Characterisation, catch per unit effort standardisation, and exploring alternative minimum legal sizes of packhorse rock lobsters in New Zealand

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September 6, 2013

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EXECUTIVE SUMMARY

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This study was contracted by the New Zealand Rock Lobster Industry Council Ltd. under the project code PHC_2013. The aim of this project was to characterise the packhorse rock lobster (PHC) fishery in New Zealand, do a catch per unit effort (CPUE) analysis, and identify changes to the current management framework that could increase economic growth opportunities and efficiency gains for the fishery, particularly for vessels operating within the CRA 1 Quota Management Area (QMA). Of particular interest was the exploration of a reduced minimum legal size (MLS) and the introduction of a maximum legal size.

The packhorse rock lobster fishery is largely restricted to the north of the North Island and the catch of PHC has mainly been bycatch of the red rock lobster (CRA) fishery. However, some targeting of PHC occurs and when vessels do target PHC their catch rates are much higher. Since the introduction of the Quota Management System (QMS), total PHC catches have been relatively low and have only begun to approach the Total Allowable Commercial Catch (TACC) in the last five years.

The standardised CPUE is based on Catch Effort Landing Return (CELR) data from 1991/92 to 2012/13. The trend in the CPUE index is optimistic, showing a rise in catch rates since the start of the series.

Information collected on the price paid for lobsters shows that packhorse lobsters fetch a lower price than red rock lobsters. Furthermore, the PHC available to the fishery generally fall into the largest and least valuable size-grade due to the relatively large MLS for the species (when compared with CRA). Exploratory modelling indicates that a reduction in the MLS for PHC would see lobsters in the smaller size-grades available to the fishery and hence improve the gross revenue possible from a unit of PHC catch. The availability of the smaller/higher value lobsters might also tempt more fishers to target PHC and could help increase the total commercial catch towards the current TACC. As it stands, it is unlikely that an increase in the TACC would improve the yield from the PHC fishery as fishers are not catching the current TACC anyway.

To compliment a reduction in the MLS a maximum legal size was also considered to help maintain the spawning stock biomass. This could not be modelled due to limitations in the way the observer catch sampling data has been recorded. However, this strategy relies on sufficient juveniles reaching the maximum legal size. This poses a difficult question that may not be answered given the current knowledge of the fishery. Despite this, a spatial approach to a reduction in the MLS could ensure that some lobsters reach the maximum legal size before being caught.

1 INTRODUCTION

Two species of rock lobster are commonly harvested in New Zealand inshore waters. The red rock lobster *Jasus edwardsii* (CRA) and the packhorse rock lobster *Sagmariasus verreauxi* (PHC). The red rock lobster supports the most valuable inshore fishery in New Zealand and is important to commercial, recreational and customary users. Conversely, few fishermen target the packhorse rock lobster which is taken mainly in the north of the North Island. However, there is considerable overlap of vessels fishing the red rock lobster and packhorse in the CRA 1 Quota Management Area (QMA, Figure 1).

S. *verreauxi* (hereafter referred to as PHC) is found in New Zealand and southern Australia, however, some provisional genetic evidence suggests that the lobsters in Australia may be a different species (Brasher et al. 1992). While much work has been done on the lobsters in Australia, where they are commonly referred to as the eastern rock lobster, there is little available information on PHC in New Zealand. A noteworthy exception to this is John Booth's book on spiny lobsters which focuses on the packhorse rock lobster (Booth 2011).

PHC is reported to be the largest species of rock lobster in the world reaching a total length over half a metre and possibly weighing as much as 18 kg. PHC in Australia are known to grow faster than red rock lobsters here in New Zealand (Montgomery et al. 2009), but little is known of the growth rates of packhorse in New Zealand. PHC in New Zealand are also thought to be the most migratory spiny lobster on Earth in terms of proportions migrating and distance covered. They generally march northwards up the east coast of the North Island, the primary destination for these lobsters being breeding grounds in the far north of the North Island. The size at onset of breeding is large in females at about 160 mm carapace-length (Booth 1984). Typical of many other rock lobster species, females and males move seasonally inshore and off as they respectively moult and reproduce.

1.1 The fishery

Packhorse rock lobsters were amalgamated into the Quota Management System (QMS) on 1 April 1990 and the fishery is currently managed as a single QMA (PHC 1) by the Ministry for Primary Industries (MPI). Initially the Total Allowable Commercial Catch (TACC) was set at 27 tonnes. This was raised in the same year to 30.5 tonnes due to quota appeals. The TACC remained at 30.5 tonnes for just two years and was increased to 40.3 tonnes during the 1992/93 fishing year where it has remained since. Since the introduction of the QMS, packhorse catches have been relatively low and have only begun to approach the TACC in the last five years (Figure 2, Table 10). Historically landings were much higher (Kensler & Skrzynski 1970, Booth 2011, Figure 2, Table 9).

While PHC 1 covers New Zealand's entire Exclusive Economic Zone (EEZ, Figure 1), PHC are caught mainly in the north of the North Island. Prior to the QMS, the PHC fishery was managed using input controls, including: minimum legal size (MLS) regulations; a prohibition on taking berried females (i.e., carrying external eggs) and soft shell lobsters; making it illegal to commercially dive for or spear them; requiring pots to have gaps or mesh large enough to allow small lobsters to escape; requiring that they are landed ashore alive; and some local area closures. Today, all of these input controls remain.

Recreational fishers may gather PHC by pot or hand (freediving or scuba) but are subject to most of the other input controls in place for commercial fishers. Recreational fishers may not take soft shell individuals or berried females, and it is illegal to spear them. Additionally, a bag limit of 6 rock lobsters (CRA and PHC combined) applies to recreational fishers. The total recreational and customary catches for PHC are not known but thought to be low.

The MLS of PHC for commercial and recreational fishers is 216 mm tail-length for both sexes. In many fish stocks a MLS is put in place to allow most females to breed at least once before becoming legal to harvest. However, the current MLS of PHC is smaller than the size at which 50% of females reach

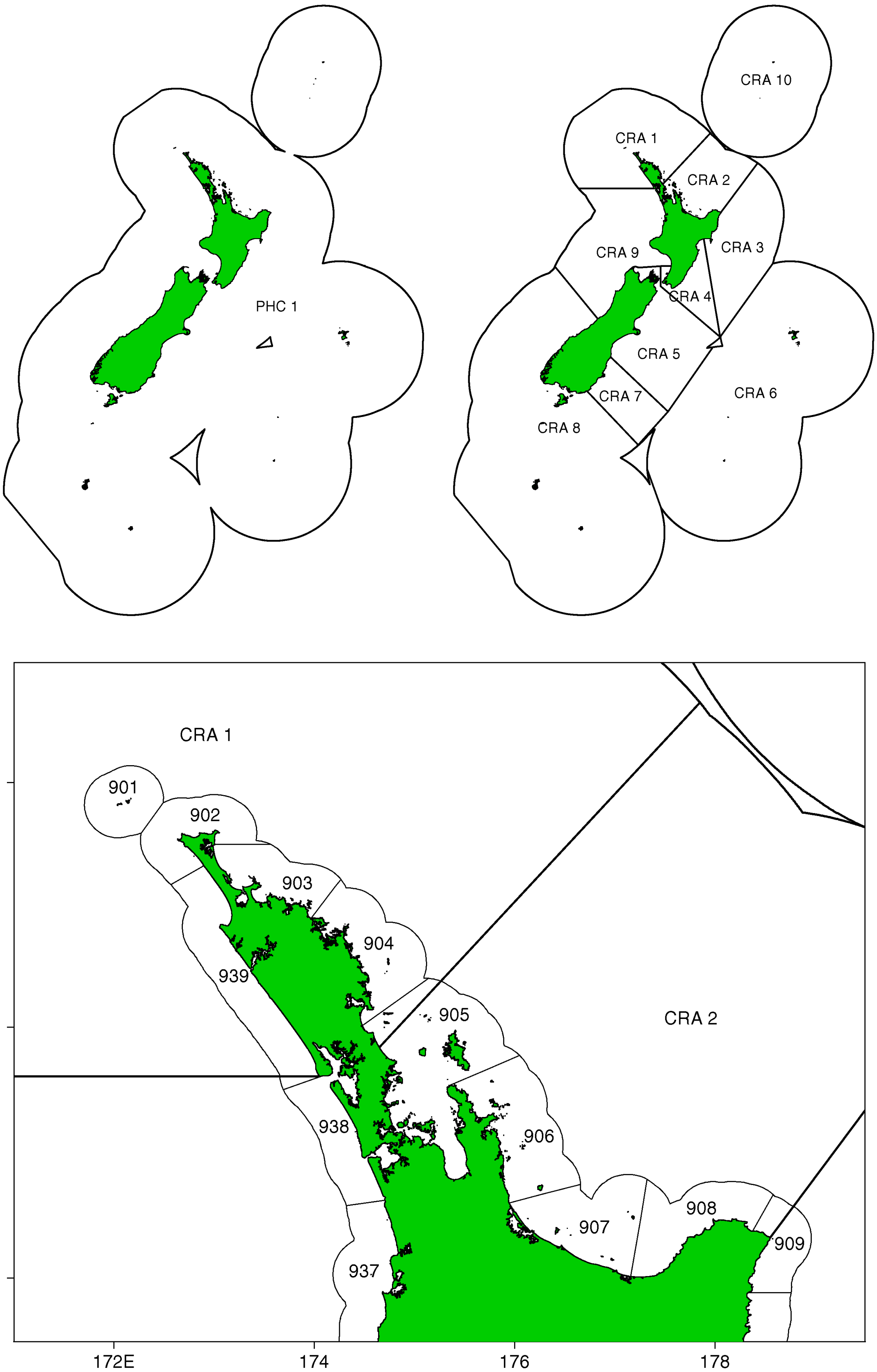

Figure 1: Rock lobster fisheries management areas for the packhorse rock lobster *Sagmariasus verreauxi* (PHC) [top-left] and the red rock lobster *Jasus edwardsii* (CRA) [top-right] and the rock lobster statistical areas within CRA 1 and CRA 2 [bottom].

maturity (Booth 1984). In comparison, the MLS in Australia is 104 mm carapace-length, much smaller than New Zealand where for females it is equivalent to 155 mm carapace-length. In Australia there is also a maximum legal size of 180 mm carapace-length that is intended to look after the stock of large breeders.

Fishers targeting PHC generally use different methods to those targeting CRA. Generally longer soak times and more bait are used (this is also the case in the Australian fisheries for PHC). Larger pots are also common when targeting the species, often due to strong tidal currents and the sandy substrate on which they are set.

To date, no catch per unit effort (CPUE) analyses have been done, no stock assessments have been attempted and there are no management procedures in place for PHC in New Zealand waters. There is also little available biological information for the species in New Zealand.

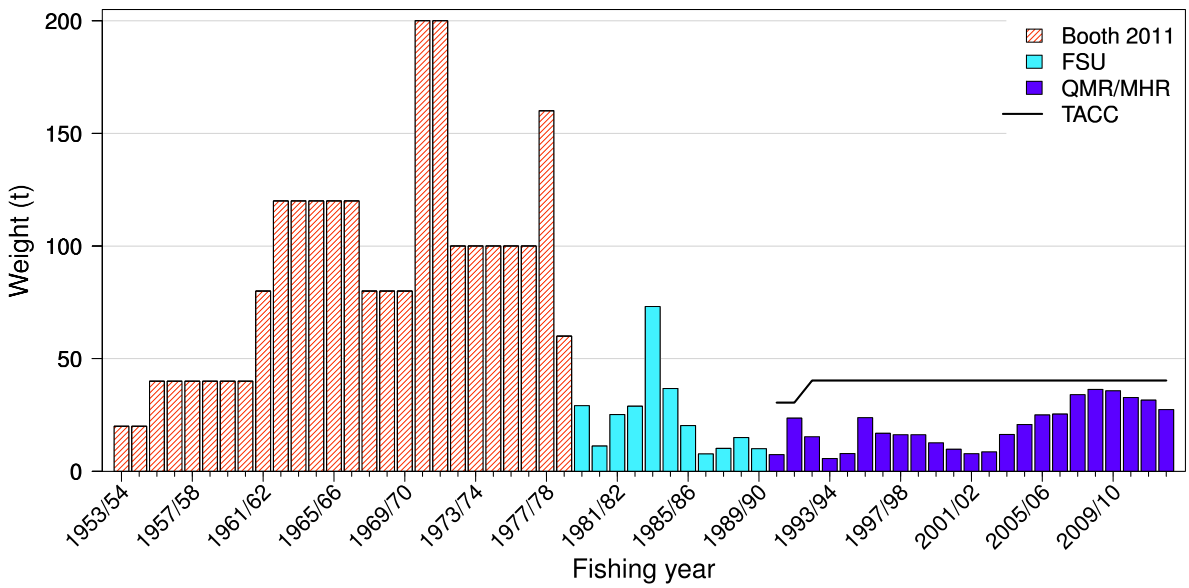

Figure 2: Packhorse rock lobster *Sagmariasus verreauxi* (PHC) landings (tonnes) and Total Allowable Commercial Catch (TACC, tonnes) from 1953/54 to 2012/13. The landings for 1953/54 to 1978/79 are estimates from Booth (2011), for 1979/80 to 1989/90 are FSU, and 1990/91 onwards are QMR/MHR.

1.2 Aims of this project

CRAMAC 1 believes there are growth and development opportunities available in the PHC 1 fishery, particularly for vessels (and quota share owners) operating in the CRA 1 QMA. Their objective is to identify any changes to the existing management framework that could be modified to improve commercial harvesting efficiency by reducing time and effort required to land the TACC. It is hoped that, in time, this could lead to a TACC increase. However, no CPUE analyses or stock assessments have been done for PHC in New Zealand and so the status of the stock is unknown.

The aim of this project is to characterise the PHC fishery in New Zealand, do a CPUE analysis, and identify changes to the current management framework that could increase economic growth opportunities and efficiency gains for the fishery, particularly for vessels operating within CRA 1. Of particular interest is the exploration of a reduced MLS and the introduction of a maximum legal size.

Exploring how changes to input controls, such as minimum and maximum legal size limits, could affect the fishery or the revenue made by the fishery can be done using bioeconomic models. The most sophisticated bioeconomic models require information on the costs of fishing, effort and catch, prices, and biology of the species or stock being assessed and are typically integrated with a current stock assessment model. These models are usually optimisation models that estimate a set of control variables such as fleet size, effort or catch, that maximise a given variable such as profit. Bioeconomic models in rock lobster fisheries have increased in popularity in Australia in the last decade (e.g., Green et al. 2006), but little bioeconomic modelling has been done in New Zealand (but see Breen et al. 1992).

Because there is no current stock assessment model, limited biological information, no information available on the costs of fishing and no information on the price paid for PHC (before this study), a full bioeconomic model is not yet possible. Instead, some exploratory modelling will be done looking at how gross revenue changes as the size-composition of the catch is altered. Scenarios will be modelled where the MLS is changed and the effect on gross revenue investigated. A maximum legal size, to ensure the spawning stock biomass is maintained and compliment any change in MLS, will also be considered.

2 DATA SOURCES AND METHODS

2.1 Grooming catch and effort data

This project analysed catch and effort, observer catch sampling, tag-recapture, voluntary logbook and price data. Catch and effort, observer and tag data were obtained from the Ministry for Primary Industries (MPI, report log 9002-04, June 2013). Logbook data were obtained from P. Starr and price data were obtained using a survey.

A new shadow database named PHCCE (PHC catch and effort) was developed to serve as a repository for all PHC data sets and structured query language queries used to groom and collate these data for stock assessment or other purposes. Only lobster caught using the rock lobster potting method are included in the database.

2.1.1 Error checking catch and effort data

Catch and effort information for the rock lobster potting method is reported on the Catch Effort Landing Return (CELR) form which reports daily totals of the number of pots lifted and the estimated catch of the top species unless the fisher has changed statistical area or target species (in which case a single record may represent only part of the day). The verified landed green weight that is obtained at the end of the trip is also reported on the bottom part of the form. Catch and effort data from 1 April 1979 to 30 June 1989 were obtained from the Fisheries Statistics Unit (FSU) database (Fisher & Sanders 2004) and data from 1 July 1989 to 31 March 2013 from the Warehou database (MPI 2010).

Records with error ratings greater than or equal to two for the fields statistical area, pots lifted, estimated subcatch and landings were excluded from this analysis. These error ratings were first described by Bentley et al. (2005) and the application of these error checks to the CELR data is described in Appendix A. Records without a vessel key were also dropped, as were records for vessel 4548 (a coded value) because of a high number of outliers from this vessel.

FSU data were not used for the calculation of CPUE indices as this data set appears to be deficient in records where catch is zero (biasing the catch rates upwards). Table 17 shows the pronounced decrease in effort (potlifts) during the FSU years. This issue is discussed further by Bentley et al. (2005).

2.1.2 Defining core areas

Statistical areas were identified in the characterisation as areas in which to monitor the abundance of packhorse rock lobsters based on a consideration of whether the area accounts for a significant proportion of landed PHC. Little PHC was caught outside of the areas 901 to 908 and 939 (CRA 1 and CRA 2, Figure 6, Table 16), so the data used in the CPUE analysis were restricted to these areas.

2.1.3 Defining the core fleet

The data used in the CPUE analysis were further restricted to those vessels that participated with some consistency in the PHC fishery. Core vessels were identified by specifying two variables: the number of trips that determined a qualifying year, and the number of qualifying years that each vessel participated in the fishery. The core fleet was selected by choosing the variable values that resulted in the fewest vessels while maintaining the highest proportion of the landed catch (bottom of the CELR form).

The variables were set at 5 trips per qualifying year for 2 years. This reduced the number of vessels in the dataset by over 70% while reducing the amount of landed catch by 14% (Figure 3).

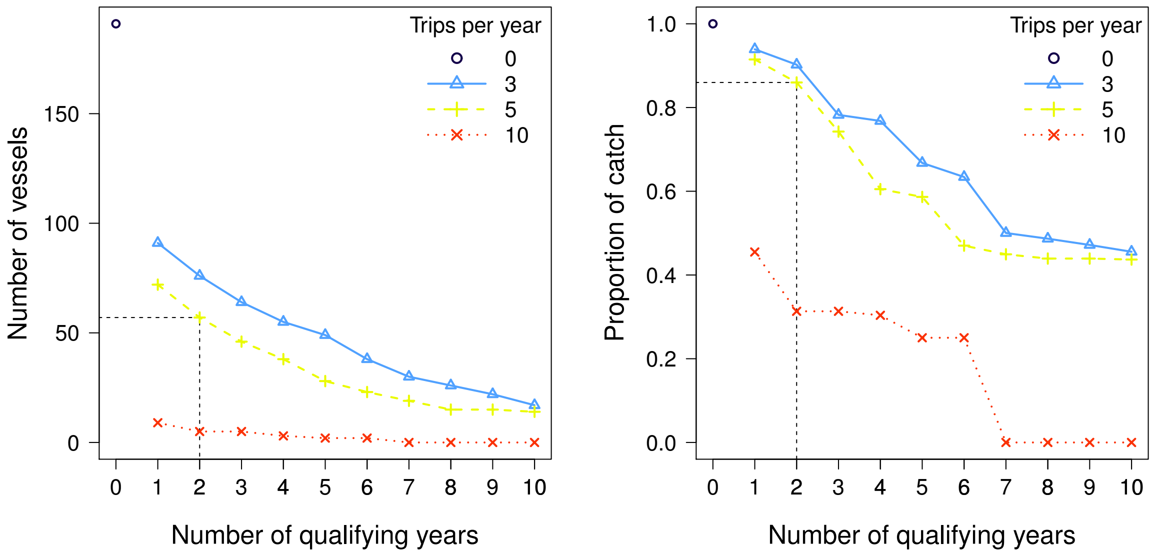

Figure 3: Number of vessels [left] and the proportion of landed catch of PHC [right] retained in the data set depending on the minimum number of qualifying years and the minimum number of trips per qualifying year used to select core vessels. The minimum number of trips per qualifying year for each series is indicated in the legend.

2.1.4 Inclusion of zero catch information

Where a species is monitored in a well defined target fishery, zero catches are rare and are usually implicitly included in lognormal CPUE standardisation models when the data is aggregated. However, in non-target fisheries, zero catches can be common and aggregating data may still result in strata with a zero catch, although the effort in that strata is positive (e.g., a vessel targeting CRA may fish during a fishing year and month in a statistical area and not catch any PHC).

Not including zero catches will positively bias catch rates and may result in a CPUE index that is not proportional to the abundance of the fish stock. For this reason, all qualifying effort, including unsuccessful effort, should be included in the calculation of CPUE indices and the standardisation process.

The initial catch and effort data extract requested all fishing events that either landed or targeted PHC. In this data set only 102 fishing events had a zero catch of PHC while effort was not zero (14 where CRA was the target species and 88 where PHC was target). This was equivalent to 9 aggregated records (aggregated by year-month-area-vessel-target) with zero catch. This extract did not include effort for fishing events that targeted CRA but did not catch any PHC. It is conceivable that vessels fishing in the core areas (defined in Section 2.1.2 above) and target CRA could capture PHC. Therefore, this initial extract was considered deficient in effort that resulted in zero PHC catch.

This was amended using a separate extract from the CRACE (CRA catch and effort) database (Bentley et al. 2005). Qualifying fishing events for the CRACE extract were defined as those events in the core areas that used the rock lobster potting method during the fishing years 1990/91 to 2012/13 for vessels that ever caught a packhorse (and targeted CRA). These data were provided aggregated by year, month, vessel and statistical area.

When combining the CRACE data with the original PHC extract, care needed to be taken that effort was not double counted (the original extract included effort from trips that targeted CRA and did catch PHC). The original extract was aggregated by year-month-area-vessel-target. All aggregated effort from the original PHC extract that targeted CRA was replaced with the aggregated effort from the CRACE extract (where target species was always CRA). All aggregated effort from the original PHC extract that targeted PHC was left as is. The combined data set contained 1,367 aggregated records with zero catch.

2.1.5 Linking catch and effort data

Recreational catch from commercial vessels and high grading practices during fishing can effect CPUE data. To address these issues, landings to the destination codes F (Section 111 recreational catch) and X (QMS returned to sea, except 6A) were included in CPUE calculations. Groomed CELR effort and estimated subcatch data were aggregated by fishing year, month, statistical area, vessel and target species. The CELR Landings data (LFX) were aggregated by year, month and vessel.

The use of holding pots and onshore holding facilities effects the capacity of CPUE to monitor the abundance of rock lobster populations. The "B4-algorithm" (Bentley et al. 2005) was not considered appropriate because a lot of the landings were to the destination codes P, Q and R, particularly in the most recent years (Table 1). The "F-algorithm" (developed by P. Starr) was developed to address this issue. The F-algorithm was applied giving the corrected catch for each year-month-area-vessel-target strata. The F-algorithm and its application is discussed further in Appendix B.

2.1.6 The groomed data

Figure 4 shows the corrected catch after removing records during error checking, the application of the F-algorithm, restricting to the core areas, and restricting to the core fleet. The series before and after restricting to the core fleet differ little except during the 1991/92 fishing year. To assess the effect of the core vessel selection (and the difference during 1991/92) on the CPUE standardisation a sensitivity was done (see Section 2.3.1). Due to a lack of estimated subcatch and landed catch the data for the 1990/91 fishing year were dropped from this analysis.

Table 1: Packhorse rock lobster (PHC 1) landings (tonnes) by destination type from 1990/91 to 2012/13. The destination types are: L = landed in NZ (to LFR), F = Section 111 recreational catch, X = QMS returned to sea (except 6A), P = holding receptacle in water, Q = holding receptacle on land, R = retained on board, and Other = a destination type other than those specified. A "-" indicates that no PHC catch was landed to that destination type in that fishing year.

	Destination type							
Fishing year	L	F	X	P	Q	R	Other	Total
1990/91	1.4	-	-	-	-	-	-	1.4
1991/92	24.1	-	-	-	-	-	-	24.1
1992/93	9.3	-	-	-	-	-	-	9.3
1993/94	5.9	-	-	-	-	-	-	5.9
1994/95	7.8	-	-	-	-	-	-	7.8
1995/96	24.1	-	-	-	-	-	-	24.1
1996/97	19.0	-	-	-	-	-	-	19.0
1997/98	14.6	-	-	-	-	-	0.1	14.7
1998/99	15.9	-	-	-	-	0.2	-	16.1
1999/00	12.7	-	-	-	-	-	-	12.7
2000/01	9.9	-	-	-	-	0.3	-	10.2
2001/02	8.8	-	-	-	-	0.3	-	9.1
2002/03	8.3	0.2	-	0.2	0.1	-	-	8.8
2003/04	16.3	0.2	-	1.8	0.1	-	0.3	18.7
2004/05	21.2	0.4	-	1.1	0.1	0.1	-	22.9
2005/06	25.0	0.5	-	2.0	0.7	0.2	-	28.4
2006/07	25.8	0.6	-	4.5	0.1	0.1	-	31.1
2007/08	34.3	0.9	-	6.0	0.3	0.3	-	41.8
2008/09	35.8	0.6	-	2.8	0.1	-	-	39.3
2009/10	36.0	0.8	-	3.4	0.1	0.7	-	41.0
2010/11	32.5	1.0	-	16.0	0.2	0.4	-	50.1
2011/12	31.7	0.9	-	13.1	0.2	0.4	-	46.3
2012/13	28.0	0.9	0.1	11.0	0.9	0.5	-	41.4
Total	449.8	7.0	0.1	61.9	2.9	3.5	0.4	525.6

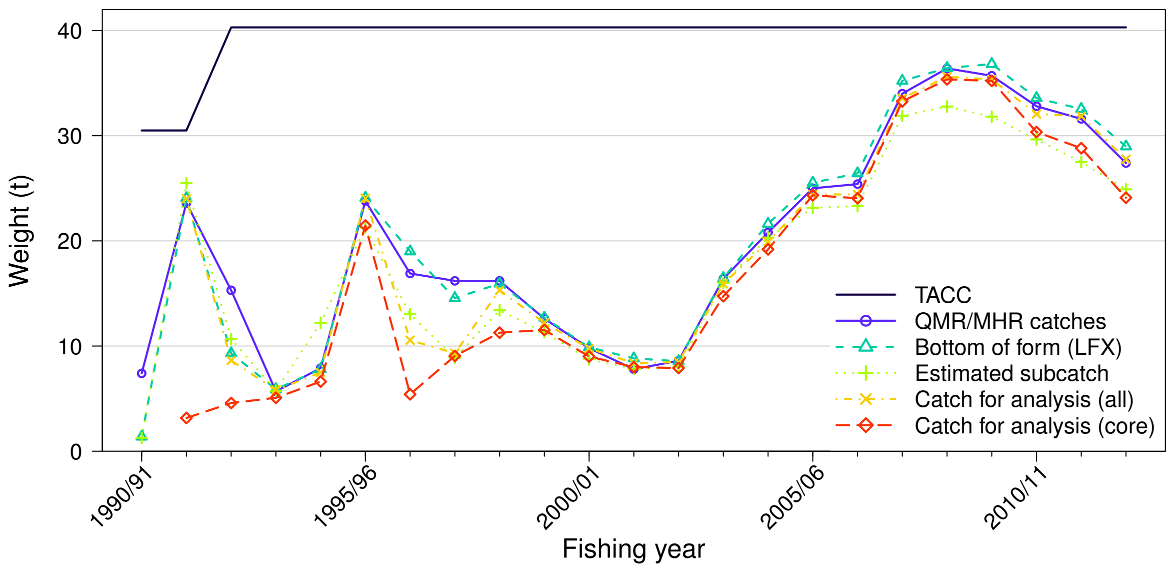

Figure 4: Packhorse rock lobster (PHC) catch data sets including the total allowable commercial catch (TACC), the QMR/MHR reported catches (QMR/MHR catches), the landings from the bottom of CELR forms aggregated by fishing year (Bottom of form, LFX), the estimated subcatch of PHC from the CELR forms (Estimated subcatch), the corrected catch after grooming procedures used in the CPUE standardisation (Catch for analysis all), and the corrected catch after the core vessel selections is applied (Catch for analysis core). All of these series are in tonnes.

2.2 Vessels, catch and effort by statistical area

The number of vessels that fished within each statistical area during each fishing year is determined using the same data set that is used in the CPUE analysis (before core vessel selection is applied). This information was split into vessels that fished within one of the core areas in any given fishing year (but did not necessarily catch any PHC) and vessels that caught PHC within a fishing year. The total number of pots lifted within each statistical area during each fishing year was also calculated from the same dataset used in the CPUE analysis.

Scaled annual catch totals for each statistical area were calculated by multiplying the estimated proportion taken in a statistical area (using estimated subcatch column in the CELR data) by the total catches from the QMR/MHR:

$$\hat{Q}_{ay} = Q_y \frac{\sum_{i \in k_{ay}} C_{iy}}{\sum_{i=1}^{n_y} C_{iy}} \tag{1}$$

where $\hat{Q}_{ay}$ is the scaled annual catch total (tonnes) in statistical area a during fishing year y, Q_y is the QMR/MHR annual catch estimate (tonnes) in fishing year y, C_{iy} is the estimated catch (tonnes) for the month-area-vessel-target combination i in fishing year y, and k_{ay} is the set of month-vessel-target records i that are from area a in fishing year y.

2.3 Catch per unit effort (CPUE) analysis

Arithmetic, unstandardised and standardised indices of annual CPUE were calculated. Arithmetic CPUE (A_y, kg/potlift) for year y or by statistical area a in year y (A_{ay}) is calculated as the total catch for the year divided by the total number of pots lifted in that year:

$$A_y = \frac{\sum_{i=1}^{n_y} C_{iy}}{\sum_{i=1}^{n_y} E_{iy}} \quad \text{and} \quad A_{ay} = \frac{\sum_{i \in k_{ay}} C_{iy}}{\sum_{i \in k_{ay}} E_{iy}} \tag{2}$$

where C_{iy} and E_{iy} are the catch (kg) and number of pots lifted for the month-area-vessel-target combination i in year y, and k_{ay} is the set of month-vessel-target records i that are from area a in year y.

The unstandardised CPUE (G_y, kg/potlift) in year y is the geometric mean of the ratio of catch (kg) to number of pots lifted for each month-area-vessel-target combination:

$$G_y = \exp\left(\frac{\sum_{i=1}^{n_y} \ln(C_i/E_i)}{n_y}\right) \tag{3}$$

where n_y is the number of month-area-vessel-target combinations i in year y. The geometric mean has the same lognormal distributional assumptions as the standardised CPUE, but does not take into account changes in the seasonal and spatial distribution of fishing effort.

Two CPUE standardisations were done: a lognormal model that excluded strata where the dependent variable (corrected catch restricted to core vessels) was zero because the logarithm of zero is undefined; and a binomial model where the dependent variable was a binary set to 1 for records which had associated PHC catch and 0 for records with no catch. Standardised CPUE is calculated from a generalised linear model (GLM) that is offered the explanatory variables fishing year, month, number of potlifts, statistical area and target species. The GLM was applied using a stepwise multiple regression procedure, selecting explanatory variables until the improvement in model r^2 was less than 0.01. The year effects were extracted as canonical coefficients (Francis 1999) so that confidence bounds could be calculated for each year. The lognormal and binomial models were combined using:

$$I_y^{\text{combined}} = \frac{I_y^{\text{lognormal}}}{1 - \rho\left(1 - 1/I_y^{\text{binomial}}\right)} \tag{4}$$

where I_y^{combined} is the combined index for year y, $I_y^{\text{lognormal}}$ is the lognormal index for year y, I_y^{binomial} is the binomial index for year y and ρ is the proportion of records with zero catch in the first year (Vignaux 1994). A bootstrap procedure was used to estimate the variability of the combined index (Francis 2001).

2.3.1 Sensitivities

Three CPUE standardisations were done as sensitivities including: a model where the core vessel selection procedure was not applied and vessel was not offered to the GLM as an explanatory variable (corrected catch, no vessel model); a model where target species was not offered to the GLM as an explanatory variable and the data was aggregated by year, month, statistical area and vessel (corrected catch, no target model); and a model that used the estimated subcatch, rather than the corrected catch, as the dependent variable (estimated catch model). Lognormal and binomial models were done and combined indices calculated for all sensitivities.

2.3.2 Voluntary logbook data

Data from the voluntary logbook programme were obtained for the 1994/95 to 2010/11 fishing years in the core areas. This dataset contained 80,462 records, each representing a single potlift. For a description of the voluntary logbook programme see Starr (2012). Arithmetic CPUE was calculated using this (ungroomed) dataset. This was done to check that the CPUE indices produced from this dataset are comparable to the trends in CPUE using the CELR dataset.

2.4 Length-frequency and tag-recapture data

During 1991/92, a special permit was granted to a commercial fisher to run an exploratory survey for packhorse rock lobsters. During this survey observers carried out a catch sampling program and these data were stored in the rlcs database (rlcs, Mackay & George 2002). To obtain this data and any other length-frequency data collected by observers since (or prior), all data were requested from the rlcs database between 1973/74 and 2012/13. Length-frequency data was summarised as length-frequency plots. Additionally, records of all PHC that have been tagged were requested from the tag database (Mackay & Wood 2010).

2.5 Bioeconomic modelling

2.5.1 Collecting economic information

In rock lobster fisheries it is common for the smaller size-grades to be worth more per kilogram than the larger size-grades. This can mean that gross revenue from a rock lobster fishery will not necessarily increase linearly as yield increases because the size-composition of the catch influences the total weight of each size-grade caught and, hence, the revenue. To explore this relationship a survey was used to collect information on the price paid for rock lobsters (both CRA and PHC) from fishers and Licensed Fish Receivers (LFR). This survey asked for the price paid for lobsters of different size-grades by month for the 2012/13 fishing year. The weight range of lobsters (kg) in each of these size-grades is given in Table 2.

Table 2: Weight range (kg) of packhorse (PHC) and red (CRA) rock lobsters in each size-grade (price paid for lobsters in grades E, F and G is the same).

Grade	Weight (kg)
A	0.0-0.6
B	0.6-0.8
C	0.8-1.0
D	1.0-1.5
EFG	1.5+

2.5.2 Exploring different minimum legal sizes

The length-frequency dataset was limited to the last 10 years (2003/04 to 2012/13, $n > 100$ for these years). A bootstrap re-sampling procedure was used to sample from this dataset to obtain distributions of gross revenues for the current MLS and a set of scenarios with reduced minimum legal sizes. The steps were as follows:

1. Bootstrap re-sample (with replacement) from the length-frequency dataset
2. Restrict this sample to records that are greater than or equal to the MLS scenario being tested
3. Calculate weight (kg) from tail-width (mm) and generate a weight-frequency distribution with bin widths equal to the size-grades
4. Scale the weight-frequency distribution to a catch of 1 tonne
5. Multiply the total weight (kg) in each size-grade by the price per kg for that grade and sum across all size-grades

These steps were repeated 500 times for a set of MLS scenarios, ranging from the current MLS in the PHC 1 fishery to the MLS currently used in the red rock lobster fishery. Conversions from tail-length to tail-width were done using:

$$L^{\text{width}} = a + bL^{\text{length}} \tag{5}$$

where L^{width} is tail-width (mm), L^{length} is tail-length (mm), and a and b are linear regression constants. These constants were only available for red rock lobster in each of the CRA QMAs so the CRA conversion constants for CRA 1 were used here (Breen et al. 1988, Table 3). To convert from tail-width (mm) to weight (kg) additional parameters were required. Again, these were not available for packhorse rock lobsters in New Zealand. They are available for PHC in Australia, but only in terms of carapace-length (Green et al. 2006). Therefore, CRA length-weight parameters were used (MPI 2012, Table 3).

It is only possible to obtain the price paid for a packhorse rock lobster in the largest set of size-grades (EFG) because legal PHC usually only fall into this size-grade. To model how a reduction in the MLS regulations for PHC might effect gross revenue in the fishery required information on the price paid for PHC in smaller size-grades if lobsters in these grades became legal to land. The price paid for PHC in the smaller size-grades was inferred by proportionately scaling down the price paid for a CRA in size-grades A to D using:

$$P^{\text{PHC}}_{m\ell\in ABCD} = P^{\text{CRA}}_{m\ell\in ABCD} \frac{P^{\text{PHC}}_{m\ell\in EFG}}{P^{\text{CRA}}_{m\ell\in EFG}} \tag{6}$$

where $P^{\text{PHC}}_{m\ell\in ABCD}$ is the price paid for PHC in the set of size-grades A to D (the price paid for PHC in size-grades EFG is already known), $P^{\text{CRA}}_{m\ell\in ABCD}$ is the price paid for CRA in the set of size-grades A to D, and $P^{\text{PHC}}_{m\ell\in EFG}$ and $P^{\text{CRA}}_{m\ell\in EFG}$ are the respective prices paid for PHC and CRA in the size-grades EFG. The gross revenue for each scenario was then calculated using:

$$R_s = \sum_{\ell} C_{\ell s} P_{\ell} \qquad \text{where} \qquad \sum_{\ell} C_{\ell s} = 1 \quad \forall s \tag{7}$$

where R_s is the gross revenue (New Zealand dollars) for scenario s, $C_{\ell s}$ is the catch (kg) in size-grade ℓ for scenario s and P_ℓ is the median price paid in New Zealand dollars for one kg of size-grade ℓ.

Exploring the effect of a maximum legal size was considered but could not be done because the length-frequency dataset aggregates all PHC with tail-widths greater than 88 mm into a plus group, ignoring the size structure of larger lobsters (Figures 15 and 16). The plus group is not much bigger than the current MLS for PHC so little insight would be gained by modelling maximum legal sizes less than or equal to the 88 mm plus group.

Table 3: Parameters used to convert from tail-length to tail-width (mm, Equation 5) and tail-width to weight (kg). These parameters are for red rock lobsters (CRA) and are the best available information for packhorse rock lobsters (PHC) in New Zealand to date.

Relationship	Parameter	Female	Male	Source
Tail width-length	a	-10.64	-1.36	Breen et al. (1988)
	b	0.464	0.383	Breen et al. (1988)
Length-weight	α	0.0000130	0.00000416	MPI (2012)
	β	2.5452	2.9354	MPI (2012)

3 RESULTS

3.1 Characterisation of the PHC fishery

Since the introduction of the QMS packhorse rock lobster catches have been relatively low, compared to historical landings, and have only begun to approach the TACC in the last five years (Figure 2, Tables 9 and 10). There is reasonable correspondence between the catch reported to the QMR/MHR system and the sum of landings from the bottom section of the CELR form, except during the 1990/91 fishing year where the sum of the landings is much lower than the QMR value (Figure 4, Table 11).

The seasonality of the PHC fishery is shown in Figure 5. PHC is mainly landed during the last half of the fishing year (with the exception of April in some fishing years), with a distinct drop in catches during the winter months (May to August). The surge of catch in April during some years does not appear to be catch from holding pots carried over from the previous year as PHC landed to the destination codes P, Q and R are not high enough at the end of the previous fishing years (Table 4).

The MPI defines 43 rock lobster statistical areas that fishers should allocate their catch to during a fishing event (901 to 943, Figure 1). In the past PHC, was mainly caught in statistical areas 901 and 902, but catches have increased in 904 and 906 in recent years (Figure 6, Table 16). The combined catch in all statistical areas, other than the core areas, was very low (Figure 7). The number of pots lifted (effort) tended to be higher in statistical areas within CRA 2 compared with CRA 1, particularly during the most recent years (Table 17).

Arithmetic CPUE trajectories were variable between statistical areas, but catch rates were higher in statistical areas within CRA 1, particularly in areas 901 and 902 (Figure 7). Arithmetic CPUE across all statistical areas was very low at around 0.1 kg/potlift.

The catch of packhorse rock lobsters in the New Zealand EEZ has largely been bycatch of the red rock lobster fishery. However, some targeting of PHC occurs and when vessels do target PHC their catch rates are much higher (Figure 8).

The number of vessels operating in the PHC 1 fishery, and how the vessels are distributed across the statistical areas, is shown in Tables 14 and 15. The total number of vessels fishing within the core areas has gradually increased since 1979/80. In contrast, the number of vessels actually catching PHC has remained relatively constant in the core areas within CRA 1, but has increased in the core areas within CRA 2 (Table 15). The overlap of vessels catching PHC across fishing years is reasonable but the majority of the catch is generally taken by one or two vessels in any given fishing year (Figure 9).

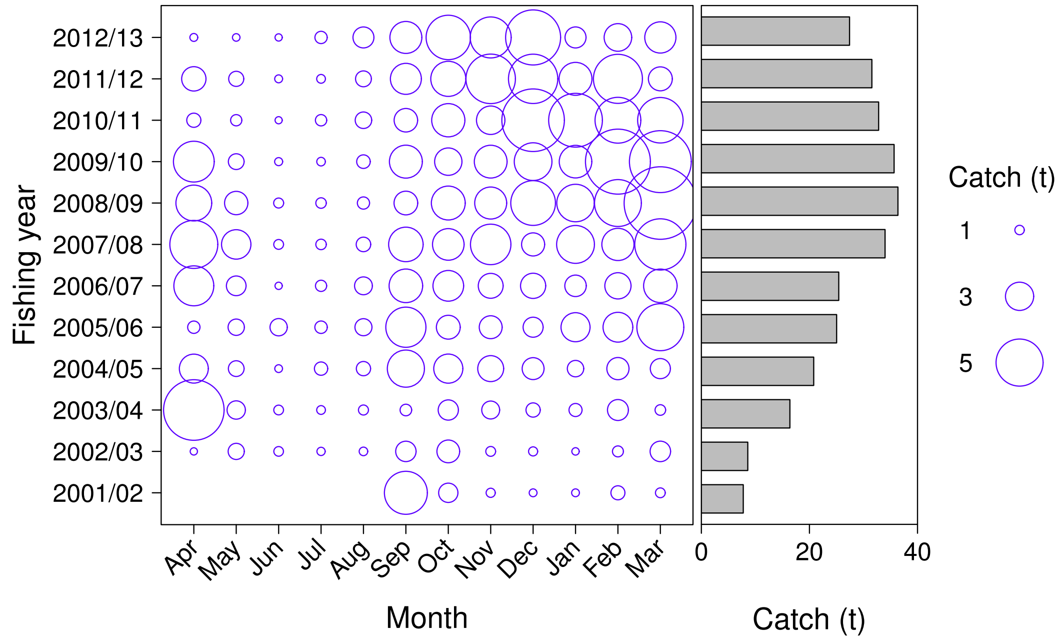

Figure 5: Monthly distribution of packhorse rock lobster (PHC 1) catches by fishing year (source: MHR). Circle areas are proportional to the total catch (tonnes) across all fishing years.

Table 4: Packhorse rock lobster (PHC 1) landings (tonnes) for the destination types P, Q and R by month from 1997/98 to 2012/13. The table begins at 1997/98 as this is the first year that the destination type P, Q or R are reported. The destination types are described in Table 1. A "-" indicates that no PHC catch was landed to the destination type P, Q, or R in that month during that fishing year.

	Month												
Fishing year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
1997/98	-	-	-	-	-	-	-	-	-	0.04	-	-	0.04
1998/99	-	0.12	-	-	-	-	-	-	-	0.02	0.05	-	0.19
1999/00	-	-	-	-	-	-	-	-	-	-	-	-	-
2000/01	-	-	-	0.05	0.18	0.10	-	-	-	0.01	0.01	-	0.35
2001/02	-	0.01	0.04	0.01	-	-	-	0.01	0.01	0.03	0.13	0.07	0.31
2002/03	-	-	-	0.01	0.02	0.08	0.04	-	0.01	-	0.10	0.11	0.37
2003/04	0.83	-	0.02	0.02	0.07	0.02	0.18	0.43	0.23	0.10	0.01	-	1.91
2004/05	0.01	0.01	0.01	0.15	0.15	0.31	0.15	0.21	0.11	0.17	0.03	0.01	1.32
2005/06	0.11	0.02	0.01	0.12	0.33	0.56	0.90	0.46	0.08	0.04	0.25	0.05	2.93
2006/07	-	0.02	0.06	0.20	0.37	0.83	0.61	0.65	0.46	0.64	0.58	0.29	4.71
2007/08	0.39	0.20	0.07	0.15	0.33	0.67	1.14	1.30	0.96	0.49	0.50	0.42	6.62
2008/09	0.36	0.15	0.02	0.07	0.11	0.48	0.69	0.34	0.20	0.27	0.12	0.14	2.95
2009/10	0.03	0.03	0.01	0.04	0.16	0.79	0.83	0.61	0.73	0.54	0.10	0.22	4.09
2010/11	0.51	0.05	0.03	0.08	0.26	0.62	0.88	1.53	4.87	3.41	2.23	2.20	16.67
2011/12	0.36	0.18	0.04	0.04	0.32	0.95	1.52	2.93	2.51	1.37	2.53	1.05	13.80
2012/13	0.08	0.09	0.04	0.14	0.29	0.85	1.16	1.75	3.83	0.88	1.61	1.58	12.30

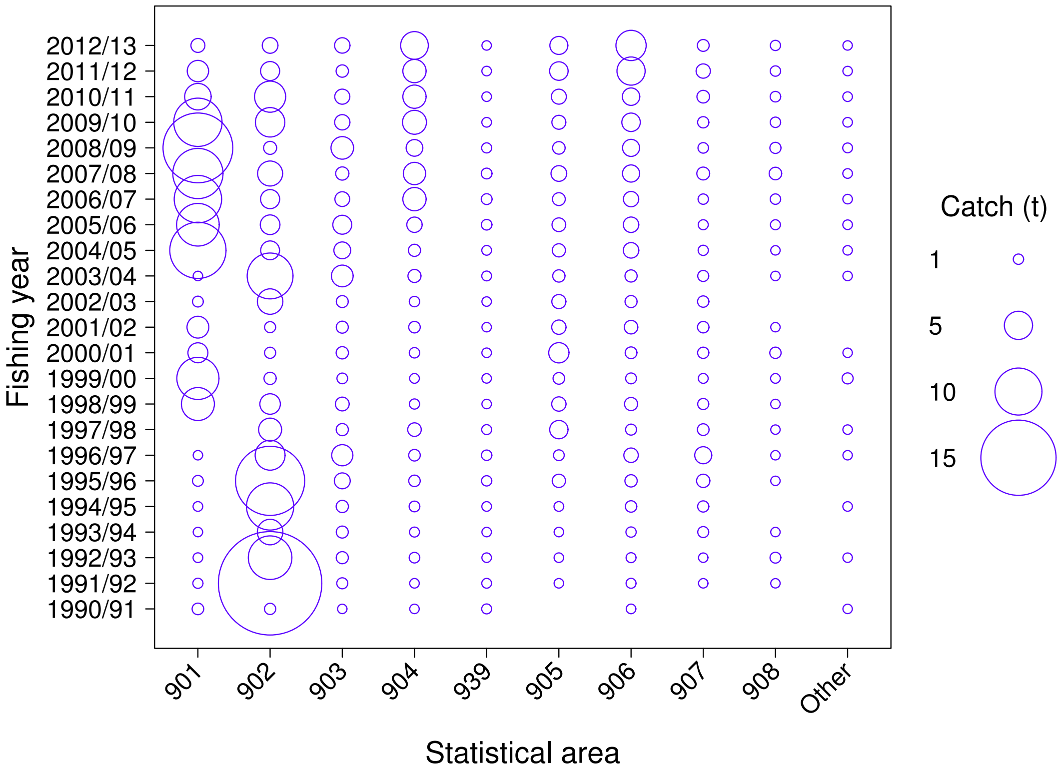

Figure 6: Distribution of packhorse rock lobster (PHC 1) catches by statistical area and fishing year (source: estimated catch from CELR). Circle areas are proportional to the total catch (tonnes) across all fishing years. The Other column refers to catch in all statistical areas other than the core areas.

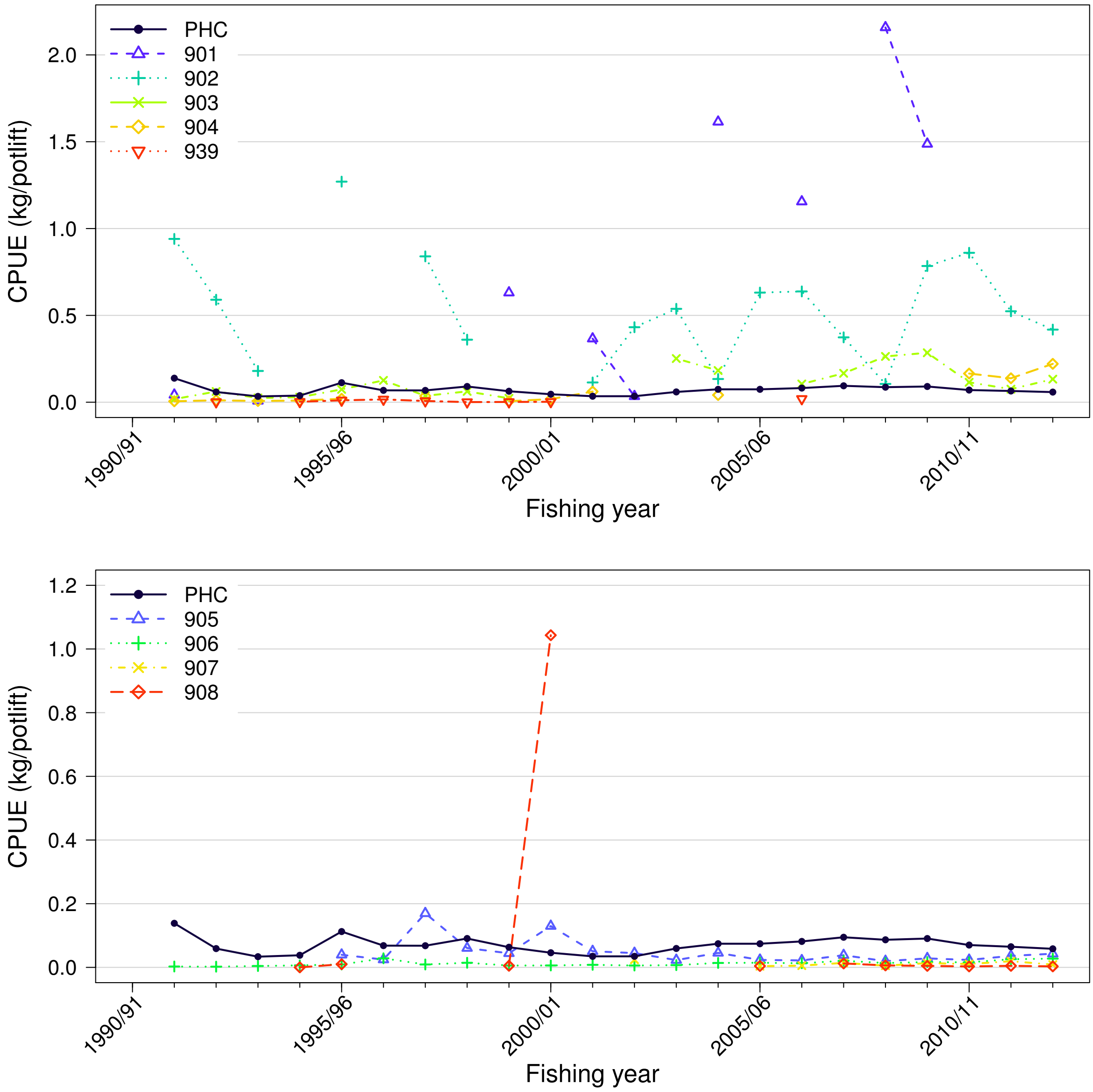

Figure 7: Arithmetic CPUE (A_y) for packhorse rock lobsters (PHC) by fishing year and statistical area from 1991/92 to 2012/13 (source: corrected catch data set, all vessels). Year-area strata derived from less than three vessels are not plotted.

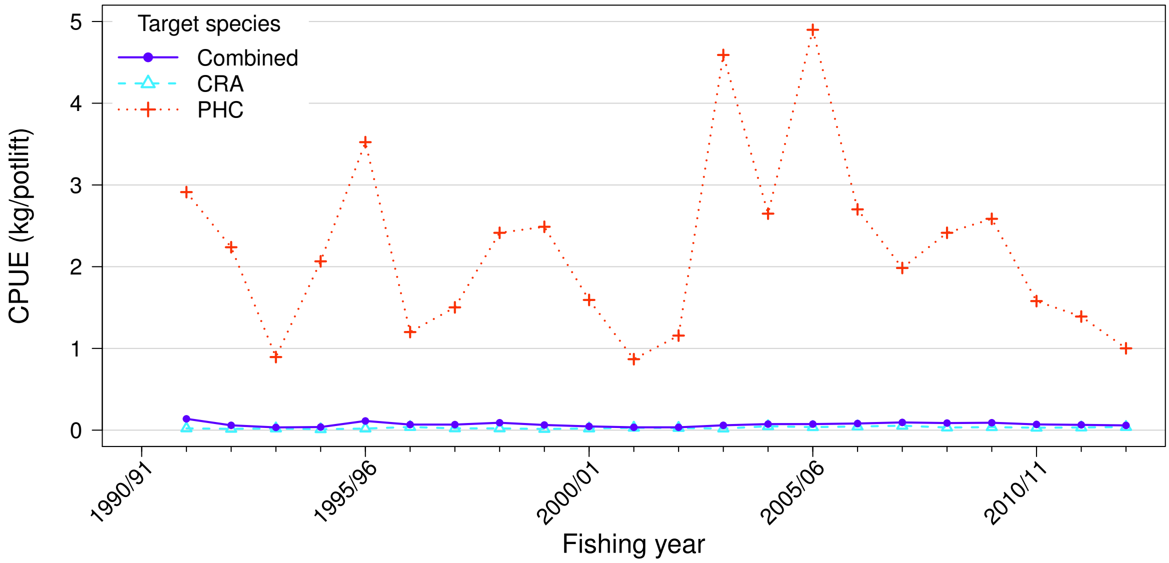

Figure 8: Arithmetic CPUE (A_y) for packhorse rock lobsters (PHC) by fishing year and target species from 1991/92 to 2012/13 (source: corrected catch data set, all vessels). The "Combined" series is the overall arithmetic CPUE by fishing year. The "CRA" and "PHC" series are the arithmetic CPUE by fishing year for vessels targeting each species. Year-area strata derived from less than three vessels are not plotted.

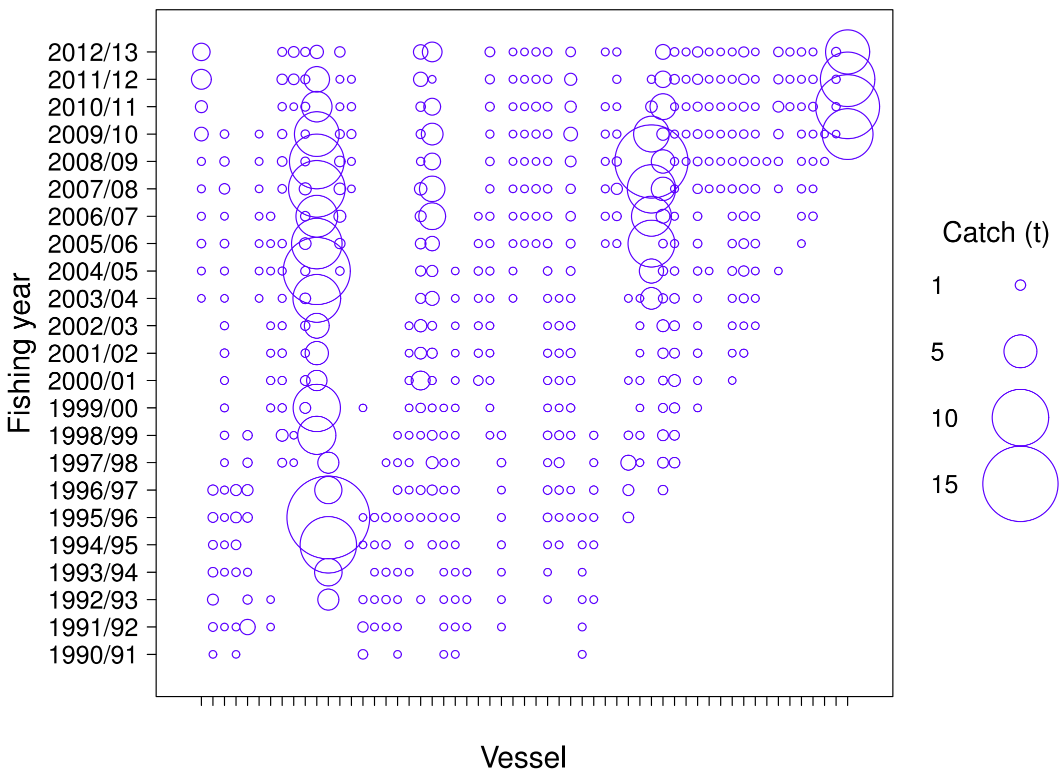

Figure 9: Distribution of packhorse rock lobster (PHC 1) catches by core vessels and fishing year (source: estimated catch from CELR). Circle areas are proportional to the total catch (tonnes) across all fishing years.

3.2 Standardised catch per unit effort and logbook data

3.2.1 Model selection and model fits

Each GLM was offered the explanatory variables fishing year, month, number of pots lifted, statistical area, vessel and target species. Lognormal and binomial models were fitted to each dataset and combined using the method of Vignaux (1994). Both the lognormal and binomial CPUE series trended upwards since 1991/92, the binomial index more so than the lognormal. The difference between the lognormal and binomial series resulted in a combined series between the two, and so the binomial series was considered to be additionally informative.

The final CPUE index chosen was the combined index based on the corrected catch with core vessel selection applied as the dependent variable (Figure 12). The lognormal and binomial models that made up this combined series are described in Tables 5 and 6. The fits of the lognormal model were examined by plotting the residuals (Figure C.1). The fit of the data to the lognormal assumption was good for the final model.

The final lognormal and binomial models respectively explained 59% and 29% of the deviance in log catch. Fishing year was forced as the first variable and explained less than 3% of the deviance in both models. Vessel was included as the factor with the greatest explanatory power in both models. Effort entered third, followed by target species and month in both models. Statistical area did not have significant explanatory power, though vessel was likely an effective proxy accounting for variance among areas.

The cumulative effect as each variable was added to the lognormal and binomial models is shown in Figure 10. These plots show the relative importance of each variable in moving the standardised series away from the unstandardised and contributing to the final CPUE index. The influence plots for each variable in Appendix C illustrate the combined effect of the expected log catch for each level of the variable (model coefficients) and the distribution of the levels of the variable in each year and, therefore, describe the influence that the variable has on the unstandardised CPUE which must be accounted for by the standardisation (Bentley et al. 2012). The vessel variable looks to be unbalanced, with three vessels having higher coefficients than the rest (Figure C.2). However, this does not make much of a difference to the final index (see Section 3.2.3). Figure C.3 suggests that putting out a lot of pots does not necessarily result in more PHC being caught. This likely occurs because a lot of the effort, particularly by vessels setting a lot of pots, is not targeting PHC. This implies that there is likely an interaction between the target and effort variables. However, removing the target variable from the model does not make much of a difference to the final index (see Section 3.2.3).

Table 5: Summary of the final lognormal model for packhorse rock lobsters (PHC) using corrected catch restricted to core vessels as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable). DF is the degrees of freedom, Deviance is the residual deviance after the addition of each term, AIC is the Akaike Information Criterion, r^2 is the proportion of the deviance explained at each step, and Final indicates whether or not the term was included in the final model.

Term	DF	Deviance	AIC	r^2	Final
None	0	9,303	12,416	0.0000	
Fishing year	21	9,056	12,372	0.0265	*
Vessel	54	5,230	10,739	0.4378	*
Poly(log(potlifts), 3)	3	4,838	10,499	0.4799	*
Target species	1	4,116	9,988	0.5576	*
Month	11	3,853	9,800	0.5858	*
Area	8	3,812	9,783	0.5902	

Table 6: Summary of the final binomial model for packhorse rock lobsters (PHC) using corrected catch restricted to core vessels as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable). The remaining columns are described in Table 5 above.

Term	DF	Deviance	AIC	r^2	Final
None	0	5,503	5,505	0.0000	
Fishing year	21	5,377	5,421	0.0229	*
Vessel	54	4,929	5,081	0.1044	*
Poly(log(potlifts), 3)	3	4,501	4,659	0.1821	*
Target species	1	4,083	4,243	0.2581	*
Month	11	3,905	4,087	0.2904	*
Area	8	3,880	4,078	0.2950	

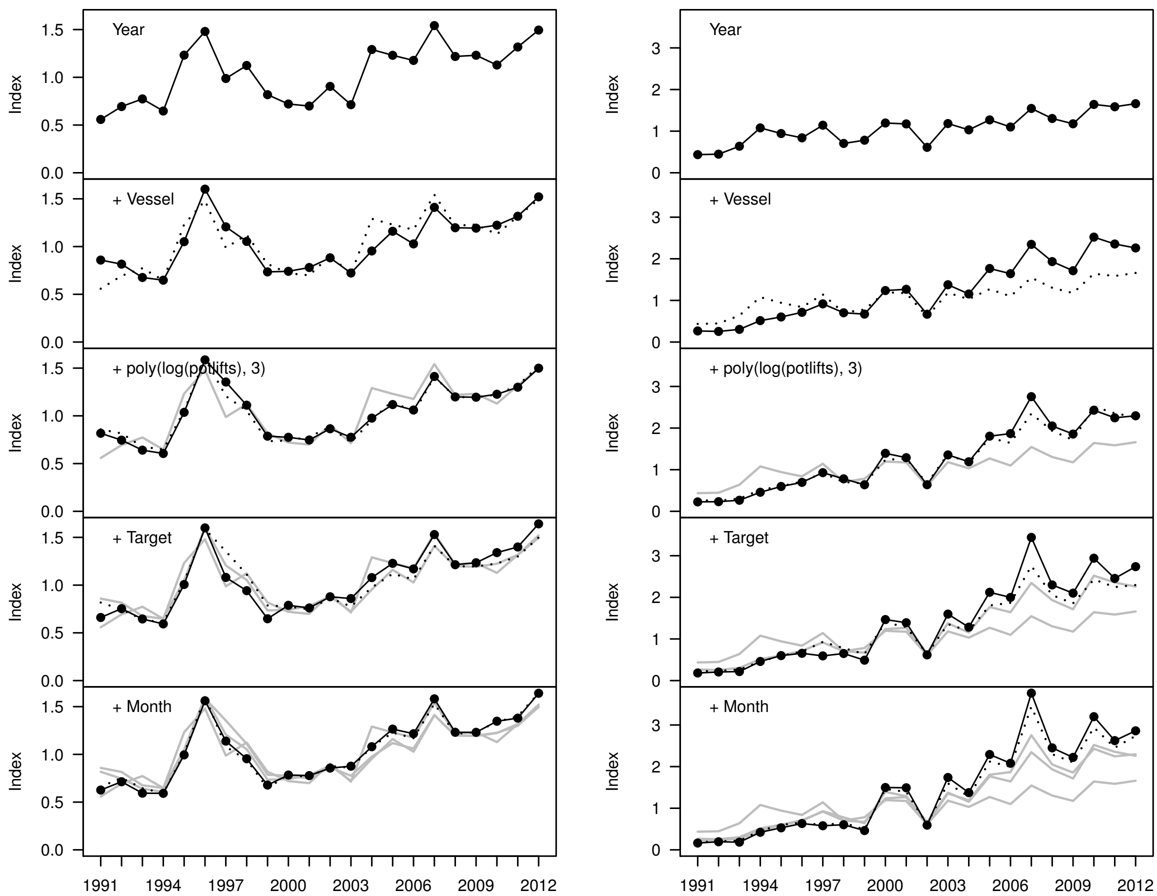

Figure 10: Annual indices from the lognormal model [left] and binomial model [right] at each step in the stepwise variable selection process in the packhorse rock lobster (PHC) CPUE standardisation. Each panel shows the standardised CPUE index as each explanatory variable is added to the model. The index obtained in the previous step is shown by a dotted line and for steps before that by grey lines.

3.2.2 Trends in model year effects

The year effects from the lognormal, binomial and combined indices are plotted in Figures 11 and 12. The arithmetic CPUE for core vessels tracked similarly to that of the overall fleet except during 1991/92. The effect that this year and the core vessel selection process had on the final lognormal CPUE series was checked using a sensitivity in which core vessel selection was not applied and vessel was not offered to the GLM (see Section 3.2.3). The lognormal series was similar to the unstandardised series, however, the effect of standardising the probability of capture (binomial model) was considerable. This resulted in the combined series being different to the lognormal series, particularly in the most recent years.

The trends in the standardised and combined CPUE indices are well determined in that there are small confidence intervals around each point, and the changes in direction are generally sustained over several consecutive years rather than manifesting as inter-annual variance. The effect of the standardisation and combining of indices was reasonably large overall. In general, early points dropped and recent points were lifted resulting in a CPUE index that increases overall. The standardised CPUE index therefore shows a more optimistic trend than the unstandardised series. The final combined CPUE index increases from its lowest level in the early 1990s to its highest by the end of the series in 2012/13 with a couple of peaks during 1996/97 and 2007/08 (Figure 12).

3.2.3 Sensitivities

Three sets of CPUE standardisations were done as sensitivities and the combined indices for these are plotted in Figure 13. This figure shows the final combined CPUE index compared to the indices produced by each of the sensitivities. The lognormal and binomial models for each sensitivity are described in Appendix D.

Comparing the final combined model with the "corrected catch, no vessel" model shows that the core vessel selection process and inclusion of vessel as an explanatory variable had little effect on the final combined CPUE index because statistical area took its place (Tables D.1 and D.2). This suggests that statistical area is a reasonable proxy for vessel and gives no concern about the representativeness of the core fleet selected. However, the fit of the lognormal "corrected catch, no vessel" model is worse than the final model fit (Figure D.1).

The "corrected catch, no target" model is also similar to the final combined index but, again, results in a poor fit to the data (Figure D.2).

Finally, the sensitivity that used the estimated catch, rather than the corrected catch, as the dependent variable also produced an index similar to the final combined index. The fit of the lognormal estimated catch model was also good (Figure D.3). The similarity between the final combined model index and the index produced using a different dependent variable (the estimated subcatch) lends support to the final CPUE series.

3.2.4 Voluntary logbook data

The arithmetic CPUE index derived using the voluntary logbook data showed an increasing trend in catch rates for the 2000/01 to 2010/11 fishing years in the core areas (Figure 14). While this index is not directly comparable to the CPUE series produced using the CELR dataset, they do show the same general increasing trend in catch rates.

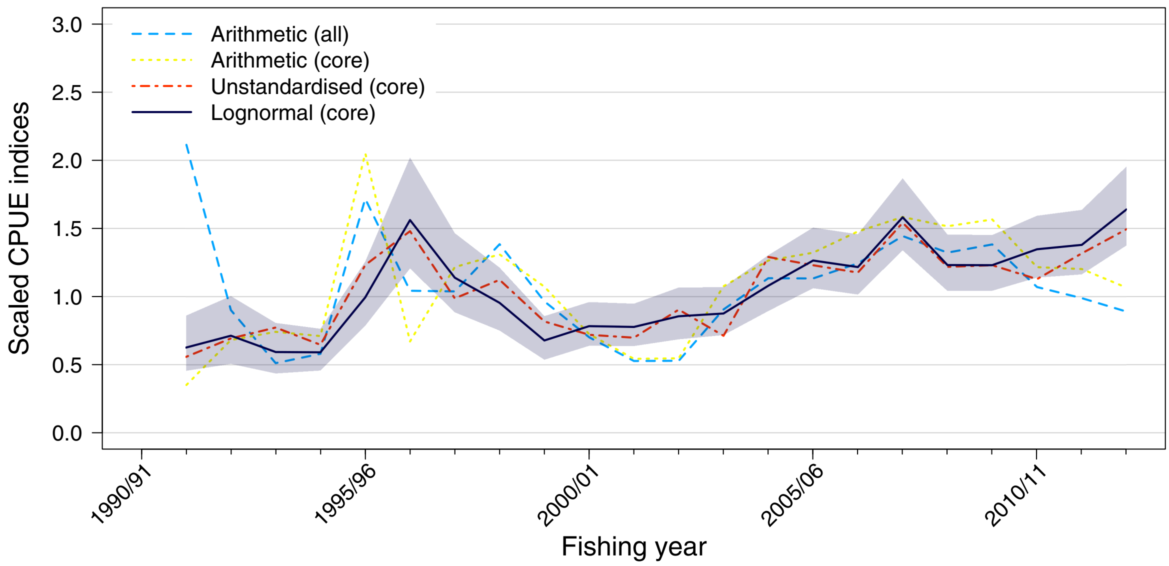

Figure 11: Arithmetic (A_y), unstandardised (G_y), and standardised (I_y) annual indices of CPUE $\pm$ 2 s.e. for packhorse rock lobster (PHC) from 1991/92 to 2012/13 (source: corrected catch data set, all vessels and core vessels only). All indices are scaled to have a geometric mean of 1.

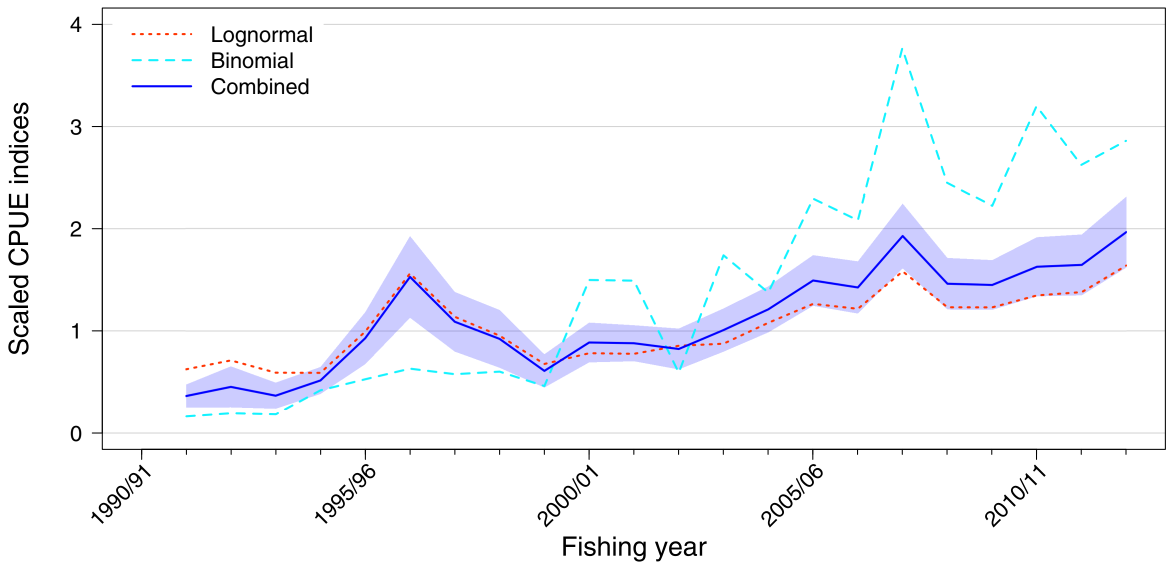

Figure 12: Standardised (I_y) annual indices of CPUE for the lognormal, binomial and combined models for packhorse rock lobster (PHC) from 1991/92 to 2012/13 (source: corrected catch data set, core vessels only). The combined model is shown $\pm$ 2 s.e. All indices are scaled to have a geometric mean of 1.

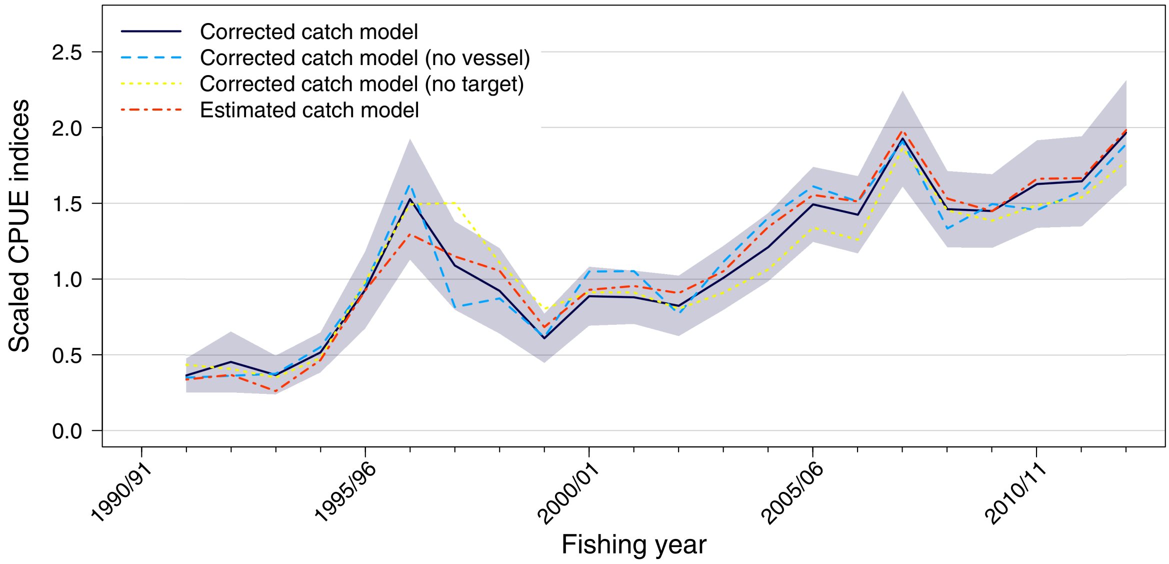

Figure 13: Standardised (I_y) annual indices of CPUE for the combined sensitivity models for packhorse rock lobsters (PHC) from 1991/92 to 2012/13. The plotted lines are the indices for the model using corrected catch data (corrected catch model), the model using corrected catch data without core vessel selection applied or vessel offered to the model (corrected catch, no vessel model), the model using corrected catch data but not offered target species (corrected catch, no target model), and the model using the estimated subcatch as the dependent variable (estimated catch model). All indices are scaled to have a geometric mean of 1.

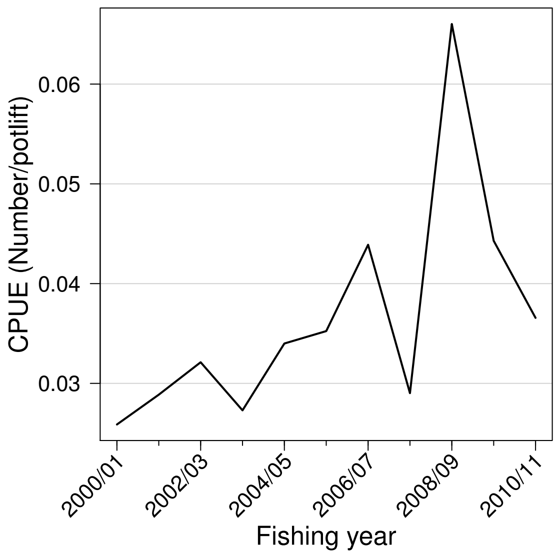

Figure 14: Arithmetic CPUE (A_y) for packhorse rock lobsters (PHC) by fishing year from 2000/01 to 2010/11 expressed as number of lobsters caught per potlift (source: ungroomed voluntary logbook data).

3.3 Length-frequency and tag-recapture summaries

The numbers and mean length of packhorse rock lobsters measured in the rlcs database are summarised in Table 7. The numbers of males measured is generally greater than that of females (without and with setae). The length-frequencies are shown in Figures 15 and 16. The 1989/90 fishing year is not plotted because only a single lobster was measured. Males, females and females with setae were plotted together on the same figures because sample sizes are low (ranging from 6 to 508 measured lobsters per fishing year). However, the sample sizes in the length-frequencies have increased through time, particularly in the last decade.

The last bar in each of the histograms is a plus group representing lobsters with a tail-width of 88 mm or larger. This plus group is reflected in the length-frequency dataset and is unfortunate as it hides much of the size-structure of larger lobsters in the PHC population. Females with setae generally don't appear until the last few length-classes, and PHC are known to become mature at larger sizes again (Booth 1984).

Little tag-recapture information was available in the tag database. Of the 83 tags set, a reasonably high number of tags were recaptured (12 tags recaptured). However, many of these recaptures were the day after the tag was first released. Furthermore, much of the tag-recapture information is from work done in the late 1970s in the statistical areas 910, 911, 927 and 928, none of which are core areas in the CPUE analysis.

Table 7: Numbers of packhorse rock lobsters (PHC) measured by sex and mean tail-width (mm) by sex in the rlcs database. The sex codes are: 1 = male, 2 = female, no setae, 3 = female, with setae.

	Number by sex				Mean length by sex		
Fishing year	1	2	3	Total	1	2	3
1989/90	1	-	-	1	70.0	-	-
1990/91	10	3	-	13	72.8	70.0	-
1991/92	11	12	-	23	64.2	65.0	-
1992/93	15	14	1	30	58.4	60.4	90.0
1993/94	20	10	-	30	61.4	67.6	-
1994/95	37	51	-	88	59.6	58.5	-
1995/96	26	22	-	48	61.9	58.0	-
1996/97	2	4	-	6	72.0	68.0	-
1997/98	14	6	5	25	81.6	84.7	90.0
1998/99	10	7	3	20	66.0	67.7	90.0
1999/00	20	8	17	45	74.7	75.8	90.0
2000/01	43	41	-	84	66.7	71.6	-
2001/02	38	33	7	78	70.8	70.4	86.3
2002/03	33	16	23	72	71.4	77.0	89.6
2003/04	94	58	13	165	68.6	71.4	87.2
2004/05	80	39	14	133	69.0	74.2	68.7
2005/06	78	45	18	141	67.0	66.2	82.6
2006/07	108	78	9	195	68.5	75.7	83.8
2007/08	259	190	62	511	75.1	74.9	87.7
2008/09	180	71	95	346	75.1	72.4	86.1
2009/10	153	107	43	303	72.2	71.4	88.4
2010/11	106	24	50	180	70.7	64.7	84.6
2011/12	88	23	55	166	73.4	70.2	84.6
2012/13	132	94	31	257	72.6	74.3	87.5
Total	1558	956	446	2960	-	-	-

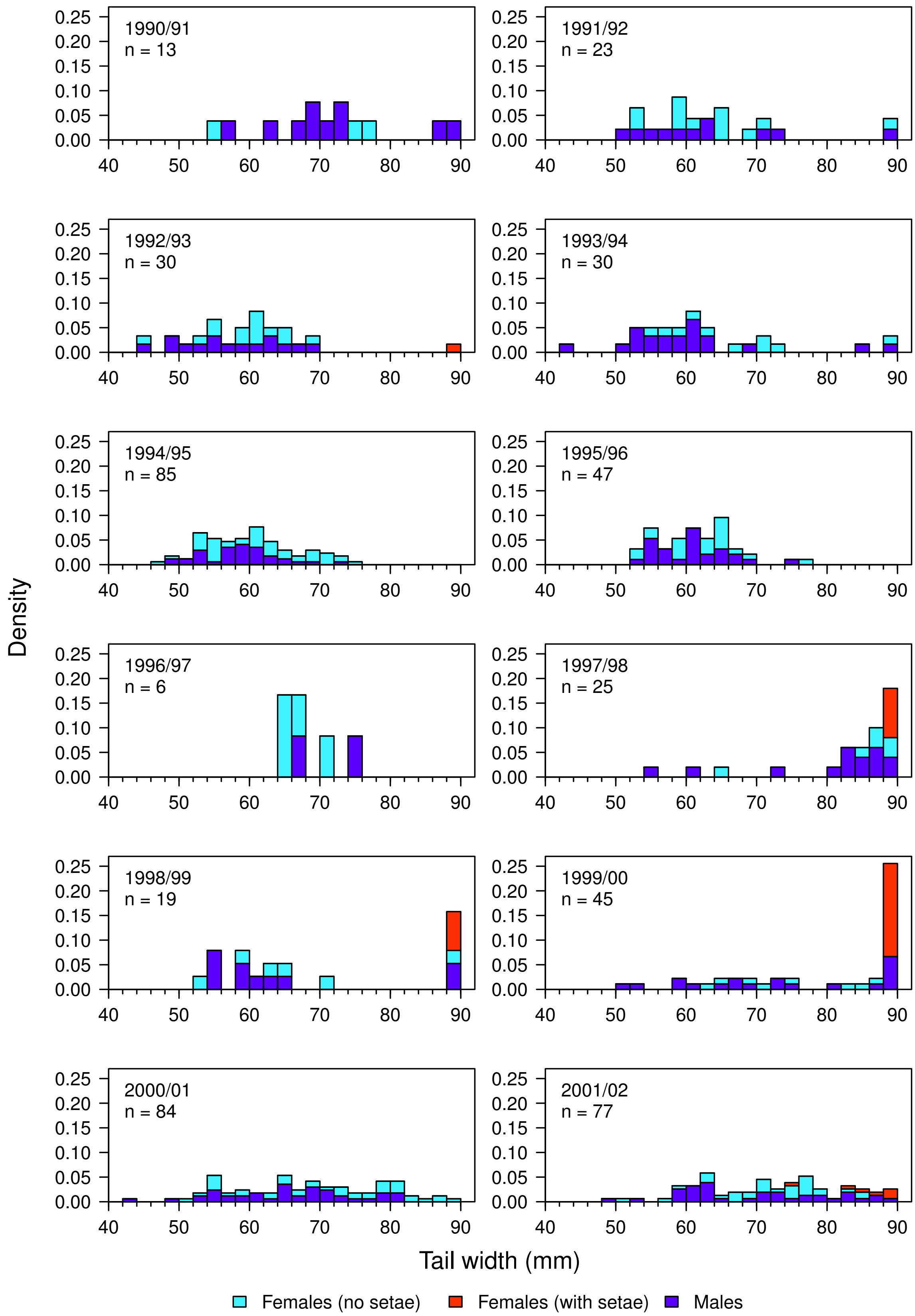

Figure 15: Length-frequency plots (2 mm length bins) of packhorse rock lobsters (PHC) by sex from 1990/91 to 2001/02.

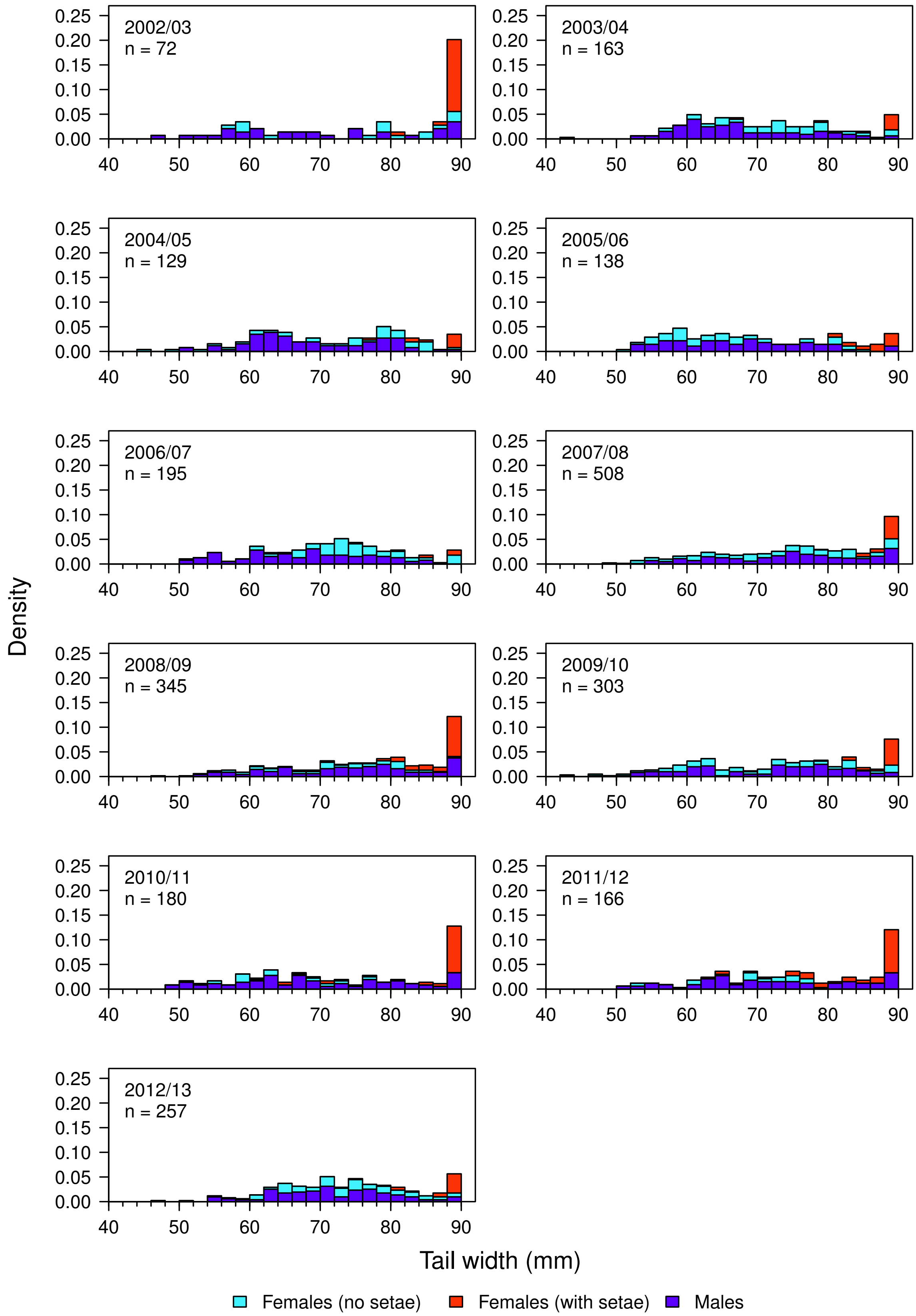

Figure 16: Length-frequency plots (2 mm length bins) of packhorse rock lobsters (PHC) by sex from 2002/03 to 2012/13.

3.4 Exploring different minimum legal sizes

The response from the price survey was poor with only a single processor completing the survey. The price by grade for this processor and the inferred price by grade for PHC (Equation 6) are shown in Figure 17. The price paid for red rock lobsters in the size-grades A to D are reasonably similar, but the price for a lobster in the grade EFG is much lower, and the price for a packhorse lobster in the grade EFG is lower again. The inferred price paid for a PHC in each size-grade shows a similar pattern to that of CRA but fetches around $20 less per kg.

Seven MLS scenarios were tested ranging from the current MLS for PHC of 216 mm tail-length (equivalent to 90 mm tail-width for females and 81 mm tail-width for males) to the current MLS for CRA (Table 8). For each of these scenarios the relative proportion of legal lobsters in each length-class and size-grade are shown in Figure 18. This figure represents the proportion of lobsters in each size-class that would be expected from a given unit of catch and illustrates how more lobsters in the smaller length-classes and size-grades become available to the fishery as the MLS is reduced in each scenario. The estimated gross revenue obtained from one tonne of PHC catch under each scenario is shown in Figure 19. The current MLS results in the lowest gross revenue per tonne of all the scenarios tested. The revenue generally increases as the MLS is reduced in each of the scenarios. A large increase in revenue from the first two scenarios to the remaining five suggests a MLS smaller than around 80 and 72 mm tail-width respectively for females and males would provide little additional revenue per tonne. This suggests that PHC could fetch around $3,000 more per tonne if smaller size-grades became available to the fishery through a reduced MLS.

This exploratory work assumes that the selectivity of the fishery (fishing gear and fisher behavior) would remain the same if the MLS were changed. While a change in the selectivity may occur (e.g., changes to the gap size on pots are made, fisher behavior changes as they begin targeting PHC more and/or shift their effort to different areas), these changes would be difficult to quantify given the available data. However, if fishers did begin targeting PHC more, they would likely target areas containing smaller individuals. This might result in a higher proportion of small individuals being caught, higher revenues being made by the fishery and more individual lobsters being caught overall (to catch the TACC).

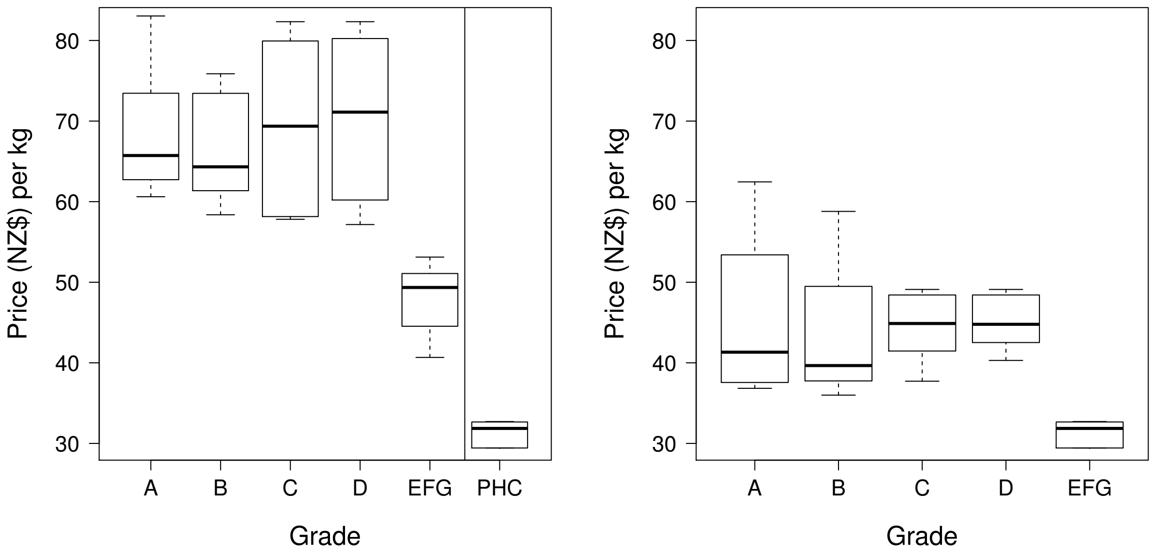

Figure 17: Price (New Zealand dollars) per kg of red rock lobsters (CRA) in the size-grades A to EFG, compared with packhorse rock lobsters (PHC) in the size-grades EFG only from the survey [left] and inferred price per kg of PHC for all size-grades [right]. Note that the y-axes in both plots do not begin at $0.

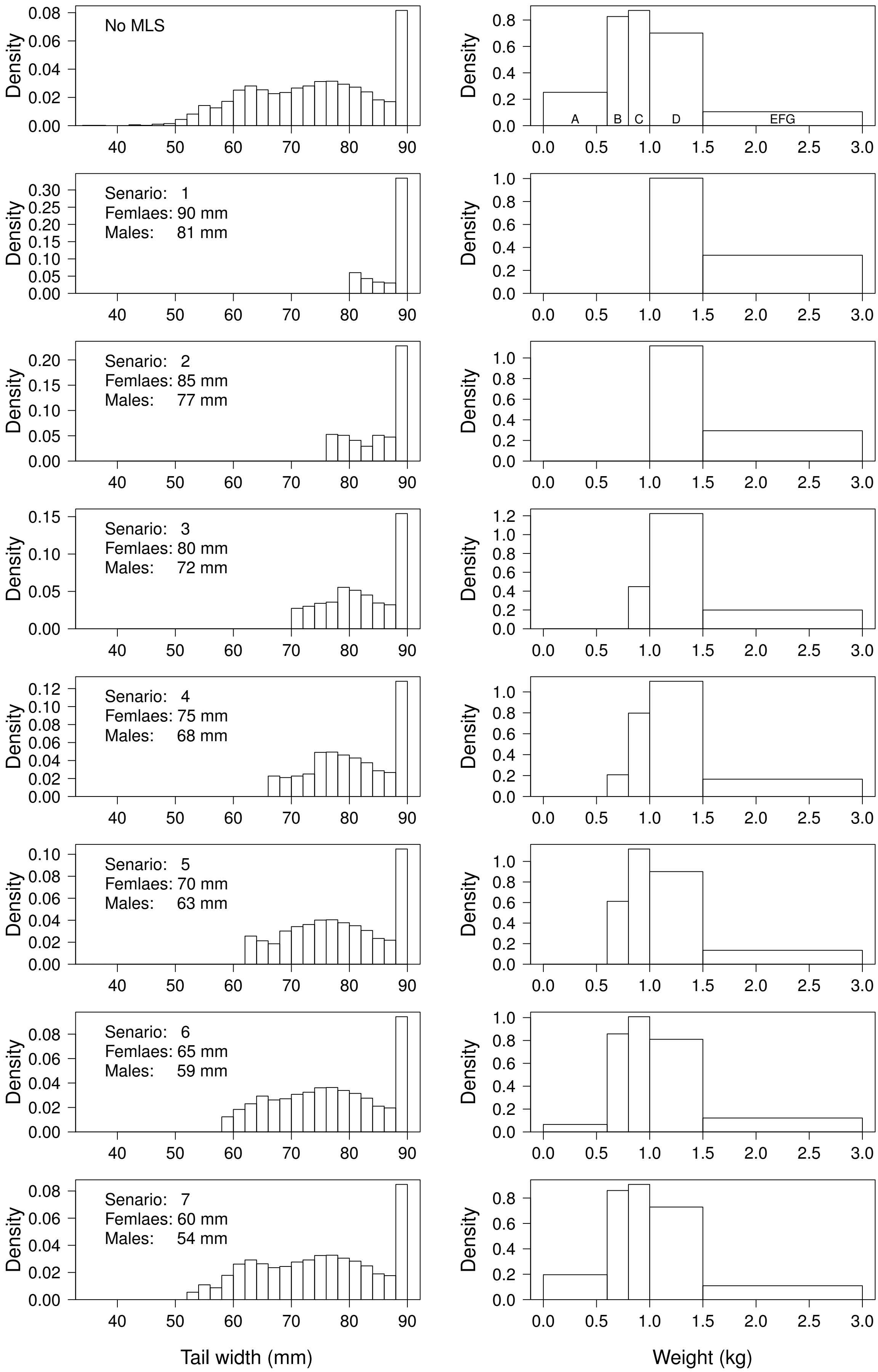

Figure 18: Relative proportion of legal packhorse rock lobsters (PHC, females and males combined) in each length-class [left] and in each size-grade [right] for each of the seven scenarios tested.

Table 8: The set of minimum legal sizes (MLS, mm) of tail-width for females and males used as scenarios in the MLS modelling. Scenario 1 is the current MLS (equivalent to 216 mm tail-length) and scenario 7 is the current MLS for red rock lobsters.

Scenario	1	2	3	4	5	6	7
Females	90	85	80	75	70	65	60
Males	81	77	72	68	63	59	54

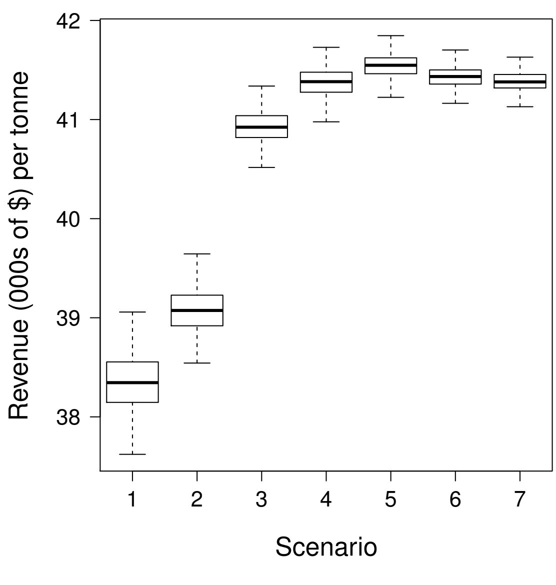

Figure 19: Estimated gross revenue (thousands of New Zealand dollars) per tonne of landed pack-horse rock lobster (PHC) under the seven minimum legal size (MLS) scenarios. The first scenario represents the estimated gross revenue for a tonne of PHC under the current MLS. Scenario 7 represents the estimated gross revenue if the MLS for PHC was the same as for CRA. The MLS used in the other scenarios are outlined in Table 8.

4 CONCLUSIONS

Although the packhorse rock lobster fishery is managed as a single stock (PHC 1) covering New Zealand's entire EEZ, the fishery itself is largely restricted to the north of the North Island. Rock lobster statistical areas in the CRA 1 QMA account for the majority of the catch, and catch rates are highest here. Catches in statistical areas within CRA 2 have increased in recent years due to an increase in the number of vessels fishing and number of pots lifted. The catch of PHC has largely been bycatch of the red rock lobster fishery. However, some targeting of PHC occurs and when vessels do target PHC their catch rates are much higher. Since the introduction of the QMS, total packhorse catches have been relatively low and have only begun to approach the TACC in the last five years. This suggests that fishers may be choosing not to target PHC and are instead focusing their efforts on catching CRA, a higher value species.

Not only does a packhorse rock lobster fetch a lower price than a red rock lobster of the same size, but the PHC available to the fishery generally fall into the largest and least valuable size-grade due to the relatively large MLS of the species (when compared with CRA). A reduction in the MLS would see lobsters in the smaller size-grades available to the fishery and, hence, improve the gross revenue possible from a unit of PHC catch. The availability of the smaller/higher value lobsters might also see more fishers targeting PHC and could help increase the total commercial catch towards the current TACC. As it stands, it is unlikely that an increase in the TACC would improve the yield from the PHC fishery as fishers are not catching the current TACC anyway.

Before a reduction in the MLS is considered the status of the PHC 1 stock should be assessed. There are several problems with the CELR data including the errors outlined in Appendix A and uncertainties in the appropriate level of catch and effort to link together (Sections 2.1.4 and 2.1.5, discussed in Bentley et al. 2005). Despite this, there was little difference between the final CPUE index and the CPUE indices produced by the set of sensitivities done (Figure 13). These sensitivities tested the standardisation process by offering the GLM datasets with different grooming procedures applied (i.e., the corrected catch, no vessel model did not apply core vessel selection or offer vessel as a variable to the GLM), different explanatory variables (i.e., the corrected catch, no target model), and different dependent variables (i.e., the estimated catch model). Furthermore, the arithmetic CPUE index produced using the voluntary logbook data displayed a similar trend in catch rates to those indices produced using the CELR data. This suggests a robust CPUE index that may reflect patterns in the relative abundance of PHC well enough to be used in a stock assessment. The trend in the final CPUE index is optimistic, showing a rise in catch rates since the start of the series in the early 1990s. However, this increase in CPUE likely comes after a period of decline associated with the high catches during the 1960s and 70s. The magnitude of this decline and the current status of the stock remains unknown until a stock assessment for this species is done.

In many fish stocks the MLS allows most females to breed at least once before becoming legal to harvest. The current MLS in the packhorse fishery is an exception to this and coincides with the mean size at which setae first appear on the females pleopods, but the first clutch of eggs is not produced until they are much larger (Booth 1984). This implies that under the current management framework, PHC are already becoming legal to harvest before they get the chance to spawn. The questions is, would reducing the MLS also reduce the spawning stock biomass (i.e., would a reduction in the MLS result in less lobsters reaching a size big enough to spawn before being caught)? A decrease in the MLS in a rock lobster fishery can result in a decrease in the number of lobsters reaching sizes above the new legal size and a decrease in the number of breeding lobsters (Hall 1989). A change in the total numbers of rock lobsters caught may occur as well (i.e., a higher number of smaller lobsters may be caught to make up the same catch in weight). However, smaller lobsters are also subject to fewer years of natural mortality than larger lobsters (e.g., each year a lobster may be subject to e^{-M} more natural mortality), thus offsetting a portion of the additional catch (in numbers) taken.

A maximum legal size to compliment any reduction in the MLS and help maintain the spawning stock biomass is a potential management option and this strategy appears to have worked well for the eastern rock lobster fishery in Australia (Booth 2011). Because bigger lobsters produce more eggs (Kensler 1968) a maximum legal size limit can help protect the big breeders in a stock. However, this strategy relies on sufficient juveniles reaching the maximum legal size. A spatially explicit approach to a reduction in the MLS could ensure that some lobsters reach the maximum legal size before being caught. For example, the MLS could be reduced in statistical areas within CRA 1 only. This might ensure that some lobsters reach maximum legal size in other areas before migrating into CRA 1. In any case, the introduction of a maximum legal size should apply to both sexes because large females require large males to fertilise their eggs (Booth 2011).

Finally, mortality associated with handling larger individuals should also be considered. A reduction in gap size on pots would help reduce the handling and associated mortality of larger individuals. Also, tail-length is difficult to measure in a standard and repeatable way and requires pressure to be put on the tail of the lobster when measuring which could result in injury and associated handling mortality in lobsters being returned (Breen et al. 1987). Changing the way the MLS is measured to tail-width as is used in the CRA fishery (or carapace-length, a more precisely measured body part) could help here as well.

4.1 Recommendations

There is a need for more basic biological information of this species, particularly morphometric work giving the relationship between tail-length, tail-width, and carapace-length, as well as length, weight and growth parameters. Better morphometrics and length-weight metrics would improve the exploratory minimum legal size modelling component of this project. As it stands, this part of the project relies largely on parameters for CRA which may or may not be appropriate for PHC.

If the CPUE index is accepted by the Rock Lobster Working Group as an adequate index of abundance for packhorse rock lobsters, then a stock assessment model should also be done to assess the current status of the PHC 1 stock. There is also some voluntary logbook data available for PHC and the arithmetic CPUE indices show an increasing trend in catch rates, similar to the CPUE series produced using the CELR data (Figure 14). It would be worthwhile analysing these data further and potentially producing a standardised CPUE index so that direct comparison can be made with CELR indices.

A plus group is used for lobsters with a tail-width of 88 mm or larger in the rlcs database (i.e., the length-frequency data). While appropriate for CRA, a lot of the population structure of larger individuals is ignored in PHC. This may or may not be an easy issue to amend.

The use of a MLS defined in terms of tail-length (rather than tail-width or carapace-length) in this fishery is unusual. Moving to a MLS measured by tail-width, as is used in the CRA fishery (or carapace-length, a more precisely measured body part), might make it easier for commercial and recreational fishers to measure lobsters and help reduce handling mortality.

Finally, a precautionary approach should be taken if considering a reduction in the MLS for PHC (and potentially a maximum legal size). Catch rates in the fishery look to have improved over the last two decades and there appear to be economic incentives for reducing the MLS. Furthermore, the availability of the smaller/higher value lobsters might see more fishers targeting PHC and could help increase the total commercial catch towards the current TACC. But, there are also associated risks in that reducing the MLS could reduce the spawning stock biomass (even if a maximum legal size is introduced). Despite this, effectively monitoring the stock (using CPUE/stock assessment) and setting appropriate output controls should reduce any such risks.

5 ACKNOWLEDGMENTS

This work was funded by the New Zealand Rock Lobster Industry Council. Thanks to members of the Rock Lobster Fishery Assessment Working Group, especially Paul Breen and Paul Starr for all of their help. Thanks also to Daryl Sykes for helpful discussions and input.

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Table 9: Estimated commercial catch (tonnes) of packhorse rock lobsters *Sagmariasus verreauxi* (PHC) from 1953/54 to 1978/79 (Booth 2011).

Fishing year	Catch
1953/54	20
1954/55	20
1955/56	40
1956/57	40
1957/58	40
1958/59	40
1959/60	40
1960/61	40
1961/62	80
1962/63	120
1963/64	120
1964/65	120
1965/66	120
1966/67	120
1967/68	80
1968/69	80
1969/70	80
1970/71	200
1971/72	200
1972/73	100
1973/74	100
1974/75	100
1975/76	100
1976/77	100
1977/78	160
1978/79	60

Table 10: Reported commercial catch and TACC (tonnes) of packhorse rock lobsters *Sagmariasus verreauxi* (PHC) from 1979/80 to 2012/13. Data from FSU for 1979/80 to 1989/90, QMR for 1990/91 to 2000/01 and MHR for 2001/02 to 2012/13 (MPI 2012).

FSU		QMR/MHR		
Fishing year	Catch	Fishing year	Catch	TACC
1979/80	29.1	1990/91	7.4	30.5
1980/81	11.2	1991/92	23.6	30.5
1981/82	25.2	1992/93	15.3	40.3
1982/83	28.9	1993/94	5.7	40.3
1983/84	73.1	1994/95	7.9	40.3
1984/85	36.8	1995/96	23.8	40.3
1985/86	20.3	1996/97	16.9	40.3
1986/87	7.7	1997/98	16.2	40.3
1987/88	10.2	1998/99	16.2	40.3
1988/89	15.0	1999/00	12.6	40.3
1989/90	10.0	2000/01	9.8	40.3
		2001/02	7.8	40.3
		2002/03	8.6	40.3
		2003/04	16.4	40.3
		2004/05	20.8	40.3
		2005/06	25.0	40.3
		2006/07	25.4	40.3
		2007/08	34.0	40.3
		2008/09	36.4	40.3
		2009/10	35.7	40.3
		2010/11	32.8	40.3
		2011/12	31.6	40.3
		2012/13	27.4	40.3

Table 11: Catch data sets including: total allowable commercial catch (TACC); QMR/MHR reported catches (QMR/MHR); landings from the bottom of CELR forms aggregated by fishing year (Landings); estimated subcatch of PHC from the CELR forms (Estimated catch); corrected catch after grooming procedures (Corrected catch all); and the corrected catch after the core vessel selection procedure is applied (Corrected catch core). All of these catches are in tonnes and are shown in Figure 4.

Fishing year	TACC	QMR/MHR	Landings	Estimated catch	Corrected catch (all)	Corrected catch (core)
1990/91	30.5	7.4	1.39	1.27	-	-
1991/92	30.5	23.6	24.06	25.49	24.01	3.16
1992/93	40.3	15.3	9.30	10.67	8.63	4.59
1993/94	40.3	5.7	5.90	5.75	5.82	5.08
1994/95	40.3	7.9	7.80	12.20	7.48	6.62
1995/96	40.3	23.8	24.09	21.28	24.05	21.46
1996/97	40.3	16.9	19.00	13.03	10.55	5.41
1997/98	40.3	16.2	14.56	8.88	9.32	9.06
1998/99	40.3	16.2	15.94	13.40	15.30	11.27
1999/00	40.3	12.6	12.70	11.32	12.20	11.53
2000/01	40.3	9.8	9.88	8.74	9.78	9.01
2001/02	40.3	7.8	8.82	7.82	8.38	8.00
2002/03	40.3	8.6	8.56	8.00	8.47	7.91
2003/04	40.3	16.4	16.46	16.02	15.92	14.74
2004/05	40.3	20.8	21.63	20.31	19.92	19.19
2005/06	40.3	25.0	25.53	23.14	24.42	24.33
2006/07	40.3	25.4	26.42	23.32	24.42	24.05
2007/08	40.3	34.0	35.22	31.89	33.56	33.26
2008/09	40.3	36.4	36.43	32.77	35.61	35.36
2009/10	40.3	35.7	36.81	31.81	35.35	35.22
2010/11	40.3	32.8	33.58	29.65	32.06	30.35
2011/12	40.3	31.6	32.54	27.50	31.86	28.81
2012/13	40.3	27.4	28.98	24.90	27.77	24.10

Table 12: Number of records by statistical area from 1991/92 to 2012/13 within the CPUE analysis (source: corrected catch data set, core vessels only). A "-" indicates no records for that year-area strata.

	CRA 1					CRA 2				
Fishing year	901	902	903	904	939	905	906	907	908	Total
1991	10	22	37	10	20	7	30	11	-	147
1992	9	19	20	17	21	9	26	-	-	121
1993	2	22	36	19	14	-	31	1	-	125
1994	-	10	27	32	17	6	40	-	3	135
1995	1	19	35	25	14	19	47	1	2	163
1996	-	10	41	17	15	16	29	-	3	131
1997	-	9	26	14	13	17	31	4	2	116
1998	7	6	18	11	12	31	49	5	9	148
1999	21	8	11	15	14	18	37	13	10	147
2000	10	9	9	14	7	33	75	15	6	178
2001	9	11	11	7	8	44	83	16	1	190
2002	6	19	10	7	14	29	89	16	-	190
2003	-	15	16	18	7	53	72	9	1	191
2004	17	20	17	16	8	41	79	24	7	229
2005	13	24	15	16	7	73	78	26	10	262
2006	22	12	23	16	9	67	75	26	10	260
2007	28	32	18	16	8	68	79	20	26	295
2008	30	18	26	14	7	65	102	14	26	302
2009	25	19	28	22	7	83	99	18	15	316
2010	17	32	11	24	6	82	83	20	25	300
2011	20	33	17	19	6	73	96	19	18	301
2012	16	28	19	23	4	49	98	16	17	270

Table 13: Number of records with positive catch (corrected catch > 0) by statistical area from 1991/92 to 2012/13 within the CPUE analysis (source: corrected catch data set, core vessels only). A "-" indicates no records for that year-area strata.

	CRA 1					CRA 2				
Fishing year	901	902	903	904	939	905	906	907	908	Total
1991	4	15	12	6	12	5	16	2	-	72
1992	4	10	13	9	7	-	17	-	-	60
1993	-	13	23	10	7	-	20	-	-	73
1994	-	10	19	18	7	6	35	-	-	95
1995	1	16	22	15	8	14	33	-	1	110
1996	-	8	27	10	10	6	22	-	2	85
1997	-	8	18	10	9	12	22	3	1	83
1998	7	5	11	5	4	23	29	3	3	90
1999	11	5	10	8	7	15	28	3	6	93
2000	7	6	6	11	5	25	53	12	4	129
2001	7	4	7	6	2	32	65	13	1	137
2002	2	12	9	5	3	16	52	10	-	109
2003	-	9	13	10	5	36	58	6	1	138
2004	16	12	13	14	5	25	63	10	1	159
2005	11	16	12	15	6	47	69	15	2	193
2006	21	10	13	14	8	38	56	16	8	184
2007	24	26	15	15	6	50	61	11	20	228
2008	23	14	19	12	6	42	78	12	18	224
2009	19	13	19	18	5	57	71	15	11	228
2010	11	22	8	20	4	68	70	20	12	235
2011	17	23	9	18	1	57	80	18	11	234
2012	10	19	15	21	2	36	84	14	11	212

Table 14: Number of vessels that fished within each statistical area from 1979/80 to 2012/13 (the vessel had to have recorded PHC catch at least once within the CELR data set). The "Other" column is the number of vessels fishing a statistical area other than those shown. The "All" column is the number of vessels from all statistical areas that landed PHC during that fishing year. A "-" indicates that no vessels reported landing PHC in that area during that fishing year.

	CRA 1						CRA 2						
Fishing year	901	902	903	904	939	Total	905	906	907	908	Total	Other	All
1979/80	2	1	6	5	4	18	6	4	1	1	12	12	42
1980/81	-	2	6	5	4	17	2	4	1	-	7	25	49
1981/82	-	4	2	3	3	12	4	3	1	3	11	6	29
1982/83	1	8	3	2	2	16	5	2	-	2	9	3	28
1983/84	2	8	2	3	3	18	6	5	-	1	12	8	38
1984/85	3	7	1	4	3	18	4	3	3	2	12	8	38
1985/86	3	4	4	2	5	18	2	2	1	1	6	6	30
1986/87	2	7	4	4	5	22	-	5	-	1	6	4	32
1987/88	2	5	5	2	3	17	-	4	2	-	6	9	32
1988/89	-	3	2	1	1	7	1	2	-	-	3	9	19
1989/90	2	1	1	1	2	7	1	-	-	-	1	3	11
1990/91	9	9	7	6	4	35	5	11	1	3	20	1	56
1991/92	5	11	12	8	6	42	8	11	2	6	27	-	69
1992/93	1	9	8	6	6	30	6	13	3	6	28	2	60
1993/94	4	7	8	6	5	30	9	13	7	5	34	-	64
1994/95	3	5	6	7	4	25	7	12	3	6	28	2	55
1995/96	3	5	6	7	4	25	8	17	5	6	36	-	61
1996/97	3	3	9	7	4	26	7	12	5	6	30	1	57
1997/98	3	6	5	7	5	26	10	11	5	6	32	4	62
1998/99	3	3	5	5	5	21	9	10	3	5	27	-	48
1999/00	6	2	4	5	5	22	7	13	3	4	27	1	50
2000/01	4	2	3	6	4	19	9	14	3	9	35	2	56
2001/02	5	4	3	6	4	22	12	12	3	8	35	-	57
2002/03	6	6	4	4	5	25	11	14	8	5	38	-	63
2003/04	2	6	5	3	5	21	10	14	5	7	36	3	60
2004/05	4	5	4	3	5	21	8	13	6	8	35	2	58
2005/06	3	5	3	2	4	17	12	13	9	6	40	8	65
2006/07	5	4	6	2	3	20	10	17	5	7	39	6	65
2007/08	5	5	6	2	3	21	10	12	6	6	34	12	67
2008/09	7	4	6	2	3	22	10	12	4	8	34	8	64
2009/10	6	6	6	2	3	23	11	13	5	6	35	9	67
2010/11	5	6	5	5	3	24	16	11	5	6	38	8	70
2011/12	5	5	8	3	3	24	14	14	5	8	41	2	67
2012/13	5	5	6	5	3	24	13	15	7	8	43	2	69

Table 15: Number of vessels by statistical area that catch PHC from 1979/80 to 2012/13. The "Other" column is the number of vessels fishing a statistical area other than those shown. The "All" column is the number of vessels from all statistical areas that landed PHC during that fishing year. A "-" indicates that no vessels reported landing PHC in that area during that fishing year.

	CRA 1						CRA 2						
Fishing year	901	902	903	904	939	Total	905	906	907	908	Total	Other	All
1979/80	2	1	6	5	4	18	6	4	1	1	12	11	41
1980/81	-	2	6	5	4	17	2	4	1	-	7	25	49
1981/82	-	4	2	3	3	12	4	3	1	3	11	6	29
1982/83	1	8	3	2	2	16	5	2	-	2	9	3	28
1983/84	2	8	2	3	3	18	6	5	-	1	12	8	38
1984/85	3	7	1	4	3	18	4	3	3	2	12	8	38
1985/86	3	4	4	2	5	18	2	2	1	1	6	6	30
1986/87	2	7	4	4	5	22	-	5	-	1	6	4	32
1987/88	2	5	5	2	3	17	-	4	2	-	6	9	32
1988/89	-	3	2	1	1	7	1	2	-	-	3	9	19
1989/90	2	1	1	1	2	7	1	-	-	-	1	3	11
1990/91	4	4	1	1	3	13	-	1	-	-	1	1	15
1991/92	3	7	7	3	2	22	1	5	2	1	9	-	31
1992/93	1	5	4	5	3	18	1	8	1	2	12	2	32
1993/94	1	4	4	4	2	15	2	7	1	1	11	-	26
1994/95	2	2	4	4	4	16	2	8	1	-	11	2	29
1995/96	2	4	4	3	4	17	6	12	1	1	20	-	37
1996/97	1	3	6	2	4	16	5	6	1	1	13	1	30
1997/98	-	5	4	4	5	18	6	6	2	1	15	4	37
1998/99	2	3	4	2	4	15	7	8	1	1	17	-	32
1999/00	4	2	3	3	4	16	3	7	2	4	16	1	33
2000/01	2	2	2	3	4	13	5	9	2	2	18	2	33
2001/02	4	2	2	3	1	12	7	9	2	1	19	-	31
2002/03	2	5	2	2	2	13	6	9	3	-	18	-	31
2003/04	1	4	4	2	3	14	9	10	2	2	23	3	40
2004/05	3	4	3	3	3	16	8	9	3	1	21	2	39
2005/06	2	3	2	2	3	12	10	9	4	3	26	8	46
2006/07	2	3	5	2	3	15	9	12	3	1	25	6	46
2007/08	2	4	6	2	2	16	8	10	4	4	26	12	54
2008/09	4	4	5	2	2	17	8	10	4	7	29	8	54
2009/10	2	6	4	2	2	16	9	11	3	4	27	9	52
2010/11	1	5	4	5	3	18	12	11	4	5	32	8	58
2011/12	2	5	5	3	2	17	12	14	4	5	35	2	54
2012/13	2	4	6	5	2	19	12	15	5	5	37	2	58

Table 16: Scaled annual catch by statistical area ($\hat{Q}_{ay}$, tonnes) of PHC from 1979/80 to 2012/13. These catches are derived using Equation 1. The "Other" column is the catch by vessels fishing a statistical area other than those shown (statistical areas in which any vessel landed PHC for less than 6 years were combined into this column). The "All" column is the catch by vessels from all statistical areas that landed PHC during that fishing year. A "-" indicates that no vessels reported landing PHC in that area during that fishing year. A zero catch indicates that fishing occurred in that area during that fishing year but no PHC was caught.

	CRA 1						CRA 2						
Fishing year	901	902	903	904	939	Total	905	906	907	908	Total	Other	All
1979/80	0.21	3.79	18.83	3.15	0.37	26.34	1.37	0.34	0.49	0.02	2.22	0.55	29.1
1980/81	-	3.53	4.19	1.39	0.08	9.19	0.06	0.27	0.02	-	0.35	1.66	11.2
1981/82	-	17.02	3.48	2.77	0.14	23.41	0.38	0.41	0.04	0.80	1.62	0.17	25.2
1982/83	0.14	25.47	0.86	0.36	0.01	26.84	0.05	0.04	-	0.02	0.11	1.95	28.9
1983/84	17.05	52.71	0.83	1.35	0.14	72.09	0.52	0.37	-	0.01	0.90	0.12	73.1
1984/85	10.49	24.58	0.53	0.52	0.06	36.18	0.11	0.18	0.07	0.02	0.38	0.24	36.8
1985/86	3.43	13.84	1.10	0.21	1.24	19.82	0.14	0.04	0.04	0.09	0.32	0.17	20.3
1986/87	3.65	0.66	2.75	0.49	0.08	7.63	-	0.04	-	0.00	0.04	0.03	7.7
1987/88	0.16	2.44	6.75	0.39	0.10	9.83	-	0.13	0.08	-	0.21	0.16	10.2
1988/89	-	1.04	8.48	0.30	0.40	10.21	0.32	0.23	-	-	0.54	4.25	15.0
1989/90	6.95	1.86	0.10	0.24	0.33	9.49	0.04	-	-	-	0.04	0.47	10.0
1990/91	3.31	2.78	0.02	0.11	0.82	7.04	0.00	0.35	0.00	0.00	0.35	0.01	7.4
1991/92	0.17	22.71	0.39	0.04	0.09	23.41	0.03	0.14	0.02	0.00	0.19	0.00	23.6
1992/93	0.11	12.87	1.02	0.44	0.04	14.48	0.06	0.20	0.01	0.54	0.81	0.01	15.3
1993/94	0.01	4.19	0.67	0.15	0.02	5.05	0.02	0.22	0.40	0.00	0.65	0.00	5.7
1994/95	0.05	6.39	0.48	0.22	0.04	7.18	0.05	0.34	0.30	0.00	0.69	0.02	7.9
1995/96	0.42	17.51	1.90	0.60	0.25	20.69	1.13	0.84	1.14	0.00	3.11	0.00	23.8
1996/97	0.01	7.00	4.01	0.74	0.35	12.10	0.46	1.72	2.61	0.01	4.80	0.00	16.9
1997/98	0.00	6.47	1.31	1.98	0.27	10.04	4.26	0.76	1.10	0.00	6.12	0.04	16.2
1998/99	7.60	3.57	1.41	0.25	0.02	12.84	1.59	1.19	0.55	0.03	3.36	0.00	16.2
1999/00	9.50	0.82	0.36	0.11	0.03	10.82	0.65	0.42	0.14	0.09	1.30	0.47	12.6
2000/01	3.10	0.51	0.84	0.30	0.05	4.80	3.19	0.69	0.54	0.56	4.99	0.01	9.8
2001/02	3.24	0.42	0.68	0.56	0.01	4.90	1.28	1.07	0.54	0.00	2.90	0.00	7.8
2002/03	0.40	4.55	0.71	0.28	0.03	5.97	1.32	0.76	0.55	0.00	2.63	0.00	8.6
2003/04	0.02	9.93	3.36	0.99	0.11	14.41	0.78	0.75	0.44	0.01	1.98	0.01	16.4
2004/05	12.58	2.53	1.99	0.74	0.09	17.92	1.01	1.64	0.22	0.00	2.87	0.01	20.8
2005/06	11.55	3.56	3.31	2.07	0.42	20.91	1.50	2.10	0.21	0.21	4.02	0.07	25.0
2006/07	12.10	3.08	1.69	4.42	0.45	21.75	1.09	1.88	0.31	0.33	3.61	0.04	25.4
2007/08	14.55	5.57	1.36	4.59	0.48	26.54	2.25	2.77	1.23	1.12	7.37	0.09	34.0
2008/09	22.17	1.33	4.84	2.67	0.25	31.26	1.15	2.81	0.41	0.63	5.01	0.14	36.4
2009/10	14.43	7.43	2.18	5.39	0.09	29.52	1.69	3.36	0.69	0.37	6.10	0.07	35.7
2010/11	7.32	9.29	2.43	5.92	0.08	25.03	2.38	3.43	1.38	0.48	7.67	0.09	32.8
2011/12	5.21	4.21	1.28	6.05	0.07	16.83	3.98	8.19	2.14	0.42	14.74	0.03	31.6
2012/13	1.84	2.54	2.43	7.39	0.02	14.21	3.46	8.41	0.98	0.33	13.18	0.01	27.4

Table 17: Number of potlifts by statistical area from 1979/80 to 2012/13. These data represent the number of potlifts for fishing events that either landed PHC, targeted PHC, or potlifts for those vessels that targeted CRA in CRA 1 or CRA 2 and caught PHC in any fishing year. A "-" indicates that no vessels reported landing PHC in that area during that fishing year.

	CRA 1						CRA 2				
Fishing year	901	902	903	904	939	Total	905	906	907	908	Total
1979/80	91	430	2,554	1,402	756	5,233	650	360	35	80	1,125
1980/81	-	290	3,003	1,448	1,150	5,891	226	1,693	271	-	2,190
1981/82	-	1,233	1,807	1,243	1,417	5,700	728	1,746	74	192	2,740
1982/83	65	2,298	2,406	947	210	5,926	270	223	-	125	618
1983/84	645	3,932	1,205	2,361	1,579	9,722	1,349	876	-	75	2,300
1984/85	407	4,919	940	2,138	551	8,955	356	344	170	91	961
1985/86	327	2,175	2,205	540	3,524	8,771	459	324	35	9	827
1986/87	444	1,417	2,420	1,748	2,154	8,183	-	820	-	80	900
1987/88	115	1,496	2,395	714	1,174	5,894	-	740	184	-	924
1988/89	-	425	517	155	142	1,239	183	224	-	-	407
1989/90	961	20	500	200	1,710	3,391	161	-	-	-	161
1990/91	22,053	28,313	23,505	20,930	30,841	125,642	17,503	97,111	9,202	11,002	134,818
1991/92	4,707	34,771	47,486	40,264	48,297	175,525	34,033	116,633	10,644	3,326	164,636
1992/93	4,944	21,604	34,858	47,244	42,636	151,286	38,465	131,922	16,795	10,489	197,671
1993/94	9,254	25,332	39,388	30,803	33,119	137,896	47,052	138,038	31,409	22,199	238,698
1994/95	8,737	17,634	27,217	46,268	27,510	127,366	48,507	121,909	23,518	8,191	202,125
1995/96	9,614	14,322	23,138	42,103	20,932	110,109	26,909	110,315	15,549	13,781	166,554
1996/97	9,171	16,809	31,882	37,657	17,735	113,254	22,329	97,245	9,548	9,275	138,397
1997/98	7,305	11,402	24,932	43,755	28,685	116,079	28,867	83,990	14,906	10,338	138,101
1998/99	11,269	11,471	19,148	26,662	30,390	98,940	41,748	85,703	17,045	22,337	166,833
1999/00	22,075	5,752	15,622	32,138	30,845	106,432	32,359	107,847	25,038	15,517	180,761
2000/01	22,098	4,275	13,714	26,964	27,078	94,129	50,305	126,553	27,860	28,077	232,795
2001/02	21,202	4,778	14,205	20,521	31,586	92,292	50,400	156,699	34,893	52,321	294,313
2002/03	22,492	9,487	11,975	20,594	33,377	97,925	53,736	182,384	66,286	75,971	378,377
2003/04	6,743	18,400	10,381	31,044	35,128	101,696	52,421	167,716	75,439	71,109	366,685
2004/05	12,120	19,233	12,093	19,982	38,185	101,613	32,278	166,401	79,791	70,519	348,989
2005/06	17,834	11,862	13,454	22,100	41,167	106,417	60,727	159,362	98,506	72,836	391,431
2006/07	19,432	10,842	18,326	24,416	22,907	95,923	48,638	159,003	81,213	62,630	351,484
2007/08	20,473	12,284	13,467	20,860	13,874	80,958	47,301	145,131	70,720	83,948	347,100
2008/09	17,795	11,850	16,880	25,058	17,747	89,330	45,832	168,014	58,938	80,469	353,253
2009/10	18,185	11,831	15,126	21,353	15,087	81,582	60,643	161,895	80,870	96,632	400,040
2010/11	21,340	19,177	15,707	23,650	16,081	95,955	86,277	141,029	88,805	102,975	419,086
2011/12	25,110	18,475	11,355	28,122	11,919	94,981	79,972	194,787	87,376	99,417	461,552
2012/13	20,184	17,336	12,075	23,103	8,019	80,717	80,338	205,179	99,271	95,488	480,276

APPENDICES

A ERROR CHECKING CELR DATA

Catch Effort Landing Return (CELR) catch and effort data from 1 July 1989 to 31 March 2013 were obtained from the Warehou database (MPI 2010, MPI report log 9002-04, June 2013). These data were checked for errors using a set of rules first described by Bentley et al. (2005). The statistical area, potlift, estimated subcatch and landings fields were all checked and apparent errors flagged.

Table A.1: Summary of fishing event statistical area error checking for the period 1 October 1989 to 31 March 2013.

Rating	Criteria	Records
0	-	20,267
1	> 0 and < 44 (add 900)	306
1	49, 50, 51 or 52	0
3	null or > 43 and not 49, 50, 51 or 52	38

Table A.2: Summary of fishing event pot lift error checking for the period 1 October 1989 to 31 March 2013.

Rating	Criteria	Records
0	-	19,945
3	lifts = null	48
3	lifts > 500	8
3	lifts = 0 and catch > 0 kg	0

Table A.3: Summary of estimated PHC subcatch weight error checking for the period 1 October 1989 to 31 March 2013.

Rating	Criteria	Records
0	-	20,594
1	catch > 2,000 kg and <= 3,000 kg	1
2	catch > 3,000 kg and <= 4,000 kg	0
3	catch > 4,000 kg or null	16

Table A.4: Summary of estimated PHC landings green weight error checking for the period 1 October 1989 to 31 March 2013.

Rating	Criteria	Records
0	-	17,912
1	landing > 2,000 kg and <= 6,000 kg	0
2	landing > 6,000 kg and <= 1,0000 kg	0
3	landing > 10,000 kg or null	13

B THE F-ALGORITHM

The F-algorithm (developed by P. Starr) calculates a corrected catch (kg) for each year-month-area-vessel-target record by proportionately adjusting the estimated catch (kg) in the effort part of the CELR form by the corresponding landed weight from the bottom of the CELR form. The F-algorithm assumes that the vessel conversion ratio is constant for each vessel within a year and was developed to deal with holding pot problems. The algorithm first calculates a conversion factor for each vessel using:

$$\nu_{vy} = \frac{\sum_{i \in k_{vy}} L_{ivy}}{\sum_{i \in k_{vy}} C_{ivy}} \tag{B.1}$$

where ν_{vy} is the vessel conversion factor (VCF) for vessel v during year y, L_{ivy} is the landed weight for record i by vessel v during year y, C_{ivy} is the estimated catch in record i for vessel v during year y, and k_{vy} is the set of month-area-vessel-target records that are from vessel v in year y. VCFs ranged between 0.01 and 20 so it was necessary to remove those records where the VCF was considered an outlier (Figure B.1). Outliers were defined as those VCFs that were outside $1.5\times$ the interquartile range (IQR). The IQR was 0.47 and 1.89. The vessel conversion factor is then applied to the estimated catches in the remaining records:

$$\hat{C}_{ivy} = \nu_{vy} C_{ivy} \tag{B.2}$$

where $\hat{C}_{ivy}$ is the corrected catch for record i by vessel v during year y.

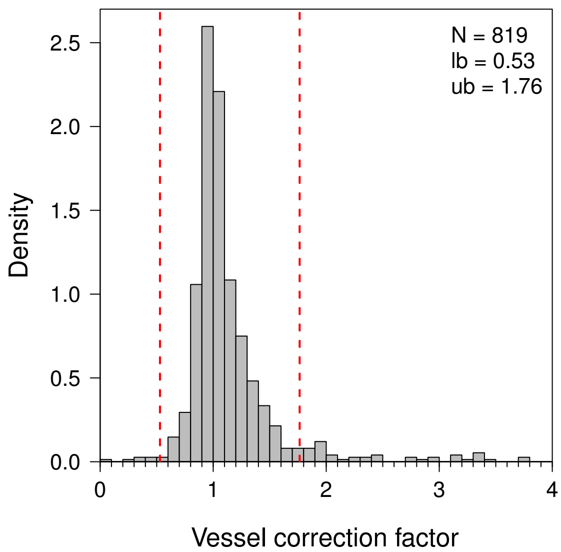

Figure B.1: Distribution of vessel conversion factors (VCF) for packhorse rock lobsters (PHC). The distribution has been truncated at 4. N = the total number of vessel-year combinations a VCF is calculated for, lb = the lower bound placed on the VCF distribution and ub = the upper bound.

C DIAGNOSTICS FOR CPUE ANALYSIS

C.1 Lognormal model

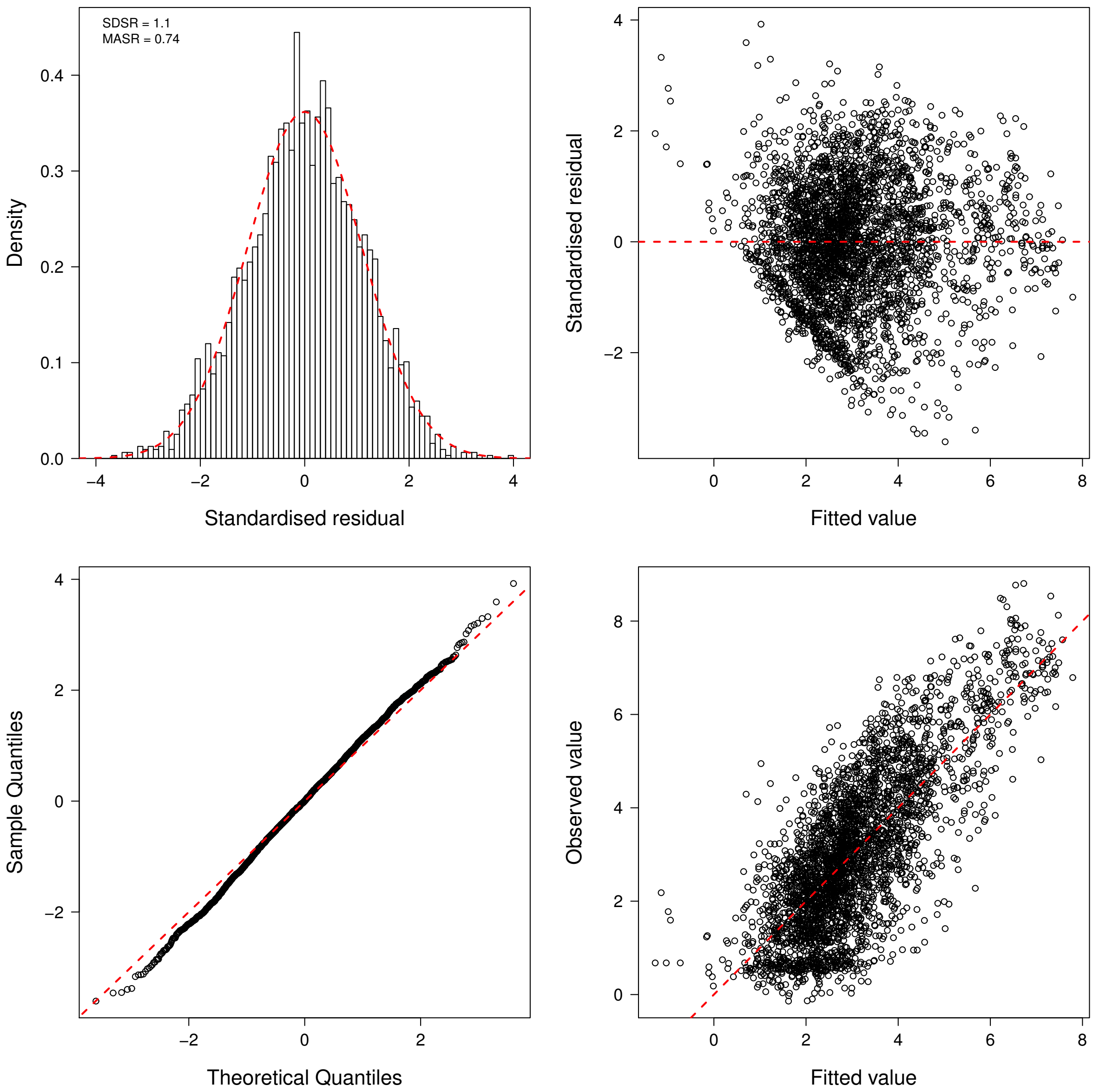

Figure C.1: Fit of the lognormal standardised CPUE model to successful catches (corrected catch data set limited to core vessels) of packhorse rock lobsters including a histogram of the standardised residuals [top-left], standardised residuals compared to predicted model catch per trip [top-right], quantile-quantile plot of the standardised residuals [bottom-left], and observed catch per record plotted against the predicted catch per record [bottom-right].

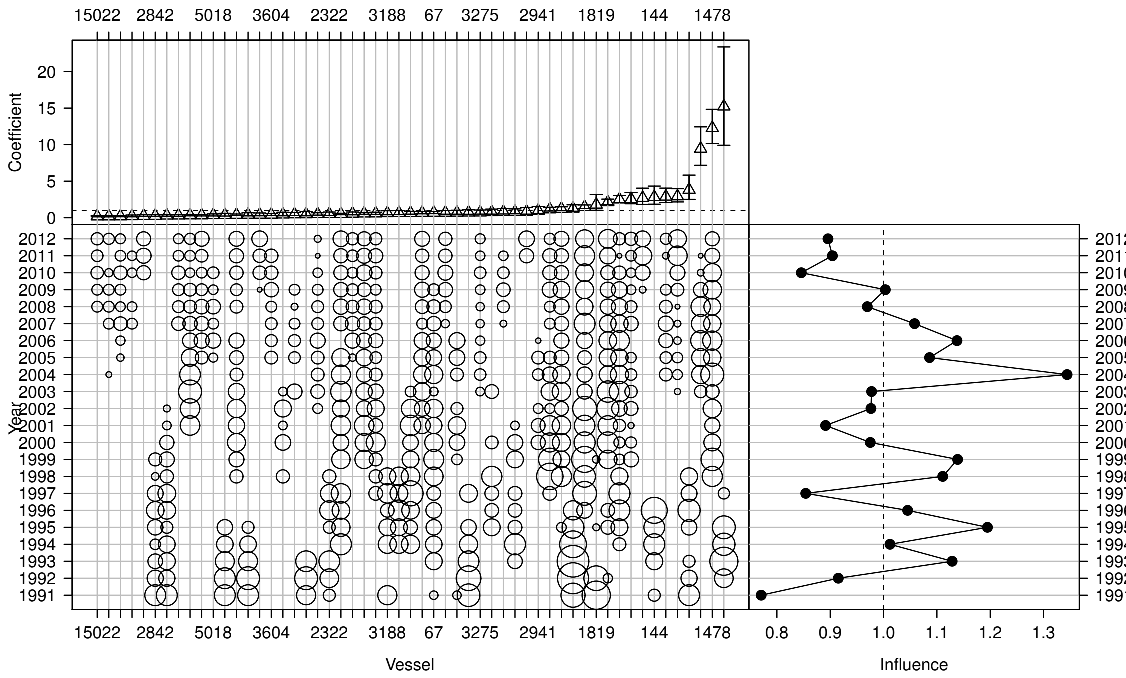

Figure C.2: The effect of vessels in the lognormal GLM to successful catches (corrected catch data set limited to core vessels) including the effect by vessel [top-left], distribution of records for vessels by year [bottom-left], and cumulative effect of vessels by fishing year [bottom-right].

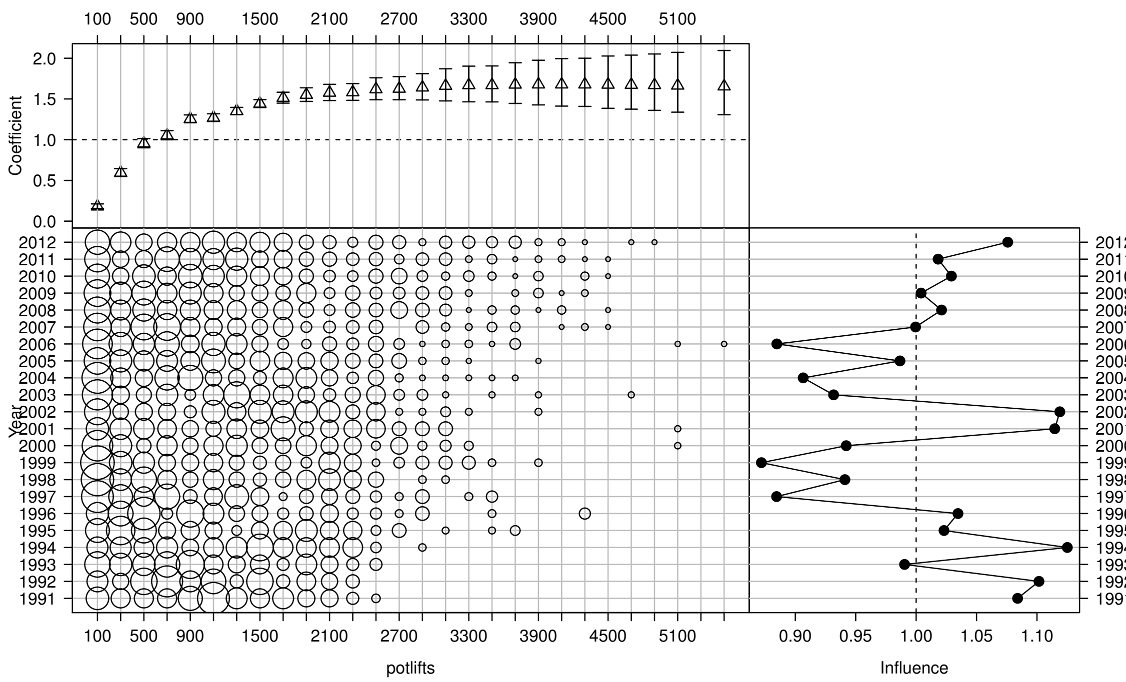

Figure C.3: The effect of potlifts in the lognormal GLM to successful catches (corrected catch data set limited to core vessels) including the effect by potlift [top-left], distribution of records for potlifts by year [bottom-left], and cumulative effect of potlifts by fishing year [bottom-right].

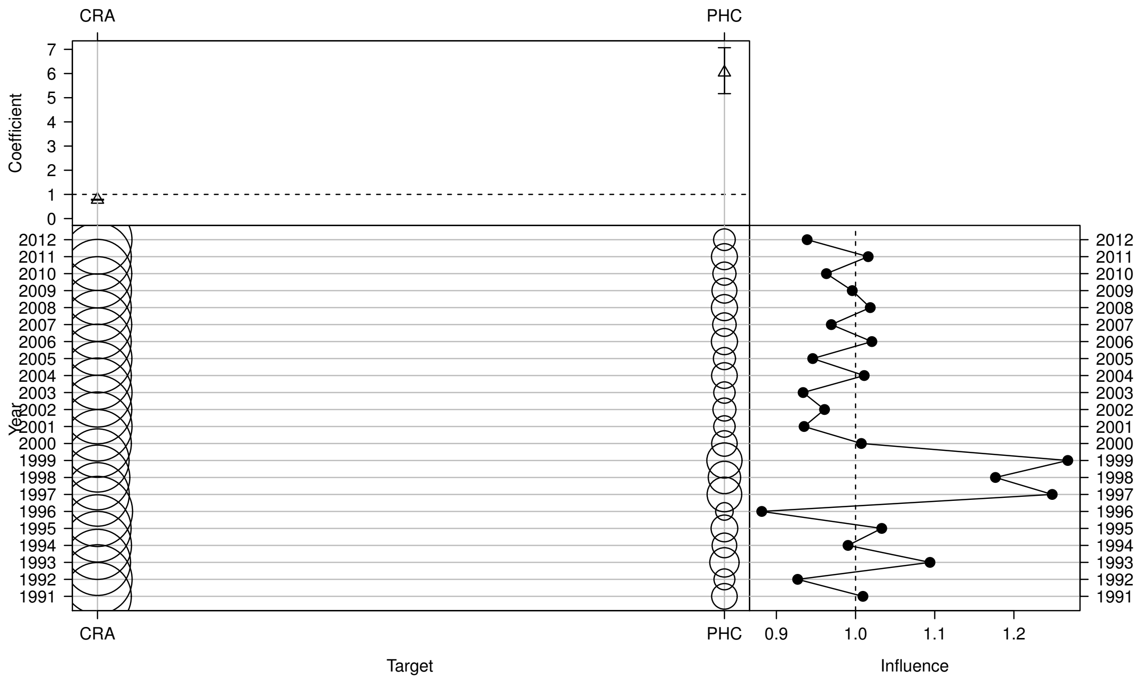

Figure C.4: The effect of target species in the lognormal GLM to successful catches (corrected catch data set limited to core vessels) including the effect by target species [top-left], distribution of records for target species by year [bottom-left], and cumulative effect of target species by fishing year [bottom-right].

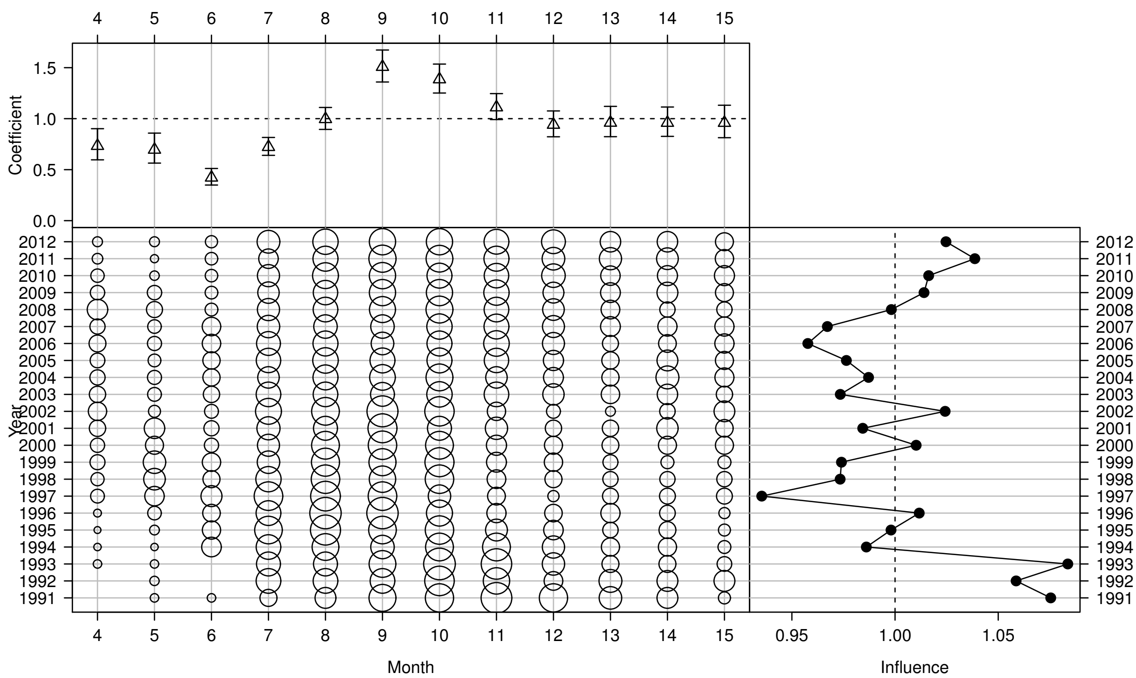

Figure C.5: The effect of month in the lognormal GLM to successful catches (corrected catch data set limited to core vessels) including the effect by month [top-left], distribution of records for months by year [bottom-left], and cumulative effect of months by fishing year [bottom-right].

C.2 Binomial model

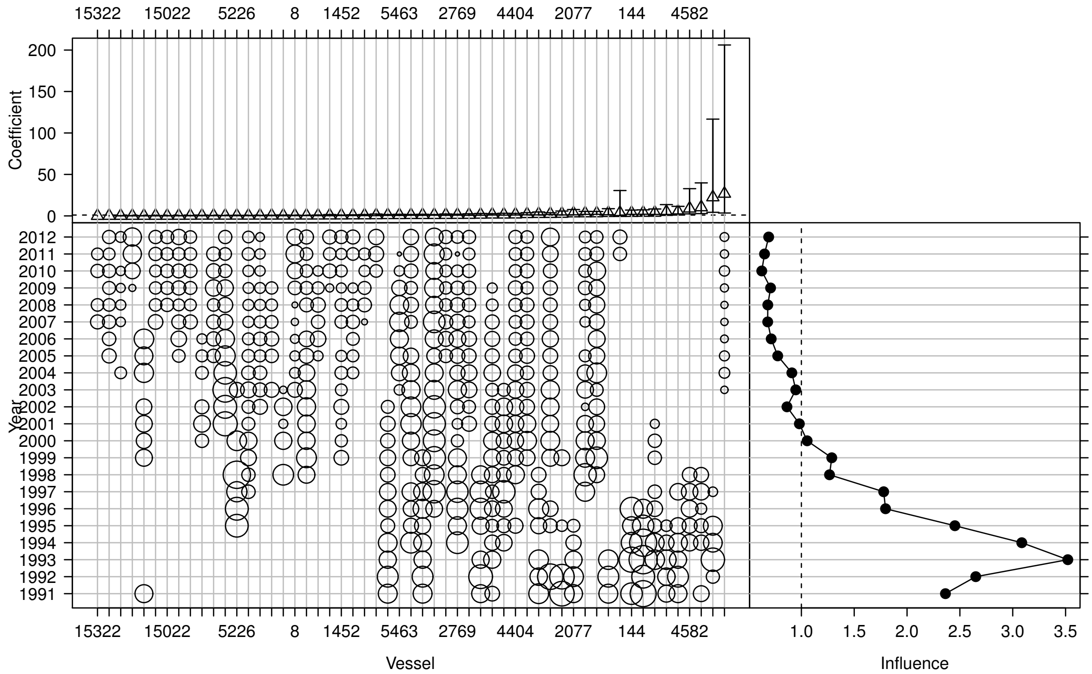

Figure C.6: The effect of vessels in the binomial GLM to successful catches (corrected catch data set limited to core vessels) including the effect by vessel [top-left], distribution of records for vessels by year [bottom-left], and cumulative effect of vessels by fishing year [bottom-right].

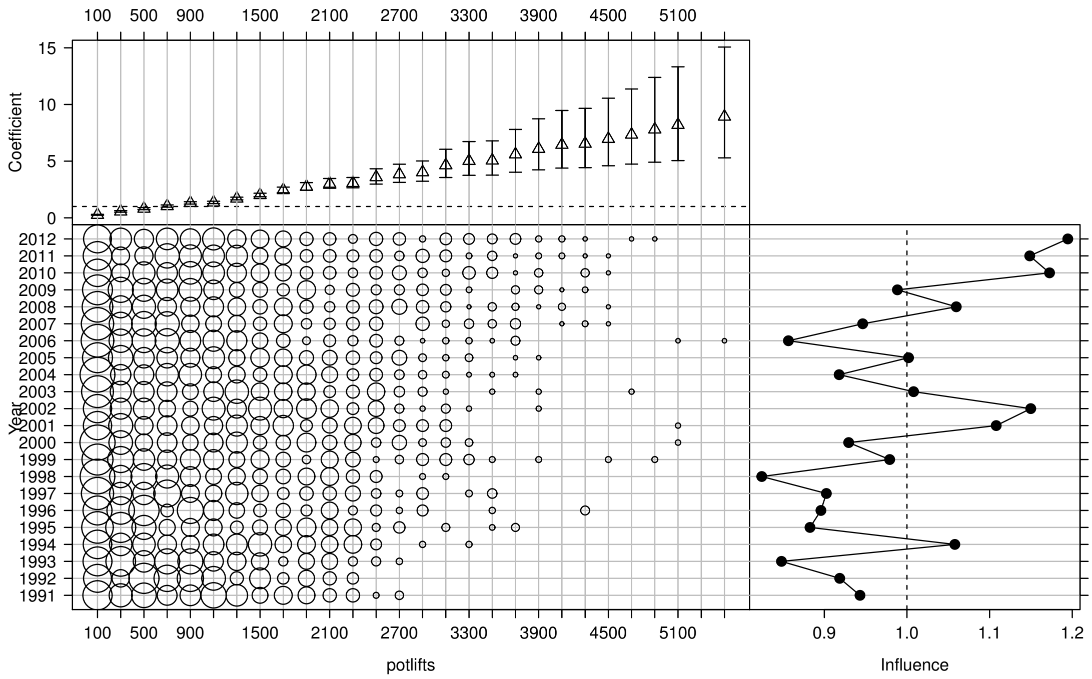

Figure C.7: The effect of potlifts in the binomial GLM to successful catches (corrected catch data set limited to core vessels) including the effect by potlift [top-left], distribution of records for potlifts by year [bottom-left], and cumulative effect of potlifts by fishing year [bottom-right].

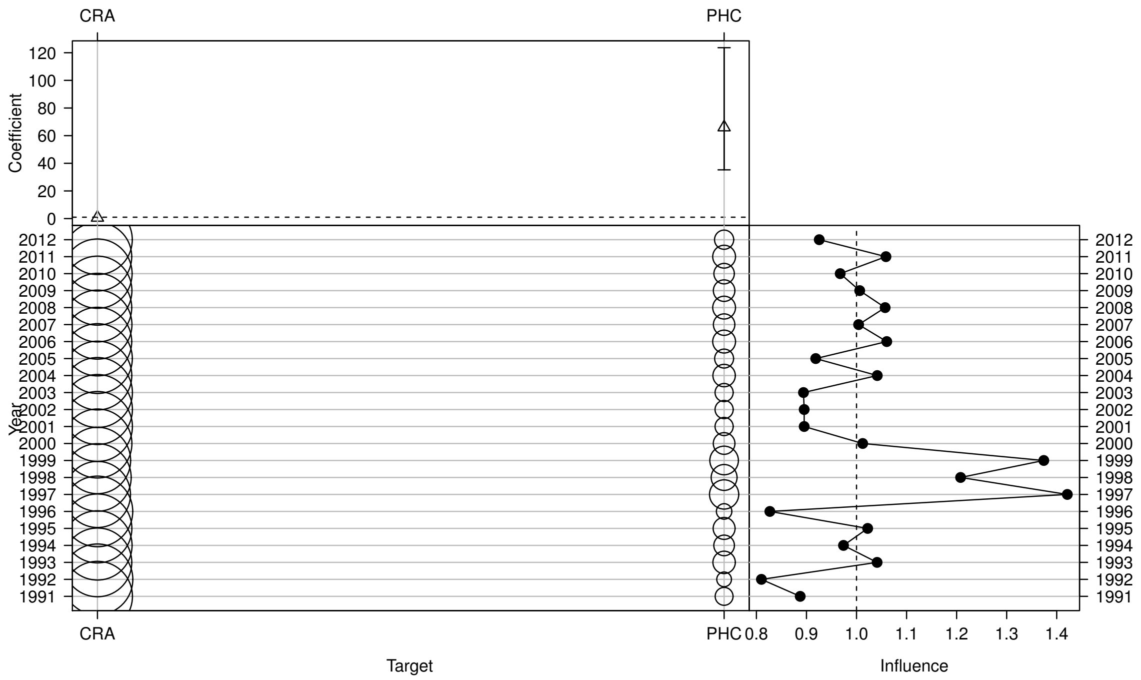

Figure C.8: The effect of target species in the binomial GLM to successful catches (corrected catch data set limited to core vessels) including the effect by target species [top-left], distribution of records for target species by year [bottom-left], and cumulative effect of target species by fishing year [bottom-right].

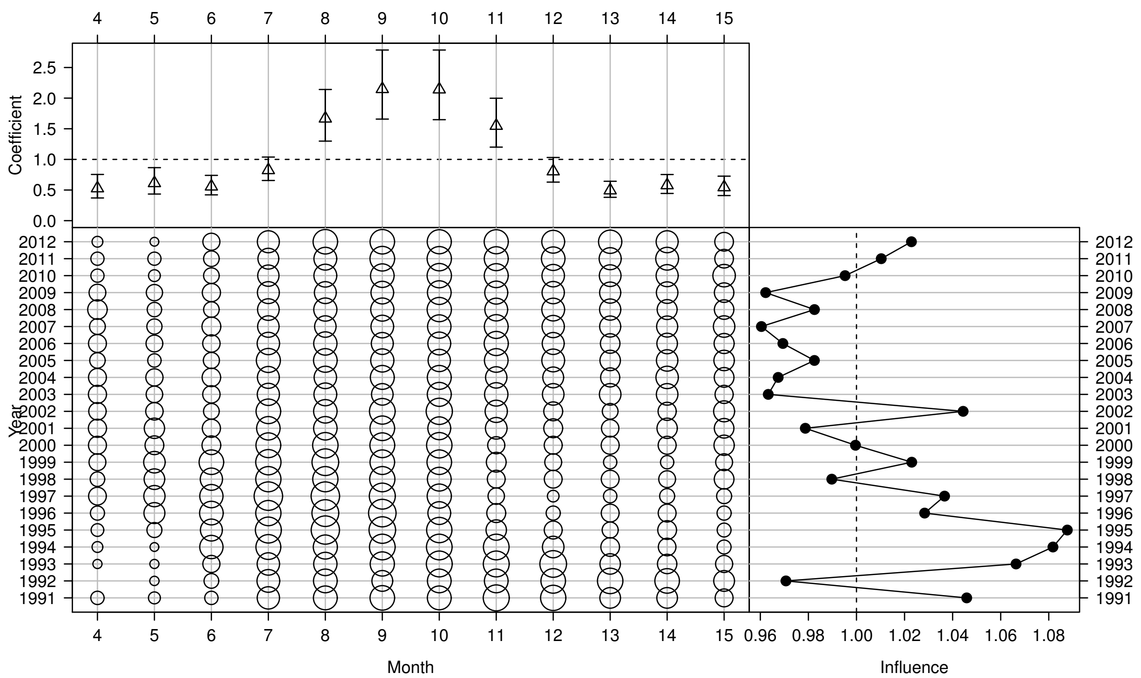

Figure C.9: The effect of month in the binomial GLM to successful catches (corrected catch data set limited to core vessels) including the effect by month [top-left], distribution of records for months by year [bottom-left], and cumulative effect of month by fishing year [bottom-right].

D CPUE SENSITIVITIES

D.1 Corrected catch, no vessel

Sensitivity using the corrected catch without core vessel selection and vessel not offered to the model.

Table D.1: Summary of the lognormal model for PHC using corrected catch without core vessel selection as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable, vessel was not offered during model selection). DF is the degrees of freedom, Deviance is the residual deviance after the addition of each term, AIC is the Akaike Information Criterion, r^2 is the proportion of the deviance explained at each step, and Final indicates whether or not the term was included in the final model.

Term	DF	Deviance	AIC	r^2	Final
None	0	10,872	14,431	0.0000	
Fishing year	21	10,680	14,407	0.0177	*
Area	8	7,979	13,351	0.2661	*
Target species	1	7,425	13,088	0.3171	*
Poly(log(potlifts), 3)	3	6,177	12,417	0.4318	*
Month	11	5,983	12,321	0.4497	*

Table D.2: Summary of the binomial model for PHC using corrected catch without core vessel selection as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable, vessel was not offered during model selection). The remaining columns are described in Table D.1 above.

Term	DF	Deviance	AIC	r^2	Final
None	0	7,064	7,066	0.0000	
Fishing year	21	6,907	6,951	0.0222	*
Month	11	6,530	6,596	0.0755	*
Target species	1	6,165	6,233	0.1272	*
Poly(log(potlifts), 3)	3	5,750	5,824	0.1860	*
Area	8	5,527	5,617	0.2176	*

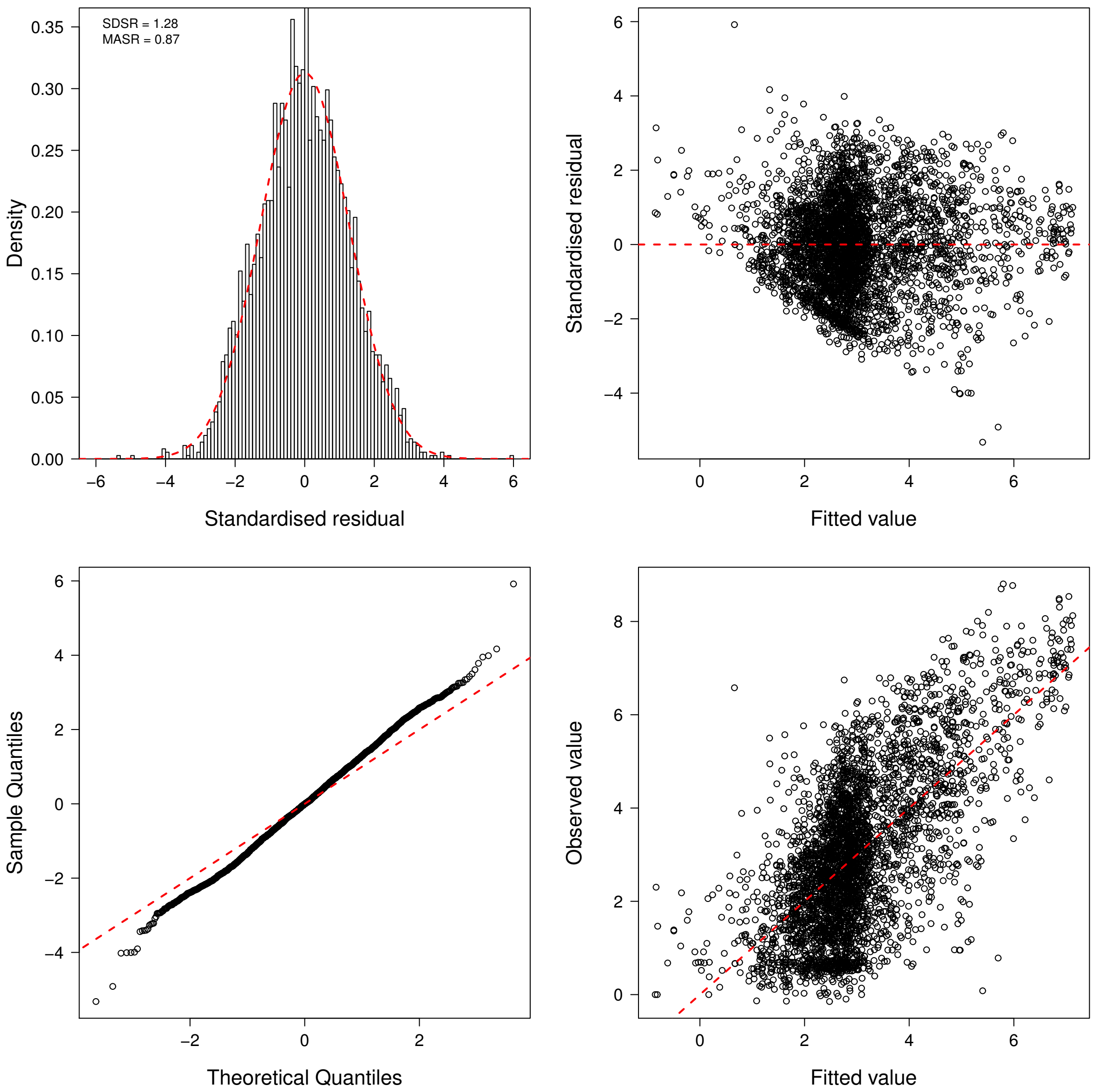

Figure D.1: Fit of the lognormal standardised CPUE model to successful catches (corrected catch without core vessel selection and vessel not offered to the model) of packhorse rock lobsters including a histogram of the standardised residuals [top-left], standardised residuals compared to predicted model catch per trip [top-right], quantile-quantile plot of the standardised residuals [bottom-left], and observed catch per record plotted against the predicted catch per record [bottom-right].

D.2 Corrected catch, no target species

Sensitivity using the corrected catch with core vessel selection applied but target species not offered to the model.

Table D.3: Summary of the lognormal model for PHC using corrected catch with core vessel selection as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable, target species was not offered during model selection). The remaining columns are described in Table D.1 above.

Term	DF	Deviance	AIC	r^2	Final
None	0	9,112	11,995	0.0000	
Fishing year	21	8,874	11,956	0.0261	*
Vessel	54	4,916	10,263	0.4605	*
Month	11	4,527	10,034	0.5032	*
Poly(log(potlifts), 3)	3	4,268	9,860	0.5316	*
Area	8	4,189	9,819	0.5403	

Table D.4: Summary of the binomial model for PHC using corrected catch without core vessel selection as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable, target species was not offered during model selection). The remaining columns are described in Table D.1 above.

Term	DF	Deviance	AIC	r^2	Final
None	0	5,198	5,200	0.0000	
Fishing year	21	5,067	5,111	0.0252	*
Vessel	54	4,625	4,778	0.1101	*
Poly(log(potlifts), 3)	3	4,080	4,238	0.2151	*
Month	11	3,909	4,089	0.2480	*
Area	8	3,878	4,074	0.2539	

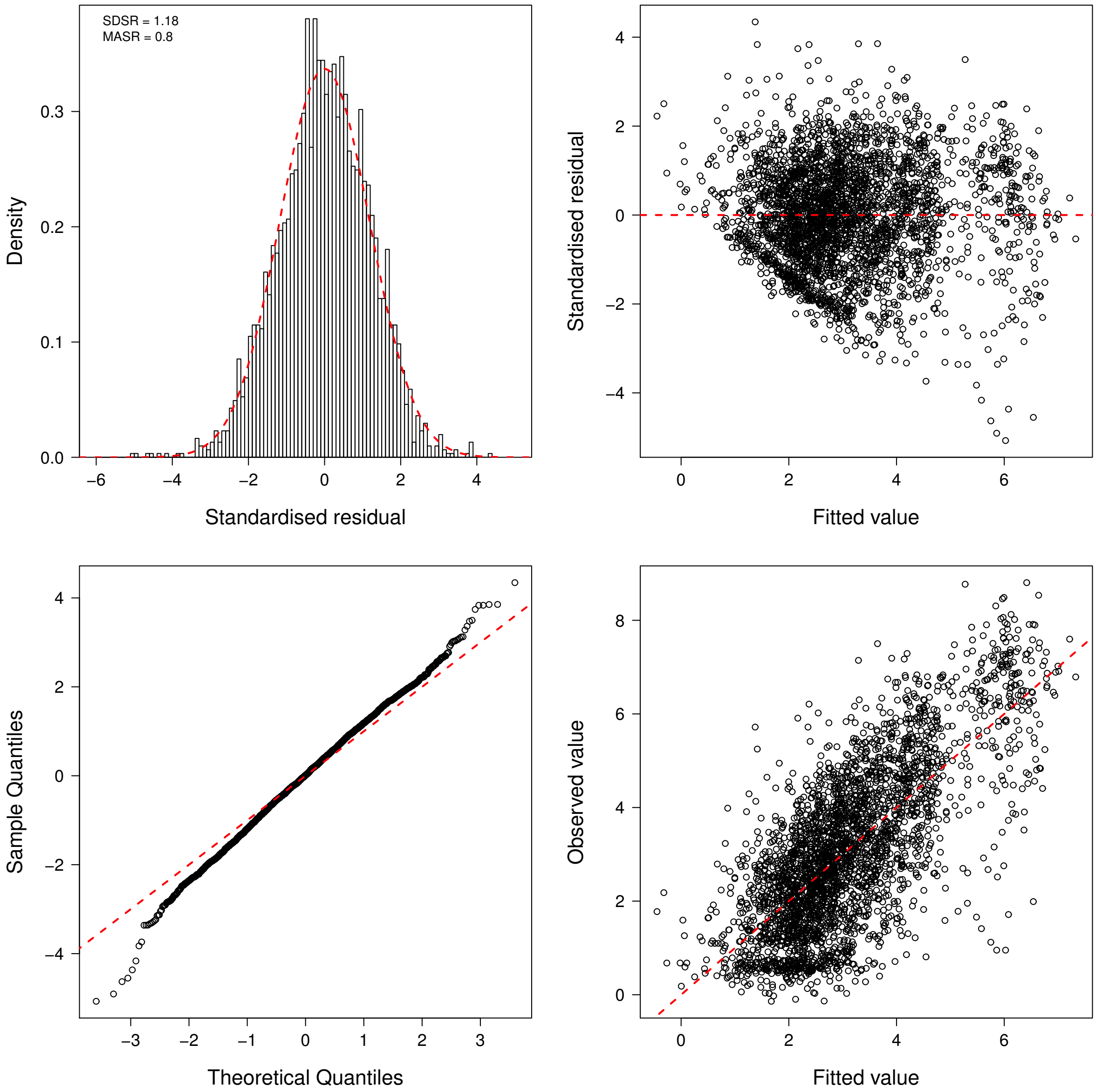

Figure D.2: Fit of the lognormal standardised CPUE model to successful catches (corrected catch with core vessel selection applied but target species not offered to the model as an explanatory variable) of packhorse rock lobsters including a histogram of the standardised residuals [top-left], standardised residuals compared to predicted model catch per trip [top-right], quantile-quantile plot of the standardised residuals [bottom-left], and observed catch per record plotted against the predicted catch per record [bottom-right].

D.3 Estimated catch

Sensitivity using the estimated catch instead of the corrected catch (i.e., estimated catch at top of CELR form, F algorithm not applied, core vessel selection applied, vessel offered to model).

Table D.5: Summary of the lognormal model for PHC using estimated catch with core vessel selection applied as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable). The remaining columns are described in Table D.1 above.

Term	DF	Deviance	AIC	r^2	Final
None	0	9,477	12,850	0.0000	
Fishing year	21	9,225	12,804	0.0266	*
Vessel	56	5,315	11,096	0.4392	*
Poly(log(potlifts), 3)	3	4,926	10,851	0.4802	*
Target species	1	4,218	10,341	0.5550	*
Month	11	3,955	10,150	0.5827	*
Area	8	3,909	10,128	0.5875	

Table D.6: Summary of the binomial model for PHC using estimated catch with core vessel selection applied as the dependent variable. Explanatory variables (terms) are listed in order of their acceptance into the model (fishing year was forced as the first variable). The remaining columns are described in Table D.1 above.

Term	DF	Deviance	AIC	r^2	Final
None	0	7,712	7,714	0.0000	
Fishing year	22	7,311	7,354	0.0521	*
Vessel	56	5,986	6,142	0.2238	*
Poly(log(potlifts), 3)	3	5,561	5,723	0.2790	*
Target species	1	5,070	5,234	0.3426	*
Month	11	4,927	5,113	0.3612	*
Area	8	4,882	5,084	0.3669	

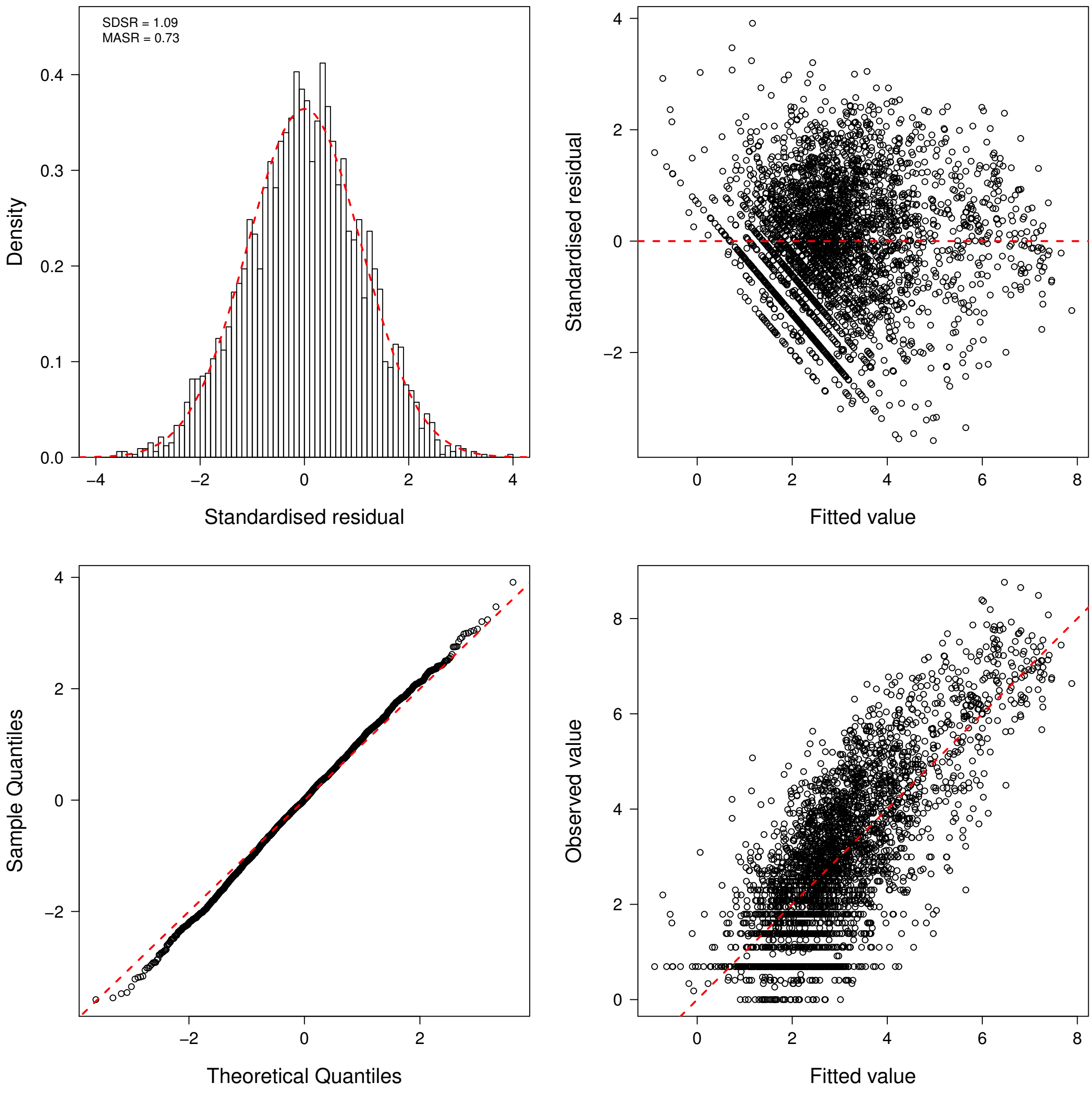

Figure D.3: Fit of the lognormal standardised CPUE model to estimated catch of packhorse rock lobsters including a histogram of the standardised residuals [top-left], standardised residuals compared to predicted model catch per trip [top-right], quantile-quantile plot of the standardised residuals [bottom-left], and observed catch per record plotted against the predicted catch per record [bottom-right].