$

Similarly, yearly egg production by female lobsters was computed as

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

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 15. 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