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P. A. Breen
S. W. Kim
V. Haist
P. J. Starr

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Paul A. Breen[1]
Susan W. Kim[1]
Vivian Haist[2]
Paul J. Starr[3]

[1]NIWA
Private Bag 14901
Wellington

[2]Haist Consultancy
1262 Marina Way
Nanoose Bay, BC
Canada V9P 9C1

[3]61A Rhine Street
Island Bay
Wellington

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EXECUTIVE SUMMARY

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We used a length-based model to assess the CRA 4 stock of rock lobster (*Jasus edwardsii*). The model simulates recruitment, growth, natural mortality and fishing mortality in 6-month periods from 1945. The fishing model includes differential vulnerability for males, immature females and mature females based on size and season.

The model is driven by estimated catches (commercial, recreational, illegal and Maori customary) and is fitted to relative abundance indices, proportions-at-length from observer catch sampling, and tag-recapture data from the CRA 4 fishery augmented by an equal number of records from CRA 3 and CRA 5. This year's assessment included CPUE estimated for autumn-winter 2005 with a predictive regression model; this removed six months of the lag between data and assessment.

There was some difficulty in finding a base case. The natural weights for datasets did not produce a good fit to CPUE; a good fit to CPUE was obtained by over-weighting, but this led to other problems. A variety of modelling approaches is described. An acceptable base case was found, but much uncertainty in the results attaches to this general problem.

The assessment was based on Bayesian techniques. Markov chain-Monte Carlo (McMC) simulations were used to estimate the marginal posterior distributions of parameters and indicators. Sensitivity trials and retrospective analysis were also based on McMC simulations. These trials did not add substantial additional uncertainty to the base case McMC results.

For CRA 4, the current vulnerable biomass is higher than the target reference biomass, *Bref*, and 2–3 times the limit reference, *Bmin*. Exploitation rate is modest. This suggests that the stock is biologically healthy.

Projections were much less certain. Under the assumptions of constant catches at current levels and seasonal distributions of catches as at present, and resampling recruitments from the past decade, projections show a slightly greater chance of decrease over three years than increase. The median decrease is only 6%, but the range is from a 40% decrease to a 40% increase. The chances of biomass falling below *Bref* and *Bmin* are small.

Some additional projections were made with alternative catch assumptions at the request of the National Rock Lobster Management Group, and these results are also presented.

1. INTRODUCTION

The red rock lobster, *Jasus edwardsii*, supports the most valuable inshore fishery in New Zealand, with annual exports worth over $100 million. For fishery descriptions see Annala (1983) and Booth & Breen (1994); for recent management details see Sullivan (2004) and Booth et al. (1994). The most recent previous assessments were described by Kim et al. (2004) and Haist et al. (2005).

The commercial fishery is an inshore trap or pot fishery in the areas described here. It has been managed since 1990 with a system of individual transferable quotas (ITQs). From 1979 through 1989, the fishery was managed with limited entry and input controls, including minimum legal sizes (MLS), recreational bag limits, protection of ovigerous females and soft-shelled lobsters, and some local spatial and seasonal restrictions. In 1990, the fishery was brought into the Quota Management System (QMS) but the input controls were retained. Ten Quota Management Areas (QMAs), each with a separate Total Allowable Commercial Catch (TACC), were established in 1990, nine of them replacing the previous Controlled Fishery Areas.

The Fisheries Act 1996 requires the Minister to set a Total Allowable Catch (TAC) that includes all known sources of fishing mortality including catches by commercial, recreational, Maori customary and illegal fishers and other fishing-related mortality. This Act also requires the Minister to manage stocks at or above B_{MSY}, the biomass associated with the maximum sustainable yield (*MSY*). B_{MSY} is not defined by the legislation, it is not a single value but may vary because of natural fluctuations in biomass, and *MSY* can be defined only in association with a specific harvest strategy (Francis 1999).

The Ministry of Fisheries (MFish) and the National Rock Lobster Management Group (NRLMG) annually advise the Minister of Fisheries whether stocks are at or above a target reference point, *Bref*, that serves as a proxy for B_{MSY}, and whether current catches are sustainable and likely to move stocks towards *Bref*. A limit reference point, *Bmin*, is also used.

The assessment work described here was conducted by fisheries scientists under contract to the New Zealand Rock Lobster Industry Council (NZ RLIC), which was contracted by MFish to provide an assessment for the CRA 4 (Wellington-Hawke's Bay) fishstock. Conduct of the work throughout was discussed by the Rock Lobster Fishery Assessment Working Group (RLFAWG) (below called the "Working Group"), comprising representatives from MFish and all stakeholder groups.

Length-based models are widely used for fished populations that cannot be aged. A length-based model of the type described by Punt & Kennedy (1997) has been used since 1998 to assess rock lobsters in New Zealand. Our model uses a growth transition matrix that has no reference to "age". In this structure it is comparable with the approach of Bergh & Johnston (1992) for South African rock lobsters (*Jasus lalandii*), Sullivan et al. (1990) for Pacific cod (*Gadus macrocephalus*), Zheng et al. (1995) for Alaskan king crabs (*Paralithodes camtschaticus*), Hobday & Punt (2001) for Victorian rock lobsters (*Jasus edwardsii*), Chen & Kanaiwa (2005) for American lobsters (*Homarus americanus*) and Breen et al. (2003) for the New Zealand abalone, *Haliotis iris*.

The specific model used in this study was first written for the 1999 assessment and revised for subsequent assessments as described by Bentley et al. (2001), Breen et al. (2002), Starr et al. (2003), Kim et al. (2004) and Haist et al. (2005). No major revisions to dynamics were made for this study, although some experimental changes were made, tested and rejected.

The assessment uses Bayesian techniques (see Punt & Hilborn (1997)) to estimate uncertainty in the assessment. The model is fitted to four data sets: standardised catch per unit effort (CPUE), historical catch rates (CR), proportions-at-size from catch sampling, and growth increments from tag-recaptures.

This report describes the revised size-based model, describes the data used for the CRA 4 assessment and presents and discusses the assessment results.

2. CRA 4 FISHERY (WELLINGTON-HAWKE'S BAY)

The CRA 4 fishery extends from the Wairoa River on the east coast of the North Island, southwards along the Hawke's Bay, Wairarapa and Wellington coasts, through Cook Strait and north to the Manawatu River.

A CRA 4 TAC was first set in April 1999 and remains at 771 t. In that 1999 decision, the TACC was increased from 495.7 t to 577 t, based on a stock assessment made in 1998. Before 1999, the TACC had remained unchanged since April 1993. Within the TAC, allowances were 85 t for amateur and 35 t for customary catches, and an implicit allowance of 74 t for illegal catch. A stock assessment for CRA 4 in 2003 did not result in any adjustment to the TAC or TACC.

The TACC of 577 t is distributed amongst 89 quota share owners. The fleet comprised an estimated 64 vessels (Starr & Bentley 2005) in the 2003–04 commercial season, most operating from coastal bases in isolated rural areas. The CRA 4 commercial catch has a landed value of more than $18 million, based on the average landed value, and supports several processing and export operations in Napier, Wellington, Auckland and Canterbury.

A moderate recreational fishing sector exists, with unknown catch history and current catch levels. Most recreational catch is taken in summer by potting and diving. The region sustains a recreational fishing and dive charter industry in summer.

A comprehensive stock monitoring programme has been established in the CRA 4 fishery, resulting in a long series of intensive catch sampling data from Napier, Castlepoint, Cape Palliser and the Wellington south coast. This series was extended in 2005–06 from 35 samples (days) to 45 samples. Tag recapture data are routinely reported by commercial fishermen, and 4000 lobsters will be tagged in CRA 4 in 2005–06.

3. ASSESSMENT MODEL

Full model details are provided in Appendix A. This description is not substantially different from that provided by Haist et al. (2005).

Two seasons are defined: "autumn-winter" (AW) from 1 April through 30 September and "spring-summer" (SS) from 1 October through 31 March.

The total fishery comprises four catching sectors that the model condenses to two. The commercial and recreational sectors are governed by the MLS and restrictions on landing berried females, and together these are called the SL fishery; the catch is called the SL catch or C^{SL}. The Maori customary and illegal fisheries are not bound by those regulations and together are called the NSL fishery; the catch is called the NSL catch or C^{NSL}.

The model is implemented in AD Model Builder™ (http://otter-rsch.com/admodel.htm).

3.1 Model fitting

Model parameters are estimated by minimising an objective function, which is the sum of negative log likelihood components from each data set, the negative log of the prior probabilities of estimated parameter values, and some penalty functions.

For each data element in each data set, the standard deviation of error used in likelihood calculations, $\sigma_{j,k}$, is calculated as

$$\sigma_{j,k} = \tilde{\sigma}\,\sigma'_j / \varpi_k$$

where j indexes the elements within a data set and k indexes data sets, $\tilde{\sigma}$ is an estimated error component that is common to all data sets, σ'_j is the standard deviation associated with the jth element of the data set and ϖ_k is the relative weight assigned to the data set.

Likelihood of the fit between observed and predicted proportions-at-size, normalised across males, immature females and mature females, is calculated assuming that proportions are normally distributed, with a pattern of standard deviations that gives most weight to large proportions and less weight to smaller (Eq 41 in Appendix A). This reflects a belief that small proportions are most likely to be affected by sampling biases and random errors.

Recruitment deviations were estimated for every year from 1945 through 2003. The 2003 annual deviation was applied to year 2004 through 2005 in the minimisation and Markov chain - Monte Carlo (McMC) phases; in the projection phase, deviations for 2004 through 2008 were obtained from re-sampling.

3.2 Markov chain-Monte Carlo simulations

After obtaining the best fit, which is the maximum of the joint posterior density (MPD), by minimising the total objective function value, we used Bayesian estimation procedures to estimate uncertainty in model parameters, quantities and projected quantities. Posterior distributions for parameters and quantities of interest were estimated using a Markov chain-Monte Carlo procedure (McMC) implemented in AD Model Builder through the Hastings-Metropolis algorithm.

McMC simulations were made in a single long chain started at the MPD estimate. No “burn-in” was used, except that the first sample was discarded. Exploratory and sensitivity runs were one million simulations, with 2000 regularly spaced samples saved. Production runs were 4 million simulations with 2000 samples saved.

For diagnostics, we examined the traces and made plots of running medians, running 5th and 95th percentiles and a moving average over 50 samples.

3.3 Projections

From each of the posterior samples for each area, we made 3-year projections of biomass, encompassing the 2006–07 through 2008–09 fishing years, under the assumptions that commercial catches would equal the TACC, other catches would remain at their 2005–06 levels during the projection and the seasonal split of catches would remain as in 2005–06. Projected catches were 618 t and 60 t for the SL and NSL catches respectively. Projected recruitments for the years 2004–05 were randomly re-sampled from the estimated model recruitments from 1994 to 2003.

3.4 Fishery indicators

The assessment used a variety of performance indicators that are summarised as follows.

B_{ref}	Mean of AW vulnerable biomass from 1979–88
B_{min}	Nadir of AW vulnerable biomass
B_{curr}	2006 AW vulnerable biomass
U_{curr}	AW exploitation rate on the SL biomass in 2006
B_{proj}	2009 AW vulnerable biomass
U_{proj}	AW exploitation rate on the SL biomass in 2009
B_{curr}/B_{ref}	Ratio of current biomass to reference biomass
B_{curr}/B_{min}	Ratio of current biomass to minimum biomass
B_{proj}/B_{ref}	Ratio of projected biomass to reference biomass
B_{proj}/B_{curr}	Ratio of projected biomass to current biomass
B_{proj}/B_{min}	Ratio of projected biomass to minimum biomass
U_{proj}/U_{curr}	Ratio of projected exploitation rate to current exploitation rate
$P\left(B_{proj} < B_{curr}\right)$	Probability that projected biomass is less than current biomass
$P\left(B_{proj} < B_{ref}\right)$	Probability that projected biomass is less than reference biomass
$P\left(B_{proj} < B_{min}\right)$	Probability that projected biomass is less than minimum biomass

Several performance indicators are based on "vulnerable biomass": the pre-season biomass that is legally available and vulnerable to the fishery (i.e., above the MLS, excluding berried females, and taking selectivity-at-size and seasonal vulnerability into account) in the AW season. The minimum biomass indicator, *Bmin*, is defined as the lowest point (nadir) of the AW vulnerable biomass trajectory. Current biomass, *Bcurr*, is defined as vulnerable biomass from AW 2006. Projected biomass, *Bproj*, is taken from AW 2009.

The choice of reference period is perforce arbitrary and open to debate. The target reference point *Bref*, a proxy for B_{MSY}, was defined for CRA 4 in 2003 as the biomass from 1979 through 1988. In this period the fishery showed good productivity and the biomass level was demonstrably safe: it subsequently declined to lower levels and then recovered.

Two exploitation rate indicators are the recent (AW 2005) and projected (AW 2008) exploitation rates on the sectors of the population that support the SL catch. We also report the posterior distributions of ratios of indicators, for example the ratio of projected biomass to current biomass, *Bproj/Bcurr*.

Three additional indicators are the probabilities (as measured by percentages of runs) for *Bproj* being less than *Bcurr* after the three-year projection, *Bproj* being less than *Bref* and *Bproj* being less than *Bmin*.

4. ASSESSMENT MODEL INPUTS

A summary of data and data sources used in the CRA 4 stock assessments is given in Table 1. A discussion of these data and their sources follows.

The model is "driven by" catch estimates and fitted to two abundance indices (a third was explored), the most important of which is 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.

The model used an estimate of CPUE for AW 2005, the same season in which the assessment was conducted. This was estimated with a regression projection model, fitted to partial season data, that uses the pattern of historical CPUE indices, which showed good historical prediction performance. The AW and SS catches for 2005 were also estimated from partial data and assuming a shortfall of 35 t from the TACC. The assessment included some length frequency data available from AW.

Incorporating these partial data reduced the lag between data and assessment, which has resulted in most previous assessments being six months out of date at the time they are made.

4.1 Fishing years and seasons

The model simulation begins in 1945, the first year for which catch data are available. Until 1979, catch data were collated by calendar year. From 1979, catch, catch rate and size frequency data are summarised by fishing year: 1 April through 31 March. Fishing years are labelled using the first calendar year in each pair (viz. the 1996–97 assessment year, 1 April 1996 through 31 March 1997, is labelled "1996").

4.2 Control variables

Catch estimates, CPUE abundance indices and other annual and seasonal information used in the assessment are provided in Appendix B and described below.

4.2.1 Catches

The assessment model uses annual values of the SL catch (taken under the MLS and other regulations) and the NSL catch (taken without reference to those regulations). Four types of catch were considered when collating SL and NSL catch totals by season.

4.2.1.1 Reported commercial catch

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

From 1 April 1986 through 30 March 1988, monthly reported catch totals for all of New Zealand were obtained from Quota Management Returns (QMRs) now maintained by the Ministry of Fisheries. These total New Zealand catches were divided into QMA catches based on landings reported on FSU forms. From 1 April 1988 through 30 September 2001, catches were summarised from monthly returns from QMRs available for each QMA. The QMRs were replaced by Monthly Harvest Returns (MHRs) on 1 October 2001, but the same information is used from these new forms.

There were three periods of relatively high catch in CRA 4: in the 1950s, the late 1960s and during the 1980s (Figure 1). Commercial catches in CRA 4 exceeded 900 t/yr in the 1980s and approached 700 t/yr in the 1950s and late 1960s. There is some uncertainty in the quality of the high catch estimates before the beginning of the FSU system in 1979, but catches in the 1980s were collected when the FSU system was operating and we have confidence in the quality of these catch estimates. Catch estimates generated from the FSU data available to us are consistent with published FSU catch estimates.

4.2.1.2 Recreational catch

Recreational catch estimates are available for four years for CRA 4 (Table 2). However, the two most recent estimates from the National Surveys (Kingett Mitchell, unpublished data) were not accepted by the Rock Lobster Fishery Assessment Working Group (RLWG) in 2003, leaving the two estimates from the 1994 and 1996 surveys. These earlier surveys were considered to be biased by a recent review of the available recreational surveys (unpublished minutes: Recreational Technical Working Group [Auckland NIWA, 10–11 June 2004]), but they remain the best estimates available for rock lobsters in this QMA. For the 2003 CRA 4 assessment, the RLWG agreed to use the mean recreational catch estimate of lobsters taken from the 1994 and 1996 surveys, multiplied by the mean weight of legal lobsters from the SS in the same years that the diary surveys were conducted.

The following procedure, similar to the method used in assessments before 2003, was used to develop a time series of recreational catches for CRA 4 (Figure 1). First, a catch estimate for 1979 onwards is generated from the mean catch in number of lobsters estimated by the 1994 and 1996 surveys and the mean weight of summer-caught lobsters in 1994 and 1996, based on weighted length frequencies from the commercial catch sampling. Mean weight is calculated using proportions-at-size for sampled rock lobsters above the MLS of 54 mm for males and 60 mm for females. Second, the recreational catch in 1945 is assumed to be 20% of the estimate just described. Third, recreational catch from 1946 through 1978 is ramped up proportionately. Finally, we assume that 90% of the recreational catch is taken in the SS and the remaining 10% in the AW.

4.2.1.3 Maori customary catch

MFish Compliance (Appendix C) provided a preliminary estimate of 20 t for customary catches for 2004–05. The 2003 assessment assumed a constant 10 t for this catch category; an allowance of 35 t had been set in 1999 for the CRA 4 customary catch within the TAC (Table 3).

The 2003 CRA 4 assessment assumed that the 10 t estimate was constant from 1945 through 2002. The same approach was adopted for this assessment, but we used the estimate of 20 t supplied by MFish. Customary catch is divided between seasons in the same proportions as recreational catch, with 90% assumed to be taken in the SS.

4.2.1.4 Illegal catch

Illegal catch estimates are based on the assumption that large unreported catches of lobsters were taken before introduction of lobsters into the QMS. Anecdotal evidence suggests that there were many cash sales and unaccounted lobster exports. These are thought to have been reduced after the change to tail width (TW) MLS and the introduction of lobsters to the QMS. Current illegal fishing is believed to be conducted mainly by fish thieves or poachers.

MFish Compliance have provided estimates of illegal catch in CRA 4 for the past decade, sometimes with explanatory comments. There is little consistency in categories provided in each year; it is unclear how data were collected and whether categories are consistent across years (Appendix C). The MFish Compliance category "reported illegal" (Table 4) is equated with the category of "illegal commercial" used in previous rock lobster assessments. This category is assumed to represent illegal commercial catch that is reported to the QMS and therefore subtracted from reported commercial catch to avoid double-counting.

We used the following procedure to prepare the series of illegal catches; it is the same as used in the 2003 assessments of CRA 4 and CRA 5. First, using estimates of export discrepancies for all New Zealand (J. McKoy, NIWA, unpub. data), the CRA 4 illegal catches for 1974 to 1980 are estimated from the ratio of CRA 4 commercial catch to the total New Zealand commercial catch for each year. The average ratio in CRA 4 for 1974 through 1980 was 0.18. Second, this ratio is used to generate an illegal catch estimate for years with no data (1945 through 1973 and 1981 through 1989): the mean ratio is multiplied by the CRA 4 commercial catch.

Third, illegal catch is based on MFish Compliance estimates from 1990 onwards (Table 4), interpolating for years without Compliance estimates (Figure 1).

Fourth, we use the estimates from Table 4 for "commercial illegal" and "reported illegal" to split the illegal catch into the "SL illegal" and "NSL illegal" categories. Estimates of "commercial illegal" for 1990 are much higher than for 1996 and 2002. Such a high level of illegal catch finding its way into the QMR in the early years of the QMS is considered credible in CRA 4 (Daryl Sykes, NZ RLIC, pers. comm.) because of uncertainty in initial application of QMS rules to this fishery. However, by 1996 the "ACE" system was in place and compliance with reporting regulations in CRA 4 was significantly improved. We therefore used the mean "reported illegal" percentage from 1996–97 and 2002–03 (7.5%) for catches from 1996–97 through the projection years. The mean "commercial illegal" percentage for 1990–91 and 1992–93 (80%) is used for 1990–91 to 1995–96. Each mean percentage is subtracted from the reported commercial catch and added to the "NSL illegal" catch.

A small but important change has been made to the interpretation of rock lobster illegal catches for this assessment. Previous assessments applied the "reported illegal" percentage back in time (from 1945 to 1989) to the estimates of illegal catch generated from the mean ratio of the "export discrepancies" relative to the reported commercial. These estimates, although based on estimates of discrepancies between reported catches and export weights, are used to represent the scale of unreported catch before the introduction of rock lobsters into the QMS. But "reported illegal" catches did not exist before the introduction of rock lobster into the QMS. Reported lobsters should all have been caught under fishing regulations of the time and are thus "SL" catch. Unreported catch was probably taken as "NSL" catch, but it does not make sense to shift a percentage of the reported catch from the "SL" to the "NSL" categories. Therefore, it was decided to suspend this adjustment before the 1990–91 fishing year.

We assume that reported and unreported annual illegal catches are distributed between seasons in the same proportions as the commercial catch for each year.

4.2.1.5 Combined catches

Commercial and recreational catches are assigned to the SL catch. Customary catch and both types of illegal catch are assigned to the NSL catch, but reported illegal catch is subtracted from the SL catch to avoid double-counting.

SL and NSL catches are shown by season in Table B2 in Appendix B and plotted in Figure 2. During the first few years' SS seasons, there were no NSL catches because there was no size limit at that time.

Annual catches are divided into seasons (Figure 3) based on a range of data sources. The earliest seasonal information on catches is in the Annala & King (1983) data from January 1963 to December 1973. We use the mean seasonal proportion from the first four years of these data (1963 through 1966) for 1945–62. The FSU/CELR catch reporting system has seasonal information for 1979 through the present. October 1972 to March 1979 is filled in using the mean of seasonal proportions from the years that bracket this period (1971, 1972, 1979 and 1980).

4.2.2 Regulation history

4.2.2.1 Conversion of total length and tail width regulations

Conversion formulae were used to convert MLS regulations and historical data to tail width measurements. Sorenson (1970) provided conversion factors for total length to tail length in inches. Breen et al. (1988) provided conversion factors for tail length to tail width, and conversion factors for carapace length to tail width were obtained from the same study (Breen, unpublished data).

4.2.2.2 MLS regulation history

Annala (1983) provided a summary of regulations in the New Zealand rock lobster fishery to 1982, including the timing of MLS changes. Booth et al. (1994) summarised changes after 1983. These regulations are summarised in Table 5; MLS by period, as used by the model, is shown in Table B2 in Appendix B.

4.2.2.3 Escape gaps

Before June 1970, escape gaps were not required (Annala 1983). Street (1973) discussed the introduction of escape gaps but concluded from limited sampling that they were not effective. Escape gap size from June 1970 was set at 54 by 305 mm except in Otago (Annala 1983). Escape gap regulations were changed again in July 1993. We fitted separate selectivity functions for two epochs: 1945 through 1992 and 1993 to the present.

4.2.2.4 Prohibition on the taking of berried females

From 1945 to the present, taking berried females was allowed only in 1950 and 1951 (Annala 1983). This is so short a period that the different regulation for these two years was not addressed in the model.

4.3 State variables

4.3.1 Biomass indices

CPUE from the commercial fishery is used as an index of biomass available to the commercial fishery. Two sources of catch and effort data were available for CRA 4: 1) catch and the number of potlifts from the FSU and CELR databases held by the Ministry of Fisheries (referred to as "CPUE") and 2) catch and the number of days fished summarised by Annala & King (1983) (referred to as "CR").

4.3.1.1 FSU and CELR data

Catch and effort data for rock lobster were obtained from MFish in the last week of August 2005 (Data request 5986, superseding an extract obtained from MFish in May 2005). These data were loaded into the CRACE database and standard error checks (Bentley et al. 2005) used to process the data.

The estimated catch from the top part of the CELR form is corrected from the landing data using the B4 algorithm (Bentley et al. 2005), first used and described to the RLWG in 2003, which summarises the data for every vessel by month by statistical area cell and corrects total estimated catch from the total landed catch for the cell. Data are excluded for vessel cells where the landed catch is zero and effort is non-zero; in this case data from the following month for that vessel are also excluded. The presumption is that some of the catch landed in the second month was held over from the first month, thus breaking the link between the catch and effort data.

Data span the period 1 April 1979 through 31 March 2005. The analysis is performed on a data set collapsed by vessel, statistical area and month in recognition of the design of the FSU system, which collected much of its data on a monthly basis (Table 6).

The standardisation procedure is similar to that documented by Maunder & Starr (1995), but with a six-month period (model period) rather than a full fishing year. Explanatory variables offered to the model are month and statistical area; in previous analyses other variables had little power to explain model deviance. A separate relative month effect is estimated for each season (AW, SS) by using the month in each period with the lowest standard error as the reference month. The total deviance explained by the model is 30% (Table 7), with most explanatory power lying with model period. This is consistent with other rock lobster standardisation analyses. Residual patterns show some deviation from the lognormal assumption at both tails of the residual distribution (Figure 4).

May and June appear to have the highest relative catchability during the AW and November and December during the SS (Figure 5). Statistical area 915 has the lowest relative catchability while area 913 is the highest (Figure 5). The CPUE series by model period shows a long period of relative stability ending in the lowest observed value for the series in period 95 (AW 1992) (Figure 6). CPUE then rose to a peak at period 108 (SS 1998) and both the AW and SS series decline gradually to the present (period 120, Figure 6).

A comparison between CPUE indices calculated for the 2005 assessment and indices used in the 2003 CRA 4 assessment shows virtually no differences, indicating stability in both the data and data handling procedure (Figure 7). The 2005 procedure is identical to the 2003 procedure and there appears to have been little change in the data.

These indices are shown in Table B2 of Appendix B and in Figure 8.

4.3.1.2 Predictive regression model

When the standardised CPUE by period is regressed against the monthly cumulative estimates of CPUE for the same period, the results show a high level of correlation and potentially good predictive power for both the AW (Table 8; Figure 9) and SS (Table 8; Figure 10). There are patterns to both sets of residuals, with the AW fits showing a "U" shape from July where both the lowest and highest predicted CPUE values seem to be estimated high (Figure 11). The residual pattern for the SS prediction appears to be biased high for the higher CPUE values; this may be indicative of a multiplicative error structure for this model (Figure 12). In general, the predicted CPUEs are reasonably close to the observed CPUE values, with the deviations generally about 0.2 kg/potlift or less from the third month onward. Residuals tend to be slightly larger in the SS than in the AW (Table 9).

The predictive power of the relationship was tested by emulating a procedure that mimics the availability of data. This was done in two steps for each month in a period, beginning with the 1995–96 fishing year (AW period 101 and SS period 102):

- a regression model similar to those plotted in Figure 9 was calculated for the month, using the data available up to the period preceding the fishing year/period in which the calculations are being made, and
- the cumulative unstandardised CPUE was calculated for the fishing year being simulated and this was used to predict the standardised CPUE for that model period.

In this way, the predictive capacity of the model could be tested for each year, using the data available in that fishing year but basing the prediction on the model generated from the previous year's data. Residuals were calculated by subtracting the predicted annual standardised CPUE from the actual standardised CPUE estimate for that year.

The prediction is based on a regression that uses the data available up to the period t-1, the period immediately before the period (t) which is being predicted, to estimate the parameters in the following linear regression:

Eq. 1 $$\mathbf{I} = \mathbf{I}_m^{CUM} \tau_m^{t-1} + \psi_m^{t-1}$$

where $\mathbf{I}$ is a vector of standardised CPUE by period from period 1 to period t-1 and $\mathbf{I}_m^{CUM}$ is a vector of observed cumulative arithmetic CPUE, calculated from the beginning of each period and ending with month m. This vector matches the same periods as those available in the vector $\mathbf{I}$. τ_m^{t-1} is the estimated slope pertaining to month m, and ψ_m^{t-1} is the estimated intercept for month m, both parameters based on the data available from periods 1 to t-1.

The equation for the prediction in period t is then:

Eq. 2 $$\hat{I}_t = I_{m,t}^{CUM} \tau_m^{t-1} + \psi_m^{t-1}$$

where $\hat{I}_t$ is the predicted CPUE for period t and $I_{m,t}^{CUM}$ is the observed cumulative CPUE for month m in period t.

The standardised CPUE used in the regression is from the most recent standardisation, which includes all data through 2004. A more rigorous representation of the predictive power would be to base the standardised index using only the data available up to that year, but adding this capacity was beyond the scope of the present analysis. The analysis presented here assumes that the standardised index for any period will not change with the addition of catch and effort data from succeeding years. The indices tend to be relatively stable across analysis years (see Figure 8).

The model performed well, with reasonable predictive power for AW CPUE beginning with the June data (Figure 13). Even the April data provided some predictive power. The model tended to underestimate the CPUE in the late 1990s, when CPUEs were rising. This trend was reversed as the CPUEs dropped, with the model tending to overestimate the next season's CPUE (Figure 14). The predictive model seems to do better in the SS (Figure 15), although there appears to be more pattern in the SS residuals compared to the AW residuals (Figure 16). When the predictions by month are examined for the two most recent fishing years (Table 10), the model underestimated the SS CPUEs by between 0.0 and 0.18 kg/potlift while the AW predictions were very close with residuals less than ±0.1 kg/potlift.

The model described above was applied to the partial data obtained for model period 121 (AW 2005–06). The cumulative data show that the total CRA 4 catch and effort were well behind the equivalent periods in recent years (Figure 17; Table 11). However, the unstandardised CPUE based on the estimated catches was similar to the 2004 AW period and was lower than the 2002 or 2003 AW periods (Table 11). The prediction for model period 121 was 0.76 kg/potlift, the same value predicted for AW 2004 (Figure 18). This prediction was driven by the 2005 cumulative CPUE for July, which is the same as the equivalent CPUE for AW 2004 (Table 11).

These indices are shown in Table B2 of Appendix B and in Figure 18.

4.3.1.3 Historical data

Monthly catch and effort (days fishing) data from 1963 through 1973 were summarised by Annala & King (1983) and used here to calculate unstandardised catch per day for each season from 1 April 1963 to 31 March 1973. These results are reported in Table B2 of Appendix B and shown in Figure 19.

4.3.1.4 Pre-recruit indices (PRI)

The PRI is based on sub-legal lobsters observed in catch sampling. Length frequency data from the CRA 4 observer catch sampling were summarised from each potlift as the number of lobsters below the MLS by sex, using the male size limit of 54 mm and the female size limit of 60 mm. Berried and maturity states of the females were not used. Only data from 1993 and later were used, because a change in escape gap regulations in that year precludes comparison between earlier and later data. Preliminary analysis of the logbook data for CRA 4 indicated that these data were highly variable and probably not representative of the fleet, and logbook data were excluded from this analysis.

The equivalent analysis was reviewed by the Working Group for the 2004 CRA 3 assessment and the following conclusions noted.

- Significant number of pots with lobsters present were not measured because catch samplers measure every fish in a pot and they only count number of lobsters in subsequent pots without measuring lobsters until they have finished with that pot;
- For pots with catch but with no measurements, it is not possible to know whether pre-recruits were present: for pots without any lobsters, there were obviously no pre-recruits; consequently, the proportion of pots with zero pre-recruits will be biased upwards; it is not possible to use the presence/absence of sub-legal lobster as a dependent variable and
- The Working Group instructed the assessment team to use only the lognormal series as index of pre-recruit abundance. All pots with catch and no measurements are dropped from the analysis, as are pots where the number measured is less than the recorded catch (there are very few of these). Finally, there are a few pots where the recorded catch is zero but there are associated measurements. These pots were included in the analysis.

The standardisation model used depth (treated as a categorical variable in 10 m bins with all depths 60 m or greater pooled), statistical area of capture, month, and period of capture as explanatory variables. As for the CPUE analysis, a lognormal model that regresses the logarithm of pre-recruit numbers against the five available explanatory variables was fitted to the non-zero data observations. A separate relative month effect was estimated for AW and SS by using April and October as the reference months. Periods with fewer than 200 potlifts were dropped from the analysis after the pots with no measured lobster were dropped (Table 12). The analysis fitted the logarithm of pre-recruit numbers against the four available explanatory variables for positive catch records only.

Statistical area and depth were the most powerful explanatory variables (Table 13). Results are reported in Table B2 of Appendix B and in Figure 20.

The PRI index was used only in preliminary model fits; the assessment did not use the PRI index.

4.3.2 Proportions-at-size

Size frequency data from observer catch sampling were binned into 31 2-mm size classes spanning 30 to 92 mm (bin midpoints from 31 to 91 mm) for each sex category (male, immature female and mature female) These model size limits spanned the size range of most lobsters caught and bins were considered small enough to provide good resolution in the model without being affected by measurement error.

There are two main sources of length frequency data – voluntary logbooks and observer catch sampling. The logbook data are available from 1997 through 2004 and observer catch sampling data from 1986 through 2004. The voluntary logbook programme measures lobsters with a precision of 1.0 mm while the observer catch sampling precision is 0.1 mm. The measuring convention for observers is to round down all measured lengths, so 0.5 mm was added to each voluntary logbook measurement before binning to avoid introducing bias to the calculated proportions-at-size.

Each data record offered to the model represents a single period for a single data type. This record may comprise data collected from several months and more than one statistical area. Observations from multiple statistical areas and months within a period are weighted within the record by the proportion of catch taken in each month/area cell. The record is then given a relative weight in the model based on the number of fish measured and the number of days sampled.

Preliminary analyses were performed on the length frequency data to determine the suitability of the data from each source. The sex ratios from the logbook data (Figure 21) showed considerable variation between periods. The CRA 4 logbook data have been collected by one very conscientious operator. While his initiative is highly commendable, data from a single source cannot be considered fully representative of the fishery, and we used only the observer catch sampling data for this assessment.

4.3.2.1 Tag-recapture data

The main sources of tag-recapture data are NZ RLIC tag-recapture experiments; there are no old tag experiments available for CRA 4.

Tagging data for each QMA were extracted from the MFish tag database using SQL code. We used a purpose-built tag processing program (Nokome Bentley, Trophia, unpublished) to exclude data with errors as described by Haist et. al (2005). Animals recaptured in the same period as release are automatically excluded from the data set because the model presumes they haven't moulted.

Each recovery event was summarised in the data file by sex, release and recovery periods, and release and recovery tail widths.

Because the number of recaptures of larger lobsters (larger than 65 mm or smaller than 50 mm and 60 mm for males and females respectively) from CRA 4 was very small, after preliminary trials we included CRA3 and CRA 5 tag-recapture data in the CRA 4 analyses.

Before making a combined data set, we limited the data to males tagged at 46 mm TW or larger and females tagged at 50 mm TW or larger. The rationale was as follows:

- few lobsters below these sizes are seen in the length frequency data: for the larger sizes, the model obtains growth information from both sources, but for small lobsters obtains growth information only from the tagging data;
- growth patterns of smaller lobsters may unduly influence the shape of the growth curve of the larger lobsters, which is the important part of the growth curve and
- growth patterns of smaller lobsters may violate the assumptions of the growth model.

The growth sub-model and model dynamics assume that male lobsters moult twice per year, at midnight of 30 September – 1 October and at midnight 31 March – 1 April. Larger lobsters may not fit this assumption: some may moult only once per year or even less often. Females are assumed to moult only once per year at midnight 31 March – 1 April. Smaller females may not fit this assumption and may moult twice per year.

We first explored whether substantial growth occurs in lobsters that are tagged and recovered in the same period, records normally eliminated by the screening process described above. For most areas and sexes, size increments in these records were dominated by values close to zero and the distributions had a central tendency towards zero (Figure 22). The major exception was for males in CRA 3, where many males less than about 55 mm TW showed growth.

For females, we examined the apparent increments of those that were tagged in one period and recaptured in the next, dividing them into those tagged in AW and those tagged in SS. Under the model assumptions we would expect positive increments from females tagged in SS but not from females tagged in AW. These predictions are generally fulfilled (Figure 23), except that females less than 45 mm TW tagged in AW in CRA 3 tend to show positive increments. This conforms to our belief that smaller females may moult twice per year but that larger females moult only once.

We screened each data set, in addition to the screening done by the basic program, to remove records with negative increments greater than 5 mm and to remove records from tagging projects before 1996 for CRA 3 and CRA 5. The logic was that negative increments larger than 5 mm were almost certainly errors of some kind and that older tagging projects used different tag types from current projects and measured lobsters in carapace length, which was then converted to TW with a regression, introducing some further observation error.

Numbers of males and females in CRA 4 after screening are shown in Table 14. We had 1072 records from CRA 4. We selected additional records, equal to these numbers in total, from CRA 3 and CRA 5. From CRA 3 we chose the 362 most recent records out of 376 available records, and all of the 46 females available. From CRA 5 we randomly selected the remaining records.

Next we examined the fit of one model for outliers. To do this we chose the Schnute model (Schnute 1981) with fixed errors. We chose to exclude those records that produced normalised residuals larger than 4.

A summary of the data by sex and source is shown in Table 14. Tag-recapture data used in the assessment are shown in Figure 24 and Figure 25.

4.3.3 Parameter priors

For all estimated parameters, prior probability distributions ("priors") were assumed after discussions in the Working Group (Table 15). The basis for each non-uniform prior distribution is outlined below.

An informative prior for M was based on estimated M from published studies of temperate lobsters. The standard deviation was arbitrary; it has been used for some years in the rock lobster assessments.

Recruitment deviations were assumed to be normally distributed with mean zero (in log space) and bounds that limit recruitment multipliers to the range 0.10 to 10.0. The normal prior on recruitment deviations implies a lognormal distribution of recruitment.

Priors for the points at which selectivity is maximum for males and females were given means equal to the MLS.

4.4 Other values

Structural and fixed values used in this assessment are shown in Table 16. The maximum seasonal exploitation rate of 0.9 was arbitrary but consistent with previous assumptions.

4.5 Sensitivity trials

4.5.1 McMC sensitivity trials

We ran three McMC sensitivity trials to explore the main areas where we thought modelling choices may have been influencing the base case. These were:

- a "domed" selectivity run with the right hand limb parameter estimated, allowing the model to create cryptic large lobsters,
- a "CPUEpow" run in which the model estimated the relationship between CPUE and biomass and

- a "doubled catch" run in which non-commercial catch estimates were doubled.

All sensitivity trials were summarised from 2000 samples from 1 million McMC simulations.

4.6 Retrospective analysis

Retrospective analysis is a way of testing the predictive ability of a model/data combination. Prediction is the only scientific test of a model, but true predictive testing would take years, in which time both technology and statistical state-of-the-art would have moved ahead to make the model obsolete. A common approach (National Research Council 1998) is retrospective analysis, in which the model's estimates are tested by removing data from one year a time. If the model's biomass trajectory is sensitive to this, then the model's predictive power is suspect.

We conducted four retrospective analyses, removing data from 2005, 2004 and 2003. These were named for the last year of data remaining, thus the third was called the "2002 retrospective". As for McMC sensitivity trials, these were based on 1 million McMC simulations started from the MPD, saving every 500th. We removed CPUE and proportions-at-length data, but tag-recapture data were not removed.

In comparing the results, we compared *Bmin*, *Bref*, *Bproj* and the vulnerable biomass estimated for AW 2002, a point common to all analyses.

5. MODEL MEETS DATA

5.1 Development of a base case

5.1.1 Overview

Notation used here is explained in Appendix A.

This section describes exploratory model runs conducted to develop a base case for the CRA 4 stock assessment. Problems in finding a natural base case included parameter estimates on bounds, exploitation rate on its upper bound and difficulty obtaining acceptable fits to the CPUE data set.

Initial exploratory runs focused on obtaining acceptable fits to the CPUE data while minimising the number of parameters on bounds. These runs pursued "natural" weights for the various data sets (weights that produced standard deviations of normalised residuals (*sdnr*s) close to 1), but with the exception of the CPUE data, where higher weights were applied to ensure visually acceptable fits.

This approach of over-weighting the CPUE data resulted in unrealistically tight marginal posterior distributions for key model outputs. Two additional exploratory approaches were pursued. The first approach was based on fitting separate catchability coefficients ("*q*s", replacing the single $\ln(q^I)$) for two intervals of time. This was based on the premise that changes in the fishery changed the form of the relationship between catch and vulnerable biomass. The second approach was based on down-weighting the length frequency and tagging data, obtaining *sdnr*s <<1 relative to the CPUE data ($sdnr \sim 1$).

5.1.2 Initial exploratory runs

Initial exploratory runs were conducted with an agreed set of protocols. These included:

- fixing the shape of the relation between biomass and CPUE to 1 (a linear relation),

- applying the recruitment residual estimated for 2003 to 2004 and 2005 as well, because there is limited information in the data about the 2004 and 2005 residuals (this made 59 estimated residuals in total),
- after looking at preliminary fits, not fitting to the pre-recruit index,
- estimating the common component of error, $\tilde{\sigma}$, in exploratory runs,
- after looking at preliminary fits, fixing the c.v. of the expected growth increment to 0.5 and
- estimating the standard deviation of observation error in the tag-recapture data.

The main differences among the initial exploratory runs lay in different values used to weight the various datasets, although early runs also varied in which parameters were fixed and the values to which they were fixed. While the initial idea pursued in these runs was to obtain *sdnr*s that were close to 1 for each data set, runs that produced balanced residuals resulted in unacceptable fits to the CPUE data. To obtain credible fits it was necessary to give the CPUE data set additional weight and accept *sdnr*s higher than 1. Additional problems with the initial fits included estimated exploitation rates that struck at the upper bound of 0.90 per season, and other estimated parameters that reached bounds.

From more than 150 initial exploratory runs, four were selected for McMC simulations. Selected runs represented a range of situations with different model parameters at their bounds (runs 1 to 4 in Table 17). Run PAB1 had the lowest maximum exploitation rate, but had three of the four estimated seasonal vulnerabilities on their upper bound of one and a growth parameter on a lower bound. Run PAB3, with the *vulnswitch* at 2 rather than 1 (see Appendix A), had only two estimated vulnerabilities on the upper bound. Fits to the CPUE data series were good for these runs (the fit from run PAB1 is shown in Figure 26).

Run PJS1, with a higher relative weight for CPUE than the other runs, had an unbounded exploitation rate and only one vulnerability parameter on the upper bound. However, this run had a different biomass trajectory from the other runs and had a very high M estimate. Run PJS2 was an independent run that did not over-weight the CPUE nearly as much as the preceding three runs and had few parameters estimated at their bounds. To obtain a credible fit to CPUE (Figure 27), this run decreased the standard deviation of the assumed CPUE process error for the last several years. This run had the maximum exploitation rate against a bound but only two vulnerability parameters on a bound.

Uncertainty was artificially reduced by the conscious decision to over-weight the CPUE data to obtain an acceptable fit. Small differences in data weighting and selection of the *vulnswitch* produced posterior distributions of derived parameters with much less overlap than might be expected (Figure 28 and Table 17); in other words the major uncertainty in the initial exploratory runs was not a result of the data but a result of modelling choices. These results were considered unsatisfactory so two additional approaches, described below, were pursued.

5.1.3 Two catchabilities: runs TQ93 and TQ01

The assessment model was modified to use the CPUE data as two independent series instead of one, by estimating a second catchability coefficient. One set of runs used CPUE from 1979–92 as one series and 1993 to the present as the other; the second group used 1979–2000 and 2001 to the present. The run is chosen from these trials were called TQ93 and TQ01 respectively (runs 5 and 6 in Table 17).

Data sets were weighted to try to obtain *sdnr*s that were as close to 1 as possible. The *vulnswitch*, which determines the sex/season combination with maximum vulnerability, was experimented with but made no difference to the number of vulnerability parameters on the upper bound.

For the best runs for each of TQ01 and TQ93, a trial McMC simulation of one million was run. Basic results are shown in Table 17 and compared with other runs. For TQ93, the two qs were similar: the posterior distribution of their ratio had median 1.03 and 5–95 percentiles of 0.86 to 1.22. The fit to the second series of CPUE is shown in Figure 29. For TQ01, the model estimated a higher q for the second series, implying that fishing efficiency has increased in recent years. The posterior of the ratio of the two *q*s had median 1.53, and 5–95% range of 1.13 to 1.94. The fit to CPUE is shown in Figure 30.

These two runs are among the most pessimistic (Table 17) of all runs: they suggested that current catches are very likely to cause biomass to decrease, the probability of going below *Bmin* is high and the probability of exceeding *Bref* in three years is zero. For the TQ01 run, the number of data in the second CPUE series is limited, which reduces reliability of the second *q* estimate. The similarity of the two *q*s in run TQ93 reflects little evidence that there was a change in catchability around this time. As a result, the TQ93 run is similar to the PJS2 run.

These runs are interesting and suggestive, but the two-*q* approach requires more work: the choice of break in CPUE was completely arbitrary and not based on any external information, and the two *q* parameters were estimated independently, which is unrealistic. The runs are useful for the purpose of sensitivity analysis, but it was considered premature to use this approach to develop a base case run.

5.1.4 Lower data weighting: runs LW1, LW2 and LW3

For the initial exploratory model runs, the magnitude of uncertainty in model parameters was unrealistically small, and only small changes in model structure (e.g., the "*vulnswitch* value) resulted in substantially different biomass trajectories. The high data weighting used in these runs likely contributes to the high parameter confidence. The CPUE data were intentionally over-weighted in these runs, resulting in CPUE *sdnr*s that were much greater than 1 (Table 17). Also, model fits to the proportion-at-size and tag-recapture data show persistent lack of fit to the model assumptions of normal error distributions for these data.

This lack of fit resulted in greater than expected numbers of very small residuals and greater than expected numbers of very large residuals (for an example see Figure 31). The very small residuals are required to balance the very large residuals and thus maintain *sdnr*s that are close to 1 (an outcome of fitting the overall variance parameter, $\tilde{\sigma}$).

A series of runs that down-weighted the LF and tag data was made to investigate model performance, in particular McMC estimates of parameter uncertainty. The lower data weight model runs (runs 7 to 9 in Table 17) were designed to:

- maintain the higher relative weighting for the CPUE data set, as in the initial exploratory models,
- obtain CPUE *sdnr*s of approximately 1 (i.e. "natural" weighting),
- decrease the number of large residuals (say, magnitude greater than 3) from the LF and tag data fits and obtain numbers closer to those expected for a normal distribution and
- maintain close adherence to one of the runs in the initial exploratory set.

Two of the initial exploratory runs were selected for this "data down-weighting" on the basis that they had fewer estimated parameters that were on bounds. These two runs differed in the value of *vulnswitch* and in their dataset weights. Two runs were conducted where the relative dataset weights employed in the initial runs were maintained, and the $\tilde{\sigma}$ parameter (common component of variance) was adjusted and then fixed to increase the overall variance by a factor of about 4: these are run 7 and run 8 in Table 17. In run 9, a variant of run 8, the CR dataset was weighted to achieve an *sdnr* of approximately 1, and tag and LF data weights were increased.

In the MPD fits for runs 7, 8 and 9, the CPUE *sdnr*s were all close to 1 (Table 17), hence the residuals conformed more closely to the assumed underlying distribution. For the other datasets (length frequency and tagging), although the number of very large residuals was reduced and more consistent with the normal distribution assumption the number of very small residuals was considerably greater than expected (see Figure 32 as an example). A future solution to the problem with residual distributions seen here might be to use robust likelihoods.

Although MPD fits for run 7 and run 8 were significantly different, marginal posteriors estimated from the McMC simulations converged to similar distributions. The McMC for Run 9 showed problems in the convergence, seen in the traces, and was rejected as a candidate for the base case on these grounds.

In all lower data weight runs, the McMC results showed larger uncertainty in the marginal posterior distributions than was shown in the initial exploratory runs. Although this is a modelling improvement, it is a less than satisfactory solution because the degree of data down-weighting is *ad hoc* and key management results will be affected by the weights. Again, this issue might benefit from the use of robust likelihoods.

5.2 Base case

From the runs shown in Table 17, run 8 (LW2) was chosen as the base case. Runs 1 through 4 were rejected because of the highly overweighted CPUE data. Runs 5 and 6 (TQ01 and TQ93) were rejected because the approach was too arbitrary and would require more work to pursue. Runs 7 and 9 (LW1 and LW3) had some poor diagnostics in the test McMC chains and both had maximum exploitation rates that were on the upper bound. Run 8 was generally well behaved and was chosen as the base case.

The weights used are shown in Table 16 and *sdnr*s obtained are shown in Table 18. Some parameters were fixed in the base case (Table 16) as follows.

We fixed χ, the exponent of the relation between CPUE and vulnerable biomass, to 1 in the base case and tested this assumption in a sensitivity trial. The $\ln(\tilde{\sigma})$ was fixed at the estimated value to stabilise the estimation.

The minimum observation error ($\varphi^{j,\min}$) and standard deviation of growth observation error ($\varphi^{j,obs}$) were fixed near the values obtained when the model was fit to tagging data only. Preliminary trials and previous assessments showed these parameters to be badly confounded with other growth parameters, leading to instability.

One maturity parameter (m_{95-50}) was fixed at 20. Lobsters in CRA 4 are largely mature at sizes represented in the data, so there is little signal from which to estimate maturity.

Parameters describing the right-hand limb of the selectivity curves were fixed at the value that gives a nearly asymptotic right-hand limb. The consequences of fixing the right-hand limb were explored in a sensitivity trial.

6. ASSESSMENT RESULTS

6.1 Base case MPD

6.1.1 Fits to data

The assessment is based on the posterior distributions estimated through McMC simulation, but in this section we explore the patterns in base case MPD results. MPD estimates are shown in the first column of Table 18.

The fit to standardised CPUE is shown in Figure 33 and the residuals in Figure 34. The model fitted reasonably well to the pattern of CPUE (Figure 33). The model predicted a small spike in CPUE in

1986–87 that does not appear in the data, and underestimated the peak in the late 1990s in both seasons.

Fits to the historical catch rate data were not tight (Figure 35 and Figure 36), but the model tended to underestimate AW catch rates before 1968 and overestimate SS after 1968, leading to seasonal patterns in the residuals.

Fits to proportions-at-length (Figure 37) were variable. The observed proportions showed much variability from year to year, especially in samples with low weights, so some variability in the fit stems from this. Low weights reflect the small sample sizes and poor representativeness of some records. For records with high weights, the fits to males and mature females were reasonably good. There were few immature females in the data and their pattern varied from year to year, so fits to this component were especially poor, but these have little weight in the fitting.

Residuals from the fits to proportion-at-length are shown plotted in different ways in Figure 38 through Figure 41. There were a few very large residuals for males, but most residuals were less than 2. When residuals are plotted against predicted proportions (Figure 38), there was some tendency for residuals to increase with increasing predicted proportions because of the assumed pattern of standard deviations. A box plot of residuals plotted against lobster size (Figure 39) shows that high residuals occurred mainly around the MLS for both males and females. A box plot of residuals plotted against lobster size by season (Figure 40) shows largest residuals just below the MLS for both sexes. In quantile-quantile (q-q) plots of residuals by sex (Figure 41), residuals between 0.05 and 0.05 have been omitted: these came from the many comparisons in which the observed and predicted proportions were both very small. Residuals do not closely follow the theoretical pattern, because this data set is down-weighted and thus has many more small residuals than would otherwise be expected. For immature females, the q-q plots are especially poor, reflecting the small proportions of immature females observed.

Fits to the tag-recapture data were generally good (Figure 42), but again the q-q plot is poor because of the down-weighting for this data set. Residuals from fits to the tag-recapture are plotted in different ways in Figure 43 through Figure 46. Residuals by statistical area, including the CRA 3 and CRA 5 areas, are shown in Figure 43. There was a geographical trend: southern areas 915, 917 and 933 tended to have higher than predicted growth than northern areas; area 909 (furthest north) had the largest negative residuals.

Residuals plotted by the number of re-releases (Figure 44), by the number of periods between release and recapture and by season of release (Figure 45) or by initial size (Figure 46) showed no strong consistent patterns.

6.1.2 MPD trajectories

Total biomass is compared with recruited biomass in Figure 47 for each sex. Total biomass is the start-of-season biomass of lobsters of all sizes, without regard for selectivity or vulnerability. Recruited biomass includes only lobsters above the MLS, without regard for selectivity or vulnerability. The total biomass is much larger than the recruited biomass. Immature females have a relatively small contribution to biomass because they mature at a small size. Males, with a higher growth rate and larger size, contribute the most to both biomass components. Recruited biomass shows a nadir in the late 1980s while total biomass shows a fluctuating pattern.

Vulnerable biomass (Figure 48) takes into account selectivity, vulnerability, MLS and the restrictions on berried females. For consistency this uses the current MLS and selectivity for all years. It shows a pattern similar to that of recruited biomass, but with a nadir near 1986 and much higher biomass afterwards that decreased in recent years. Exploitation rate (Figure 49) peaked near 80% in the mid to late 1980s, declined in the 1990s and switched to lower levels in SS in the mid 1990s.

Recruitment (Figure 50) showed a small spike in 1979 and a very large spike in 1984. There appears to be a declining trend from the early 1990s.

Initial length structure estimated for the base case fit (Figure 51) shows most females maturing by 55 mm and a small plus-group for males. The predicted growth increment (Figure 52) shows a positive predicted increment at the largest model size for males, while the female increment reached zero at 90 mm. Variability of growth was very high for both sexes.

Estimated selectivity-at-size (Figure 53) shows a shift to larger sizes for both males and females in the second epoch after escape gaps requirements were changed in 1993.

Surplus production is calculated as the change in AW biomass between years t and t+1 plus all catches in year t. The trajectory of surplus production plotted against pre-season recruited biomass (Figure 54) indicates a wide range of biomass that produced about 500 t, shows the highest production in 1987, at almost the lowest biomass, and shows two distinctly different production levels from the same level of biomass: one in the 1970s and a much higher level in the mid-1990s. Current surplus production has returned to the lower regime.

6.2 McMC results

6.2.1 Fits to data

From the base case we made one long (4 million simulations) McMC chain starting at the MPD parameter estimates. As we did for the CRA 3 assessment in 2004 (Haist et. al 2005), we focused on the traces (Figure 55) and moving mean and running statistics of estimates as the primary diagnostic for McMC behaviour (Figure 56).

Traces (Figure 55) are mostly well mixed and stable, with some exceptions. The second and third seasonal vulnerability parameters were at the upper bound in the MPD, which causes their estimated variance to be too small and leads to very poorly mixed traces that show trends. But the estimates remain near the upper bound, and this behaviour is inconsequential (it might be better to fix these parameters). Some of the growth parameters take excursions away from the body of the trace, but then return. A much longer chain might be appropriate to estimate the posteriors for these parameters more accurately.

The moving mean and running statistics plots (Figure 56) are mostly acceptable, again with some exceptions. The two seasonal vulnerability parameters show poor diagnostics, as expected from the poorly mixed traces. Some of the growth parameters show wide fluctuations in the moving mean, although the running median is generally stable. The maturity parameter plot looks slightly shaky, and again a longer chain might have been useful. Diagnostic plots for indicators all look acceptable.

Posterior distributions for the objective function value, estimated and some derived parameters are shown in Figure 57. The MPD estimates for estimated parameters are generally near the centre of the posterior distribution; for biomass estimates the MPD estimates tend to be at the low end of the posterior distribution. Posteriors appear to be well determined except for the problem parameters discussed above.

The posterior distributions of fits to CPUE and their residuals are shown in Figure 58 and Figure 59 respectively. The fit is generally good, but the discrepancies noted in the MPD persist in the McMC results: for some years the predicted CPUE never matches the observed, causing a consistent pattern in the residuals. The AW CPUE of 1987 was over-estimated, but most other AW points fitted well. SS CPUE for 1998, 2000 and 2003 were under-estimated, but the SS fishery was much smaller than the AW fishery in these years (see Figure 2).

Posteriors of the fits to historical catch rate and their residuals (Figure 60 and Figure 61) showed the same pattern as the MPD fits discussed above (see Figure 35).

The posterior fit to one example of the proportion-at-length data (AW 2001, Figure 62) and posteriors of residuals (Figure 63) suggest a tight fit despite low weighting of this dataset (the *sdnr* was about 0.25).

6.2.2 Posterior trajectories

Posterior trajectories are shown in Figure 64, Figure 65 and Figure 66 for total, recruited and vulnerable biomass respectively. For vulnerable biomass, uncertainty is small in 1985–95, higher in the last decade and still higher in projections, and is large in the early years of the fishery to about 1970.

Trajectories for SL and NSL exploitation rates (Figure 67 and Figure 68) show patterns similar to the MPD (see Figure 49). They suggest a quite stable exploitation rate in AW since the early 1980s. The SS rate reached low levels in the late 1990s and is now increasing, but remains well below its 1987 peak.

The estimated SS exploitation rate was always well below the model's upper bound. Thus the narrow posterior on estimated vulnerable biomass (see Figure 66) is not caused by a bounded exploitation rate, as in some other assessments.

The posterior trajectory of recruitment deviations (Figure 69) showed a pattern similar to the MPD recruitment (see Figure 50). Most deviations were close to average, but some were consistently high or low in the McMC chain, suggesting that the data (probably proportions-at-length) contain strong recruitment signals for the model. The pattern also suggests a declining recruitment over the past 12 years.

The posterior trajectory of surplus production (Figure 70) shows a base level of about 500 t over much of the fishery history, with about twice that in the late 1980s and again in the mid 1990s. Current surplus production appears to be near 500 t. Because this is based on the AW biomass only, it is an under-estimate of the total.

7. CRA 4 ASSESSMENT

Posterior distributions of estimated and derived parameters were summarised by their median and 5th and 95th percentiles (Table 19, left columns).

Estimated current AW vulnerable biomass, *Bcurr*, has a median of 855 t with 5th to 95th percentiles of 677 to 1068 t. This is well above the reference biomass *Bref*, with a median of 478 t (393–580 t). The ratio of *Bcurr* to *Bref* has a median of 178% (150–212%). Thus current biomass is 1.5 to 2 times the target reference level.

The minimum biomass estimate, *Bmin*, has a median of 360 t (278–455 t). The ratio of *Bcurr* to *Bmin* has a median of 237% (194–295%). Thus current biomass is estimated to be 2–3 times the minimum reference level.

Current exploitation rate was estimated as 25% (21–30%) for the SL catch in AW.

The assessment of the state of the stock is quite optimistic: the current stock appears to be well above both *Bmin* and *Bref* and current exploitation rate is modest.

By contrast with these estimates, projections were uncertain. Biomass increased in 40% of runs, decreased in 60%. Projected biomass, *Bproj*, had a median of 808 t but the 5–95% range was 426–1331 t. The ratio of *Bproj* to *Bcurr* suggests a median expectation of decline, to a median of 94% *Bcurr*, with a wide range (57 to 139%). Projected biomass had a median of 168% *Bref* (92–273%) and a median of 224% of *Bmin*, (123–367%). The chance of biomass falling below *Bref* was 7% and below *Bmin* only 2%.

Projections thus suggest a better than even chance of stock decline, but uncertainty is high: the stock in three years could have decreased by 40% or increased by 40%. The high uncertainty was a major feature of the projections. However, these results suggest that the stock will remain well above *Bmin* and above *Bref*.

7.1 McMC sensitivity trials

Four sensitivity trials were performed, including the retrospective analysis. All sensitivity trials were started from the base case: (LW2, run 8 of Table 17) with only the changes, made singly, discussed below. Each involved an McMC chain of one million simulations, started from the MPD estimate, with 2000 samples saved. Diagnostics are not shown for these trials, for which results are summarised in Table 19.

7.1.1 Domed selectivity

In the first trial, the right-hand limb of the selectivity-at-length was estimated, whereas the shape was fixed (nearly flat, see Figure 53) in the base case. This trial was called the "domed" selectivity trial because the model estimated a relatively steeply declining limb for selectivity (Figure 71).

Although the right-hand limb selectivity parameters were greatly reduced compared with the fixed base case values (Table 19, Figure 71), the function value did not improve very much. *M* tended to decrease, growth rate for larger females decreased slightly and one of the estimated vulnerability parameters came down from the upper bound. The current stock was estimated to be greater, with lower exploitation rate than in the base case, but estimated reference biomass was also greater, so that the ratio of *Bcurr* to *Bref* was about the same as in the base case. Projections were more optimistic, with even chances of increase and decrease, less chance of going below *Bmin* and most runs remaining above reference biomass. The biomass trajectory is shown in Figure 72 and the recruitment trajectory in Figure 73.

7.1.2 Estimated CPUE power parameter

In the second trial, the shape of the relation between CPUE and biomass was estimated; in the base case this had been fixed as a linear relation. This is called the "CPUEpow" trial after the informal name of the shape parameter.

Posteriors are summarised in Table 19. The posterior of the shape parameter (Table 19) had a median near 0.80 (range 0.66 to 0.94), indicating a slight hyperstability in CPUE; again the fit improved only slightly. Most posteriors had only small differences between the base case and this trial, and the summary percentages (the three bottom rows of Table 19) changed hardly at all.

The posterior of biomass trajectory is shown in Figure 74 and the recruitment trajectory in Figure 75. Both are similar to the base case.

7.1.3 Doubled non-commercial catches

In this sensitivity trial, called "double catch", the vectors of all non-commercial catches were doubled, increasing the projected SL catch from 618 t to 660 t, and NSL catch from 60 to 120 t. This sensitivity trial showed very little difference from the base case (Table 19).

The biomass trajectory is shown in Figure 76 and the recruitment trajectory in Figure 77.

7.2 McMC retrospectives

Posteriors are summarised in Table 20. Estimated parameters changed only slightly in these retrospectives, and the tendency was for the projections to become more slightly more optimistic as data were removed: for the 2002 retrospective, 18% of runs increased from period 113, compared with only 10% in the base case. The chances of projected biomass being less than reference levels was least for the 2002 retrospective, but of course this trial's projections started at higher biomass levels than the others.

Biomass trajectories (Figure 78) showed differences in the unfished biomass and in projections, but were all very similar in the 1980s through mid 1990s. Differences are more clearly seen in the exploitation rate trajectories (Figure 79). Recruitment trajectories were nearly the same across all trials (Figure 80).

7.3 Additional projections

Some members of the Working Group requested additional projections. These used projections of the TAC allowances for non-commercial catch, not the current estimates. The current TAC comprises 567 t of commercial catch, 85 t of recreational catch, 35 t of customary catch, and 74 t of illegal catch (10 t of which are reported illegal catch) (Table 21). Using the TAC increased total catch from 678 t, used in the base case, to 761 t, a 12% increase.

Each catch level was translated into the SL and NSL catches (Table 21). The seasonal pattern of these assumed catch combinations followed the assumptions used in the base case projections: commercial catch was divided seasonally in the same way as in 2003 and illegal catch followed the seasonal split for commercial catch.

The posteriors of biomass indicators (Table 22) all shifted to the left (lower values) when the TAC values were used in projections. The probability of a stock decline increased from 60% in the base case to 76%, and the median projected stock size fell from 94% of *Bcurr* in the base case to 84%. The probability of falling below *Bmin* increased from 2% to 6% while that of falling below *Bref* increased from 7% to 16%.

This trial shows the sensitivity of projections to assumptions about future catches.

8. DISCUSSION

8.1 Model and data

Changes to the model for the 2005 assessment were minor: some coding was tested but not used in the assessment; the two-q dynamics was coded in a test during trials to find a base case; all other changes were cosmetic or involved input/output only.

Compiling the data file was relatively straightforward. Preliminary analyses suggested that we should ignore the voluntary logbook data, not because of low quality but because of limited representativeness. Early runs persuaded us to ignore the PRI in finding a base case. We added randomly chosen tag-recapture data from CRA 3 and CRA 5 after first comparing growth estimates from the same overlapping range of sizes, to augment the numbers of females and of larger lobsters in this database. As in most areas, there is a need for more tag-recapture data from larger animals in CRA 4. Apart from these changes, the data file was orthodox.

8.2 Model behaviour

The model/data combination did not behave especially well for CRA 4. Symptoms of this were: exploitation rates that went to their upper bound, other parameters on bounds, great trouble obtaining seasonal vulnerability parameters that were not against the upper bound of 1, difficulty in obtaining a visually acceptable fit to CPUE, high sensitivity to the dataset weights, and poor behaviour in McMCs in trial runs. A substantial part of the assessment workshop was taken up with exploring alternative approaches to try to find a credible base case.

In the exploratory work, the estimated MPD value for *M* varied substantially among trials. As in previous assessments, it is possible that the model uses *M* as an alias for other processes, such as reduced vulnerability of larger lobsters.

At the end of the assessment, the base case appears to be acceptable, but the variety of results obtained in explorations indicates that the base case should be treated cautiously: there is much uncertainty outside the base case results.

The model fitted reasonably well to the data set in the base case, except for the pre-recruit index. It is possible that escape gaps allow such a high proportion of small lobsters to escape that any abundance signal is lost. Growth parameter estimates were not markedly different from the values estimated from tagging data alone.

The McMC sensitivity trials did not, a bit surprisingly, show great differences from the base case results. A strongly domed selectivity curve, an estimated shape for the relation between CPUE and biomass, and doubled non-commercial catches all produced summary results that were similar to the base case results. These trials show that choosing to fix the right-hand limb of selectivity and the CPUE shape parameter are not influential, and that the magnitude of non-commercial catches (we did not test changes in their historical patterns) don't influence results unduly.

Similarly the retrospective trial showed some, not excessive, sensitivity of the model to recent data, in turn suggesting that new data could change the estimates of current and reference biomass, adding to the overall uncertainty of the assessment.

8.3 CRA 4 assessment

The assessment, based on the base case McMC results, suggests a stock that is 2–3 times the limit reference point *Bmin* (Table 19) and well above the target reference point *Bref.* Current exploitation rate is estimated to be 20–30% for the AW fishery on the SL biomass. These indicators suggest a fishery that is in a good position, at least biologically. Some fishers complain that the stock is in poor shape, but the problem is likely to be economic rather than biological. Economic problems may include a high valued New Zealand dollar, high fuel prices and high expectations following the abundance peak of the late 1990s.

Projections are highly uncertain because recruitment is so variable. At the 2005 catch levels, the median expectation is for a slight decrease in biomass over 3 years, to 94% of current biomass, but the range includes a 40% increase and 60% decrease. Risk appears to be low in the base case: risk of falling below *Bmin* is 2% and risk of falling below *Bref* about 7%. Both risks were similar in McMC sensitivity trials, but they varied dramatically in the exploratory trials used in finding a base case (see

Table 17). That variation suggests much uncertainty outside the base case and the sensitivity trials; results should be treated with caution.

The uncertainty caused by catches, illustrated in the comparison between base case results projections and those made using the TAC allowances for non-commercial catches (Table 22), is not extreme, but higher non-commercial catches than those assumed in projections will degrade the stock performance.

Uncertainties are also associated with the model. Foremost among these is the assumption that CPUE is a useful index of abundance. Changes in fishing pattern may affect CPUE, although a simulation (Breen & Kim, unpublished) suggested that changes in spatial and seasonal patterns of fishing did not affect CPUE unduly unless biomass and fishing effort were disconnected, which seems unlikely. Changes in fishing power as a result of technological change may affect CPUE (e.g., Brown et al. 1995), making assessments over-optimistic when based on uncorrected CPUE. Saturation effects may occur, with the same effect (e.g., Groeneveld et al. 2003).

Frusher et al. (2003) suggest that selectivity is more complex than the ways it is usually modelled: larger lobsters may inhibit smaller lobsters from entering, such that selectivity changes over time as the size structure of the population changes in response to fishing. This mechanism would cause standard assessment models to over-estimate recent recruitment.

Another uncertainty arises from aggregating data from a large area, when in reality lobster population processes probably vary over the spatial scale used here (Punt 2003).

These results have been considered by the NRLMG in forming its annual advice to the Minister.

9. ACKNOWLEDGMENTS

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Table 1: Data types and sources for the 2005 assessment of CRA 4. NZ RLIC – New Zealand Rock Lobster Industry Council; FSU – Fisheries Statistics Unit; CELR – Catch and Effort Landing Returns.

Data type	Data source	Begin	End
Historical catch rate	Annala & King (1983)	1963	1973
CPUE	FSU & CELR	1979	2005
Pre-recruit index	MFish	1993	2004
Research proportions-at-size	MFish	1986	2005
Current tag recovery data	NZ RLIC & MFish	1996	2005
Historical MLS regulations	Annala (1983)	1945	2005
Escape gap regulation changes	Annala (1983)	1945	2005

Table 2: Information used to estimate recreational catch for CRA 4.

Category	CRA 4
Catch estimate in numbers	
1994	65 000
1996	118 000
2000	371 000
2001	289 000
Derived values	
1994/1996 average numbers	91 500
1994/96 SS mean weight (kg)	0.510
1994/1996 average catch (kg)	46 709
20% of 1994/1996 average catch (kg)	9 342
1979 scaled catch (kg)	46 709

Table 3: Information used to develop a CRA 4 customary catch estimate.

Year	Data source	CRA 4
1999	Allowance from TAC decision	35 t
2003	Assessment FAR (Kim et al. 2004)	10 t
2005	Email from MFish (Appendix C)	20 t

Table 4: Estimates of illegal catches (t) for CRA 4 used in the 2005 assessment. The estimates by indicated category were provided by MFish Compliance; except for abbreviations this table shows exactly what was supplied. Categories shaded in grey were assumed to have been eventually reported as legal catch in the QMS. Comm. - commercial; Trad. - traditional; Rec. - recreational

Year	Comm.	Non-comm.	Incl. trad.	Illegal	Trad.	Rept illegal	Unrept. illegal	Poaching	Rec.	Illegal comm.	Illegal rec.	Total
1990–91	125	35										160
1992–93	25	5										30
1994–95			70									70
1995–96				64	0							64
1996–97						0	75					75
2001–02				64	0							64
2002–03						9		17	34			60
2004–05								20		10	10	40

Table 5: Summary of historical minimum size limit regulations for CRA 4. Regulation changes through 1959 are taken from Annala (1983); changes from 1988 to 1990 are summarised from table 1 in Booth et al. (1994). Regulations are expressed in inches (") or mm. Equivalent measurements in mm tail width were made using the conversion factors of Sorenson (1970) and Breen et al. (1988 and unpublished). The lower size limit of 5.75 inches tail length was used from 1952 to 1958. Abbreviations: TL, total length; tl, tail length; TW, tail width.

	Regulation		Model interpretation in tail width (mm)	
Year	Males	Females	Males	Females
1945	No limit	No limit	No limit	No limit
1950	9" TL	9" TL	47	49
1952	10" TL or 5.75" tl	10" TL or 5.75" tl	51	53
1959	6" tl	6" tl	53	58
1988	54 mm TW	58 mm TW	54	58
1993	54 mm TW	60 mm TW	54	60

Table 6: Number of vessel/statistical area/month records in the dataset used to calculate the CRA 4 CPUE time series.

Fishing		Model	Statistical Area					
year	Season	period	912	913	914	915	934	Total
1979	AW	69	89	80	92	50	1	312
1979	SS	70	136	113	136	96	1	482
1980	AW	71	101	80	102	61	1	345
1980	SS	72	149	90	135	110	7	491
1981	AW	73	109	72	103	55		339
1981	SS	74	146	76	122	97	1	442
1982	AW	75	122	66	117	64	1	370
1982	SS	76	147	98	157	108	3	513
1983	AW	77	109	84	121	74	2	390
1983	SS	78	137	111	157	101	5	511
1984	AW	79	99	91	137	73	3	403
1984	SS	80	118	96	149	91	5	459
1985	AW	81	112	77	134	71	1	395
1985	SS	82	133	79	158	97	8	475
1986	AW	83	102	85	131	67		385
1986	SS	84	127	103	152	85	6	473
1987	AW	85	98	80	125	53		356
1987	SS	86	121	94	160	79	3	457
1988	AW	87	94	71	127	54	2	348
1988	SS	88	105	92	149	66		412
1989	AW	89	99	93	126	47	2	367
1989	SS	90	125	112	168	67	6	478
1990	AW	91	93	85	115	58	2	353
1990	SS	92	114	98	147	76	3	438
1991	AW	93	118	103	150	50	3	424
1991	SS	94	127	105	146	62	5	445
1992	AW	95	140	111	124	51	2	428
1992	SS	96	145	119	120	59	7	450
1993	AW	97	137	102	138	60	7	444
1993	SS	98	99	98	85	48	4	334
1994	AW	99	96	107	163	63	17	446
1994	SS	100	54	81	58	39	12	244
1995	AW	101	81	89	166	46	12	394
1995	SS	102	42	55	45	17	1	160
1996	AW	103	89	65	147	67	4	372
1996	SS	104	29	12	19	11		71
1997	AW	105	85	55	146	43		329
1997	SS	106	16	5	19	9		49

Table 6 continued.

Fishing Year	Season	Model period	Statistical Area 912	913	914	915	934	Total
1998	AW	107	94	44	138	48		324
1998	SS	108	22	9	17	13		61
1999	AW	109	90	58	140	53	4	345
1999	SS	110	23	2	20	8	4	57
2000	AW	111	106	46	102	46	9	309
2000	SS	112	31	9	19	14	2	75
2001	AW	113	92	67	112	57	13	341
2001	SS	114	38	26	26	10		100
2002	AW	115	81	80	114	52	4	331
2002	SS	116	41	27	48	21		137
2003	AW	117	61	80	110	44		295
2003	SS	118	42	42	46	28		158
2004	AW	119	65	62	115	44	5	291
2004	SS	120	64	51	73	30	4	222
		Total	4 893	3 836	5 826	2 893	182	17 630

Table 7: Proportion of the total deviance explained by each variable in the CRA 4 standardised CPUE model.

Variable	Iteration 1	2	3
Period	0.2273		
Month	0.0471	0.2708	
Area	0.0238	0.2558	0.2983
Additional deviance explained	0.0000	0.0435	0.0275

Table 8: Regression parameters for each month from the relations plotted in Figure 9 and Figure 10 and described in Eq 1. Months with potential good predictive power have been shaded grey.

Month	Slope	Sigma slope	Intercept	Sigma intercept	R^2
AW					
April	0.705	0.120	0.183	0.119	0.726
May	0.750	0.091	0.073	0.098	0.840
June	0.861	0.085	-0.033	0.090	0.887
July	0.916	0.070	-0.025	0.070	0.929
August	0.972	0.073	-0.019	0.067	0.932
September	0.973	0.061	-0.015	0.057	0.951
SS					
October	1.338	0.076	-0.132	0.087	0.960
November	1.203	0.086	-0.085	0.106	0.938
December	1.132	0.102	-0.039	0.131	0.904
January	1.051	0.091	0.006	0.122	0.911
February	1.065	0.066	-0.016	0.088	0.953
March	1.082	0.064	-0.029	0.085	0.956

Table 9: Residual statistics for each month from the relations plotted in Figure 9 and Figure 10. Each average treats the months independently.

Month	Minimum	Maximum	5%	95%
AW				
April	-0.343	0.271	-0.343	0.271
May	-0.243	0.227	-0.243	0.227
June	-0.244	0.202	-0.244	0.202
July	-0.213	0.144	-0.213	0.144
August	-0.207	0.173	-0.207	0.173
September	-0.181	0.105	-0.181	0.105
Average	-0.343	0.271	-0.207	0.202
SS				
October	-0.189	0.170	-0.189	0.170
November	-0.256	0.300	-0.256	0.300
December	-0.373	0.437	-0.373	0.437
January	-0.257	0.495	-0.257	0.495
February	-0.233	0.309	-0.233	0.309
March	-0.221	0.313	-0.221	0.313
Average	-0.373	0.495	-0.221	0.300

Table 10: Comparison of cumulative unstandardised monthly CPUE with the annual standardised CPUE and the model's prediction of standardised CPUE for the two most recent fishing years with data. Residuals for each prediction are also provided.

	2003–04				2004–05			
	Cumulative CPUE	Standard-ised CPUE	Predicted CPUE	Residual (kg/potlift)	Cumulative CPUE	Standard-ised CPUE	Predicted CPUE	Residual (kg/potlift)
AW								
April	1.17	0.99	1.00	-0.01	0.64	0.72	0.63	0.10
May	1.06	0.99	0.86	0.13	0.92	0.72	0.77	-0.05
June	1.15	0.99	0.96	0.03	0.95	0.72	0.78	-0.06
July	1.09	0.99	0.97	0.02	0.86	0.72	0.76	-0.04
August	1.02	0.99	0.97	0.02	0.82	0.72	0.78	-0.06
September	0.99	0.99	0.95	0.04	0.78	0.72	0.74	-0.02
SS								
October	1.21	1.65	1.47	0.18	1.08	1.36	1.31	0.05
November	1.32	1.65	1.48	0.17	1.10	1.36	1.22	0.14
December	1.35	1.65	1.47	0.18	1.16	1.36	1.27	0.10
January	1.47	1.65	1.53	0.12	1.29	1.36	1.36	0.00
February	1.48	1.65	1.55	0.10	1.27	1.36	1.34	0.02
March	1.47	1.65	1.55	0.11	1.26	1.36	1.33	0.03

Table 11: Monthly values for cumulative catch (estimated in tonnes), cumulative potlifts (thousands) and the associated CPUE (kg/potlift) for the four most recent AW seasons. Values for the month of July have been shaded grey.

Month	Cumulative catch (t)	Cumulative potlifts (1000s)	Cumulative CPUE (kg/potlift)
AW 2002			
April	34.4	48.7	0.706
May	104.8	120.6	0.869
June	240.9	215.2	1.120
July	312.8	290.3	1.077
August	361.4	362.7	0.996
September	441.7	441.4	1.001
AW 2003			
April	25.3	21.7	1.168
May	79.3	75.0	1.058
June	189.3	164.2	1.153
July	267.4	245.7	1.088
August	290.5	286.0	1.016
September	349.1	351.9	0.992
AW 2004			
April	18.7	29.1	0.642
May	72.1	78.2	0.922
June	177.2	187.5	0.945
July	217.1	253.8	0.855
August	231.1	282.6	0.818
September	247.6	318.5	0.778
AW 2005			
April	6.3	9.5	0.658
May	62.1	55.3	1.122
June	107.3	107.2	1.001
July	142.1	165.5	0.859

Table 12. Number of potlift records in the dataset, by period and data source for sampling data (logbook or catch sampling), used to calculate the CRA 4 PRI time series. Periods shaded with grey with less than 200 potlifts were dropped from the analysis, as were all the logbook data.

Fishing			Before pruning data			After pruning
year	Season	Period	Catch sampling	Logbook	Total	Catch sampling
1993	AW	97	112		112	
1993	SS	98	2 188		2 188	1 953
1994	AW	99	195		195	
1994	SS	100	1 184		1 184	1 143
1995	AW	101	206		206	
1995	SS	102	1 428		1 428	1 414
1996	AW	103	711		711	681
1996	SS	104			0	
1997	AW	105	4 425	205	4 630	3 719
1997	SS	106	8	8	16	
1998	AW	107	3 217	94	3 311	2 403
1998	SS	108	80	80	160	
1999	AW	109	2 712	119	2 831	2 231
1999	SS	110				
2000	AW	111	2 740	23	2 763	2 118
2000	SS	112				
2001	AW	113	3 204		3 204	2 881
2001	SS	114	776		776	605
2002	AW	115	4 082	176	4 258	3 796
2002	SS	116	651	24	675	600
2003	AW	117	4 095		4 095	3 826
2003	SS	118	709		709	464
2004	AW	119	2 815		2 815	2 360
2004	SS	120	1 582		1 582	1 368
		Total	37 120	729	37 849	31 562

Table 13: Proportion of the total deviance explained by each variable in the CRA 4 lognormal standardised PRI model.

			Iteration	
Variable	1	2	3	4
Period	0.0257			
Area	0.1341	0.1642		
Depth interval	0.0076	0.0320	0.1800	
Month	0.0049	0.0331	0.1734	0.1915
Additional deviance explained	0.0000	0.1385	0.0157	0.0115

Table 14: Summary of the number and sources of tag recoveries from CRA 4 used in the 2005 assessment.

	Male	Female	Total
CRA 4	722	350	1 072
CRA 3	361	46	407
CRA 5	360	307	667
Total	1 443	703	2 146

Table 15: Parameters estimated in the model, their informal names, upper and lower bounds and base case prior distributions. Parameters were estimated in several phases as shown; in phase 2, for instance, all parameters of phase 2 or less are estimated and the others remain at their initial values. Prior types: U, uniform; N, normal; L, lognormal. For definitions of parameters see Appendix A.

Parameter	Informal name	Function	Phase	LB	UB	Type	Mean	c.v.
$\ln(R_0)$	ln*R0*	Natural log of base recruitment	1	1	25	U	–	–
ε_y	Rdevs	Recruitment deviation parameters	3	-2.3	2.3	N	0	0.4
M	*M*	Natural mortality	1	0.01	0.35	L	0.12	0.4
$\ln(q^I)$	ln(*q*)	Log of catchability for CPUE	1	-25	0	U	–	–
$\ln(q^{CR})$	ln(*qCR*)	Log of catchability for CR	1	-25	0	U	–	–
$\ln(q^{PRI})$	ln(*qPRI*)	Log of catchability for PRI	1	-25	0	U	–	–
d_{50}^{male}	*Galpham*	Growth at 50 mm	2	1	8	U	–	–
d_{50}^{female}	*Galphaf*	Growth at 50 mm	2	1	20	U	–	–
d_{50-80}^{male}	*Gdiffm*	Growth diff. between 50 and 80 mm	2	0.001	30	U	–	–
d_{50-80}^{female}	*Gdifff*	Growth diff. between 50 and 80 mm	2	0.001	30	U	–	–
h^{male}	*Gshapem*	Shape parameter for growth	4	0.1	10	U	–	–
h^{female}	*Gshapef*	Shape parameter for growth	4	0.1	10	U	–	–
m_{50}	*mat50*	Size at 50% maturation	4	0	60	U	–	–
r_{SS}^{male} etc.	*vuln*	Relative seasonal vulnerability	2	0.01	1	U	–	–
η_1^{male}	*Smax1m*	Male size at maximum selectivity, Epoch 1	3	10	80	N	54	2
η_1^{female}	*Smax1f*	Feale size at maximum selectivity, Epoch 1	3	10	80	N	60	2
η_2^{male}	*Smax2m*	Male size at maximum selectivity, Epoch 2	3	10	80	N	54	2
η_2^{female}	*Smax2f*	Feale size at maximum selectivity, Epoch 2	3	10	80	N	60	2
$v_1^{male,l}$	*SVL1m*	Shape of left-hand limb selectivity	2	1	50	U	–	–
$v_1^{female,l}$	*SVL1f*	Shape of left-hand limb selectivity	2	1	50	U	–	–
$v_2^{male,l}$	*SVL2m*	Shape of left-hand limb selectivity	2	1	50	U	–	–
$v_2^{female,l}$	*SVL2f*	Shape of left-hand limb selectivity	2	1	50	U	–	–

Table 16: Structural and fixed values used in the base case assessment. For definitions of parameters see Appendix A.

Variable	Function	Value
$\bar{S}_1$	lower edge of smallest size bin	30
$\bar{S}_{s_{max}}$	centre of largest size bin	91
s_{max}	number of size bins	31
a^{male}	scalar of length-weight relation	4.16E-06
a^{female}	scalar of length-weight relation	1.30E-05
b^{male}	exponent of length-weight relation	2.935
b^{female}	exponent of length-weight relation	2.545
ϕ	mean size of recruits	32
γ	std. dev. of size of recruits	2
U^{max}	maximum exploitation rate per period	0.9
f_k^g	moult probability for sex g in season k	males: AW 1 SS 1 females: AW 0, SS 1
λ	shape parameter for mixing left and right halves of selectivity curves	5
w^g	shape parameter for the right hand limb of the selectivity curve for sex g	200
	handling mortality rate multiplier on SL fishery exploitation rate	0.1
χ	shape of biomass - CPUE relation	Fixed at 1.0
$\ln(\tilde{\sigma})$	Log of common sigma	Fixed at -2.2
$\varphi^{j,\min}$	Minimum observation error in increment	Fixed at 1
$\sigma^{j,obs}$	Standard deviation of observation error	Fixed at 2.68
m_{95-50}	Difference between sizes at which 50% and 95% of females mature	Fixed at 5.86
ϖ^{I}	Relative weight applied to CPUE likelihoods	0.317186
ϖ^{CR}	Relative weight applied to CR likelihoods	0.05
ϖ^{PRI}	Relative weight applied to PRI likelihoods	–
ϖ^{p}	Relative weight applied to proportions-at-size	1.25
ϖ^{TAG}	Relative weight applied to tagging data	0.05
	CPUE process error	0.25
	Sigma for catch rate (CR)	0.3
	Sigma for pre-recruit index (PRI)	0.3
	Assumed maximum seasonal vulnerability	AW females
	Switch from Epoch 1 to Epoch 2 (selectivity change)	SS 1993
	Projected size-limited catch (t)	618
	Projected not size-limited catch (t)	60

Table 17: Summary of the exploratory runs. The percentages in the last three lines for run 8 are taken from the final McMC of 4 million runs.

	Initial exploratory runs				Two-*q* runs		Lower data weight runs		
Run	1	2	3	4	5	6	7	8	9
Name	PAB1	PAB3	PJS1	PJS2	TQ01	TQ93	LW1	LW2	LW3
Chain (millions)	4	4	4	4	1	1	1	4	0.3
vulnswitch	1	2	3	2	2	2	3	2	2
Extra process error	No	No	No	Yes	No	No	No	No	No
sigmatilde	Est.	Est.	Est.	Est.	Est.	Est.	Fixed	Fixed	Fixed
M (MPD value)	0.142	0.173	0.308	0.137	0.218	0.137	0.270	0.259	0.256
sdnr CPUE1	3.41	4.16	5.95	1.72	1.05	1.40	1.12	1.09	1.05
sdnr CPUE2	–	–	–	–	1.00	0.93	–	–	–
q2/q1	–	–	–	–	1.60	0.99	–	–	–
sdnr LFs	0.90	0.85	0.62	0.98	1.00	1.00	0.22	0.23	0.34
sdnr tags	1.04	1.04	1.04	1.04	1.04	1.04	0.36	0.35	0.42
Max*ERate*				on bound	on bound	on bound	on bound	0.79	on bound
Pars on bounds	3 *vuln* lb*Gdiff1*	2 *vuln* lb*Gdiff2*	1 *vuln*	2 *vuln*	3 *vuln*	3 *vuln*	1 *vuln*	2 *vuln*	2 *vuln*
P(Bproj<Bcurrent)	96%	89%	46%	98%	70%	91%	64%	60%	85%
P(Bproj<Bmin	21%	12%	0%	46%	73%	27%	2%	2%	10%
P(Bproj<Bref)	71%	40%	0%	97%	100%	100%	9%	7%	30%

Table 18: MPD parameter estimates and summaries of the posterior distributions of negative log likelihoods and performance indicators from the CRA 4 base case. LF refers to proportions-at-size data. The last three rows show probabilities.

	MPD	0.05	Median	0.95
f	1156.2	1188.2	1198.5	1209.5
Ln*R0*	14.99	14.69	14.94	15.22
M	0.259	0.216	0.269	0.316
Ln*q1*	-6.72	-7.05	-6.87	-6.71
Ln*qCR*	-2.86	-3.42	-2.98	-2.46
Galpham	1.66	1.44	1.58	1.73
Galphaf	3.22	2.49	3.15	3.61
GBetam	1.22	0.89	1.26	1.51
GBetaf	0.69	0.03	1.04	1.75
Gdiffm	0.44	0.04	0.32	0.76
Gdifff	2.53	0.81	2.11	3.42
Gshapem	6.97	6.32	8.42	10.47
Gshapef	3.89	2.86	5.45	10.82
mat50	52.8	31.9	45.2	53.9
vuln1	0.810	0.731	0.790	0.853
vuln2	1.000	0.956	0.977	0.999
vuln3	1.000	0.990	0.997	1.000
vuln4	0.570	0.516	0.595	0.681
SVL1m	3.09	2.17	3.23	4.53
SVL1f	5.14	4.07	6.66	9.38
SVL2m	3.06	2.46	3.00	3.61
SVL2f	4.29	3.21	4.30	5.47
SMax1m	52.4	51.1	52.4	53.7
SMax1f	58.7	57.4	60.8	65.0
SMax2m	54.2	53.4	54.0	54.7
SMax2f	61.4	60.5	61.8	63.2
Bmin	300	278	360	455
Bref	400	393	478	580
Bcurr	742	677	855	1068
Bproj	–	426	808	1331
Bcurr/Bmin	247%	194%	237%	295%
Bcurr/Bref	186%	150%	178%	212%
Bproj/Bcurr	–	57%	94%	139%
Bproj/Bmin	–	123%	224%	367%
Bproj/Bref	–	92%	168%	273%
Ucurr	29%	21%	25%	30%
Uproj	–	18%	27%	45%
Uproj/Ucurr	–	76%	111%	167%
P*(Bproj<Bcurr)*		60%		
P*(Bproj<Bmin)*		2%		
P*(Bproj<Bref)*		7%		

Table 19: Summary statistics (median, 5th and 95th percentiles) for posterior distributions from McMC simulations for the CRA 4 base case and three sensitivity trials described in the text. Shading indicates fixed parameters. The last three rows show probabilities.

	Basecase			Domed			CPUEpow			Double catch		
	0.05	Median	0.95	0.05	Median	0.95	0.05	median	0.95	0.05	Median	0.95
f	1188.2	1198.5	1209.5	1185.6	1194.9	1206.3	1185.4	1194.6	1205.7	1190.6	1200.3	1212.3
Ln*R0*	14.69	14.94	15.22	14.66	14.95	15.29	14.69	15.00	15.43	14.84	15.08	15.36
M	0.216	0.269	0.316	0.168	0.215	0.264	0.230	0.267	0.306	0.221	0.256	0.299
CPUEpow	1	1	1	1	1	1	0.66	0.79	0.94	1	1	1
Ln*qI*	-7.05	-6.87	-6.71	-7.29	-7.01	-6.78	-6.46	-5.42	-4.52	-7.17	-7.00	-6.82
Ln*qCR*	-3.42	-2.98	-2.46	-3.36	-2.91	-2.38	-3.41	-3.00	-2.50	-3.60	-3.15	-2.68
Galpham	1.44	1.58	1.73	1.38	1.52	1.66	1.39	1.49	1.65	1.41	1.53	1.67
Galphaf	2.49	3.15	3.61	2.94	3.30	3.68	3.01	3.30	3.64	2.62	3.16	3.66
GBetam	0.89	1.26	1.51	0.99	1.32	1.51	0.74	1.35	1.51	0.90	1.29	1.51
GBetaf	0.03	1.04	1.75	-0.44	0.71	1.39	-0.17	0.74	1.39	0.05	1.09	1.76
Gdiffm	0.04	0.32	0.76	0.02	0.17	0.59	0.01	0.13	0.90	0.02	0.22	0.72
Gdifff	0.81	2.11	3.42	1.66	2.58	4.02	1.74	2.55	3.72	0.94	2.07	3.50
Gshapem	6.32	8.42	10.47	6.26	8.74	10.44	4.70	8.81	10.89	6.45	8.60	10.51
Gshapef	2.86	5.45	10.82	2.30	4.60	7.65	2.71	4.59	6.00	3.12	5.50	9.41
mat50	31.9	45.2	53.9	39.0	50.2	54.8	31.7	46.8	54.1	32.0	46.7	54.2
vuln1	0.731	0.790	0.853	0.752	0.821	0.892	0.756	0.823	0.896	0.735	0.790	0.850
vuln2	0.956	0.977	0.999	0.929	0.944	0.997	0.979	0.992	0.998	0.955	0.977	0.995
vuln3	0.990	0.997	1.000	0.617	0.840	0.987	0.996	0.999	1.000	0.975	0.994	0.999
vuln4	0.516	0.595	0.681	0.414	0.522	0.623	0.454	0.536	0.622	0.508	0.582	0.674
SVL1m	2.17	3.23	4.53	2.58	3.62	4.87	2.57	3.48	4.71	2.12	3.06	4.10
SVL1f	4.07	6.66	9.38	2.14	3.58	5.09	3.97	5.97	8.36	3.83	6.38	9.12
SVL2m	2.46	3.00	3.61	2.16	2.70	3.27	2.52	3.02	3.57	2.42	2.95	3.53
SVL2f	3.21	4.30	5.47	4.08	5.24	6.57	3.35	4.42	5.65	3.29	4.31	5.45
SMax1m	51.1	52.4	53.7	51.6	52.8	53.9	51.9	53.0	54.4	51.2	52.4	53.5
SMax1f	57.4	60.8	65.0	54.9	56.2	57.5	57.3	60.0	63.2	57.0	60.3	64.3
SMax2m	53.4	54.0	54.7	53.0	53.6	54.3	53.5	54.1	54.8	53.4	54.0	54.6
SMax2f	60.5	61.8	63.2	60.9	62.1	63.5	60.4	61.6	62.9	60.6	61.8	63.3
SVRm	200	200	200	6.99	10.00	21.24	200	200	200	200	200	200
SVRf	200	200	200	4.21	5.75	8.02	200	200	200	200	200	200

Table 19 continued.

	Basecase			Domed			CPUEpow			Double catch		
	0.05	Median	0.95	0.05	Median	0.95	0.05	median	0.95	0.05	Median	0.95
Bmin	278	360	455	310	438	602	213	295	386	309	403	508
Bref	393	478	580	443	576	753	333	412	508	434	533	653
Bcurr	677	855	1068	738	961	1265	628	788	1001	759	963	1216
Bproj	426	808	1331	579	971	1512	362	725	1231	488	899	1514
Bcurr/Bmin	194%	237%	295%	179%	218%	281%	211%	268%	360%	195%	238%	294%
Bcurr/Bref	150%	178%	212%	140%	166%	200%	158%	191%	237%	150%	180%	216%
Bproj/Bcurr	57%	94%	139%	69%	100%	141%	52%	91%	141%	57%	94%	141%
Bproj/Bmin	123%	224%	367%	140%	219%	349%	126%	244%	433%	121%	223%	379%
Bproj/Bref	92%	168%	273%	107%	166%	252%	90%	174%	300%	93%	168%	280%
Ucurr	21%	25%	30%	17%	22%	28%	22%	27%	32%	19%	23%	28%
Uproj	18%	27%	45%	16%	24%	36%	19%	31%	49%	17%	26%	40%
Uproj/Ucurr	76%	111%	167%	77%	108%	147%	76%	113%	173%	76%	111%	165%
P(*Bproj*<*Bcurr*)		60%			50%			62%			60%	
P(*Bproj*<*Bmin*)		2%			0%			2%			2%	
P(*Bproj*<*Bref*)		7%			3%			8%			7%	

Table 20: Parameter estimates from McMC retrospective analysis compared with the base case.

	Basecase			Retro04			Retro03			Retro02		
	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95
f	1188.2	1198.5	1209.5	1270.2	1280.6	1291.9	1748.5	1757.7	1769.2	2129.0	2138.5	2149.9
Ln*R0*	14.69	14.94	15.22	14.71	14.95	15.24	14.58	14.97	15.49	14.62	14.89	15.37
M	0.216	0.269	0.316	0.218	0.265	0.314	0.177	0.252	0.306	0.208	0.262	0.314
Ln*qI*	-7.05	-6.87	-6.71	-7.05	-6.88	-6.70	-7.17	-6.96	-6.78	-7.22	-6.99	-6.79
Ln*qCR*	-3.42	-2.98	-2.46	-3.44	-2.99	-2.48	-3.53	-3.10	-2.62	-3.52	-3.07	-2.56
Galpham	1.44	1.58	1.73	1.43	1.55	1.71	1.40	1.53	1.74	1.39	1.55	1.72
Galphaf	2.49	3.15	3.61	2.58	3.15	3.67	2.00	2.97	3.51	1.91	2.13	3.24
GBetam	0.89	1.26	1.51	0.92	1.28	1.52	0.70	1.25	1.48	0.91	1.31	1.52
GBetaf	0.03	1.04	1.75	0.00	1.01	1.68	0.00	1.10	1.89	0.76	1.81	2.04
Gdiffm	0.04	0.32	0.76	0.03	0.27	0.70	0.03	0.27	0.97	0.02	0.22	0.71
Gdifff	0.81	2.11	3.42	0.97	2.13	3.58	0.20	1.89	3.42	0.03	0.28	2.48
Gshapem	6.32	8.42	10.47	6.49	8.50	10.29	5.46	8.14	9.95	7.35	9.63	11.48
Gshapef	2.86	5.45	10.82	3.01	5.23	8.33	2.14	4.71	11.50	3.97	13.70	16.08
mat50	31.9	45.2	53.9	31.7	44.1	53.3	32.2	44.7	54.3	31.2	44.6	53.0
vuln1	0.731	0.790	0.853	0.734	0.789	0.847	0.760	0.831	0.917	0.761	0.828	0.911
vuln2	0.956	0.977	0.999	0.981	0.989	0.998	0.984	0.994	0.999	0.971	0.993	0.999
vuln3	0.990	0.997	1.000	0.993	0.997	1.000	0.985	0.996	1.000	0.979	0.991	0.998
vuln4	0.516	0.595	0.681	0.520	0.595	0.687	0.543	0.644	0.785	0.552	0.664	0.800
SVL1m	2.17	3.23	4.53	2.36	3.30	4.48	2.21	3.18	4.35	2.16	3.38	4.72
SVL1f	4.07	6.66	9.38	4.07	6.60	9.05	3.82	6.25	8.98	4.65	7.45	9.58
SVL2m	2.46	3.00	3.61	2.47	3.03	3.59	2.58	3.21	3.84	2.58	3.18	4.00
SVL2f	3.21	4.30	5.47	3.32	4.30	5.54	3.60	4.78	6.08	3.56	4.71	6.09
SMax1m	51.1	52.4	53.7	51.4	52.5	53.7	51.2	52.4	53.7	51.1	52.4	53.7
SMax1f	57.4	60.8	65.0	57.4	60.7	64.6	57.1	60.3	65.3	58.4	63.3	66.0
SMax2m	53.4	54.0	54.7	53.4	54.0	54.6	53.5	54.2	55.0	53.4	54.1	55.0
SMax2f	60.5	61.8	63.2	60.6	61.7	63.1	60.8	62.3	63.8	61.1	62.7	64.3
Bmin	278	360	455	277	364	465	300	403	526	316	421	552
Bref	393	478	580	391	482	588	429	533	666	439	551	700
B115	1011	1163	1366	1017	1173	1372	1093	1294	1572	1079	1310	1638
Bproj	426	808	1331	434	772	1168	612	1004	1567	620	1061	1650

Table 20 continued.

	Basecase			Retro04			Retro03			Retro02		
	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95
B115/Bmin	281%	324%	386%	279%	323%	387%	282%	323%	383%	269%	312%	371%
B115/Bref	222%	244%	269%	221%	244%	272%	223%	244%	268%	215%	239%	265%
Bproj/B115	38%	69%	113%	38%	65%	98%	49%	77%	118%	49%	80%	120%
Bproj/Bmin	123%	224%	367%	122%	211%	325%	155%	249%	401%	150%	250%	400%
Bproj/Bref	92%	168%	273%	95%	159%	239%	119%	188%	289%	115%	191%	295%
U113	34%	40%	46%	34%	40%	46%	30%	37%	43%	29%	36%	43%
Uproj	18%	27%	45%	25%	35%	52%	26%	37%	54%	28%	41%	62%
Uproj/U113	46%	69%	109%	64%	88%	127%	72%	102%	140%	82%	116%	166%
P*(Bproj<Bcurr)*		90%			96%			85%			82%	
P*(Bproj<Bmin)*		2%			2%			0%			0%	
P*(Bproj<Bref)*		7%			7%			1%			2%	

Table 21: Summary of the catch levels (t) used in additional projections. The catch model assumes a small percentage of "reported illegal" catch that is subtracted from the commercial catch.

Catch category	Size-limited (SL) catch			Not size-limited (NSL) catch			
	Comm.	Rec.	Total	Reported illegal	Unreported illegal	Cust.	Total
Base case	571	47	618	5	35	20	60
TAC allowances	567	85	652	10	64	35	109

Table 22: Summary of indicators from additional three-year projections made under the base case and additional projections (Table 21).

	Base case			TAC		
	0.05	Median	0.95	0.05	Median	0.95
Bproj	426	808	1331	344	722	1237
Bcurr/Bmin	194%	237%	295%	194%	237%	295%
Bcurr/Bref	150%	178%	212%	150%	178%	212%
Bproj/Bcurr	57%	94%	139%	46%	84%	128%
Bproj/Bmin	123%	224%	367%	101%	200%	338%
Bproj/Bref	92%	168%	273%	75%	150%	253%
Ucurrent	21%	25%	30%	21%	25%	30%
Uproj	18%	27%	45%	20%	31%	52%
Uproj/Ucurrent	76%	111%	167%	85%	126%	195%
P*(Bproj<Bcurr)*		60%			76%	
P*(Bproj<Bmin)*		2%			6%	
P*(Bproj<Bref)*		7%			16%	

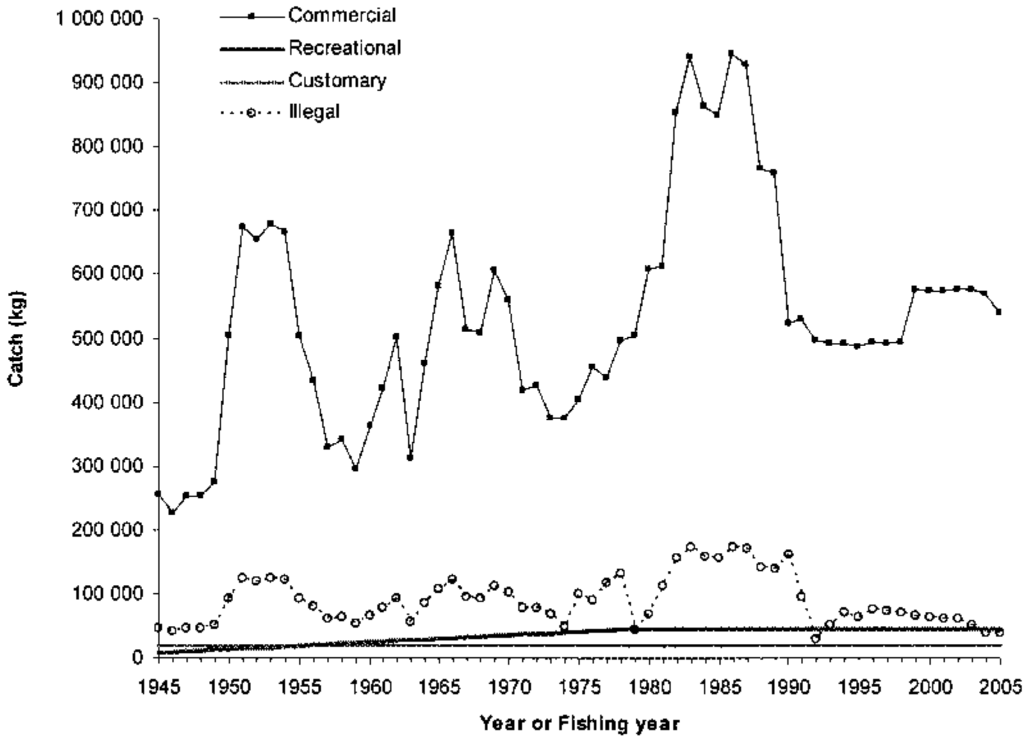


Figure 1: Annual CRA 4 catches (kg) by fishery sector.

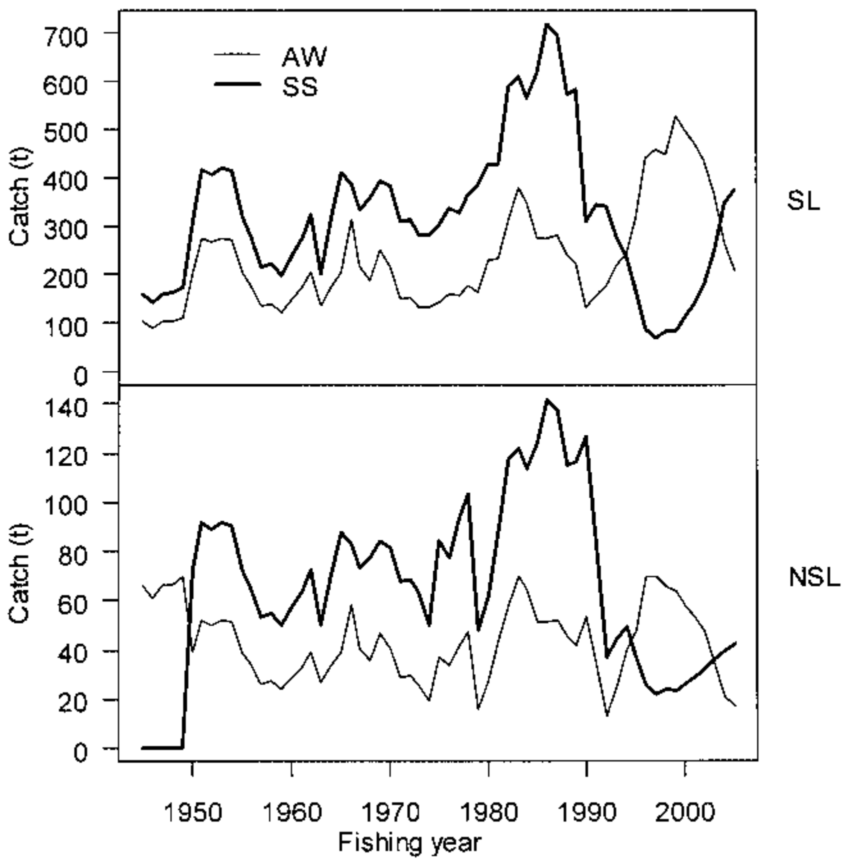


Figure 2: CRA 4 catches: upper: SL (size-limited) and lower: NSL (non-size-limited) catches by season.

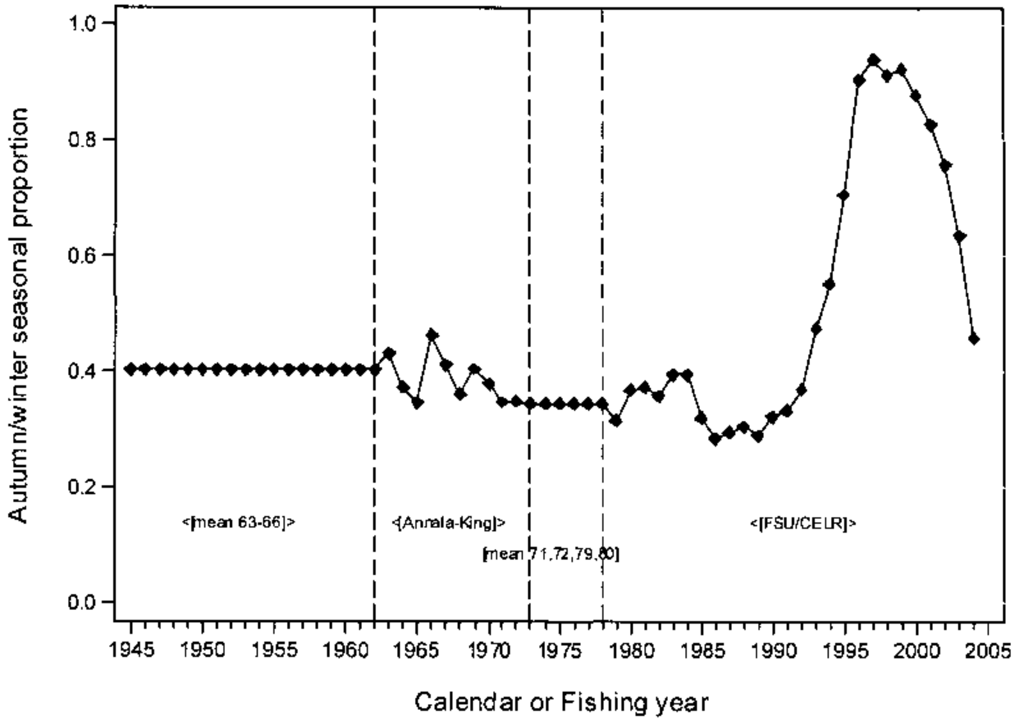


Figure 3: Proportion of the AW catch by calendar year or fishing year. Also shown are the data sources for the indicated ranges of years.

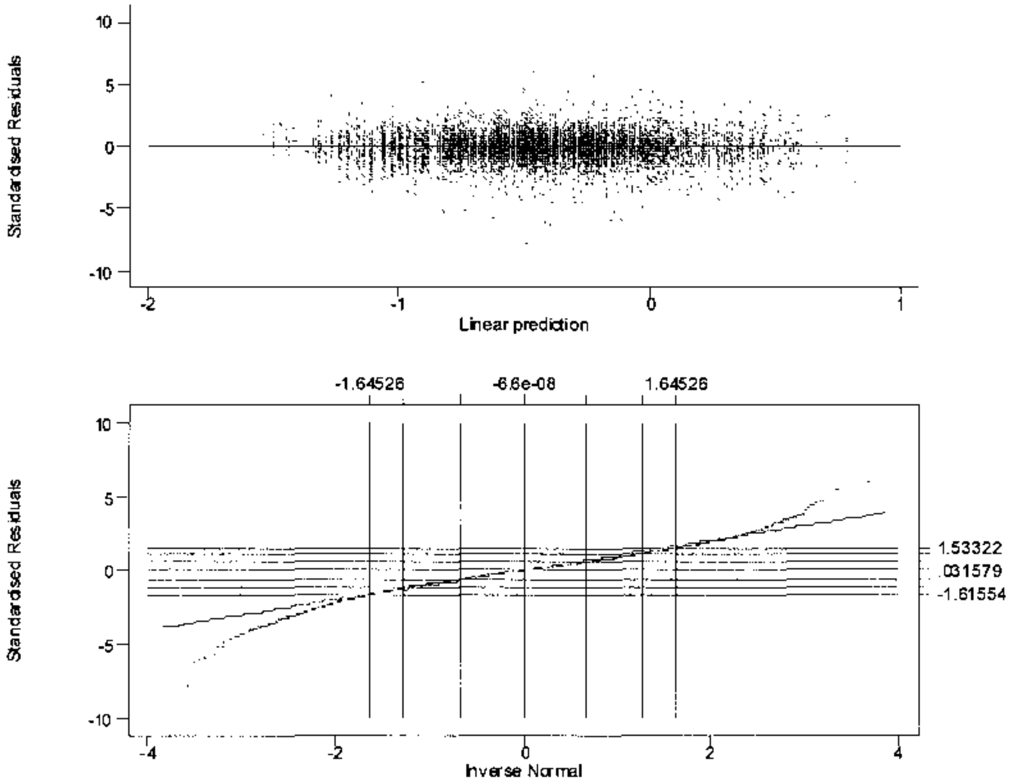


Figure 4: Standardised residuals for the CRA 4 standardised CPUE analysis.

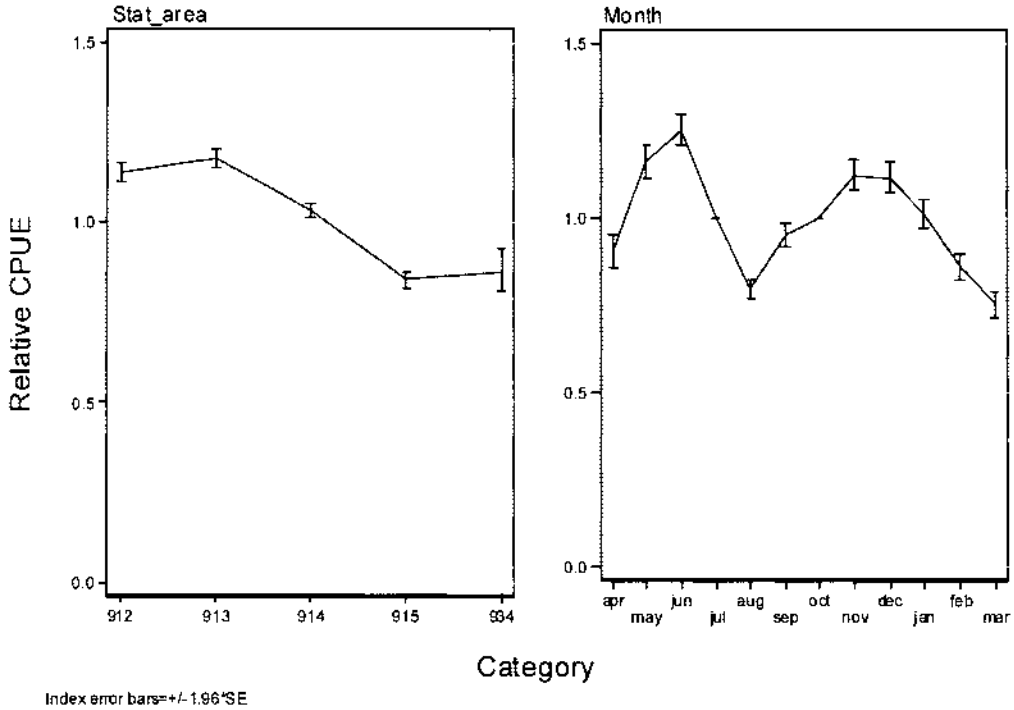


Figure 5: Coefficients for statistical area (left) and month from the CRA 4 CPUE standardisation. Month coefficients are not in canonical form. Each of the two reference months are set to 1.0; they have no estimated error bars because the SE is set to zero for the reference months.

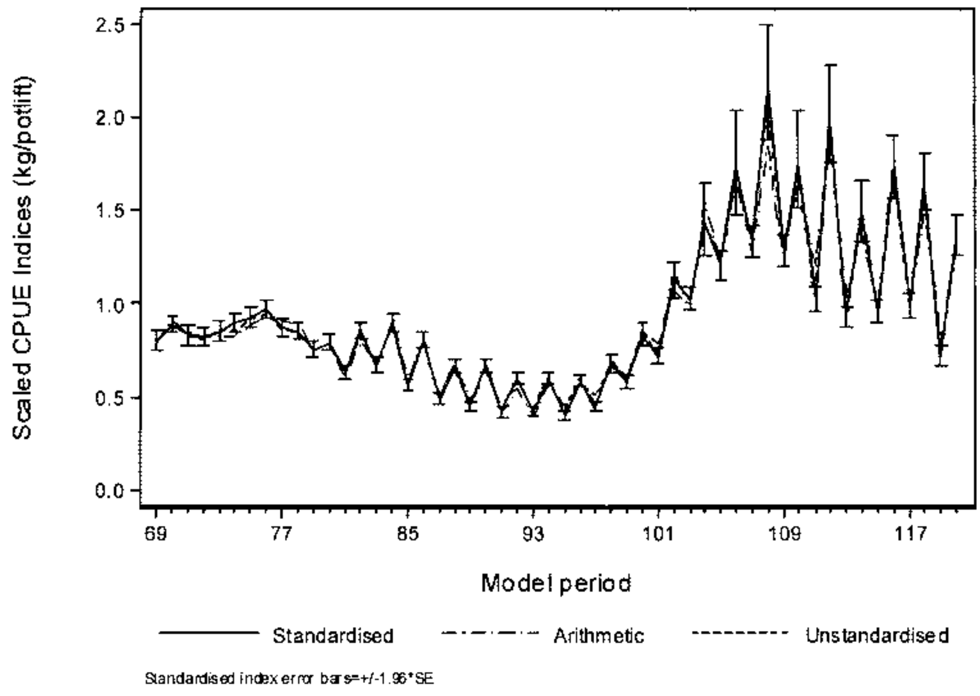


Figure 6: Scaled standardised CPUE (kg/potlift) by period for CRA 4. Also shown are the arithmetic or "raw" CPUE series and the geometric mean of the CPUE ("unstandardised"). The standardised series is scaled by multiplying each index in the unscaled series (where the geometric mean=1) by the geometric mean of the arithmetic CPUE series (geometric mean=0.87 kg/potlift).

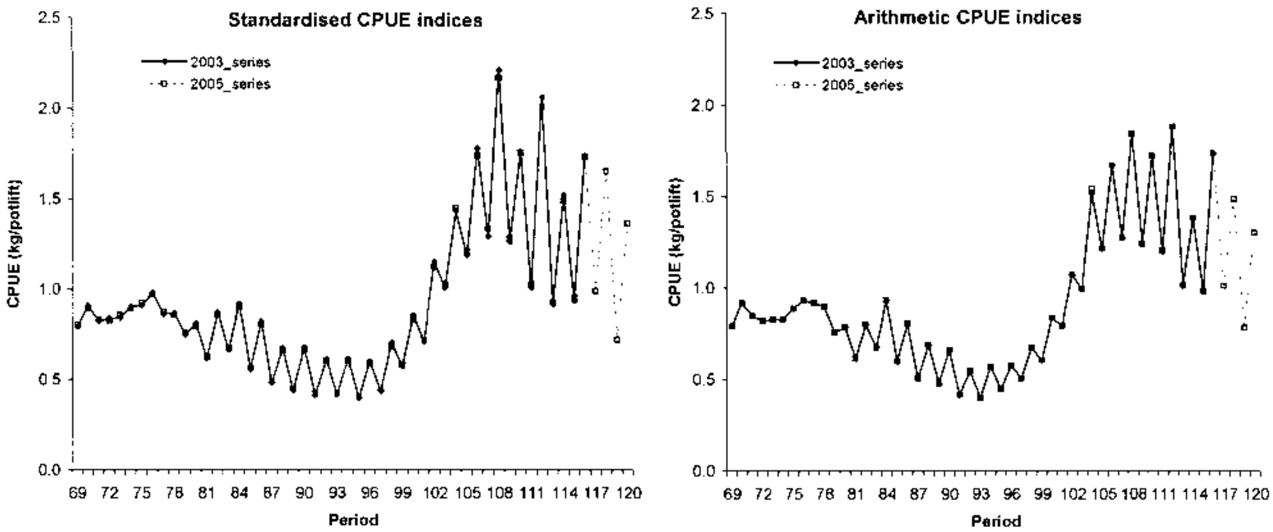


Figure 7: [left panel] comparison of the 2003 and 2005 scaled standardised CPUE indices; [right panel] comparison of the 2003 and 2005 scaled arithmetic (or "raw") CPUE series for CRA 4.

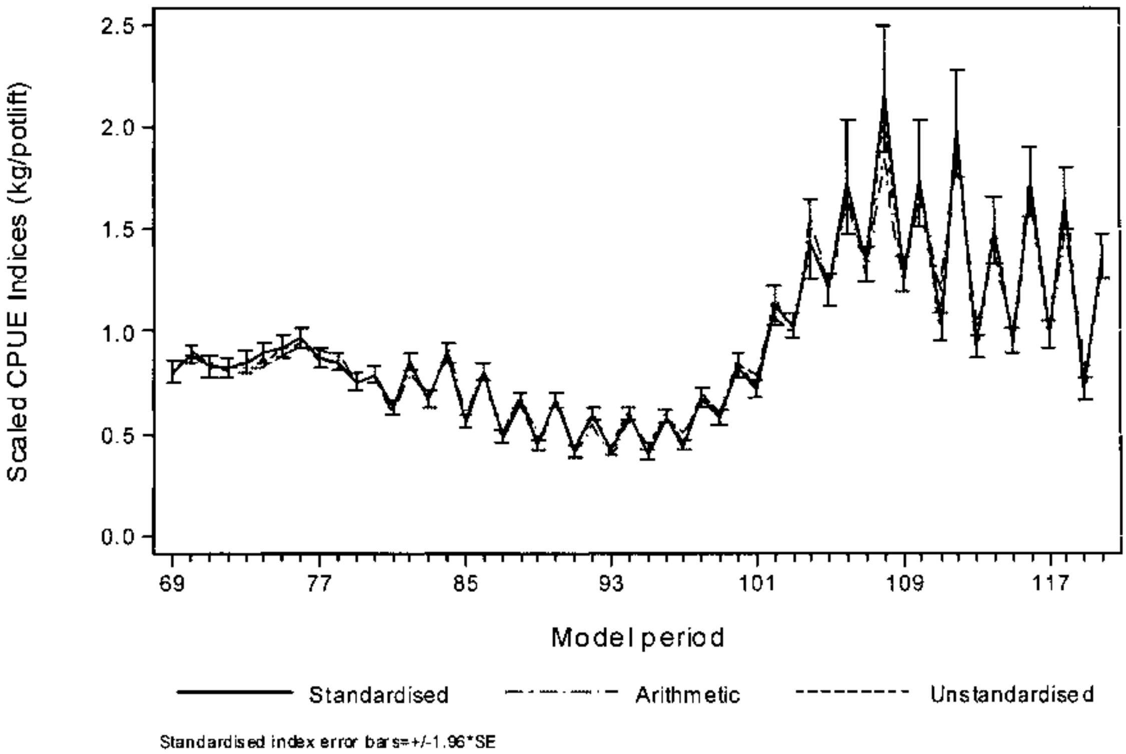


Figure 8: Standardised CPUE used for the CRA 4 assessment. Period 69 is AW 1979; period 120 is SS 2004.

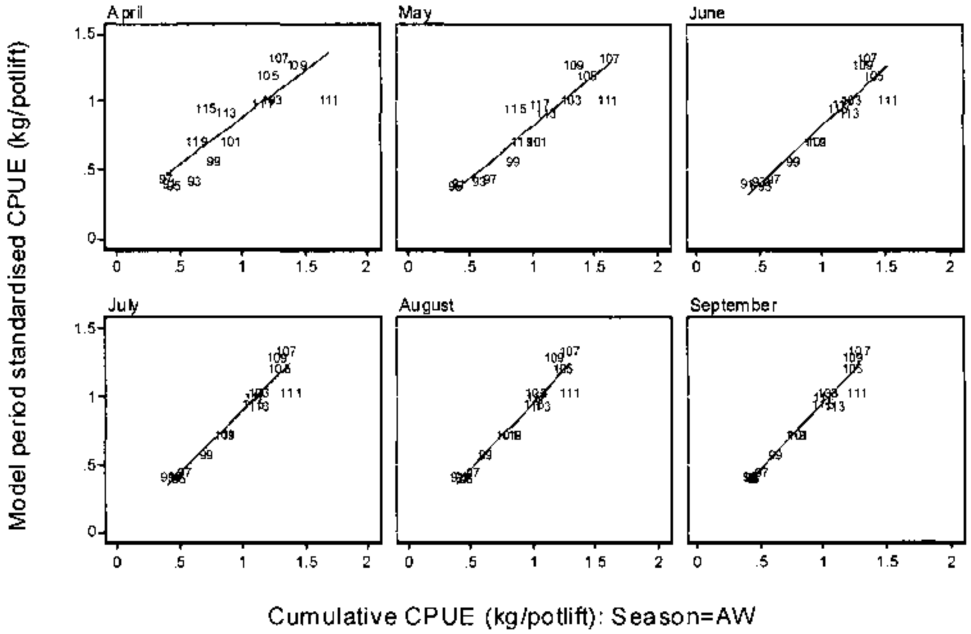


Figure 9: AW standardised CPUE (kg/potlift) by model period plotted against the cumulative CPUE (kg/potlift) up to and including the month shown for CRA 4 from period 91 [1990 AW] to period 119 [2004 AW]. A least squares regression has been fitted to each month of cumulative data. The period is used as a plotting symbol.

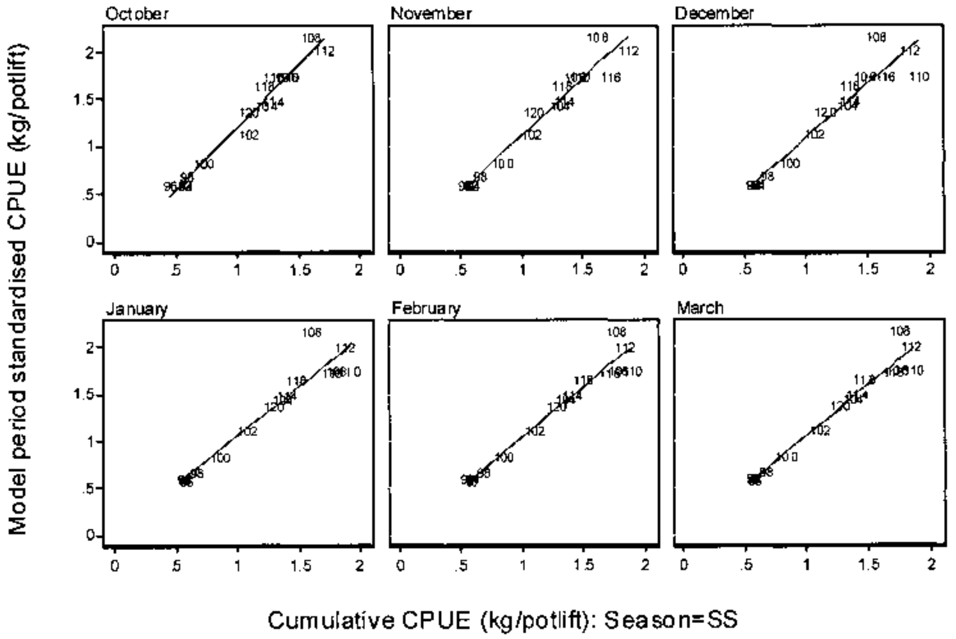


Figure 10: SS standardised CPUE (kg/potlift) by model period plotted against the cumulative CPUE (kg/potlift) up to and including the month shown for CRA 4 from period 92 [1990 SS] to period 120 [2004 SS]. A least squares regression has been fitted to each month of cumulative data. The period is used as a plotting symbol.

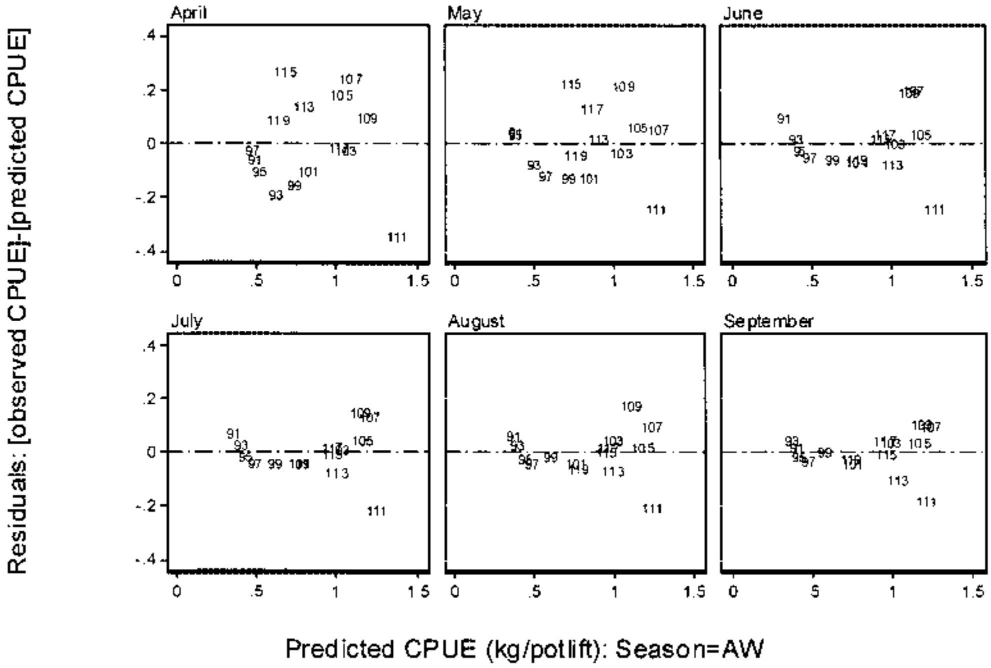


Figure 11: Residuals from the monthly regression models fitted in Figure 9 plotted against predicted model period standardised CPUE (kg/potlift) for CRA 4 for all fishing years from period 91 [1990 AW] to period 119 [2004 AW]. The period is used as a plotting symbol.

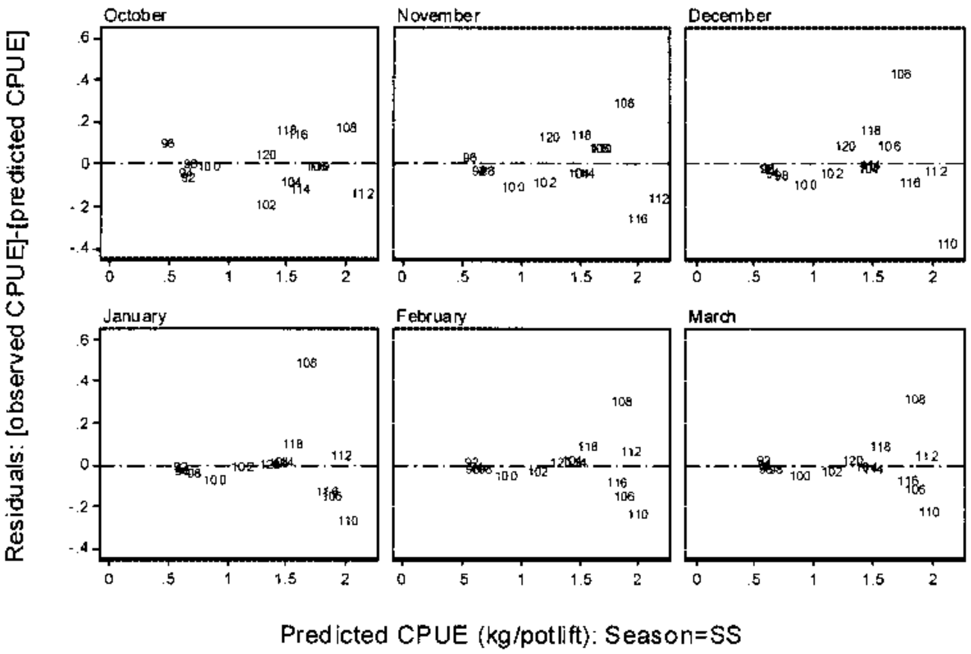


Figure 12: Residuals from the monthly regression models fitted in Figure 10 plotted against predicted model period standardised CPUE (kg/potlift) for CRA 4 for all fishing years from period 92 [1990 SS] to period 120 [2004 SS]. The period is used as a plotting symbol.

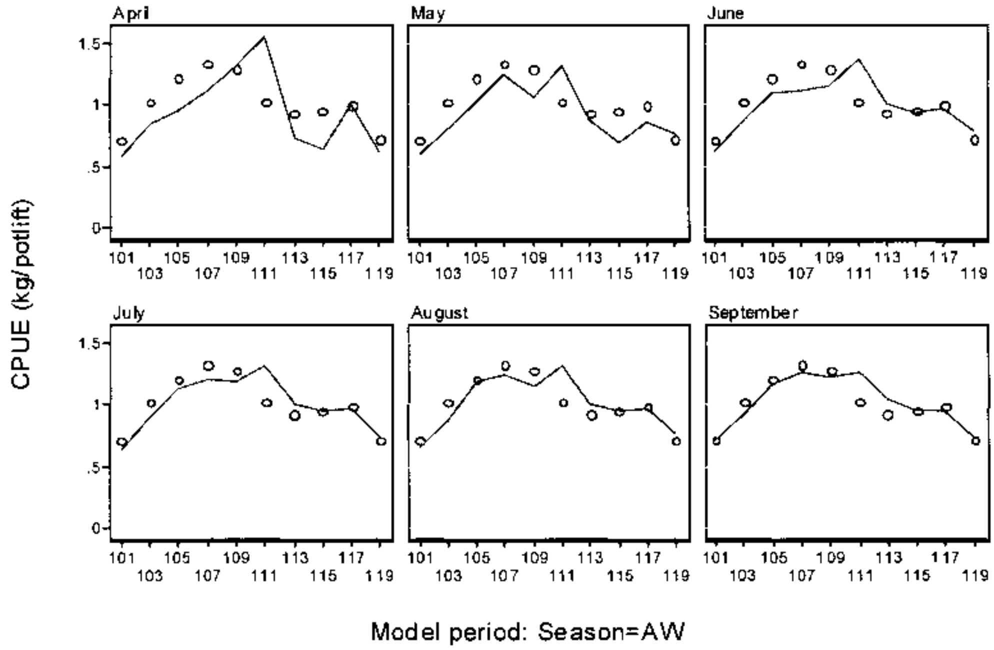


Figure 13: Plot of predicted AW standardised CPUE (kg/potlift) based on the cumulative monthly CPUE (kg/potlift) for each month within a period (Eq. 2). The predicted CPUEs are plotted as a line and the observed annual standardised CPUEs are plotted as open circles. Each data point uses only the data available up to the year prior to the indicated model period.

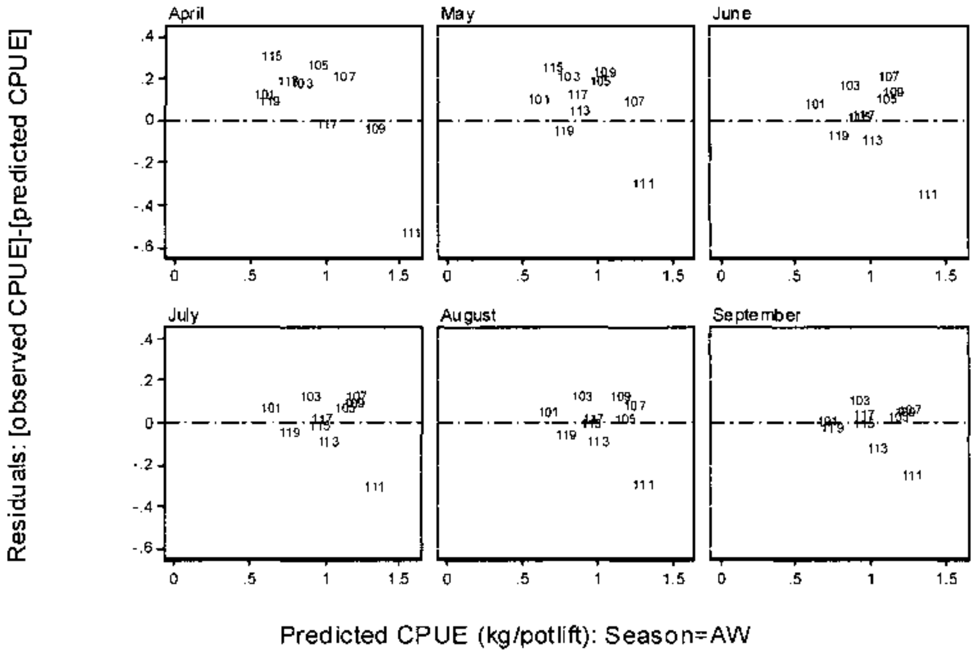


Figure 14: Residuals from the predictive models presented in Figure 13 plotted against the predicted standardised CPUE (kg/potlift). The model period is used as a plotting symbol.

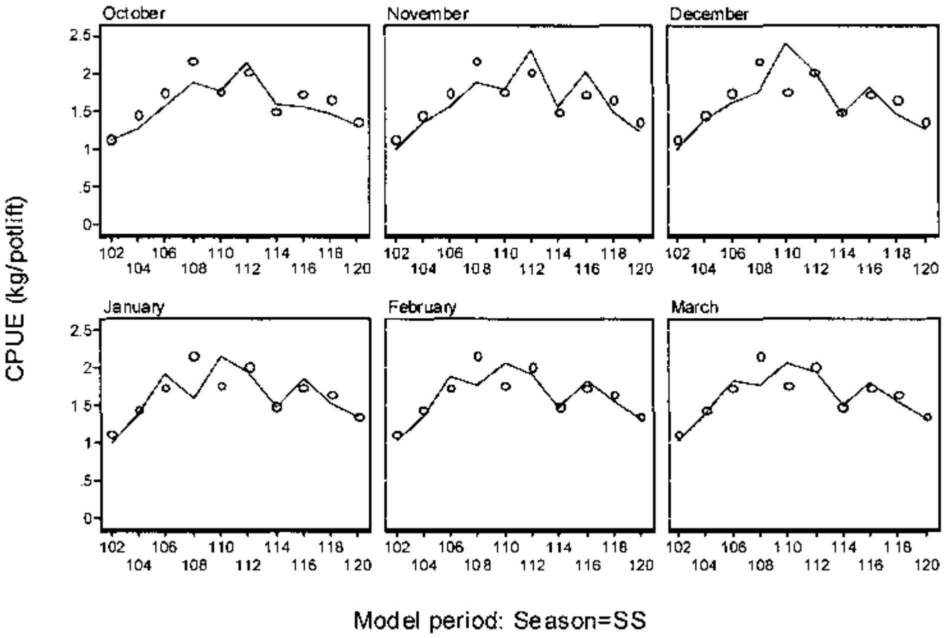


Figure 15: Plot of predicted SS standardised CPUE (kg/potlift) based on the cumulative monthly CPUE (kg/potlift) for each month within a period (Eq. 2). The predicted CPUEs are plotted as a line and the observed annual standardised CPUEs are plotted as open circles. Each data point uses only the data available up to the year prior to the indicated model period.

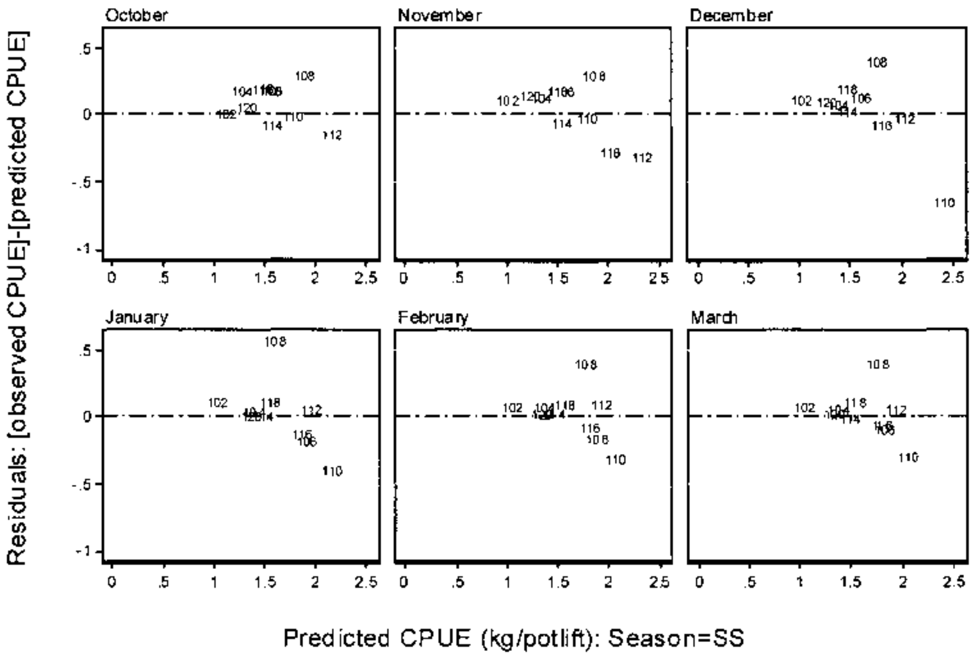


Figure 16: Residuals from the predictive models presented in Figure 15 plotted against the predicted standardised CPUE (kg/potlift). The model period is used as a plotting symbol.

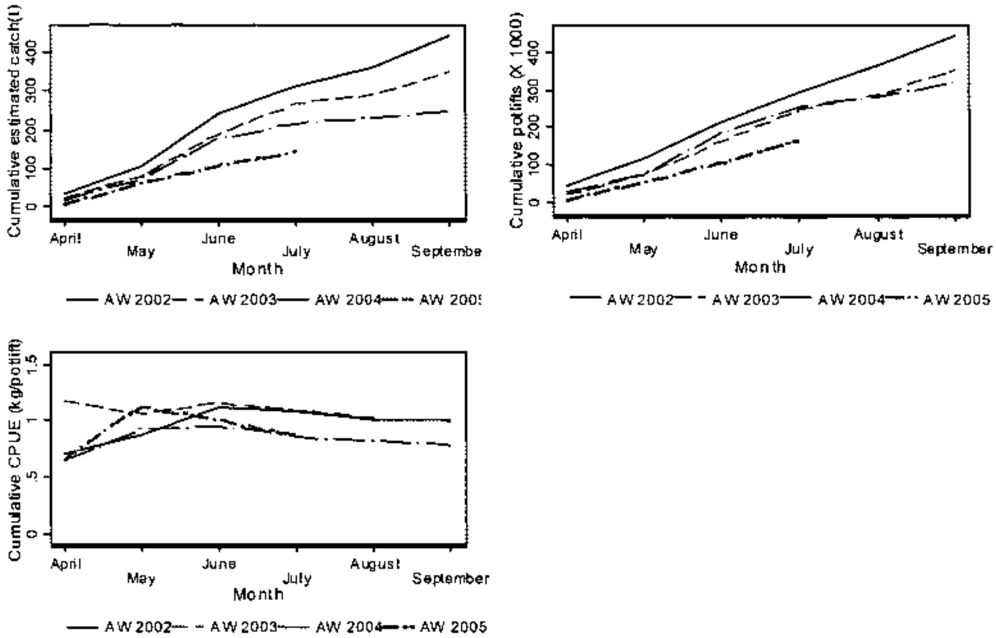


Figure 17: Monthly cumulative catch (top left, tonnes), cumulative potlifts (top right, thousands) and the associated CPUE (lower left, kg/potlift) for the four most recent AW seasons.

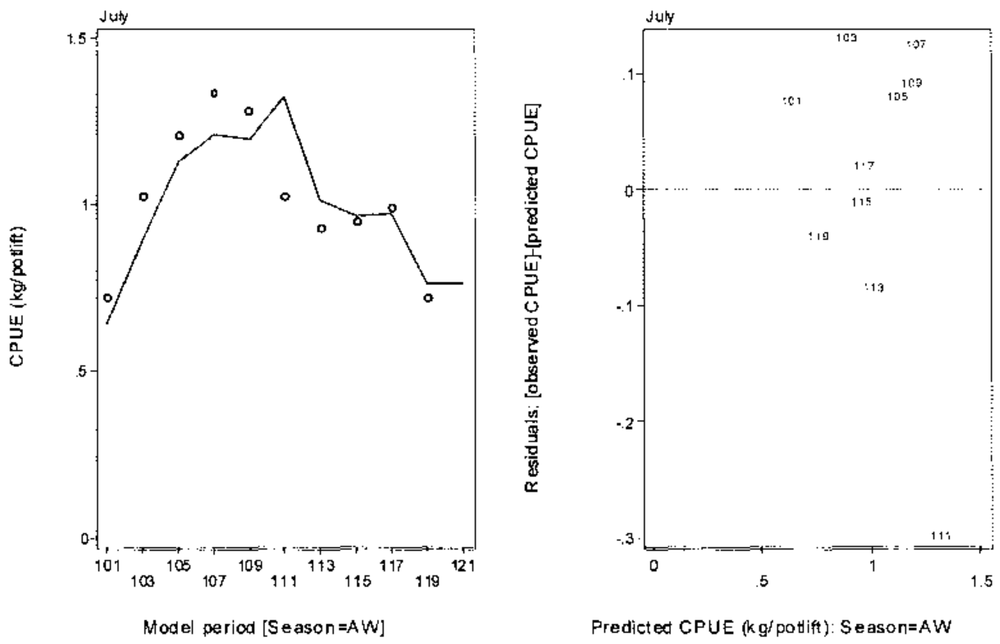


Figure 18: Plot of predicted AW standardised CPUE (left, kg/potlift) for July, showing the prediction for model period 121 (2005 AW), and residuals (right) from the July predictive models plotted against the predicted standardised CPUE (kg/potlift).

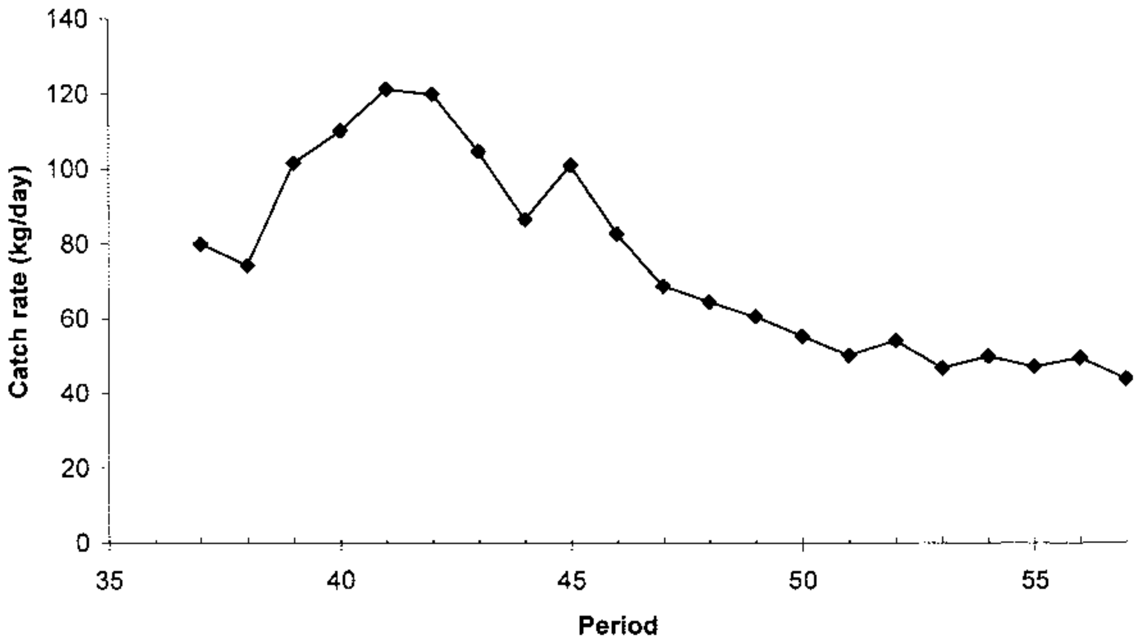


Figure 19: Historical catch rate (CR) by period for CRA 4. Period 37 is AW 1963; period 57 is AW 1973.

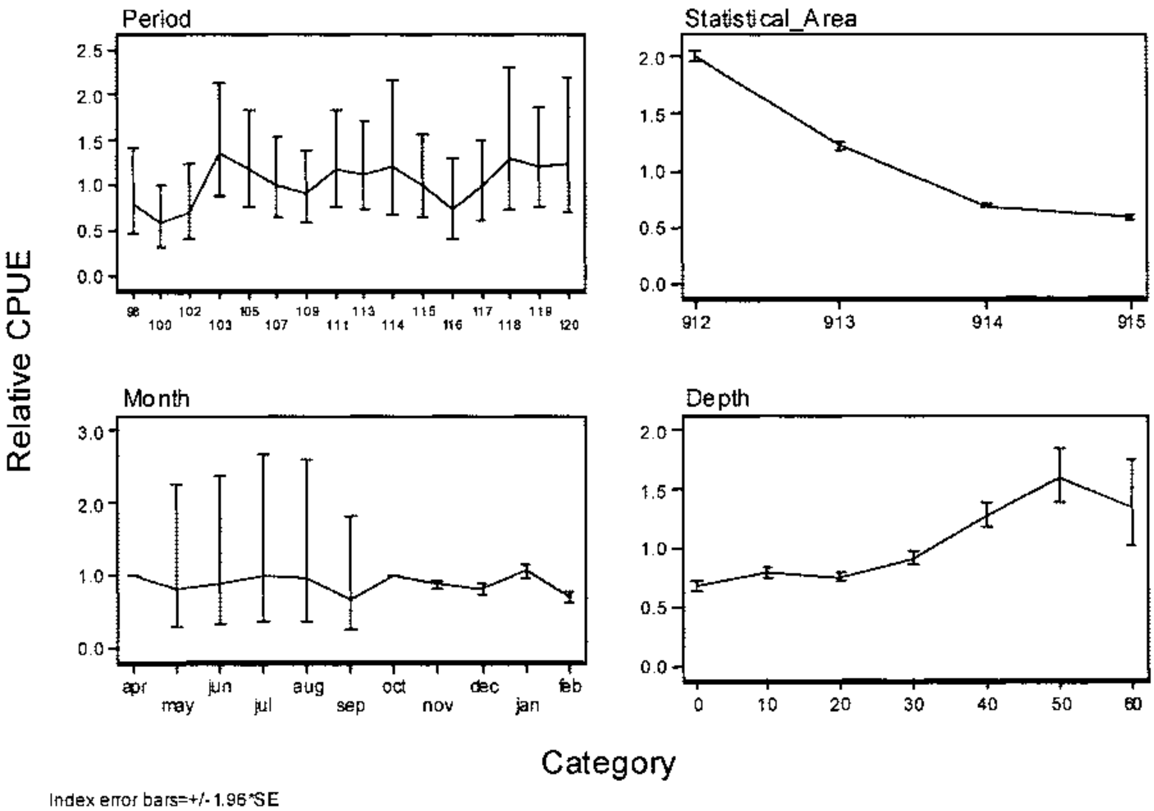


Figure 20: Pre-recruit index (PRI) by period for CRA 4. Period 97 is AW 1993; period 118 is SS 2003.

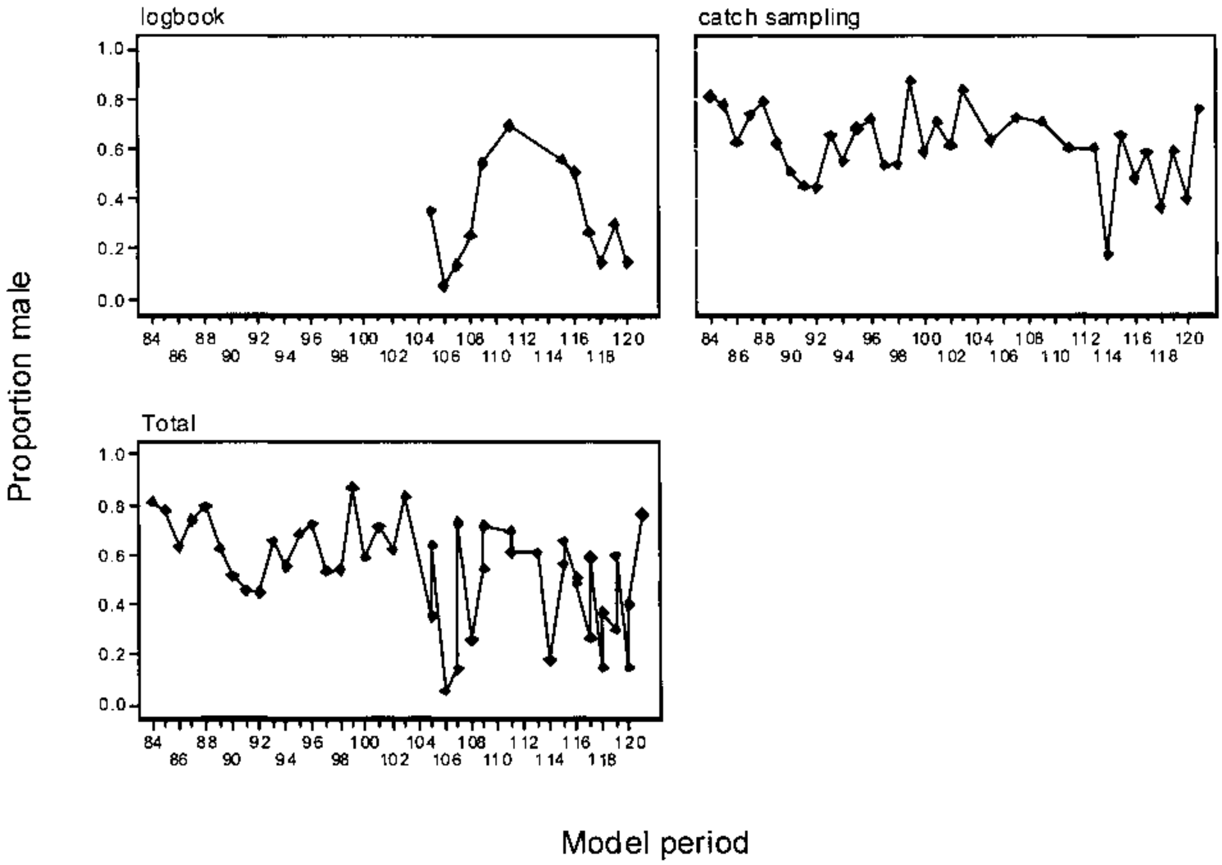


Figure 21. Proportion males by period and data source for CRA 4. Period 84 is SS 1986 and period 120 is SS 2004.

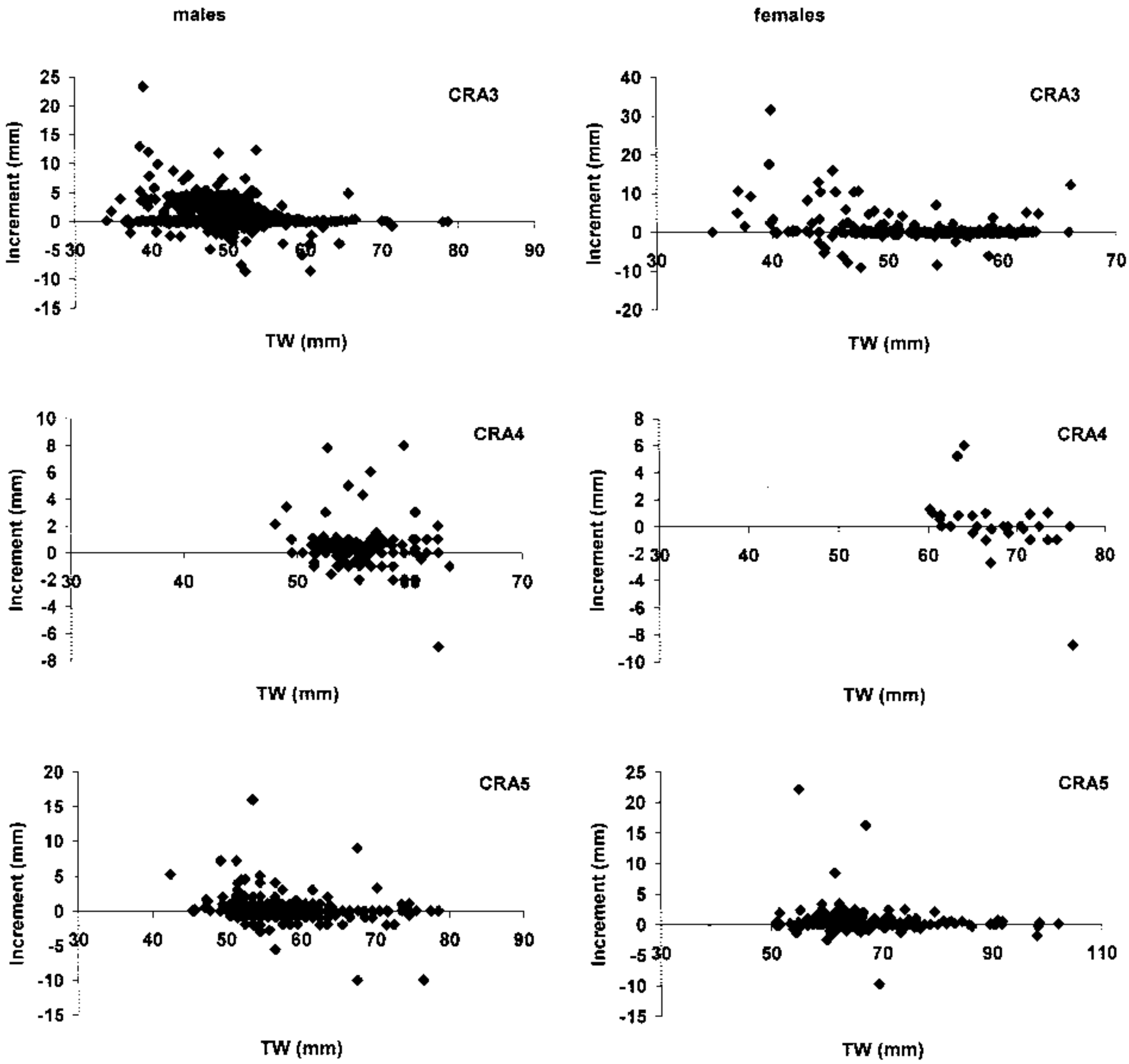


Figure 22: Apparent growth increments in tagged lobsters recovered in the same period as release, from areas CRA 3, CRA 4 and CRA 5; males on the left. Note different y-axis scales.

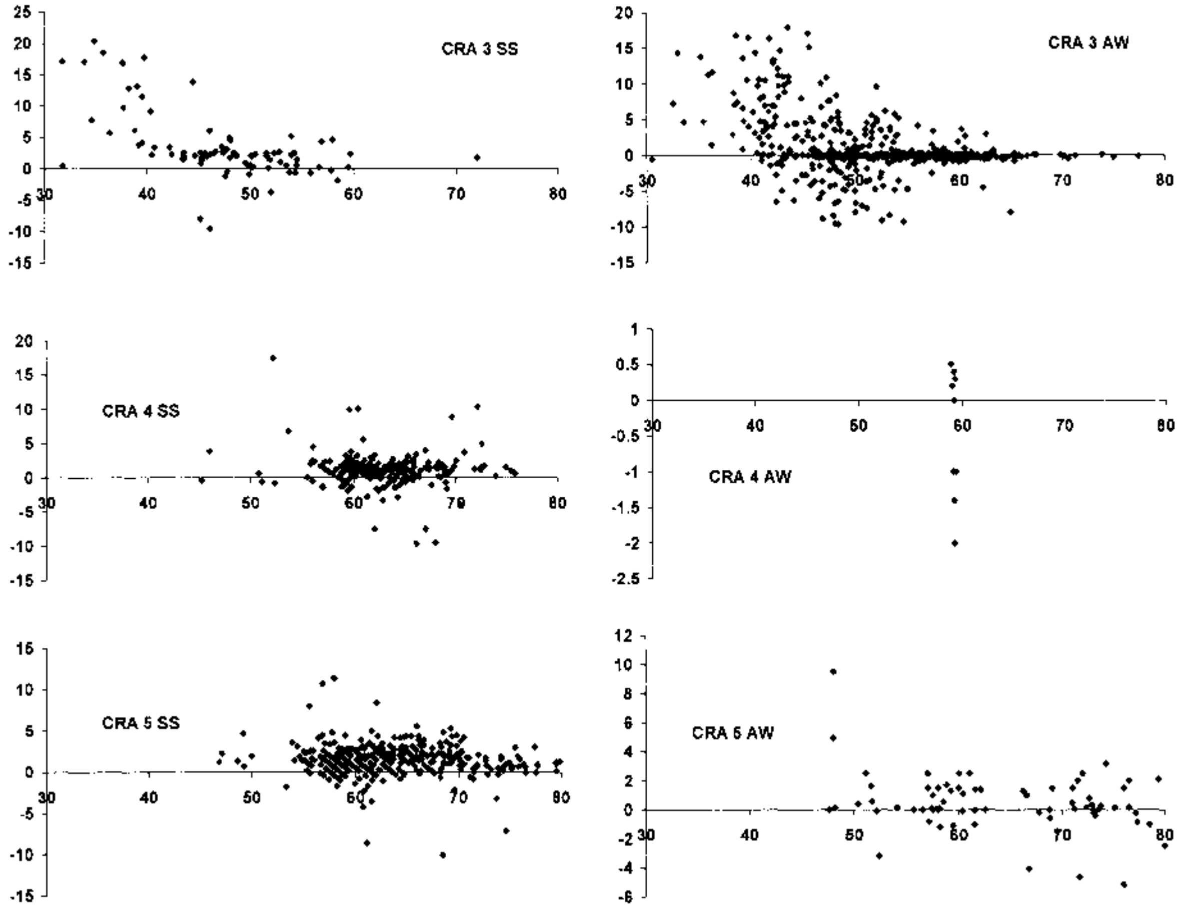


Figure 23: Increments for females tagged in SS (left) or AW and recovered in the following period for the three areas shown.

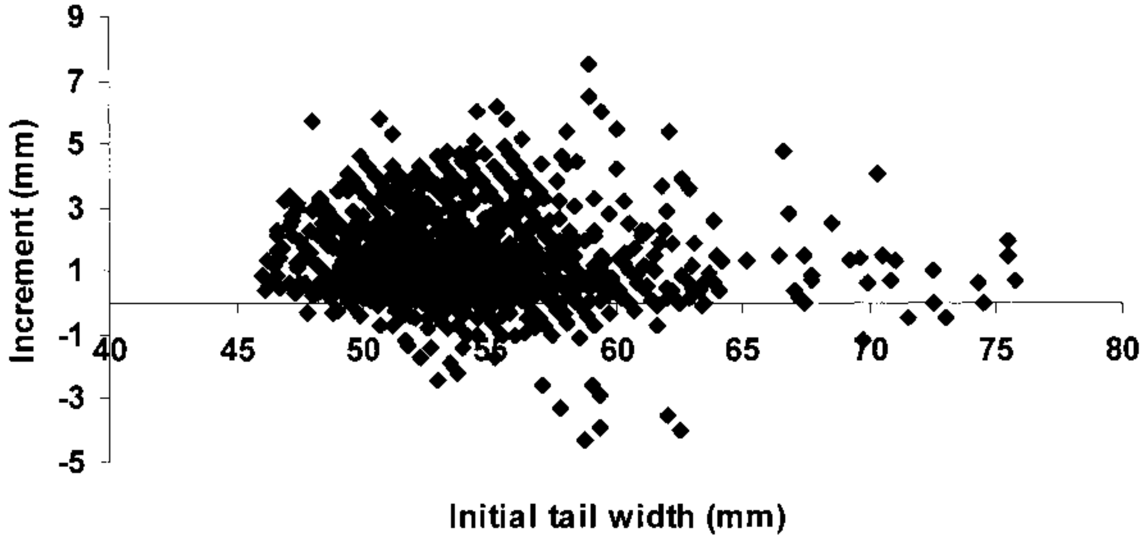


Figure 24: Combined CRA 3, CRA 4 and CRA 5 tag-recapture data: growth increment per period for males plotted against size at release.

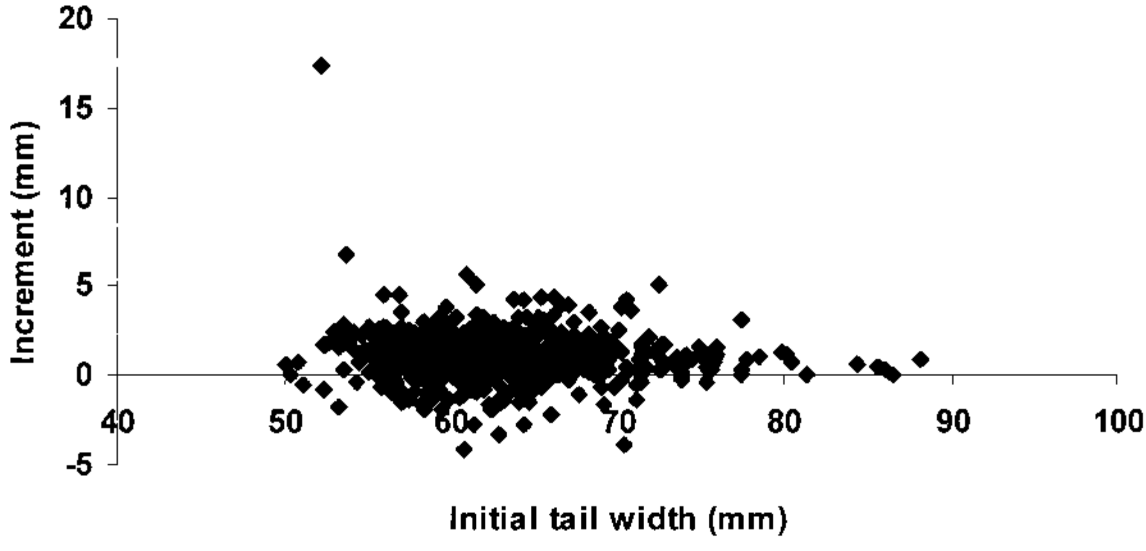


Figure 25: Combined CRA 3, CRA 4 and CRA 5 tag-recapture data: growth increment per period for females plotted against size at release.

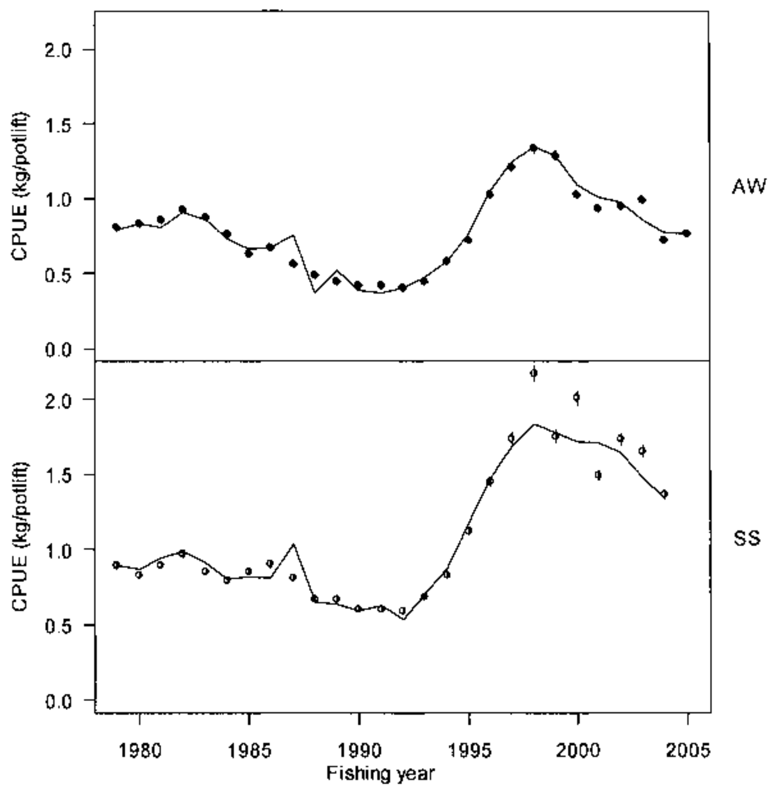


Figure 26: Observed (circles) and predicted (line) CPUE for run PAB3. Error bars of one standard deviation are shown around observations.

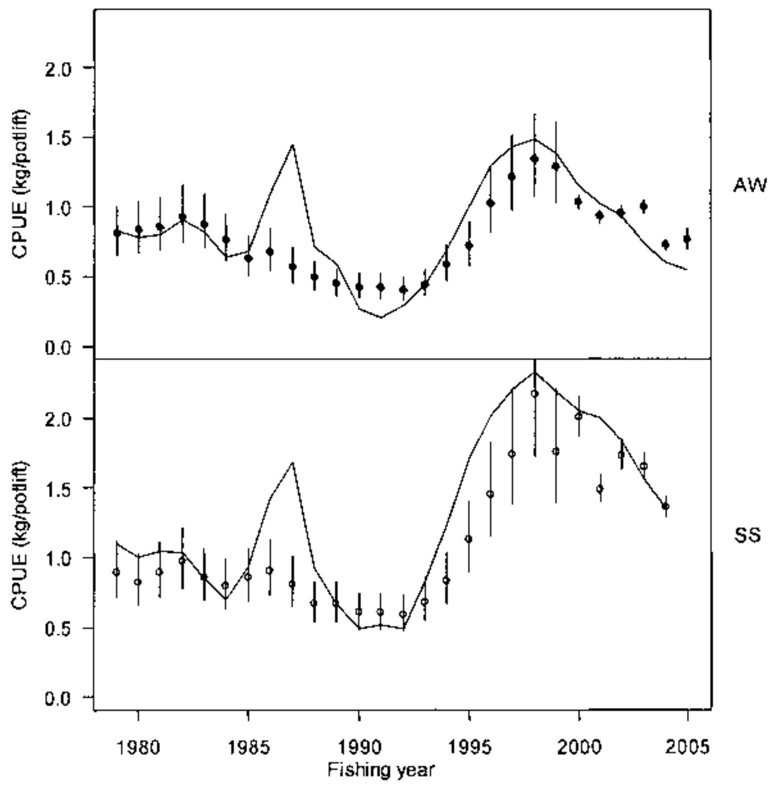


Figure 27: Observed (circles) and predicted (line) CPUE for run PJS2. Error bars of one standard deviation are shown around observations.

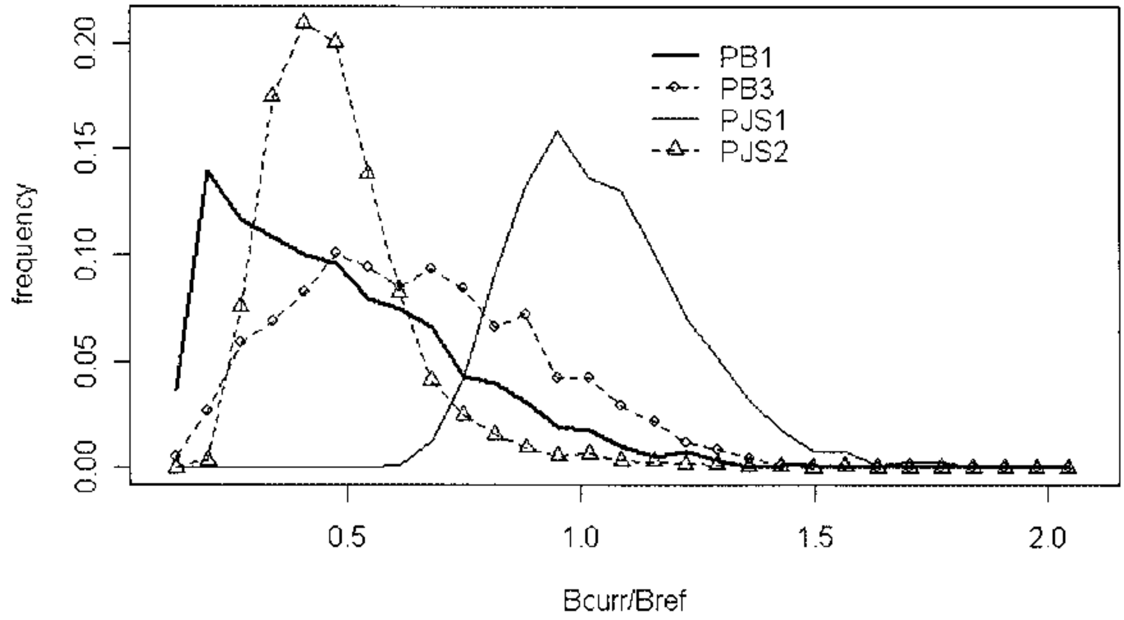


Figure 28: Comparison of posterior distributions of the ratio of current biomass to reference biomass from the exploratory runs 1 to 4 (Table 17).

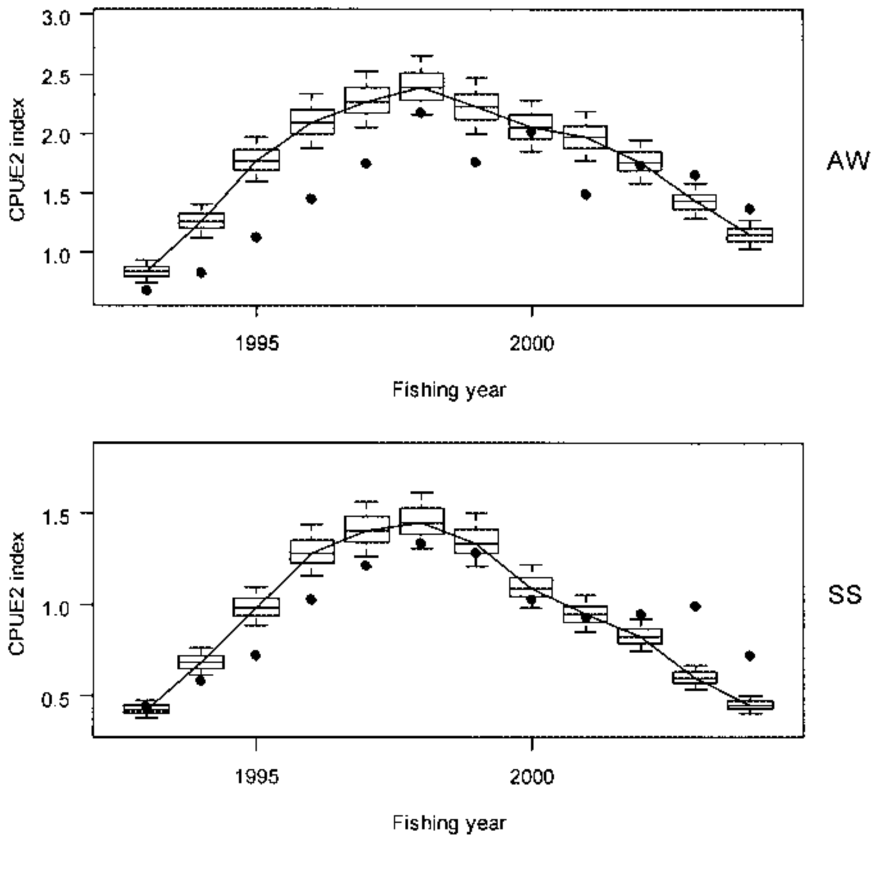


Figure 29: Posterior distributions of the fit to the second series of CPUE, 1993–2004, from the TQ93 model.

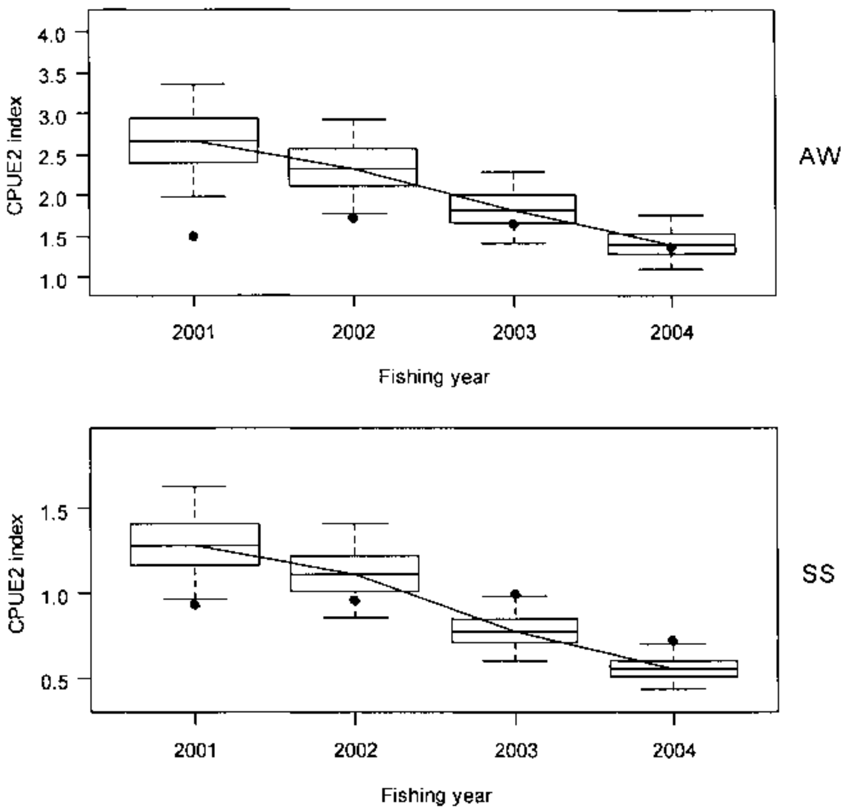


Figure 30: Posterior distributions of the fit to the second series of CPUE, 2001–2004, from the TQ01 model.

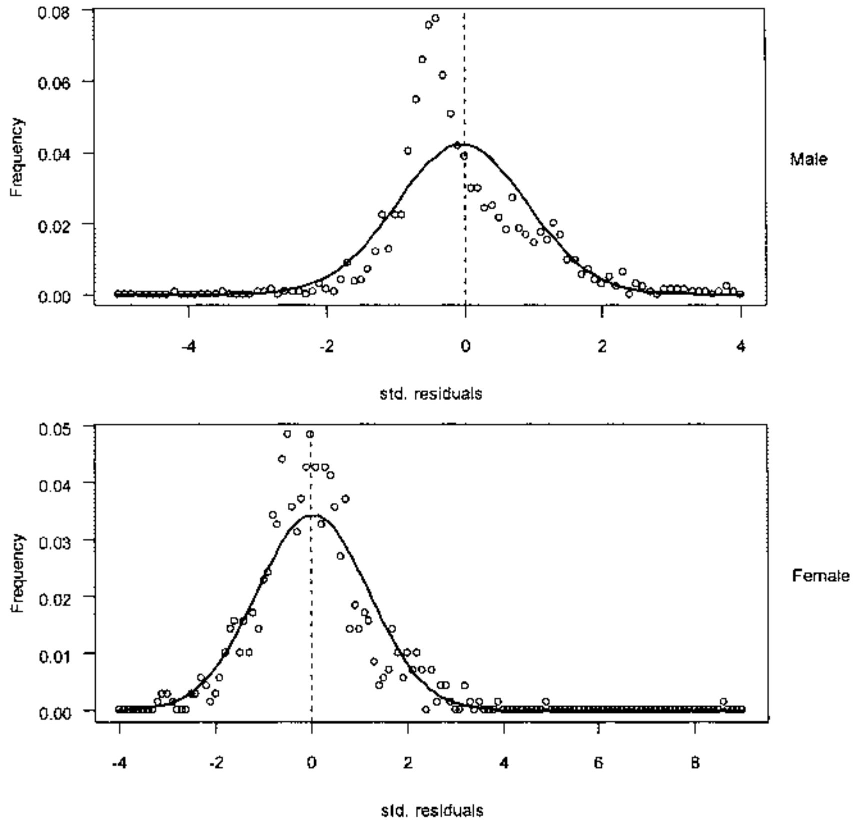


Figure 31: Residuals from the fit to the tag-recapture data from run PAB1 as an example of poor fits by residuals to the normal distribution: note the very large residuals and the considerable numbers of very small residuals.

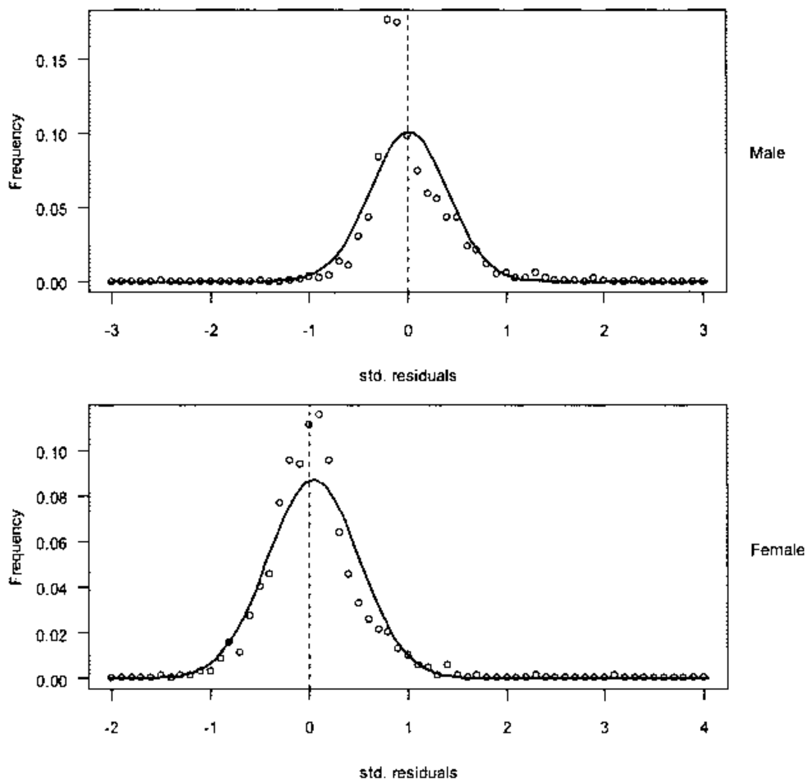


Figure 32: Residuals from run 9 (LW3) to the fit of tag-recapture data.

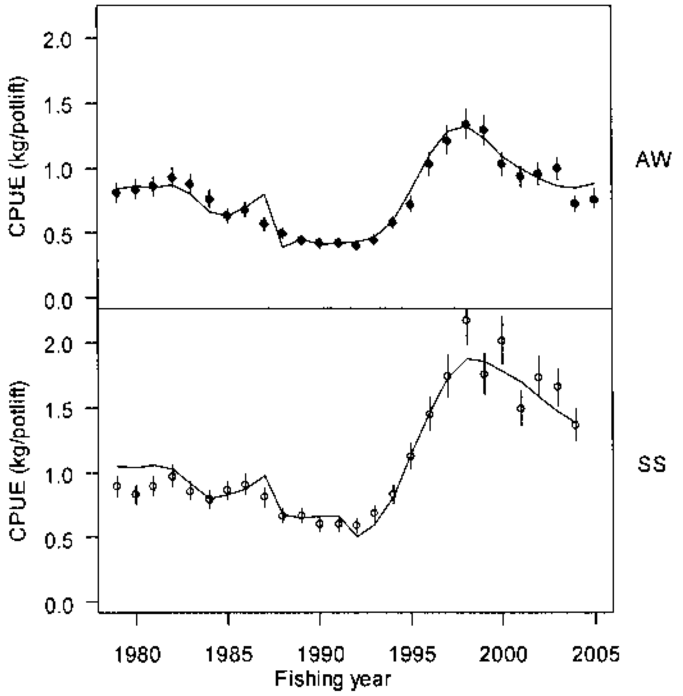


Figure 33: Predicted (line) and observed (circles with one standard error, taking all sources of variability into account) standardised CPUE index by season from the base case MPD results for CRA 4.

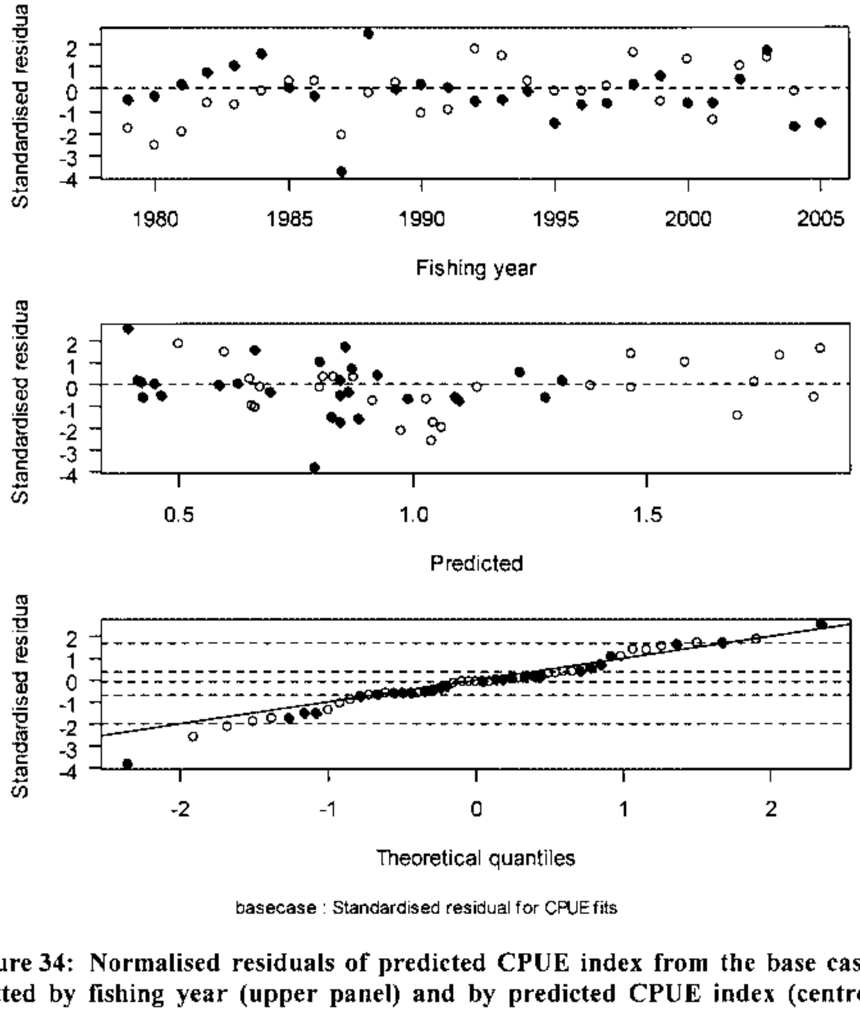


Figure 34: Normalised residuals of predicted CPUE index from the base case MPD results for CRA 4, plotted by fishing year (upper panel) and by predicted CPUE index (centre panel), and the quantile-quantile plot (lower panel). Closed circles, AW; open circles, SS.

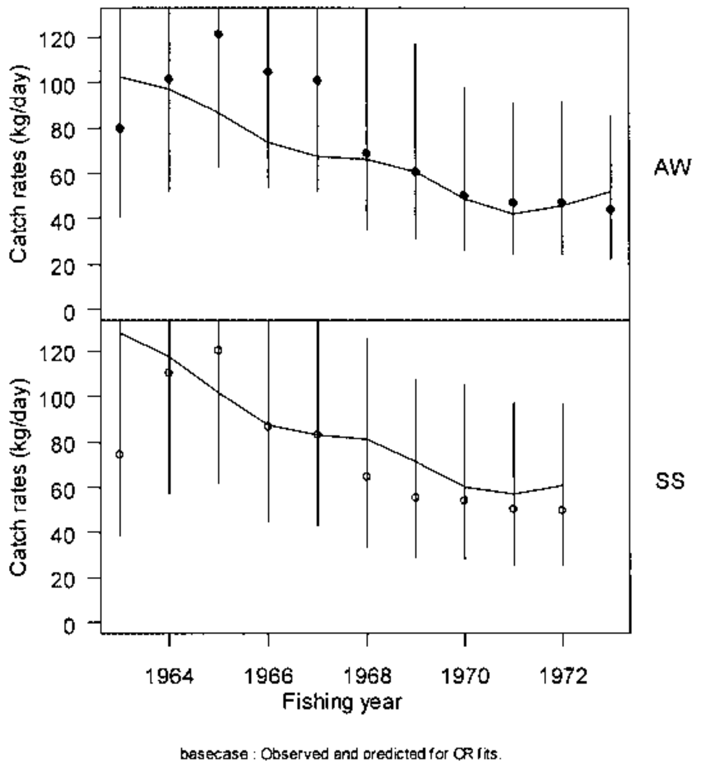


Figure 35: Predicted (solid line) and observed (circles with one standard error, taking all sources of variability into account) catch rate (CR) by season from the base case MPD results for CRA 4.

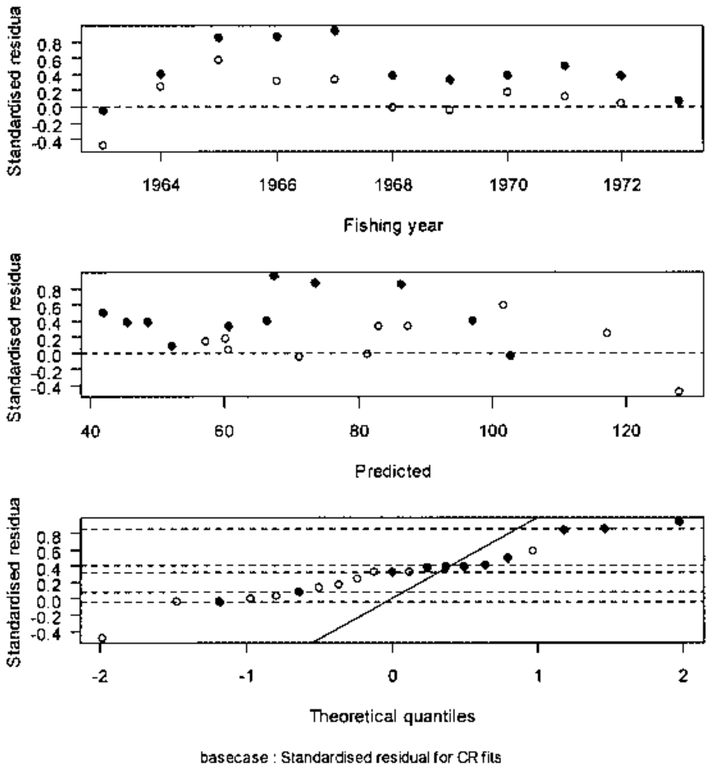


Figure 36: Normalised residuals of predicted CR index from the base case MPD results for CRA 4, plotted by fishing year (upper panel) and by predicted CR index (centre panel), and the quantile-quantile plot (lower panel). Closed circles, AW; open circles, SS.

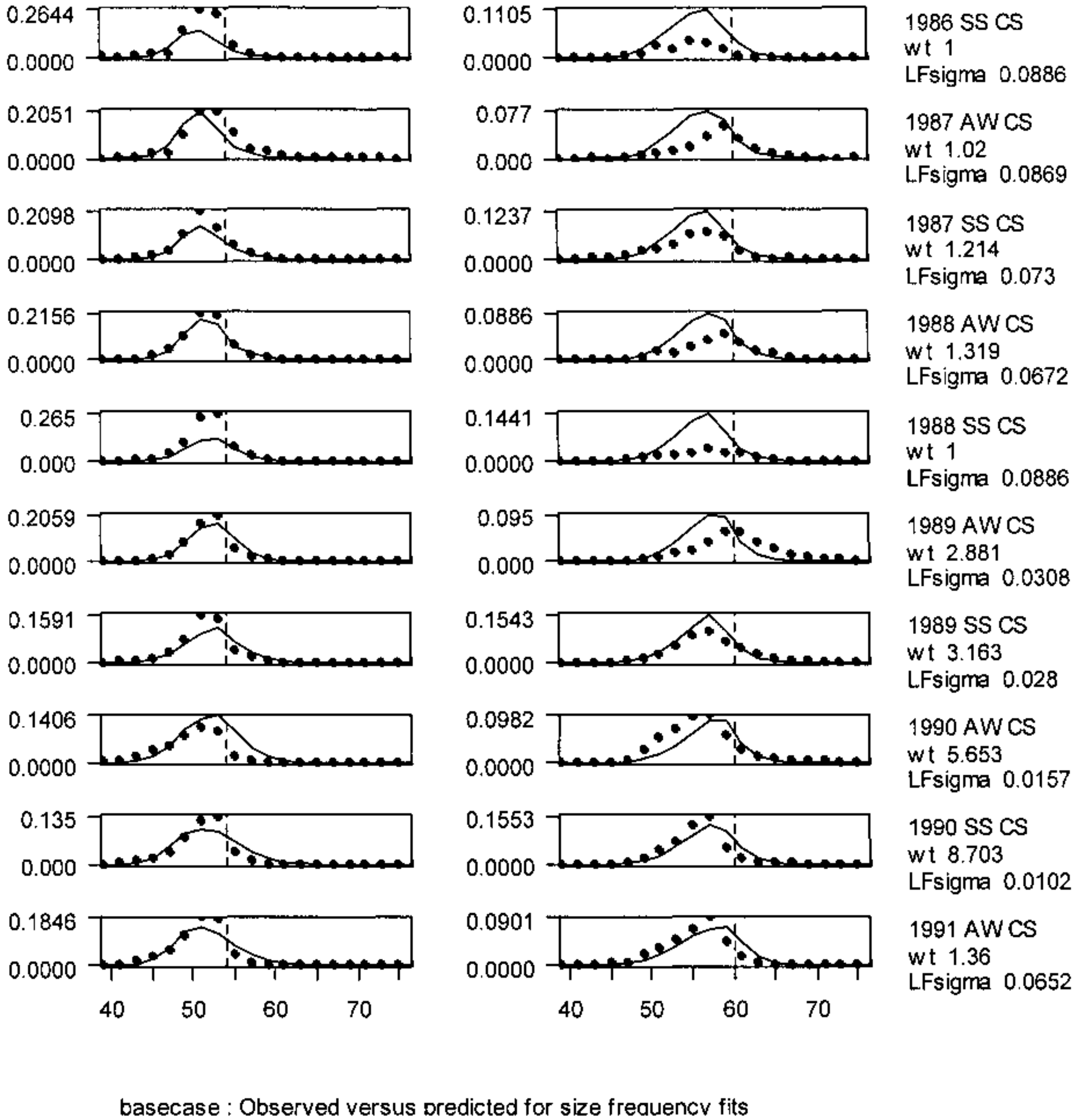
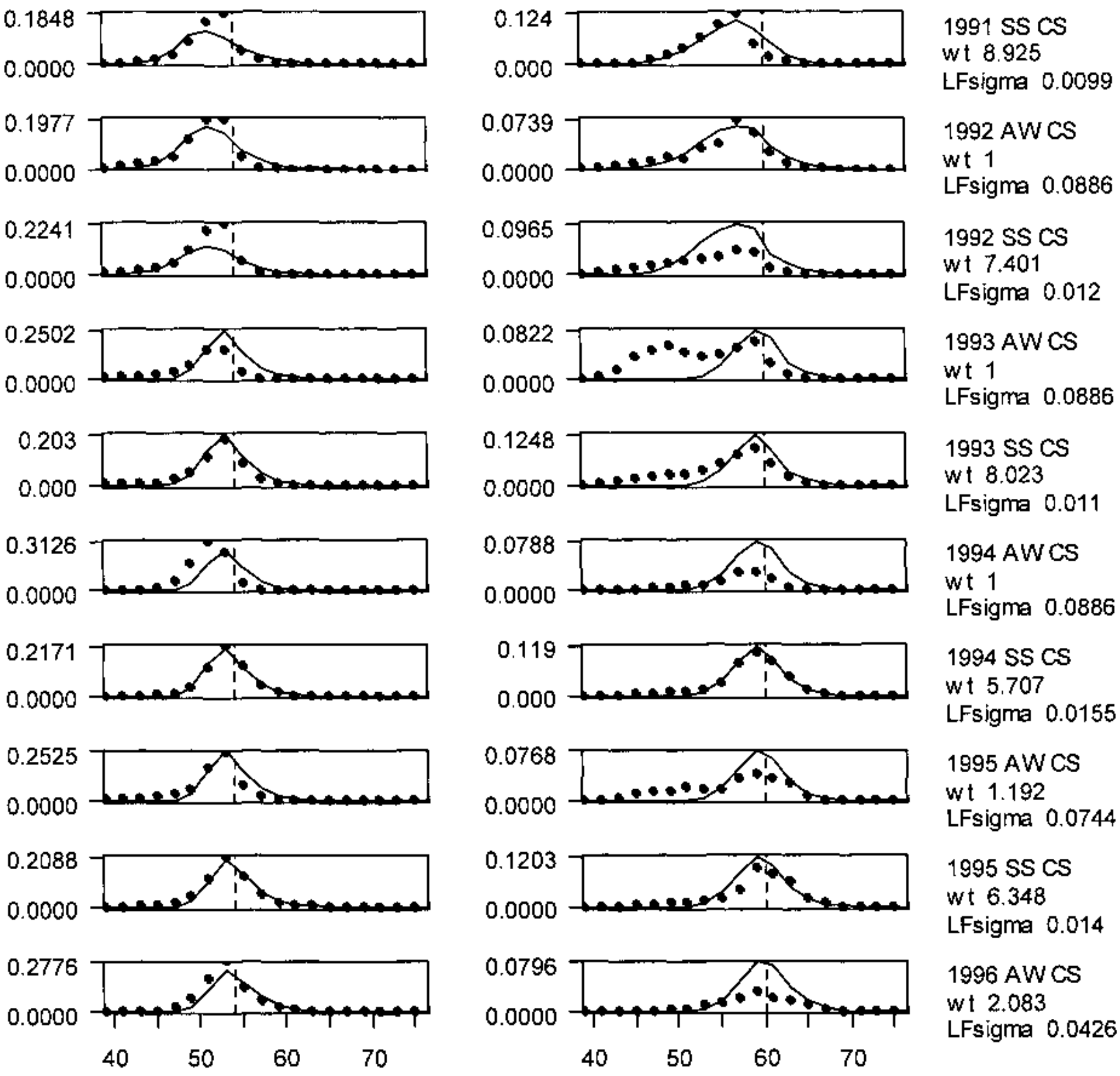


Figure 37: The CRA 4 base case MPD fit to the proportion-at-length data, plotted by year and season, sex category and data source type. The left column shows males and the right mature females. Note that y-axis scales are unique to each diagram. MS, market sampling; LB, log book data; CS, catch sampling data; wt ($=\kappa_t$), relative weight given to each data set. The dotted vertical line is the current summer MLS.



basecase : Observed versus predicted for size frequency fits

Figure 37: continued.

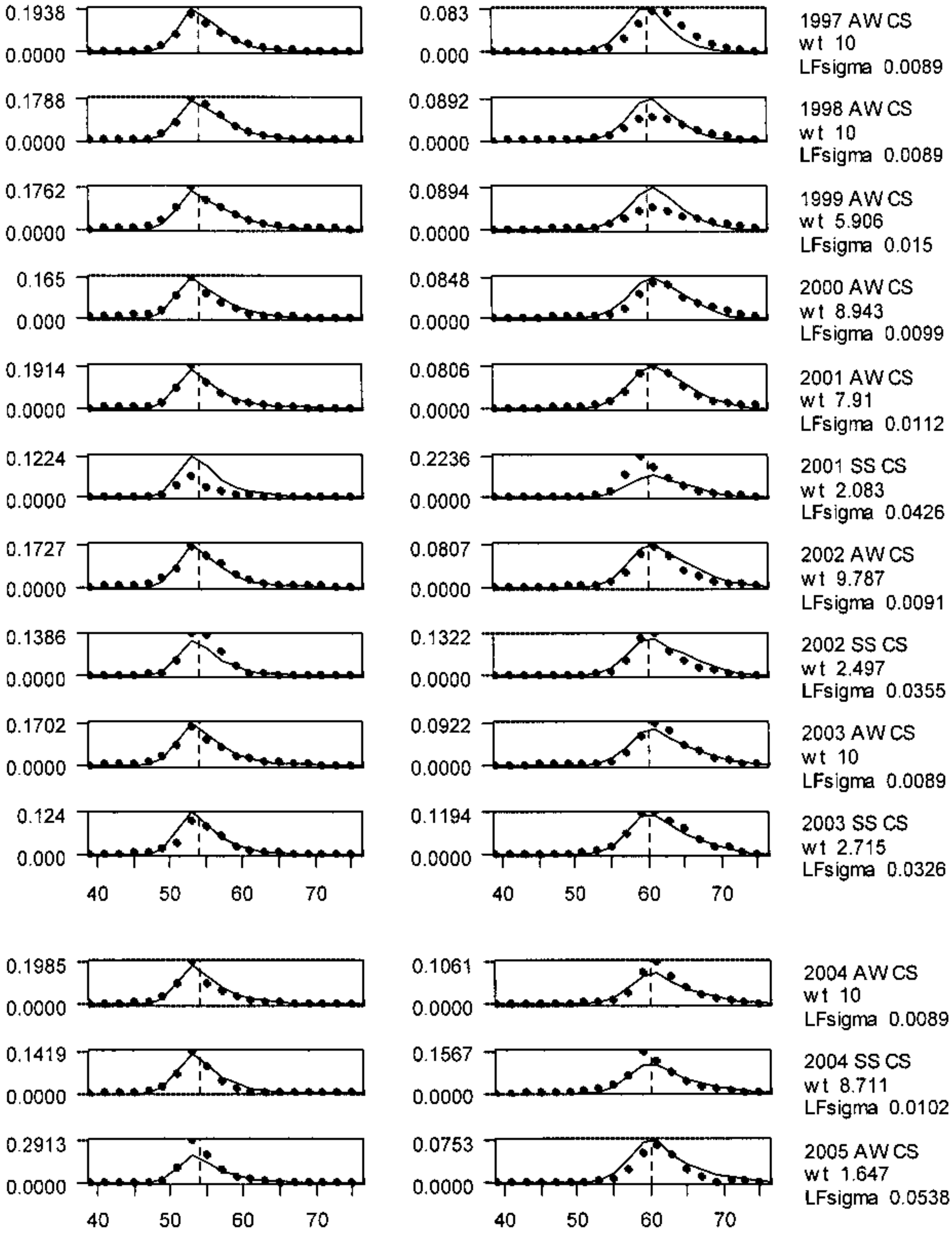


Figure 37: continued.

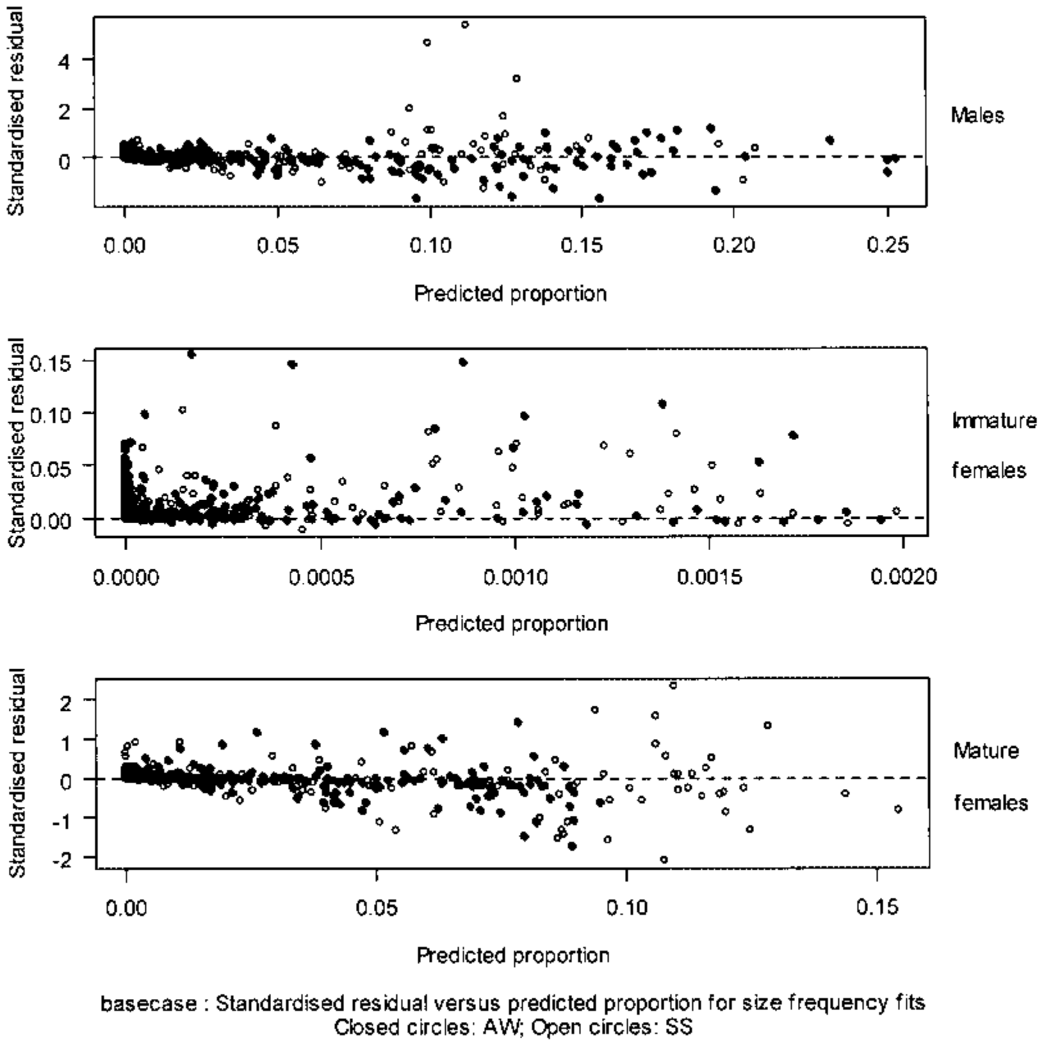


Figure 38: Normalised residuals from the base case CRA 4 MPD fits to proportions-at-length, plotted against predicted proportions-at-length for the three sex categories.

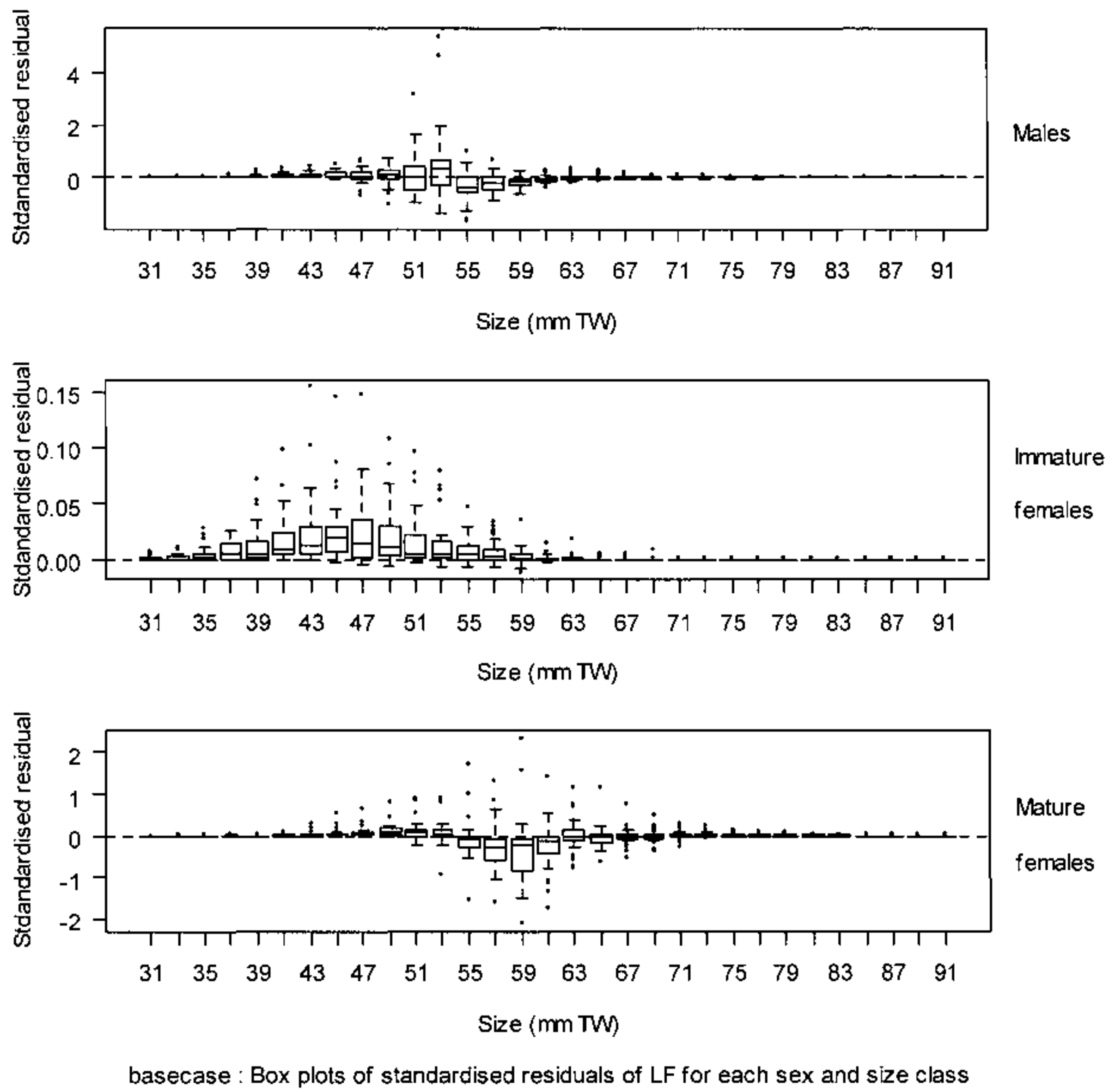


Figure 39: Normalised residuals from the base case CRA 4 MPD fits to proportions-at-length plotted against length for the three sex categories. The box plots show the median as a horizontal line, the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles and other points indicate outliers.

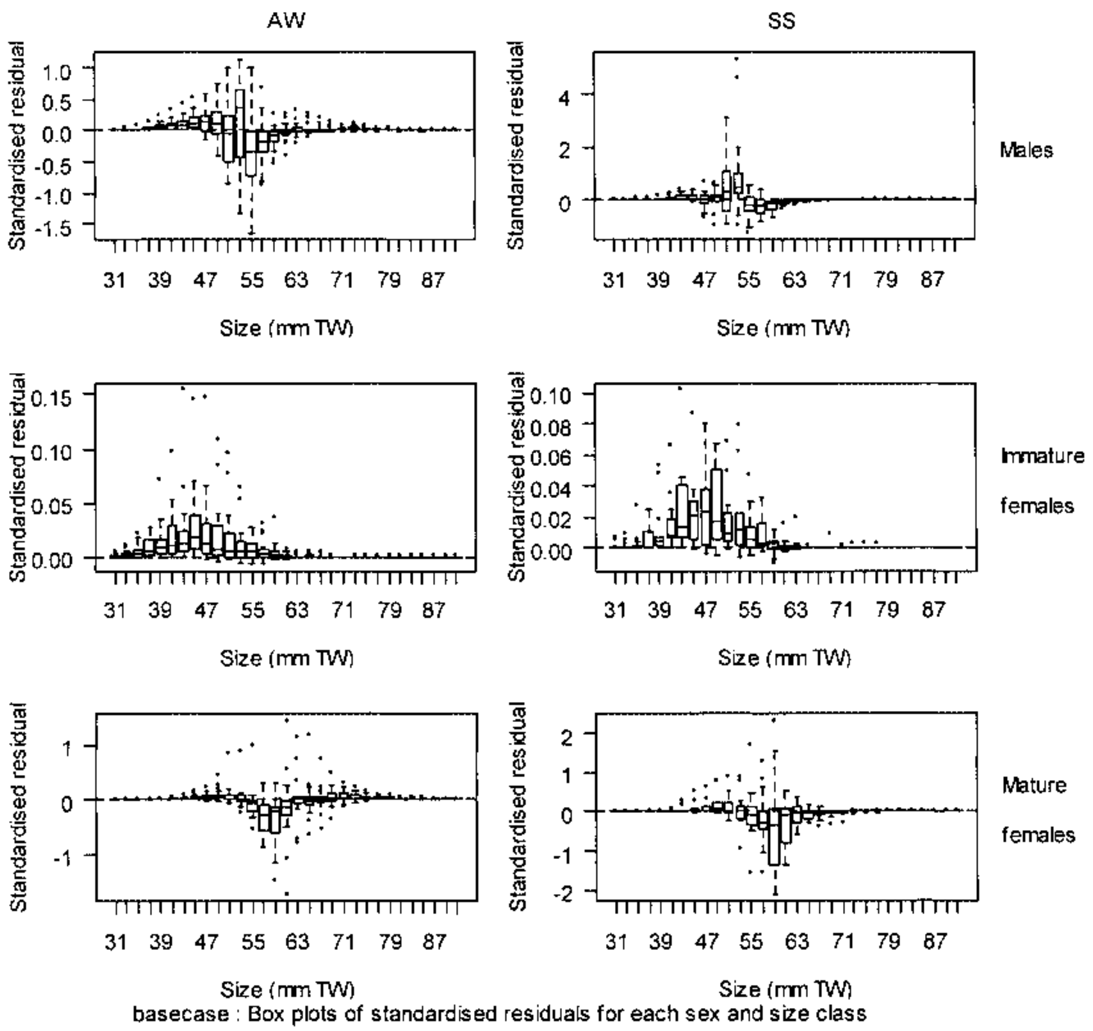


Figure 40: Normalised residuals from the base case CRA 4 MPD fits to proportions-at-length plotted against length by season for the three sex categories. Left panels are AW, right panels are SS. The box plots show the median as a horizontal line, the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles and other points indicate outliers.

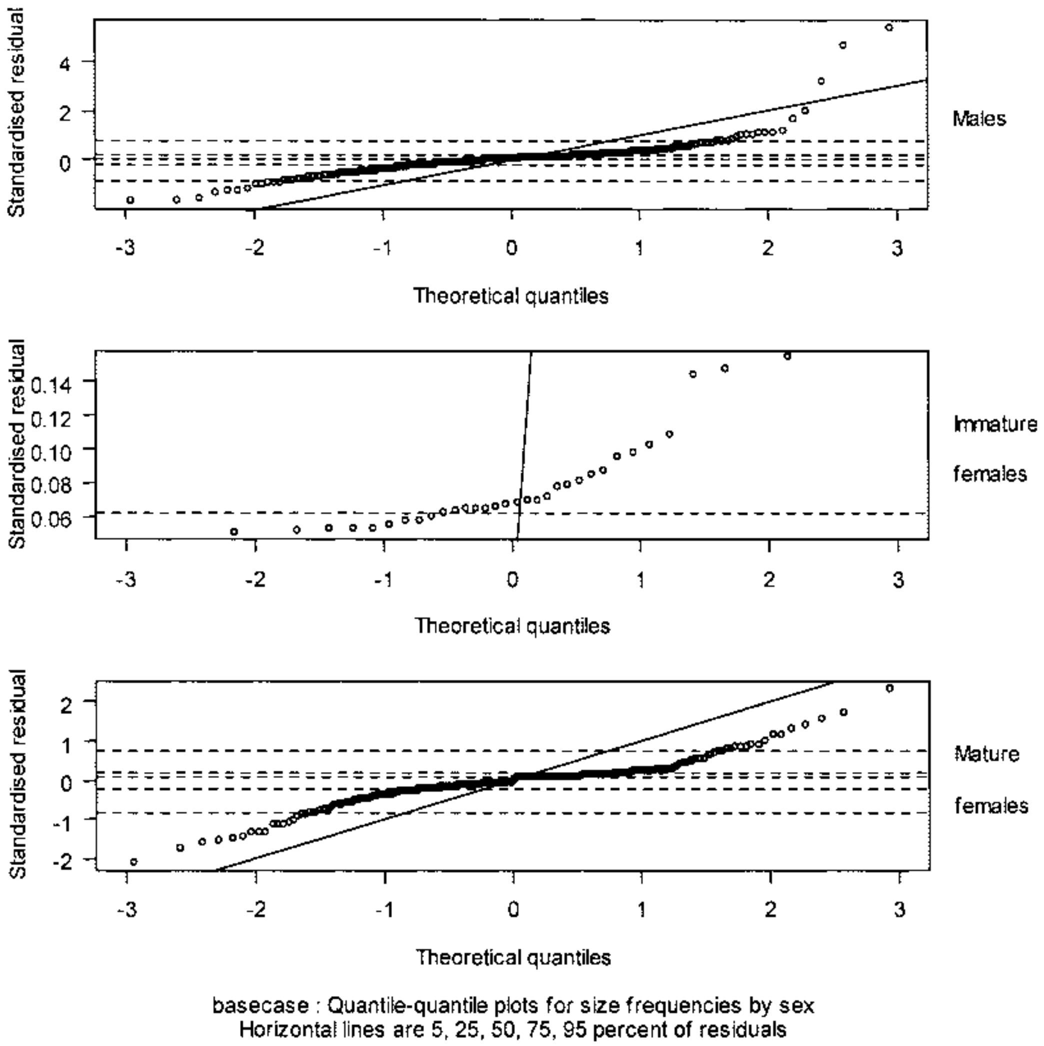


Figure 41: Quantile-quantile plot of normalised residuals from the base case CRA 4 MPD fits to proportions-at-length for the three sex categories.

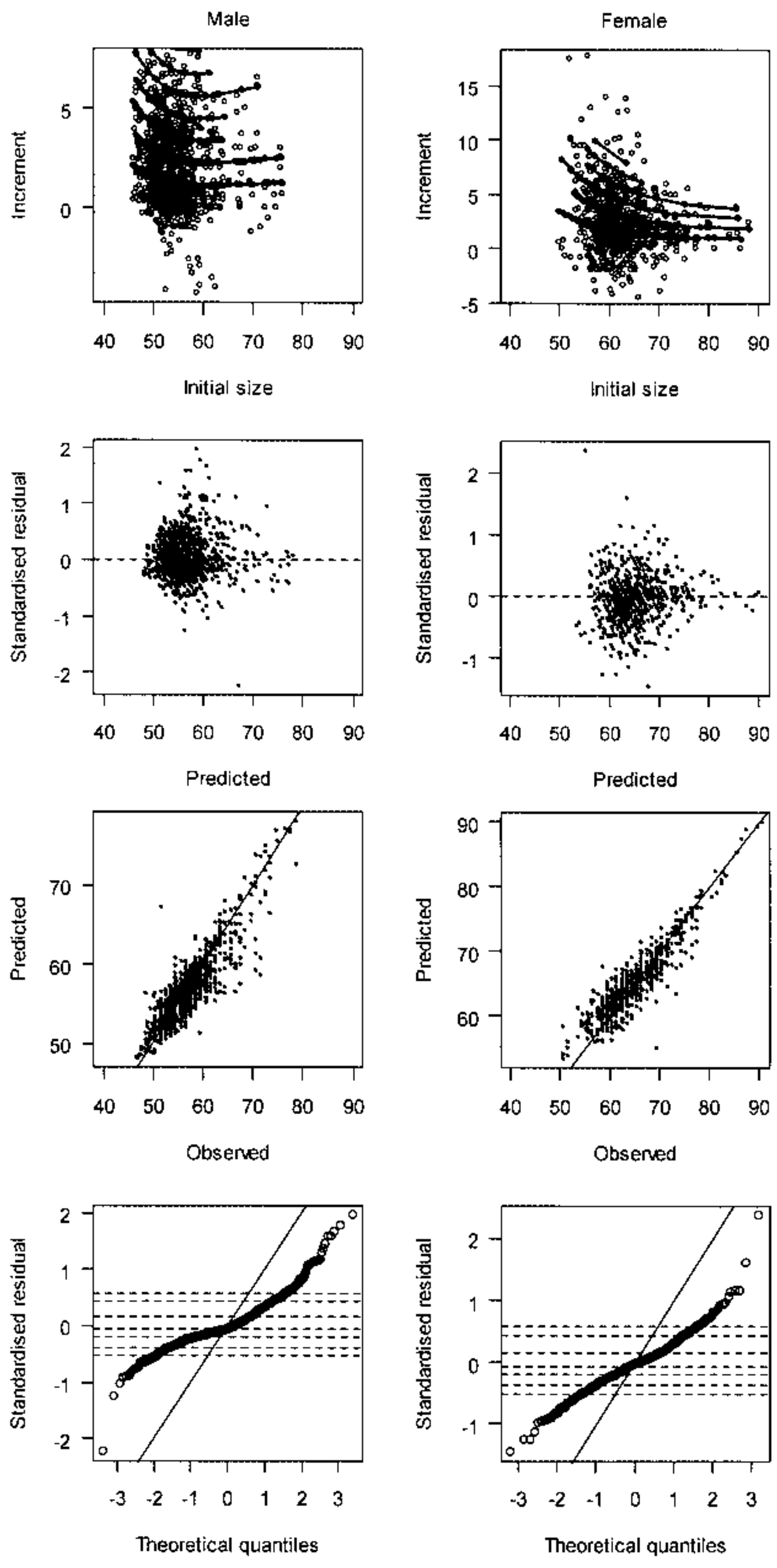


Figure 42: Predicted and observed size at recapture from the base case CRA 4 MPD fit to the tag-recapture data (top panels); normalised residuals plotted against predicted size at recapture (middle panels); quantile-quantile plots of the normalised residuals (bottom panels). Left panels are males and right panels are females.

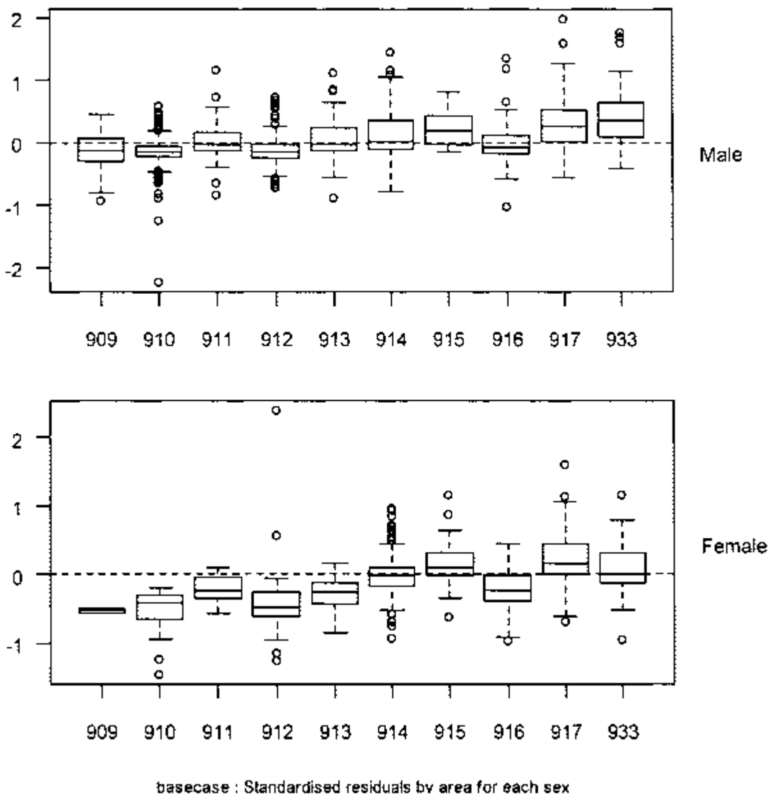


Figure 43: Box plots of the residuals from the base case CRA 4 MPD fit to tag-recapture data, plotted by area of release.

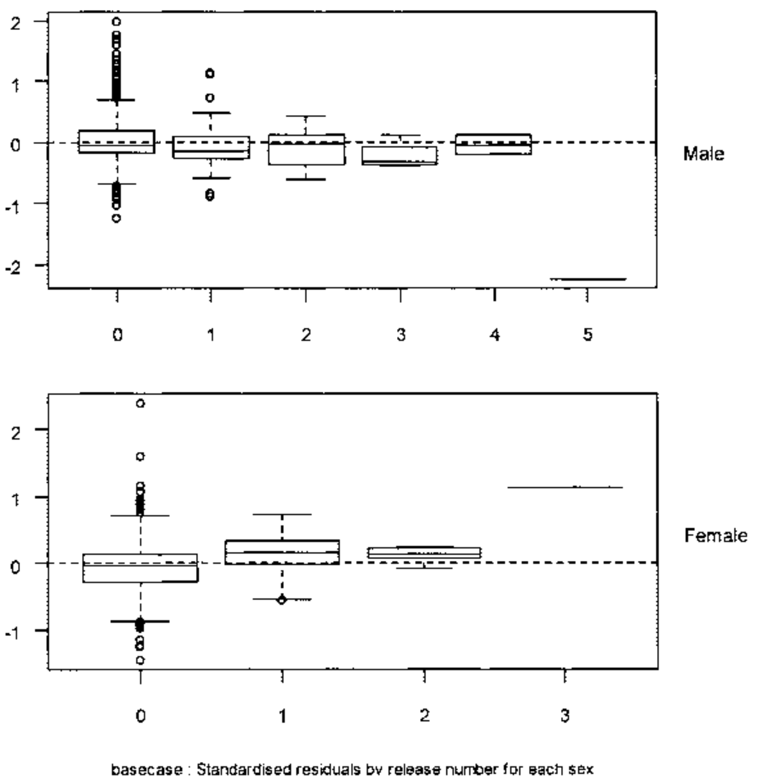


Figure 44: Box plots of the residuals from the base case CRA 4 MPD fit to tag-recapture data, plotted by the number of re-releases for males and females.

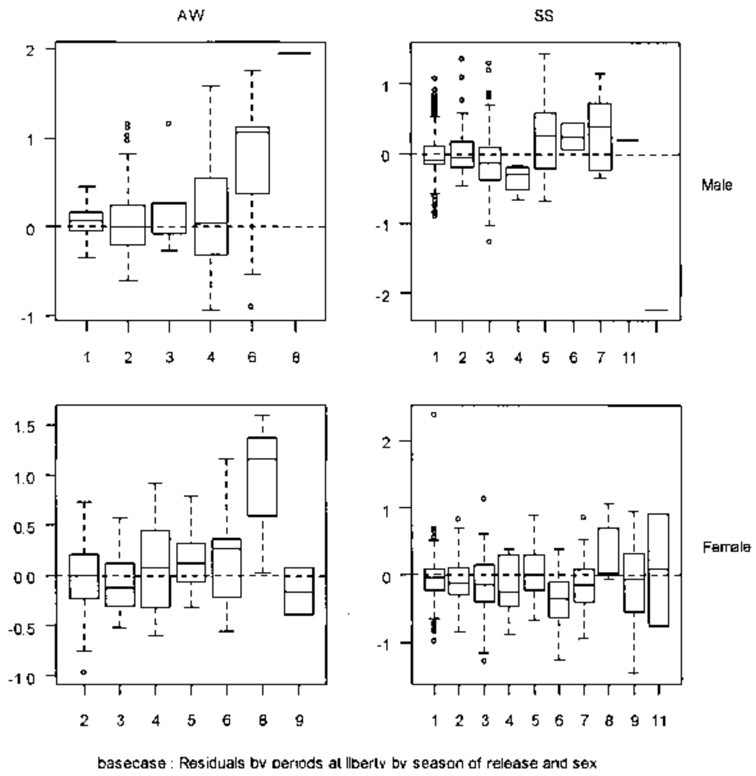


Figure 45: Box plots of residuals from the base case CRA 4 MPD fit to tag-recapture data, plotted by the number of periods at liberty and by season of release.

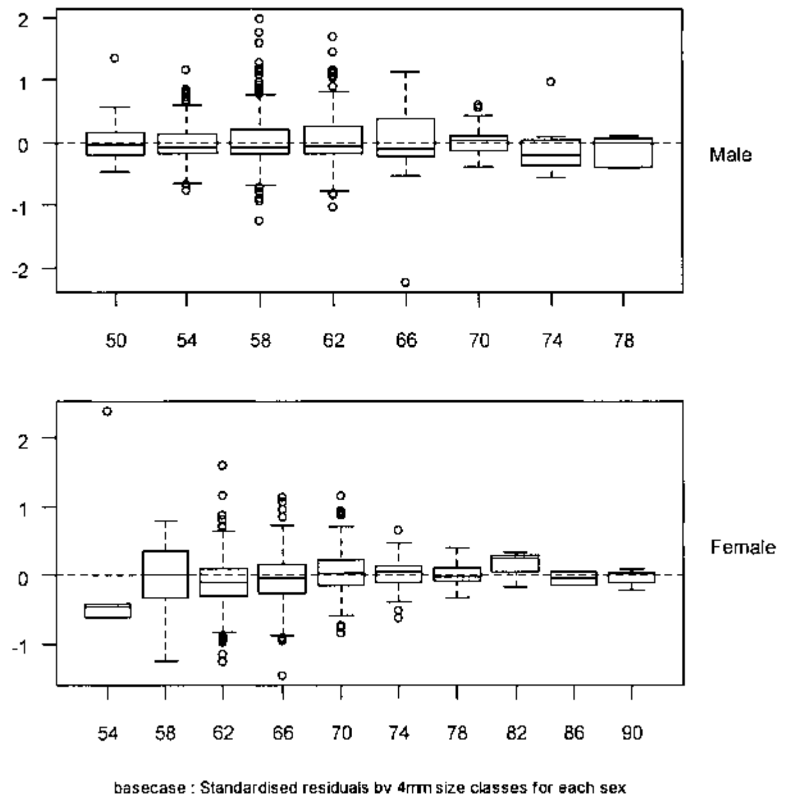


Figure 46: Box plots of residuals from the base case CRA 4 MPD fit to tag-recapture data, plotted by initial size.

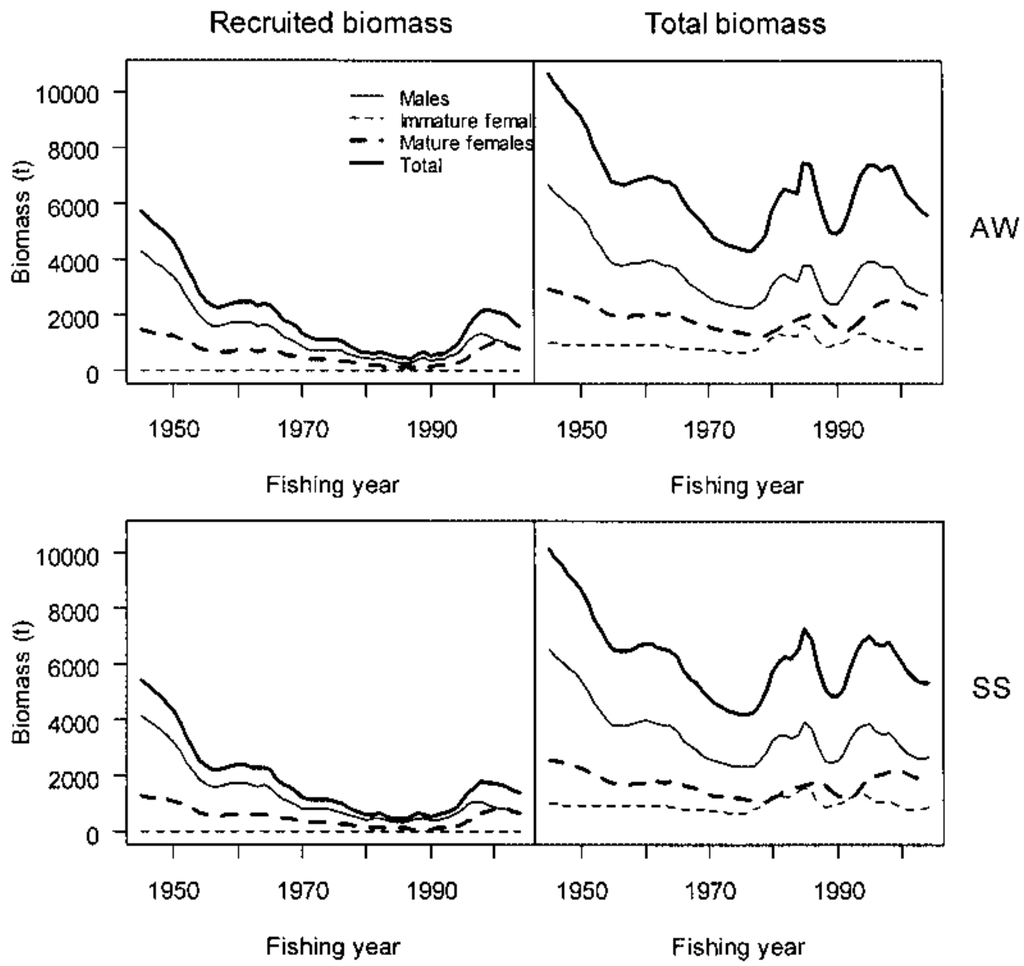


Figure 47: Recruited (left panels) and total biomass (right panels) from the base case CRA 4 MPD fit, plotted by sex and season.

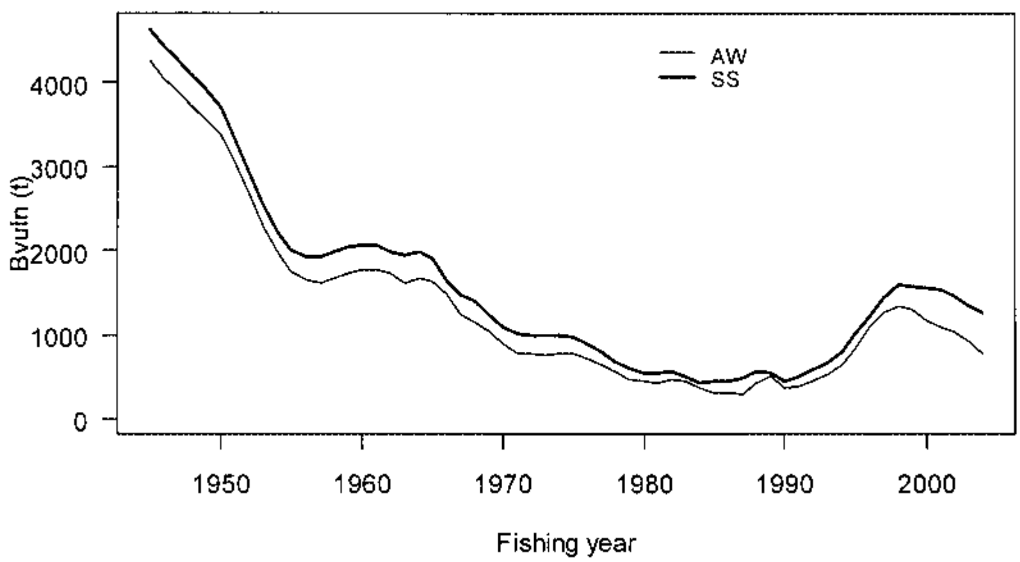


Figure 48: Predicted vulnerable biomass from the CRA 4 base case MPD fit, plotted by season.

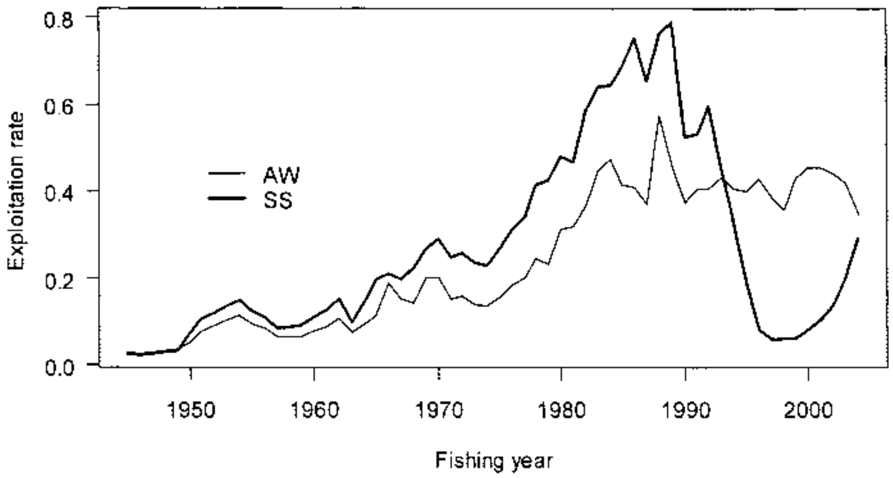


Figure 49: SL exploitation rate trajectories from the CRA 4 base case MPD fit plotted by season.

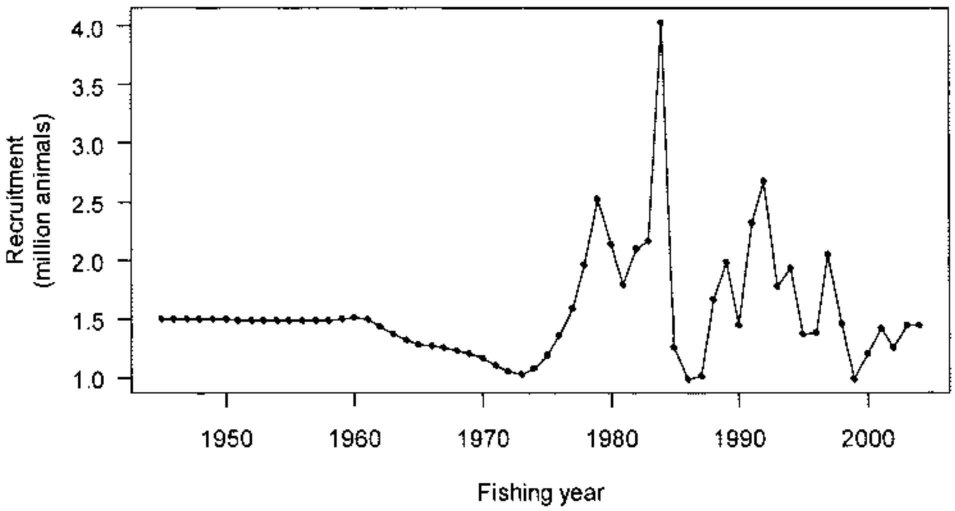


Figure 50: Recruitment trajectory (millions) from the CRA 4 base case MPD fit.

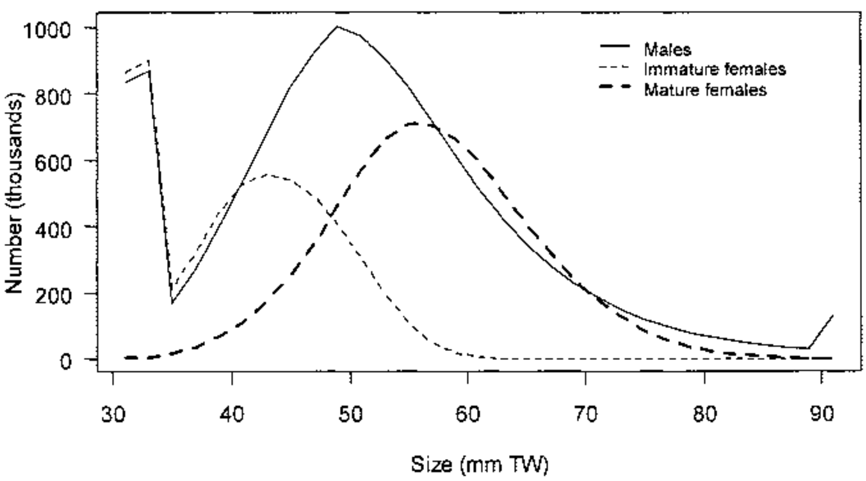


Figure 51: Initial length structure from the CRA base case MPD fit for each sex category.

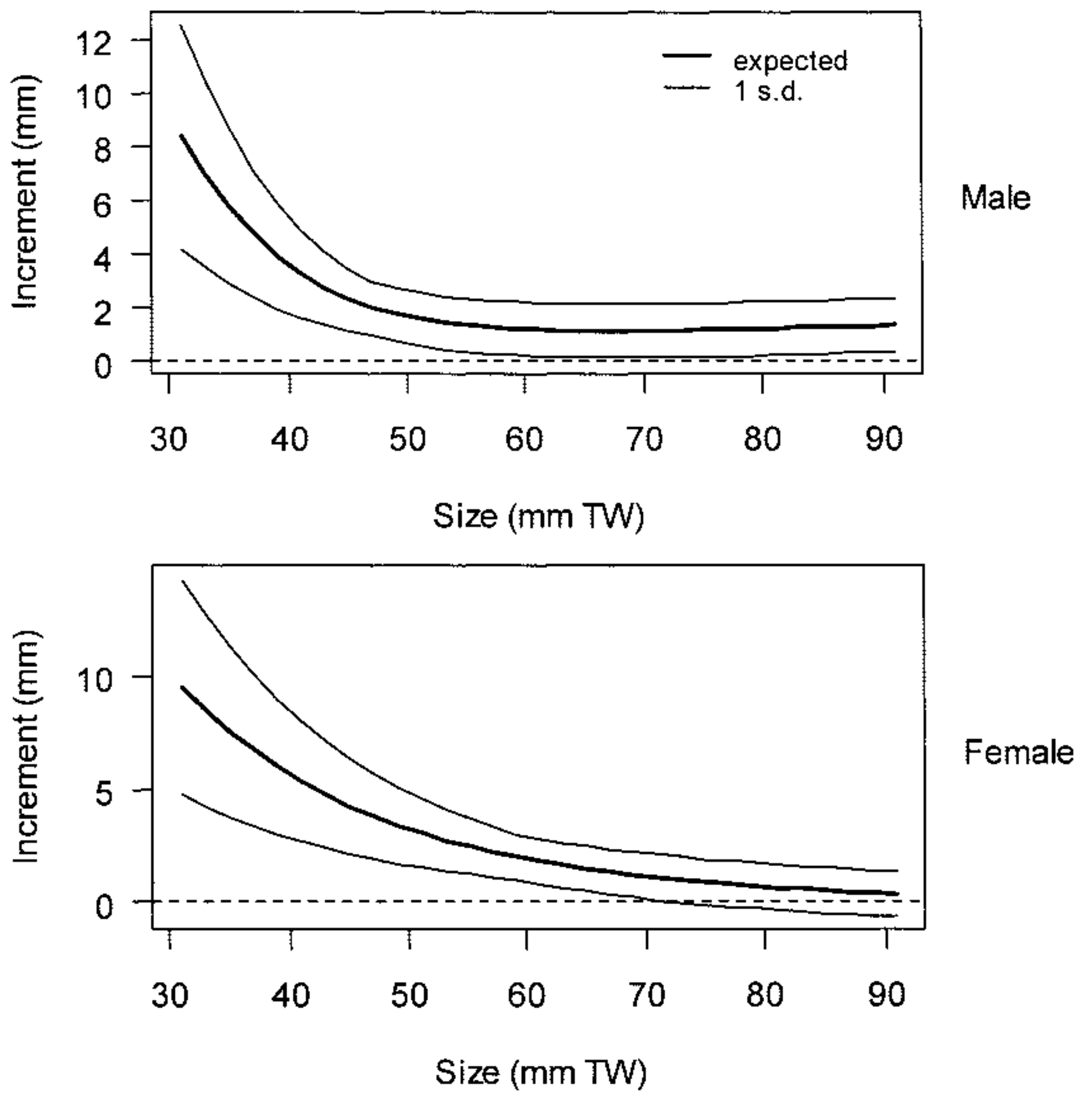


Figure 52: Annual growth increments (thick line) from the CRA 4 base case MPD fit plotted against initial size by sex, shown with one standard deviation around the increment (thin line).

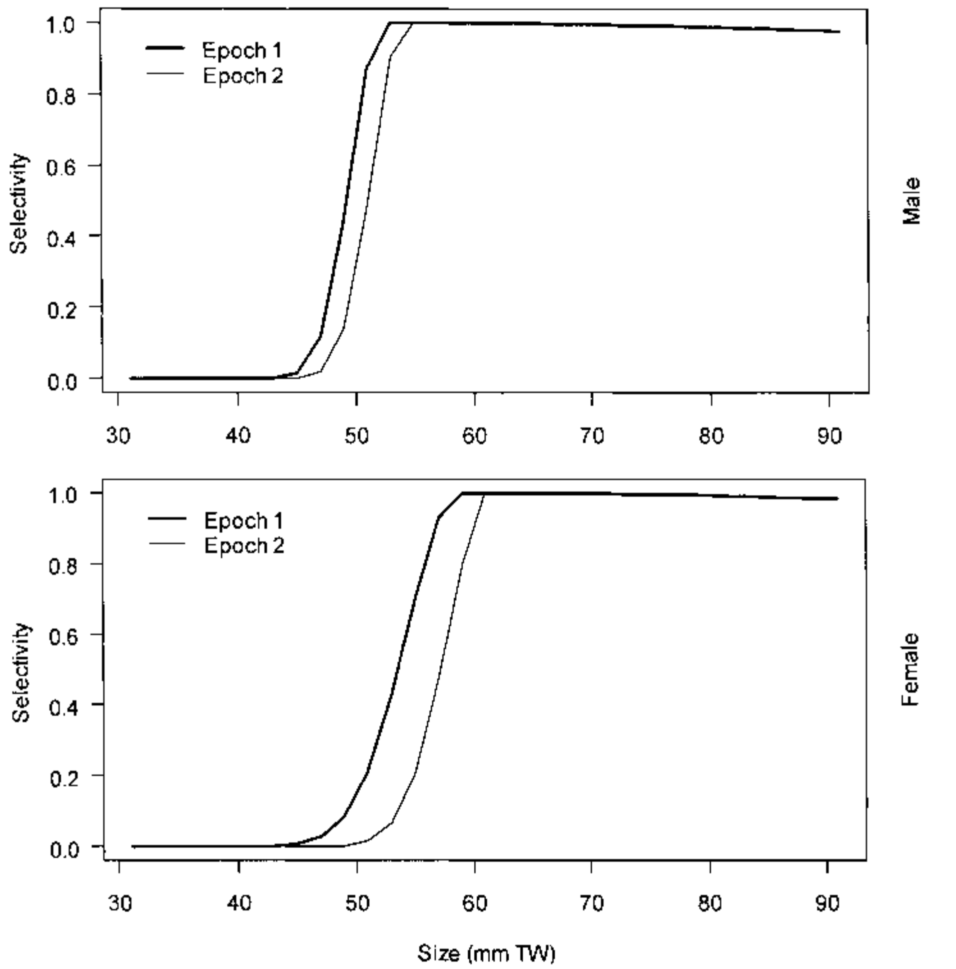


Figure 53: Selectivity in each epoch from the CRA 4 base case MPD fit: epoch 1 extends from 1945 to 1992, epoch 2 from 1993 onwards.

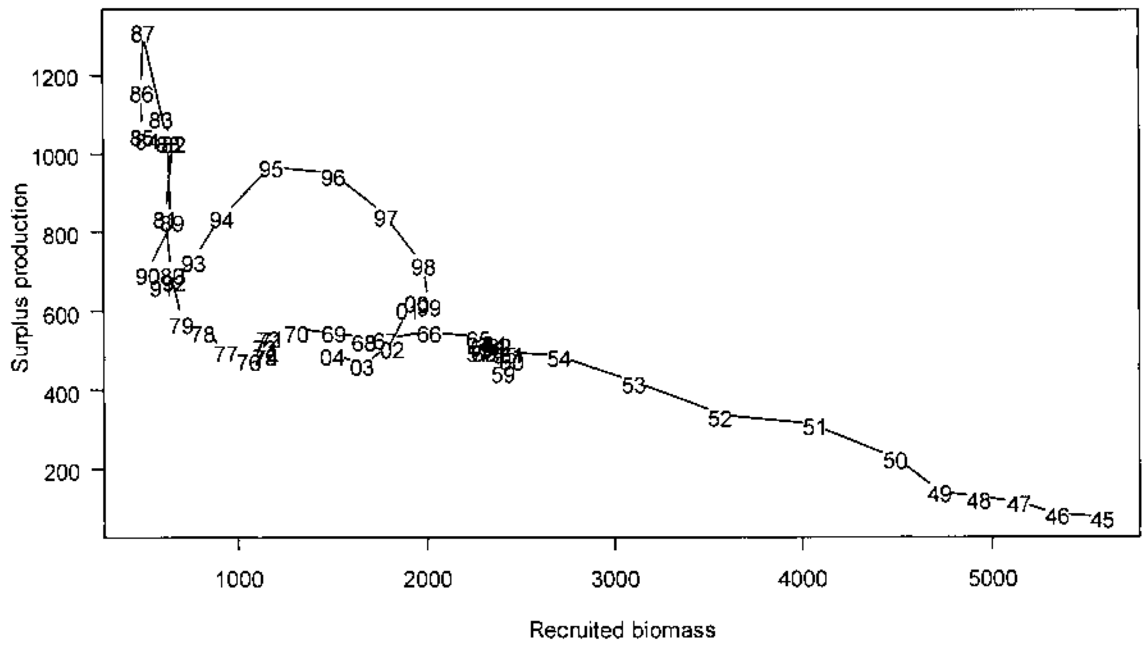


Figure 54: Surplus production from the CRA 4 base case MPD fit plotted against recruited biomass. The labels indicate the last two digits of the fishing year.

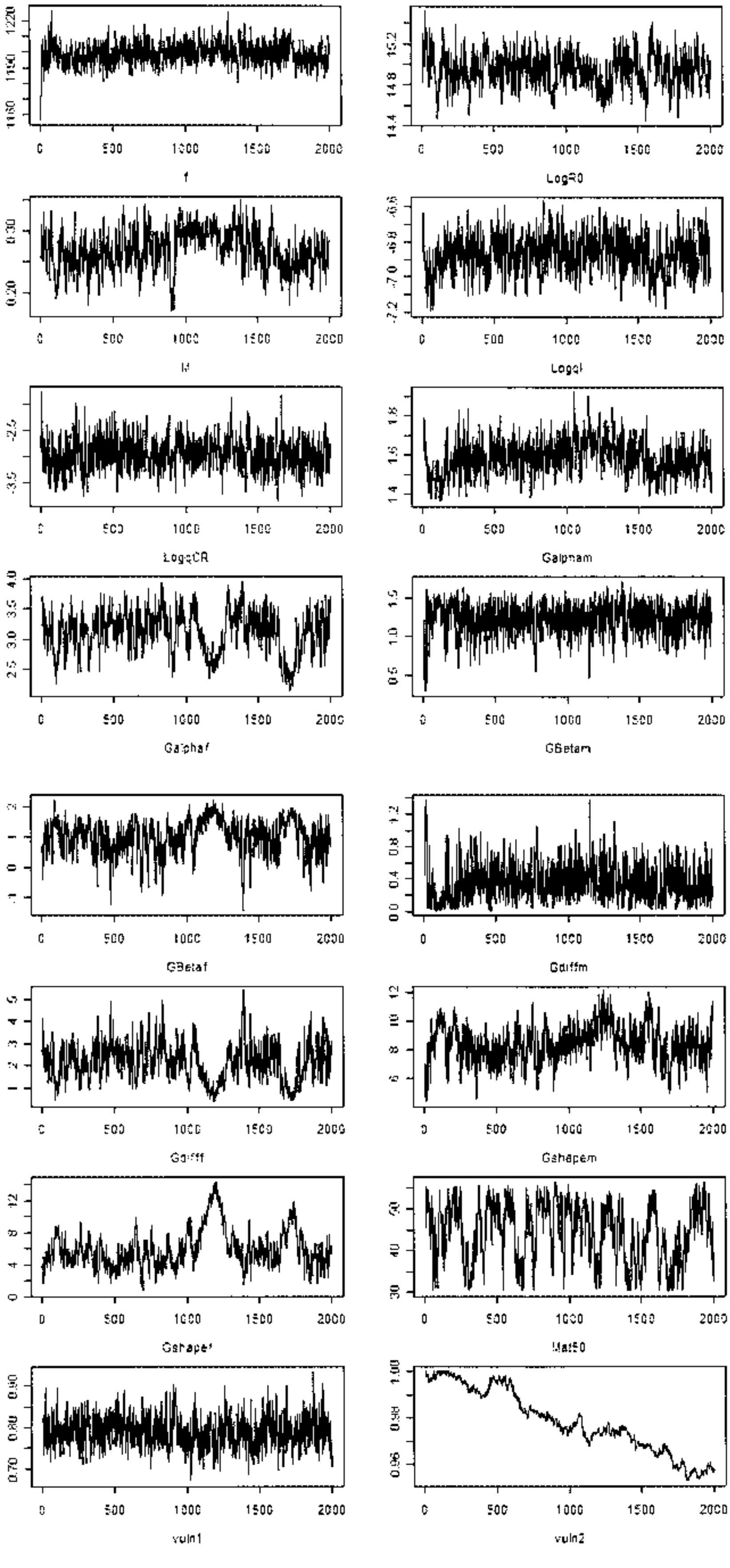


Figure 55: Traces from the CRA 4 base case McMC simulations.

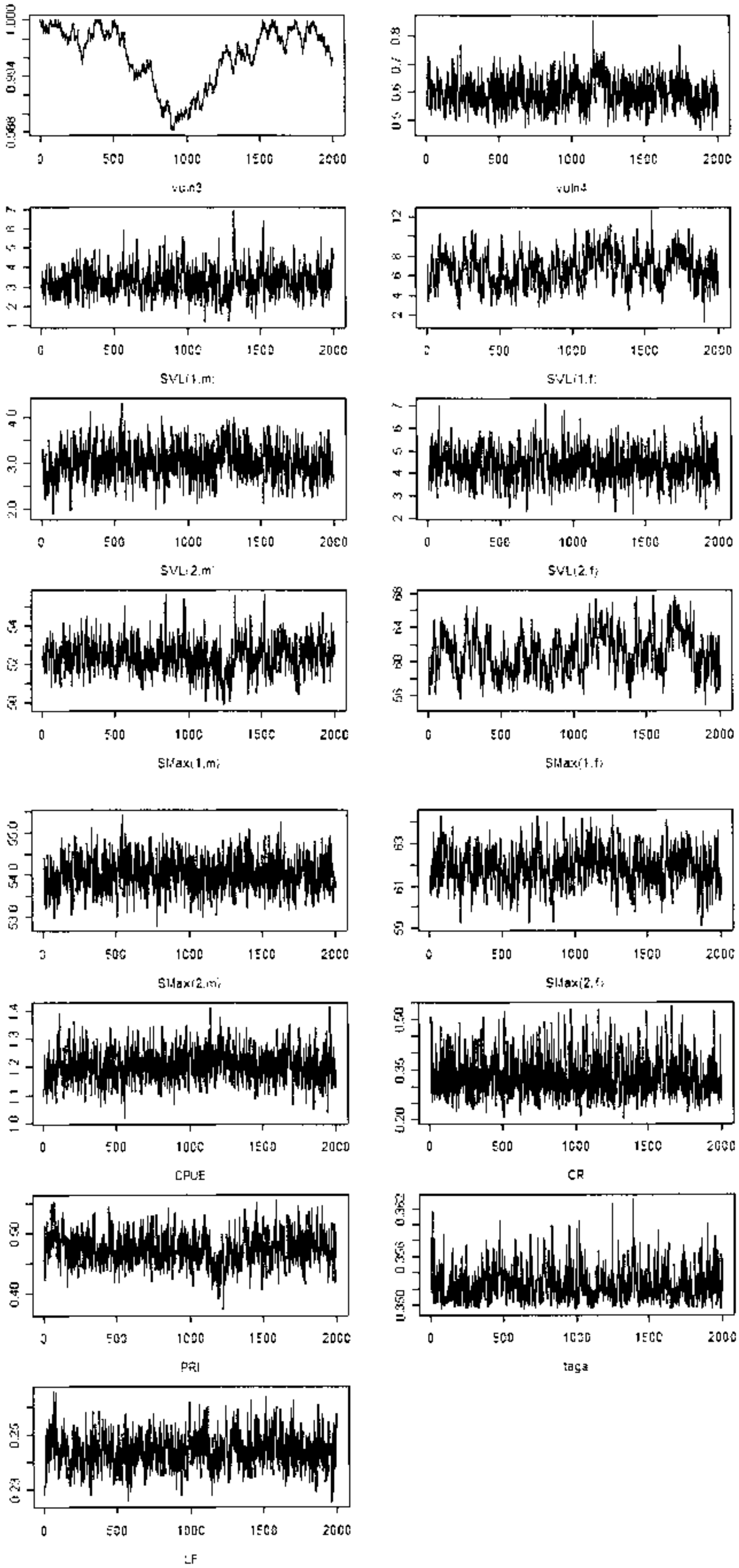


Figure 55: continued.

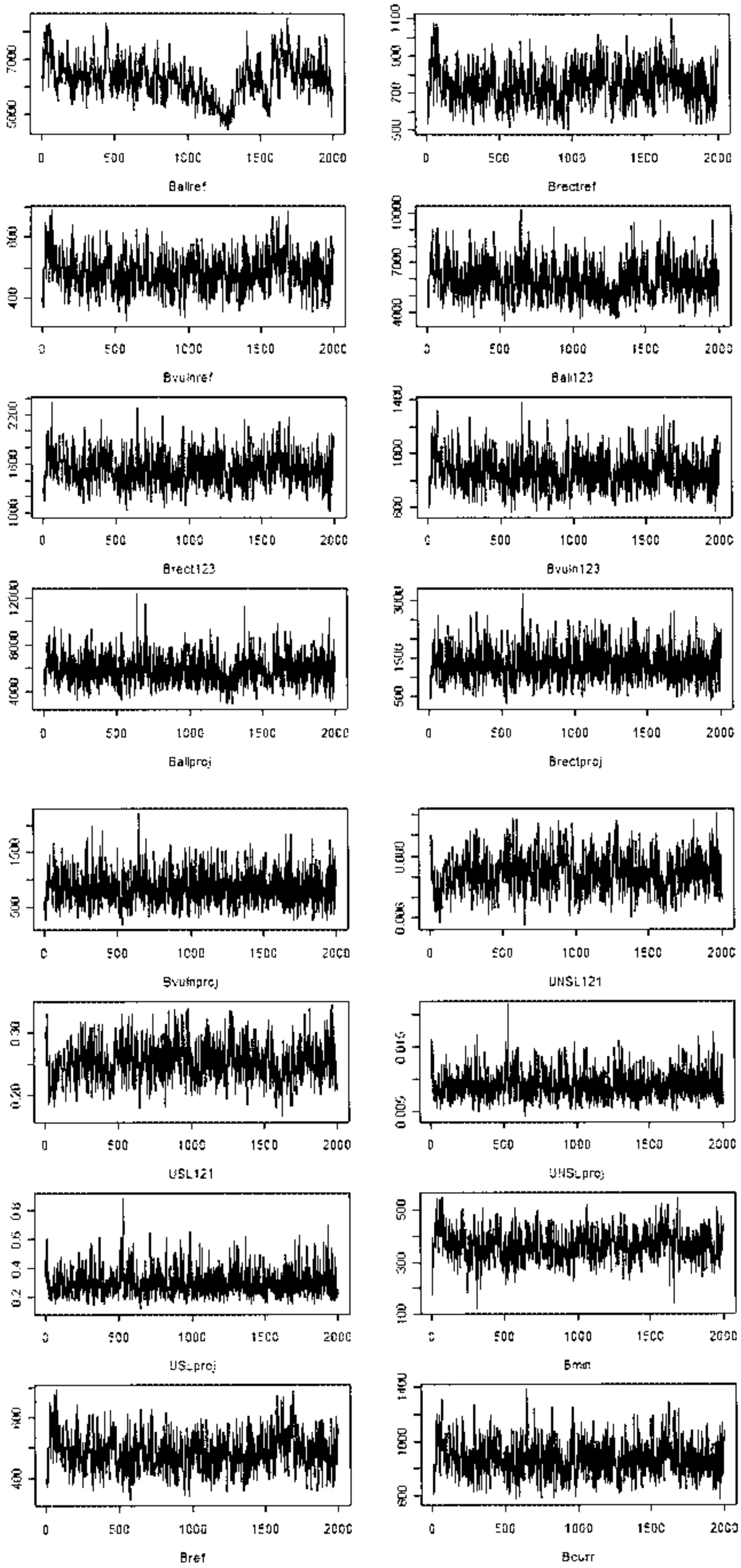


Figure 55: continued.

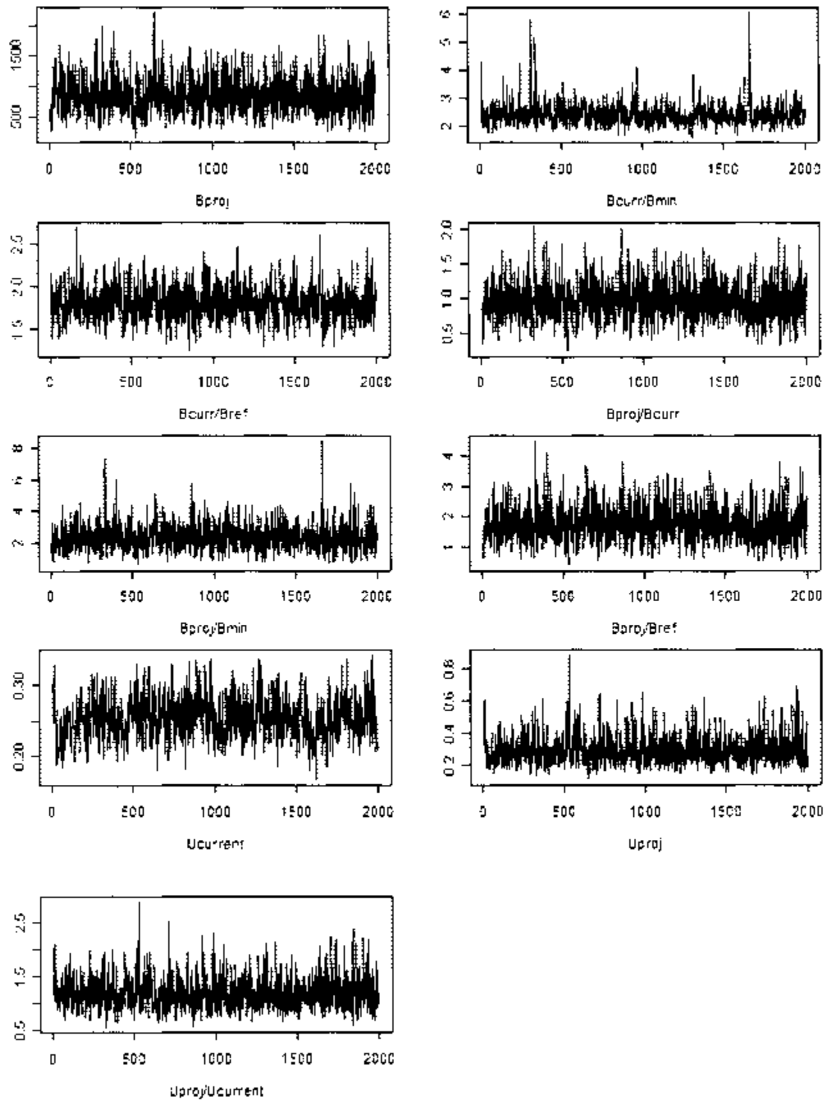


Figure 55: continued.

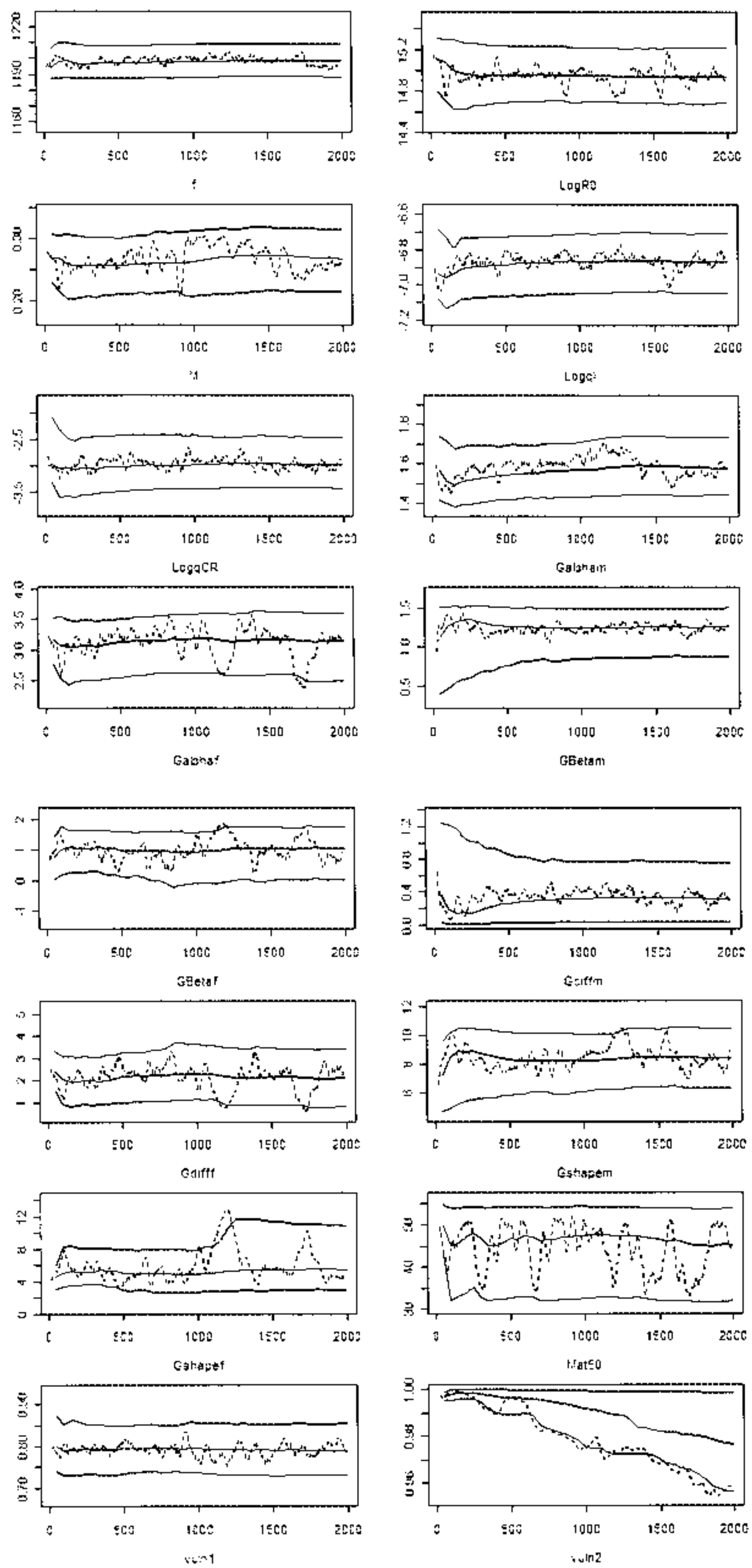


Figure 56: Diagnostic plots for chains: Moving averages (from 50 samples, dotted line), and running medians and 5th and 95th percentiles of traces from the CRA 4 base case McMC simulations. After the parameter traces are shown the *sndrs*, then derived quantities.

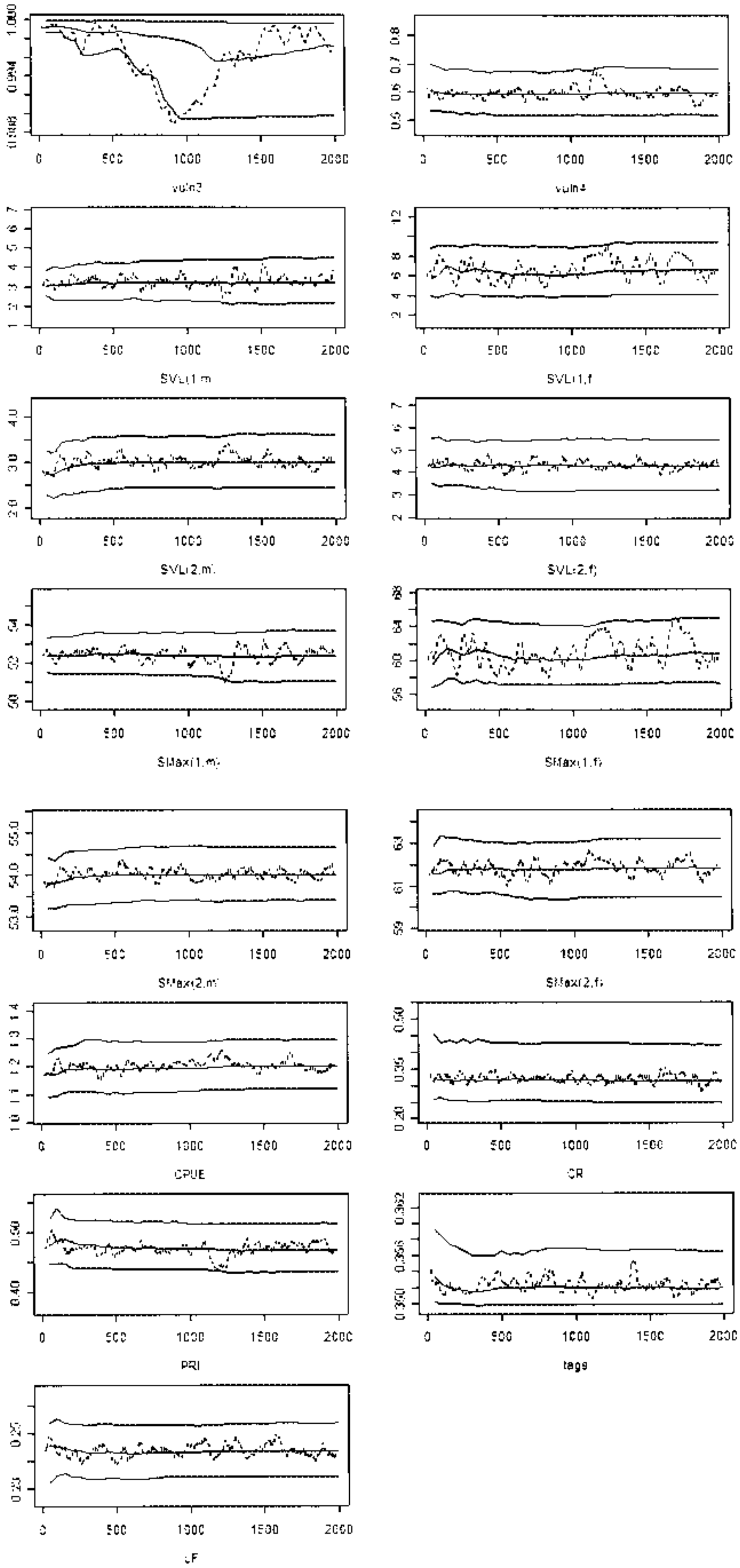


Figure 56 continued.

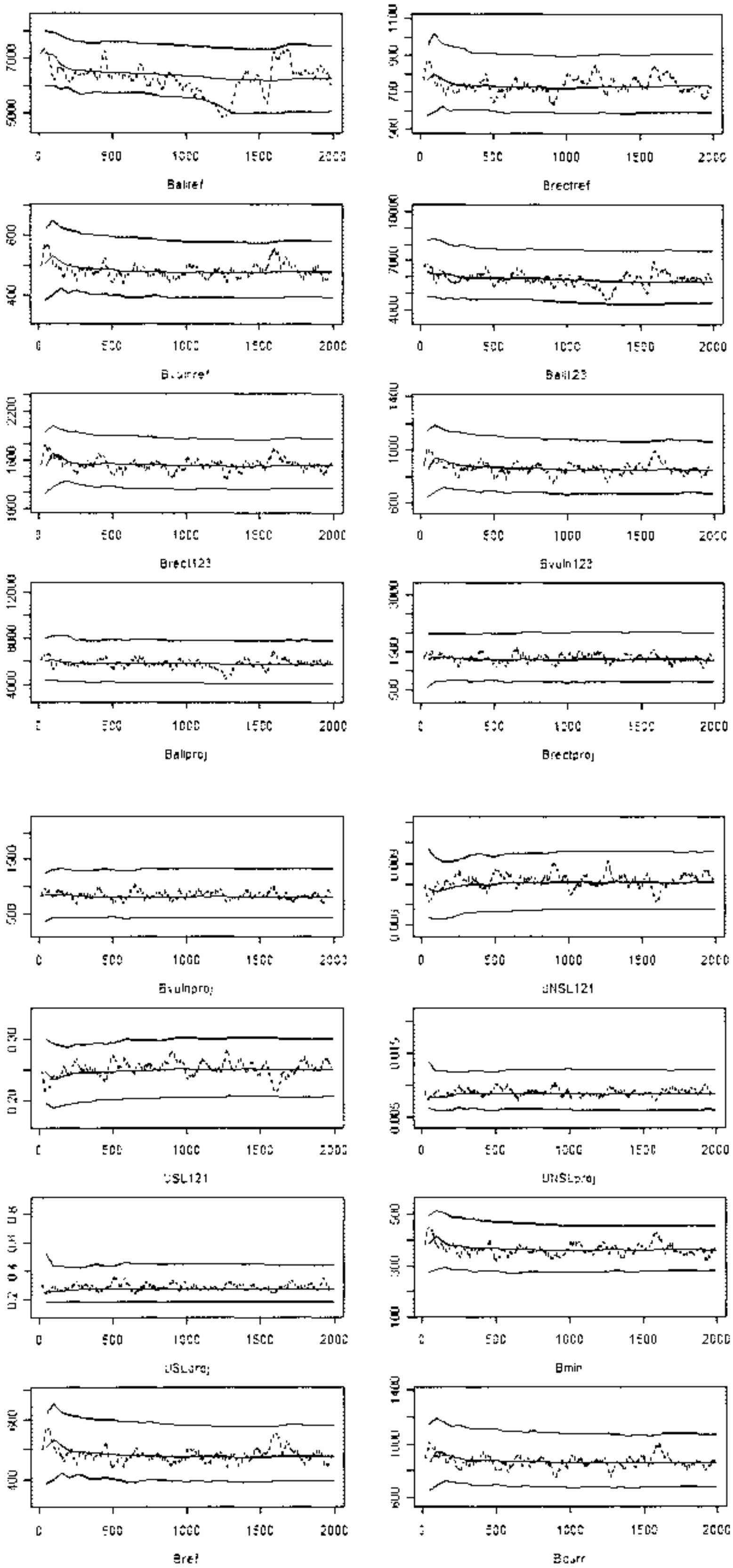


Figure 56 continued.

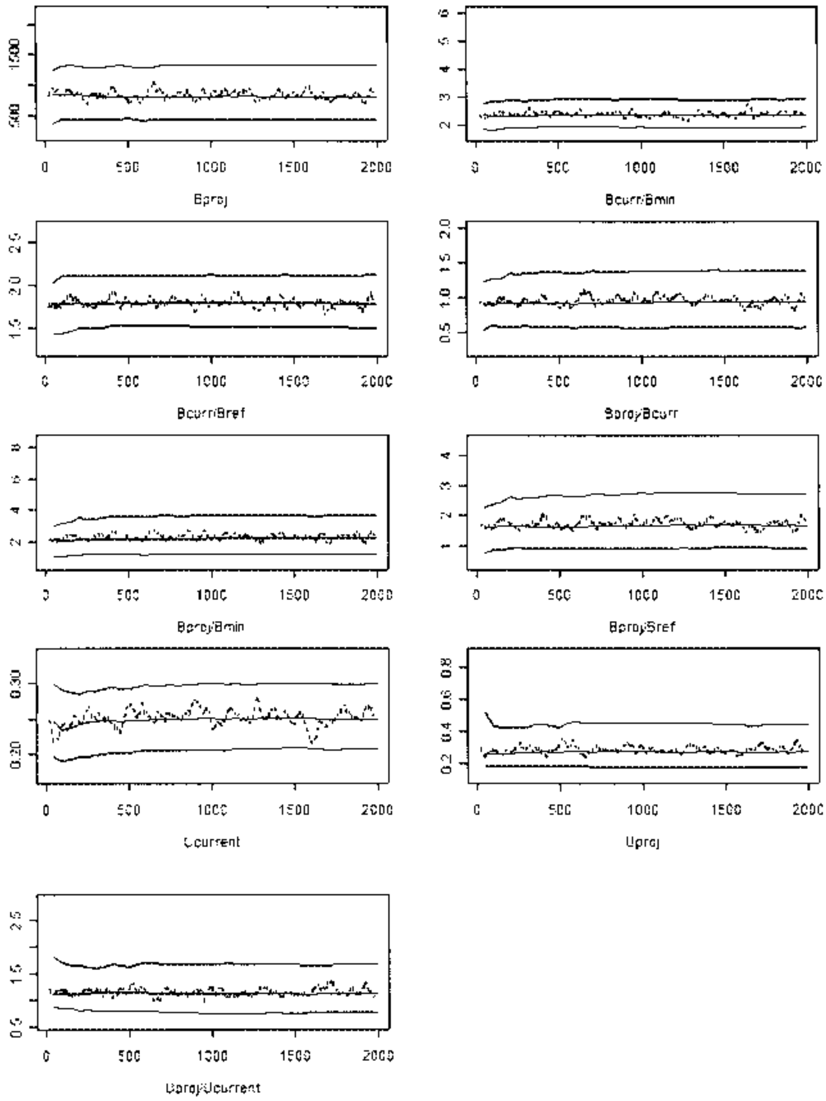


Figure 56 continued.

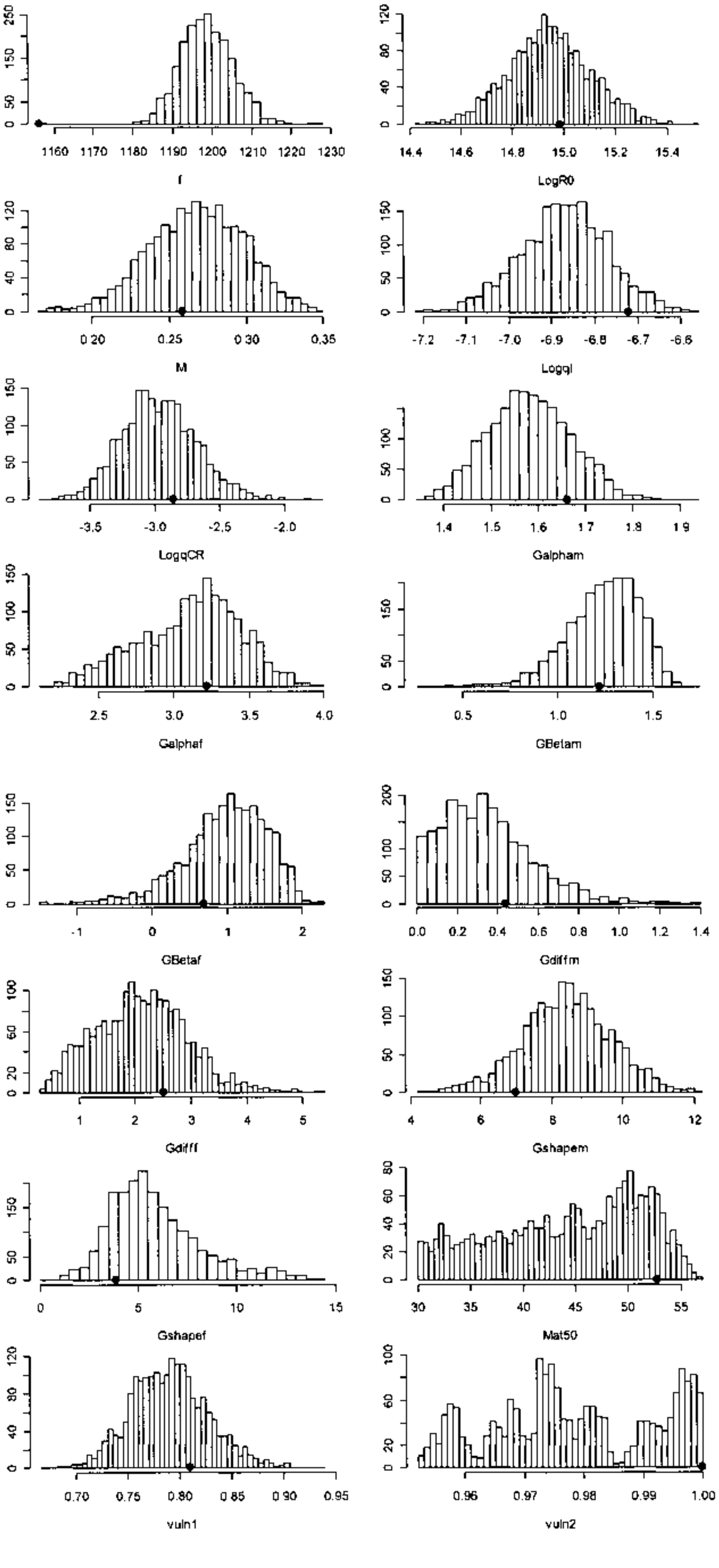


Figure 57: Marginal posterior distributions of parameters and performance indicators from the CRA 4 base case McMC simulations. The MPD estimate for each parameter or performance indicator is indicated by a dot on the x-axis.

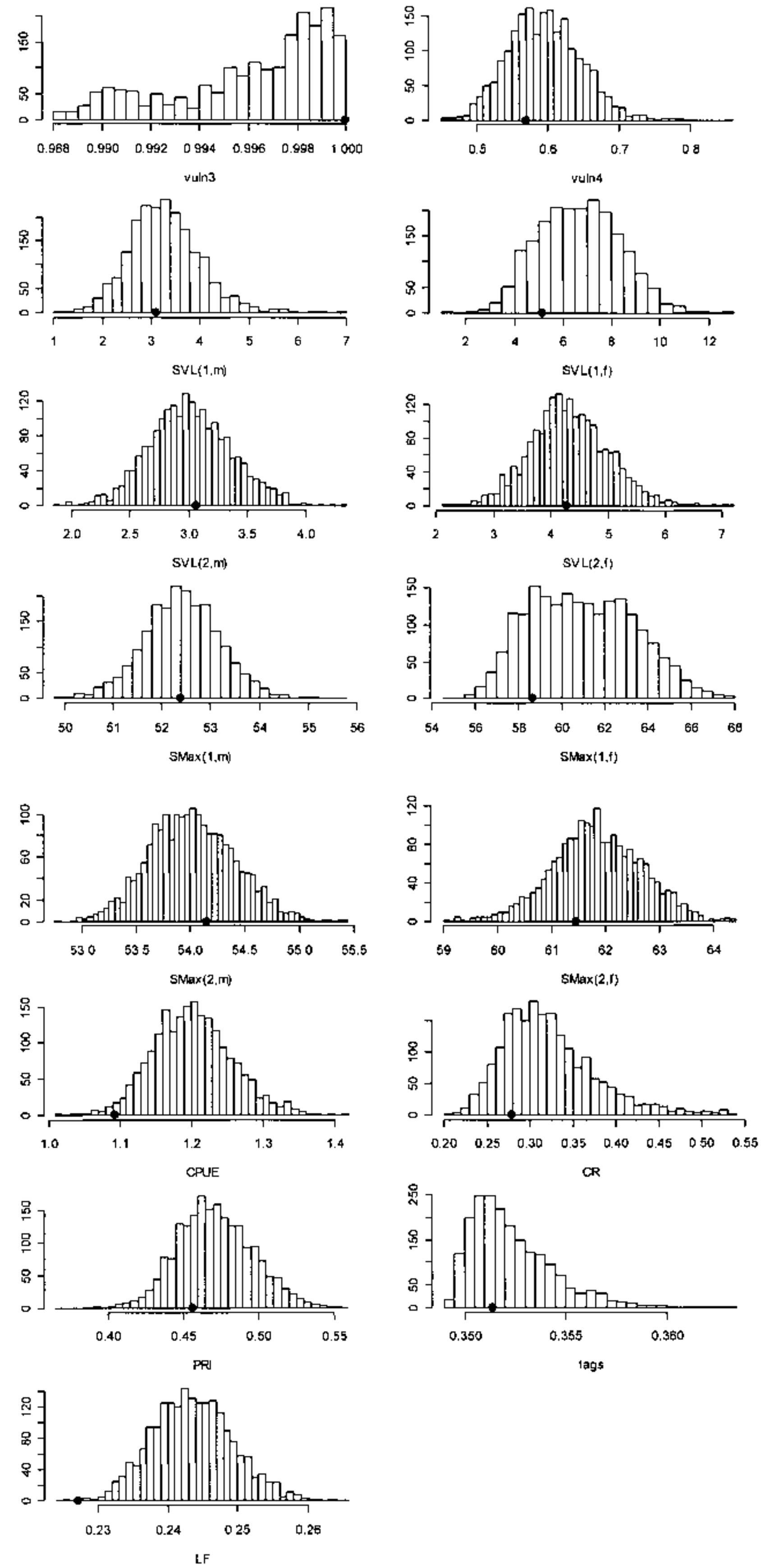
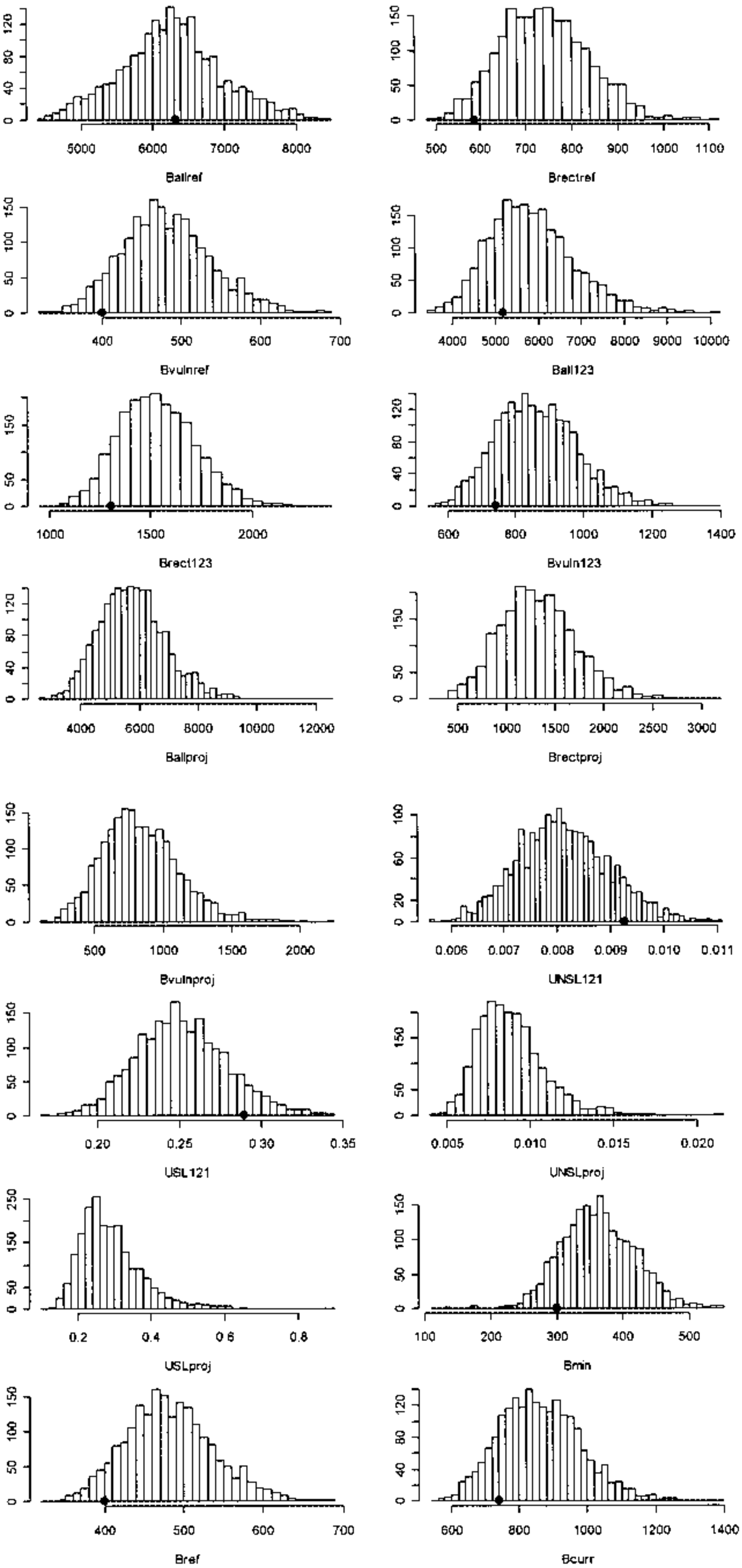


Figure 57: continued.



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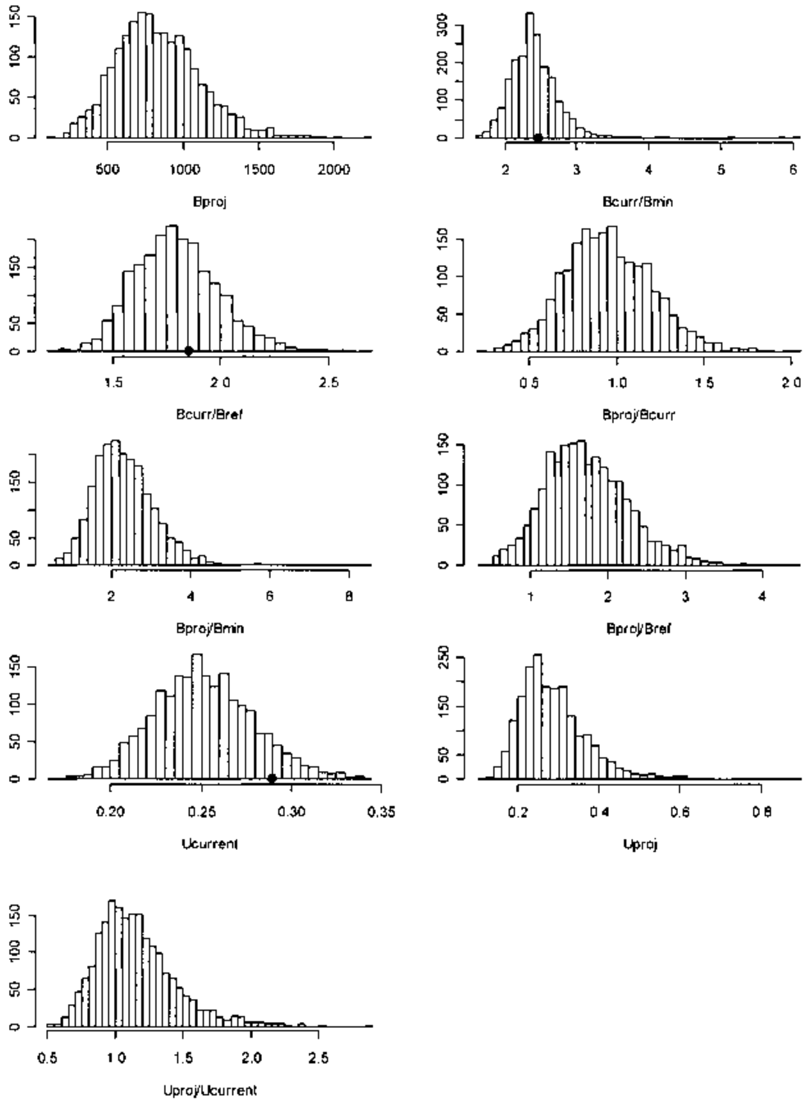

Figure 57: continued.

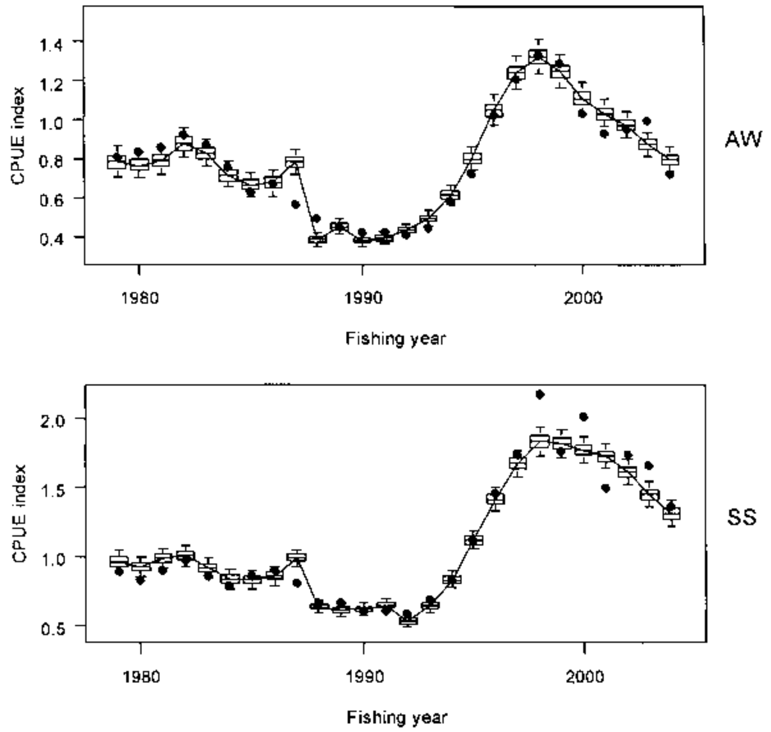

Figure 58: The posterior distributions of the fits to CPUE data from the base case CRA 4 McMC simulations.

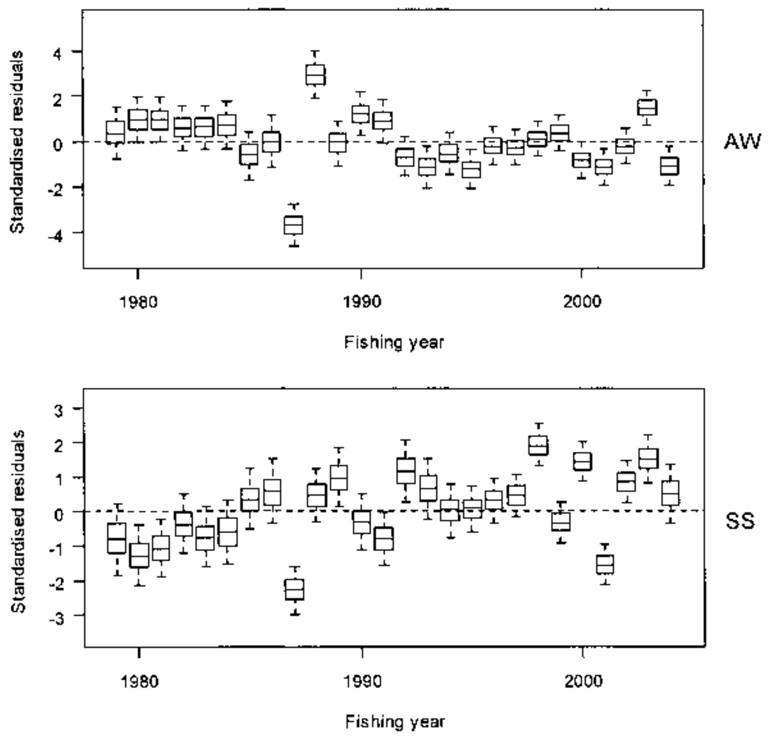

Figure 59: The posterior distributions of the normalised residuals from fit to CPUE in the base case CRA 4 McMC simulations.

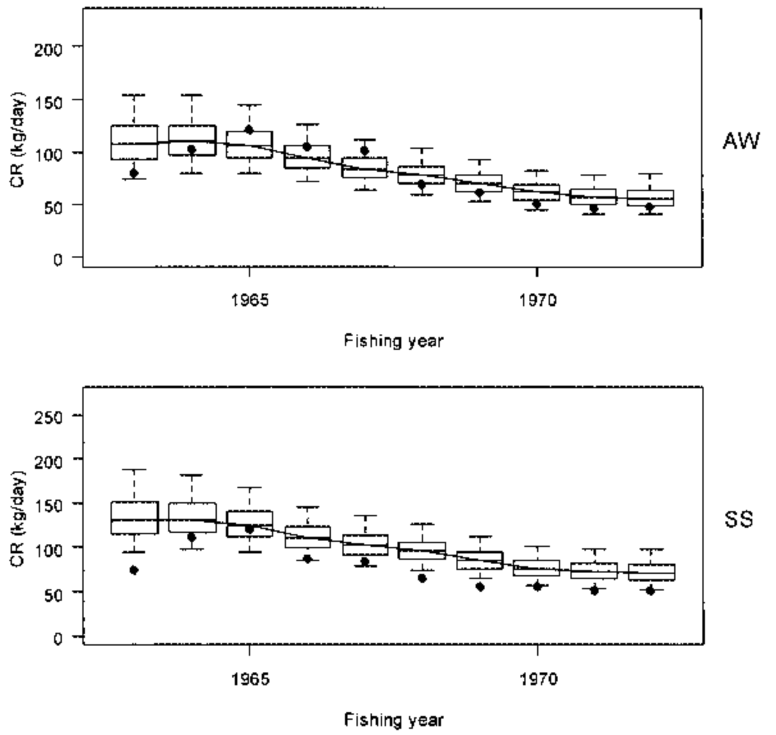

Figure 60: The posterior distributions of the fits to CR data in the base case CRA 4 McMC simulations.

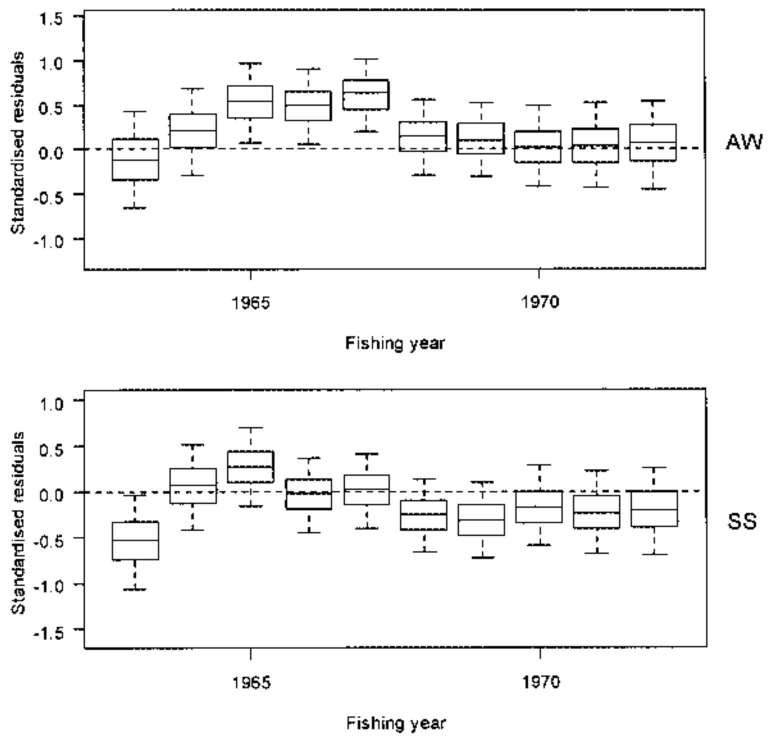

Figure 61: The posterior distributions of the normalised residuals from the CR fit in the base case CRA 4 McMC simulations.

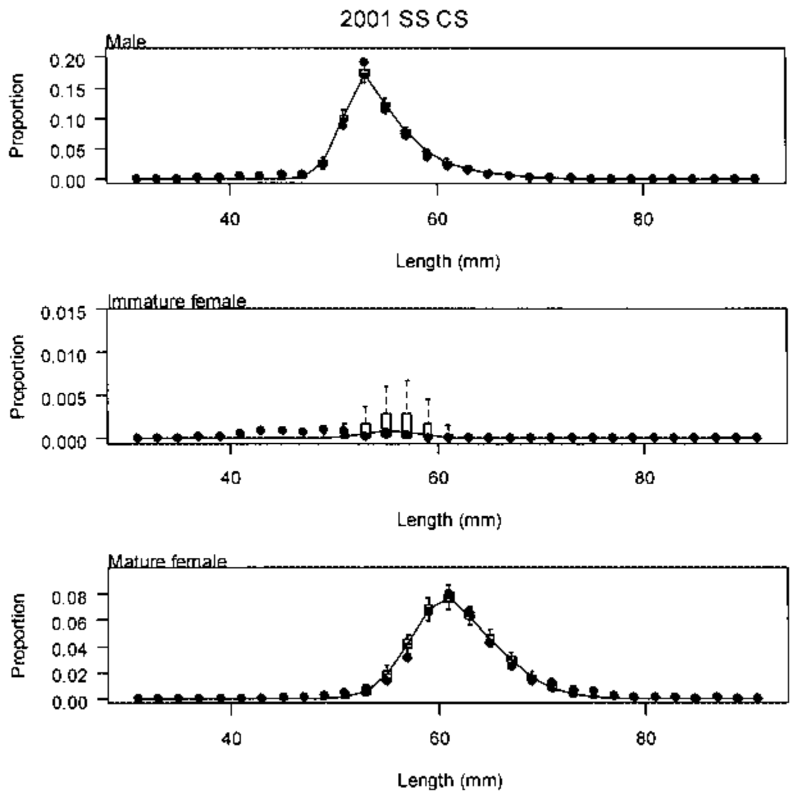

Figure 62: The posterior distributions of the fits to proportions-at-length from 2001 SS catch sampling in the base case CRA 4 McMC simulations.

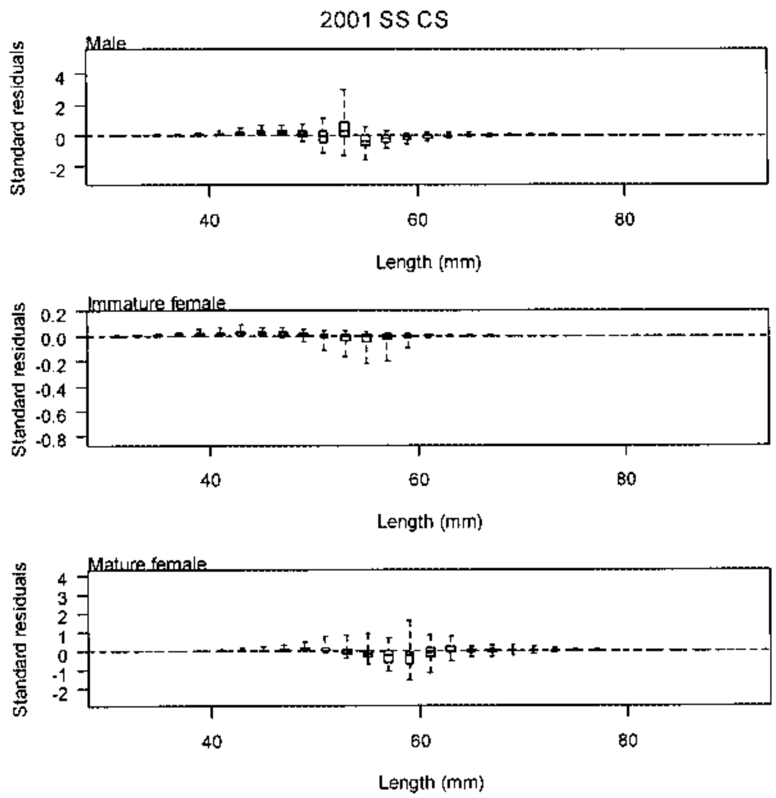

Figure 63: The posterior distributions of the normalised residuals from the fits to proportions-at-length from 2001 SS catch sampling in the base case CRA 4 McMC simulations.

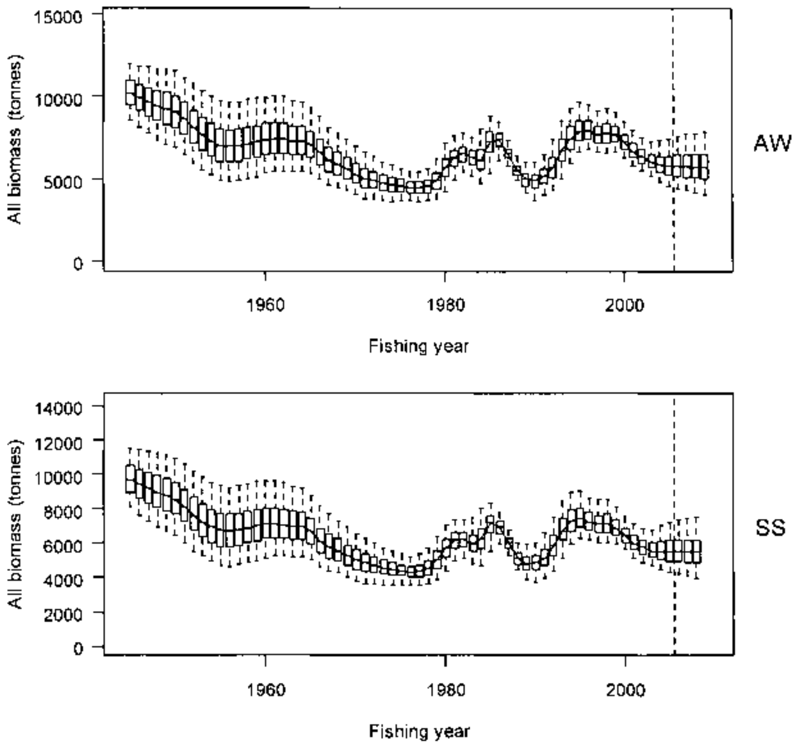

Figure 64: The posterior trajectory of total biomass, by season, from the CRA 4 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

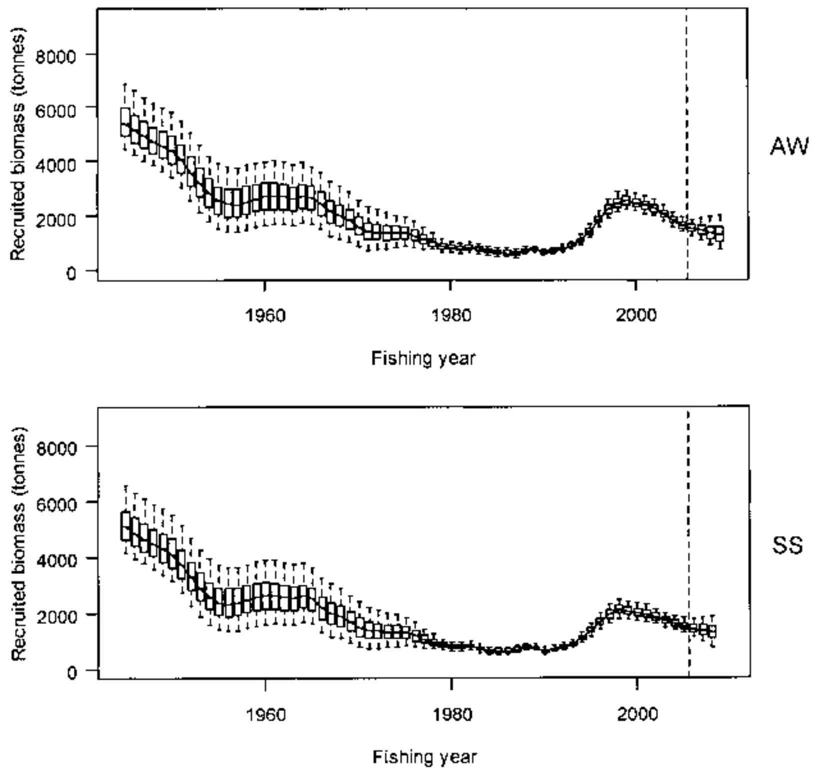

Figure 65: The posterior trajectory of recruited biomass, by season, from the CRA 4 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

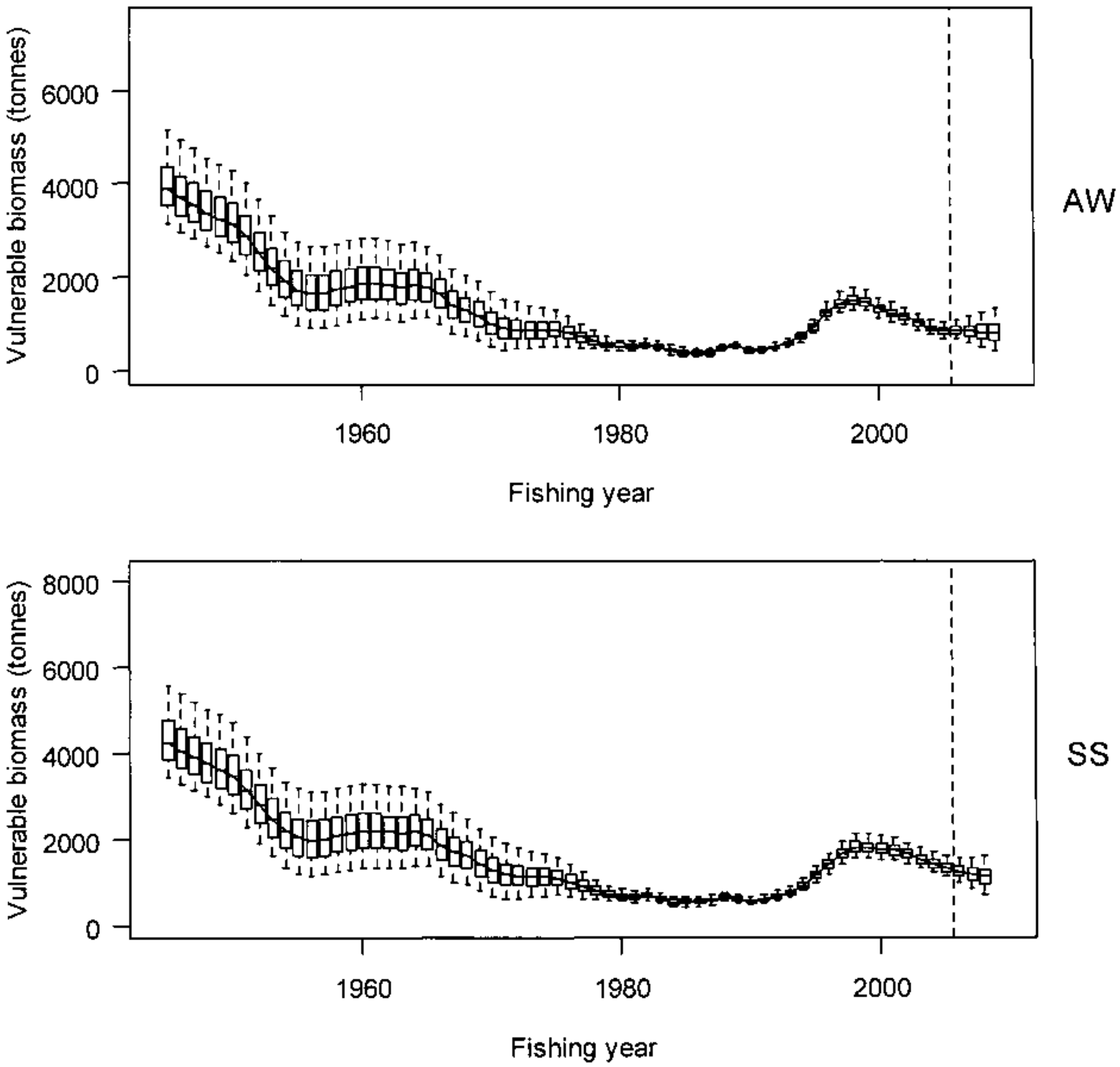

Figure 66: The posterior trajectory of vulnerable biomass, by season, from the CRA 4 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

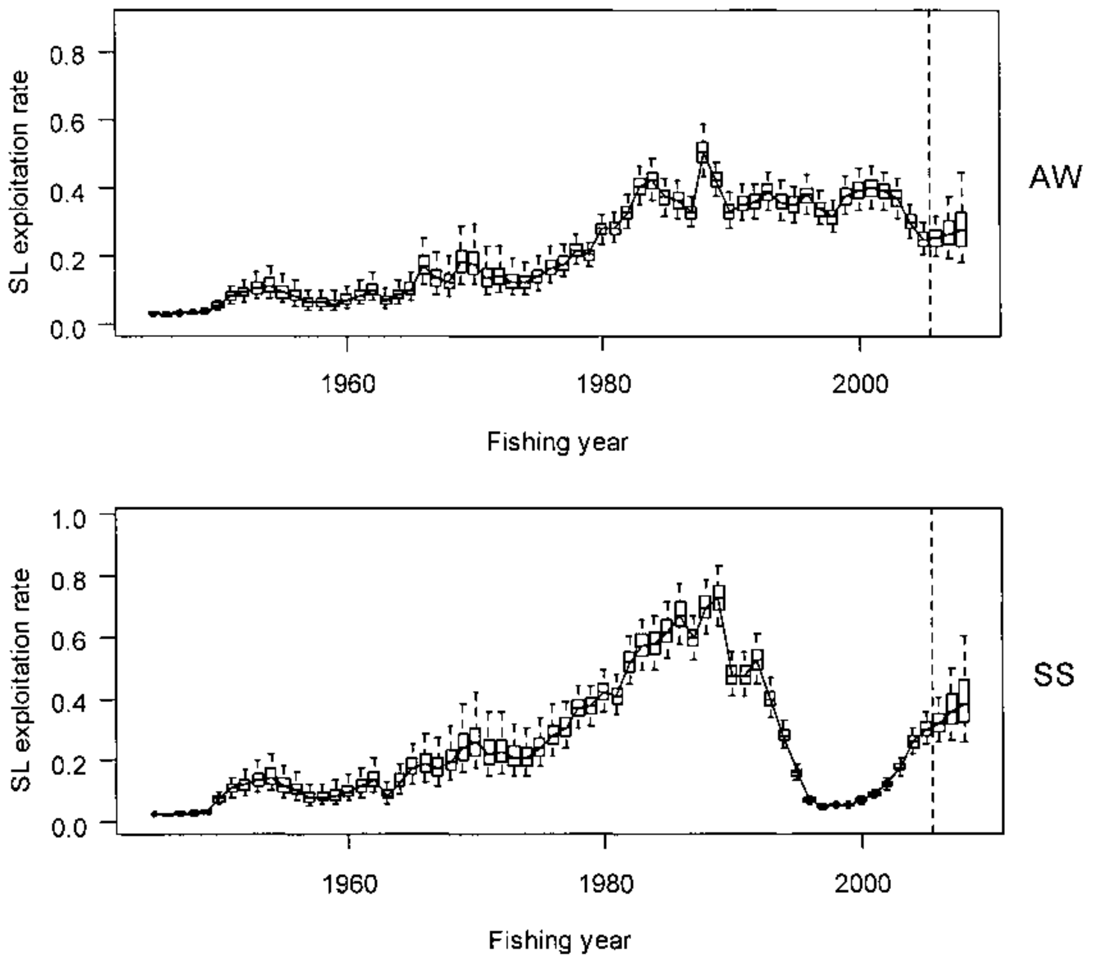

Figure 67: The posterior trajectories of SL exploitation rate, by season, from the CRA 4 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

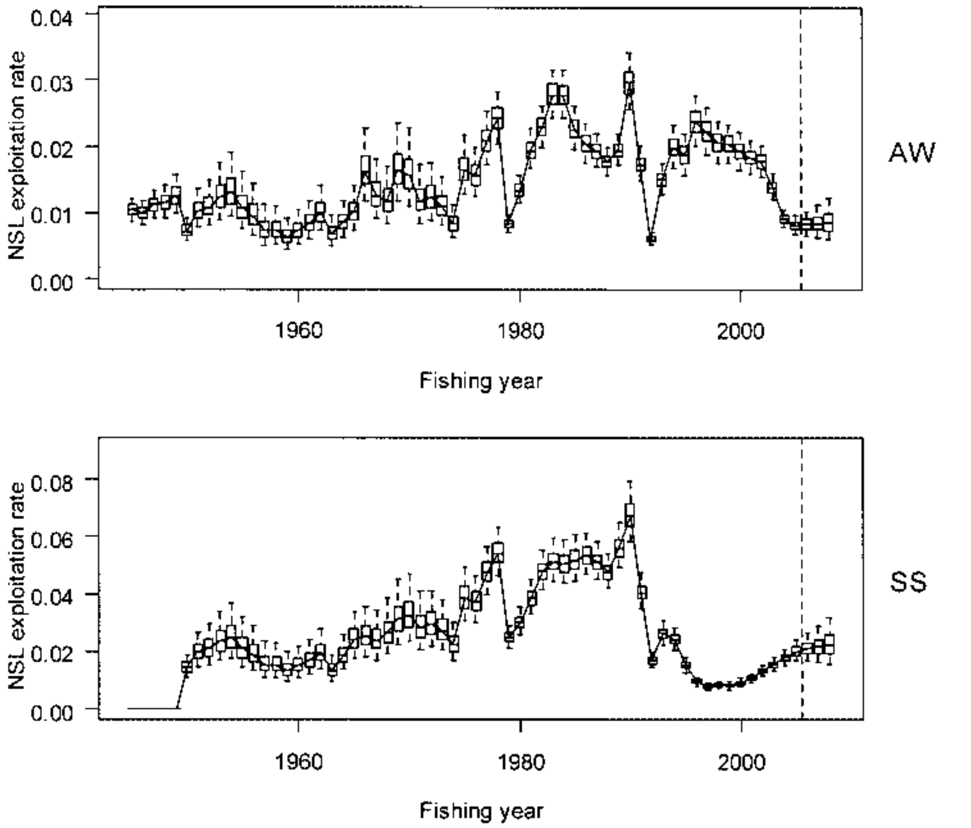

Figure 68: The posterior trajectories of NSL exploitation rate, by season, from the CRA 4 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

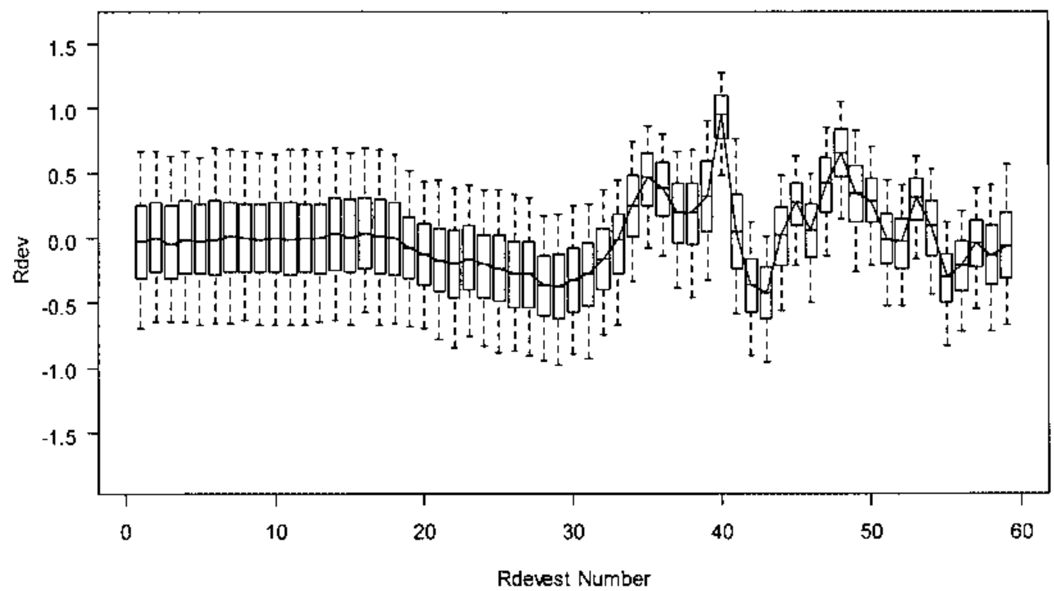

Figure 69: The posterior trajectory of recruitment deviations from the CRA 4 base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

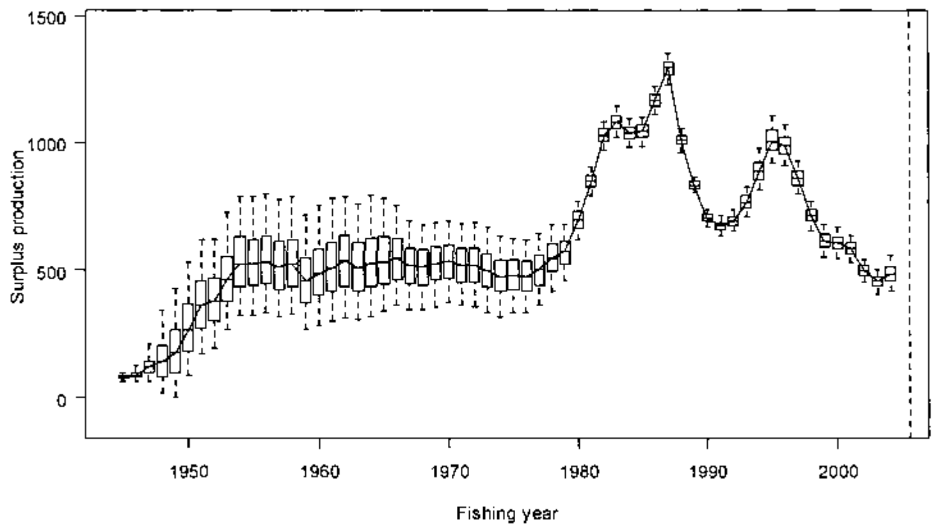

Figure 70: The posterior trajectory of surplus production from the CRA 4 base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

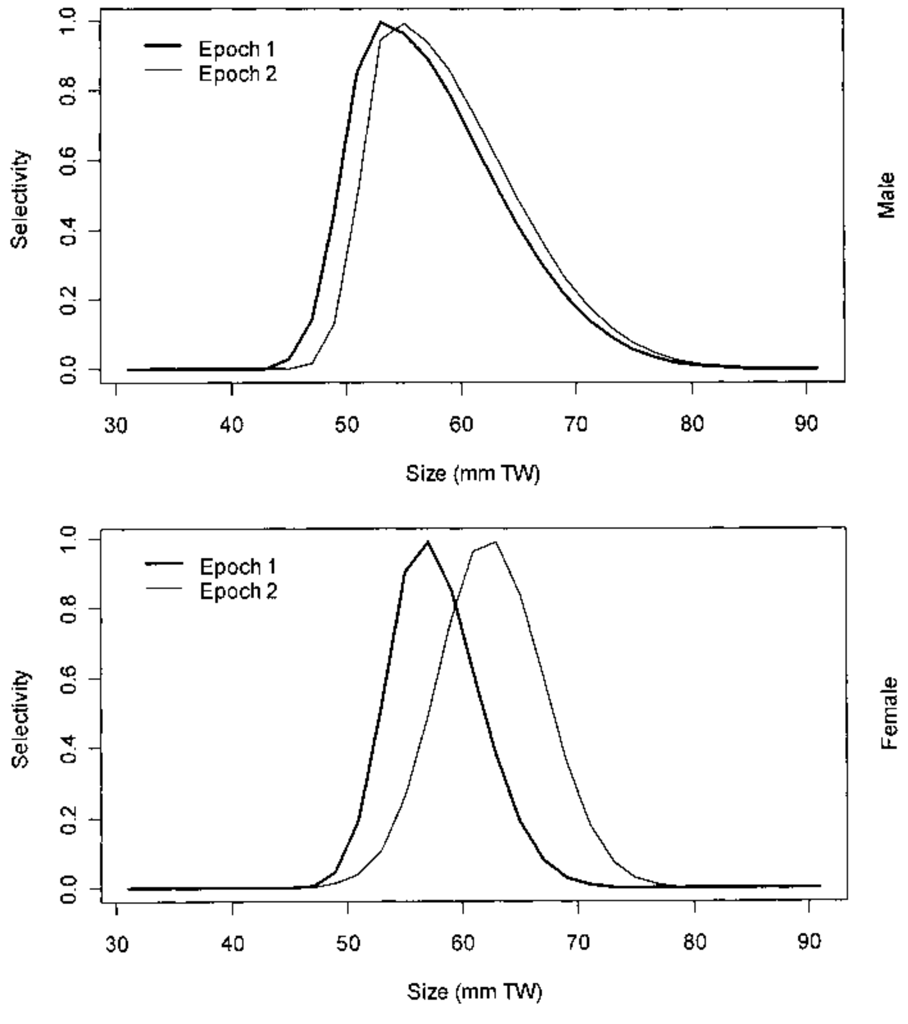

Figure 71: Selectivity curves from the MPD results of the domed selectivity trial: compare with Figure 53.

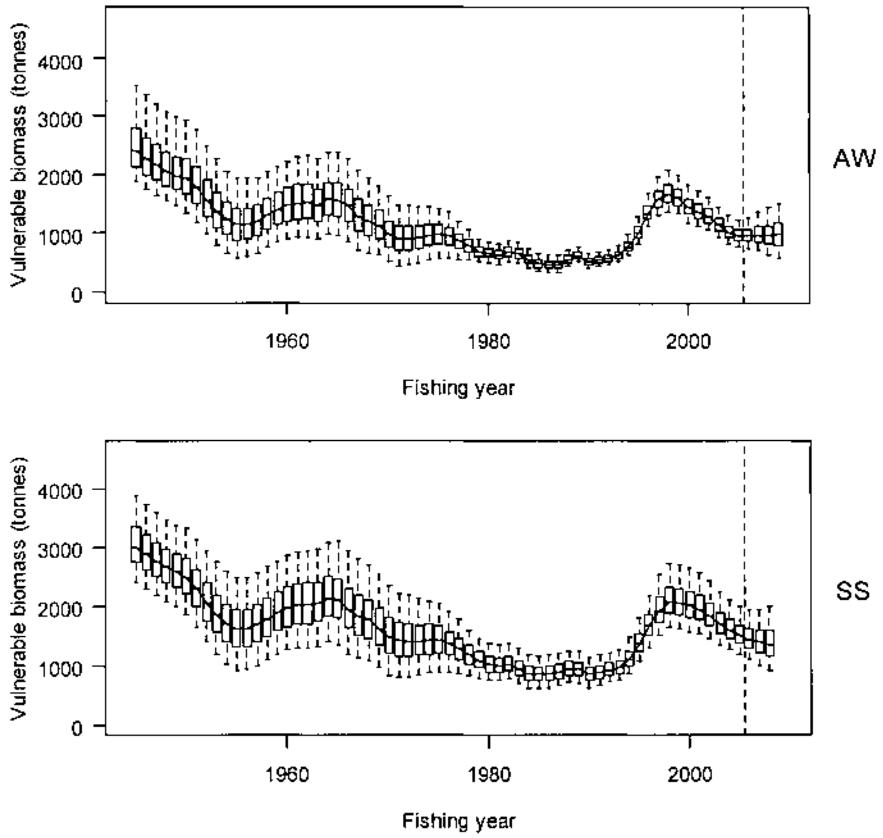

Figure 72: Vulnerable biomass trajectory for the domed sensitivity trial.

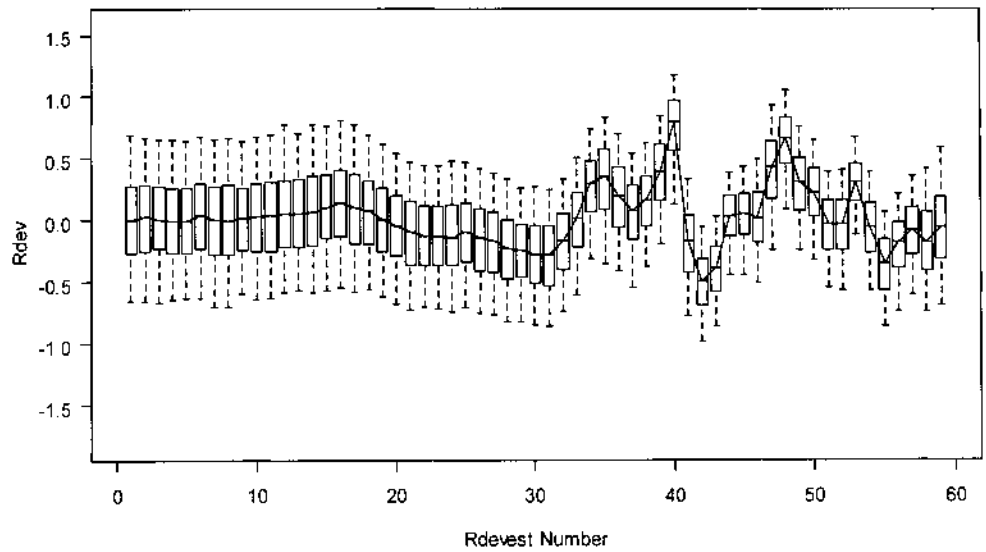

Figure 73: Recruitment trajectory from the CPUEpow sensitivity trial.

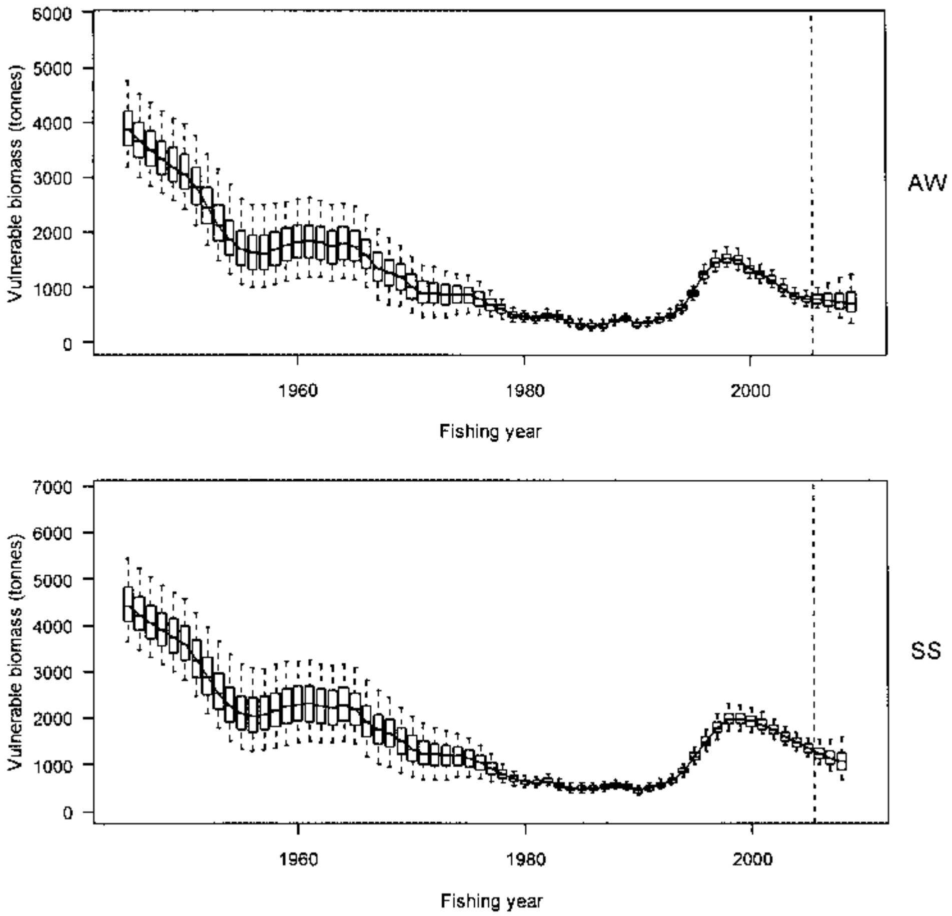

Figure 74: Posterior of the vulnerable biomass trajectory from the "CPUEpow" sensitivity trial.

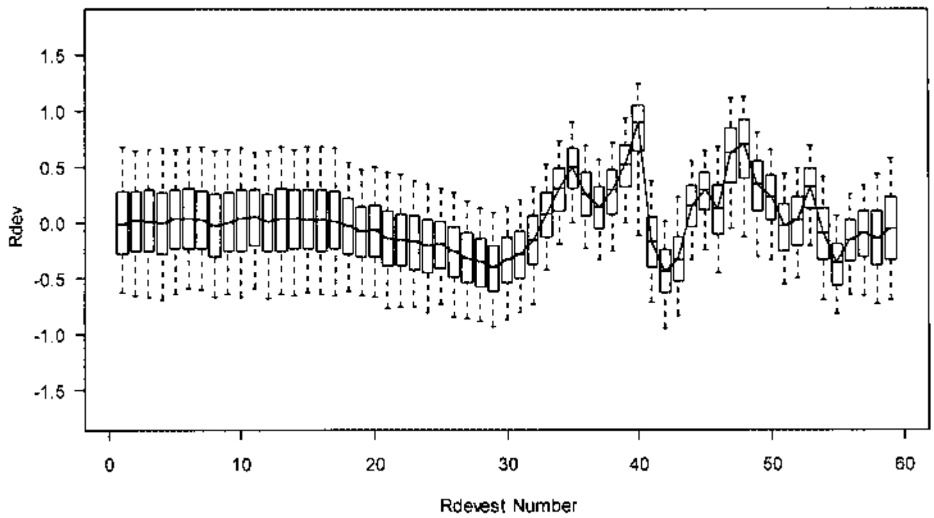

Figure 75: Posterior of the recruitment trajectory from the "CPUEpow" sensitivity trial.

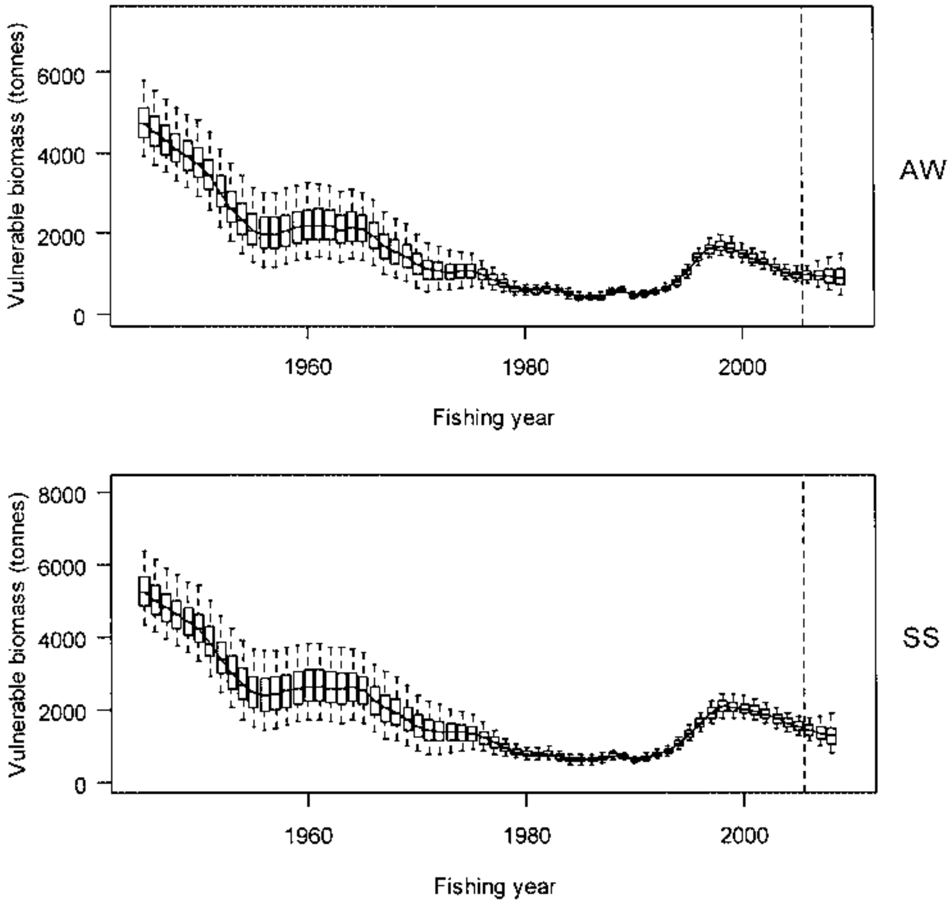

Figure 76: Biomass trajectory from the doubled catch sensitivity trial.

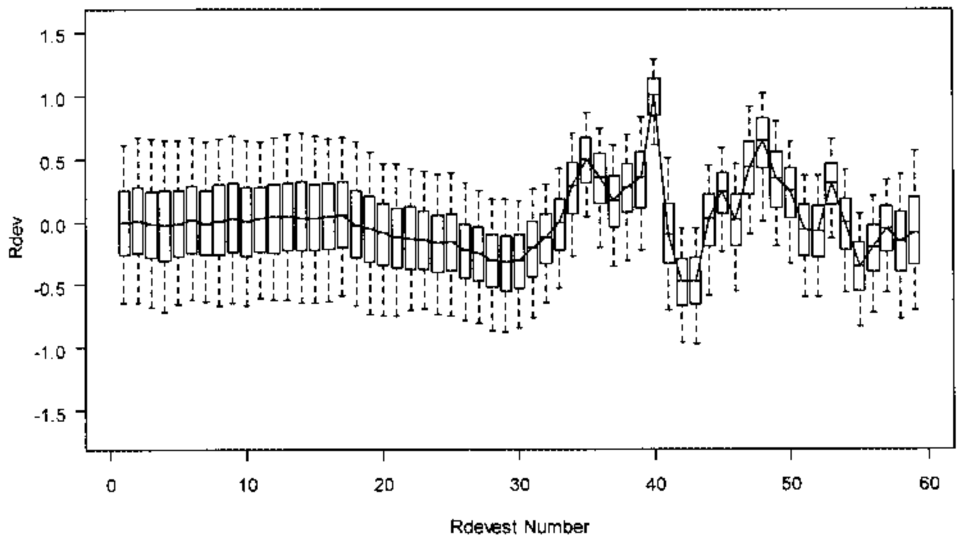

Figure 77: Recruitment trajectory from the doubled catch sensitivity trial.

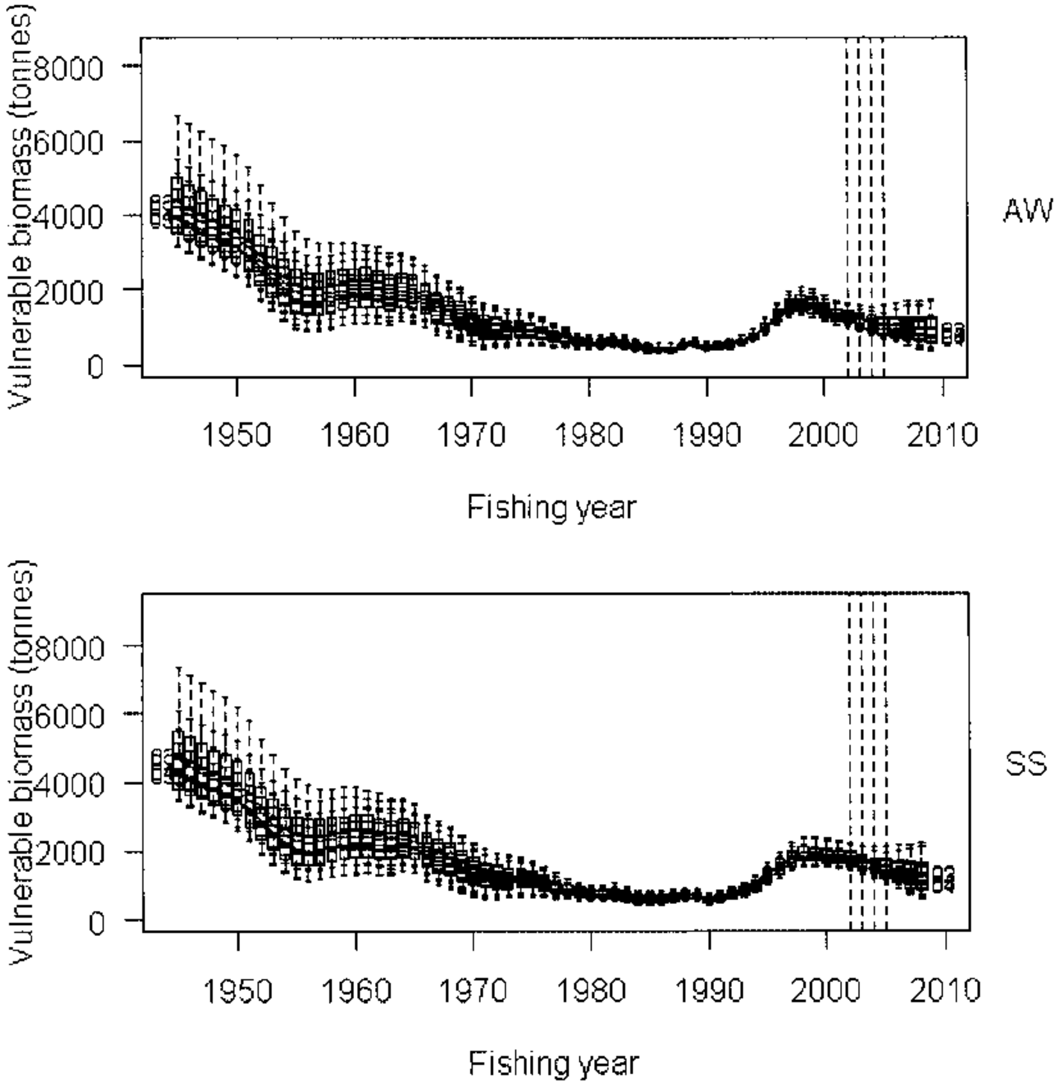

Figure 78: The posterior trajectories of vulnerable biomass, by season, from the base case (05) and retrospectives (02 to 04) CRA 4 McMC simulations.

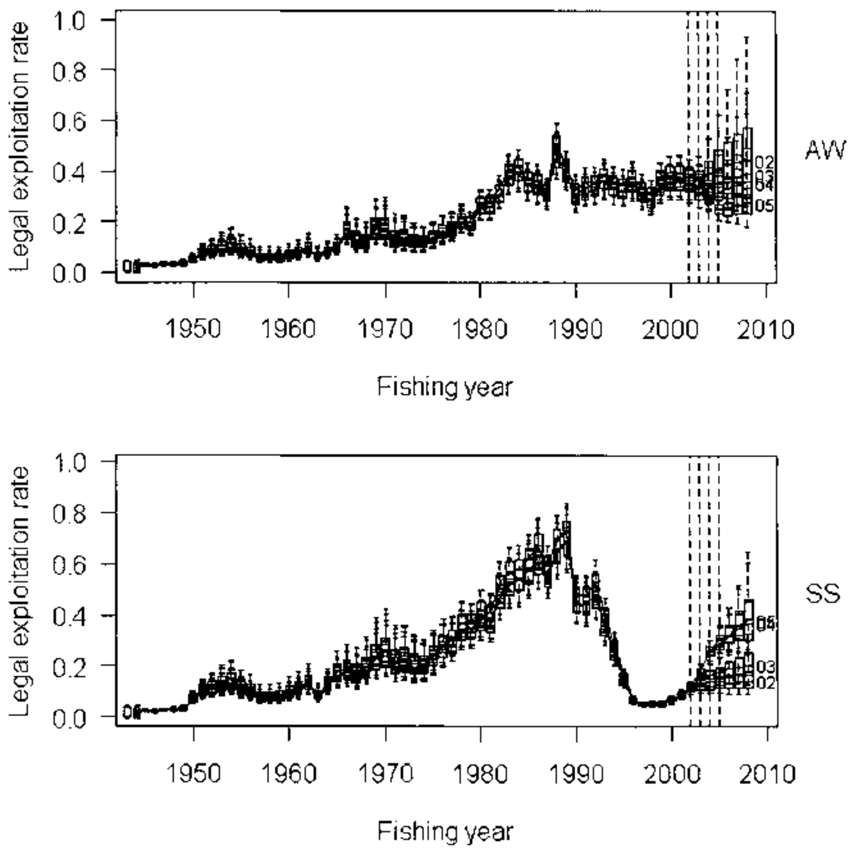

Figure 79: The posterior trajectories of SL exploitation rate from the base case (05) and retrospectives (02 to 04) CRA 4 McMC simulations.

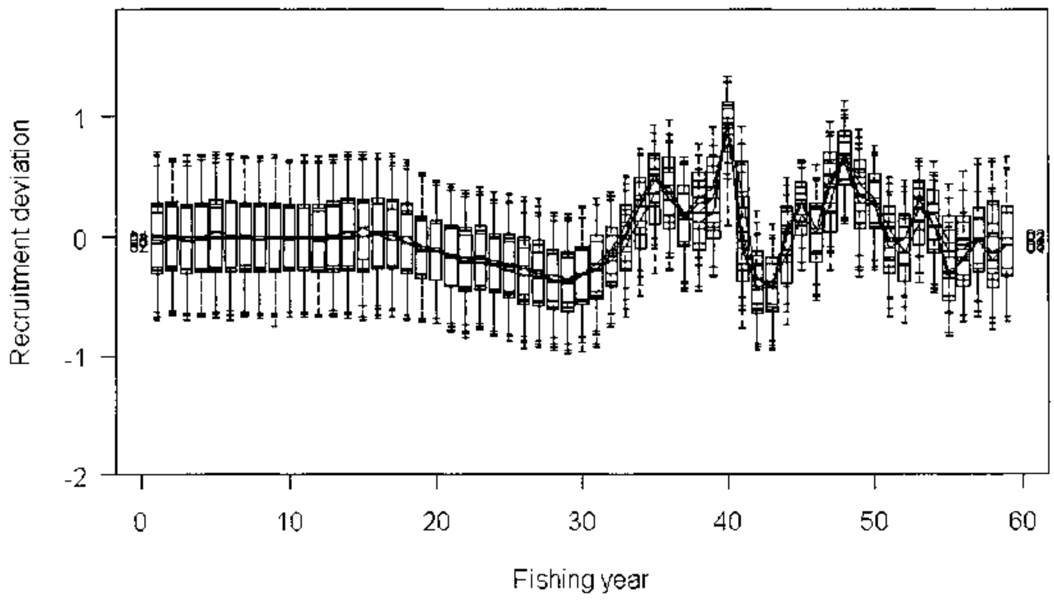

Figure 80: The posterior trajectories of recruitment deviation from the base case (05) and retrospectives (02 to 04) CRA 4 McMC simulations.

APPENDIX A. ASSESSMENT MODEL

The parameters and variables used by the model can be divided into the following.

- **Structural variables** that are fixed and define the structure of the model.
- **Observations** that are known and influence the history of the fishery in the model.
- **Model parameters** that influence the dynamics and that are either estimated or fixed at assumed values.
- **Derived variables** that are dependent on the model parameters and used to calculate state variables or to make predictions.
- **State variables,** dependent on model parameters, which describe the modelled state of the stock and are used to make model predictions.
- **Predictions** for comparison with observations
- **Likelihood variables** that are used in comparing the model's predictions with observations.

These parameters and variables are described in Table A1. The model uses a half-year time step: autumn-winter (AW) from 1 April to 30 September and spring-summer (SS) from 1 October to 31 March. Six-month periods are indexed by *t*. Season, indexed by *k*, can be calculated from *t* by

$\mathrm{mod}(t-1,2)+1$.

Three sex categories, indexed by *g*, are kept distinct in the model: males (*male*), immature females (*female*), and mature females (*femmat*). Size classes are indexed by *s*, years by *l*, and tag return records by *i*. In describing how length frequency records are handled, month is indexed by *m* and area by o. In discussing how growth of tagged lobsters is predicted, the number of moults is indexed by *j*. The subscript used to index the selectivity function parameters is *z*.

Table A1: Major variables and parameters of the assessment model.

Structural and fixed variables	
$\overleftarrow{S}_s$	Smallest size modelled in size class s
$\overrightarrow{S}_s$	Largest size modelled in size class s
$\overline{S}_s$	Size of an individual in size class s (mid point of the size class bounds)
$s_{\max}$	Number of size classes modelled
a^g	Scalar of the size-weight relation for sex g
b^g	Exponent of the size-weight relation for sex g
w_s^g	Weight of an individual of size s and sex g
ϕ	Mode of the size distribution of recruits to the model
γ	Standard deviation of the size distribution of recruits
$\mathbf{I}$	Identity matrix for model size classes
λ	Shape parameter for mixing left and right halves of selectivity curves
$U^{\max}$	Maximum permitted exploitation rate in a period
f_k^g	Moult probability for sex g in season k
Observations	
C_t^{SL}	Catch limited by regulations in period t
C_t^{NSL}	Catch not limited by regulations in period t
I_t	Observed standardised CPUE in period t
CR_t	Observed historical catch rate in period t
I_t^{PR}	Observed pre-recruit index in period t

l_t^g	Minimum legal size limit for sex g in period t
$p_{s,t}^g$	Observed proportions-at-size in the catch in period t
$D_{m,o}$	Numbers of days sampled in month m and area o
$C_{m,o}$	Catch in month m and area a within a period
$c_{m,o}$	Calculated weight for length frequencies from month m and area o
$n_{m,o,s}^g$	Number of lobsters sampled in month m, area o and size s within a period
$p_{m,o,s}^g$	Proportion of lobsters sampled in month m, area o and size s within a period
κ_t	Calculated relative weight for proportions-at-size in period t
$S_i^{g,tag}$	Size and sex of the ith tagged lobster at release
$S_i^{g,recap}$	Size and sex of the ith tagged lobster at recapture

Estimated parameters

θ	Denotes the vector of model parameters
$\ln(R_0)$	Natural logarithm of R_0, the mean annual recruitment to the model for each sex in each period
ε_l	Recruitment deviation for year l
M	Instantaneous rate of natural mortality (per year)
r_k^g	Relative seasonal vulnerability for sex g and season k
$\ln(q^I)$	Natural logarithm of catchability for CPUE
$\ln(q^{CR})$	Natural logarithm of catchability for historical catch rates
$\ln(q^{PRI})$	Natural logarithm of catchability for pre-recruit indices
η_z^g	Size of maximum selectivity of sex g in selectivity epoch z
v_z^g	Shape parameter for the left hand limb of the selectivity curve of sex g in selectivity epoch z
w^g	Shape parameter for the right hand limb of the selectivity curve for sex g in all epochs
d_{50}^g	Mean expected moult increment for a lobster of size 50 mm TW and sex g
d_{50-80}^g	Difference between expected increments for lobsters of 50 and 80 mm TW for sex g
h^g	Shape parameter of the growth curve
CV^g	c.v. of the expected growth increment for sex g
$\varphi^{d,\min}$	Minimum standard deviation of the expected growth increment (sex-independent)
$\sigma^{d,obs}$	Standard deviation of the observation error in observed moult increments
m_{50}	Size at which the probability of a female maturing is 50%
m_{95-50}	Difference between sizes at 50% and 95% probability of a female maturing
χ	Determines shape of biomass-CPUE relation
$\tilde{\sigma}$	Component of error common to all data sets

Derived variables

$C_t^{NSL,BSL}$	Portion of C_t^{NSL} taken from B_t^{SL} in period t
$C_t^{NSL,BNSL}$	Portion of C_t^{NSL} taken from B_t^{NSL} in period t
$C_t^{total,BSL}$	Total catch taken from B_t^{SL} in period t
$F_{s,t}^g$	Legal status flag (zero or one) for individuals of sex g and size s in period t. Mature females are assumed to be berried and are therefore not legal in AW.

$\mathbf{R}_0$	Vector of average recruitment-at-size
$\mathbf{N}_0^g$	Vector of numbers-at-size for sex g in the unexploited population at equilibrium
x^g	Derived variable used for the growth increment calculation
y^g	Derived variable used for the growth increment calculation
d_s^g	Expected growth increment of an individual of size s and sex g
φ_s^g	Standard deviation of the growth increment for an animal of sex g and size s
$\mathbf{X}_k^g$	Growth transition matrix for sex g in season **k**
$X_{s,s',k}^g$	One cell of $\mathbf{X}_k^g$: the proportion of individuals of sex g that grow from size-class s to size-class s' in season k
$\hat{s}_{s,t+1}^g$	Expected size of an individual of size s and sex g after moulting
$V_{s,k,z}^g$	Total vulnerability, incorporating selectivity and seasonal vulnerability, of an individual of sex g and size s in epoch z
$T_{s,z}^g$	Intermediate term used in calculating $V_{s,k,z}^g$
$\mathbf{Q}$	Vector of the probability of females maturing-at-size
Q_s	Probability that an immature female at size s will become mature during period
P_t	Surplus production in period t

State variables

$N_{s,t}^g$	Numbers of sex g and size s at the start of period t
$N_{s,t+0.5}^g$	Numbers of sex g and size s in the mid-season of period t
$\dot{N}_{s,t}^g$	Numbers of sex g and size s after fishing in period t
$\ddot{N}_{s,t}^g$	Numbers of sex g and size s after fishing and natural mortality in period t
$\dddot{N}_{s,t}^g$	Numbers of sex g and size s after fishing, natural mortality, growth and recruitment in period t
R_t	Recruitment to the model (males and females, all sizes) in period t
$R_{s,t}$	Recruitment to the model for size class s in period **t** (same for males and females)
B_t^{SL}	Biomass vulnerable to the SL fishery at the beginning of period t
B_t^{NSL}	Biomass vulnerable only to the NSL fishery at the beginning of period **t**
B_t^{total}	Sum of B_t^{SL} and B_t^{NSL} at the beginning of period t
U_t^{SL}	Exploitation rate on B_t^{SL} in period t
U_t^{NSL}	Exploitation rate on B_t^{NSL} in period t
H_t	Handling mortality rate in period **t**

Model predictions

$\hat{I}_t$	Predicted CPUE for period t
$C\hat{R}_t$	Predicted historical catch rate for period t
$\hat{I}_t^{PR}$	Predicted pre-recruit index for period t
$\hat{p}_{s,t}^g$	Predicted proportion-at-size for size g and sex s in period t
$\hat{S}_i^{g,recap}$	Predicted size at recapture for the ith tagged lobster
φ_i^g	Predicted standard deviation of the growth increment for the ith tagged lobster

Likelihood variables

σ^{ε}	Standard deviation of recruitment deviation
q^{I}	Scaling coefficient for CPUE index
σ_t^{I}	Standard deviation of standardised CPUE indices in period t
ϖ^{I}	Relative weight applied to CPUE likelihoods
q^{CR}	Scaling coefficient for catch rate index
σ^{CR}	Standard deviation of catch rate index
ϖ^{CR}	Relative weight applied to historical catch rate likelihood
q^{PRI}	Scaling coefficient for pre-recruit index
σ_t^{PRI}	Standard deviation of standardised pre-recruit indices in period t
ϖ^{PRI}	Relative weight applied to PRI likelihoods
ϖ^{P}	Relative weight applied to proportions-at-size
ϖ^{TAG}	Relative weight applied to tagging data

A.1 Initial size structure

The population is assumed to be in an initial unexploited equilibrium, in this case at the start of period 1, AW 1945. The number of each sex in each size class is the equilibrium function of the growth transition matrices for each season, recruitment, and natural mortality:

Eq 1
$$\mathbf{N}_0^{male} = \left[1 + \mathbf{X}_{AW}^{male} e^{-0.5M}\right]\left[\mathbf{R}_0\left(\mathbf{I} - \mathbf{X}_{AW}^{male}\mathbf{X}_{SS}^{male}\left(e^{-0.5M}\right)^2\right)^{-1}\right]$$

$$\mathbf{N}_0^{female} = \left[1 + \mathbf{X}_{AW}^{female} e^{-0.5M}(1-\mathbf{Q})\right]\left[\mathbf{R}_0\left(\mathbf{I} - \mathbf{X}_{AW}^{female}\mathbf{X}_{SS}^{female}\left(e^{-0.5M}\right)^2(1-\mathbf{Q})^2\right)^{-1}\right]$$

$$\mathbf{N}_0^{femmat} = \left[1 + \mathbf{X}_{AW}^{female} e^{-0.5M}\right]\left[\mathbf{R}_0\left(\mathbf{I} - \mathbf{X}_{AW}^{female}\mathbf{X}_{SS}^{female}\left(e^{-0.5M}\right)^2\right)^{-1}\right] - \mathbf{N}_0^{female}$$

where the vector of recruitment-at-size, $\mathbf{R}_0$ (same for males and females), is derived from the multiplication of R_0 and the equilibrium recruitment proportions-at-size, calculated as in Eq 26, $\mathbf{X}_{SS}^{g}$ and $\mathbf{X}_{AW}^{g}$ are growth transition matrices for SS and AW for sex g and $\mathbf{Q}$ is the vector of the probability of females maturing-at-size.

A.2 Overview of dynamics

The dynamics proceeds in a series of steps through each time step, the 6-month period. First, the biomass vulnerable to fishing is calculated from number-at-size, weight-at-sex, selectivity-at-size and relative seasonal vulnerability, all for each sex. This is done twice – once for the fishery that respects the size limit and berried female restrictions (the SL fishery) and once for the fishery that does not (the NSL fishery).

From biomass and the observed SL and NSL catches, exploitation rates are calculated; if they exceed the assumed maximum value $U^{\max}$ they are reduced to $U^{\max}$ and the model's function value is penalised. Then the two fisheries are simulated, reducing numbers-at-size in two steps to obtain the mid-season numbers and the post-fishing numbers.

After fishing, growth is simulated, recruitment is calculated and added to the vector of numbers-at-size, and then maturation of immature to mature females is simulated, giving the numbers at the beginning of the next period.

A.3 Selectivity and relative vulnerability

The ascending and descending limbs of the selectivity curve are modelled using halves of two normal curves with the same mean but with different shapes, one for the left half and one for the right. These are determined by parameters analogous to the variance of a normal curve. This is sometimes called a "double-normal" but is really a "bi-hemi-normal" curve. A logistic selectivity curve can be approximated by setting the shape parameter for the right hand limb to a large number.

The model can calculate different curves for each of a number of epochs, for instance, if the MLS or escape gap regulations change, in this study 2 epochs were used. Total vulnerability is the product of the selectivity curve and the relative seasonal vulnerability for each sex, r_k^g:

Eq 2
$$V_{s,k,z}^{g} = r_k^g \left[\left(1 - T_{s,z}^{g}\right) e^{\frac{\ln 0.5\left(\bar{S}_s^g - \eta_z^g\right)^2}{\left(v_z^g\right)^2}} + T_{s,z}^{g} e^{\frac{\ln 0.5\left(\bar{S}_s^g - \eta_z^g\right)^2}{\left(w^g\right)^2}} \right]$$

$$T_{s,z}^{g} = 1/\left(1 + \exp\left(-\left(\bar{S}_s^g - \eta_z^g\right)\lambda\right)\right)$$

Selectivity curves are assumed to be the same for mature and immature females. A switch allows maximum seasonal vulnerability to any sex/season combination and it is assumed that the relative seasonal vulnerability of mature females differs from that of immature females only in AW, i.e. $r_{SS}^{femmat} = r_{SS}^{female}$. The normal assumption is that males in SS have the maximum vulnerability, but this can be varied to any sex/season combination (Table A2).

Table A2: Switch values and the assumed sex/season with maximum relative vulnerability.

Switch	Vulnerability
1	r_{SS}^{male}
2	r_{AW}^{male}
3	r_{AW}^{female}
4	r_{SS}^{female}
5	r_{AW}^{femmat}

A.4 Vulnerable biomass

The model must simulate two kinds of fishing: fishing that takes all vulnerable lobsters, and fishing that takes only those that are both above the MLS and not berried females. The first fishery includes the illegal and Maori customary fisheries; Maori customary fishing is not illegal so this fishery cannot simply be called the illegal fishery, and we call it the NSL fishery. The other fishery, governed by the regulations, comprises the commercial and recreational fisheries, and we call it the SL fishery.

The total biomass vulnerable to the NSL fishery at any time is the product of numbers, weight, and vulnerability-at-size:

Eq 3 $$B_t^{total} = \sum_g \sum_s N_{s,t}^g W_s^g V_{s,k,z}^g$$

where mean weight of individuals in each size class is determined from:

Eq 4 $$W_s^g = a^g \left(\bar{S}_s\right)^{b^g}$$

The a^g and b^g parameters are assumed to be the same for immature and mature females. The legal switch $F_{s,t}^g$ for the SL fishery is determined by comparing size with the minimum legal size:

Eq 5 $$F_{s,t}^g = \begin{cases} 0 & \bar{S}_s \le S_{g,t}^{MLS} \\ 1 & \bar{S}_s > S_{g,t}^{MLS} \end{cases}$$

and $F_{s,t}^g$ is zero for all mature females in AW. The SL biomass is

Eq 6 $$B_t^{SL} = \sum_g \sum_s N_{s,t}^g W_s^g V_{s,k,z}^g F_{s,t}^g$$

The biomass vulnerable **only** to the NSL fishery is

Eq 7 $$B_t^{NSL} = B_t^{total} - B_t^{SL} = \sum_g \sum_s N_{s,t}^g W_s^g V_{s,k,z}^g \left(1 - F_{s,t}^g\right)$$

A.5 Exploitation rates

The observed catches are partitioned in the data file into catches from the two fisheries: C_t^{SL} and C_t^{NSL}. Exploitation rate is calculated as catch over biomass. The model must calculate the total exploitation rate expended by both fisheries on the biomass available to the SL fishery, and limit it if necessary. The portion of C_t^{NSL} to be taken from the SL biomass is

Eq 8 $$C_t^{NSL,BSL} = \frac{C_t^{NSL} B_t^{SL}}{B_t^{total}}$$

and from the NSL biomass is

Eq 9 $$C_t^{NSL,BNSL} = \frac{C_t^{NSL} B_t^{NSL}}{B_t^{total}} = C_t^{NSL} - C_t^{NSL,BSL}$$

The total catch to be taken from the SL biomass is the sum of components from the two fisheries

Eq 10 $$C_t^{total,BSL} = C_t^{NSL,BSL} + C_t^{SL}$$

Total catch from the NSL biomass is $C_t^{NSL,BNSL}$.

Now the model can calculate, and limit if necessary, the exploitation rates applied to these two components of the population. The exploitation rate applied to the SL biomass is

Eq 11 $$U_t^{SL} = \frac{C_t^{total,BSL}}{B_t^{SL}}$$

and to the NSL biomass is

Eq 12 $$U_t^{NSL} = \frac{C_t^{NSL,BNSL}}{B_t^{NSL}}$$

If U_t^{SL} exceeds a value specified, U^{max}, 0.90 for this assessment, then U_t^{SL} is restricted to just over U^{max} with the AD Model Builder™ *posfun* and a large penalty is added to the total negative log-likelihood function. This keeps the model away from parameter combinations that do not allow the catch to have been taken. U_t^{NSL} is similarly limited.

Handling mortality is exerted by the SL fishery on vulnerable animals returned to the water because they are under-sized or berried females. This is assumed to be a constant proportion (0.1) of the exploitation rate exerted by the SL fishery:

Eq 13 $$H_t = 0.1\frac{C_t^{SL}}{B_t^{SL}}.$$

This is reduced proportionally if *posfun* has reduced the exploitation rate and C_t^{SL}.

A.6 Fishing mortality

Fishing mortality from the SL, NSL and handling mortality are applied simultaneously to the population. This occurs in two steps so that mid-season biomass and mid-season size structures can be calculated. The numbers at mid-season are calculated from numbers at the start of the period, using half the exploitation rates described above:

Eq 14 $$N_{s,t+0.5}^g = N_{s,t}^g\left[1-0.5\left(U_t^{NSL}+H_t\right)V_{s,k,z}^g\left(1-F_{s,t}^g\right)\right]\left[1-0.5U_t^{SL}V_{s,k,z}^g\left(F_{s,t}^g\right)\right]$$

The model then recalculates vulnerable biomass in each category, recalculates the exploitation rate required to take the remaining catch (if *posfun* reduced the exploitation rate, the required catch was reduced proportionally), and calculates numbers after all fishing in the period:

Eq 15 $$\dot{N}_{s,t}^g = N_{s,t+0.5}^g\left[1-\left(U_{t+0.5}^{NSL}+H_{t+0.5}\right)V_{s,k,z}^g\left(1-F_{s,t}^g\right)\right]\left[1-U_{t+0.5}^{SL}V_{s,k,z}^g\left(1-F_{s,t}^g\right)\right]$$

A.7 Natural mortality

Natural mortality is applied to numbers after all fishing has taken place in a period:

Eq 16 $$\ddot{N}_{s,t}^g = \dot{N}_{s,t}^g e^{-0.5M}.$$

A.8 Growth

Moult-based growth is modelled explicitly using a two part model. The first part of the model describes the sex- and size-specific moult increment of a lobster in size class *s*, and its variability. The growth model used is a version of the Schnute (1981) model, adopted after the von Bertalanffy model proved too limited. McGarvey & Feenstra (2001) describe using a polynomial model. The parameters of the model are d_α^g and d_β^g, the expected increments for lobsters of size α (50 mm) and β (80 mm) TW for sex *g*, and h^g, a shape parameter for sex *g*. Instead of d_β^g we estimate $d_{\alpha-\beta}^g$, the difference between growth at 50 and 80 mm, to constrain d_β^g to be less than d_α^g.

Define two new variables as functions of these 5 variables:

Eq 17 $$x^g = \left(\beta^{h^g} - \alpha^{h^g}\right) \Big/ \left(\left(\beta + d_\beta^g\right)^{h^g} - \left(\alpha + d_\alpha^g\right)^{h^g}\right)$$

and

Eq 18 $$y^g = \frac{\left(\beta^{h^g}\left(\alpha + d_\alpha^g\right)^{h^g} - \alpha^{h^g}\left(\beta + d_\beta^g\right)^{h^g}\right)}{\left(\left(\alpha + d_\alpha^g\right)^{h^g} - \alpha^{h^g} + \beta^{h^g} - \left(\beta + d_\beta^g\right)^{h^g}\right)}$$

The mean predicted increment for length l_s is:

Eq 19 $$d_s^g = -\bar{S}_s + \left[\frac{\bar{S}_s^{\,h^g}}{x^g} + y^g\left(1 - \frac{1}{x^g}\right)\right]^{\left(1/h^g\right)}$$

but is constrained with the AD Model Builder™ *posfun* function to be positive.

Variability in the growth increment is assumed to be normally distributed around d_s^g with a standard deviation φ_s^g that is a constant proportion the expected increment, but is truncated at a minimum value $\varphi^{d,\min}$. The equation below is used to give a smooth differentiable function:

Eq 20 $$\varphi_s^g = \left(j_s^g CV^g - \varphi^{d,\min}\right)\left(\frac{1}{\pi} \times \tan^{-1}\left(\left(d_s^g CV^g - \varphi^{d,\min}\right) \times 10^6\right) + 0.5\right) + \varphi^{d,\min}$$

The second part of the growth model describes the sex- and size-specific probability of moulting. Males are assumed to moult in both seasons; females are assumed to moult only at the beginning of AW. The seasonal moult probability f_k^g is set to zero or one, depending on the sex and season as just described.

From this growth model, the growth transition matrix $\mathbf{X}_k^g$ is generated as follows. The expected size, after moulting, of an individual of sex g and size $\bar{S}_s^g$ (in size class s) is:

Eq 21 $$\hat{S}_{s,t+1}^g = \bar{S}_s + d_s^g f_k^g$$

Because of variability in growth, not all individuals move into the size class containing $\hat{S}^g_{s,t+1}$; some move into smaller or larger size classes, depending on φ^g_s. For each size class s, the probability that the individual will grow into each of the other size classes, s', is calculated by integrating over a normal distribution with mean $\hat{S}^g_{s,t+1}$ and standard deviation φ^g_s. The largest size group is cumulative, i.e., no animals grow out of this group, so the integration is done from the smallest size in that size class, $\ddot{S}_{s'}$ to ∞. With the sex index, g, and the season index, k, suppressed this is:

Eq 22
$$X_{s,s'} = \begin{cases} \displaystyle\int_{\ddot{S}_{s'}}^{\ddot{S}_{s'}} \frac{1}{\sqrt{2\pi}\varphi_s} \exp\left(-\frac{\left(\bar{S}_s - \hat{S}_{s,t+1}\right)^2}{2\left(\varphi_s\right)^2} \right) \partial S & \text{if } s' < s_{\max} \\ \displaystyle\int_{\ddot{S}_{s'}}^{\infty} \frac{1}{\sqrt{2\pi}\varphi_s} \exp\left(-\frac{\left(\bar{S}_s - \hat{S}_{s,t+1}\right)^2}{2\left(\varphi_s\right)^2} \right) \partial S & \text{if } s' = s_{\max} \end{cases}$$

Moulting in this model occurs at the beginning of each period. Growth is applied to the numbers remaining in each size class after fishing and natural mortality, $\ddot{N}^g_{s,t}$:

Eq 23
$$\dddot{N}^g_{s',t} = \sum_s \left(X^g_{s,s'} \ddot{N}^g_{s,t} \right) + R_{s',t+1}$$

for males and females, where $R_{s',t+1}$ is calculated as described below. For mature females:

Eq 24
$$\dddot{N}^{femmat}_{s',t} = \sum_s \left(X^{femmat}_{s,s'} \ddot{N}^{femmat}_{s,t} \right)$$

A.9 Recruitment

The number of lobsters recruiting to the model in a year is assumed to be equal for males and females and is divided equally over the two seasons. Recruitment deviations are estimated for those years likely to have information on the strength of recruitment, and total recruitment is calculated from:

Eq 25
$$R_t = 0.5 R_0 \, e^{\left[\varepsilon_t - \frac{\left(\sigma^\varepsilon\right)^2}{2} \right]}$$

where it is assumed that the recruitment deviations ε_t are normally distributed with mean zero and standard deviation σ^ε. The term $-\frac{\left(\sigma^\varepsilon\right)^2}{2}$ corrects for the log-normal bias associated with different values of σ^ε.

Recruitment is dispersed over the size-classes, assuming a normal distribution truncated at the smallest size class:

Eq 26 $$R_{s,t} = R_t \frac{\exp\left(-(\bar{S}_s - \phi)^2 \big/ 2\gamma^2\right)}{\sum_s \exp\left(-(\bar{S}_s - \phi)^2 \big/ 2\gamma^2\right)}$$

where $\bar{S}_s$ is the mean size in size class s, ϕ is the (assumed) mean size-at-recruitment and γ is the (assumed) standard deviation about mean size-at-recruitment.

A.10 Maturation

The probability of a female maturing during a period is modelled as a logistic curve:

Eq 27 $$Q_s = \frac{1}{1 + \exp\left[-\ln(19)\left(\bar{S}_S - m_{50}\right) \big/ \left(m_{95-50}\right) \right]}$$

Maturation occurs after growth, and this determines the numbers at the beginning of the next period. Males are not involved:

Eq 28 $$N_{s,t+1}^{male} = \ddot{N}_{s,t}^{male}$$

Immature females that mature are subtracted from the number of immature females in size class s:

Eq 29 $$N_{s,t+1}^{female} = \ddot{N}_{s,t}^{female}\left(1 - Q_s\right)$$

and added to the number of mature females in size class s:

Eq 30 $$N_{s,t+1}^{femmat} = \ddot{N}_{s,t}^{femmat} + Q_s \ddot{N}_{s,t}^{female}$$

A.11 Predictions and likelihoods for abundance indices

The predicted CPUE index is calculated from mid-season vulnerable biomass:

Eq 31 $$\hat{I}_t = e^{\ln\left(q^I\right)}\left(B_{t+0.5}^{SL}\right)^{\chi}$$

where χ determines the shape of the relationship and the scaling coefficient $\ln\left(q^I\right)$ is an estimated parameter.

A log-normal likelihood function is used to compare predicted ($\hat{I}_t$) and observed (I_t) biomass indices,

Eq 32 $$L\left(\hat{I}_t \mid \theta\right) = \frac{\varpi^I}{I_t \sigma_t^I \tilde{\sigma}\sqrt{2\pi}} \exp\left[\frac{-\left(\ln(I_t) - \ln(\hat{I}_t) + 0.5\left(\sigma_t^I \tilde{\sigma} / \varpi^I\right)^2\right)^2}{2\left(\sigma_t^I \tilde{\sigma} / \varpi^I\right)^2} \right].$$

The normalised residual is:

Eq 33 $$residual = \frac{\ln(I_t) - \ln(\hat{I}_t) + 0.5\left(\sigma_t^I \tilde{\sigma} / \varpi^I\right)^2}{\left(\sigma_t^I \tilde{\sigma} / \varpi^I\right)}$$

Similarly, the predicted historical catch rate index is calculated as:

Eq 34 $$C\hat{R}_t = e^{\ln\left(q^{CR}\right)} B^{SL}_{t+0.5}$$

where the scaling coefficient $\ln\left(q^{CR}\right)$ is an estimated parameter.

A log-normal likelihood function is used to compare predicted ($C\hat{R}_t$) and observed (I_t) biomass indices,

Eq 35 $$L\left(C\hat{R}_t \mid \theta\right) = \frac{\varpi^{CR}}{CR_t \sigma_t^{CR} \tilde{\sigma} \sqrt{2\pi}} \exp\left[\frac{-\left(\ln(CR_t) - \ln(C\hat{R}_t) + 0.5\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)^2\right)^2}{2\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)^2}\right]$$

The normalised residual is

Eq 36 $$residual = \frac{\ln(CR_t) - \ln(C\hat{R}_t) + 0.5\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)^2}{\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)}$$

The predicted pre-recruit index is calculated as:

Eq 37 $$\hat{I}_t^{PR} = e^{\ln\left(q^{PRI}\right)} \sum_g \sum_{s<l_g} N^g_{s,t+0.5} V^g_{s,k,z}$$

where the scaling coefficient $\ln\left(q^{PRI}\right)$ is an estimated parameter.

A log-normal likelihood function is used to compare predicted ($\hat{I}_t^{PR}$) and observed (I_t^{PR}) biomass indices,

Eq 38 $$L\left(\hat{I}_t^{PR} \mid \theta\right) = \frac{\varpi^{PRI}}{I_t^{PR} \sigma_t^{PRI} \tilde{\sigma} \sqrt{2\pi}} \exp\left[\frac{-\left(\ln(I_t^{PR}) - \ln(\hat{I}_t^{PR}) + 0.5\left(\sigma_t^{PRI} \tilde{\sigma} / \varpi^{PRI}\right)^2\right)^2}{2\left(\sigma_t^{PRI} \tilde{\sigma} / \varpi^{PRI}\right)^2}\right]$$

The normalised residual is

Eq 39 $$residual = \frac{\ln(I_t^{PR}) - \ln(\hat{I}_t^{PR}) + 0.5\left(\sigma_t^{PRI}\tilde{\sigma} / \varpi^{PRI}\right)^2}{\left(\sigma_t^{PRI}\tilde{\sigma} / \varpi^{PRI}\right)}$$

A.12 Predictions and likelihood for proportion-at-size

The observed relative proportions-at-size $p_{s,t}^{g}$ for each sex category are fitted for each period. In each period, these proportions sum to one across the three sex categories. The model predictions for the relative proportions-at-size in each category are:

Eq 40 $$\hat{p}_{s,t}^{g} = \frac{V_{s,k,z}^{g} N_{s,t+0.5}^{g}}{\sum_{g}\sum_{s} V_{s,k,z}^{g} N_{s,t+0.5}^{g}}$$

We use the normal likelihood proposed by Bentley (Breen et al. 2002) for fitting the model predictions to the observed proportions-at-size:

Eq 41 $$L(\hat{p}_{s,t}^{g} \mid \theta) = \frac{\kappa_t \varpi^{p} \sqrt{\left(p_{s,t}^{g} + 0.1\right)}}{\tilde{\sigma}\sqrt{2\pi}} \exp\left(\frac{-\left(p_{s,t}^{g} + 0.1\right)\left(\hat{p}_{s,t}^{g} - p_{s,t}^{g}\right)^2}{2\left(\tilde{\sigma} / \kappa_t \varpi^{p}\right)^2}\right)$$

where ϖ^{p} is the relative weight applied to the proportion-at-size data.

The relative weight κ_t is calculated for each sample from a six-month period, t. Each sample comprises measurements from the various months with the period and various statistical areas within the larger area being assessed (CRA 4 or CRA 5). If m indexes month and o indexes statistical area, the proportion of lobsters in sex g at size s, aggregated within the area x month cell, $p_{m,o,s}^{g}$, can be expressed as

Eq 42 $$p_{m,o,s}^{g} = n_{m,o,s}^{g} \Big/ \sum_{g}\sum_{s} n_{m,o,s}^{g}$$

The weight given to this cell, $c_{m,o}$, is a function of the cube root of the number measured, the cube root of the number of days sampled, $D_{m,o}$, and the proportion of the total catch in period t taken in that month x area cell:

Eq 43 $$c_{m,o} = \frac{\sqrt[3]{\sum_{g}\sum_{s} n_{m,o,s}^{g}} \sqrt[3]{D_{m,o}}\, C_{m,o}}{\sum_{m}\sum_{o} C_{m,o}}$$

The proportion of lobsters at size and sex in the whole sample for period t is:

Eq 44 $$p_{s,t}^{g}=\frac{c_{m,o}p_{m,o,s}^{g}}{\sum_{m}\sum_{o}\sum_{s}\sum_{g}\left(c_{m,o}p_{m,o,s}^{g}\right)}$$

and the effective sample size is then the sum of the cell weights:

Eq 45 $$\kappa_{t}=\sum_{m}\sum_{o}c_{m,o}\,.$$

To prevent individual datasets from having functionally either most of the weight or no weight in the model fitting, we truncated κ_t values greater than 10 to 10, and less than 1 to 1.

The normalised residual for a proportion-at-length is:

Eq 46 $$residual=\frac{\sqrt{p_{s,t}^{g}+0.1}\left(\hat{p}_{s,t}^{g}-p_{s,t}^{g}\right)}{\left(\tilde{\sigma}\big/\kappa_{t}\varpi^{p}\right)}$$

A.13 Likelihood of tag size increments

The predicted size of a recaptured tagged lobster is calculated by simulating each moult during the time at liberty. For the first moult the predicted size after moulting , $\hat{S}_{i}^{g,recap}$, is

Eq 47 $$\hat{S}_{i}^{g,recap}=\left[\frac{S_{i}^{g,tag^{h^{g}}}}{x^{g}}+y^{g}\left(1-\frac{1}{x^{g}}\right)\right]^{\left(1/h^{g}\right)}$$

If the animal was at liberty for more than one moulting period for that sex, then the resulting size is calculated as above, replacing $S_{i,j}^{g,tag}$ with the result of Eq 47, and so on.

A normal likelihood function is used to compare predicted and observed sizes at recapture:

Eq 48 $$L\left(\hat{S}_{i}^{g,recap}\mid\theta\right)=\frac{1}{\sqrt{2\pi}\varphi_{i}^{g}}\exp\left(-\frac{\left(S_{i}^{g,recap}-\hat{S}_{i}^{g,recap}\right)^{2}}{2\left(\varphi_{i}^{g}\right)^{2}}\right)$$

where the standard deviation φ_{i}^{g} is calculated as follows. For a single moult, the standard deviation is the determined from the c.v. and the expected increment:

Eq 49

$$\varphi_{s,1}^{g}=\left(\left(y^{g}+h^{g}\;S_{i}^{g,tag}\right)CV^{g}-\varphi^{d,\min}\right)\left(\frac{1}{\pi}\times\tan^{-1}\left(\left(\left(y^{g}+h^{g}\;S_{i}^{g,tag}\right)CV^{g}-\varphi^{d,\min}\right)\times10^{6}\right)+0.5\right)+\varphi^{d,\min}$$

This differentiable function constrains the $\varphi_{s,1}^{g}$ to be equal to or greater than $\varphi^{d,\min}$. For more than one moult,

Eq 50 $$\left(\varphi_s^g\right)^2 = \sum_j \left(\varphi_{s,j}^g\right)^2 + \left(\sigma^{d,obs}\tilde{\sigma} / \varpi^{TAG}\right)^2$$

where

Eq 51

$$\varphi_{s,j}^g = \left(\left(y^g + h^g\ S_{i,j}^{g,tag}\right)CV^g - \varphi^{d,\min}\right)\left(\frac{1}{\pi} \times \tan^{-1}\left(\left(\left(\left(y^g + h^g\ S_{i,j}^{g,tag}\right)CV^g - \varphi^{d,\min}\right) \times 10^6\right) + 0.5\right) + \varphi^{d,\min}$$

where j indexes the number of moults and $\sigma^{d,obs}$ is the standard deviation of observation error.

The normalised residual is:

Eq 52 $$residual = \frac{S_i^{g,recap} - \hat{S}_i^{g,recap}}{\varphi_i^g}$$

A.14 Likelihood of recruitment residuals

Annual recruitment deviations, which cause recruitment to move away from average recruitment, are penalised with a normal likelihood function:

Eq 53 $$L\left(\varepsilon_l \mid \theta\right) = \frac{1}{\sigma^\varepsilon \sqrt{2\pi}} \exp\left[\frac{-\sum\left(\varepsilon_l\right)^2}{2\left(\sigma^\varepsilon\right)^2}\right]$$

A.15 Surplus production

The model calculates surplus production as catch plus the change in biomass between years:

Eq 54 $$P_t = B_{t+2}^{rect} - B_t^{rect} + C_t^{SL} + C_t^{NSL} + C_{t+1}^{SL} + C_{t+1}^{NSL}$$

where t indexes period.

APPENDIX B. DATA USED IN THE ASSESSMENT

Table B1: Catch data (kg) used for the CRA 4 assessment. Catches were reported by calendar year up to 1978; from 1979, catches are reported by fishing year (1 April to 31 March).

Fishing year	Season[1]	Period	Commercial reported[2]	Recreational[4]	Reported commercial illegal[5]	Customary[7]	Unreported illegal[6]
1945	1	1	102946	934	0	2000	18835
1945	2	2	151781	8408	0	18000	27769
1946	1	3	91079	1044	0	2000	16664
1946	2	4	134284	9397	0	18000	24568
1947	1	5	102515	1154	0	2000	18756
1947	2	6	151146	10386	0	18000	27653
1948	1	7	102310	1264	0	2000	18718
1948	2	8	150843	11375	0	18000	27598
1949	1	9	110707	1374	0	2000	20255
1949	2	10	163223	12364	0	18000	29863
1950	1	11	203491	1484	0	2000	37230
1950	2	12	300020	13353	0	18000	54891
1951	1	13	272252	1594	0	2000	49810
1951	2	14	401399	14343	0	18000	73439
1952	1	15	264244	1704	0	2000	48345
1952	2	16	389593	15332	0	18000	71279
1953	1	17	274325	1813	0	2000	50190
1953	2	18	404456	16321	0	18000	73998
1954	1	19	269418	1923	0	2000	49292
1954	2	20	397222	17310	0	18000	72674
1955	1	21	203593	2033	0	2000	37249
1955	2	22	300172	18299	0	18000	54918
1956	1	23	175382	2143	0	2000	32087
1956	2	24	258578	19288	0	18000	47309
1957	1	25	132450	2253	0	2000	24233
1957	2	26	195281	20277	0	18000	35728
1958	1	27	137645	2363	0	2000	25183
1958	2	28	202939	21267	0	18000	37129
1959	1	29	118838	2473	0	2000	21742
1959	2	30	175211	22256	0	18000	32056
1960	1	31	146269	2583	0	2000	26761
1960	2	32	215654	23245	0	18000	39455
1961	1	33	169675	2693	0	2000	31043
1961	2	34	250163	24234	0	18000	45769
1962	1	35	202628	2803	0	2000	37072
1962	2	36	298749	25223	0	18000	54658
1963	1	37	134094	2912	0	2000	24533
1963	2	38	176204	26212	0	18000	32238
1964	1	39	172091	3022	0	2000	31485
1964	2	40	287831	27201	0	18000	52661
1965	1	41	201451	3132	0	2000	36857
1965	2	42	379960	28191	0	18000	69516
1966	1	43	307700	3242	0	2000	56296

Fishing year	Season[1]	Period	Commercial reported[2]	Recreational[4]	Reported commercial illegal[5]	Customary[7]	Unreported illegal[6]
1966	2	44	355781	29180	0	18000	65093
1967	1	45	211129	3352	0	2000	38628
1967	2	46	301509	30169	0	18000	55163
1968	1	47	184032	3462	0	2000	33670
1968	2	48	325523	31158	0	18000	59557
1969	1	49	245779	3572	0	2000	44967
1969	2	50	360969	32147	0	18000	66042
1970	1	51	211455	3682	0	2000	38687
1970	2	52	347504	33136	0	18000	63578
1971	1	53	145665	3792	0	2000	26650
1971	2	54	273673	34125	0	18000	50070
1972	1	55	149010	3902	0	2000	27262
1972	2	56	277321	35115	0	18000	50738
1973	1	57	129074	4012	0	2000	23615
1973	2	58	244745	36104	0	18000	44778
1974	1	59	129482	4121	0	2000	17051
1974	2	60	245518	37093	0	18000	32331
1975	1	61	139495	4231	0	2000	34799
1975	2	62	264505	38082	0	18000	65985
1976	1	63	157450	4341	0	2000	31429
1976	2	64	298550	39071	0	18000	59594
1977	1	65	151234	4451	0	2000	39964
1977	2	66	286766	40060	0	18000	75779
1978	1	67	171376	4561	0	2000	44977
1978	2	68	324958	41049	0	18000	85284
1979	1	69	159214	4671	0	2000	13821
1979	2	70	344443	42039	0	18000	29899
1980	1	71	223720	4671	0	2000	25517
1980	2	72	383993	42039	0	18000	43797
1981	1	73	229068	4671	0	2000	41910
1981	2	74	385167	42039	0	18000	70469
1982	1	75	306571	4671	0	2000	56089
1982	2	76	546931	42039	0	18000	100065
1983	1	77	372421	4671	0	2000	68137
1983	2	78	567969	42039	0	18000	103914
1984	1	79	341258	4671	0	2000	62436
1984	2	80	522011	42039	0	18000	95506
1985	1	81	271059	4671	0	2000	49592
1985	2	82	576895	42039	0	18000	105547
1986	1	83	270780	4671	0	2000	49541
1986	2	84	676685	42039	0	18000	123804
1987	1	85	275466	4671	0	2000	50398
1987	2	86	653840	42039	0	18000	119625
1988	1	87	234890	4671	0	2000	42975
1988	2	88	530424	42039	0	18000	97045
1989	1	89	219254	4671	0	2000	40114
1989	2	90	539188	42039	0	18000	98648
1990	1	91	168382	4671	41589	2000	9950

Fishing year	Season[1]	Period	Commercial reported[2]	Recreational[4]	Reported commercial illegal[5]	Customary[7]	Unreported illegal[6]
1990	2	92	354817	42039	87637	18000	20967
1991	1	93	176262	4671	25490	2000	6098
1991	2	94	354244	42039	51228	18000	12256
1992	1	95	183120	4671	8942	2000	2139
1992	2	96	312618	42039	15266	18000	3652
1993	1	97	233692	4671	19163	2000	4585
1993	2	98	258350	42039	21184	18000	5068
1994	1	99	271306	4671	31252	2000	7477
1994	2	100	219060	42039	25234	18000	6037
1995	1	101	343853	4671	36448	2000	8720
1995	2	102	143363	42039	15196	18000	3636
1996	1	103	446454	4671	9045	2000	58793
1996	2	104	47130	42039	955	18000	6207
1997	1	105	460931	4671	9054	2000	58852
1997	2	106	29489	42039	579	18000	3765
1998	1	107	450468	4671	8463	2000	55008
1998	2	108	42789	42039	804	18000	5225
1999	1	109	532443	4671	8220	2000	53432
1999	2	110	44030	42039	680	18000	4418
2000	1	111	503900	4671	7494	2000	48710
2000	2	112	69901	42039	1040	18000	6757
2001	1	113	474554	4671	6834	2000	44419
2001	2	114	99514	42039	1433	18000	9315
2002	1	115	436283	4671	6063	2000	39409
2002	2	116	139393	42039	1937	18000	12591
2003	1	117	365858	4671	4236	2000	27537
2003	2	118	209866	42039	2430	18000	15796
2004	1	119	261828	4671	2450	2000	15928
2004	2	120	308023	42039	2883	18000	18738
2005	1	121	204773	4671	2023	2000	13151
2005	2	122	335004	42039	3310	18000	21515

[1] 1=AW; 2=SS

[2] Total reported commercial catches from catch statistics. Seasonal splits are calculated as reported in Section 3.3.1.1. These are added to the SL catch category.

[3] Estimates for unreported export discrepancies are calculated from a comparison of total reported commercial catch with published export statistics (Breen 1991). The appropriate seasonal splits and size limits are applied to this category.

[4] Recreational catch is added to the SL catch category and a 10%:90% (AW – SS) seasonal split is used.

[5] Illegal catch thought by MFish Compliance to have been processed through normal legal channels. This catch is subtracted from the total reported commercial catch when calculating the total legal catch in order to avoid double counting of catch. This value has only been estimated in the most recent years and its proportion has been applied retrospectively to the period of illegal catch estimates.

[6] Remaining illegal catch thought by MFish Compliance to have been processed through other channels, This catch is added to the NSL catch. Total illegal catch is the sum of these two illegal components.

[7] Customary catches are added to the NSL catch category and a 10%:90% (AW – SS) seasonal split is used.

Table B2: Data input file for the CRA 4 assessment: year, period, SL and NSL catches (t), CPUE indices and their associated standard errors, historical catch rate (CR) indices, pre-recruit (PRI) indices, male and female size limits (MLS), selectivity epochs and sequential recruitment deviation (Rdev) indices.

Year	Period	SL catch	NSL catch	CPUE indices[1]	S. E. CPUE indices[2]	CR indices[3]	PRI indices[4]	Male MLS	Female MLS	Sel. epoch	Rdev
1945	1	103.88	66.60	0	0	0	0	0	0	1	1
1945	2	160.19	0.00	0	0	0	0	0	0	1	1
1946	3	92.12	61.23	0	0	0	0	0	0	1	2
1946	4	143.68	0.00	0	0	0	0	0	0	1	2
1947	5	103.67	66.41	0	0	0	0	0	0	1	3
1947	6	161.53	0.00	0	0	0	0	0	0	1	3
1948	7	103.57	66.32	0	0	0	0	0	0	1	4
1948	8	162.22	0.00	0	0	0	0	0	0	1	4
1949	9	112.08	70.12	0	0	0	0	0	0	1	5
1949	10	175.59	0.00	0	0	0	0	0	0	1	5
1950	11	204.97	39.23	0	0	0	0	47	49	1	6
1950	12	313.37	72.89	0	0	0	0	47	49	1	6
1951	13	273.85	51.81	0	0	0	0	47	49	1	7
1951	14	415.74	91.44	0	0	0	0	47	49	1	7
1952	15	265.95	50.35	0	0	0	0	51	53	1	8
1952	16	404.92	89.28	0	0	0	0	51	53	1	8
1953	17	276.14	52.19	0	0	0	0	51	53	1	9
1953	18	420.78	92.00	0	0	0	0	51	53	1	9
1954	19	271.34	51.29	0	0	0	0	51	53	1	10
1954	20	414.53	90.67	0	0	0	0	51	53	1	10
1955	21	205.63	39.25	0	0	0	0	51	53	1	11
1955	22	318.47	72.92	0	0	0	0	51	53	1	11
1956	23	177.53	34.09	0	0	0	0	51	53	1	12
1956	24	277.87	65.31	0	0	0	0	51	53	1	12
1957	25	134.70	26.23	0	0	0	0	51	53	1	13
1957	26	215.56	53.73	0	0	0	0	51	53	1	13
1958	27	140.01	27.18	0	0	0	0	51	53	1	14
1958	28	224.21	55.13	0	0	0	0	51	53	1	14
1959	29	121.31	23.74	0	0	0	0	53	58	1	15
1959	30	197.47	50.06	0	0	0	0	53	58	1	15
1960	31	148.85	28.76	0	0	0	0	53	58	1	16
1960	32	238.90	57.46	0	0	0	0	53	58	1	16
1961	33	172.37	33.04	0	0	0	0	53	58	1	17
1961	34	274.40	63.77	0	0	0	0	53	58	1	17
1962	35	205.43	39.07	0	0	0	0	53	58	1	18
1962	36	323.97	72.66	0	0	0	0	53	58	1	18
1963	37	137.01	26.53	0	0	79.97	0	53	58	1	19
1963	38	202.42	50.24	0	0	74.12	0	53	58	1	19
1964	39	175.11	33.49	0	0	101.60	0	53	58	1	20
1964	40	315.03	70.66	0	0	110.17	0	53	58	1	20
1965	41	204.58	38.86	0	0	121.27	0	53	58	1	21
1965	42	408.15	87.52	0	0	119.91	0	53	58	1	21
1966	43	310.94	58.30	0	0	104.71	0	53	58	1	22
1966	44	384.96	83.09	0	0	86.56	0	53	58	1	22

Year	Period	SL catch	NSL catch	CPUE indices[1]	S. E. CPUE indices[2]	CR indices[3]	PRI indices[4]	Male MLS	Female MLS	Sel. epoch	Rdev
1967	45	214.48	40.63	0	0	101.05	0	53	58	1	23
1967	46	331.68	73.16	0	0	82.74	0	53	58	1	23
1968	47	187.49	35.67	0	0	68.69	0	53	58	1	24
1968	48	356.68	77.56	0	0	64.51	0	53	58	1	24
1969	49	249.35	46.97	0	0	60.55	0	53	58	1	25
1969	50	393.12	84.04	0	0	55.32	0	53	58	1	25
1970	51	215.14	40.69	0	0	50.13	0	53	58	1	26
1970	52	380.64	81.58	0	0	54.18	0	53	58	1	26
1971	53	149.46	28.65	0	0	46.79	0	53	58	1	27
1971	54	307.80	68.07	0	0	49.92	0	53	58	1	27
1972	55	152.91	29.26	0	0	47.20	0	53	58	1	28
1972	56	312.44	68.74	0	0	49.49	0	53	58	1	28
1973	57	133.09	25.61	0	0	43.99	0	53	58	1	29
1973	58	280.85	62.78	0	0	0	0	53	58	1	29
1974	59	133.60	19.05	0	0	0	0	53	58	1	30
1974	60	282.61	50.33	0	0	0	0	53	58	1	30
1975	61	143.73	36.80	0	0	0	0	53	58	1	31
1975	62	302.59	83.98	0	0	0	0	53	58	1	31
1976	63	161.79	33.43	0	0	0	0	53	58	1	32
1976	64	337.62	77.59	0	0	0	0	53	58	1	32
1977	65	155.69	41.96	0	0	0	0	53	58	1	33
1977	66	326.83	93.78	0	0	0	0	53	58	1	33
1978	67	175.94	46.98	0	0	0	0	53	58	1	34
1978	68	366.01	103.28	0	0	0	0	53	58	1	34
1979	69	163.88	15.82	0.805	0.034	0	0	53	58	1	35
1979	70	386.48	47.90	0.890	0.028	0	0	53	58	1	35
1980	71	228.39	27.52	0.833	0.032	0	0	53	58	1	36
1980	72	426.03	61.80	0.824	0.028	0	0	53	58	1	36
1981	73	233.74	43.91	0.855	0.032	0	0	53	58	1	37
1981	74	427.21	88.47	0.892	0.029	0	0	53	58	1	37
1982	75	311.24	58.09	0.923	0.031	0	0	53	58	1	38
1982	76	588.97	118.06	0.969	0.027	0	0	53	58	1	38
1983	77	377.09	70.14	0.873	0.030	0	0	53	58	1	39
1983	78	610.01	121.91	0.853	0.027	0	0	53	58	1	39
1984	79	345.93	64.44	0.759	0.030	0	0	53	58	1	40
1984	80	564.05	113.51	0.790	0.028	0	0	53	58	1	40
1985	81	275.73	51.59	0.627	0.030	0	0	53	58	1	41
1985	82	618.93	123.55	0.855	0.028	0	0	53	58	1	41
1986	83	275.45	51.54	0.672	0.031	0	0	53	58	1	42
1986	84	718.72	141.80	0.899	0.028	0	0	53	58	1	42
1987	85	280.14	52.40	0.564	0.032	0	0	53	58	1	43
1987	86	695.88	137.62	0.806	0.029	0	0	53	58	1	43
1988	87	239.56	44.97	0.489	0.032	0	0	54	58	1	44
1988	88	572.46	115.04	0.663	0.030	0	0	54	58	1	44
1989	89	223.92	42.11	0.446	0.031	0	0	54	58	1	45
1989	90	581.23	116.65	0.665	0.028	0	0	54	58	1	45
1990	91	131.46	53.54	0.419	0.032	0	0	54	58	1	46
1990	92	309.22	126.60	0.600	0.029	0	0	54	58	1	46

Year	Period	SL catch	NSL catch	CPUE indices[1]	S. E. CPUE indices[2]	CR indices[3]	PRI indices[4]	Male MLS	Female MLS	Sel. epoch	Rdev
1991	93	155.44	33.59	0.422	0.029	0	0	54	58	1	47
1991	94	345.05	81.48	0.601	0.029	0	0	54	58	1	47
1992	95	178.85	13.08	0.403	0.029	0	0	54	60	1	48
1992	96	339.39	36.92	0.587	0.029	0	0	54	60	1	48
1993	97	219.20	25.75	0.442	0.029	0	0.000	54	60	2	49
1993	98	279.20	44.25	0.680	0.033	0	0.790	54	60	2	49
1994	99	244.72	40.73	0.580	0.029	0	0.000	54	60	2	50
1994	100	235.86	49.27	0.830	0.038	0	0.566	54	60	2	50
1995	101	312.08	47.17	0.718	0.030	0	0.000	54	60	2	51
1995	102	170.21	36.83	1.123	0.046	0	0.697	54	60	2	51
1996	103	442.08	69.84	1.025	0.031	0	1.381	54	60	2	52
1996	104	88.21	25.16	1.449	0.068	0	0.000	54	60	2	52
1997	105	456.55	69.91	1.209	0.033	0	1.185	54	60	2	53
1997	106	70.95	22.34	1.737	0.081	0	0.000	54	60	2	53
1998	107	446.68	65.47	1.334	0.033	0	0.996	54	60	2	54
1998	108	84.02	24.03	2.169	0.073	0	0.000	54	60	2	54
1999	109	528.89	63.65	1.285	0.032	0	0.906	54	60	2	55
1999	110	85.39	23.10	1.753	0.076	0	0.000	54	60	2	55
2000	111	501.08	58.20	1.027	0.034	0	1.182	54	60	2	56
2000	112	110.90	25.80	2.008	0.066	0	0.000	54	60	2	56
2001	113	472.39	53.25	0.929	0.032	0	1.118	54	60	2	57
2001	114	140.12	28.75	1.490	0.057	0	1.204	54	60	2	57
2002	115	434.89	47.47	0.952	0.033	0	1.013	54	60	2	58
2002	116	179.49	32.53	1.731	0.050	0	0.720	54	60	2	58
2003	117	366.29	33.77	0.992	0.034	0	0.972	54	60	2	59
2003	118	249.47	36.23	1.652	0.046	0	1.288	54	60	2	59
2004	119	264.05	20.38	0.722	0.035	0	1.213	54	60	2	59
2004	120	347.18	39.62	1.364	0.039	0	1.234	54	60	2	59
2005	121	207.42	17.17	0.760	0.100	0	0.000	54	60	2	59
2005	122	373.73	42.83	0.000	0.000	0	0.000	54	60	2	59

[1] Normalised standardised CPUE indices scaled to units of kg per potlift
[2] Standard error of the CPUE estimates for each period
[3] Unstandardised CR indices in kg per day from Annala & King (1983)
[4] Annual standardised pre-recruit indices

APPENDIX C. NON-COMMERCIAL CATCH ESTIMATES

Original request

From: Paul Breen <p.breen@niwa.co.nz>
To: mitchell@fish.govt.nz
Subject: illegal
Cc: Paul Starr <paul@starrfish.net>, haistv@shaw.ca, s.kim@niwa.co.nz, daryl@seafood.co.nz, stokesk@seafood.co.nz
Date: Fri, 12 Aug 2005 10:08:25 +1200

Leigh:

On behalf of the assessment team I am writing to request the MFish estimates of illegal and customary catches from CRA 4.

For illegal catches, the assessment needs the most recent estimate and some estimate of the historical trends in these catches. MFish has provided estimates in the past from CRA 4:
160 t for 1990-91
30 t for 1992-93
70 t for 1994 labelled "prelim"
70 t for 1994-95
64 t for 1995-96
75 t for 1996-97
64 t for 2001-02
60 t for 2002-03

We are interested in whether MFish supports these previously made estimates, and whether it can provide guidance on the likely pattern of illegal catches before 1990.

In addition to the simple quantum of catch, the model requires us to specify the source of catch: for instance, does the illegal catch in a season come mostly from scrubbed or berried females, or alternatively is it mostly undersized fish caught in pots, or does it come from the whole range of fish available to pots?

Equally important, we need to know what proportion of the illegal catch is reported. If commercial fishers land scrubbed females or undersized, it is reported against quota, and we need to know that to avoid double-counting this catch.

Last year I suggested a form to Scott that we thought might be useful; I attach it again this year in the spreadsheet "Scott".

Last year we had an extensive email exchange with Compliance; I also attach one of the documents with Paul Starr's comment's because this might assist you in understanding what is required by the assessment.

For customary catch the requirements are similar: we need the current magnitude and likely historical trend of customary catch. The source of customary catch is extremely important: we need to know whether customary catch is taken from the whole range of fish available to pots (or divers) or whether it comprises mostly commercially undersized lobsters and berried females.

On Tuesday I said that we needed these data by 12 September. Apologies, but the schedule has been brought forward one week, partly because of the unforeseen proliferation of MFish meetings in the week of September 12. We now require this information no later than 5 September.

Thanks in advance for your assistance with this request. I am happy to answer any queries or to clarify.

Cheers
Paul

Response

Hello Paul

Please find attached the report on the illegal take and customary harvest, as requested. I apologise for the delay in getting this to you; as noted there was some delay in getting verification on some matters.

Most notable in the document is the estimate of illegal take. The estimate provided is 40 tonnes - 20 tonnes less than the preliminary figure.

The information provided represents the best information we have at this time. You will note, however, that MFish is still unable to provide the more detailed information you have requested (eg, does the illegal catch in a season come mostly from scrubbed or berried females, or alternatively is it mostly undersized fish caught in pots, or does it come from the whole range of fish available to pots and whether customary catch is taken from the whole range of fish available to pots (or divers) or whether it comprises mostly commercially undersized lobsters and berried females.

Regards
Leigh

To	Leigh Mitchell (Fisheries Operations – Nelson)
From	Aoife Martin (Compliance Advice Team)
Issue	Estimates of customary and illegal take from the CRA 4 fishery
Date	22 September 2005

Introduction

You have requested information to support the CRA 4 stock assessment particularly information on:

- Legitimate removals of rock lobster for customary purposes
- Illegal removals
- Validation of estimates provided in previous years.

Overview

A summary of our estimates of illegal take and legitimate customary take in the CRA4 fishery in 2004-05[1] is detailed in the table below.

Sector	Quantity (tonnes)
Illegal take	35-40
Legitimate customary take	20

Approach

MFish does not currently have a reliable robust and defensible methodology to estimate illegal fishing. Our approach uses the 'method' employed last year to provide information on the CRA3 fishery. We identified the base line estimates from known prosecutions and infringement notices. Using fishery officer knowledge and intelligence information on activities within the fishery, we then aggregated the baseline date to give, what we believe is, a reasonable estimate of illegal activity in the fishery.

Our method to identify levels of customary removals also has difficulties. As you are aware fish taken for customary purposes does not have to be reported. We rely on information provided by iwi to identify quantities of legitimate customary take. This process has improved in recent years because of the creation of the Pou Hononga who work directly with iwi. In addition, parts of the CRA 4 area have adopted the Kaimoana regulations (customary regulations). This means fewer permit issuers operate in this area and they are required to maintain records of the permits issued which includes information on the quantity of rock lobster taken under the authority of the permit.

[1] The period 2004-05 runs from 1 April 2004 to 31 March 2005

Categories

In providing this estimate we have used the same categories of illegal activity that were used in 2004 to provide estimates on the CRA3 fishery. These categories are:

- Poaching
- Illegal commercial activity
- Illegal recreational activity
- Illegal customary activity

Definitions of each category are provided in Attachment 1. Our information systems do provide us with information to make the distinction between reported and unreported removals but this is only available for baseline data on known offending and it is not possible to apply this to the total aggregated estimate across the fishery.

Changes to the profile of the fishery

MFish believes the following factors have led to changes in illegal activity in the CRA4 fishery:

- Large scale poaching activity for supply into the blackmarket is believed to have fallen in comparison to previous years as poor prices and increasing costs make illegal fishing of rock lobster less economic than poaching other species, such as paua for example.
- In contrast poor prices, higher fuel costs and poor catch rates are putting extra pressure on commercial fishers, which we believe is leading to an increase in slippage amongst some commercial operators.
- Overall CRA catches have declined which is likely to mean less illegal fish removed from the fishery. Most of the baseline offending identified relates to illegal activity in the recreational sector in the form of catching in excess of daily bag limit and double dipping. This activity is mostly seasonal taking place typically from Labour weekend until Easter.

Legitimate customary take is also believed to have reduced. The reasons for the reduction are unknown at this time.

Illegal take

Our analysis of the CRA4 fishery suggests that the quantity of illegal removals has fallen from the estimate of 60 tonnes provided in 2002-03. We estimate that a maximum of 40 tonnes were removed in 2004-05. The table below details the breakdown of this 40 tonne across the different sectors.

Category	Quantity of illegal removals (tonne)
Illegal commercial activity	10
Illegal recreational activity	5
Illegal customary activity	Unknown
Poaching	20
Total	35-40

Customary take

Our estimates suggest that 20 tonnes of rock lobster were legitimately removed from the fishery for customary purposes in 2004-05. This estimate is based on the information collected from the customary permit issuers.

Validation of previous estimates

You have also asked us to review estimates provided in previous years. We have reviewed these estimates and we do not have any additional information which would cause us to amend these estimates at this time.

Conclusion

If you require any further information please do not hesitate to contact me on 04 470 2675 or aoife.martin@fish.govt.nz.

Definition of illegal activity

Definitions of illegal activity

The following table defines the categories of illegal activity used. These categories are discussed in more detail in the sections following this table – text in bold relates to the categories that feature in the table below.

CATEGORIES OF ILLEGAL ROCK LOBSTER REMOVALS			
Sector activity	**Operating within management framework**		**Operating outside management framework**
	Outside catch entitlement	**State offences**	**Poaching: Taking without unlawful authority and/or sale**
Recreational	Taking in excess of dailybag limit	Taking undersized rock lobster	Selling/bartering recreational catch
		Taking berried females	
		Taking broken or unmeasurable rock lobster	
Commercial	Under reporting mortalities	Taking berried females	Fishing without a permit
	Area misreporting	Taking undersized rock lobster	For sale other than to LFR/Wharf Sales
	High-grading	Taking broken or unmeasurable rock lobster	
Customary	Exceeding catch authorised by a customary permit	CRA taken in state not authroised by Tangata Kaitaki	Fishing for rock lobster without customary authorisation
	Taking catch in contravention of maitai bylaws/taipure regulations		Selling/bartering rock lobster authorised by a customarypermit

Notes:

1.Taking rock lobster that is in breach of the permitted physical state, e.g. it is an offence to take of possess broken or unmeasurable rock lobster

Poaching

Poachers are defined as an individual or entity who:

- take without lawful authority, to sell, trade or barter
- take with lawful authority, but unlawfully engages in sale, trade or barter.

Poaching can take place under the guise of legitimate recreational, commercial or customary activity. The table below describes how poaching activity has been characterised.

Description of poaching activity	Estimated annual volume removed by each poaching activity (tonnes of rock lobster)	Characteristics
Large scale	5-8	• Well organised • Fish to specific orders with established distribution networks • Use large quantities of gear (40-60 pots) • Linked to organized crime • Illegally remove rock lobster from other user's pots • May operate under the guise of a commercial or customary fisher.
Medium scale	2-5	• Organised • Create own market and act as sales agents • Have been known to link with regular poaching activity on occasion • Typically work 10 to 20 pots • May operate under the guise of a commercial, customary or recreational fisher.
Small scale	Up to 2 tonnes	• Not well organised • Sells direct to user • Intermittent operation depending on weather and sea conditions • Target back door trade such as pubs and hotels • Quantity taken can vary considerably • May operate under the guise of a recreational user • May fish to a specific order to supply a local restaurant.

Illegal commercial activity

Legal operators in the commercial sector e.g. fishers who hold a permit and appropriate ACE, can participate in three categories of illegal activity:

1. hold fishing permit but sell unreported catch on blackmarket – this activity has been included in **poaching** estimates
2. hold fishing permit but take unreported rock lobster **outside catch entitlement** e.g. high-grading but is sold through the legitimate supply chain
3. hold fishing permit but take rock lobster in breach of **state offences** e.g. taking berried rock lobster – this activity is reported and is sold through the legitimate supply chain.

Illegal recreational activity

Illegal recreational activity occurs when rock lobster are removed in breach of restrictions put in place under Regulation 25 of the Fisheries (Amateur Fishing) Regulations 1986. There are three categories of illegal activity:

1. unlawfully selling rock lobster taken as part of recreational entitlement – this is classed as **poaching** activity and removals are included in the poaching estimates
2. **state offences** – taking rock lobster in breach of the permitted physical state, eg. undersized rock lobster, broken or unmeasurable rock lobster, berried rock lobster
3. taking rock lobster **outside catch entitlement** e.g. in excess of daily bag limits.

Illegal customary activity

There are three categories of illegal customary activity:

1. unlawfully selling rock lobster taken under the authority of a customary permit – this is classed as poaching activity and removals are included in the **poaching** estimates
2. **outside catch entitlement** - taking in excess of the quantity authorised by the relevant permit
3. **state offences** - taking in breach of any other conditions on the relevant customary permit.
