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Data for the 2012 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8

New Zealand Fisheries Assessment Report 2013/59

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This document presents the collation of data used in the 2012 stock assessment of rock lobsters in CRA 7 and CRA 8. Data sets described include catch estimates, an historical catch and effort series from 1963–73, standardised catch per unit of effort (CPUE), size data (LFs) from observer catch sampling and voluntary commercial fishery logbooks, tag-recapture data, puerulus settlement data and sex- and year-specific retention in CRA 8 from analyses of voluntary logbooks.

Catch estimates included the commercial, recreational, customary and illegal fisheries. The estimates were collated by year through to 1978 and then by season (spring-summer and autumn-winter) and by size-limited and non-size-limited fisheries. Recreational catch was based on commercial CPUE and scaled to recreational survey estimates from 1992–2001, using an algorithm agreed by the Rock Lobster Fishery Assessment Working Group (RLFAWG). Catches were divided into seasons and into two sub-categories: the catch that was limited by size restrictions and the protection of ovigerous females and the non-restricted catch.

CPUE was standardised using methodology that had been approved by the RLFAWG, producing separate indices for the two seasons.

Length frequency data were collated by sex category (males, immature and mature females), season and source (observers or logbooks). Each record was weighted by the number of days sampling, fish measured and representativeness of the sampling with respect to the commercial catch pattern in time and space. Exploratory analyses are reported.

Tag-recapture data were screened to remove records with insufficient information. Exploratory analyses are reported.

Standardised puerulus settlement indices were provided by NIWA.

Retention analysis was a new feature of this assessment. Fishers can legally return legal lobsters to the sea, and they do this to try to maximise the dollar return for their catch. The voluntary logbook data show whether a measured fish was retained, and these data were analysed to explore the patterns of sex- and size-specific retention over time. Generalised relations were obtained by fitting a model that used abundance to predict the parameters of the retention curves.

1. INTRODUCTION

This document describes work conducted under Objectives 3 and 4 of contract CRA2009-01C, awarded by the Ministry for Primary Industries (MPI, formerly the Ministry of Fisheries) to the New Zealand Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contracted Objectives 3 and 4 to the authors of this report. The authors collaborated on all aspects of Objective 4 to produce jointly authored stock assessments for CRA 7 and CRA 8. This document describes the data used in these stock assessments, and a companion document (Haist et al. 2013) describes the stock assessments and the development of management procedures for each QMA.

Overall objective:
To conduct assessments of rock lobster (Jasus edwardsii) stocks including estimation of biomass and sustainable yields.

Specific objectives addressed by this report:

Objective 3 - CPUE and decision rules: To update the standardised CPUE analysis from all lobster QMAs and report on the operation of current decision rules.

Objective 4 - Stock assessment: To estimate biomass and sustainable yields for rock lobster stocks.

Haist et al. (2013) present a comprehensive glossary of terms used in the rock lobster stock assessment: if there are undefined terms in this document, that glossary should be consulted.

Specific objectives confirmed by the National Rock Lobster Management Group (NRLMG) and MFish under Objective 4 were: 1) a stock assessment for red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8 followed immediately by 2) CRA 7 and CRA 8 management procedure review.

1.1 CRA 7

The CRA 7 fishery extends from the Waitaki River south along the Otago coastline to Long Point. The most recent previous stock assessment was in 2006 (Breen et al. 2006; Haist et al. 2009), using the then new Bayesian multi-stock length-based model (MSLM). This was fitted to CRA 7 and CRA 8 simultaneously, and estimated movements between CRA 7 and CRA 8. The model was fitted to tag-recapture data, standardised CPUE from 1979–2006, historical catch rate data from 1963–1973 and length frequency data from voluntary logbooks and observer catch sampling. Changes in MLS and selectivity caused by escape gap regulations were taken into account.

The CRA 7 TAC for 2012–13 was 83.9 t. Allowances set by the Minister of Fisheries were 10 t for customary catch, 5 t for recreational catch, 5 t for illegal unreported removals and 63.9 t for the commercial catch (TACC). The CRA 7 commercial season runs from 1st June to 19th November inclusive and the MLS is a tail length of 127 mm for both male and female lobsters. The fishery is open to recreational fishing all year with a MLS regime of 54 mm TW for males and 60 mm TW for females. The CRA 7 fishery has a buffer zone, closed to commercial rock lobster fishing, that was incorporated into a regional harvest initiative agreed by recreational and commercial users in 1993 in response to concerns over sustainability of the stock.

The CRA 7 catch is exported or sold to the domestic market by several Dunedin and Christchurch fishing companies. Stock monitoring coverage in CRA 7 comprises 15 observer sampling days across both statistical areas, and has included periodic tagging, with over 2000 tagged lobsters released in 2012–13.

1.2 CRA 8

The CRA 8 fishery extends from Long Point south to Stewart Island and the Snares, through the islands and coastline of Foveaux Strait, then north along the Fiordland coastline to Bruce Bay. The most recent stock assessment was in 2006 (Breen et al. 2006, Haist et al. 2009), as described above.

The CRA 8 TAC for 2012–13 was 1053 t. Allowances set by the Minister of Fisheries were 30 t for customary catch, 33 t for recreational catch, 28 t for illegal unreported removals and 962 t for the commercial catch (TACC).

The industry supplies processing and export operations in Te Anau, Riverton, Stewart Island, Invercargill, Bluff, Christchurch, and Wellington. The CRA 8 Management Committee Inc. has developed and implemented codes of practice in relation to use and disposal of fishing gear and refuse, and was a founding member of the Guardians of Fiordland Fisheries.

The stock assessment model is “driven by” catch estimates and is fitted to an abundance index (two others were explored), derived from commercial CPUE. It is also fitted to length frequency data and tag-recapture data. Other important inputs are historical size limits, length-weight relations and assumed prior probability distributions for estimated parameters.

2. CATCH DATA

Catch data were collated on an annual basis through to 1978, then by season: spring-summer (SS, October to March) and autumn-winter (AW, April to September). The fishing year runs from 1 April through to 31 March, and fishing years are labelled using the first calendar year in each pair (i.e. the 1996–97 assessment year is labelled “1996”).

2.1 Commercial catch

The fishing year and calendar year were the same before 1979; in 1979 the fishing year changed to an April to March year. Reported annual commercial catches from 1945 to 1978, summarised by calendar year, were obtained from Annala (unpublished). From 1 January 1979 through to 31 March 1986, catches were taken from monthly data summarised by fishing year from data collected by the Fisheries Statistics Unit (FSU), a version of which is now held by the Ministry of Primary Industries (MPI). The three months of catch from January to March 1979 were added to the 1978 annual total to ensure that no catch was lost when switching from calendar year to fishing year collation.

From 1 April 1986 to 30 March 1988, monthly reported catch totals from all of New Zealand were obtained from Quota Management Returns (QMRs) maintained by MPI. Because QMR returns by individual QMAs were not available for this period, these total NZ catches were divided into QMA catches based on the proportional landings reported on FSU forms. From 1 April 1988 through to 30 September 2001, catches were summarised from monthly QMRs from each QMA. The QMRs were replaced by Monthly Harvest Returns (MHRs) on 1 October 2001, but the same information is available from these new forms.

Annual commercial catches before 1979 averaged 425 t in CRA 7 and 1840 t in CRA 8 (Figure 1). The maximum recorded annual catches were 905 t in CRA 7 and 3868 t in CRA 8, both in 1956. Catches from other areas may be included in the early totals because catches before the 1970s were recorded from the port of landing rather than the area of origin. There is some uncertainty in the quality of the catch estimates in the years before the FSU system began in 1979, but catches in the 1980s were collected when the FSU system was operating and there is confidence in the quality of these catch estimates. Catch estimates generated from the FSU data available to the stock assessment team are consistent with published historical catch estimates from the FSU system.

Catches in both stocks declined steadily from peaks in the mid-1950s until the introduction of rock lobster into the QMS in 1990. Catches continued to decline after 1990, but at a slower rate, until the late 1990s, then increased in both stocks to a peak near 2007 (Figure 2). Since then, CRA 7 annual CPUE has dropped to almost as low as it was in the mid-1990s; CRA 8 annual CPUE has also dropped but still exceeds 3 kg/potlift, a high average compared to historical (pre-2005) CPUE levels (Figure 2).

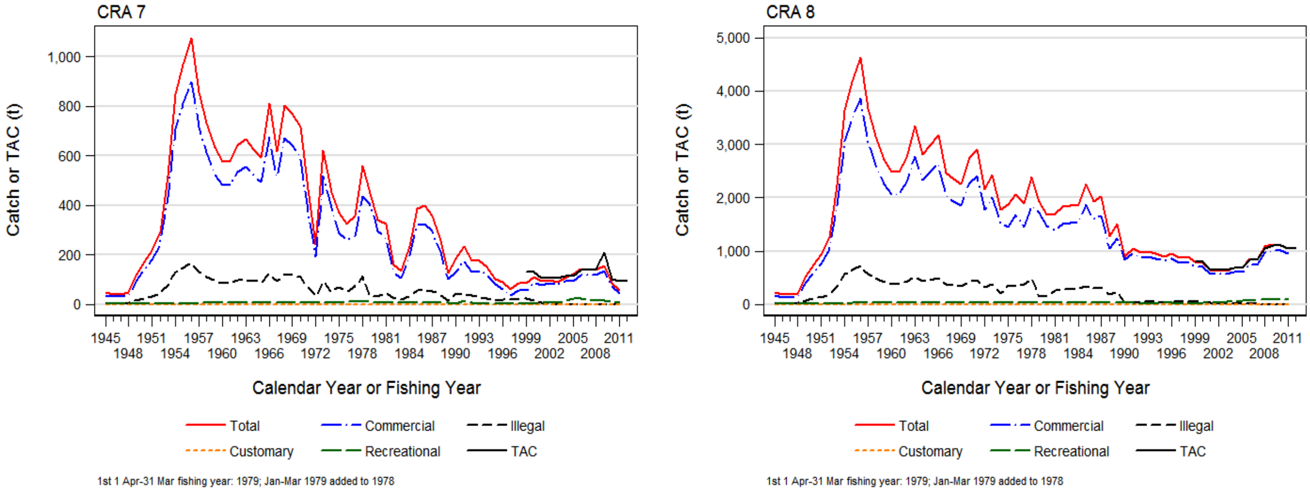

Figure 1: CRA 7 [left] and CRA 8 [right] annual catches (t) by fishery (commercial, illegal, recreational & customary), using the proportional recreational catch series (see text).

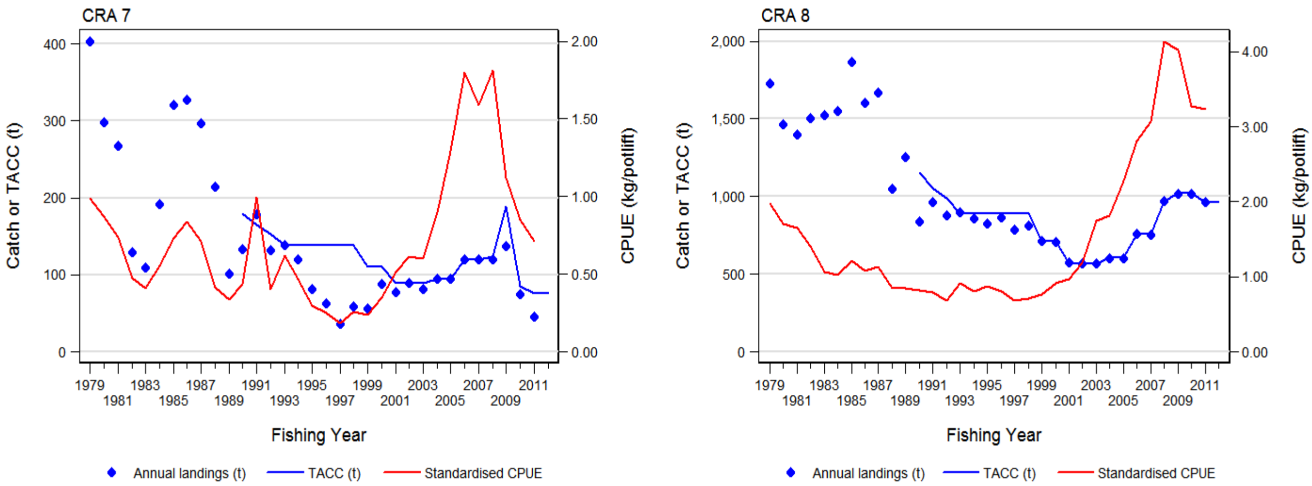

Figure 2: Plot of annual commercial landings (t), the TACC (t) and the annual standardised CPUE index for CRA 7 [left] and CRA 8 [right] by fishing year, 1979–2011, with the 2012 TACC shown.

2.2 Recreational catch

Four annual recreational catch estimates are available for each of CRA 7 and CRA 8 (Table 1). Estimates from the two Kingett Mitchell National Surveys (Boyd & Reilly 2004; Boyd et al. 2004) were accepted by the RLFAWG for the 2006 combined CRA 7 and CRA 8 assessments (Breen et al. 2006), although the Kingett Mitchell estimates were discarded by the RLFAWG for the more northerly rock lobster QMAs. The Kingett Michell estimates are similar to those reported from earlier surveys, conducted by researchers at the University of Otago (1991–92 survey: Tierney et al. (1997);

1996 survey: Bradford (1998)). Those estimates were thought to be biased in a review of the available recreational surveys (unpublished minutes: Recreational Technical Working Group [Auckland NIWA, 10–11 June 2004]).

MPI were asked to provide estimates of current and historical recreational catches, and an appreciation of their uncertainty. MPI did not provide estimates, and responded by saying that "*the best available information of current and historical catches are those derived from regional and national telephone and diary surveys*" (Alicia McKinnon, MPI, pers. comm.).

Table 1: Information used to estimate recreational catch for CRA 7 and CRA 8.

Catch estimates in numbers	CRA 7	CRA 8
1992	8 000	29 000
1996	3 000	22 000
2000	1 000	13 000
2001	10 000	29 000
Derived values		
1992/1996 average numbers	5 500	25 500
1992/1996 SS mean weight (kg)	0.669	0.663
2000/2001 average numbers	5 500	21 000
2000/2001 SS mean weight (kg)	0.917	0.676
Mean (1992, 1996, 2000, 2001) catch (kg)	4 362	15 549
Reconstructed catch in 1979 (kg)	9 457	33 737
20% of 1979 catch (kg)	1 891	6 747
Maximum Section 111 catch (kg)	1 675	14 775

The recreational catch vectors prepared for these assessments assume that recreational catch has been proportional to abundance in each stock, as reflected by SS CPUE, and are scaled by the mean of the four recreational surveys shown in Table 1. Catches in other years in the range 1979–2011 were then scaled proportionally by the SS CPUE (described below). This algorithm is analogous to that used for CRA 4 in 2011 (Starr et al. 2012). Catch in 1945 was assumed to be 20% of that in 1979 (Table 1) and was scaled proportionately in the intermediate years to reach the 1979 catch in 1979.

The resulting recreational catch vector is shown in Figure 3, after adding to each year the maximum reported recreational landings from the annual reports by commercial vessels under Section 111 of the Fisheries Act (this procedure was agreed by the RLFAWG in 2006; see Table 1 for values used). Recreational catch was split between seasons, with 90% assumed taken in the SS and the remainder in AW. The mean annual recreational catch from these two vectors was 9.663 t for CRA 7 and 46.208 t for CRA 8.

At the request of the RLFAWG, an alternative recreational catch vector was created, using the mean catch from the four surveys in CRA 7 and CRA 8 plus the agreed Section 111 catch. This resulted in a vector of constant catches of 6.0 t and 30.2 t for CRA 7 and CRA 8 (Figure 3).

2.3 Customary catch

MPI were asked to provide estimates of current and historical customary catches, and an appreciation of their uncertainty. MPI provided tables of customary permits and realised catches for both CRA 7 and CRA 8, some by weight and some by numbers of lobsters. On the basis of the information in these tables, MPI concluded for CRA 7: "*Based on the information supplied above, the Ministry considers it appropriate to continue to use a 1 tonne constant customary catch estimate for CRA 7*" (Alicia McKinnon, MPI, pers. comm.).

For CRA 8, MPI concluded as follows: "*For CRA 8, available information from the 2006–07 to 2011–12 fishing years suggests the actual quantity of rock lobsters harvested under the customary regulations ranged from approximately 2 to 12 tonnes, with an average of 6 tonnes (using an arbitrary weight of 0.5 kg for each rock lobster). This information suggests that the 2 tonne constant customary* *catch estimate for CRA 8, which has been used in previous assessments, should be increased. I suggest the details of this increase are discussed further by the RLFAWG*" (Alicia McKinnon, MPI, pers. comm.).

The stock assessment therefore used constant annual customary catches of 1 t for CRA 7 and 6 t for CRA 8 (Figure 3). Customary catch was split between seasons using the same proportions as for the recreational catch, with 90% assumed taken in the SS and the balance in the AW.

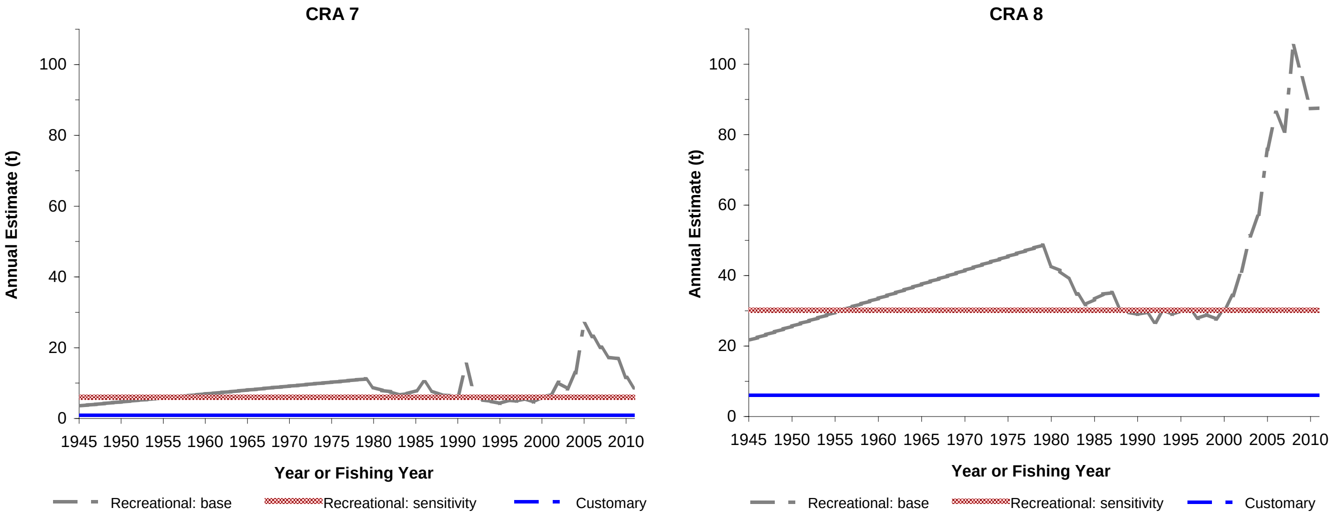

Figure 3: Recreational (grey) and customary (blue) catch trajectories (t) for the 2012 stock assessment of CRA 7 [left panel] and CRA 8 [right panel]. Section 111 catches (CRA 7: 1.68 t; CRA 8: 14.78 t) have been added to each year of the 2012 recreational catch trajectory. The alternative constant recreational catch vector used as a sensitivity is shown in red.

2.4 Illegal catch

MPI were asked to provide estimates of current and historical customary catches, and an appreciation of their uncertainty. MPI were also asked to provide an estimate of the proportion of illegal catch that was eventually reported as legal catch. MPI pointed to estimates given in the past (Table 2) and suggested the following for CRA 7 and CRA 8:

CRA 7: "*With respect to a current illegal take estimate for the CRA 7 fishery, anecdotal information from the Ministry's Compliance and Response team suggests illegal activity in the CRA 7 fishery is currently low, which is potentially related to the current state of low abundance. The Ministry considers that a 1 tonne illegal catch estimate is reasonable for this fishery at this time.*" (Alicia McKinnon, MPI, pers. comm.).

CRA 8: "*The last illegal catch estimate that was supplied by the Ministry for CRA 8 was for 18 tonnes in 2002. Monitoring and enforcement information from the Ministry's Compliance and Response team suggests a more realistic figure for the CRA 8 fishery at this time is in the vicinity of 3 tonnes (unreported to the QMS). Reasons for this lower figure are potentially related to the introduction of an amateur accumulation limit within the Fiordland Marine Area in 2005 and current industry dynamics.*" (Alicia McKinnon, MPI, pers. comm.).

The stock assessment therefore used constant annual illegal catches of 1 t for CRA 7 for 2003–2011 (Table 2). For CRA 8, the stock assessment used 3 t for 2011 and scaled the catch down proportionally for 2003–2010 from the 18 t estimated for 2002.

The MFish (now MPI) estimates for illegal catch were usually provided in two categories per QMA by year, although these categories had many missing estimates (Table 2). Missing categories were treated as zeroes by MPI Compliance. The category of “commercial illegal reported” or “reported” was assumed to represent illegal commercial catch that was eventually reported to the QMS as legitimate catch; this catch was subtracted from the reported commercial catch to avoid double-counting.

In past assessments, illegal catch estimates have been based on a belief that a large amount of unreported catch was taken before the introduction of lobsters to the QMS. Anecdotal evidence suggested that there were many cash sales and unaccounted exports of lobster. These were thought to have been reduced after the change to tail width minimum legal size (MLS) and the introduction of lobsters to the QMS. Current illegal fishing is believed to be conducted mainly by fish thieves or poachers and consequently is rarely reported in the legal catch data.

Table 2: Available estimates of illegal catches (t) by QMA from 1990, as provided by MPI Compliance over a number of years. R (reported): illegal catch that will eventually be processed though the legal catch/effort system; NR (not reported): illegal catch outside of the catch/effort system. Cells without data or missing rows have been left blank. Estimates provided by MPI for 2011–12 are highlighted in yellow.

	CRA 1		CRA 2		CRA 3		CRA 4		CRA 5		CRA 6		CRA 7		CRA 8		CRA 9	
Year	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR
1990		38		70		288.2		160.1		178		85	34	9.6	25	5		12.8
1992		11		37		250		30		180		70	34	5	60	5		31
1994		15		70	5	37		70		70		70		25		65		18
1995		15		60	0	63		64		70		70		15		45		12
1996	0	72	5	83	20	71	0	75	0	37	70	0	15	5	30	28	0	12
1997					4	60												
1998					4	86.5												
1999					0	136								23.5		54.5		
2000					3	75		64										
2001		72		88	0	75												
2002					0	75	9	51		40		10		1		18		1
2003					0	89.5			5	47								
2004							10	30										
2005																		
2006																		
2007																		
2008																		
2009																		
2010																		
2011														1		3		

The following procedure has been followed to estimate illegal catch in stock assessments since the 2003 assessments of CRA 4 and CRA 5 (Kim et al. 2004):

1. Starting with the estimates of export discrepancies for all of NZ for the period 1974 to 1980 (McKoy, unpub. data), the CRA 7 and CRA 8 illegal catches for each of these seven years were estimated from the ratio of the reported commercial catch in CRA 7 or CRA 8 relative to the total New Zealand reported commercial catch for the same years.
2. The average ratio in the CRA 7 or CRA 8 of the export discrepancy catch relative to the reported commercial catch was calculated for the period 1974–80. These ratios were used to generate an illegal catch estimate for all years with no data (1945 to 1973 and 1981 to 1989) by multiplying the reported catch by the average ratio. This approach is consistent with a decision reached by the RLFAWG on 15 Aug 2002.
3. Beginning with 1990, which is the first year that estimates were provided by QMA, illegal catch was based on MPI Compliance estimates (Table 2). For years without Compliance estimates, the level of illegal catch was interpolated between estimates.

4. Estimates for “commercial illegal reported” (i.e. “reported”, see Table 2) were used to split the illegal catch into the “SL illegal” and “NSL illegal” categories (see the next section). The catch allocated to “SL illegal” was 18% for CRA 7 and 19% for CRA 8.

5. We assumed that both the reported and unreported annual illegal catches were distributed between seasons in the same proportion as the commercial catch for each year.

2.5 Size-limited and non-size-limited catch

The size-limited (SL) catch is the catch taken under the MLS regulations and the restriction on landing berried females; it is the sum of the commercial and recreational catches minus the reported illegal catches (Figure 4 and Figure 5). The non-size-limited (NSL) catch is taken without regard to those restrictions; it is the sum of reported and unreported illegal catches and the customary catches.

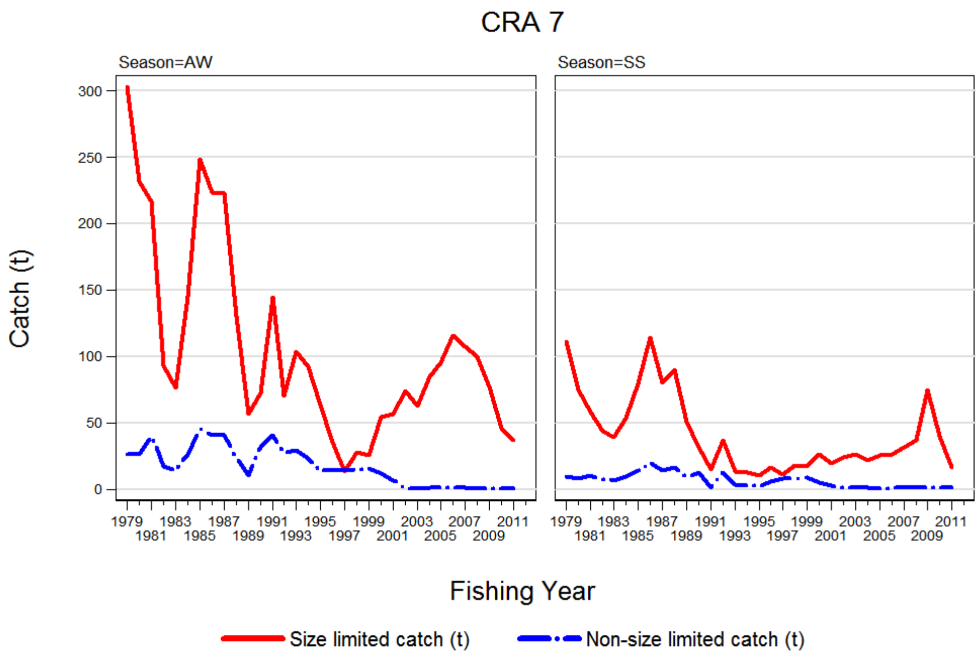

Figure 4: The seasonal SL and NSL catches (t) for CRA 7 plotted by fishing year, beginning in 1979.

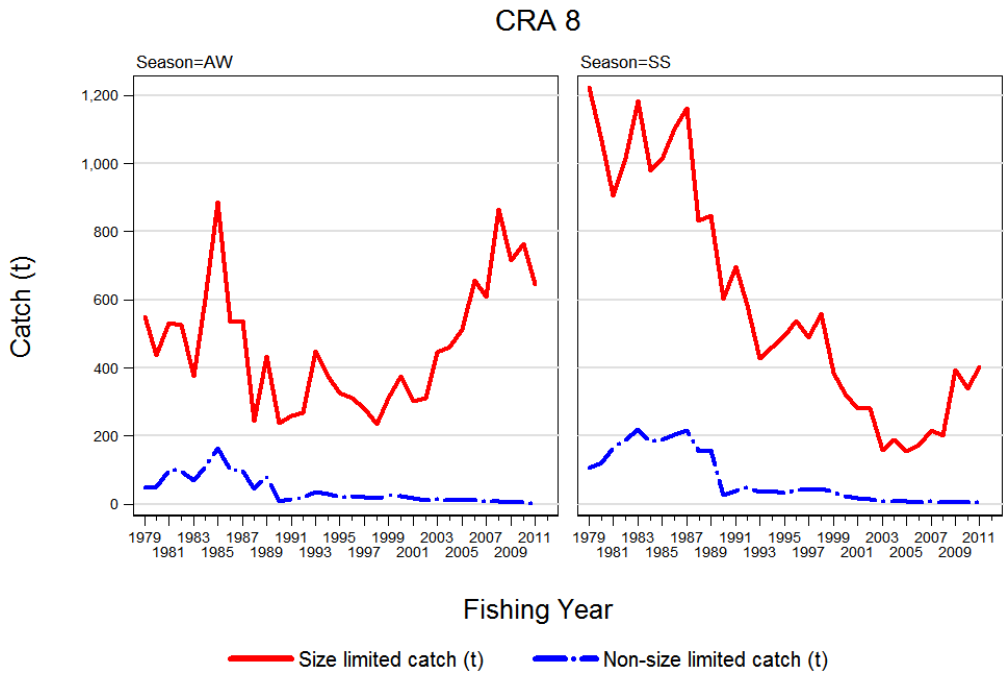

Figure 5: The seasonal SL and NSL catches (t) for CRA 8 plotted by fishing year, beginning in 1979.

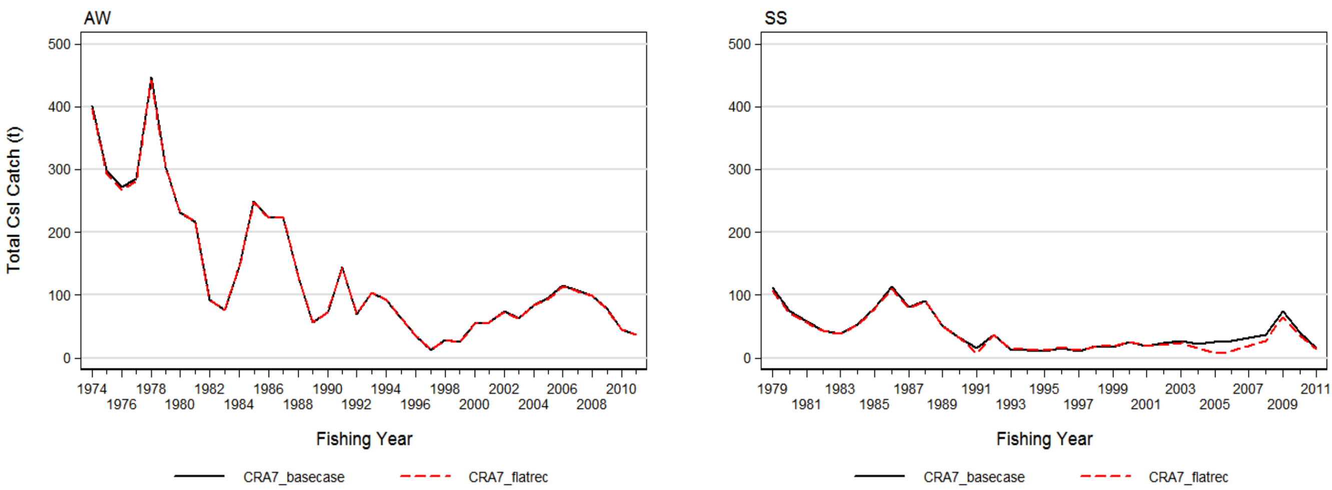

Figure 6: Comparison of AW [left panel] and SS [right panel] total SL (size limited) catch for CRA 7 under two recreational catch assumptions (basecase: vary proportionately with SS CPUE and flatrec: constant annual catch of 6.0 t)

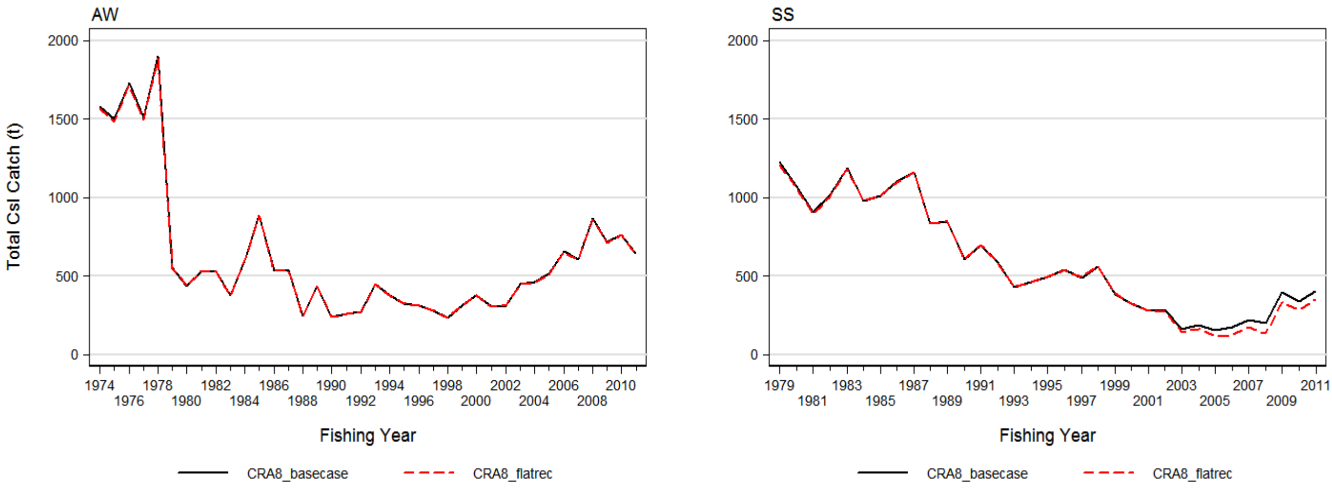

Figure 7: Comparison of AW [left panel] and SS [right panel] total SL (size limited) catch for CRA 8 under two recreational catch assumptions (basecase: vary proportionately with SS CPUE and flatrec: constant annual catch of 30.2 t)

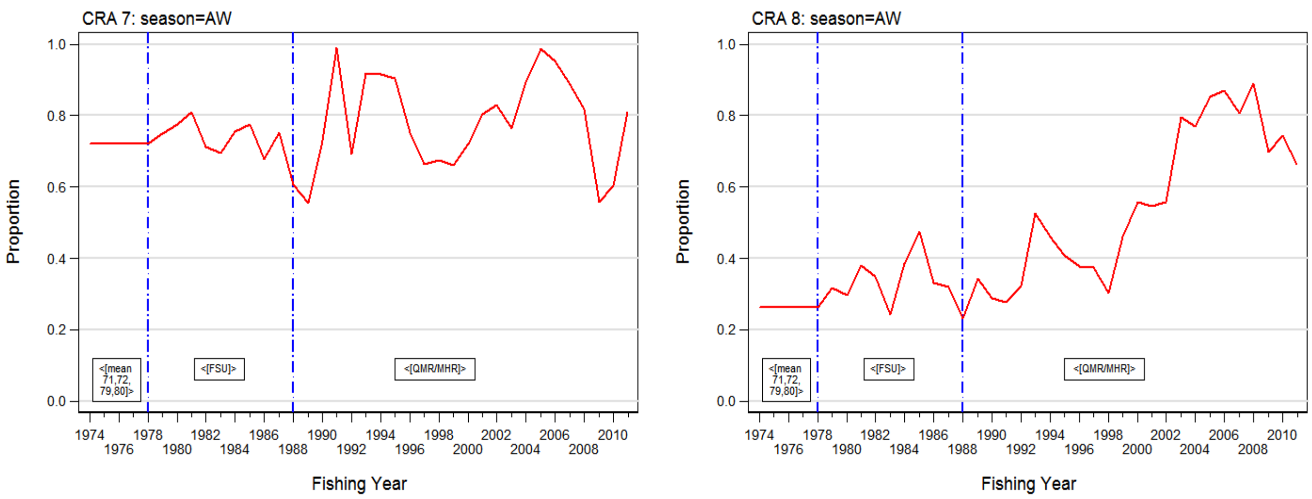

Figure 8. Proportion of the commercial catch taken in the AW season by fishing year for CRA 7 (left) and CRA 8 (right). Vertical lines delimit the data periods defined in the text boxes.

The overall effect from the two recreational catch assumptions on the SL catch vector is not large for either CRA 7 (Figure 6) or CRA 8 (Figure 7); it is apparent only in catches during the SS season of recent years and is relatively small compared with the total size-limited catch. The effect is small in AW because 90% of the recreational catch is assumed taken in SS.

2.6 Seasonal proportion of catch

Annual commercial catches were divided into seasons (Figure 8) beginning in 1979, based on catches reported seasonally to the FSU or QMR/MHR data systems. Illegal catches were divided into the same proportions.

3. CPUE

3.1 Introduction

Catch and effort data for 1 April 1979 through to 31 March 2012, from the FSU and CELR systems, were obtained from MPI in September 2012 (Replog 8651), loaded into the CRACE database and processed using standard error checks (Bentley et al. 2005).

Following the recommendation of the RLFAWG in May 2012, data preparation used the “F2” algorithm instead of the “B4” procedure that was used in all assessments since 2003. The F2 algorithm corrects the monthly estimated catch taken by a vessel in a statistical area using a “vessel correction factor” (VCF: ratio of landed catch to estimated catch for one vessel in a year) (Starr 2013). The version of the F2 algorithm implemented for the analysis reported here used 0.8 and 1.2 as lower and upper bounds to the observed VCF distribution (by agreement with the RLFAWG), discarding from the analysis records from vessels outside these bounds in a given year. The F2 algorithm was scaled to the combined “L” (LFR) landings, the “X” (discarded to sea) and “F” (Section 111 recreational catch) destination codes.

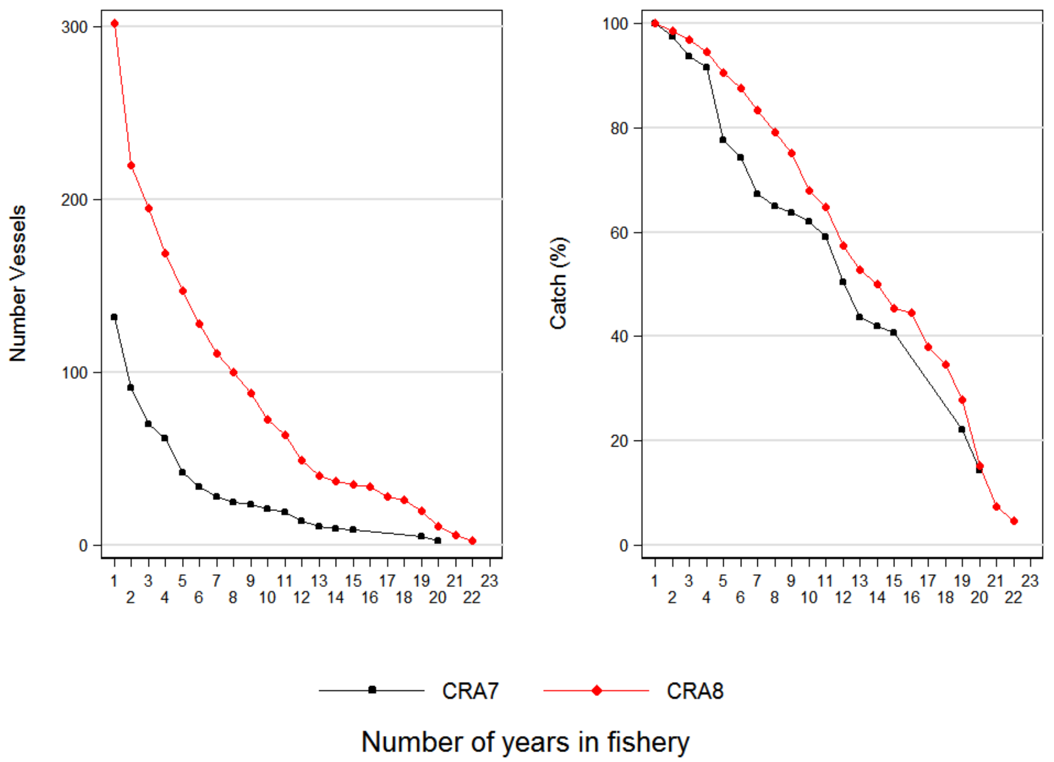

Figure 9: Plots for CRA 7 and CRA 8 showing the relationship between the number of vessels and the proportion of the total catch included in the analysis as vessels are restricted on the basis of the number of years of experience in the fishery.

The CPUE standardisation procedure used sequential six-month periods as the time-dependent explanatory variable. Three other explanatory variables were available for this analysis: [month] of capture, [statistical_area] of capture and [vessel], all of which were offered as categorical variables. [vessel] as an explanatory factor has not been used previously in rock lobster standardised CPUE analyses on the basis of Maunder & Starr’s (1995) advice that, once [statistical_area] and [month] were added to the model, other variables had little additional power to explain model deviance. Starr (2012) showed that [vessel] was potentially an important factor and the RLFAWG requested, in May 2012, that [vessel] be included as an explanatory variable in future analyses. Two sets of analyses are presented here for each QMA: one includes and the other omits [vessel] as an explanatory variable. The series that includes [vessel] begins in 1989–90 instead of 1979–80: vessel codes were not consistently assigned between the FSU and CELR data systems. For the assessment, the RLFAWG agreed to use the series without [vessel] but both series are shown here for completeness. These analyses estimate separate relative [month] effects in each half-year period by using, as the reference [month], the [month] in each period with the lowest standard error.

3.2 CRA 7

When using vessels as an explanatory variable, there was a trade-off between the number of vessels included in the analysis and the proportion of the catch lost when restricting vessels on the basis of experience in the fishery. Vessels were restricted so there would be sufficient data available to estimate each vessel coefficient, while not overly reducing the amount of catch in the analysis, and also reducing the number of coefficients to estimate. An experience level of 4 years was used for the CRA 7 analysis, resulting in a fleet of 62 vessels and reducing the catch by 9% (Figure 9). An experience level of 5 years resulted in too few data in the 2008–09 SS season. The resulting core vessel fleet showed good overlap across all fishing years (Figure 10), but there were considerably fewer available records by statistical area and period with the inclusion of the vessel explanatory variable, along with the vessel experience criterion, than in the data set that did not use the [vessel] explanatory variable (Table 3).

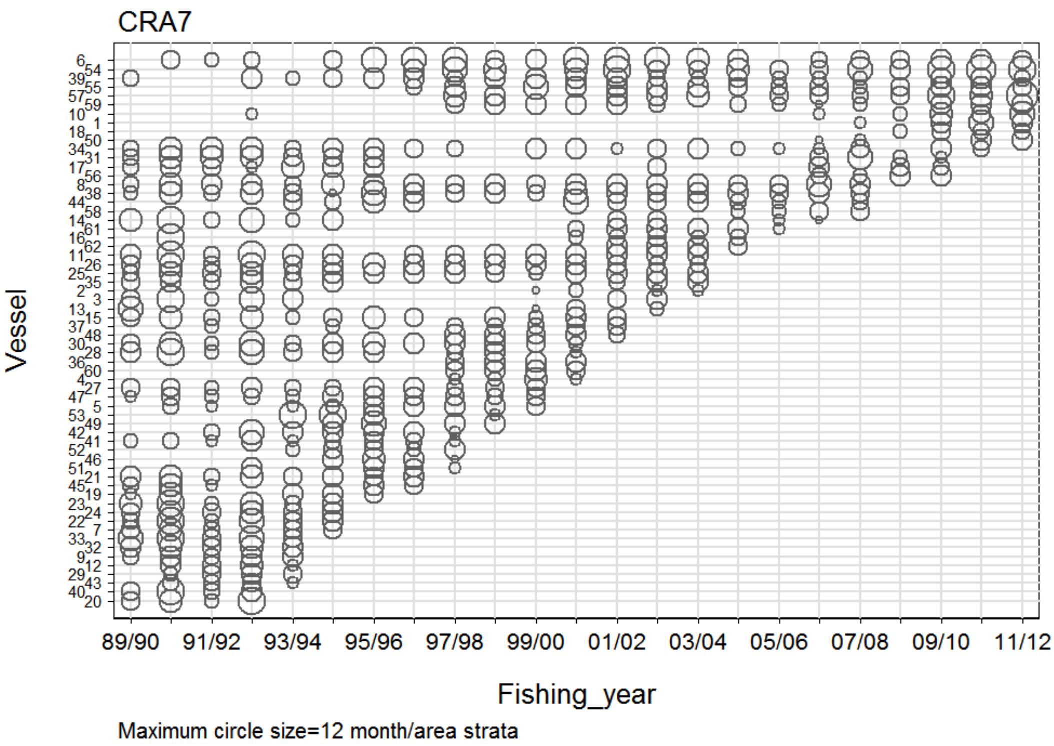

Figure 10: Bubble plot showing vessel participation (number of month/statistical area records) by the CRA 7 core fleet by fishing year, based on an experience level of 4 years.

The total deviance explained by the CRA 7 seasonal standardised model was 34% without using [vessel] as an explanatory variable, increasing to 63% with [vessel] (Table 4). The greatest explanatory power in both models was in the [period] variable, followed by [statistical_area] when [vessel] was not present but with [vessel] having high explanatory power when present. [month] had little explanatory power in either model. Residual patterns showed some deviation from the lognormal assumption at both tails of the residual distribution (Figure 11). The [statistical_area], [month] and [vessel] effects are shown for both models in Figure 12.

Statistical area 921 had a higher expected catch rate than statistical area 920 (Figure 12). The months of June to November all had similar catch rates (Figure 12), which is why [month] had little impact in the model. These are the months when the concession fishery operates, and there appears to be little seasonal variation in the catch of these small lobsters. The contrast between vessels in terms of catch rates was about four-fold.

Table 3: Number of vessel/statistical area/month records in the dataset used to calculate the CRA 7 CPUE time series. Highlighted cells are those with very low numbers of records.

	Autumn-winter season						Spring-summer season					
Fishing	Without vessel factor			Vessels w/ at least 4 years			Without vessel factor			Vessels w/ at least 4 years		
Year	920	921	Total	920	921	Total	920	921	Total	920	921	Total
79/80	252	162	414	–	–	–	184	85	269	–	–	–
80/81	221	128	349	–	–	–	171	63	234	–	–	–
81/82	231	133	364	–	–	–	146	48	194	–	–	–
82/83	184	109	293	–	–	–	107	50	157	–	–	–
83/84	169	95	264	–	–	–	113	46	159	–	–	–
84/85	186	96	282	–	–	–	113	41	154	–	–	–
85/86	191	91	282	–	–	–	129	56	185	–	–	–
86/87	170	75	245	–	–	–	117	57	174	–	–	–
87/88	146	55	201	–	–	–	118	52	170	–	–	–
88/89	111	60	171	–	–	–	74	32	106	–	–	–
89/90	110	30	140	50	10	60	105	22	127	76	14	90
90/91	148	30	178	106	26	132	110	44	154	85	29	114
91/92	132	37	169	103	19	122	16	6	22	16	1	17
92/93	119	22	141	108	20	128	89	17	106	84	12	96
93/94	116	24	140	111	21	132	21	8	29	19	8	27
94/95	114	25	139	109	15	124	43	8	51	43	6	49
95/96	101	36	137	91	29	120	38	9	47	36	7	43
96/97	79	14	93	77	13	90	33	6	39	31	6	37
97/98	78	25	103	75	25	100	24	11	35	24	11	35
98/99	68	30	98	65	26	91	28	8	36	26	8	34
99/00	61	16	77	60	16	76	25	10	35	25	8	33
00/01	72	25	97	66	22	88	28	17	45	27	13	40
01/02	60	28	88	60	24	84	25	14	39	25	13	38
02/03	80	14	94	76	14	90	19	6	25	18	6	24
03/04	61	8	69	58	6	64	25	4	29	23	4	27
04/05	39	12	51	39	12	51	7	5	12	7	5	12
05/06	27	13	40	27	10	37	3	2	5	3	2	5
06/07	31	23	54	31	20	51	9	3	12	9	3	12
07/08	41	19	60	38	13	51	9	11	20	9	6	15
08/09	24	14	38	24	9	33	5	8	13	5	3	8
09/10	39	21	60	37	12	49	22	19	41	20	10	30
10/11	35	16	51	31	14	45	18	10	28	16	8	24
11/12	34	25	59	30	17	47	12	11	23	11	7	18
Total	3 530	1 511	5 041	1 472	393	1 865	1 986	789	2 775	638	190	828

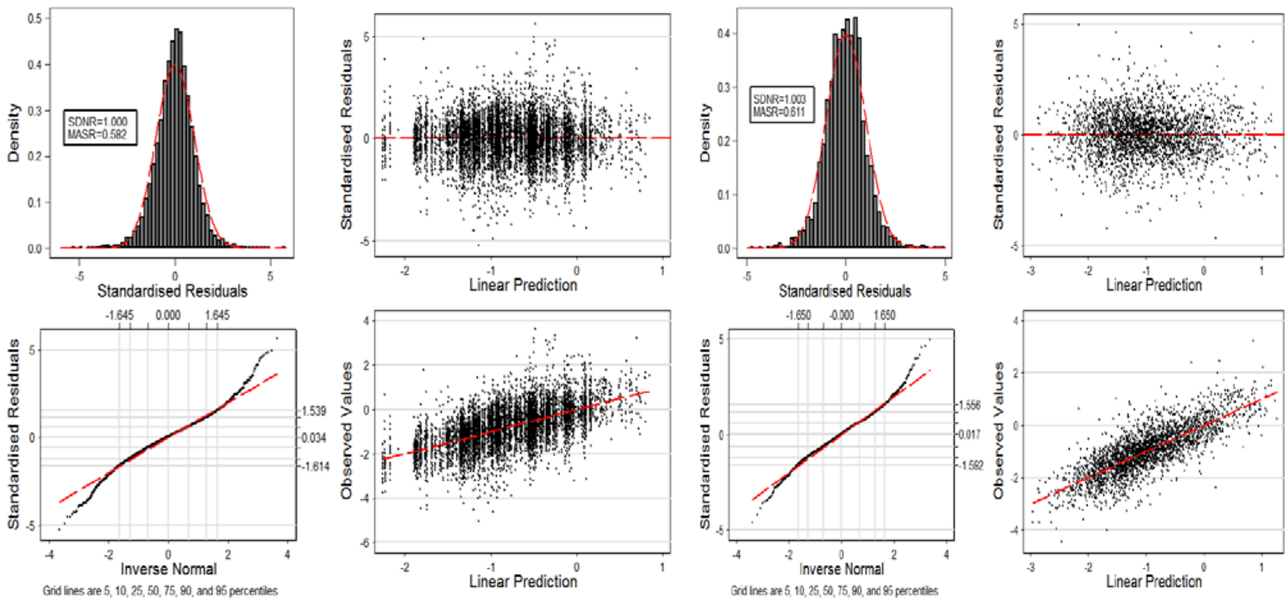

Figure 11: Standardised residuals for the CRA 7 standardised seasonal CPUE analysis: [left panel] without vessel as categorical factor; [right panel]: use vessels with a minimum of 4 years of experience in fishery.

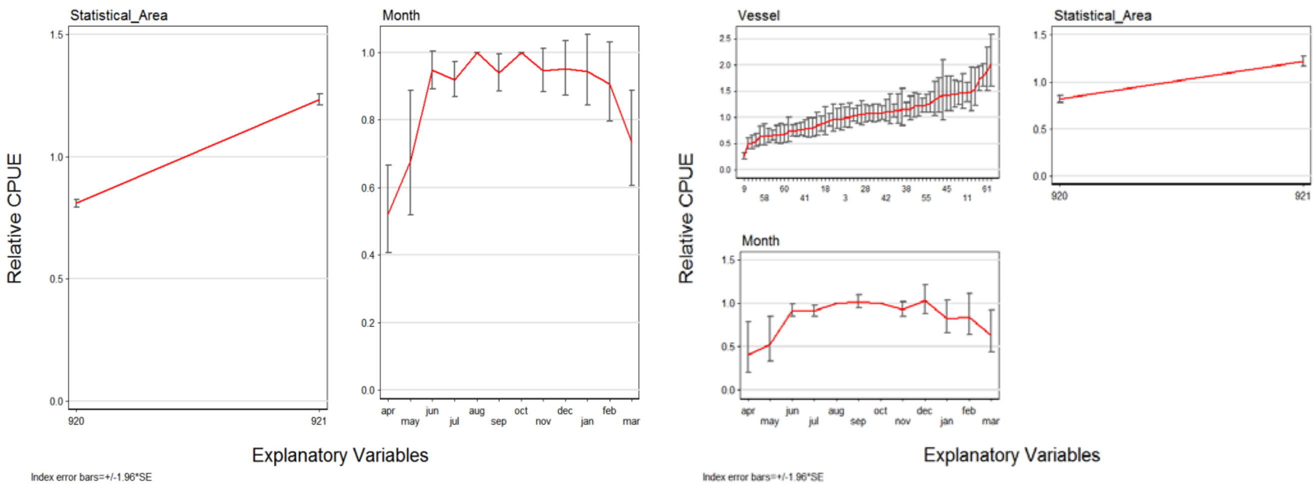

Figure 12: Coefficients for month, statistical area and vessel from the CRA 7 seasonal CPUE standardisation. Month coefficients are not in canonical form, with each of the two reference months (August and October) set to 1.0 and the associated SE set to zero. [left panel] without vessel as categorical factor; [right panel]: use vessels with a minimum of 4 years of experience in fishery.

Table 4: Total deviance (R^2) explained by each variable in the CRA 7 standardised seasonal CPUE model for each of the two models based on the use of the [`vessel`] categorical variable. The number of categories in each explanatory variable is given in parentheses.

	Model without vessel factors		
Variable	1	2	3
Period (66)	0.297		
Statistical Area (2)	0.064	0.340	
Month (10)	0.005	0.301	0.344
–	–	–	–
Additional deviance explained	0.000	0.043	0.004

	Model with vessel explanatory factors			
Variable	1	2	3	4
Period (46)	0.461			
Vessel (62)	0.300	0.609		
Statistical Area (2)	0.064	0.511	0.620	
Month (10)	0.006	0.466	0.614	0.626
Additional deviance explained	0.000	0.147	0.012	0.005

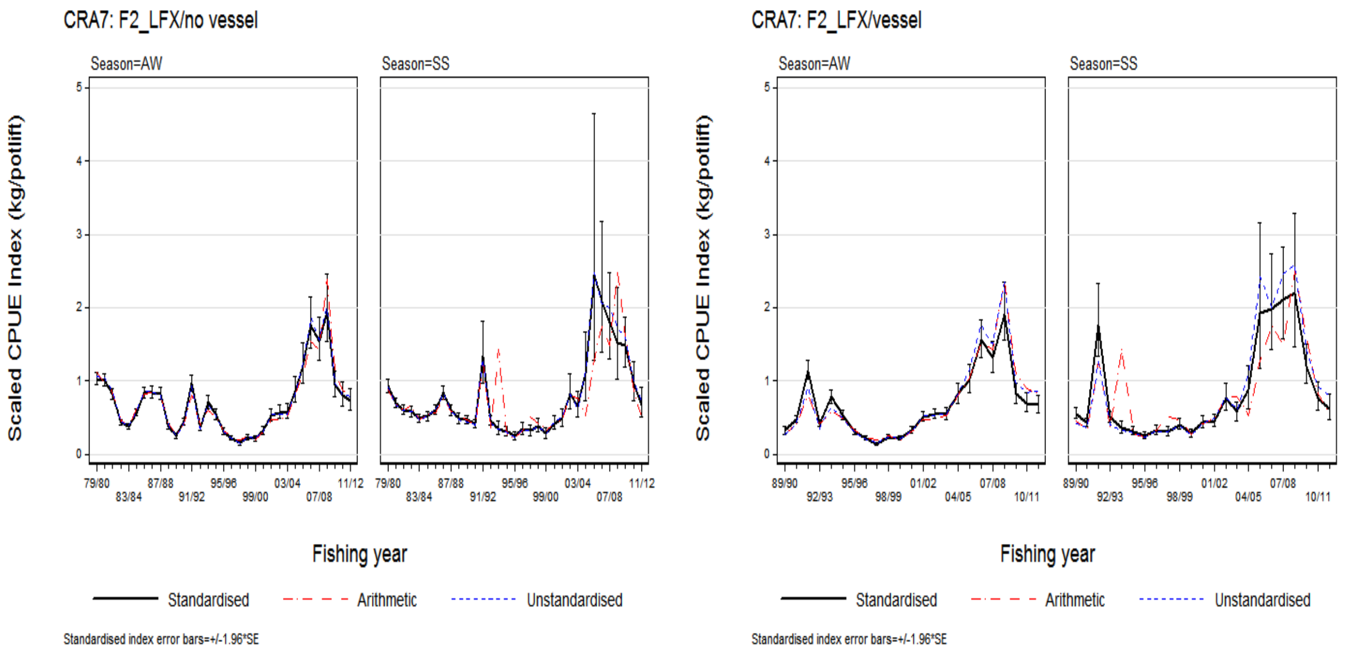

Figure 13: Standardised, unstandardised, and arithmetic CPUE indices (kg/potlift) by season and fishing year for CRA 7 using the F2 algorithm scaled to "LFX" landings. [left panels] 1979–80 to 2010–12 series without vessel factor: AW (geometric mean = 0.59 kg/potlift) and SS (geometric mean = 0.65 kg/potlift); [right panels] 1989–90 to 2011–12 including vessel factor with 4 years experience: AW (geometric mean = 0.55 kg/potlift) and SS (geometric mean = 0.65 kg/potlift).

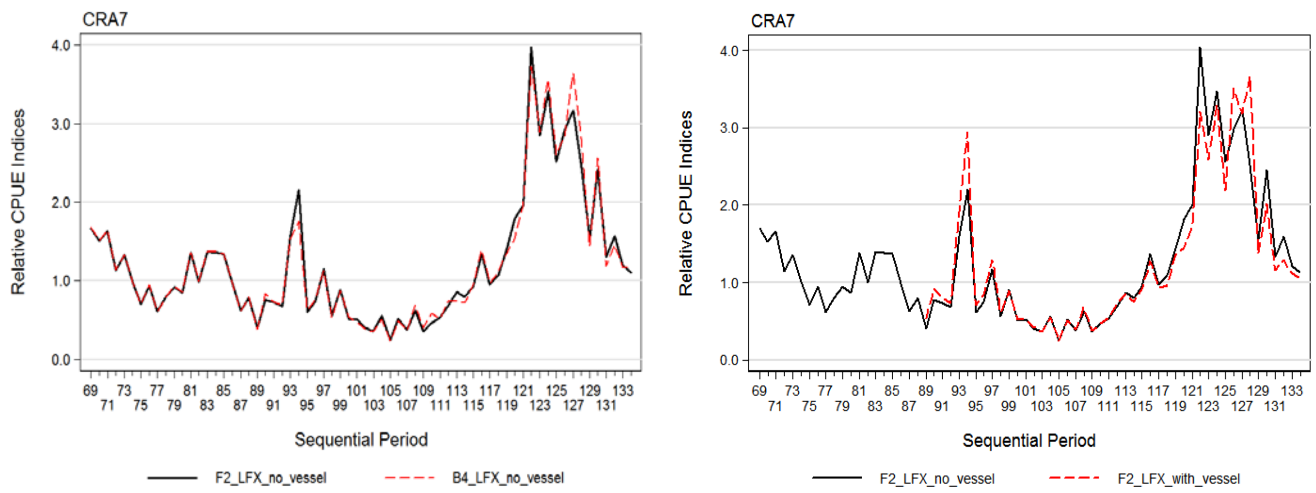

Figure 14: Comparative plots showing the effect of changed assumptions in preparing the CRA 7 standardised analyses: [left panel] comparison of series showing the effect of changing from the B4 to the F2 algorithm; [right panel] comparison of series showing the effect of adding [`vessel`] to the analysis using a year vessel experience cut-off criterion.

CPUE peaked in the mid-2000s at levels several times greater than the long-term average in both seasons and has since declined to near the long-term average (Figure 13). The 2011 AW index dropped by 5–9% from the 2010 AW index (depending on which model is used), but the equivalent drop between 2010 and 2011 in the SS season was 19–29%. A comparative plot of the two data preparation methods (B4 and F2) showed very little sensitivity to this change (left panel, Figure 14).

There is also relatively little sensitivity in the resulting series trajectory with the addition of the [vessel] explanatory variable, in spite of the increased explanatory power of the model which included [vessel]. This observation is in line with the statement by Maunder & Starr (1995) who suggested that [vessel], at least in CRA 7, had a similar explanatory effect as the more generic [month] and [statistical_area] variables. The primary difference between the models with and without [vessel] was the small amount of data available in a few of the recent SS seasons when the fishing was very good in the AW season and there was a consequent low level of activity in the corresponding SS season.

3.3 CRA 8

When using vessels as an explanatory variable, there was a trade-off between the number of vessels included in the analysis and the proportion of the catch lost when restricting vessels on the basis of experience in the fishery. Vessels were restricted as for CRA 7. An experience level of 11 years was used for the CRA 8 analysis, resulting in a fleet of 64 vessels and reducing the catch by 35% (Figure 9). Including more of the catch into the data set resulted in a substantial increase in the number of vessels included in the analysis. For instance, dropping the vessel experience criterion from 11 to 10 years increased the number of vessels to 73 from 64, but improved the amount of catch in the analysis only from 65 to 68%. One hundred vessels were required to include just under 80% of the total catch for the data set. The core vessel fleet resulting from the experience level of 11 years showed very good overlap across all fishing years (Figure 15) but there were 60% fewer available records by statistical area and period in the data set that included the [vessel] explanatory variable, along with the vessel experience criterion, than in the data set that did not use the [vessel] explanatory variable (Table 5).

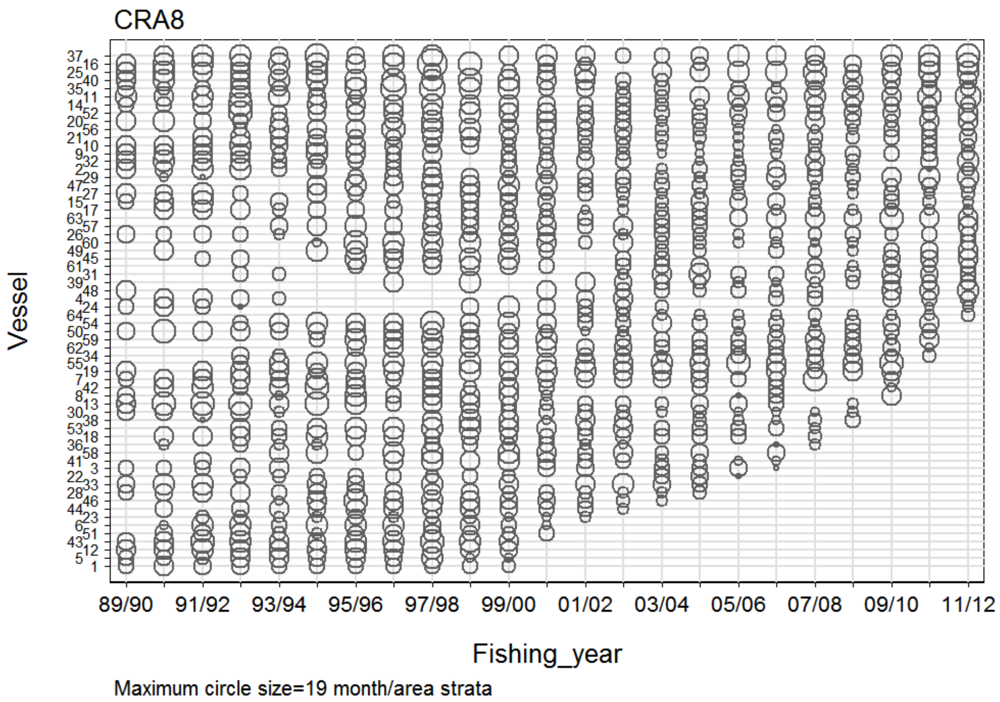

Figure 15: Bubble plot showing vessel participation (number of month/statistical area records) by the CRA 8 core fleet (11 years of experience) by fishing year.

The total deviance explained by the CRA 8 seasonal standardised model was 29% without using [vessel] as an explanatory variable, increasing to 61% with the addition of [vessel] (Table 6). The greatest explanatory power in both models was in the [period] variable, followed by [month] and [statistical_area] when [vessel] was not present, but with [vessel] having high explanatory power when used. The explanatory power for [statistical_area] disappeared with the inclusion of [vessel]. Residual patterns showed some deviation from the lognormal assumption at both tails of the residual distribution for both models (Figure 16). The [statistical_area], [month] and [vessel] effects are shown for both models in Figure 17.

Contrast in the [statistical_area] coefficients in the model without [vessel] disappears with the inclusion of [vessel] (Figure 17). The [month] coefficients also show this decrease in contrast when [vessel] is included (Figure 17). The contrast among vessel catch rates is about four-fold, with a few vessels having much higher catch rates.

Table 5: Number of vessel/statistical area/month records in the dataset used to calculate the CRA 8 CPUE time series: autumn-winter season only

	Autumn-winter season															
Fishing	Without vessel factor								Vessels w/ at least 11 years experience							
Year	922	923	924	925	926	927	928	Total	922	923	924	925	926	927	928	Total
79/80	15	104	177	2	107	129	123	657	–	–	–	–	–	–	–	–
80/81	9	103	170	1	109	101	72	565	–	–	–	–	–	–	–	–
81/82	20	90	162	–	108	72	46	498	–	–	–	–	–	–	–	–
82/83	24	63	159	4	153	96	64	563	–	–	–	–	–	–	–	–
83/84	16	81	130	6	151	115	53	552	–	–	–	–	–	–	–	–
84/85	21	73	142	3	153	109	53	554	–	–	–	–	–	–	–	–
85/86	6	85	140	6	168	145	69	619	–	–	–	–	–	–	–	–
86/87	12	65	119	10	131	133	66	536	–	–	–	–	–	–	–	–
87/88	18	58	125	1	108	95	47	452	–	–	–	–	–	–	–	–
88/89	11	65	80	2	91	50	30	329	–	–	–	–	–	–	–	–
89/90	4	39	74	5	94	69	25	310	–	1	11	–	28	18	4	62
90/91	8	20	57	6	80	62	25	258	–	6	20	–	37	21	12	96
91/92	16	29	63	6	113	88	65	380	–	15	20	3	44	29	11	122
92/93	7	21	59	5	123	74	76	365	–	9	27	–	57	26	11	130
93/94	7	28	57	12	120	77	73	374	–	9	29	2	49	39	13	141
94/95	8	14	61	20	113	74	83	373	–	3	23	10	54	48	21	159
95/96	2	19	31	16	78	73	71	290	–	9	13	5	47	60	33	167
96/97	2	13	39	14	87	63	78	296	–	6	18	3	50	51	37	165
97/98	4	22	34	9	98	74	101	342	–	11	19	1	67	57	44	199
98/99	–	16	27	5	54	48	82	232	–	12	15	2	34	35	49	147
99/00	–	26	30	9	72	54	49	240	–	13	16	6	49	46	38	168
00/01	–	11	30	2	85	55	36	219	–	8	19	2	57	38	27	151
01/02	–	4	22	5	79	35	39	184	–	4	19	3	54	35	33	148
02/03	2	4	21	4	84	42	51	208	–	2	21	4	62	35	36	160
03/04	2	6	20	3	91	36	36	194	–	5	18	2	74	32	33	164
04/05	3	7	16	1	94	38	47	206	1	5	16	1	79	33	39	174
05/06	2	9	15	2	85	35	46	194	–	5	12	2	76	21	36	152
06/07	5	5	21	–	82	52	40	205	–	2	19	–	82	30	34	167
07/08	5	4	26	2	79	42	44	202	–	2	22	2	73	30	36	165
08/09	5	2	34	1	63	49	55	209	–	1	25	1	53	25	39	144
09/10	3	3	29	–	58	37	69	199	–	1	23	–	54	16	52	146
10/11	3	1	29	1	79	43	67	223	–	–	24	1	64	17	51	157
11/12	–	–	34	1	97	41	64	237	–	–	25	–	70	17	43	155
Total	240	1 090	2 233	164	3 287	2 306	1 945	11 265	1	129	454	50	1 314	759	732	3 439

CPUE peaked in the late-2000s at levels several times the long-term average in both seasons and has since declined only slightly (Figure 18). Both seasonal 2011 AW indices are about the same as or slightly greater those in 2010, depending on which model is used. CPUE in 2011–12 dropped about 15–25% from the peak year, again depending on which model is used. A comparative plot of the two data preparation methods (B4 and F2) showed little sensitivity to this change up to the mid-2000s when abundance started to increase (left panel, Figure 19). After that, indices based on the F2 algorithm showed much more contrast between the seasons compared with B4. Addition of the vessel explanatory variable caused little change in the series trajectory, in spite of the increased explanatory power of the model that included [vessel] and the consequent substantial reduction in the amount of available data (right panel, Figure 19). This observation is in line with the statement by Maunder &

Starr (1995) who suggested that [vessel], at least in CRA 8, had a similar explanatory effect as the more generic [month] and [statistical_area] variables.

Table 5 (cont.): Number of vessel/statistical area/month records in the dataset used to calculate the CRA 8 CPUE time series: SS only.

Fishing	Spring-summer season															
	Without vessel factor								Vessels w/ at least 11 years experience							
Year	922	923	924	925	926	927	928	Total	922	923	924	925	926	927	928	Total
79/80	24	151	272	5	182	216	223	1 073	–	–	–	–	–	–	–	–
80/81	22	132	260	9	185	162	201	971	–	–	–	–	–	–	–	–
81/82	11	116	220	12	190	100	155	804	–	–	–	–	–	–	–	–
82/83	24	89	208	9	230	166	164	890	–	–	–	–	–	–	–	–
83/84	23	121	233	13	266	162	175	993	–	–	–	–	–	–	–	–
84/85	13	90	194	16	237	202	180	932	–	–	–	–	–	–	–	–
85/86	7	95	173	10	187	198	164	834	–	–	–	–	–	–	–	–
86/87	12	115	182	4	221	167	168	869	–	–	–	–	–	–	–	–
87/88	15	97	182	2	217	151	142	806	–	–	–	–	–	–	–	–
88/89	16	94	136	9	137	73	92	557	–	–	–	–	–	–	–	–
89/90	–	58	120	10	179	132	39	538	–	3	35	1	64	39	8	150
90/91	5	52	131	15	182	106	65	556	–	17	44	5	74	35	17	192
91/92	12	38	105	12	185	132	107	591	–	20	41	5	69	43	19	197
92/93	8	40	103	9	189	126	143	618	–	15	56	2	75	51	28	227
93/94	7	18	49	11	127	93	126	431	–	3	21	4	51	45	23	147
94/95	6	25	67	32	119	99	105	453	–	7	24	15	56	61	31	194
95/96	2	25	46	19	101	85	81	359	–	10	19	10	67	66	36	208
96/97	3	25	50	13	105	82	105	383	–	7	24	5	58	63	51	208
97/98	4	34	47	11	125	86	146	453	–	16	24	2	88	62	69	261
98/99	–	24	47	8	96	68	138	381	–	20	25	3	61	54	75	238
99/00	1	27	29	11	81	69	83	301	1	13	18	5	61	60	59	217
00/01	–	15	31	4	80	75	54	259	–	13	19	4	59	52	34	181
01/02	–	7	24	–	50	30	31	142	–	7	21	–	36	30	24	118
02/03	1	4	18	1	50	22	39	135	–	3	18	1	33	21	28	104
03/04	–	6	12	–	31	12	22	83	–	5	11	–	27	8	16	67
04/05	1	15	13	2	28	8	16	83	–	12	13	2	27	8	8	70
05/06	1	6	4	–	26	11	12	60	–	6	4	–	24	5	8	47
06/07	1	4	7	–	30	12	7	61	–	4	7	–	30	6	4	51
07/08	1	10	19	3	38	14	10	95	–	5	17	1	37	8	5	73
08/09	1	5	13	–	19	15	12	65	–	–	7	–	17	6	7	37
09/10	1	4	27	1	37	25	30	125	–	2	21	1	30	14	22	90
10/11	1	1	22	–	42	13	17	96	–	–	16	–	31	8	8	63
11/12	–	–	19	2	61	20	23	125	–	–	14	–	33	10	13	70
Total	223	1 543	3 063	253	4 033	2 932	3 075	15 122	1	188	499	66	1 108	755	593	3 210

Table 6: Total deviance (R^2) explained by each variable in the CRA 8 standardised seasonal CPUE model for each of the two models based on the use of the [*vessel*] categorical variable. The number of categories in each explanatory variable is given in parentheses.

Model without vessel factors				Model with vessel explanatory factors				
Variable	1	2	3	Variable	1	2	3	4
Period (66)	0.232			Period (46)	0.438			
Month (10)	0.038	0.267		Vessel (64)	0.210	0.560		
Statistical Area (7)	0.030	0.262	**0.292**	Month (10)	0.047	0.489	0.605	
–	–	–	–	Statistical Area (7)	0.040	0.461	0.564	**0.609**
Additional deviance explained	0.000	0.034	0.026	Additional deviance explained	0.000	0.121	0.046	0.004

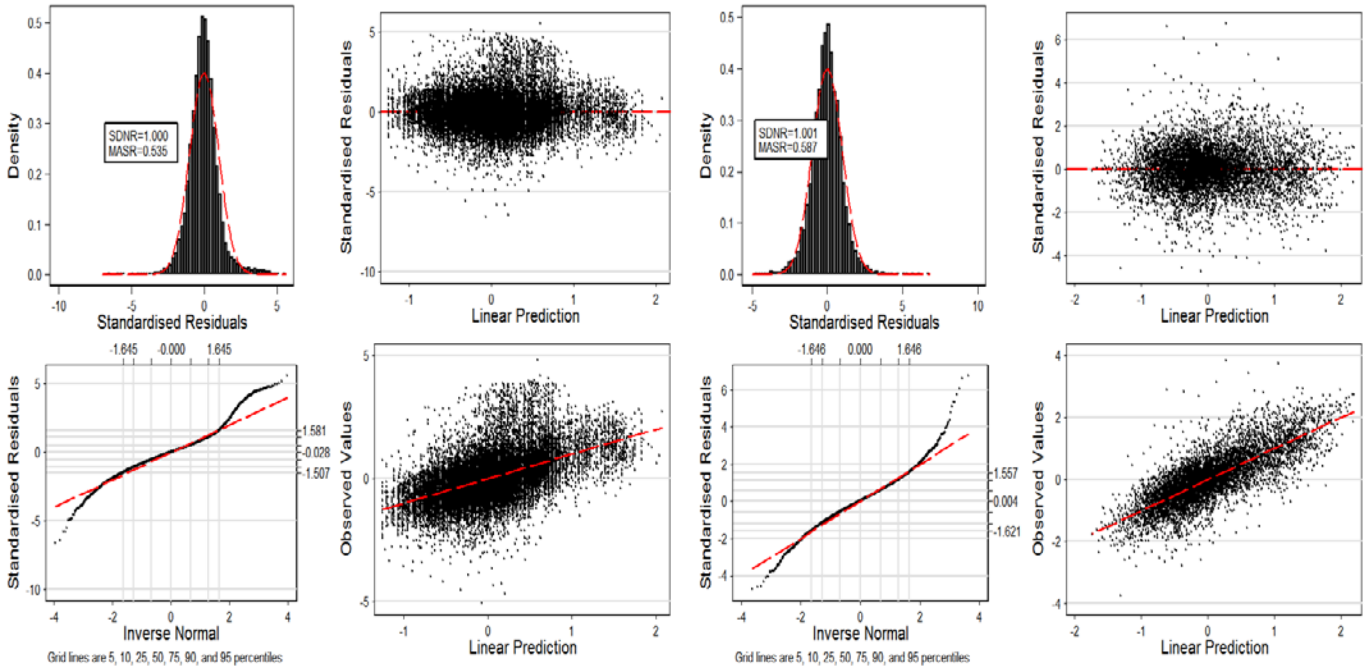

Figure 16: Standardised residuals for the CRA 8 standardised seasonal CPUE analysis: [left panel] without vessel as categorical factor; [right panel]: use vessels with a minimum of 11 years of experience in fishery.

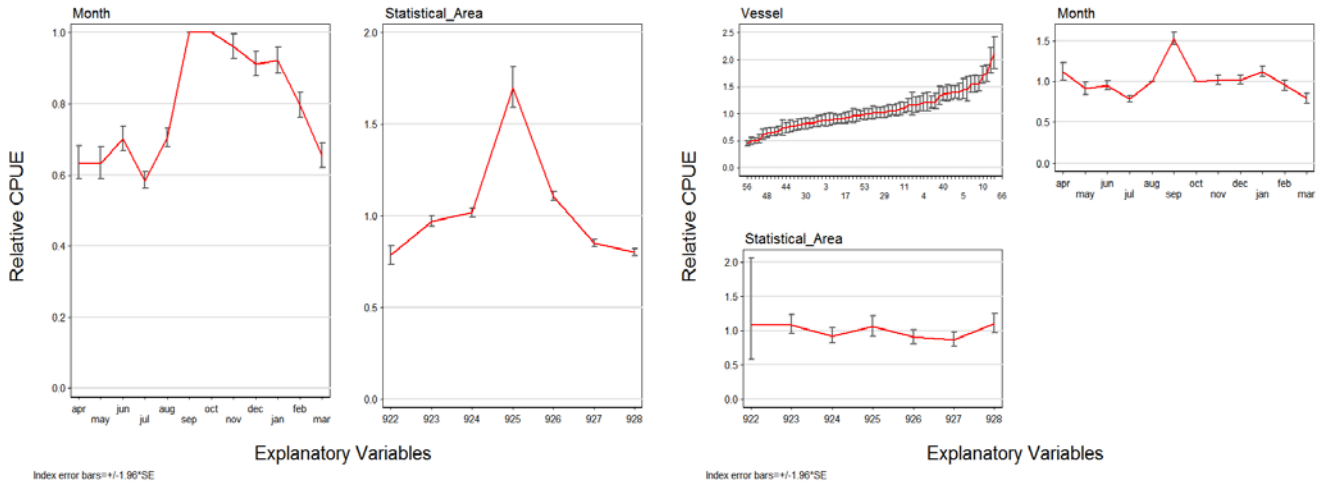

Figure 17: Coefficients for month, statistical area and vessel from the CRA 8 seasonal CPUE standardisation. Month coefficients are not in canonical form, with each of the two reference months (September and October) set to 1.0 and the associated SE set to zero. [left panel] without vessel as categorical factor; [right panel]: use vessels with a minimum of 11 years of experience in fishery.

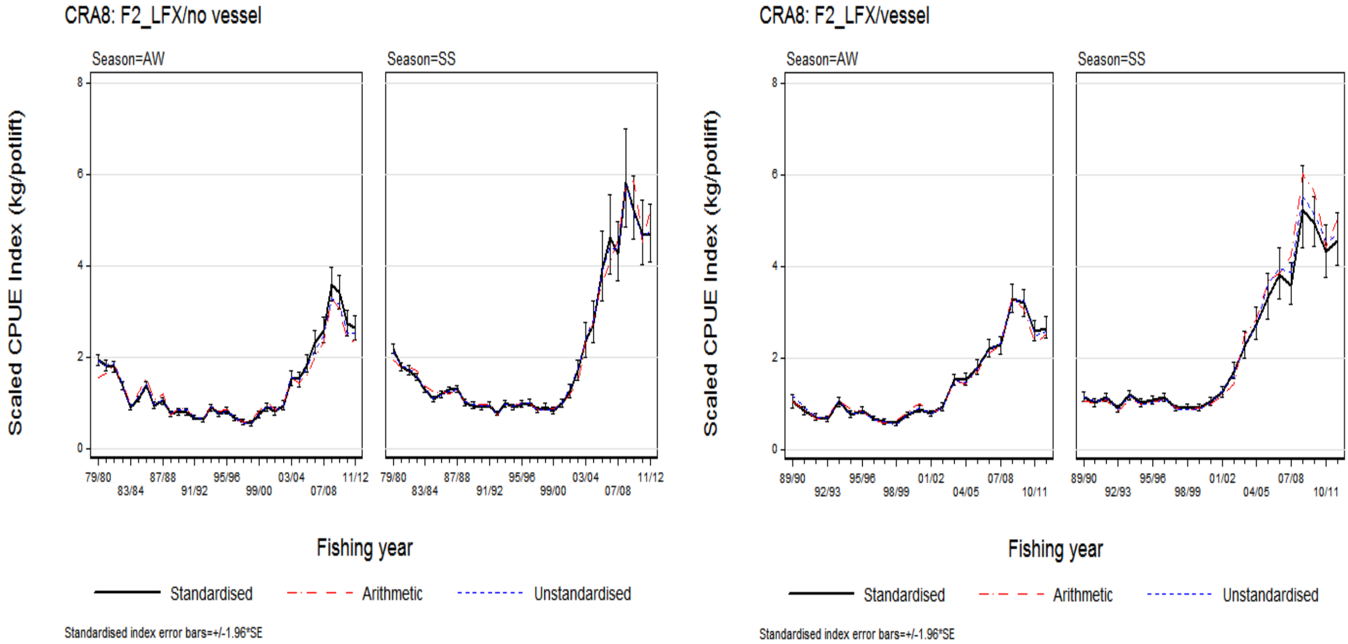

Figure 18: Standardised, unstandardised, and arithmetic CPUE indices (kg/potlift) by season and fishing year for CRA 8 using the F2 algorithm scaled to "LFX" landings. [left panels] 1979–80 to 2010–12 series without vessel factor: AW ($^{g}\overline{\mu}$ =1.19 kg/potlift) and SS ($^{g}\overline{\mu}$ =1.61 kg/potlift); [right panels] 1989–90 to 2011–12 including vessel factor with 11 years experience: AW ($^{g}\overline{\mu}$ =1.18 kg/potlift) and SS ($^{g}\overline{\mu}$ =1.76 kg/potlift).

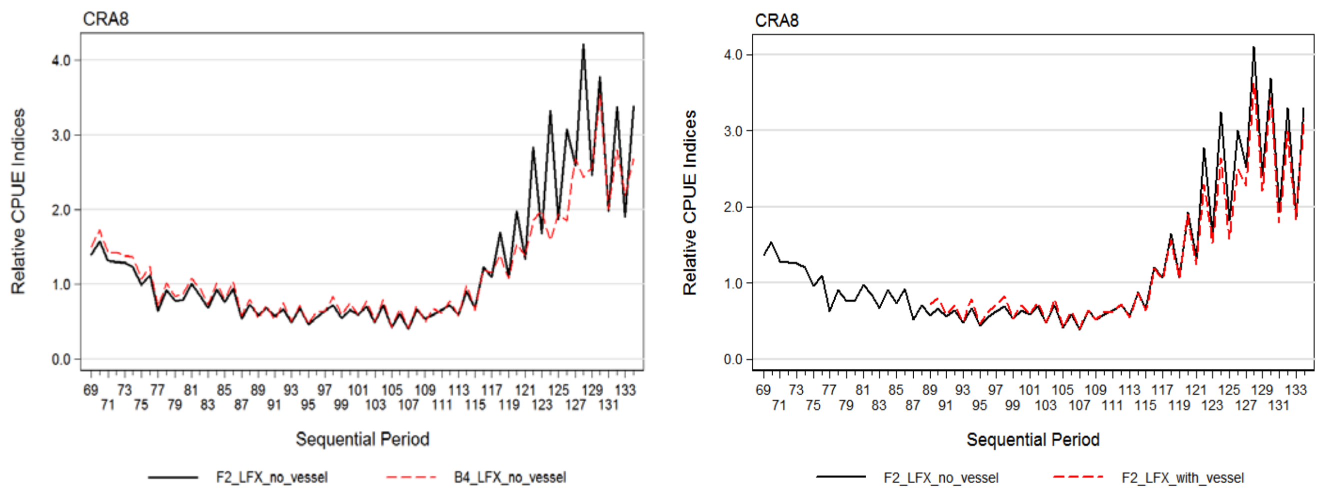

Figure 19: Comparative plots showing the effect of changed assumptions in preparing the CRA 8 standardised analyses. [left panel] comparison of series showing the effect of changing from the B4 to the F2 algorithm; [right panel] comparison of series showing the effect of adding `[vessel]` to the analysis using a 11 year vessel experience cut-off criterion.

4. HISTORICAL CATCH RATE (CR)

Monthly catch and effort (days fishing) data from 1963 to 1973 were summarised by Annala & King (1983) and used to calculate unstandardised catch per day for each calendar year from 1963 to 1973 (Figure 20). These data were not used by the stock assessment except in exploratory fits, because the final model started in 1974.

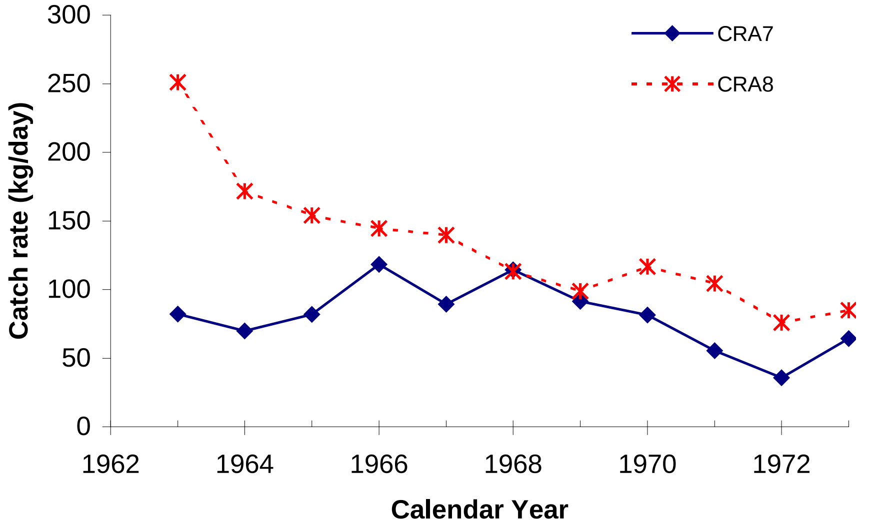

Figure 20: Catch rate (kg/day) by year for CRA 7 and CRA 8 from Annala & King (1983).

5. LENGTH FREQUENCY (LF) DATA

The two sources of length frequency data are voluntary logbooks and observer catch sampling. Data were summarised by year, season and source over three sex categories – male, immature female and mature female. Logbooks in CRA 7 operated only from 2001–2003 (Table 7), while observer catch sampling data were available from 1988–2011 in CRA 7, with the most observations in AW (Table 8). In CRA 8, logbook data were available from 1993–2011, from 14 to 58 participants (Table 7); observer catch sampling data were available for most seasons, 1987–2002 and 2010, in CRA 8 (Table 9).

Data were collated by source, period and sex into 2-mm size classes from 30–90 mm. The voluntary logbook program measures lobsters with a precision of 1 mm and participants round down the lengths, so 0.5 mm was added to each voluntary logbook measurement before binning to avoid introducing bias. Observer catch sampling precision is 0.1 mm so no adjustment was made before binning.

Each record used in model fitting represents data from a single period from a single data source. The record may comprise data from several months and more than one statistical area. Observations from multiple statistical areas and months within a period were weighted within the record by the proportion of catch taken in each month/area cell, the cube root of the number of sample days and the cube root of the number of fish measured. The weights assigned to samples from this procedure are shown in Table 10.

Table 7: Logbook participation in CRA 7 and CRA 8 by fishing year, showing number of fishers and number of trips.

QMA	Fishing Year	Fishers	Vessels	Trips	Potlifts	Lobsters
CRA 7	2001	6	6	187	478	1 816
	2002	3	3	71	208	1 067
	2003	2	2	43	116	1 106
CRA 8	1993	34	42	1 632	5 264	37 653
	1994	43	54	1 929	5 987	33 179
	1995	58	66	2 964	9 125	44 923
	1996	42	51	2 181	6 847	28 450
	1997	37	42	2 058	6 578	21 421
	1998	33	36	1 700	5 487	21 780
	1999	20	19	818	2 670	11 472
	2000	24	24	1 329	4 176	21 041
	2001	19	19	820	2 782	12 364
	2002	15	15	962	3 105	17 745
	2003	17	17	777	2 425	17 090
	2004	15	15	767	2 450	15 766
	2005	16	16	741	2 377	17 024
	2006	17	18	860	2 796	22 538
	2007	16	16	685	2 235	21 234
	2008	17	17	652	2 115	22 671
	2009	14	14	612	2 114	22 772
	2010	16	17	933	3 240	27 670
	2011	15	15	906	3 165	28 466

Table 8: Number of days sampled and number of fish sampled for length by fishing year, season and data source for CRA 7. Year/season combinations highlighted in grey were not used in the assessment: see text.

	Days sampled				Number fish sampled			
Fishing	Observer		Logbook		Observer		Logbook	
Year	AW	SS	AW	SS	AW	SS	AW	SS
1988	8	6			1 997	526		
1989	6	3			693	544		
1990	6	3			1 979	432		
1991	6				1 836			
1992	6	3			1 847	256		
1993	5	2			1 121	857		
1994	9	3			4 055	479		
1995	12	3			2 672	243		
1996	15	13			1 645	1 272		
1997	18	2			2 836	264		
1998	9	5			2 113	321		
1999	10	8			2 196	487		
2000	10	5			2 833	453		
2001	10	2	185	2	3 536	404	1 800	7
2002	13	2	71		4 167	845	1 062	
2003	10	5	43		4 670	1 732	1 105	
2004	10	5			5 419	1 723		
2005	15				7 475			
2006	14	1			7 049	354		
2007	14	1			6 681	121		
2008	9	6			3 872	2 824		
2009	7	8			2 408	2 640		
2010	8	7			2 078	733		
2011	6	9			1 788	914		
Total	236	102	299	2	76 966	18 424	3 967	7

There were only a few logbook samples available from CRA 7 (Table 10). Examination of these data cast doubt on the classification of females: there were few mature females and much larger immature lobsters than those seen in the observer samples. On that basis, these samples were discarded.

The remaining samples from observer catch sampling were also examined. None of the CRA 7 or CRA 8 AW samples was considered unusual, but 8 of the 22 CRA 7 SS samples appeared to come from a period that was not representative of the modelled CRA 7 fishery (Figure 21). The main CRA 7 fishery (the fishery modelled for this QMA) takes place from June to mid-November with a small MLS (47 mm TW males and 49 mm TW females). After mid-November, the legal size reverts to 54 mm for males and 60 mm for females; some fishing does take place during this period but reported catch has been low and may include landings from holding pots. Since 2009, fishing in CRA 7 has been restricted to 1 June–19 November. The assessment team considered that samples from the 8 suspect samples should be discarded based on the comparatively large size of the mature females, indicating that these samples probably came from an unmodelled component of the CRA 7 fishery.

Table 9: Number of days sampled and number of fish sampled for length by fishing year, season and data source for CRA 8.

Fishing Year	Days sampled				Number fish sampled			
	Observer		Logbook		Observer		Logbook	
	5. AW	6. SS	7. AW	8. SS	9. AW	10. SS	11. AW	12. SS
1987	2	6			500	1 359		
1988		6				1 309		
1989	11	34			4 811	13 683		
1990	26	39			13 679	17 374		
1991	27	36			17 462	20 253		
1992	24	35			14 160	16 612		
1993	28	25	1 007	586	11 924	9 848	23 059	13 604
1994	25	32	896	990	17 357	10 402	16 851	14 769
1995	25	39	1 358	1 556	9 791	10 075	21 452	22 114
1996	40	39	999	1 134	15 295	18 887	13 888	14 009
1997	15	29	1 046	969	6 825	8 882	11 649	9 312
1998		10	673	1 019		4 125	10 824	10 890
1999	9		452	337	4 232		7 120	4 127
2000	16	5	761	536	8 067	1 741	13 925	6 749
2001	7	8	451	323	3 657	1 807	7 504	4 283
2002	9	5	654	222	5 399	4 186	12 140	4 620
2003			655	83			14 708	1 435
2004			656	48			12 903	1 507
2005			625	43			14 277	1 053
2006			688	77			17 208	2 235
2007			496	79			14 061	3 028
2008			520	35			17 832	1 837
2009			420	84			15 682	4 471
2010	18	3	734	54	9 644	1 542	22 321	1 780
2011			675	100			21 509	3 675
Total	282	351	13 766	8 275	142 803	142 085	288 913	125 498

The proportion of males showed no trend in either QMA using either data source (Figure 22). There was no trend in the mean length of either sex in CRA 7 during the autumn/winter season but an increasing trend during the spring/summer season (Figure 23). Mean lengths show a strong increasing trend in the CRA 8 logbook data, but there was a lack of observer sampling during the period of increasing mean length (Figure 23).

Table 10: Total sample weight (before truncation) by fishing year, season, and sample type for both QMAs. LB: logbook; CS: observer catch sampling. Year/season combinations from the logbook and observer data which have been highlighted in grey were not used in the assessment for reasons given in the text.

Fishing	CRA 7				CRA 8			
	AW		SS		AW		SS	
Year	CS	LB	CS	LB	CS	LB	CS	LB
1987					2.65		2.22	
1988	8.04		5.16				1.71	
1989	5.25		3.60		4.70		6.38	
1990	5.30		2.82		15.54		10.49	
1991	4.52				13.75		9.52	
1992	5.87		4.08		13.67		8.74	
1993	3.00		8.72		12.28	52.53	7.56	30.39
1994	7.51		6.09		11.51	47.19	8.11	33.62
1995	8.01		5.16		10.49	55.01	10.38	47.29
1996	6.47		10.83		14.43	43.66	13.55	37.43
1997	8.54		2.59		9.24	41.35	8.90	31.44
1998	6.84		4.70			40.82	1.34	30.11
1999	8.05		6.60		3.01	30.31		16.80
2000	8.55		5.08		7.60	50.41	1.28	21.26
2001	9.06	22.52	4.85	0.32	3.39	30.40	2.61	19.27
2002	10.20	11.96	7.16		9.59	37.43	5.99	16.13
2003	8.95	12.02	7.78			46.44		9.02
2004	8.61		7.26			38.93		5.24
2005	12.33					33.82		4.06
2006	11.71		3.49			31.20		7.43
2007	13.39		1.58			26.49		12.13
2008	8.44		15.97			29.01		7.90
2009	5.32		10.35			25.92		14.56
2010	5.24		6.53		5.29	32.70	2.63	5.80
2011	5.41		4.61			29.20		9.78

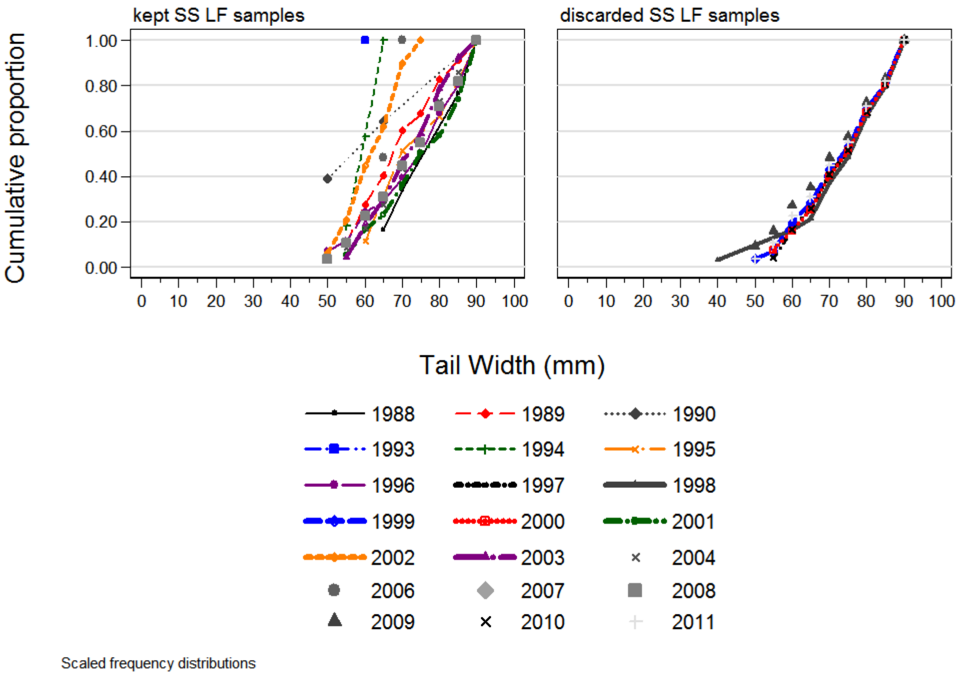

Figure 21: Empirical cumulative frequency distributions for mature female lobsters in CRA 7 measured during the spring/summer (SS: October–March) season. Eight of the 22 available sets of LF data were discarded because they were shifted to the right of the remaining LF series.

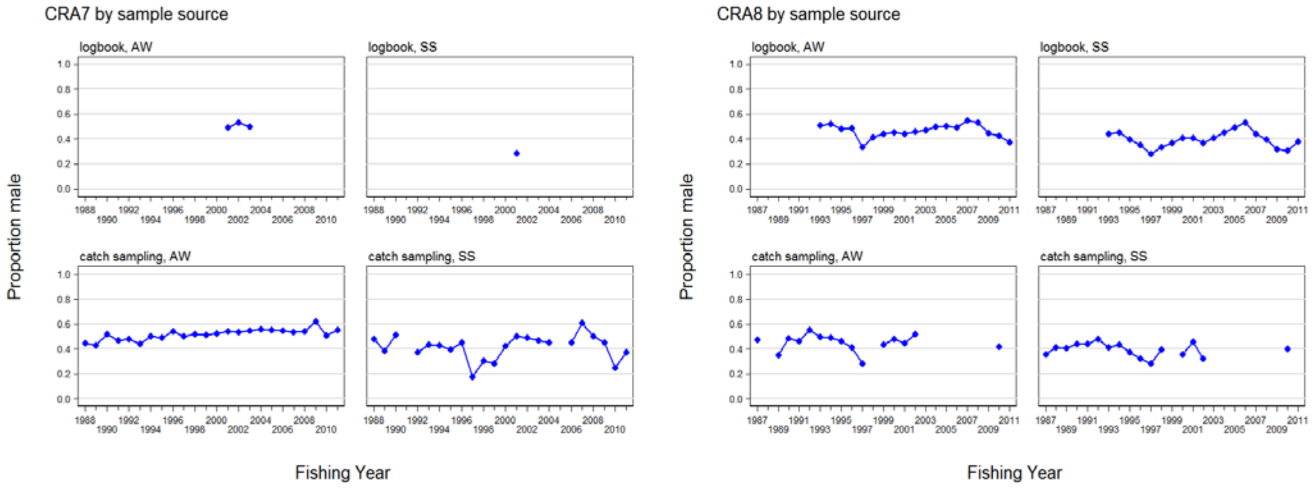

Figure 22: Proportion males by sample data source, season and fishing year and data source for CRA 7 [left panel] and CRA 8 [right panel].

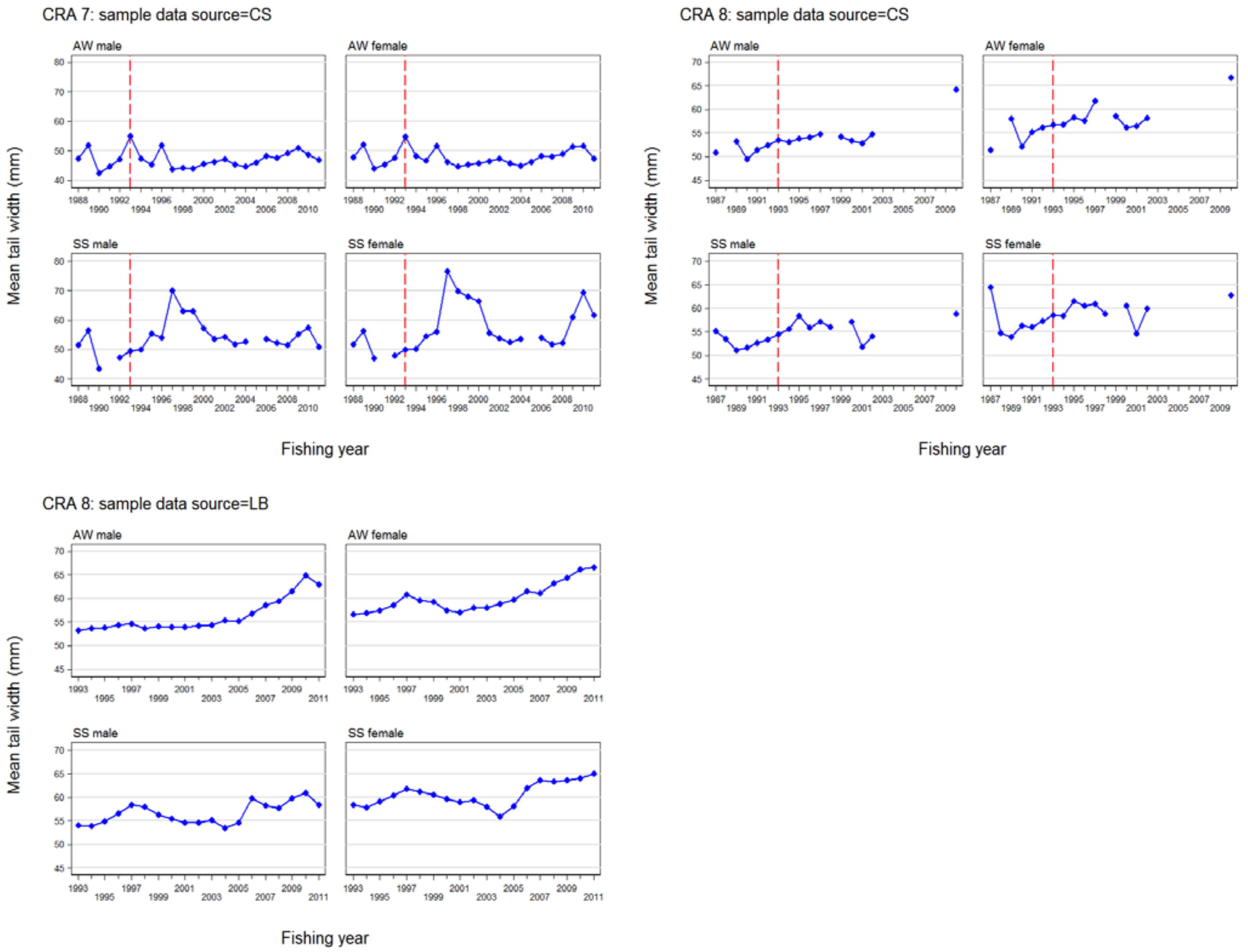

Figure 23: Mean length by fishing year, season and sex for all measured lobsters from the CRA 7 observer (CS) catch sampling programme and the CRA 8 observer (CS) and logbook (LB) programmes. The vertical line indicates the fishing year when escape gap regulations were changed (observer catch sampling only).

6. TAG-RECAPTURE DATA

Data were extracted from the tag database (Mackay & Wood 2008) by MPI and groomed with purpose-built software used in previous assessments. This software matches recaptures to releases, treating re-recaptures as having been released at the previous recapture and converts from carapace length (CL) to tail width (TW) where necessary, using relations developed in the Breen et al. (1988) morphometrics program. The data preparation software discards records with missing tail widths at release or recapture, records with inappropriate sex codes or apparent sex changes, records with apparent shrinkage greater than 10 mm or an apparent increment greater than 40 mm and records from fish at liberty for less than 31 days.

For CRA 7, the groomed dataset contained 173 records (83 males and 90 females), from releases in 1965–2008 and recoveries in 1966–2010. Time at liberty ranged from 31 to 1188 days, but only 5% were more than 500 days; half were 370 days or less (Figure 24). Nearly all fish (96%) were recaptured only once, and the rest were captured only twice. Most tagging (73%) was done in area 920 (Table 11). Where statistical area was available for both release and recovery, 95% of fish were recovered in the same area as released (Table 11); all movements were clockwise, one as far as area 928. When increments were adjusted proportionally by time-at-liberty to 183 days, they ranged from -4 to 11 mm (Figure 25).

Table 11: CRA 7: for those recoveries with areas given at both release and recovery, the area of release (rows) and recovery (columns); bold indicates the same areas at both release and recovery.

Release	Area of recovery					
area	920	921	922	924	928	Total
920	121	4	1	0	0	126
921	0	44	1	1	1	47
Total	121	48	2	1	1	173

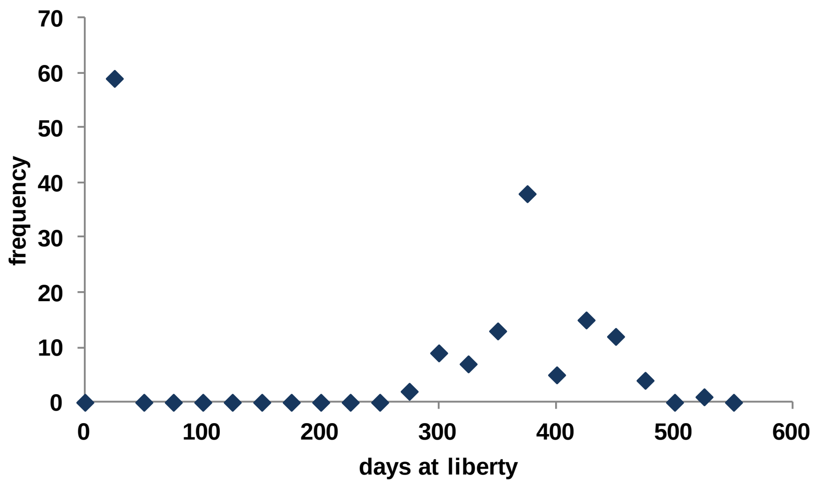

Figure 24: CRA 7: distribution of tag recaptures by number of days at large, up to 550 days (95% of the data).

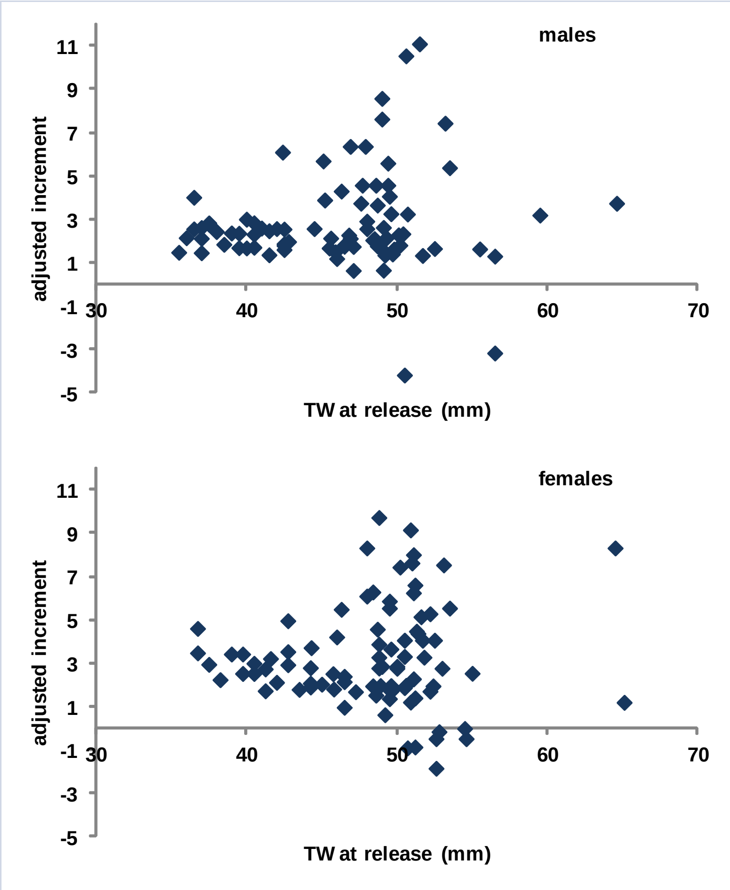

Figure 25: CRA 7: adjusted increments plotted against initial size.

For CRA 8, the groomed dataset consisted of 8451 records (4642 males and 3809 females). Releases were made from 1966–2011 and recoveries from 1967–2012. Time at liberty ranged from 31 to 5144 days, but only 10% were more than 700 days; half were 320 days or less (Figure 26). Most fish were recaptured only once (75%) or twice (14%) (Table 12). Where area was available for both release and recovery, 92% of fish were recovered in the same area as released (Table 13), while 85% of fish that moved were recovered in one of the two statistical areas clockwise from the area of release; only a few moved counter-clockwise. When increments were adjusted proportionally by time-at-liberty to 183 days, they ranged from 50 to 155 mm, the extremes coming from apparent increments after short times at liberty; only 111 records (1.3%) fell outside the range -5 to 10 mm (Figure 27).

Table 12: CRA 8: number of records by the number of re-recaptures.

Re-recaptures	Number of Records
0	6 315
1	1 160
2	495
3	252
4	113
5	49
6	33
7	20
8	10
9	3
10	1
Total	8451

Table 13: CRA 8: for those recoveries with areas given at both release and recovery, the area of release (rows) and recovery (columns); bold indicates the same areas at both release and recovery.

Release	Area of recovery								
area	922	923	924	925	926	927	928	929	Total
922	**2**	5	8						15
923		**70**	78		12	5	1		166
924		4	**1951**		18	5	1		1979
925			3	**14**	2				19
926		6	5	3	**967**	245	54	1	1281
927			1		9	**2948**	23	1	2982
928					1	19	**294**	1	315
Total	2	85	2046	17	1009	3222	373	3	6757

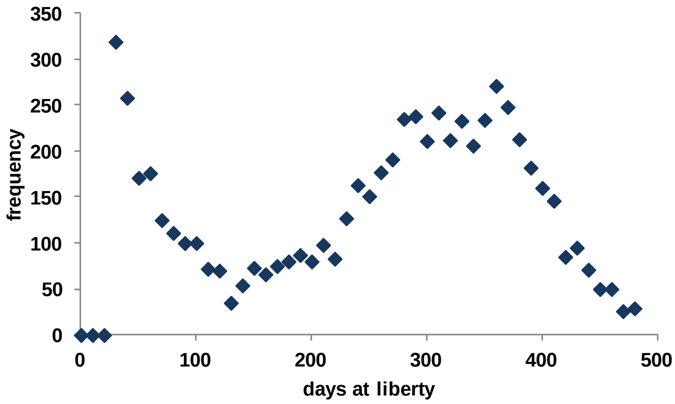

Figure 26: CRA 8: distribution of tag recaptures by number of days at large, up to 500 days (77% of the data).

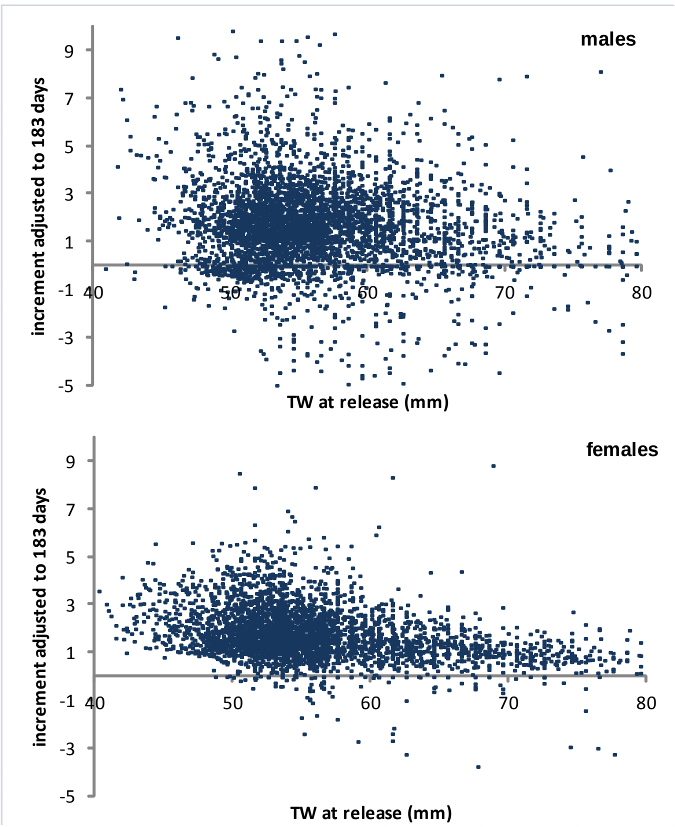

Figure 27: CRA 8: adjusted increments plotted against initial size.

6.1 Exploring for change in growth

The CRA 8 data were explored for possible changes in growth over time by dividing the data into three epochs based on annual CPUE (see Figure 2, right panel), which suggested three natural periods: a long period of low CPUE from 1988 to 2000, a period of higher but declining CPUE before that, and a period of much higher CPUE after 2000.

However, the sizes of lobsters recaptured were not the same in the three epochs (Figure 28). For males, there was good overlap between the first and second epochs, with modes near 50 mm initial TW, but limited overlap between these and the third epoch, which had no initial tail width less than 53 mm. Females showed good overlap between the first and second epochs, but there were few female recoveries in the third epoch (Figure 28).

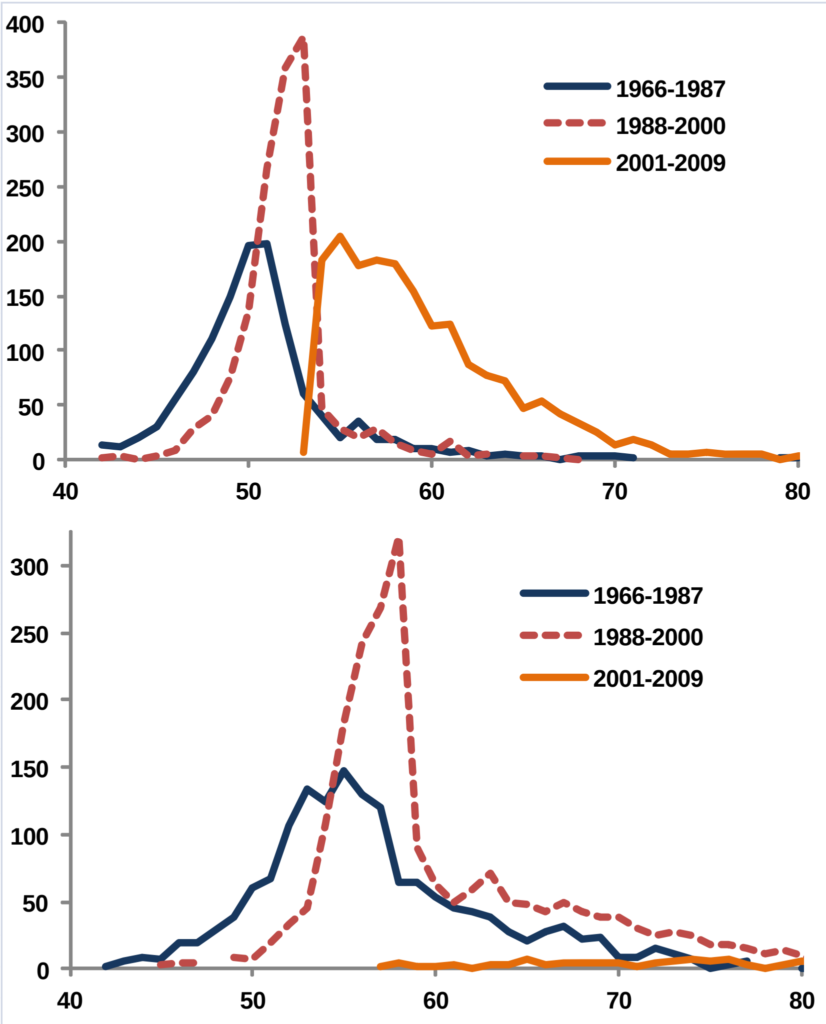

Figure 28: CRA 8 size distributions of males (top) and females (bottom) in the three epochs discussed in the text.

For the sizes at which the number of recoveries was at least 10 in an epoch, the mean adjusted increments are compared in Figure 29. For males, epochs 1 and 3 appeared similar. Epoch 2 had higher increments than the other two epochs for fish below the MLS and lower increments above the MLS. For females, the patterns for epoch 1 and 2 appear similar above 54 mm TW, but epoch 2 had larger apparent increments at small sizes. For epoch 3 there was no size with 10 female recoveries. This simplistic way of looking at the data generated the hypothesis in 2008 that growth had changed in CRA 3 (Breen et al. 2009). For CRA 8 there is no strong support from this approach for an hypothesis that growth has changed.

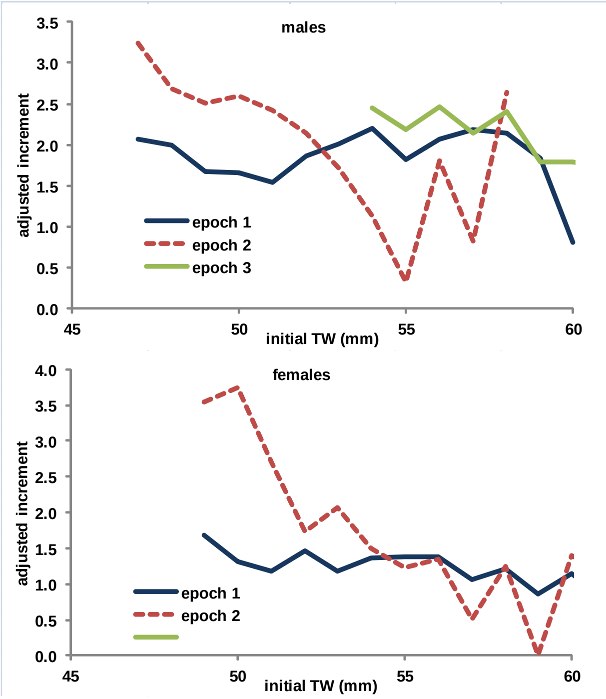

Figure 29: CRA 8: comparison of the mean adjusted increments among the three epochs for males (top) and females (bottom). Only those means based on at least 10 recoveries are shown.

The assessment model MSLM was also used to explore possible differences in growth in these three epochs, estimating only the growth parameters, using only the tag-recapture data set and fixing the shape parameter (Table 14). The predicted growth curves, made with fixed shape and *Gdiff* parameters, are compared in Figure 30. Although the comparisons are hampered by the differences in size distributions in the three epochs, the results do not support any suggestion of a change in growth in CRA 8.

Table 14: CRA 8: estimates from exploratory fitting; grey indicates values that were fixed. See Haist et al. (2013) for explanation of parameter codes.

	Estimated shape GCV	Fixed shape GCV	Epoch 1	Epoch 2	Epoch 3
Tags-sdnr	1.28	1.323	0.96	1.48	1.29
Tags-MAR	0.621	0.642	0.538	0.714	0.645
Tags-LL	18067.4	18113.2	5327.85	8418.7	4227.02
galphaM	4.475	4.599	4.041	4.854	5.367
gbetaM	1.907	2.534	3.875	4.200	1.359
gdiffM	0.426	0.551	0.959	0.865	0.253
GshapeM	0.100	2*	2*	2*	2*
GrowthCVM	0.343	0.3*	0.3*	0.3*	0.3*
galphaF	3.683	3.649	3.324	4.091	4.624
gbetaF	1.372	1.385	1.475	1.316	0.939
gdiffF	0.373	0.379	0.444	0.322	0.203
GshapeF	2.035	2*	2*	2*	2*
GrowthCVF	0.254	0.3*	0.3*	0.3*	0.3*
Male: yrs to MLS	5.0	4.5	5.0	4.0	3.0
Female: yrs to MLS	6.5	6.5	7.5	6.0	5.0

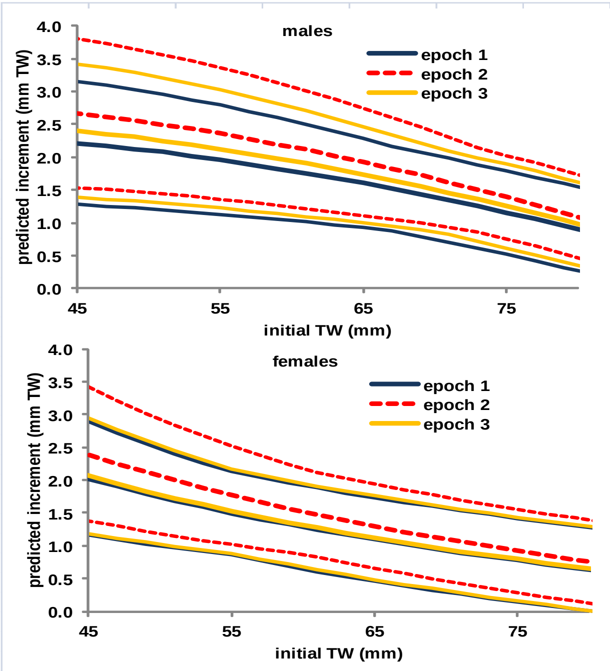

Figure 30: CRA 8: predicted growth increments for males (top) and females (bottom) when shape and *Gdiff* were fixed to the all-data estimates for each sex. The upper and lower sets of lines are the confidence bounds.

Table 15: Annual standardised puerulus settlement indices for locations specific to CRA 7 and CRA 8: Moeraki, Halfmoon Bay and Jackson Bay. The CRA 8 analysis combines Halfmoon Bay and Jackson Bay into a single analysis. Analysis by Andy McKenzie (NIWA, pers. comm.)

Year	Moeraki	Halfmoon Bay	Jackson Bay	CRA 8
1980	–	1.77	–	0.81
1981	–	7.66	–	8.60
1982	–	0.36	–	0.32
1983	–	4.28	–	3.78
1984	–	0.36	–	0.34
1985	–	0.00	–	0.00
1986	–	0.10	–	0.09
1987	–	1.53	–	1.25
1988	–	0.20	–	0.18
1989	–	0.51	–	0.53
1990	0.77	0.42	–	0.39
1991	0.00	0.80	–	0.72
1992	0.15	0.59	–	0.49
1993	0.00	0.00	–	0.00
1994	0.00	1.06	–	0.92
1995	0.12	0.30	–	0.27
1996	1.14	0.30	–	0.27
1997	0.68	0.51	–	0.45
1998	0.66	0.25	–	0.22
1999	0.14	0.23	0.74	0.30
2000	3.93	1.14	0.75	0.65
2001	2.44	1.63	0.81	0.91
2002	0.95	1.25	3.07	1.60
2003	7.46	3.34	1.53	1.45
2004	0.43	0.12	0.32	0.18
2005	0.11	0.00	3.58	1.70
2006	0.06	0.13	0.41	0.28
2007	0.04	0.44	0.50	0.38
2008	0.10	0.08	0.34	0.19
2009	0.46	0.91	0.29	0.58
2010	1.40	1.60	4.50	2.44
2011	0.97	0.13	4.62	1.72

7. PUERULUS SETTLEMENT DATA

Standardised puerulus settlement data were provided by Andy McKenzie of NIWA (pers. comm.) (Table 15). The collector sites relevant to this assessment were Moeraki (CRA 7), Halfmoon Bay (CRA 8) and Jackson Bay (CRA 8). Other CRA 8 sites have been monitored in the past, but only these three were considered a current times series.

The analytical methodology used to standardise the puerulus settlement data was documented in Bentley et al. (2004); a recent summary of these indices was given by Booth et al. (2007). An index for CRA 8 was developed by NIWA by combining the data for Halfmoon Bay and Jackson Bay and standardising with respect to [`year`], [`month`], and [`collector`]. The site location (Halfmoon Bay or Jackson Bay) was also offered, but the model did not converge, so this explanatory variable was not used. Results are shown in Table 15 and plotted for each site in Figure 31.

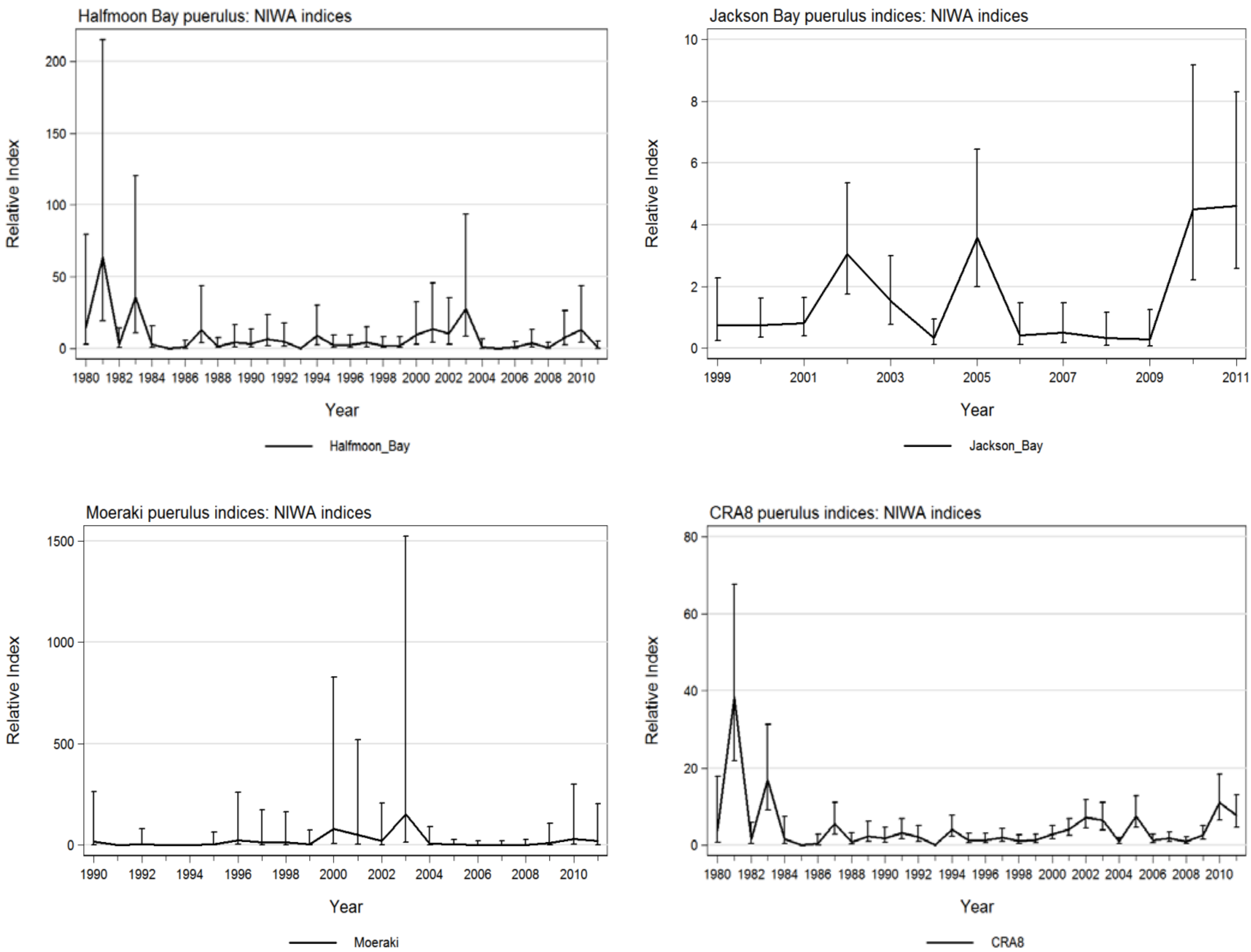

Figure 31. Plots of annual standardised puerulus settlement indices for locations specific to CRA 7 and CRA 8: Halfmoon Bay, Jackson Bay, Moeraki, and combined CRA 8. Confidence bounds are 2.5–97.5%. Analyses provided by Andy McKenzie (NIWA, pers. comm.).

8. CRA 8 RETENTION

8.1 Background

When fishers catch a rock lobster that is legal, they can choose to return it to the sea, an activity that is legal. Returned rock lobsters are thought to have a high survival rate: in CRA 8 tag-recapture data, about 25% of the total recaptures have been captured more than once, one as many as 10 times (see Table 12). The survival rate is unknown, but the assessment model assumes 90%.

Lobsters might be returned because recent moulting or injuries such as broken antennae and missing legs make them less valuable. Because unit price depends on size and market conditions, a large lobster can be less valuable than two smaller lobsters. If the fisher can be confident of catching two such smaller lobsters at a cost less than the price difference, he may choose to return the large lobster to the sea; this is sometimes termed "high-grading" without any connotation of wrongdoing. At low abundance, the large lobster in the hand might be kept because of the cost and uncertainty of catching two replacement lobsters.

This behaviour may affect the size distribution of lobsters removed from the stock. Until now, the stock assessment model MSLM (Haist et al. 2009) has assumed that the legal fish taken out of the stock have the same size distribution as the legal fish that are caught, a function of selectivity and seasonal vulnerability. For the first time, retention was explored in CRA 8 and the model dynamics were modified.

This study looks at voluntary logbook data from CRA 8 to explore the size distribution of fish that are retained, by sex and over time. The logbook program was described by Starr & Vignaux (1997): participating fishers tag three to five pots, and they record the sex, size and maturity of fish that are caught in those pots, as well as other information such as injuries and whether the fish was kept.

In this section, "legal" means a fish at or above MLS, not being a berried female; "retained" means recorded in the voluntary logbook as "1" in the "status code" field and is defined as meaning "kept for sale to an LFR"; "not retained" means recorded as "0" in the "status code" field.

8.2 Data

Nokome Bentley (Trophia, pers. comm.) provided a voluntary logbook data extract by fisher (coded to preserve confidentiality), month and year, statistical area, sex, tail width and retention.

Sex codes for logbook data differ from those used in observer catch sampling; they are: 1-male, 2-immature female, 3-mature female, 4-berried female and 5-spent female.

This study used a subset of the data that included only statistical areas in CRA 8: 922 to 928 (the straddle area 929 was excluded), and that included calendar years 2000 to 2011. The data subset contained 246 297 measurements from 43 fishers.

A "legal" code was constructed: true (1) for males 54 mm TW and above, true for sex codes 2, 3 and 5 for females 57 mm and above, false (0) for males 53 mm and below, false for females 56 mm and below and false for sex code 4 females. Spent females were included in the "legal" class, but it was not clear whether they should be treated that way. Fishers differ in how many they see and how they treat them; spent female numbers are relatively low.

Of the 43 fishers in this data subset, 21 made reports in fewer than four years and were eliminated from the subset. Four other fishers classified only 1–8% of their fish as sex code 3, 4, or 5 compared to 37% of the fish in the whole dataset. The data from these four fishers were removed. Only one of the four had operated after 2008.

Four fishers reported zero or very low retention in 2000 and 2001, their proportion then increased towards the average, suggesting initially poor retention recording. Data from these four were removed for those two years. In the analysis described below, there were six ID/year/month cells, all in 2000 or 2011, among five fishers, where retention was zero or very low but adjacent cells had average retention; these data suggested initially poor retention recording and were removed.

The final data subset contained 193 683 measurements from 17 fishers (79% of the original measurements from 43 fishers). Annual numbers of fish measured ranged from 3981 in 2001 to 26 301 in 2011. Legal fish were 48% of the total and 79% of these were retained; only 0.3% of illegal fish were retained. Six of the 17 fishers fished for all or nearly all of the period. The annual number of fish measured by a logbook participant ranged from about 110 to over 4300; total measurements by a logbook participant ranged from 3 200 to over 26 000.

Table 16: The overall percentage of measured legal fish retained by fishing year across all months and month across all years in the final data subset.

Year	% retained	Month	% retained
2000	89.5%	1	84.1%
2001	93.3%	2	80.1%
2002	92.7%	3	70.8%
2003	91.9%	4	72.3%
2004	92.9%	5	73.7%
2005	89.9%	6	74.9%
2006	86.8%	7	77.9%
2007	85.0%	8	84.3%
2008	78.9%	9	80.0%
2009	71.0%	10	79.1%
2010	65.8%	11	87.9%
2011	66.2%	12	94.1%

Table 17: The number of measured legal fish caught by sex code by the CRA 8 logbook fishers, summed across all years.

Fisher	Sex code					
ID	1	2	3	4	5	Total
18	7 108	275	329	0	403	8 115
23	8 410	1 213	3 028	0	22	12 673
35	6 939	995	3 845	0	491	12 270
39	6 080	665	2 200	0	377	9 322
40	4 936	406	2 166	0	1 020	8 528
49	817	806		0	54	1 677
65	4 859	314	869	0	1 137	7 179
74	2 560	414	290	0	71	3 335
89	1 846	764	34	0	114	2 758
96	1 401	60	611	0	0	2 072
98	1 007	246	574	0	1	1 828
157	1 070	276	187	0	52	1 585
180	3 315	553	154	0	3	4 025
233	4 592	617	2 222	0	16	7 447
235	2 823	184	167	0	23	3 197
257	992	532	180	0	51	1 755
262	4 978	898	11	0	273	6 160
Total	63 733	9 218	16 867	0	4 108	93 926
%	67.9%	9.8%	18.0%	0.0%	4.4%	

For each of the final 17 fishers, the percentage retention by year and month was calculated and inspected: there was little evidence of inconsistent reporting of retention except for the six ID/year/month cells with zero or low retention, described above, that were removed.

The patterns of legal retention by year and month in the final data subset are shown in Table 16. Retention in 2000 appeared somewhat less than in the following few years, suggesting that retention reporting may have been less consistent in 2000 (despite the removal of obvious poor reporting) or else less widespread than in succeeding years. Retention was low in March, increased from April to December and then declined, but changes in abundance during 2000–11 are accompanied by changes in fishing patterns.

Most of the legal fish caught were males (Table 17), and, by definition, none of the “legal” fish was a berried female. Fishers varied in their reported legal sex composition: for instance, ID code 18 caught 88% males while ID code 49 caught 50%; ID 49 never measured a code 3 female. Spent females were fewer than 5% of the total, with wide variation: ID codes 40 and 65 classified 12–16% of their legal catch as spent and the remaining codes classified only 0–5%. Seven ID codes retained 48–100% of spent females, averaging 74%, while the rest retained only 0–8%; five ID codes retained zero or less than 1% spent females.

Variation in recording spent females could have a variety of causes. Some fishers may not fish much during the period when spent females are prevalent (August to October). There is some room for subjectivity in classifying spent females: a female who has hatched most, but not quite all, her eggs could be considered either berried or spent, and a female with no eggs but with adhering egg cases and ratty setae could be considered either spent or mature.

The size distributions of males, immature and mature females are shown in Figure 32.

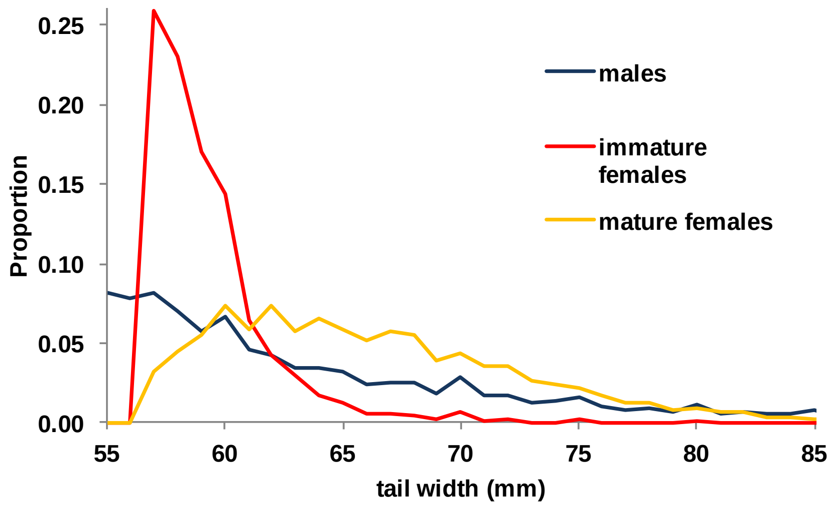

Figure 32: From the final CRA 8 data subset, using all years from 2000-11, the size distributions of measured legal fish.

8.3 Annual retention curves

After discussion by the RLFAWG, the data from legal fish were analysed by the two sex codes “male” (sex code 1) and “female” (combined sex codes 2, 3 and 5). At the 27 September 2012 meeting, the RLFAWG suggested that spent females should be included in the retention estimates and agreed that females of all maturity codes could be grouped.

For each year for each sex, an inverse logistic curve was fitted to the proportion that was retained in each length bin. For each sex, the model was:

Eq. 1 $$\hat{R}_{yl} = \frac{\alpha_y}{\left(1+\exp\left(-\ln(19)\left((\beta_y - l)/\gamma_y\right)\right)\right)}$$

where $\hat{R}_{yl}$ is the predicted proportion retained at length l (mm TW) in year y, α_y is the maximum proportion retained in year y, β_y is the length in year y at which 50% were retained and γ_y is the difference in year y in length between 50% and 95% retention. This model was fitted using a binomial distribution for the proportion retained observations. The annual parameter estimates are compared in Table 18 and the fitted curves are shown in Figure 33 and Figure 34.

Table 18: Retention parameters for the inverse logistic model fitted to CRA 8 male and female retention by year.

		Males			Females		
Year	CPUE	α_y	β_y	γ_y	α_y	β_y	γ_y
2000	0.917	0.921	114.8	3.3	1.000	123.4	91.2
2001	0.972	0.946	89.7	6.2	0.970	164.6	100.0
2002	1.182	0.958	119.0	1.0	0.934	89.5	26.0
2003	1.753	0.942	91.3	10.0	0.916	83.5	19.3
2004	1.821	0.943	87.2	10.1	0.912	88.5	0.1
2005	2.277	0.933	86.0	11.5	1.000	106.1	68.7
2006	2.806	0.914	84.2	8.0	0.920	129.8	100.0
2007	3.071	0.915	78.7	7.9	0.815	90.2	5.7
2008	4.142	0.892	77.5	7.5	0.744	89.4	13.0
2009	4.028	0.839	77.6	6.1	0.802	109.8	100.0
2010	3.280	0.855	77.9	6.6	0.492	168.0	5.3
2011	3.239	0.882	77.3	7.6	0.938	80.0	85.2

For males, there were two strong patterns. First, in the earlier years most males were retained, while in later years far fewer were retained. Second, in the later years, retention of small males was about 90% but retention fell away steeply after 70 mm to low values at large sizes. Some small males were rejected because of soft shells or injuries such as missing legs and aerials that reduced their export value.

For females the lower retention of large sizes was less dramatic, with much more variability between years than for males. The overall retention pattern for females was less clear-cut, except that fish near the MLS had less retention than larger fish, unlike the pattern seen for males.

8.4 Discarding by weight

For each year, the distributions of legal fish measured were converted to weight, using the coefficients from the previous CRA 8 stock assessment (Haist et al. 2009):

	a	b
Male	3.39E-06	2.9665
Immature	1.04E-05	2.6323
Mature	1.04E-05	2.6323

where

Eq. 2 $\hat{w}_l = al^b$ (for length (l) in millimetres TW and predicted weight $(\hat{w})$ in kilograms)

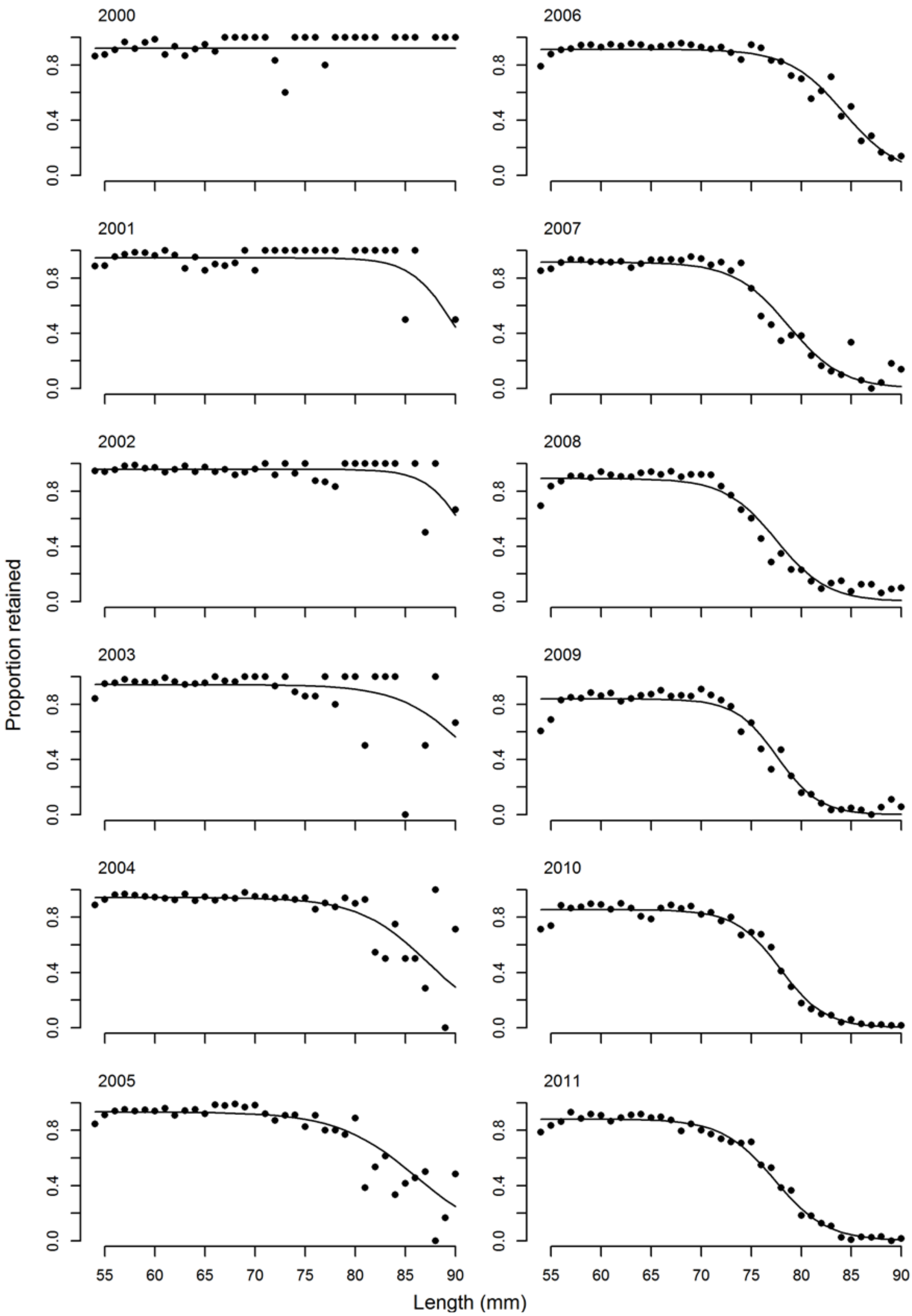

Figure 33: Fits of annual retention proportions for males to the inverse logistic model (Eq. 1).

This procedure was also followed for the logbook retained catch and all weights for each year were scaled so that total weight caught was 1000 kg and comparisons could be made across years (Table 19). Total discards by weight increased from about 5–6% of the logbook-measured legal catch in 2000 to 40% in 2010 and 2011, with males being the major component of discards by weight.

Mature females were only about 1% of discards by weight, and this was stable over time. Males increased over time both as a proportion of the measured legal catch by weight and as a proportion of the total discards by weight.

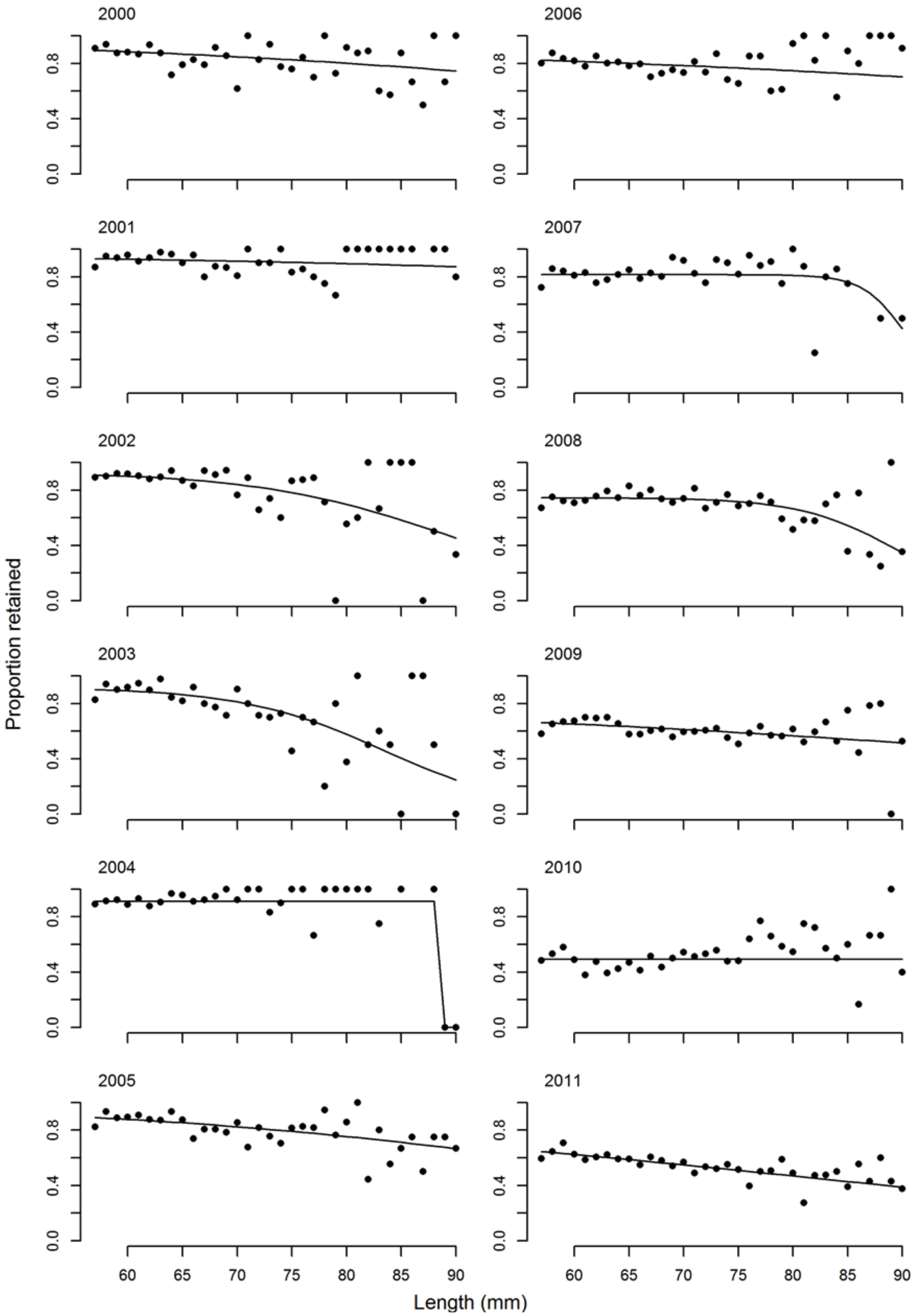

Figure 34: Fits of annual retention proportions for females to the inverse logistic model (Eq. 1).

Table 19: Weights (kg) of lobster caught, scaled so that in each year the total weight caught is 1000 kg, and the total weight of discarded fish.

	Males			Immature females			Mature females			Total
Year	Total	Retained	Discarded	Total	Retained	Discarded	Total	Retained	Discarded	Discards
2000	523	485	38	152	146	7	324	307	17	62
2001	533	501	32	114	106	9	353	348	5	45
2002	639	611	28	158	144	14	203	193	10	52
2003	747	704	43	194	177	16	59	53	6	65
2004	802	742	60	115	106	10	83	76	7	77
2005	775	692	82	113	100	12	112	103	9	104
2006	736	648	88	86	76	10	177	151	27	125
2007	822	661	161	67	55	12	111	93	18	191
2008	769	571	198	49	36	13	181	136	46	257
2009	700	492	208	51	39	12	249	170	78	299
2010	857	506	350	25	13	12	119	71	48	410
2011	761	447	314	29	22	7	210	126	84	405

8.5 Predicted retention curves

The inverse logistic model was also fitted to all years simultaneously by using annual offset-year CPUE (Starr 2013) as a predictor of the annual model parameters. This fit was developed for predicting future retention rates as a function of CPUE in model projections. For this model the parameters α_y, β_y, and γ_y in 1 above were replaced with:

Eq. 3

$$\alpha_y = a^\alpha + b^\alpha I_y$$

$$\beta_y = a^\beta + b^\beta I_y^\delta$$

$$\gamma_y = a^\gamma + b^\gamma I_y$$

where I_y is the offset year CPUE in year *y*, and $a^\alpha, a^\beta, a^\gamma, b^\alpha, b^\beta, b^\gamma$, and δ are the estimated parameters. This model was fitted assuming a binomial distribution for the proportion retained observations. For fitting female retention, the δ parameter was fixed at 1 to ensure retention did not decrease at low CPUE. The estimated parameters are compared in Table 20, and fitted curves are shown in Figure 35 and Figure 36.

Table 20: Retention parameters (Eq. 3) for the inverse logistic model, with inverse logistic parameters a function of CPUE, fitted to CRA 8 male and female retention data.

	Males	Females
a^α	0.988	0.919
b^α	-0.030	-2E-08
a^β	178.66	111.25
b^β	-88.77	-4.82
δ	0.100	1*
a^γ	10.30	0.500
b^γ	-0.851	25.553

* Fixed parameter

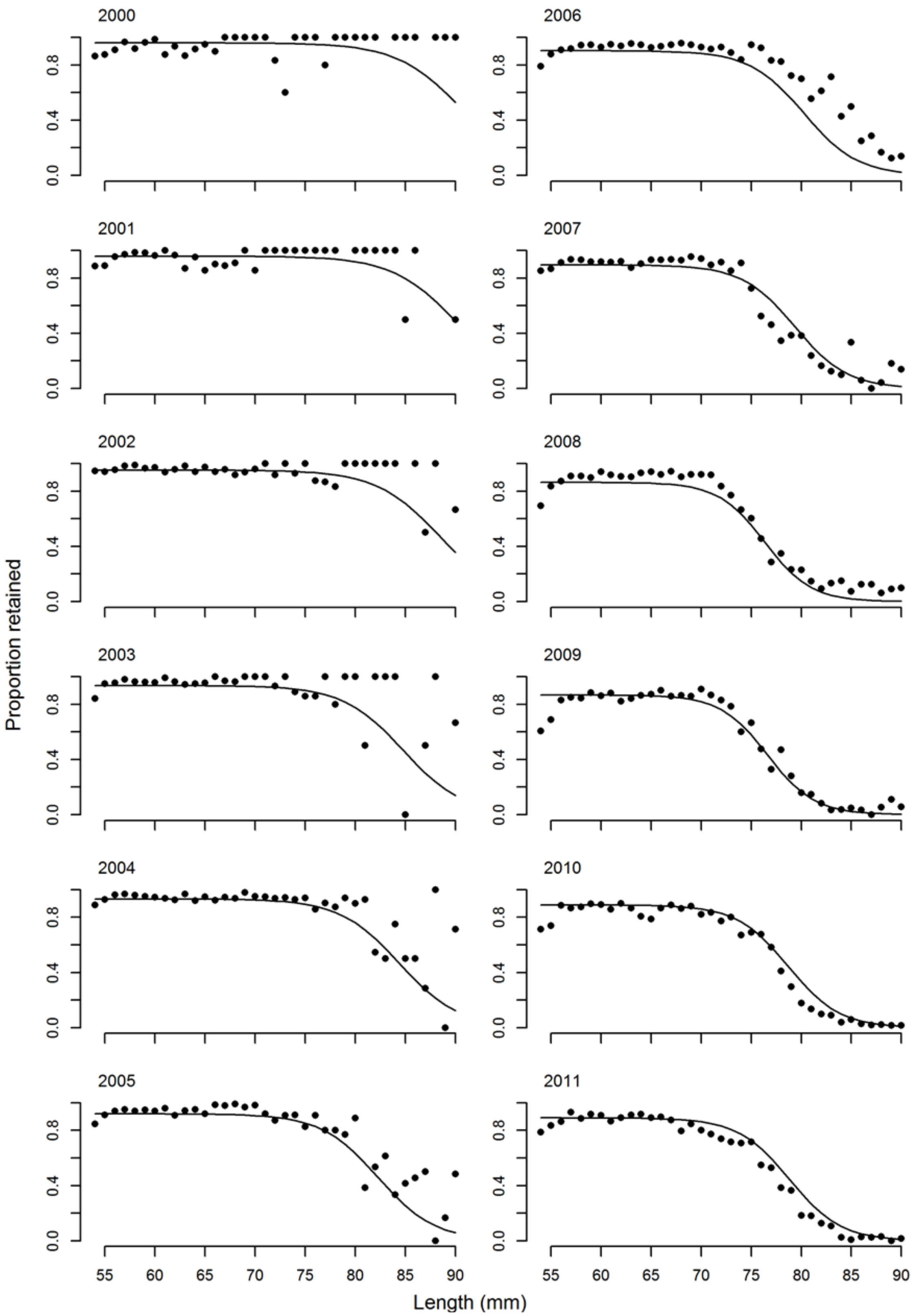

Figure 35: Fits of annual retention proportions for males to an inverse logistic model (Eq. 1), parameterised as a function of annual offset-year CPUE (Eq. 3).

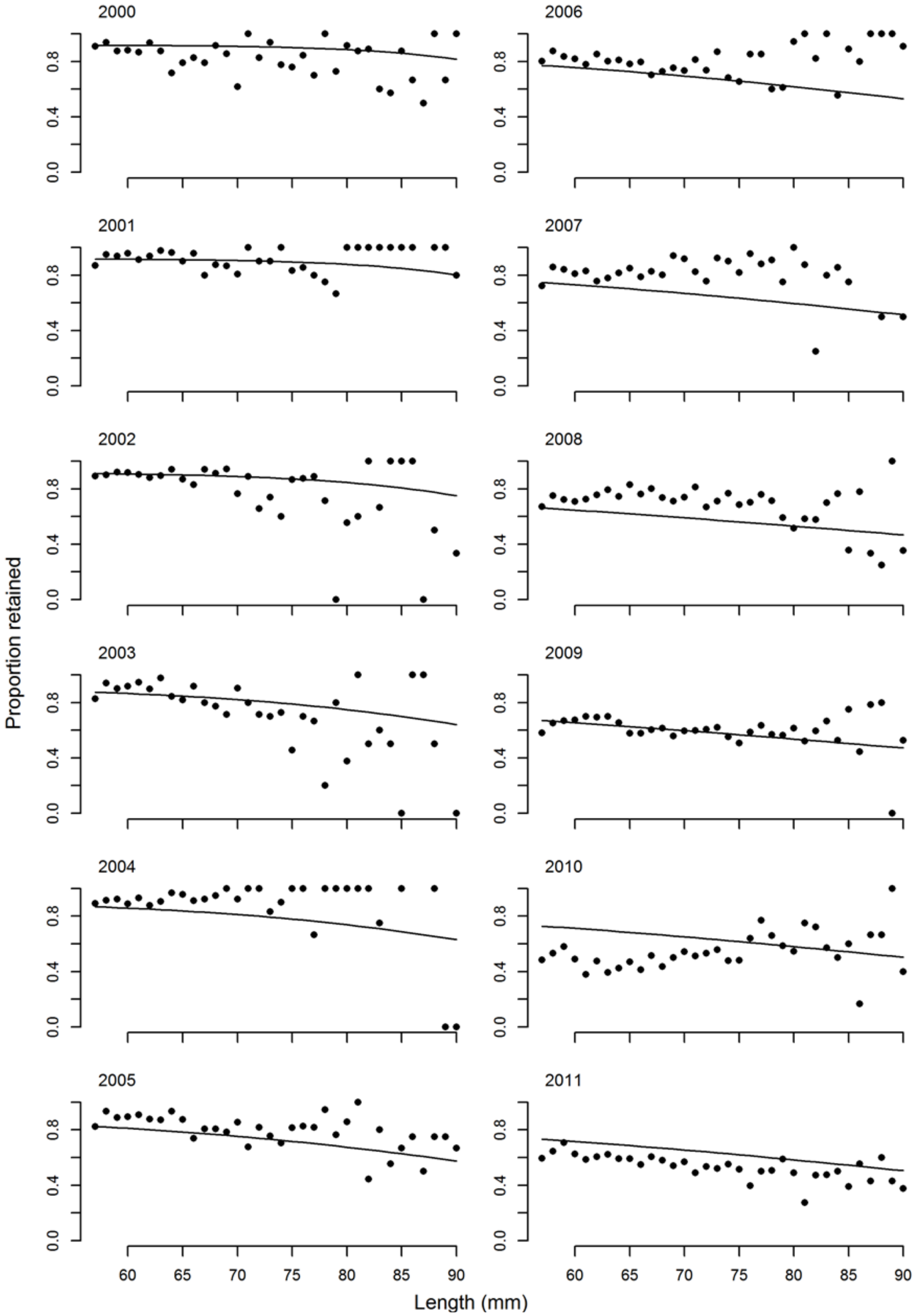

Figure 36: Fits of annual retention proportions for females to an inverse logistic model (Eq. 1), parameterised as a function of annual offset-year CPUE (Eq. 3).

9. ACKNOWLEDGEMENTS

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