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CONTENTS

EXECUTIVE SUMMARY

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The revised length-based model for assessing New Zealand lobster stocks is described. The model simulates recruitment, growth, natural mortality and fishing mortality in 6-month seasons from 1945. The fishing model includes differential vulnerability for each of males, immature and mature females based on size and season. This model is driven by estimated catches (commercial, recreational, Maori customary and illegal) and was applied to relative abundance and proportion-at-length data from the CRA 4 and CRA 5 fisheries. These two areas were assessed separately because patterns in catch per unit of effort (CPUE) were substantially different.

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 analyses were based on modes of joint posterior distributions.

The model appeared to behave reasonably well in the CRA 5 assessment. Iterative re-weighting was used successfully to find a base case, and a relatively short McMC chain was used to estimate the marginal posterior distributions. For CRA 4 the model had some apparent difficulties in minimising when we attempted to balance the normalised (standardised) residuals. An agreed base case was used to make a single long McMC chain, and this demonstrated some undesirable attributes. Despite those, the posterior of projected biomass as a fraction of current biomass appeared to be converged, and this assessment was accepted at the Plenary.

For both stocks, the current vulnerable biomass is above that in a reference period, 1979–88. Under the assumptions of the projections – constant catches at the current levels, constant seasonal distributions of catches at the current levels, and recruitments resampled from the past decade – biomass appears likely to decline from the current level, but is likely to remain above the reference levels. Projections are uncertain, and stocks could either increase or decrease. Additional uncertainty is caused by the poor estimates of current non-commercial catches and their historical patterns.

Further projections were made for CRA 4 at the request of the National Rock Lobster Management Group, and the probabilities of future recruited biomass declining below reference values were tabulated for each year.

1. INTRODUCTION

The spiny lobster *Jasus edwardsii* supports the most valuable inshore fishery in New Zealand, with annual exports worth over $100 million. Continuing sustainability and optimum use of this fishery are major management goals. For a literature review of New Zealand *J. edwardsii*, see Breen & McKoy (1988); for fishery descriptions see Annala (1983) and Booth & Breen (1994); for recent management details see Annala et al. (2003) and Booth et al. (1994). Recent assessments were described by Bentley et al. (2001), Breen et al. (2002) and Starr et. al (2003).

The commercial fishery (an inshore trap or pot fishery in the areas described here) has been managed since 1990 with a system of individual transferable quotas (ITQs). Before quotas were introduced in 1990, the fishery was managed with limited entry and by "input control" methods. These included minimum legal sizes (MLS), recreational bag limits, protection of ovigerous females and soft-shelled lobsters, and some local closures. In 1990, the fishery was brought into the Quota Management System (QMS), but the input controls (size limits, protection of berried females, some spatial and seasonal restrictions) were retained. Ten Quota Management Areas (QMAs), each with a separate Total Allowable Commercial Catch (TACC), were put in place in 1990. The revision to the Fisheries Act in 1996 also requires the Minister to set a Total Allowable Catch (TAC) which includes all known sources of fishing mortality including commercial catch, recreational catch, Maori customary catch, illegal catch and fishing-related mortality.

The Fisheries Act 1996 requires that New Zealand fishstocks be managed so that stocks are maintained at or above B_{MSY}, the biomass associated with the maximum sustainable yield (*MSY*). 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 B_{MSY} and whether current TACs and TACCs are sustainable and likely to move stocks toward B_{MSY}. The work described here was conducted by fisheries scientists under contract to the New Zealand Rock Lobster Industry Council (NZ RLIC), which in turn was contracted by MFish, to provide an assessment for CRA 4 (Wellington-Hawke's Bay) and CRA 5 (Canterbury-Marlborough) fishstocks. Conduct of the work throughout was described to and discussed by the Rock Lobster Fishery Assessment Working Group (RLFAWG), comprising representatives from MFish and all stakeholder groups.

Length-based models of the type described by Punt & Kennedy (1997) have been used since 1998 to assess rock lobsters in New Zealand. For fished populations that cannot be aged, length-based models are becoming widely used. The model used here models growth with a transition matrix that has no reference to "age" except at the recruitment phase. 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*) and Breen & Kim. (2003) for the New Zealand abalone (*Haliotis iris*). The heart of such models is a stochastic growth transition matrix that calculates the probabilities that animals of a given length will grow into a vector of possible future lengths.

The specific model used in this study was first written for the 1999 assessment (Breen et al. 2001b) of the NSS stock (CRA 7 and CRA 8) and the combined CRA 4 and CRA 5 stock. The model was revised for the 2000 assessment as described by Bentley et al. (2001), for the 2001 assessment after an extensive review (Breen et al. 2002), and for the 2002 assessment of CRA 1 and CRA 2 (Starr et al. 2003). Revisions to dynamics were made for this study as described below.

The assessment uses Bayesian techniques to improve the representation of uncertainty in the assessment (see Punt & Hilborn (1997) for a discussion of Bayesian techniques and their use in fisheries stock assessments). These techniques are becoming standard tools in this field (e.g., McAllister et al. 1994, Meyer & Millar 1999).

The model is fitted to five data sets: standardised catch per unit effort (CPUE), historical catch rates (CR), pre-recruit indices from catch sampling and voluntary logbook programs, proportions-at-size from catch sampling and voluntary logbook programs, and growth increments from tag-recapture programs.

This report describes the revised size-based model, describes and lists the data used for the CRA 4 and CRA 5 assessments, and presents and discusses the assessment results.

2. ASSESSMENT MODEL

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

The 2003 assessment of CRA 4 and CRA 5 used a revision of the model described by Starr et al. (2003). Much of the model structure and dynamics are based on a similar model developed for the rock lobster fishery in Tasmania by Punt & Kennedy (1997). This model has been revised in some respects each year since being developed. Full model details are provided in Appendix A. Main changes made to the model were as follows.

- Growth model: the parameterisation was changed to allow estimation of a shape parameter - previously the relation between initial size and predicted increment was a straight line.
- Catchability coefficients: previously these were calculated as "nuisance parameters"; for this assessment they were estimated as free parameters with uniform priors in log space.
- The log-normal likelihood calculations were altered slightly to make them true log-likelihoods.
- Previously, it was assumed that relative seasonal vulnerability was greatest for males in SS. In this assessment a switch allowed the maximum seasonal vulnerability to be in either sex for either season, and we experimented to find the most appropriate choice.

The total fishery comprises four elements – the commercial and recreational sectors are governed by the MLS and restrictions on landing berried females. These two fisheries together are called the SL fishery (fishery bound by the size limits) and the catch is called C^{SL}. The Maori customary and illegal fisheries are not bound by those regulations; together we call them the NSL fishery and estimate the catch as C^{NSL}.

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

2.1 Model fitting

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

For each data element in each data set, the standard deviation of a common error component used in the likelihood component, $\sigma_{j,k}$, 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 the component common to all data sets and estimated by the model, 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 with a revised normal function which gives most weight to the larger proportions and least to the smallest. 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 1999. The 1999 annual deviation was applied to year 2000 to 2002 in the minimisation and McMC phases; deviations for 1999 through 2008 were obtained from re-sampling in the projection phase.

2.2 Markov chain-Monte Carlo simulations

After obtaining the best fit, or mode of the joint posterior distribution (MPD), by minimising the total 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. The posteriors were based on 5000 samples selected from one chain of 10 million simulations for CRA 4, and from 10 000 samples selected from one chain of two million McMC simulations for CRA 5. Both the CRA 4 and CRA 5 chains were started from the MPD. After analysis of diagnostics, we discarded the first 1000 samples from the CRA 5 chain.

2.3 Projections

From each of the posterior samples for each area, we made 5-year projections of biomass, encompassing the 2003–04 through 2007–08 fishing years, under the assumptions that commercial catches would equal the current TACCs and that other catches would remain at their 2002 levels during the projection. For CRA 4 these catches were 644 t and 70 t for the SL and NSL catches respectively; for CRA 5 they were 447 t and 62 t. Projected recruitments for the years 1999–2008 were randomly re-sampled from the estimated model recruitments from the period 1989 – 1998.

For CRA 4 we were asked by the National Rock Lobster Management Group to make further projections using different catch levels. We were instructed to reduce the recreational and commercial catch components by 10%, 20%, and 30% and to let the illegal and customary catches remain at their estimated 2002 values.

2.4 Fishery indicators

The RLFAWG agreed to use the following fishery indicators as measures of the status and risk for each stock unit that was assessed. Vulnerable biomass is defined as the biomass available to the commercial and recreational fisheries (the SL fisheries): it is the biomass of individuals above the MLS after selectivity-at-length, protection of berried females, and seasonal vulnerability are taken into account. Recruited biomass is defined as the biomass of all individuals above the MLS. We used the biomass at the start of the fishing year, or beginning of the AW season.

1. $BVULN_{03}/BVULN_{79\text{-}88}$
2. $BVULN_{08}/BVULN_{03}$
3. $BVULN_{08}/BVULN_{79\text{-}88}$
4. $Bmin$
5. $UNSL_{03,AW}$
6. $USL_{03,AW}$
7. $UNSL_{07,AW}$
8. $USL_{07,AW}$

The period 1979–88 was chosen as a reference period after inspecting some early model fits. It was the earliest period whence good data were available from which to estimate biomass, and biomass was relatively stable despite increasing catches during this period. This period is defensible as a period of relative stability and productivity in both CRA 4 and CRA 5 fisheries. Biomass in this reference period is a useful reference level that appears to have proven safe over time.

Current vulnerable biomass, $BVULN_{03}$, is defined as the beginning season vulnerable biomass on 1 April 2003, the beginning of the autumn-winter season for the 2002–03 fishing season. It is calculated from B_{117}^{SL} (see Appendix A), where period 117 is the AW season in 2003 (Table B1). Similarly, projected vulnerable biomass $BVULN_{08}$ is defined as the beginning season vulnerable biomass on 1 April 2008, the beginning of the autumn-winter season for the 2008–09 fishing season, and calculated as B_{127}^{SL}. The reference period biomass, $BVULN_{79-88}$, is calculated as the mean of the AW values (odd-numbered periods) for B_{69}^{SL} through B_{87}^{SL}. *Bmin* is the lowest point in recruited biomass.

$USL_{03,AW}$ is the exploitation rate for catch taken from the SL vulnerable biomass in the autumn-winter season of 2003–04, B_{117}^{SL}. It is calculated as U_{115}^{SL} (see Appendix A), and $USL_{07,AW}$ is the exploitation rate for catch taken from the SL vulnerable biomass in the autumn-winter season of 2007–08, the last year of projections, and calculated as U_{125}^{SL}. $UNSL_{03,AW}$ and $UNSL_{07,AW}$ are similarly defined except that they describe the exploitation rate for catch taken from the biomass vulnerable only to the NSL fishery, B_{117}^{NSL} and B_{125}^{NSL}, and are calculated as U_{115}^{NSL} and U_{125}^{NSL}.

2.5 Sensitivity trials

Sensitivity of the MPD results was examined to see which, if any, data sets were inconsistent with other data sets, and to explore the effects of other modelling choices.

We ran sensitivity trials by:

- estimating the shape of the increment-initial size growth relation (it was fixed in the base case),
- estimating the shape of the CPUE-biomass relation (it was fixed in the base case),
- estimating both these shapes together,
- estimating the shape of the right-hand selectivity curve (fixed in the base case to prevent the model from creating large numbers of cryptic lobsters),
- doubling the relative weights for each of the five data sets in turn,
- assuming a lower value for maximum exploitation rate, and
- fitting to alternative series of assumed recreational catches.

For the alternative sets of recreational catches, we assumed that recreational catch was 2.78 times the 1996 recreational catch estimate in the first trial, where the factor 2.78 came from comparisons made between the 1996 and 2000–01 surveys (David Gilbert, NIWA, pers. comm.). In the second trial the recreational catch vector was doubled.

2.6 Retrospective analysis

Retrospective analysis is a common approach (National Research Council 1998) in which the model's estimates that would have been made in the past are examined by removing data from the model one year at a time. If the biomass trajectory is sensitive to this, then the model's predictive power is suspect.

For each area, we removed abundance indices and proportions-at-length data, one year at a time, from the years 2002, 2001, 2000 and 1999. Tagging data were not removed. In each trial, we estimated the MPD results and examined the trajectories of biomass, CPUE and recruitment.

3. ASSESSMENT MODEL INPUTS

A summary of data and data sources used in the CRA 4 and CRA 5 stock assessments is given in Table 1. A discussion of these data and their sources follows.

3.1 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, spanning the period 1 April through 31 March. Fishing years are labelled using the first calendar year in each pair (for example, the 1996–97 assessment year which covers the period 1 April 1996 through 31 March 1997 is labelled as "1996").

3.2 Catches

The assessment model uses annual values of the SL catch (taken under the MLS and protection of berried females) and the NSL catch (taken without reference to those rules). Five types of catch were considered when collating SL and NSL catch totals by season.

3.2.1 Reported commercial catch

From 1945 through 1978, reported annual commercial catches were obtained from Breen & Kendrick (1998), who compiled them from published sources. Beginning with 1 January 1979, catches were taken from data compiled by the Fisheries Statistics Unit (FSU) and held by the Ministry of Fisheries. Three months of catch from 1 January 1979 through 31 March 1979 were added to the annual catch for 1978 to effect the change from calendar year to fishing year. From 1 April 1979 through 31 March 1986, catch totals from the FSU were used to calculate catch by fishing year. Beginning 1 April 1986, catch totals by fishing year were obtained from Quota Management Returns (QMRs) maintained by the Ministry of Fisheries. QMR catches were not available by QMA for the 1986–87 and 1987–88 fishing years; catch proportions from each by QMA from the FSU catch data for those fishing years were used to apportion the total New Zealand QMR catches into QMA totals. These catches were all assigned to the SL catch category, C^{SL}.

To divide commercial catch data into seasonal periods for each area from 1 April 1979 to the present, we applied the seasonal proportions from the FSU and Catch Effort Landing Returns data (CELR: held by the Ministry of Fisheries) to the reported catches by fishing year. For 1973 through 1978 the seasonal catch data were not available, and the mean seasonal proportions from 1 April 1971 through 31 March 1973 and 1 April 1979 through 31 March 1982 were applied. Monthly catch data from 1 January 1963 through 31 December 1973 were available for CRA 4 and CRA 5. These data were summarised by year by Annala & King (1983) and used to calculate seasonal proportions for 1 April

1963 through 31 March 1973. For the pre-1963 seasonal proportions, the mean seasonal proportions for 1 April 1963 through 31 March 1966 were applied.

The commercial catch trajectory is shown in Figure 1 for CRA 4 and CRA 5.

3.2.2 Recreational catch

Recreational catch estimates are available from 1994 and 1996 (see Teirney et al. 1997). More recent estimates have not been accepted. As in previous assessments, the RLFAWG agreed to assume that the 1945 recreational catches were 20% of the 1979 catch. For the years 1979 through 2002, except for 1994 and 1996, recreational catch was estimated as proportional to the standardised CPUE. The average of 1994 and 1996 CPUE and the average of 1994 and 1996 recreational catch estimates were used to estimate each year's recreational catch from 1979 through 2002. It was assumed that recreational catch increased at a constant rate between 1945 and 1979.

For 1994 and 1996, recreational catch was estimated as numbers. These were converted to weight by using the best estimate of mean weight available at the time of the survey, obtained from catch sampling data. The values used for each area are shown in Table 2. Ninety percent of the recreational catch was assumed to be taken in the spring-summer (SS) season and 10% in the autumn-winter (AW). These catches were assigned to SL catch category, C^{SL}.

The assumed recreational catch trajectory is shown in Figure 2 for CRA 4 and CRA 5.

3.2.3 Maori customary catch

In the absence of estimates from MFish, the assessment team agreed to use a constant catch of 10 t for the traditional catch in both CRA 4 and CRA 5. As for recreational catch, 90% of the traditional catch was assumed to be taken in the spring-summer (SS) season and 10% in the autumn-winter (AW). These catches were assigned to NSL catch category, C^{NSL}.

3.2.4 Illegal catch

The illegal catch estimates were based on a belief that a large amount of unreported catch was taken before the introduction of lobsters to the QMS. Anecdotal evidence suggests there were a lot of cash sales and unaccounted exports of lobster. This is believed to have reduced after the change to tail width MLS and the introduction of lobsters to the QMS; current illegal fishing is believed to be mostly poaching by fish thieves.

We calculated the mean ratio of export discrepancies to the reported catch for period 1974 through 1980 (Breen 1991). This ratio is the best estimate of the non-reporting behaviour. We apply this ratio to the reported commercial catch for the period 1945 through 1989. This is the only estimate of illegal catch for this period - MFish Compliance estimates for 1979 and 1987 are of uncertain provenance.

For the years 1990 onwards, Ministry of Fisheries Compliance staff have supplied estimated illegal catches by areas at various times (Table 3). Beginning with 1990, illegal estimates were based on the MFish Compliance estimates. Illegal catch estimates for years without Compliance estimates were interpolated as in previous assessments.

Two Compliance estimates of "commercial reported" illegal catch were used to split the illegal catch into reported and unreported illegal catches. The reported illegal catch was less than 10%. We applied this percentage back to the whole series of illegal catch estimates.

Illegal catches were divided between seasons in the same proportion as the commercial catch for each year. The reported and unreported illegal catches were both assigned to the NSL catch category, C^{NSL}, and the reported illegal catches were subtracted from the SL catch category, C^{SL}.

The RLFAWG members have very little confidence in the estimates of illegal catch. The estimates cannot be verified and have an associated low level of confidence.

The assumed reported and unreported illegal catch trajectory is shown in Figure 3 and Figure 4 for CRA 4 and CRA 5 respectively.

The SL and NSL catch data by season provided to the model are shown in Tables B1 and Table B3 in Appendix B for CRA 4 and CRA 5 respectively; also in Figure 5 and Figure 6. During the first few years' SS season, there were no NSL catches in both fisheries because there was no size limit at that time (but in the AW season, mature females cannot legally be taken).

3.3 Regulation history

3.3.1 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, unpub. data). Values used are shown in Table 4.

3.3.2 MLS regulation history

Annala (1983) provided an overall 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; MLSs by period, as used by the model, are shown in Appendix B.

3.3.3 Escape gaps

Before June 1970, escape gaps were not required (Annala 1983). Street (1973) discussed the introduction of escape gaps, but concluded, on the basis of limited sampling, that they were not effective. Escape gap size from June 1970 was set at 54 x 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.

3.3.4 Prohibition on taking berried females

From 1945 to the present, taking of 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.

3.4 Biomass indices

CPUE for the commercial fishery, in kg per pot-lift, is used as an index of biomass available to the commercial fishery. Two sources of catch and effort data were available for CRA 4 and CRA 5: catch and the number of potlifts from the FSU and CELR data bases held by the Ministry of Fisheries, and catch and the number of days fished from historical monthly data held by NIWA.

3.4.1 FSU and CELR data

For CRA 4, standardised abundance indices were estimated from catch per potlift from statistical areas 912 through 915 plus 934 in the FSU and CELR databases. For CRA 5, areas 916 through 919 were used. The different CPUE trends in CRA 4 and CRA 5 in recent years led us to make separate stock assessments for these two areas. Relative indices of catch rates are generated for each period by standardising for month and statistical area (Maunder & Starr 1995, Breen & Kendrick 1998).

The abundance indices were made relative to the first period in the series and the months which define each season were treated independently. The month with the lowest standard deviation in each season was selected as the base month. The coefficients for the categorical variables (including the abundance indices) are presented as "canonical" indices to remove the dependence on the reference coefficient (Francis 1999), with each coefficient calculated relative to the geometric mean ($\bar{y}$) of the series. This procedure allows the calculation of a standard error for each coefficient, rather than the more usual procedure of leaving the base coefficient with no standard error and apportioning the error associated with the base coefficient to the other indices.

These indices are shown in Appendix B and in Figure 7 and Figure 8.

3.4.2 Historical data

Monthly catch and effort (days fishing) data from 1963 to 1973 were summarised by Annala & King (1983). Monthly catch and effort data from this data set were used to calculate catch per day for each season from 1 April 1963 to 31 March 1973 using the former statistical areas 6, 7, and 8 for CRA 4 and former areas 8, 13, 14, and 15 for CRA 5. These results are reported in Appendix B and in Figure 9.

3.4.3 Pre-recruit indices (PRI)

Data from the voluntary logbook and observer catch sampling data sets were summarised from each potlift to provide the number of lobsters below the relevant MLS. Berried females were treated as being above the size limit. Only data from 1993 and later were used, because the 1993 change in escape gap regulations made previous data difficult to compare with current data.

The standardisation model used depth (treated as a categorical variable in 20 m bins), statistical area of capture, month, season and year of capture as explanatory variables. The source of the data (logbook or catch sampling) was also offered to the model.

Two standardised regression analyses were performed on the pre-recruit numbers from the sampling data: a lognormal model, which regressed the logarithm of pre-recruit numbers against the five available explanatory variables, and a binomial (logit) model, which regressed the presence or absence of pre-recruits in the sample against the same five explanatory variables. This additional regression model was required because of the large number of potlifts with no pre-recruits. The two regressions were combined into a single standardised index using the method of Vignaux (1994). These results are reported in Appendix B and in Figure 10.

3.5 Proportions-at-size

3.5.1 Structure of length frequency data

Tail width size frequency (LF) data from research catch sampling and voluntary logbook programs were binned into 2 mm size classes from 30 to 92 mm. These limits spanned the size range of most lobsters caught in the catch, and 2 millimetre size classes were considered small enough to provide good resolution in the model. The voluntary logbook program measures lobsters with a precision of 1.0 mm while the research sampling precision is 0.1 mm. The measuring convention 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.

3.5.2 Recent LF data

Estimates of the proportions-at-size were obtained from data summarised for the research sampling and logbooks separately, aggregated in area x month cells. These were then combined into records containing all the data for a given sample type (observer or voluntary logbook) for 6-month periods (the AW or SS season). In combining the area x month cells, data were weighted by the relative proportion of the total seasonal commercial catch taken in each cell, the number of days sampled, and the number of lobsters measured. The weight given to each record was based on the sum of these weights.

3.5.3 Historical LF data

Some historical sampling data (from 1974 to 1984) were found for CRA 5 (K. George, NIWA, pers. comm.). Most of these sets were market sampling and one was catch sampling. No historical data were found from CRA 4. Measurements in carapace length were converted to tail width using sex- and area-specific regressions (*see* Table 4). For market samples, we discarded the data from the first size class above MLS to reduce the effect caused by morphological variation in carapace length vs tail width near the MLS.

3.6 Tag-recovery data

The main sources of tag-recovery data are the NZ RLIC tag recovery experiments (K. George, pers. comm.) and older sets of data in the historical database, for which measurements in carapace length were converted to tail width (*see* Table 4).

Tag recovery data were handled as follows.

- For the NZ RLIC tag recoveries, multiple recaptures were treated as separate and independent release and recovery events.
- Records were excluded if dates were missing, size at release or recapture was missing, or sex recorded at recapture was different from sex at release.
- Records were automatically excluded if the apparent increment was less than –10 mm, but records with smaller negative increments were retained, at least in preliminary runs.
- Recoveries made in the same period as the release were excluded. These may be useful in estimating the observation error of the growth increment, but this parameter is confounded with other estimated growth parameters, and preliminary trials made with only the tagging data suggested this parameter could be fixed.
- A series of preliminary fits were made, and records that produced large normalised residuals were examined and discarded, especially if large negative increments were involved.

A summary of the data by sex and source is shown in Table 6. Each recovery event was summarised in the data file by sex, release and recovery periods and release and recovery tail widths.

Because numbers of recaptures were small from CRA 4, after preliminary trials we used combined CRA 4 and CRA 5 data for the CRA 4 assessment, and used only CRA 5 data for the CRA 5 assessment.

The tag-recapture data used in the assessment is shown in Figure 11 and Figure 12 for males and females.

3.7 Parameter priors

For all parameters estimated, prior probability distributions ("priors") were assumed after discussions in the RLFAWG (Table 7). The basis for each prior that was set other than uniform is outlined below.

An informative prior placed on M was based on the presumption that M was reasonably well known from published studies of temperate lobsters. The standard deviation (0.4) was determined after inspecting the prior.

Recruitment deviations were given a normal prior with bounds that cause recruitment multipliers to remain in the range 0.10 to 10.0. The normal prior on recruitment deviations implies a lognormal distribution of recruitment. The mean for this prior was zero, with a c.v. of 0.4.

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

3.8 Other values

Structural and fixed values used in this assessment are shown in Table 8.

3.9 Development of a base case

For both areas, we started with relative weights, ϖ , of 1 for each dataset and looked at the standard deviations of normalised residuals (sdnr) for each dataset. We adjusted these relative weights for all data sets until we obtained sdnrs close to 1. For CRA 5 this approach gave a fit that was judged acceptable for all data sets, and this became the base case.

For CRA 4 this approach was unsuccessful. When sdnrs were forced to approach to 1, the fit to CPUE deteriorated, especially for the recent years, and the minimisation was unstable, reflected in non-positive definite Hessian matrices. A variety of experimental approaches failed to improve this. We abandoned the attempt to produce sdnrs close to 1, and adjusted the weights until we obtained an acceptable fit.

The weights used and sdnrs obtained are shown in Table 9. Other weights were used in an exploration of the sensitivity of this procedure. Increasing the weight on PRI had little effect on the fit, so we left the weight for this data set at a low value.

Some estimated parameters were fixed in the base case (Table 8) as follows.

We did not estimate χ, the exponent of the relation between CPUE and vulnerable biomass, but fixed it to 1 in the base case and tested this assumption in a sensitivity trial. Similarly, h, the parameter the shape of the growth curve, was fixed to 1 in the base case and tested in a sensitivity trial.

The standard deviation of growth observation error, $\sigma^{d,obs}$, was fixed near the value obtained when the model was fit to tagging data only. Preliminary trials showed this to be confounded with other growth parameters.

The second maturity parameter, m_{95-50}, was fixed at a value obtained when fitting to the proportion-at-length data only. This was done to stabilise the minimisation. The lobsters in this assessment tend to be largely mature by the time they appear in the data, so the model has little signal from which to estimate maturity.

Parameters describing the right-hand limb of the selectivity curves were fixed at values that gave a nearly flat right-hand limb. This was consistent with the approach taken in previous assessments. The consequences of fixing the right-hand limb were explored in sensitivity trials.

4. ASSESSMENT RESULTS

4.1 CRA 4

4.1.1 CRA 4 base case MPD estimates

4.1.1.1 Fits to data

Results of the base case MPD estimation are shown in the first column of Table 9. The fit to standardised CPUE is shown in Figure 13 and the residuals in Figure 14. The model fit reasonably well to the pattern of CPUE (Figure 13), but tended to overestimate SS CPUE before 1990. The model predicted a spike in CPUE in 1987 that does not appear in the data, and underestimated CPUE in the early 1990s in both seasons.

Historical catch rates were not fit tightly (Figure 15 and Figure 16), and again the model tended to overestimate the SS catch rate and underestimate the AW, leading to a seasonal pattern in the residuals. Fitting to pre-recruit indices was very poor (Figure 17 and Figure 18).

Fits to proportions-at-length (Figure 19) 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.

Residuals from the fits to proportion-at-length plotted in different ways are shown in Figure 20 through Figure 23. There were a few very large residuals for males and mature females, but most residuals were less than 2. When residuals are plotted against predicted proportions (Figure 20), 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 is shown in Figure 21, showing that the high residuals seen in Figure 20 occurred mainly around the MLS for both males and females. A box plot of residuals plotted against lobster size by season is shown in Figure 22. Large residuals tended to occur in both seasons for both sexes. Quantile-quantile (q-q) plots of residuals by sex are shown in Figure 23. In these q-q plots only, residuals between –0.05 and 0.05 have been omitted. These small residuals came from the many comparisons in which the observed and predicted proportions were zero or nearly so. The residuals for males and mature generally followed the theoretical residuals, but had more large residuals than predicted. For immature females, the q-q plots reflect the poor data.

Fits to the tag-recapture data were generally good (Figure 24), suggesting that tagging data were consistent with the proportions-at-length data. Figure 25 through Figure 30 shows residuals from fits to the tag-recapture in different forms. Figure 25 shows residuals by statistical area. Because we used CRA 4 and CRA 5 tag-recapture data for the CRA 4 assessment, this plot includes tag-recapture data from CRA 5 statistical areas. Areas 912 and 916 stand out as areas that contribute strongly to the variation for both males and females.

Residuals plotted by injury index are shown in Figure 26. For injury condition code 7, fits to the males and females were very different: the model underestimated male growth and overestimated female growth. Residuals by the number of re-releases are shown in Figure 27. For females there was little pattern. For males, growth for lobsters re-released many times tended to be over-estimated. Residuals plotted by the number of periods between release and recapture and by season of release are shown in Figure 28. The only consistent pattern was that, for summer releases, the model tended to over-estimate the growth of lobsters that remained at liberty for long periods.

Residuals plotted by initial size are shown in Figure 29. The pattern for males suggested that a curved growth relation might fit the data better; for females there was little pattern. Tag type (Figure 30) showed little effect.

4.1.1.2 Trajectories

Total biomass is compared with recruited biomass in Figure 31 for each sex. Total biomass is the biomass of all lobsters of all sizes, without regard for selectivity or vulnerability. Recruited biomass is the biomass of lobsters that are above the MLS, without regard for selectivity or vulnerability. Total biomass is much larger than recruited. Immature females showed a low contribution to biomass because of their relatively early maturation. Males, with their faster growth and larger size, had the greatest contribution to both biomass components. Recruited biomass showed a nadir in the early 1990s while total biomass showed a fluctuating pattern.

Vulnerable biomass (Figure 32) takes into account selectivity, vulnerability and the restrictions on berried females. It showed a pattern similar to that of recruited biomass, but with a nadir near 1992 and much higher biomass afterwards. Exploitation rate (Figure 33) peaked in the mid 1980s to early 1990s near 80%, a decline in the 1990s, and a switch to lower exploitation rate in the SS season in the mid 1990s.

Recruitment estimates (Figure 34) showed a spike in 1959 and numerous spikes and lows between 1978 and the present.

The initial length structure of the base case fit (Figure 35) showed most females maturing by 55 mm and a small plus-group for males. Figure 36 shows the base case maturation curve, the predicted growth increment at length is shown in Figure 37: males had a positive predicted increment at the largest model size while the female increment reached zero at 90 mm. The variability of growth was very high for both sexes. Estimated selectivity-at-size for males and females respectively are shown in Figure 38 and Figure 39. The size at 50% selectivity for females occurred at larger sizes than for males, reflecting the larger MLS and different morphology of females, and selectivity shifted to larger sizes for both sexes when escape gaps requirements were changed in 1993.

The trajectory of surplus production plotted against recruited biomass at the start of each year (Figure 40) indicates a wide range of production values from the lower end of the recruited biomass range.

4.1.2 Sensitivity trials with the CRA 4 base case

Various sensitivity trials, based on MPD results, were made to explore the effects of modelling choices made in selecting the base case (Table 9).

When the shape of the growth function was estimated, it changed from 1.0 to 5.61 and 2.62 for males and females respectively. The fit was improved and growth parameters were changed, but the effect on indicators was small except that estimated reference and current total biomass decreased. When the shape of the biomass-abundance relation was estimated, it changed from 1.0 to 0.723, indicating a slight hyperstability; the fit was improved somewhat but parameters and indicators changed little. Estimating both biomass and growth shape parameters gave a much better fit, most parameters and indicators were similar to the first trial, but current biomass was higher.

When the right-hand limb parameters of the selectivity curves were estimated, it became small for females (Table 9) (low selectivity) but went to its upper bound for males; i.e., the model wanted to the fishery to "see" all the males but wanted to allow cryptic females. Total and recruited current biomass increased as a result, but the effect on most indicators was minor.

Fitting with doubled weights for each of the data sets in turn also had generally small effects. Doubling CPUE and CR both increased M slightly. Results were most sensitive to doubling the weight on proportions-at-size. Many of the parameter estimates changed substantially, and projected biomass became more optimistic. Decreasing the assumed maximum exploitation from 0.9 to 0.7 had no major effect on any indicators.

The two alternative catch vectors, both of which assumed more recreational catch than in the base case, both gave more optimistic projections: 2008 biomass increased from 53% to 76% or more of current catch. This sensitivity is one of the most important results in these trials because of the uncertainty about true recreational catches.

These trials suggest the assessment is somewhat sensitive to the relative weightings for different data sets, and to the assumed non-commercial catches.

4.1.3 MPD retrospective analysis for CRA 4

Retrospective analyses were made by successively removing one year's CPUE and proportion-at length data back to 1998's data. Tag data were not removed. The parameter estimates and indicators are compared in Table 10. The retrospective vulnerable biomass estimates are shown in Figure 41, recruitment multipliers in Figure 42 and estimated CPUE in Figure 43.

These showed little effect of the various data sets on recruitment trajectories. Recruitment changed in the final few estimates when data were removed, essentially removing any signal about the level of recruitment. These results showed good retrospective stability from the model.

4.1.4 CRA 4 McMC simulations and Bayesian results

4.1.4.1 Fits to data

For CRA 4 we made one long (10 million simulations) McMC chain. The McMC chain was characterised by a startling jump in some parameters, especially ln($R0$) and M, that occurred around 7 million simulations (Figure 44). The function value did not change much during this shift. Before this jump, the chain appeared to be stable and diagnostics up to this point would have been good.

For diagnostics, we used tests by Heidelberger & Welsh (1983), Raftery & Lewis (1992), Geweke (1992) and the single chain Gelman test (see Brooks & Roberts 1998). These are single chain tests that examine for stationarity and convergence.

Most parameters, biomass and exploitation rates failed all these tests (Table 11). The indicators involving projected vulnerable biomass passed all the tests. When we compared the posteriors obtained from sections of the chains before and after the jump (Table 12), the jump was reflected in the summaries for many parameters. Some important estimates, however, did not change very much as a result of the jump. The mean of current vulnerable biomass changed from 640 t to 661 t; from 134% to 127% of reference biomass. Projected vulnerable biomass changed from a mean of 87% current biomass to 86%.

Some representative diagnostic plots are shown in Figure 45. For parameters affected by the jump, diagnostics such as the cumulative means and autocorrelation were very poor. For some of the indicators, however, these diagnostics were acceptable. The RLFAWG and Plenary agreed that the posteriors of indicators could be accepted. Clearly much longer runs are desirable, and runs should be started from different places. There was insufficient time to employ this approach for this assessment.

Posteriors distributions for the function value, some estimated and some derived parameters are shown in Figure 46. Some, especially ln(*R0*) and *M*, showed bimodality resulting from the shift in the McMC chain. In these and most others, the MPD estimate was in the centre of the posterior.

The posterior for *M* contained the MPD between its two disjunct modes (Figure 47), and was distinctly different from the prior, indicating that the data contained some information about *M*.

Summaries of the posterior distributions of fits to CPUE and posteriors of the residuals of the fits are shown in Figure 48 and Figure 49 respectively. The fit was generally good, but the discrepancies noted in the MPD persist in the McMC results: for some years the predicted CPUE never matched the observed, thus the consistent pattern in the residuals. Posterior fit to the catch rate data and residuals of the fit showed the same phenomenon (Figure 50 and Figure 51). Based on the poor fit to the pre-recruit index data (Figure 52 and Figure 53) and after exploratory work, the decision was made to give this data set a low weight. The posterior fit to the 2002 autumn-winter catch sampling proportion-at-length data is shown in Figure 54 and the posteriors of residuals in Figure 55. These figures suggest that the relative weight given to length frequency data was high.

4.1.4.2 Trajectories

Posterior trajectories are shown in Figure 56, Figure 57, and Figure 58 for total, recruited and vulnerable biomass respectively. Trajectories for SL and NSL exploitation rates (Figure 59 and Figure 60) differed from each other (NSL are much lower) and between seasons (higher in AW in recent years). Because exploitation rate was constrained by the upper bound in SS in 1989 and 1991 in nearly all runs (Figure 60), the uncertainty in vulnerable biomass became very small for these years (Figure 58). Projections diverged strongly with increasing time. Projected exploitation rates under the 2002 catch levels sometimes exceeded the assumed maximum of 90% in the AW season, suggesting that the projected catches might not always be caught.

The posterior trajectory of recruitment deviations (Figure 61) showed that, although most deviations were close to average, some were consistently high or low in the McMC chain, suggesting that the data contained strong recruitment signals for the model. The posterior trajectory of surplus production (Figure 62) showed large uncertainty in the early years, but very tight distributions since the mid 1980s. This trajectory also was constrained by the high exploitation rates near 1990.

4.1.5 Summary of the CRA 4 assessment

Posteriors were summarised by calculating the mean, median, and 5th and 95th percentiles (Table 13). Most parameters were reasonably tightly estimated: exceptions are ln(*R0*), *M* and m_{50}, the last because there are few data with a maturity signal; the proportions of observed immature females are small. Two of the seasonal vulnerability parameters are jammed against the upper bound, leading to the bad traces seen in Figure 44. Current estimated vulnerable biomass had a median of 742 t and varied (5th to 95th percentiles) from 659 to 836 t. This had a median of 132% of the reference level (116 – 148%). Projections were very uncertain: vulnerable biomass after five years varied from 29.5% to

191.5% of current levels. The median was 71% of current biomass, and 69% of the runs showed a decrease in the projections.

4.1.6 Additional projections

The NRLMG requested additional projections made with alternative catches for CRA 4. The base case assumed that all catch components would remain at their 2002 levels. The NRLMG requested that alternative catch projections be constructed with commercial and recreational catches decreasing by 10%, 20%, and 30%, with the other two catch components remaining the same. The resulting catches are shown in Table 14.

The NRLMG requested output for each year of the projections, and focused on 2006 as the last projected year to consider, because of the large variation in subsequent years. Average projected biomass, with current catch levels, declined through 2006 and then increased again (Table 15 and Table 16).

The percentage of runs in which biomass became less than *Bref* (Table 15) was 60% at the current levels of catch, 50% after a 10% catch reduction as described, and fell to 23% with a 30% catch reduction. The median of biomass divided by *Bref* (Table 16) in 2006 was 87% with the current catch level, rising to 100% with a 10% catch reduction and to higher levels with greater reductions. Thus, with a 10% reduction in catch, biomass has a median expectation of being at *Bref* in 2006.

In all sets of runs through 2006, the chance of falling below *Bmin* was less than 5% (Table 17).

4.2 CRA 5

4.2.1 CRA 5 base case MPD estimates

4.2.1.1 Fits to data

Results of the base case MPD estimation are shown in the first column of Table 18. The fit to standardised CPUE is shown in Figure 63 and the residuals in Figure 64. There were small difficulties with the fit to CPUE: the model fit reasonably well to the general pattern of observed CPUE, but tended to underestimate AW CPUE in the late 1980s and 1999–2002, creating trends in the residuals (Figure 64).

As for CRA 4, historical catch rates were not fit tightly (Figure 65) and residuals for the AW showed a trend (Figure 66). Fitting to the pre-recruit indices fitting was poor (Figure 67 and Figure 68).

Fits to proportions-at-length (Figure 69) were variable, and were especially poor for the early market and catch sampling data. For the data obtained after formal catch sampling began in 1989, the fits improved and were generally good for data sets with high weights. Low weights reflect the small sample sizes and poor representativeness of some data records. As in CRA 4, the observed proportions of immature females were small and this group was not fitted well. Residuals from the fits to proportion-at-length plotted in different ways are shown in Figure 70 through Figure 73. There were a few large residuals for males and mature females. The residuals plotted against the predicted proportions-at-length showed a tendency to increase with increasing proportion because of the assumed likelihood function (Figure 70). Box plots of residuals against size for each sex show that most problems occurred near the MLS (Figure 71). Residual q-q plots by sex show, as in CRA 4, more large and small residuals than predicted, and poor fits to immature females (Figure 72). In these plots only, residuals between –0.05 and 0.05 were not been included in the q-q plots because of the large number of zero observations.

Box plots of residuals against size by season for each sex are shown in Figure 73. Very large residuals in both males and females tended to occur in SS.

Fits to the tag-recapture data were generally good (Figure 74), suggesting that tagging data were consistent with the proportions-at-length data. The residuals by area, tag type, injury code etc. were already examined in the CRA 4 results, which were based on both CRA 4 and CRA 5 tags, so these are not repeated here.

4.2.1.2 Trajectories

Seasonal recruited and total biomass trajectories are shown in Figure 75 for each sex. Immature females showed a zero contribution to recruited biomass because of their relatively early maturation. Males, with their faster growth and larger size, had the greatest contribution.

Vulnerable biomass (Figure 76) showed a nadir in the mid 1990s followed by a continuing strong increase. Exploitation rate (Figure 77) peaked in the mid 1980s near 90% in the SS, followed by steep declines. The season of higher exploitation rate switched from SS to AW in 1996.

Recruitment estimates were similar to those described for CRA 4, and are plotted with the CRA 4 base case recruitments in Figure 78. For several years the two areas showed the same recruitment spike, and for several years there is a one-year lag between spikes for both areas. These data are independent except for tag-recapture data, suggesting that a strong recruitment signal was common to the data from these two areas.

Initial length structure of the base case is shown in Figure 79. This showed similar patterns for males and females in the initial population, except for a large plus-group for males above 90 mm. This is quite different from CRA 4 (Figure 35) probably because estimated M in CRA 4 is higher. The base case maturation curve is shown in Figure 80. Growth increments were similar to those from CRA 4 (Figure 81), with large males continuing to grow past 90 mm and females showing a zero predicted increment at 90 mm. Selectivity curves (Figure 82 and Figure 83) showed the same differences noted for CRA 4, but with more pronounced differences between the pre-1993 and 1993 curves. The surplus production trajectory plotted against recruited biomass (Figure 84) showed a variety of production values for low biomass.

4.2.2 Sensitivity trials with the CRA 5 base case

Various sensitivity trials, based on MPD results, were made with the base case (Table 18).

When the shape of the growth model was estimated, it changed from 1.0 to 6.65 and 9.92 for males and females respectively, growth parameters changed, the fits to both tag and proportions-at-size data was improved substantially (164 units overall) and projected biomass was decreased by half. Other indicators were not strongly changed. The growth curves described by these parameters (Figure 85) show less variability than in the base case (*see* Figure 81); both have long flat sections and both show increasing increments at large sizes. These were considered unrealistic and thus were not used as the base case despite the better fits.

When the shape of the biomass-abundance relation was estimated, it changed from 1.0 to 0.887, indicating a very slight hyperstability, the fit improved by 3 units, but nothing else changed much. When both shapes were estimated, the fit improved by 186 units and other estimates were similar to those in the first trial.

When the right-hand limb parameters of the selectivity curves were estimated (Table 18), the parameter became small for males (low selectivity at large size), but went to its upper bound for females, i.e., the converse situation from CRA 4. The model wanted the fishery to "see" all the females but wanted to allow cryptic males. Total and recruited current biomass increased as a result, but the effect on most indicators was minor.

Fitting with doubled weights for each of the data sets in turn (Table 18) also had generally small effects. Doubling weight for CPUE and CR changed *M* slightly. The indicators involving current biomass were most sensitive to doubling the weight on proportions-at-size, which caused the assessment to become slightly less optimistic.

Decreasing the assumed maximum exploitation from 0.9 to 0.7 had a large effect on projected biomass and the relation between current biomass and reference biomass: both became less.

The two alternative catch vectors, both of which assumed more recreational catch than in the base case, gave different results. The first improved the ratio of projected to current biomass; the second degraded it. This underscores the importance of the historical trends in catches as well as their current values. This sensitivity was one of the most important results in these trials because of the uncertainty about true recreational catches.

These trials suggested that the assessment is largely insensitive to the relative weightings for different data sets, sensitive to assumed maximum exploitation rate and sensitive to the assumed non-commercial catches.

4.2.3 MPD retrospective analysis for CRA 5

Estimates from retrospective analyses are compared in Table 19. Parameter estimates were stable except for ln(*R0*) and *M*, which tended to decrease as data were removed. The last recruitment spike disappeared as data were removed (Figure 87), but earlier spikes were amplified. Biomass trajectories showed no change (Figure 86). CPUE trajectories (Figure 88) showed a trend in which removing one year of data caused recent CPUE to decrease. This is opposite to the pattern seen in CRA 3 in 2001 (Breen et al. 2002).

These were relatively stable retrospectives overall.

4.2.4 CRA 5 McMC simulations and Bayesian results

4.2.4.1 Fits to data

For CRA 5 we made a single short (2 million simulations) McMC chain started from the MPD. Ten thousand samples were saved. Traces of some parameters and indicators from these nine thousand samples are shown in Figure 89. Figure 90 shows some diagnostic plots for representative parameters. Posteriors for the function value, some estimated and some derived parameters are shown in Figure 91. MPD values lie in the centres of most of these posteriors.

The likelihood profile of *M* compared with its posterior and prior distribution is shown in Figure 92. The posterior and the prior distributions do not overlap and the posterior distribution has higher *M* values.

Based on diagnostics done on the whole set of samples, we discarded the first 1000 samples. Diagnostic tests described for CRA 4, performed on the remaining 9000 samples, showed (Table 20) that most parameters and sdnrs failed at least two tests. Some indicators did better: for instance, reference, current and projected vulnerable biomass, and their ratios, passed all tests. On the strength of this, the RLFAWG accepted the assessment.

The posterior fit to the CPUE and residuals of the fit is shown in Figure 93 and Figure 94 respectively. The fit was generally good, but the discrepancies noted in the MPD persisted in the McMC results: for some years the predicted CPUE never matched the observed, thus the consistent pattern in the residuals. The posterior fit to the catch rate data and residuals of the fit showed the same phenomenon (Figure 95 and Figure 96). The poor fit to the pre-recruit index data is shown in Figure 97 and Figure 98. The posterior fit to the 1999 autumn-winter catch sampling proportion-at-length data is shown in Figure 99 and the residuals in Figure 100. These figures suggest that the relative weight given to length frequency data was high.

4.2.4.2 Trajectories

Posterior biomass trajectories (Figure 101, Figure 102 and Figure 103) were all similar in form and showed much less variation than in CRA 4. Vulnerable biomass in the mid 1980s showed very little variation because the exploitation rate in the mid 1980s reached the upper bound (Figure 104). Projections showed steeply increasing variation with increasing length.

Trajectories for SL and NSL exploitation rates differed from each other and between seasons (Figure 104 and Figure 105). Exploitation rate peaked in the mid 1980s in the SS and then declined, the recent AW rates (near 35%) were higher than the SS rates (near 10%). NSL rates were much lower than the SL rates.

The trajectories of recruitment posteriors (Figure 106) showed some structure (particular years had consistently high or low recruitment), and later recruitment was estimated with less certainty than the earlier years. This was probably a result of the fewer data on recent recruitments for the model to use. The posterior trajectory of surplus production (Figure 107) showed large uncertainty in early years and a narrow range around 1990 that was related to the peak in exploitation rate. Generally surplus production was similar to the CRA 5 catch history.

4.2.5 Summary of the CRA 5 assessment

Posteriors were summarised by calculating the mean, median, and 5th and 95th percentiles (Table 21). Most parameters were reasonably tightly estimated except $\ln(R0)$ and some of the seasonal vulnerability parameters. Current vulnerable biomass had a median of 1102 t and varied (5th to 95th percentiles) from 966 to 1261 t. This was a median of 198% of the reference level (177 – 221%). Projections were uncertain: vulnerable biomass after five years varied from 45% to 149% of current levels. The median was 84% of current biomass, and 69% of the runs showed a decrease in the projections.

5. DISCUSSION

5.1 Model behaviour

Changes to the model for the 2003 assessment were relatively minor except for the change in growth model and the change allowing maximum vulnerability to be in either season and for either sex. The previous assumption that this would be for males in the SS was apparently flawed, because trials in this assessment indicated that females in the SS should have the maximum. For CRA 4 this was less stable than for CRA 5: the model estimated relative vulnerabilities to be less than 1 for other sex/season combinations when females in the SS were set to 1; for CRA 4 some other relative vulnerabilities were always 1.

The additional shape parameter for growth might allow the tag and size data to be fitted better. Sensitivity trials certainly obtained better fits when this parameter was estimated for each sex, but the shapes of the growth curves were considered suspect. The tag-recapture data have few very large lobsters, so the model can fit an increasing predicted increment to these; it is difficult to see how the growth increment could increase with increasing size. Because growth of large animals may affect biomass at higher population sizes and rates of biomass increase under low exploitation rates, we thought it best to fix the shape parameter for the base case. This exercise indicates there is a need for more tag-recapture data from larger animals.

The model did not fit the pre-recruit indices well for either area. It may be that insufficient information is contained in the index, given the steep left-hand limb of the selectivity curves for both sexes, or it may be that more exploratory fitting is required to diagnose a problem.

A few very large residuals were seen in the fits to proportions-at-size, and many residuals were near zero because of the structure of the observed data. There is a good case for exploring robust likelihoods for these data in future assessments.

The model generally behaved well in comparison with other recent assessments, especially the CRA 3 assessment for 2001 (Breen et al. 2002). Unlike that assessment, we were not forced to fix one of the selectivity parameters. A minor problem was that the low numbers of immature females gave poor estimates of the maturity parameter $m_{95\text{-}50}$, which we fixed. For CRA 4 but not CRA 5, the model exhibited minimisation difficulties when we attempted to balance the sdnrs, and some sensitivity trials had deformed Hessians. The McMC behaviour from CRA 4 was not good, although the main assessment results appear insensitive to the problems we observed. Some traces for seasonal vulnerabilities were "tight", probably because the MPD estimate was at the upper bound, so the estimated standard error was small, resulting in a too-small step size used in the McMC. This did not appear to be a problem: examination of the relation between this parameter and other estimates found no relation.

The McMC from CRA 5 fared badly in the diagnostic tests, but a longer chain or multiple chains may have corrected this.

5.2 CRA 4 assessment

The model fit reasonably well to the CRA 4 data set in the base case, except for the pre-recruit index. Growth parameters were close to the values estimated from tagging data alone. Recruitment showed much variability, and was closely related to recruitment in CRA 5.

Sensitivity of the MPD fit to a variety of trials showed some sensitivity to the relative weight on proportions-at-size. Changing the relative weights for individual records in exploratory trials, in an attempt to reduce the influence of the very large residuals, also changed model results and minimisation behaviour. It is hoped that robust estimators will reduce this problem in future assessments.

The retrospective trials, based on MPD fits, showed good stability, with little sensitivity to the recent data.

The McMC results of the assessment suggested that the current vulnerable biomass at the beginning of AW was 742 t (median of the posterior) with 5th and 95th percentiles 659 to 1457 t. Current exploitation rate was estimated to be 62% (55–70%). The current biomass was estimated at 132% of that in the reference period (116–148%).

Under the assumptions of the projections – current catches, current seasonal distribution of catches and recruitment with the same pattern as the past decade of estimated values – projected biomass is likely to decrease over the next five years (69%), but inspection of individual years shows that many runs decrease to 2006 and then increase. Given the increasing uncertainty seen in the projected biomass trajectories with time, the projections should not be used past three years, or 2006. Such projections suggest a median 14% decrease by 2006, and a 60% chance of being less than *Bref*, although a very small risk of being below *Bmin*. Tables were presented to the NRLMG showing the behaviour of projections under alternative reduced catches.

These results thus suggest a stock in reasonably healthy current state, but one likely to decline in the near future. The decline in projections was modest, and 40% of runs were still at or above *Bref*. A 10% catch reduction would be required to bring this probability up to 50%.

The non-commercial catch estimates are a major source of uncertainty for this assessment. MPD sensitivity trials showed that alternative recreational catch vectors affected the direction of projections. The assessment used 1994 – 96 values for recreational catches because newer values have not yet been accepted by MFish. In addition, the RLFAWG has little confidence in the estimates of illegal catches.

These results suggest that current catch levels are not sustainable, in that they cause, on average, decreases in future biomass levels. There is much variability in projections, however. The risk of falling below *Bmin* is very small.

5.3 CRA 5 assessment

The model fit more comfortably to the data for CRA 5 than for CRA 4: the base case was chosen from iterative re-weighting, minimisations usually led to good Hessians, and McMC behaviour was good. Choice of maximum exploitation rate and recreational catch vector were the main sensitivities identified in the MPD trials.

Retrospective trials showed low sensitivity of model estimates to removal of data.

McMC results suggested that the current vulnerable biomass at the beginning of AW was 1102 t (966–1261 t). This was 198% (177–221%) of the reference period biomass. Current exploitation rate is estimated to be 29% (26–34%).

Under the assumptions of the projections, the model suggested that vulnerable biomass in 2008 would decrease to 84% of the current level, but with high uncertainty (45–139%). The projected biomass would be at a median of 167% of *Bref* (86-283%).

These results suggest a fishery in a very healthy current state. Current catch levels are technically unsustainable in that they will, on average, decrease population size in projections, but the extent of decrease should leave the stock well above *Bref*. As well as the uncertainties discussed above, it is a major source of uncertainty that current levels and historical patterns of non-commercial catch levels are poorly determined.

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Table 1: Data types and sources for the 2003 assessments for CRA 4 and CRA 5. Year labels apply to the first 9 months of each fishing year, viz 1998-99 is called 1998. MFish - NZ Ministry of Fisheries; RLIC – Rock Lobster Industry Council.

Data type	Data source	Start year	End year
Historical catch rate	Annala & King (1983)	1963	1973
CPUE	FSU & CELR	1979	2002
Pre-recruit index	MFish and RLIC	1993	2002
Historical proportions-at-size	Various	1974	1984
Observer proportions-at-size	MFish	1990	2002
Logbook proportions-at-size	RLIC	1993	2002
Historical tag recovery data	MFish	1975	1986
Current tag recovery data	RLIC & MFish	1996	2002
Historical MLS regulations	Annala (1983)	1945	2002
Escape gap regulation changes	Annala (1983)	1945	2002

Table 2: Recreational catch estimates used in the assessments.

	CRA 4	CRA 5
1994	65 000	67 000
1996	118 000	41 000
1994 – 96 Mean numbers	91 500	54 000
1994 – 96 Mean weight (kg)	0.510	0.563
1994 – 96 Catch in kg	46 694	30 417
1996 Catch in kg	60 218	23 094
multiplier	2.78	2.78

Table 3: MFish estimates of illegal catches (t) for the 2003 assessment for CRA 4 and CRA 5. For the years not listed, the assessment interpolated annual estimates linearly.

Year	CRA 4	CRA 5
1990	160	178
1992	30	180
1994	70	70
1995	64	70
1996	75	37
2000	64	40
2002	60	52

Table 4: Parameter estimates for lobster size conversions. Conversion factors for total length to tail length (in inches) are taken from Sorensen (1970). Other conversion factors apply to mm measurements and are taken from the study described by Breen et al. (1988).

	Male		Female	
	Slope	Intercept	Slope	Intercept
Total length (in.) to tail length (in.)	0.571	0.196	0.604	-0.032
Carapace length (mm) to tail width (mm) CRA 4	0.536	-0.15	0.762	-12.53
Carapace length (mm) to tail width (mm) CRA 5	0.509	2.15	0.814	-16.04

Table 5: Summary of historical minimum size limit regulations for CRA 4 and 5. Regulation changes to 1959 are taken from Annala (1983); changes from 1988 to 1990 are summarised from Table 1 of Booth et al. (1994). Regulations are expressed in inches (designated as ") or mm. Equivalent measurements in mm tail width were made using the conversion factors in 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: Summary of the number and sources of tag recoveries from CRA 4 and CRA 5 used in the assessments. Both CRA 4 and 5 data combined were used for CRA 4 assessment; for CRA 5 assessment, only CRA 5 data were used.

	CRA 4	CRA 5	Total
Male	725	2 451	3 176
Female	308	1 186	1 494
Total	1 033	3 637	4 660

Table 7: Parameters estimated in the model, their upper and lower bounds, prior distributions and initial values. 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. Negative phases indicate fixed values. Prior types: U, uniform; N, normal; L, lognormal. For definitions of parameters see Appendix A. Phases are shown for CRA 4 and were slightly different for CRA 5.

	Phase	Lower bound	Upper bound	Prior type	Mean	c.v.
$\ln(R_0)$	1	1	25	U	-	-
$\tilde{\sigma}$	2	0.01	20	U	-	-
ε_y	3	-2.3	2.3	N	0	0.4
M	1	0.01	0.35	L	0.12	0.4
$\ln(q^I)$	1	-25	0	U	-	-
$\ln(q^{CR})$	1	-25	0	U	-	-
$\ln(q^{PRI})$	1	-25	0	U	-	-
d_{50}^g	2	1	8	U	-	-
d_{80}^g	2	-10	3	U	-	-
$CV^{g,j}$	3	0.01	2	U	-	-
m_{50}	4	30	80	U	-	-
r_k^g	2	0.01	1	U	-	-
$v_1^{male,l}$ and $v_2^{male,l}$	3	10	80	N	54	2
$v_1^{female,l}$ and $v_2^{female,l}$	3	10	80	N	60	2
η_1^g and η_2^g	2	1	50	U	-	-

Table 8: Structural and fixed values used in the base case assessments. 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	Standard deviation 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 except in sensitivity trial
	Handling mortality rate multiplier on SL fishery exploitation rate	0.1
σ_t^{CR}	Std. dev. of historical catch rates	0.3
σ_t^{PRI}	Std. dev. of pre-recruit indices	0.3
$\sigma^{d,obs}$	Std. dev. of increment observation error	0.5
χ	Shape of biomass - CPUE relation	1
m_{95-50}	Difference between sizes at 50% and 95% probability of maturing	20.00 (CRA 4) 18.35 (CRA 5)
h	Shape parameter of the growth model,	1
$\varphi^{j,\min}$	Minimum observation error in increment	1
$\sigma^{j,obs}$	Standard deviation of observation error	0.5
$S_{g,t=1945}^{MLS}$	MLS, 1945-49	0
$S_{g,t=1950}^{MLS}$	MLS, 1950-51 (tail width)	Male 47 mm, female 49 mm
$S_{g,t=1952}^{MLS}$	MLS, 1952-58	Male 51 mm, female 53 mm
$S_{g,t=1959}^{MLS}$	MLS, 1959-87	Male 53 mm, female 58 mm
$S_{g,t=1988}^{MLS}$	MLS, 1988-92	Male 54 mm, female 58 mm
$S_{g,t=1993}^{MLS}$	MLS, 1993-2008	Male 54 mm, female 60 mm

Table 9: Data weights, MPD parameter estimates, negative log likelihoods, sdnrs and performance indicators for CRA 4. LF: Size frequency data; VR: $w^{g,r}$ *estimated. Shading in the parameters indicates fixed values. BALL, BRECT, BVULN: total, recruited and vulnerable biomass respectively.* "pd" indicates positive, definite Hessian. The alt. 1 catch is sensitivity with recreational catch calculated as 1996 catch estimate times a scalar (2.78) and the alt. 2 catch is sensitivity with doubled recreational catch of the base case.

	Base case	Est. h	Est. χ	Est. h & χ	Est. w^g	Est. u_{95-50}	ϖ^I x2	ϖ^{CR} x2	ϖ^{PRI} x2	ϖ^P x2	ϖ^{TAG} x2	*Umax* 0.7	Alt. 1 catch	Alt. 2 catch
Hessian	pd	pd	pd	pd	pd	pd	pd	pd	not pd	not pd	pd	not pd	pd	not pd
$\ln(R_0)$	15.08	14.82	15.00	14.77	14.91	15.06	15.22	15.39	15.08	14.97	15.05	14.90	14.98	15.03
M	0.226	0.229	0.212	0.218	0.190	0.223	0.246	0.271	0.226	0.215	0.219	0.200	0.195	0.217
χ	1	1	0.723	0.704	1	1	1	1	1	1	1	1	1	1
$\tilde{\sigma}$	0.492	0.490	0.491	0.488	0.489	0.492	0.500	0.501	0.492	0.848	0.527	0.494	0.491	0.517
$\ln(q^I)$	-6.309	-6.347	-4.605	-4.516	-6.293	-6.303	-6.336	-6.412	-6.310	-6.321	-6.264	-6.309	-6.448	-6.404
$\ln(q^{CR})$	-2.950	-3.025	-3.114	-3.212	-3.376	-2.923	-2.880	-2.729	-2.948	-3.137	-2.913	-2.954	-3.172	-2.995
$\ln(q^{PRI})$	-13.10	-13.17	-13.13	-13.21	-13.15	-13.10	-13.07	-13.10	-13.92	-11.07	-12.87	-13.08	-13.20	-13.13
d_{50}^{male}	1.80	1.76	1.80	1.76	1.81	1.80	1.79	1.77	1.80	1.91	1.75	1.81	1.81	1.86
d_{50}^{female}	2.78	2.98	2.77	2.95	2.83	2.78	2.83	2.83	2.78	3.09	2.65	2.65	2.72	2.95
d_{80}^{male}	1.01	1.71	1.01	1.70	0.97	1.01	1.03	1.01	1.01	0.59	1.11	1.01	0.98	0.61
d_{80}^{female}	0.72	0.91	0.70	0.93	0.81	0.71	0.70	0.70	0.72	0.32	0.85	0.74	0.81	0.60
CV^{male}	0.769	0.768	0.768	0.767	0.766	0.769	0.763	0.761	0.769	0.537	0.913	0.765	0.769	0.551
CV^{female}	0.873	0.878	0.877	0.888	0.854	0.869	0.859	0.873	0.873	0.694	0.967	0.898	0.853	0.832
h^{male}	1	5.61	1	5.59	1	1	1	1	1	1	1	1	1	1
h^{female}	1	2.62	1	2.81	1	1	1	1	1	1	1	1	1	1
m_{50}	49.56	48.02	49.81	48.06	51.70	54.99	49.09	30.00	49.55	50.44	49.79	47.56	49.90	48.84
m_{95-50}	20	20	20	20	20	60.0	20	20	20	20	20	20	20	20
r_{AW}^{male}	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
r_{SS}^{male}	0.838	0.817	0.881	0.862	0.922	0.843	0.805	0.715	0.838	0.922	0.861	0.852	0.890	0.807
$r_{SS}^{female} = r_{SS}^{femmat}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
r_{AW}^{femmat}	0.586	0.583	0.556	0.553	0.537	0.582	0.616	0.683	0.586	0.515	0.579	0.585	0.555	0.605
$v_1^{male,l}$	53.2	53.2	53.2	53.2	53.2	53.2	53.1	53.1	53.2	53.2	53.2	53.1	53.1	53.1
$v_1^{female,l}$	61.3	61.3	61.4	61.5	60.7	61.2	61.2	61.5	61.3	60.8	61.3	63.5	61.4	61.2
$v_2^{male,l}$	55.0	55.0	55.0	54.9	55.0	55.0	55.0	54.8	55.0	54.8	55.4	55.0	54.9	54.7

Table 9 ***continued.***

	Base case	Est. h	Est. χ	Est. h & χ	Est. w^g	Est. $u_{95\text{-}50}$	ϖ^I x2	ϖ^{CR} x2	ϖ^{PRI} x2	ϖ^p x2	ϖ^{TAG} x2	*Umax* 0.7	Alt. 1 catch	Alt. 2 catch
$\nu_2^{female,l}$	63.0	63.0	62.9	63.0	63.2	62.9	63.1	63.1	63.0	62.8	63.0	63.0	63.2	63.0
η_1^{male}	3.38	3.46	3.41	3.49	3.39	3.38	3.34	3.32	3.38	3.49	3.37	3.32	3.44	3.42
η_1^{female}	6.12	6.36	6.23	6.52	5.90	6.01	6.00	5.89	6.12	6.18	6.04	7.48	6.25	6.12
η_2^{male}	3.45	3.47	3.44	3.44	3.46	3.45	3.41	3.30	3.45	3.42	3.61	3.48	3.47	3.40
η_2^{female}	5.03	5.17	5.04	5.19	5.40	5.01	5.01	4.89	5.03	5.29	4.95	5.00	5.18	5.16
w^{male}	200	200	200	200	250.0	200	200	200	200	200	200	200	200	200
w^{female}	200	200	200	200	5.8	200	200	200	200	200	200	200	200	200
f(CPUE)	-24.5	-23.7	-34.1	-35.1	-12.1	-24.8	-7.8	-25.9	-24.6	-5.5	-23.0	-22.3	-29.4	-23.7
f(CR)	100.1	94.9	115.2	110.2	92.5	101.0	89.9	98.2	100.0	95.0	100.7	101.1	112.7	93.9
f(PRI)	17.3	17.3	17.3	17.3	17.3	17.3	17.5	17.5	9.3	24.2	18.2	17.4	17.4	17.9
f(LFs)	-8 189.2	-8 206.1	-8 208.1	-8 224.9	-8 222.9	-8 193.5	-8 169.4	-8 135.8	-8 189.0	-8 131.4	-8 181.6	-8 180.6	-8 205.6	-8 183.8
f(tags)	9 914.3	9 887.0	9 913.9	9 885.3	9 915.7	9 914.0	9 918.5	9 921.3	9 914.4	10 206.0	9 941.1	9 912.4	9 910.8	9 973.2
f(Priors)	7.5	7.5	7.1	7.3	6.8	7.3	7.9	8.5	7.5	6.9	7.4	-1.0	7.0	7.2
f(Rdevs)	37.0	34.1	38.3	35.5	38.6	37.1	35.2	36.7	36.9	26.4	40.2	40.1	39.4	28.3
penalty(U)	2.8	2.4	3.2	2.7	1.9	2.9	2.4	3.8	2.8	2.1	2.4	3.9	2.9	2.3
f(total)	1 865.4	1 813.5	1 852.6	1 798.2	1 837.8	1 861.3	1 894.1	1 924.3	1 857.3	2 223.7	1 905.6	1 870.9	1 855.2	1 915.3
sdnr(CPUE)	1.007	1.030	0.788	0.767	1.243	1.001	1.751	0.960	1.006	0.847	0.971	1.049	0.902	0.975
sdnr(CR)	2.096	1.977	2.414	2.317	1.917	2.115	1.839	2.358	2.091	1.677	2.076	2.115	2.364	1.923
sdnr(PRI)	0.221	0.223	0.230	0.232	0.243	0.221	0.210	0.195	0.441	0.144	0.206	0.221	0.245	0.210
sdnr(tags)	0.977	0.979	0.978	0.981	0.978	0.978	0.975	0.979	0.977	0.824	1.034	0.977	0.980	1.062
sdnr(LFs)	1.015	1.016	1.013	1.013	1.012	1.015	1.006	1.013	1.015	1.168	0.948	1.015	1.012	0.968
$BALL_{79\text{-}88}$	7952	6018	7 652	5857	7441	7 893	8 376	9 090	7 956	6 937	8 079	7 577	8 467	7 446
$BRECT_{79\text{-}88}$	465	482	472	496	730	458	469	538	465	502	456	475	504	503
$BVULN_{79\text{-}88}$	553	570	544	559	532	553	564	640	554	561	539	555	607	594
$BALL_{03}$	6 984	5 364	6 994	5 659	7 112	6 901	7 203	7 777	6 992	6 915	6 660	6 677	6 971	6 987
$BRECT_{03}$	1 541	1 584	1 672	1 752	1 836	1 533	1 479	1 492	1 542	1 731	1 500	1 588	1 619	1 608
$BVULN_{03}$	731	741	781	808	712	727	715	773	732	758	718	755	752	756
$USL_{03\ AW}$ (%)	58.6	56.9	56.3	53.9	59.5	58.9	58.7	54	58.5	56.9	61	57.9	57	55.7
$USL_{03\ SS}$ (%)	18.4	17.9	16.6	15.8	18.5	18.5	19.5	20.4	18.4	15.6	18.9	17.8	23	22.4
$BVULN_{07}/BVULN_{03}$	56.7	50.9	56.3	50.2	67.7	56.5	53.2	49.2	56.7	78.4	50.7	50	76.1	80.7
$BVULN_{03}/BVULN_{79\text{-}}$	132.0	130.1	143.6	144.5	133.8	131.5	126.8	120.9	132.2	135.1	133.1	136	123.9	127.2

Table 10: Parameter estimates from CRA 4 MPD retrospective analysis. Years are named for the last year of data that were used. For definition of parameters *see* Appendix A.

Parameters	Base case	Retro01	Retro00	Retro99	Retro98
$\ln(R_0)$	15.08	15.07	15.06	15.06	15.04
M	0.226	0.225	0.220	0.223	0.224
$\tilde{\sigma}$	0.492	0.510	0.514	0.523	0.527
$\ln(q^I)$	-6.309	-6.273	-6.264	-6.246	-6.219
$\ln(q^{CR})$	-2.950	-2.958	-3.015	-2.987	-2.957
$\ln(q^{PRI})$	-13.10	-13.01	-13.06	-13.02	-12.97
d_{50}^{male}	1.80	1.80	1.79	1.79	1.79
d_{50}^{female}	2.78	2.80	2.79	2.78	2.76
d_{80}^{male}	1.01	0.98	0.98	0.97	0.95
d_{80}^{female}	0.72	0.72	0.75	0.74	0.74
$CV^{male,j}$	0.769	0.756	0.755	0.750	0.744
$CV^{female,j}$	0.873	0.852	0.851	0.848	0.855
m_{50}	49.56	49.63	49.70	49.29	49.19
r_{AW}^{male}	1.000	1.000	1.000	1.000	1.000
r_{SS}^{male}	0.838	0.846	0.859	0.864	0.876
r_{SS}^{female} or r_{SS}^{femmat}	1.000	1.000	1.000	1.000	1.000
r_{AW}^{femmat}	0.586	0.563	0.572	0.570	0.571
$v_1^{male,l}$	53.2	53.2	53.2	53.2	53.2
$v_1^{female,l}$	61.3	61.3	61.3	61.3	61.3
$v_2^{male,l}$	55.0	55.0	55.1	55.3	55.5
$v_2^{female,l}$	63.0	63.2	63.4	63.4	63.6
η_1^{male}	3.38	3.39	3.40	3.41	3.43
η_1^{female}	6.12	6.12	6.17	6.18	6.17
η_2^{male}	3.45	3.44	3.54	3.67	3.85
η_2^{female}	5.03	5.24	5.40	5.39	5.46
f(CPUE)	-24.5	-22.2	-21.4	-20.8	-20.1
f(CR)	100.1	101.0	104.8	103.6	104.1
f(PRI)	17.3	15.2	12.1	10.7	9.7
f(LFs)	-8 189.2	-7 243.8	-6 712.1	-6 200.0	-5 679.1
f(tags)	9 914.3	9 920.9	9 922.3	9 925.5	9 926.9
f(Priors)	7.5	7.6	7.7	7.9	8.0
f(Rdevs)	37.0	35.1	34.4	32.3	34.0
penalty(U)	2.8	2.4	2.4	2.1	1.8
f(total)	1 865.4	2 816.2	3 350.2	3 861.3	4 385.2
sdnr(CPUE)	1.007	1.016	1.022	1.022	1.040
sdnr(CR)	2.096	2.097	2.178	2.145	2.152
sdnr(PRI)	0.221	0.245	0.245	0.248	0.274
sdnr(tags)	0.977	0.975	0.973	0.971	0.971
sdnr(LFs)	1.015	1.021	1.023	1.028	1.030
$BALL_{79\text{-}88}$	7 952	7 928	7 849	7 932	7 961
$BRECT_{79\text{-}88}$	465	447	443	431	415
$BVULN_{79\text{-}88}$	553	540	532	527	518

Table 11: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from CRA 4 (* indicates the test failed).

Parameters	Mean	RL	Geweke	HW	Gelman
$\ln(R_0)$	14.96	•	*	*	*
M	0.217	*	*	*	•
$\tilde{\sigma}$	0.495	*	•	*	
d_{50}^{male}	1.80	*	*	*	*
d_{50}^{female}	2.73	•	*	•	•
d_{80}^{male}	0.97	*	*	*	*
d_{80}^{female}	0.74	*	*	*	*
$CV^{male,j}$	0.768	•	•	•	•
$CV^{female,j}$	0.890		•	•	*
m_{50}	46.26	*	•	•	*
r_{AW}^{male}	1.000	•	•	*	•
r_{SS}^{male}	0.839		*	*	•
r_{SS}^{female} or r_{SS}^{femmat}	0.999	*	*	*	*
r_{AW}^{femmat}	0.590	*	•	•	*
$v_1^{male,l}$	3.4	•		•	
$v_1^{female,l}$	6.2	*	•	*	•
$v_2^{male,l}$	3.4	*	*	*	*
$v_2^{female,l}$	5.0	*	*	*	
η_1^{male}	53.16	*	*	*	*
η_1^{female}	61.51	*	*	•	*
η_2^{male}	54.96		*	*	
η_2^{female}	62.97	*	•	•	
$USL_{03\ AW}$ (%)	62.2	•	*	*	*
$USL_{03\ SS}$ (%)	78.9				
$BALL_{79\text{-}88}$	7 851	•	*	*	*
$BRECT_{79\text{-}88}$	477		*	•	•
$BVULN_{79\text{-}88}$	565		•	*	*
$BALL_{03}$	7 217		•	*	*
$BRECT_{03}$	1 566	*		•	
$BVULN_{03}$	744	•	*	*	*
$BALL_{07}$	7 345		*	*	*
$BRECT_{07}$	1 216				
$BVULN_{07}$	646				
$BVULN_{03}/BVULN_{79\text{-}88}$ (%)	132		*	•	•
$BVULN_{07}/BVULN_{03}$ (%)	86.6				
$BVULN_{07}/BVULN_{79\text{-}88}$ (%)	114				
sdnrCPUE	1.079	*	*	*	*
sdnrCR	2.152	*	*	*	*
sdnrPRI	0.220	•	*	•	•
sdnrtags	0.975	•	*	*	
sdnrLFs	1.013	*	•	*	

Table 12: Summaries of the posterior distributions of parameters and indicators from sections the CRA 4 base case McMC before and after the jump described in the text.

	Before jump			After jump		
Parameters	5%	Mean	95%	5%	Mean	95%
f	1 893.3	1 903.4	1 914.3	1 895.0	1 905.7	1 916.0
$\ln(R_0)$	14.67	14.79	14.91	15.23	15.37	15.53
M	0.190	0.201	0.212	0.242	0.258	0.279
$\tilde{\sigma}$	0.485	0.495	0.505	0.487	0.496	0.505
d_{50}^{male}	1.784	1.817	1.848	1.731	1.762	1.793
d_{50}^{female}	2.594	2.677	2.762	2.773	2.857	2.938
d_{80}^{male}	0.813	0.934	1.058	0.957	1.066	1.172
d_{80}^{female}	0.645	0.762	0.880	0.556	0.671	0.789
$CV^{male,j}$	0.734	0.763	0.791	0.751	0.781	0.811
$CV^{female,j}$	0.852	0.902	0.956	0.815	0.860	0.906
m_{50}	44.30	49.24	51.85	30.83	38.85	48.41
r_{AW}^{male}	0.999	1.000	1.000	0.999	1.000	1.000
r_{SS}^{male}	0.824	0.852	0.880	0.778	0.808	0.836
r_{SS}^{female} or r_{SS}^{femmat}	0.999	1.000	1.000	0.999	0.999	0.999
r_{AW}^{femmat}	0.552	0.581	0.611	0.581	0.611	0.642
$v_1^{male,l}$	3.25	3.40	3.54	3.25	3.38	3.52
$v_1^{female,l}$	5.90	6.31	6.73	5.59	5.94	6.29
$v_2^{male,l}$	3.31	3.46	3.63	3.24	3.38	3.54
$v_2^{female,l}$	4.74	5.03	5.33	4.67	4.95	5.21
η_1^{male}	53.0	53.1	53.3	53.1	53.2	53.4
η_1^{female}	60.9	61.6	62.2	60.8	61.3	61.8
η_2^{male}	54.7	55.0	55.2	54.7	54.9	55.2
η_2^{female}	62.6	62.9	63.3	62.7	63.0	63.4
$BALL_{79\text{-}88}$	7 181	7 463	7 770	8 378	8 813	9 363
$BRECT_{79\text{-}88}$	410	449	492	497	545	595
$BVULN_{79\text{-}88}$	519	550	582	568	605	644
$BALL_{03}$	5 156	6 810	8 801	6 035	8 228	11 106
$BRECT_{03}$	1 441	1 561	1 678	1 453	1 578	1 721
$BVULN_{03}$	653	735	818	684	768	867
$BALL_{07}$	4 130	6 867	9 915	5 226	8 533	12 522
$BRECT_{07}$	545	1 212	2 362	517	1 224	2 426
$BVULN_{07}$	212	640	1 439	228	661	1 473
$UNSL_{03,AW}$ (%)	2.5	2.7	3.0	2.3	2.6	2.9
$USL_{03\,AW}$ (%)	56.3	62.9	70.4	53.2	60.2	67.1
$UNSL_{03\,SS}$ (%)	1.8	3.6	5.9	1.7	3.4	5.7
$USL_{03\,SS}$ (%)	36.4	79.2	99.2	35.6	78.1	99.1
$BVULN_{03}/BVULN_{79\text{-}88}$ (%)	118.7	133.8	149.4	112.5	127.1	142.3
$BVULN_{07}/BVULN_{03}$ (%)	29.3	86.9	191.8	30.1	85.8	189.5
$BVULN_{07}/BVULN_{79\text{-}88}$ (%)	38.7	116.5	262.4	38.3	109.3	243.9

Table 18. Data weights, MPD parameter estimates, negative log likelihoods and performance indicators for CRA 5. LF: Size frequency data; VR: $w^{g,r}$ estimated. Shading in the parameters indicates fixed values. *BALL*, *BRECT*, *BVULN*: total, recruited and vulnerable biomass respectively. The alt1 catch is sensitivity with recreational catch calculated as 1996 catch estimate times a scalar (2.78) and the alt2 catch is sensitivity with doubled recreational catch of the base case.

	Base case	Est. h	Est. χ	Est. h & χ	Est. w^g	Est. u_{95-50}	ϖ^I x2	ϖ^{CR} x2	ϖ^P x2	ϖ^{TAG} x2	*Umax* 0.7	Alt. 1 catch	Alt. 2 catch
Hessian	pd	pd	pd	pd	pd	pd	pd	pd	pd	pd	pd	pd	pd
$\ln(R_0)$	14.05	13.87	14.05	13.93	13.72	14.05	13.55	14.27	14.10	13.88	13.62	14.11	14.06
M	0.127	0.169	0.126	0.178	0.086	0.127	0.083	0.149	0.132	0.115	0.091	0.129	0.123
χ	1	1	0.887	0.716	1	1	1	1	1	1	1	1	1
$\tilde{\sigma}$	0.750	0.722	0.750	0.718	0.751	0.750	0.866	0.755	1.272	0.776	0.808	0.752	0.750
$\ln(q^I)$	-6.668	-6.613	-5.963	-4.877	-6.729	-6.668	-6.762	-6.669	-6.568	-6.630	-6.823	-6.723	-6.708
$\ln(q^{CR})$	-3.897	-3.304	-3.903	-3.351	-3.737	-3.897	-3.904	-3.802	-3.861	-3.856	-4.064	-3.963	-3.945
$\ln(q^{PRI})$	-13.43	-13.45	-13.45	-13.56	-13.48	-13.43	-13.41	-13.42	-12.48	-13.35	-13.46	-13.47	-13.48
d_{50}^{male}	1.89	1.97	1.89	1.98	1.91	1.89	2.05	1.88	1.90	1.86	1.90	1.89	1.88
d_{50}^{female}	3.35	3.03	3.37	3.08	3.23	3.35	3.26	3.39	3.41	3.18	3.45	3.33	3.41
d_{80}^{male}	1.03	1.69	1.02	1.68	0.91	1.03	0.24	1.10	1.24	1.24	0.90	1.02	1.05
d_{80}^{female}	0.91	1.97	0.90	1.90	0.96	0.91	0.88	0.90	1.04	0.95	0.60	0.91	0.90
$CV^{male,j}$	0.538	0.527	0.538	0.524	0.534	0.538	0.274	0.422	0.430	0.850	0.536	0.538	0.374
$CV^{female,j}$	0.826	0.904	0.828	0.913	0.824	0.826	0.761	0.816	0.787	0.923	0.753	0.827	0.813
h^{male}	1	6.65	1	6.51	1	1	1	1	1	1	1	1	1
h^{female}	1	9.92	1	9.75	1	1	1	1	1	1	1	1	1
m_{50}	55.25	52.94	55.25	52.69	55.54	55.25	55.22	55.15	55.14	55.42	56.11	55.29	55.21
m_{95-50}	18.349	18.349	18.349	18.349	18.349	18.348	18.349	18.349	18.349	18.349	18.349	18.349	18.349
r_{AW}^{male}	0.845	0.962	0.833	0.968	0.951	0.845	0.852	0.802	0.764	0.895	1.000	0.848	0.844
r_{SS}^{male}	0.592	0.592	0.594	0.622	0.635	0.592	0.568	0.568	0.576	0.633	0.741	0.600	0.589
r_{SS}^{female} or r_{SS}^{femmat}	0.828	0.785	0.842	0.853	0.823	0.828	0.869	0.818	0.775	0.821	0.703	0.825	0.807
r_{AW}^{femmat}	0.836	0.901	0.833	0.928	0.891	0.836	0.917	0.811	0.726	0.822	0.712	0.830	0.817
$v_1^{male,l}$	53.7	54.0	53.9	54.6	53.3	53.7	52.9	53.8	53.9	54.1	53.9	53.9	53.8
$v_1^{female,l}$	61.4	58.5	61.8	58.9	61.1	61.4	62.5	61.4	61.1	61.5	58.7	61.6	61.1
$v_2^{male,l}$	53.3	53.3	53.3	53.3	53.3	53.3	50.5	53.3	53.4	53.4	53.3	53.3	53.3

Table 18 *continued.*

	Base case	Est. h	Est. χ	Est. h & χ	Est. w^g	Est. u_{95-50}	ϖ^I x2	ϖ^{CR} x2	ϖ^P x2	ϖ^{TAG} x2	*Umax* 0.7	Alt. 1 catch	Alt. 2 catch
$v_2^{female,l}$	61.3	61.4	61.4	61.5	61.2	61.3	60.9	61.4	61.3	61.4	56.3	61.4	61.4
η_1^{male}	6.49	7.67	6.57	7.88	6.52	6.49	6.70	6.34	6.46	6.77	6.61	6.63	6.42
η_1^{female}	8.59	10.65	8.85	10.88	8.56	8.59	9.24	8.52	8.50	8.60	7.59	8.80	8.50
η_2^{male}	2.32	2.29	2.32	2.28	2.34	2.32	1.00	2.28	2.30	2.30	2.35	2.34	2.31
η_2^{female}	4.49	4.66	4.54	4.73	4.46	4.49	4.22	4.48	4.50	4.44	1.00	4.54	4.54
w^{male}	200	200	200	200	22.0	200	200	200	200	200	200	200	200
w^{female}	200	200	200	200	250.0	200	200	200	200	200	200	200	200
f(CPUE)	-55.5	-44.9	-57.2	-57.7	-57.2	-55.5	-55.0	-56.2	-38.2	-51.4	-36.5	-55.2	-55.7
f(CR)	57.1	53.8	57.0	54.7	55.5	57.1	61.8	54.0	62.3	58.0	60.0	57.1	57.1
f(PRI)	24.3	25.3	24.3	25.4	24.7	24.3	24.8	24.2	27.8	24.2	24.1	24.1	24.2
f(LFs)	-9 586.1	-9 747.4	-9 587.5	-9 758.2	-9 577.4	-9 586.1	-8 995.7	-9 583.2	-9 530.3	-9 598.8	-9 285.1	-9 574.8	-9 597.6
f(tags)	7 872.2	7 835.0	7 873.3	7 835.2	7 860.1	7 872.2	7 862.6	7 880.4	8 124.3	7 898.5	7 853.1	7 870.1	7 880.4
f(Priors)	4.9	5.5	5.1	5.6	5.0	4.9	7.2	5.2	4.9	4.9	6.5	5.0	4.8
f(Rdevs)	25.3	49.9	25.1	50.7	25.8	25.3	29.2	26.7	24.2	39.6	29.2	24.5	24.4
penalty(U)	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
f(total)	-1 657.9	-1 822.6	-1 660.0	-1 844.3	-1 663.5	-1 657.9	-1 065.1	-1 648.8	-1 324.9	-1 625.0	-1 348.5	-1 649.3	-1 662.3
sdnr(CPUE)	0.965	1.205	0.927	0.963	0.925	0.965	1.432	0.944	0.771	1.016	1.253	0.967	0.960
sdnr(CR)	0.989	0.863	0.985	0.918	0.910	0.989	1.070	1.436	0.649	1.000	1.054	0.990	0.991
sdnr(PRI)	0.994	1.086	0.997	1.098	1.020	0.994	0.874	0.984	0.574	0.958	0.904	0.981	0.991
sdnr(tags)	1.038	1.057	1.037	1.060	1.038	1.038	0.984	1.040	0.773	1.033	1.018	1.037	1.043
sdnr(LFs)	0.969	0.962	0.969	0.964	0.970	0.969	0.994	0.964	1.136	0.930	0.980	0.969	0.965
$BALL_{79\text{-}88}$	3 870	2 567	3 831	2 532	3 921	3 870	3 347	4118	3 938	3 816	3 622	4 101	3 994
$BRECT_{79\text{-}88}$	756	766	769	771	1 293	756	797	786	809	716	939	792	801
$BVULN_{79\text{-}88}$	539	516	537	519	586	539	596	533	501	524	619	566	559
$BALL_{03}$	4 824	2 979	5 085	3 686	5 112	4 824	4 508	5 080	4 566	4 519	4 124	5 098	4 815
$BRECT_{03}$	2 535	2 036	2 741	2 520	2 982	2 535	2 806	2 521	2 335	2 428	2 493	2 700	2 488
$BVULN_{03}$	1 077	892	1 171	1 174	1 202	1 077	1 216	1 039	863	1 062	1 022	1 158	1 046
$USL_{03\,AW}$ (%)	30.0	32.0	28.1	25.8	27.3	30.0	26.8	30.7	36.5	30.7	30.1	28.2	30.7
$USL_{03\,SS}$ (%)	9.8	11.8	9.0	9.0	8.8	9.8	8.8	10.0	11.1	10.0	9.7	7.4	15.5
$BVULN_{07}/BVULN_0$	61.6	28.0	67.0	37.6	67.2	61.6	53.7	63.2	54.2	52.1	30.4	73.7	47.8
$BVULN_{03}/BVULN_7$	199.7	172.9	218.1	226.5	204.9	199.7	204.2	194.8	172.2	202.8	165.1	204.4	187.2

Table 19: Parameter estimates from CRA 5 MPD retrospective analysis. Years are named for the last year of data that were used.

Parameters	Base case	Retro01	Retro00	Retro99	Retro98
$\ln(R_0)$	14.05	14.18	13.90	13.75	13.56
M	0.127	0.138	0.113	0.103	0.094
$\tilde{\sigma}$	0.750	0.740	0.728	0.716	0.629
$\ln(q^I)$	-6.668	-6.673	-6.661	-6.666	-6.578
$\ln(q^{CR})$	-3.897	-3.912	-3.966	-3.995	-3.918
$\ln(q^{PRI})$	-13.43	-13.49	-13.27	-13.32	-13.31
d_{50}^{male}	1.89	1.88	1.89	1.89	1.90
d_{50}^{female}	3.35	3.28	3.32	3.36	3.37
d_{80}^{male}	1.03	1.05	1.01	1.00	1.19
d_{80}^{female}	0.91	0.85	0.86	0.82	0.73
$CV^{male,j}$	0.538	0.540	0.537	0.537	0.763
$CV^{female,j}$	0.826	0.858	0.836	0.811	0.832
m_{50}	55.25	55.43	55.58	55.73	55.74
r_{AW}^{male}	0.845	0.836	0.937	0.991	0.992
r_{SS}^{male}	0.592	0.597	0.661	0.691	0.712
r_{SS}^{female} or r_{SS}^{femmat}	0.828	0.838	0.794	0.770	0.734
r_{AW}^{femmat}	0.836	0.892	0.919	0.969	1.000
$v_1^{male,l}$	53.7	53.8	54.1	54.3	54.9
$v_1^{female,l}$	61.4	61.6	60.6	60.2	60.1
$v_2^{male,l}$	53.3	53.4	53.4	53.4	53.4
$v_2^{female,l}$	61.3	61.4	61.3	61.6	62.5
η_1^{male}	6.49	6.52	6.82	6.96	7.26
η_1^{female}	8.59	8.59	8.16	7.94	7.89
η_2^{male}	2.32	2.32	2.35	2.37	2.35
η_2^{female}	4.49	4.52	4.61	4.99	5.58
f(CPUE)	-55.5	-53.9	-49.6	-49.3	-35.6
f(CR)	57.1	56.6	58.2	59.2	59.8
f(PRI)	24.3	21.8	17.0	14.1	10.9
f(LFs)	-9 586.1	-9 007.8	-8 454.1	-7 451.5	-6 725.0
f(tags)	7 872.2	7 872.6	7 872.3	7 872.6	7 821.8
f(Priors)	4.9	5.1	4.6	4.7	5.3
f(Rdevs)	25.3	23.5	27.1	27.5	42.7
penalty(U)	0.0	0.0	0.0	0.0	0.2
f(total)	-1 657.9	-1 082.1	-524.5	477.3	1 180.1
sdnr(CPUE)	0.965	1.007	1.104	1.115	1.465
sdnr(CR)	0.989	0.980	1.072	1.127	1.259
sdnr(PRI)	0.994	1.057	0.514	0.522	0.487
sdnr(tags)	1.038	1.043	1.052	1.064	0.975
sdnr(LFs)	0.969	0.963	0.957	0.944	0.981
$BALL_{79\text{-}88}$	3 870	4 014	3 744	3 649	3 532
$BRECT_{79\text{-}88}$	756	749	713	709	687
$BVULN_{79\text{-}88}$	539	539	536	539	496

Table 20: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from CRA 5 (* indicates the test failed).

Parameters	Mean	RL	Geweke	HW	Gelman
$\ln(R_0)$	14.06	*		*	
M	0.13	*	*	*	
$\tilde{\sigma}$	0.754	*	*	*	
d_{50}^{male}	1.88	*	*	*	
d_{50}^{female}	3.34	*	*	*	
d_{80}^{male}	1.04	*		*	
d_{80}^{female}	0.91	*	*	*	
$CV^{male,j}$	0.541	*	*	*	*
$CV^{female,j}$	0.829	*		*	
m_{50}	55.22	*	*	*	
r_{AW}^{male}	0.86	*	*	*	
r_{SS}^{male}	0.598	*	*	*	
r_{SS}^{female} or r_{SS}^{femmat}	0.842	*	*	*	
r_{AW}^{femmat}	0.853	*		*	
$v_1^{male,l}$	6.552	*		*	
$v_1^{female,l}$	8.63	*	*	*	
$v_2^{male,l}$	2.31	*	*	*	
$v_2^{female,l}$	4.49	*		*	
η_1^{male}	53.85	*			
η_1^{female}	61.47	*	*	*	
η_2^{male}	53.34	*		*	
η_2^{female}	61.35	*	*	*	
$USL_{03\,AW}$ (%)	29.5		*	*	
$USL_{03\,SS}$ (%)	37.3	*		*	
$BALL_{79\text{-}88}$	3 929	*	*	*	
$BRECT_{79\text{-}88}$	778		*	*	*
$BVULN_{79\text{-}88}$	557				
$BALL_{03}$	5 341	*		*	
$BRECT_{03}$	2 562	*	*	*	
$BVULN_{03}$	1 106				
$BALL_{07}$	5 676		*		
$BRECT_{07}$	2 424		*		
$BVULN_{07}$	969	*		*	
$BVULN_{03}/BVULN_{79\text{-}88}$ (%)	198				
$BVULN_{07}/BVULN_{03}$ (%)	87.2				
$BVULN_{07}/BVULN_{79\text{-}88}$ (%)	174				
sdnrCPUE	1.02	*			
sdnrCR	1.03	*	*	*	
sdnrPRI	0.99	*	*	*	
sdnrtags	1.04	*	*	*	
sdnrLFs	0.97	*		*	

Table 21: Summary statistics for performance indicators from posterior distributions from the CRA 5 base case. "% decrease": the probability of decrease in vulnerable biomass in 2007 compare to 2003.

Parameters	0.05	Median	Mean	0.95
f	-1630.1	-1621.5	-1620.9	-1610.3
$\ln(R_0)$	13.86	14.05	14.06	14.27
M	0.11	0.13	0.13	0.15
$\tilde{\sigma}$	0.740	0.753	0.754	0.768
d_{50}^{male}	1.84	1.88	1.88	1.91
d_{50}^{female}	3.24	3.34	3.34	3.44
d_{80}^{male}	0.92	1.04	1.04	1.18
d_{80}^{female}	0.77	0.91	0.91	1.06
$CV^{male,j}$	0.530	0.541	0.541	0.552
$CV^{female,j}$	0.777	0.828	0.828	0.879
m_{50}	54.58	55.23	55.22	55.81
r_{AW}^{male}	0.773	0.854	0.856	0.947
r_{SS}^{male}	0.547	0.598	0.598	0.653
r_{SS}^{female} or r_{SS}^{femmat}	0.774	0.841	0.842	0.916
r_{AW}^{femmat}	0.775	0.851	0.853	0.937
$v_1^{male,l}$	5.77	6.54	6.55	7.38
$v_1^{female,l}$	7.49	8.63	8.63	9.78
$v_2^{male,l}$	2.19	2.31	2.31	2.43
$v_2^{female,l}$	4.23	4.49	4.49	4.74
η_1^{male}	52.88	53.82	53.85	54.93
η_1^{female}	59.96	61.45	61.47	63.05
η_2^{male}	53.23	53.34	53.34	53.46
η_2^{female}	61.05	61.35	61.35	61.66
$BALL_{79\text{-}88}$	3 744	3 918	3 929	4 151
$BRECT_{79\text{-}88}$	708	776	778	855
$BVULN_{79\text{-}88}$	517	555	557	606
$BALL_{03}$	4 475	5 281	5 341	6 394
$BRECT_{03}$	2 314	2 555	2 562	2 827
$BVULN_{03}$	966	1 102	1 106	1 261
$BALL_{07}$	3 928	5 610	5 676	7 659
$BRECT_{07}$	1 516	2 364	2 424	3 494
$BVULN_{07}$	472	930	969	1 586
$UNSL_{03}$ (%)	1.5	1.7	1.7	2.0
USL_{03} (%)	25.7	29.4	29.5	33.5
$UNSL_{07}$ (%)	1.3	1.8	1.9	2.5
USL_{07} (%)	22.7	35.6	37.3	57.8
$BVULN_{03}/BVULN_{79\text{-}88}$ (%)	176.9	197.9	198.5	221.1
$BVULN_{07}/BVULN_{03}$ (%)	44.5	84.3	87.2	139.4
$BVULN_{07}/BVULN_{79\text{-}88}$ (%)	85.5	167.4	173.7	282.8
% decrease	69.2			

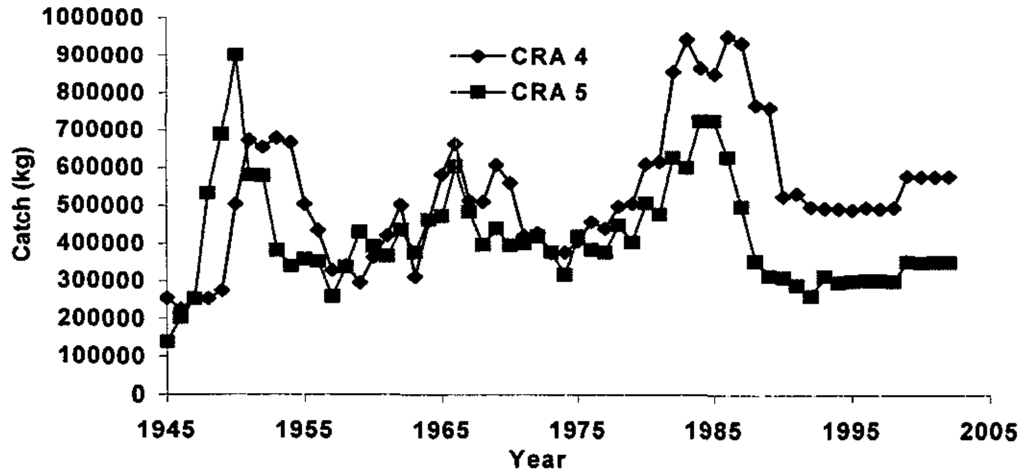


Figure 1: Commercial catches (kg) for CRA 4 and CRA 5.

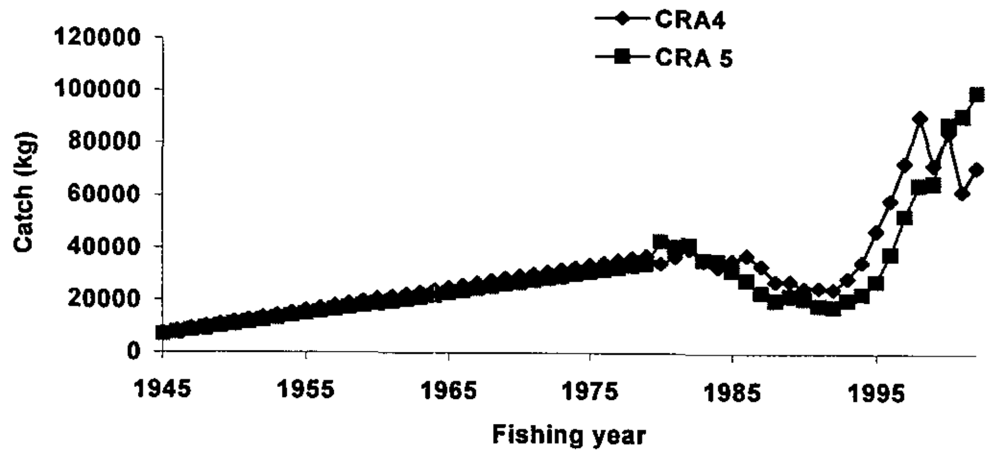


Figure 2: Assumed recreational catches (kg) for CRA 4 and CRA 5.

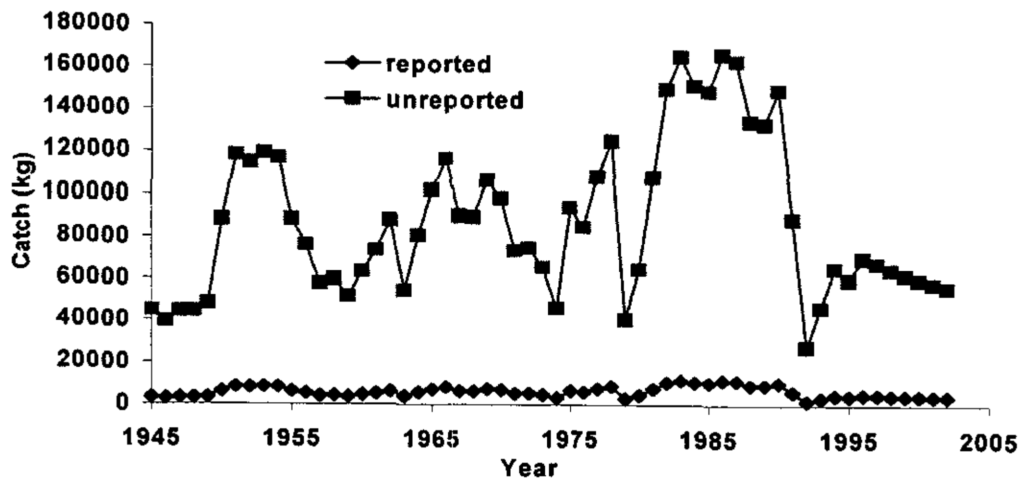


Figure 3: Assumed illegal catches (kg) for CRA 4.

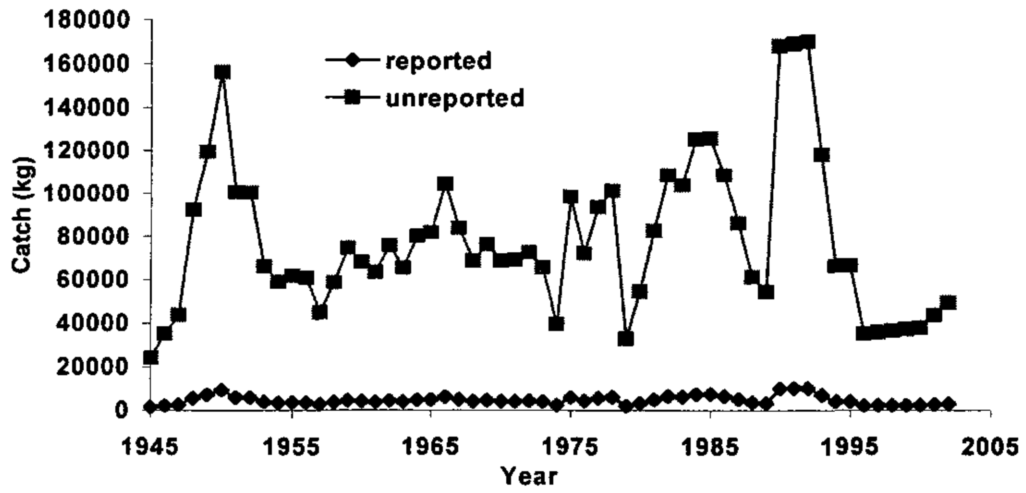


Figure 4: Assumed illegal catches (kg) for CRA 5.

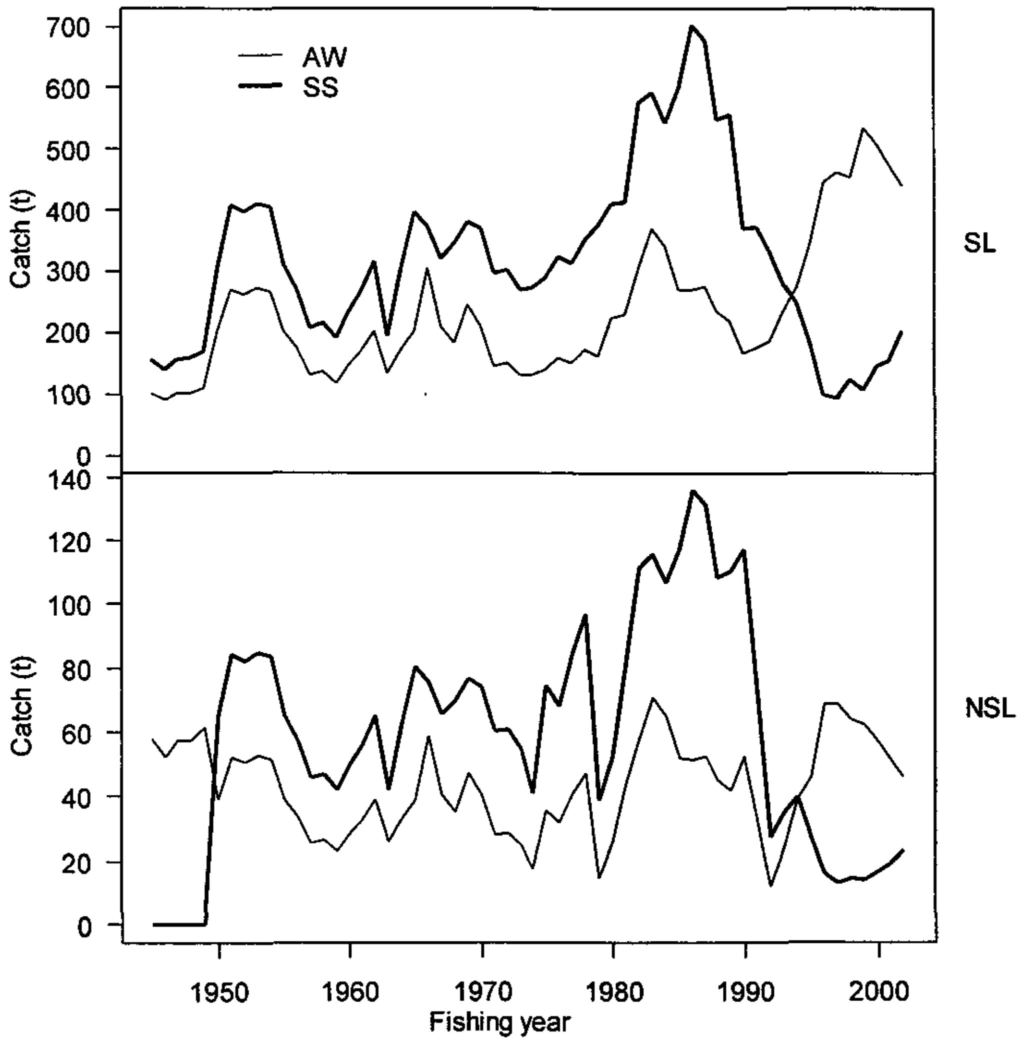


Figure 5: CRA 4: SL (size limited) and NSL (non size limited) catch by season.

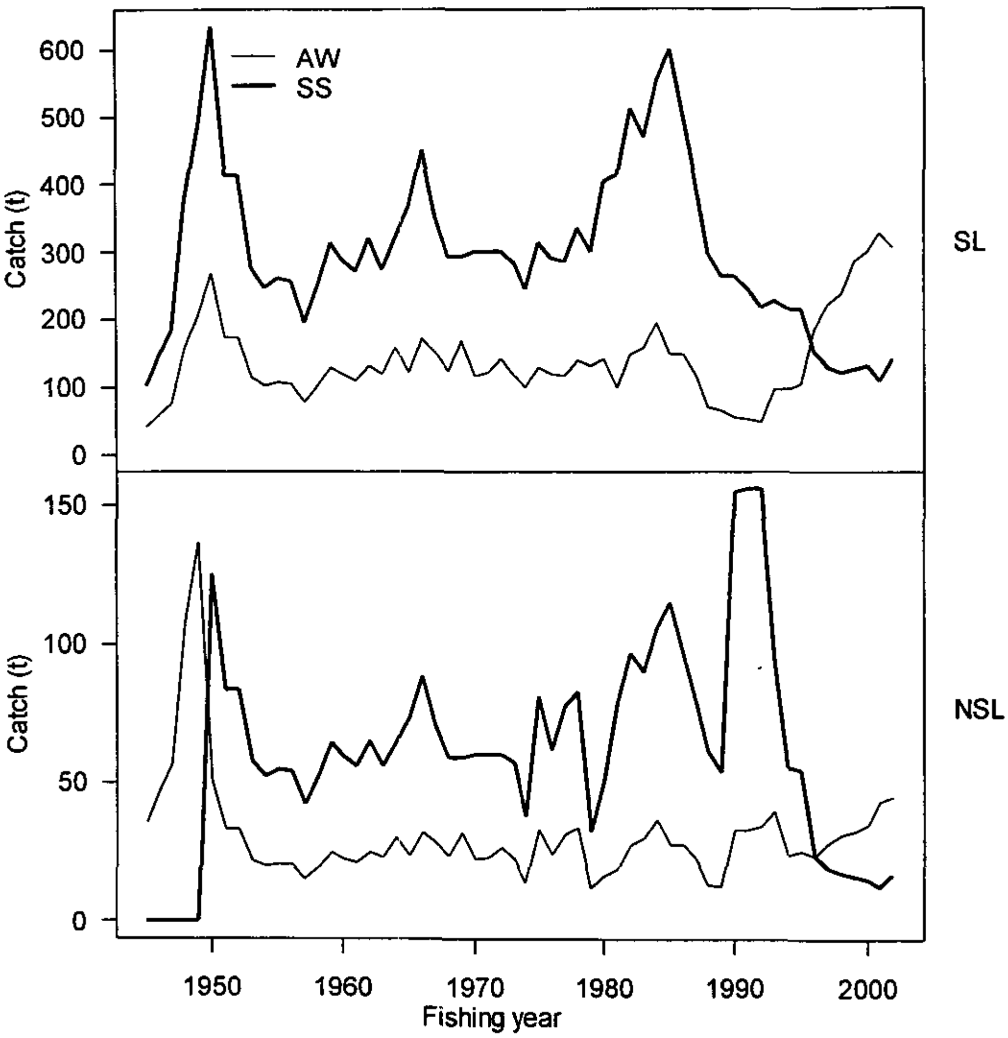


Figure 6: CRA 5: SL and NSL catch by season.

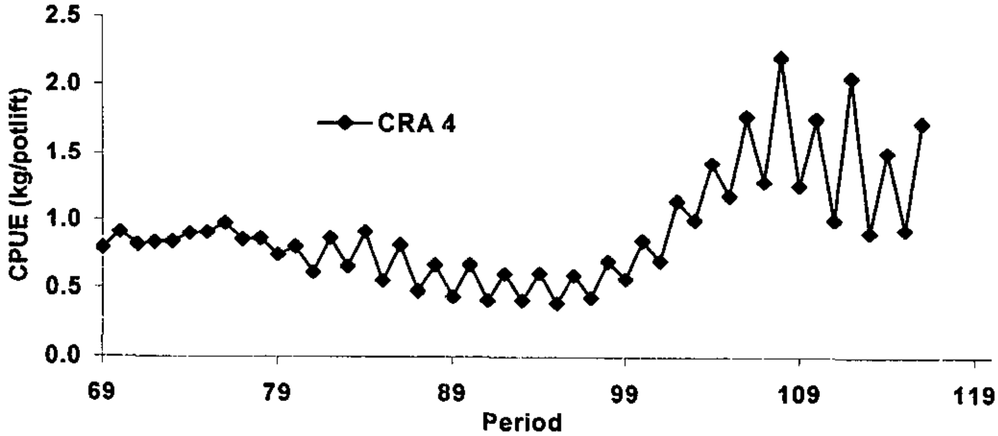


Figure 7: Standardised CPUE by period for CRA 4.

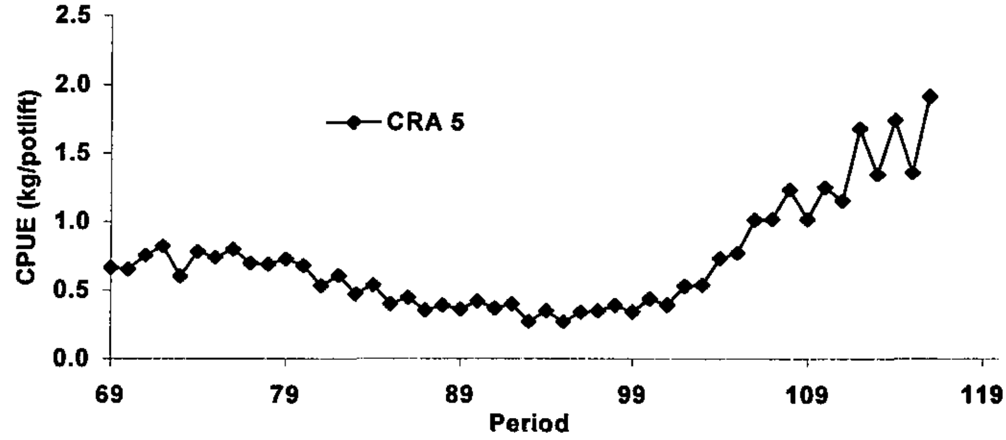


Figure 8: Standardised CPUE by period for CRA 5.

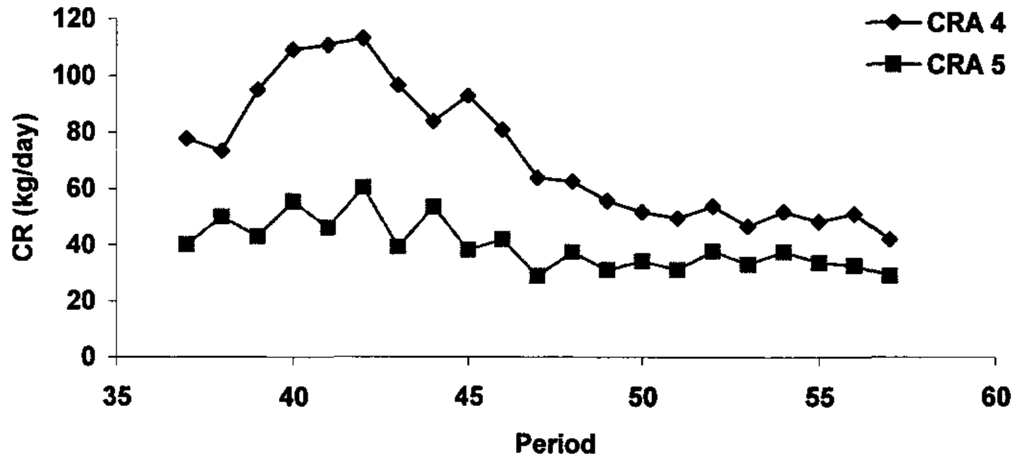


Figure 9: Historical catch rate (CR) by period for CRA 4 and CRA 5.

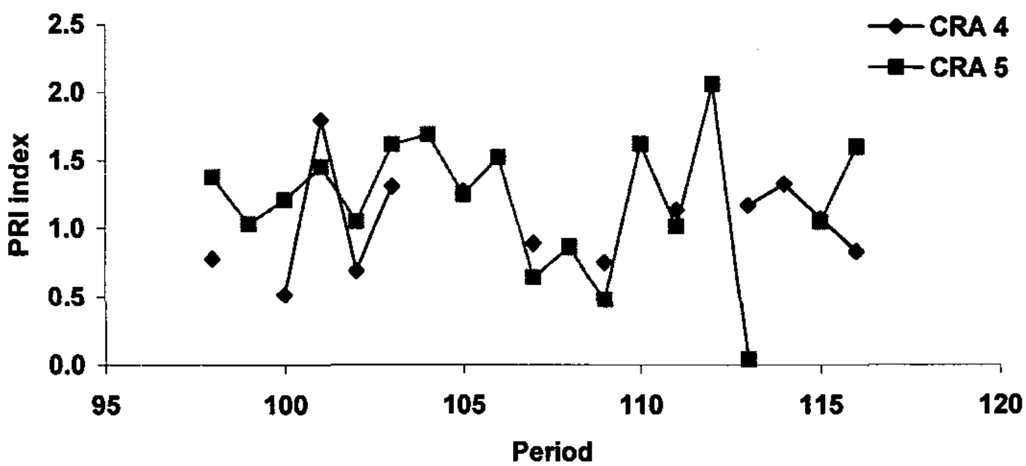


Figure 10: Pre-recruit index (PRI) by period for CRA 4 and CRA 5.

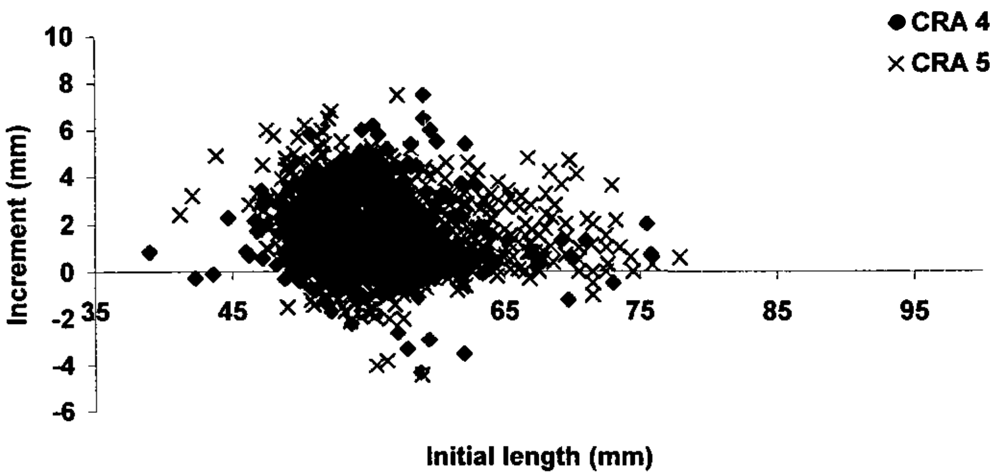


Figure 11. Growth increment per period for males plotted against size at release for CRA 4 and CRA 5.

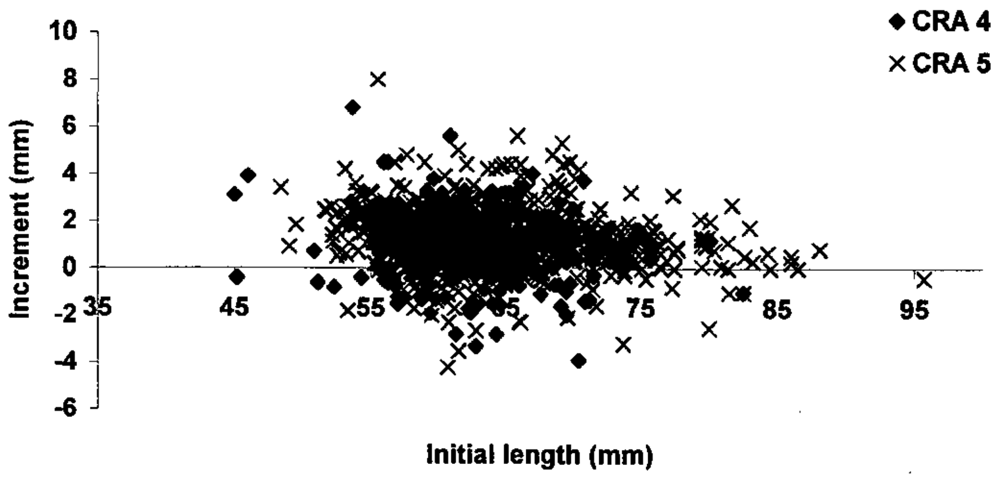


Figure 12. Growth increment per period for females plotted against size at release for CRA 4 and CRA 5.

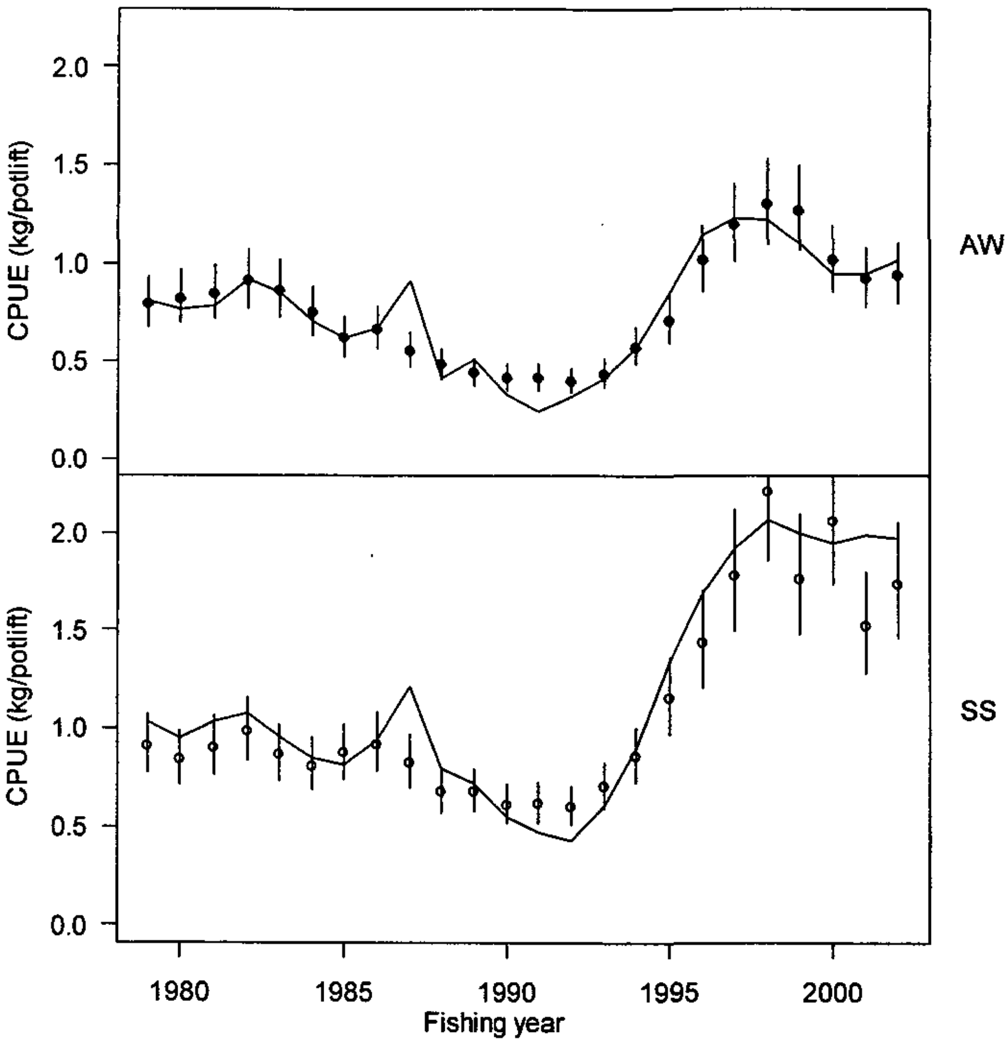


Figure 13: CRA 4: Predicted (line) and observed (circles with one standard error, taking all sources of variability into account) standardised CPUE index by season from the base case MPD results: upper, autumn-winter (AW) season; lower, spring-summer (SS) season.

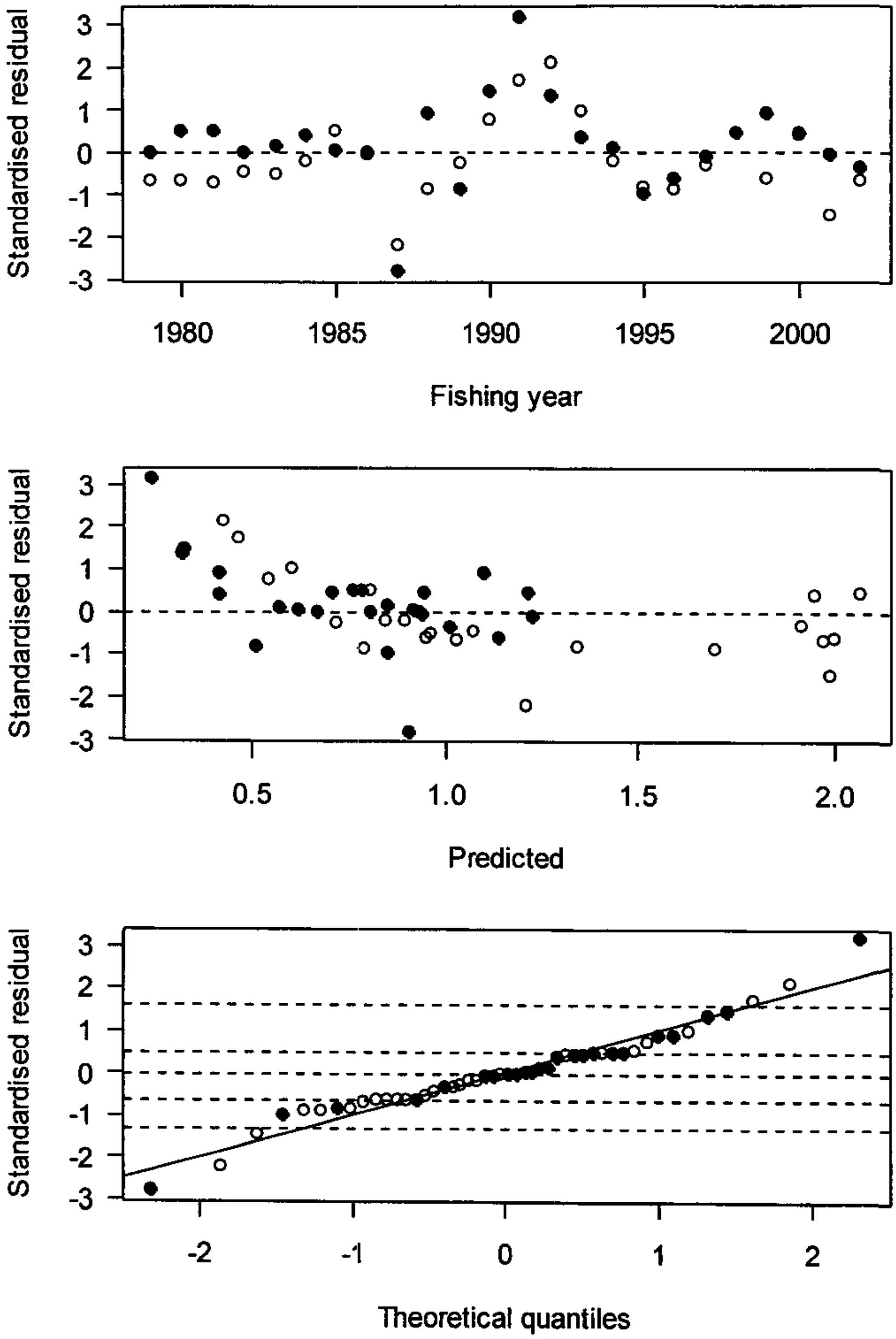


Figure 14: CRA 4: Standardised residuals of predicted CPUE index from the base case MPD results, plotted by fishing year [upper panel] and by predicted CPUE index [middle panel]; q-q plot of residuals [lower panel]. Closed circles, autumn-winter (AW) season; open circles, spring-summer (SS) season.

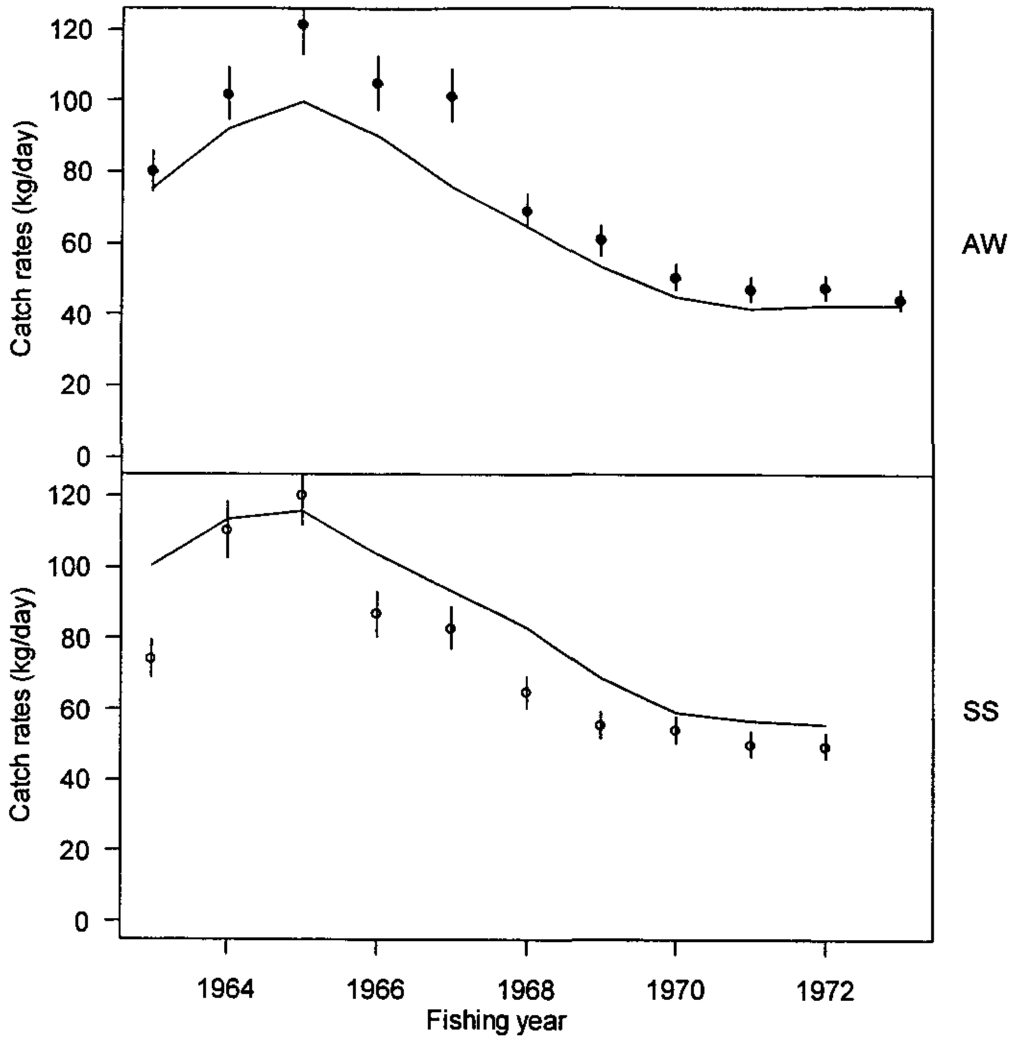


Figure 15: CRA 4: Predicted (solid line) and observed (circles with one standard error, taking all sources of variability into account) catch rate (CR) by season from the base case MPD results: upper, autumn-winter (AW) season, lower, spring-summer (SS) season.

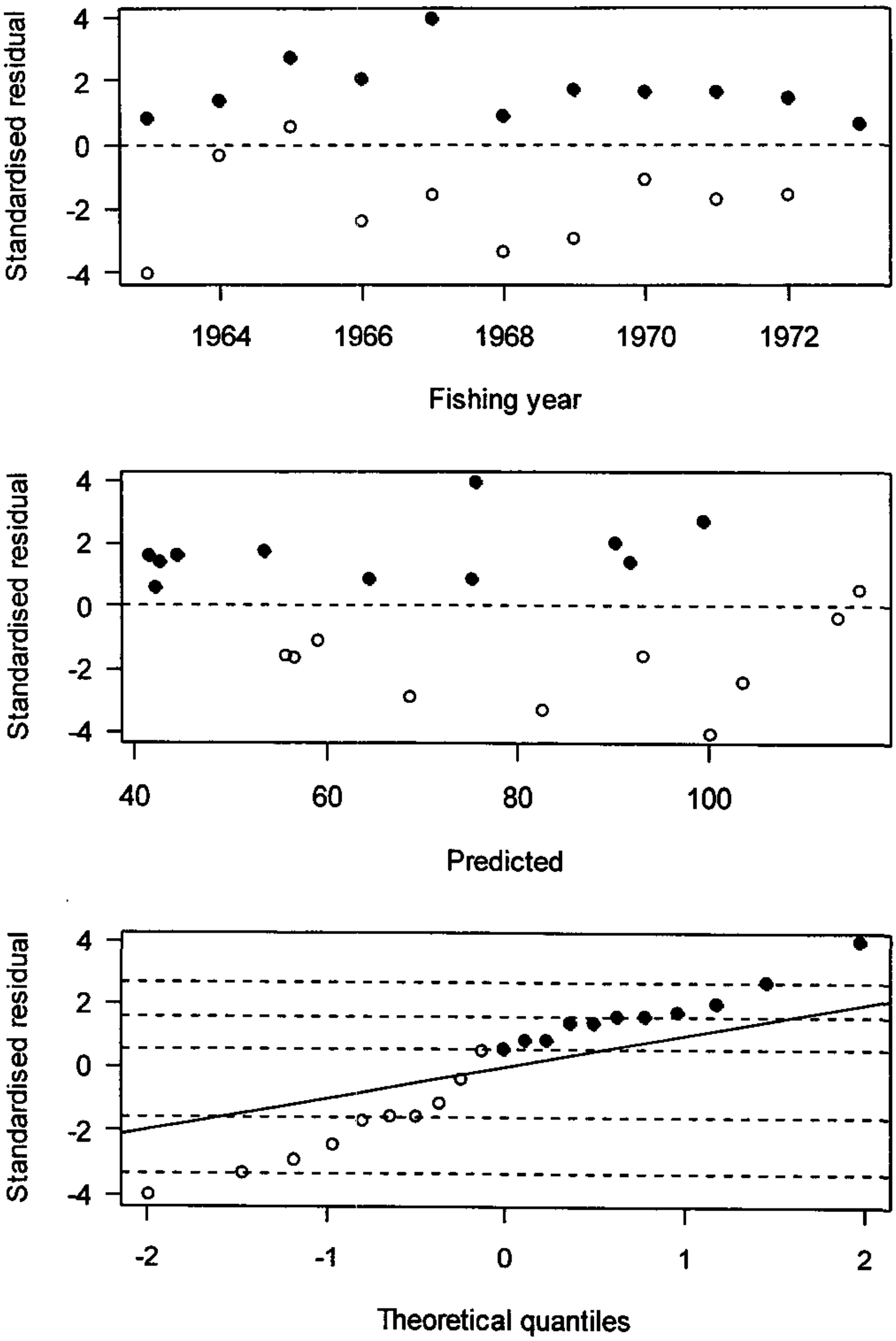


Figure 16: CRA 4: Standardised residuals of catch rate from the base case MPD results, plotted by fishing year [upper panel] and by predicted catch rate [lower panel]; q-q plot of residuals [lower panel]. Closed circles, autumn-winter (AW) season; open circles, spring-summer (SS) season.

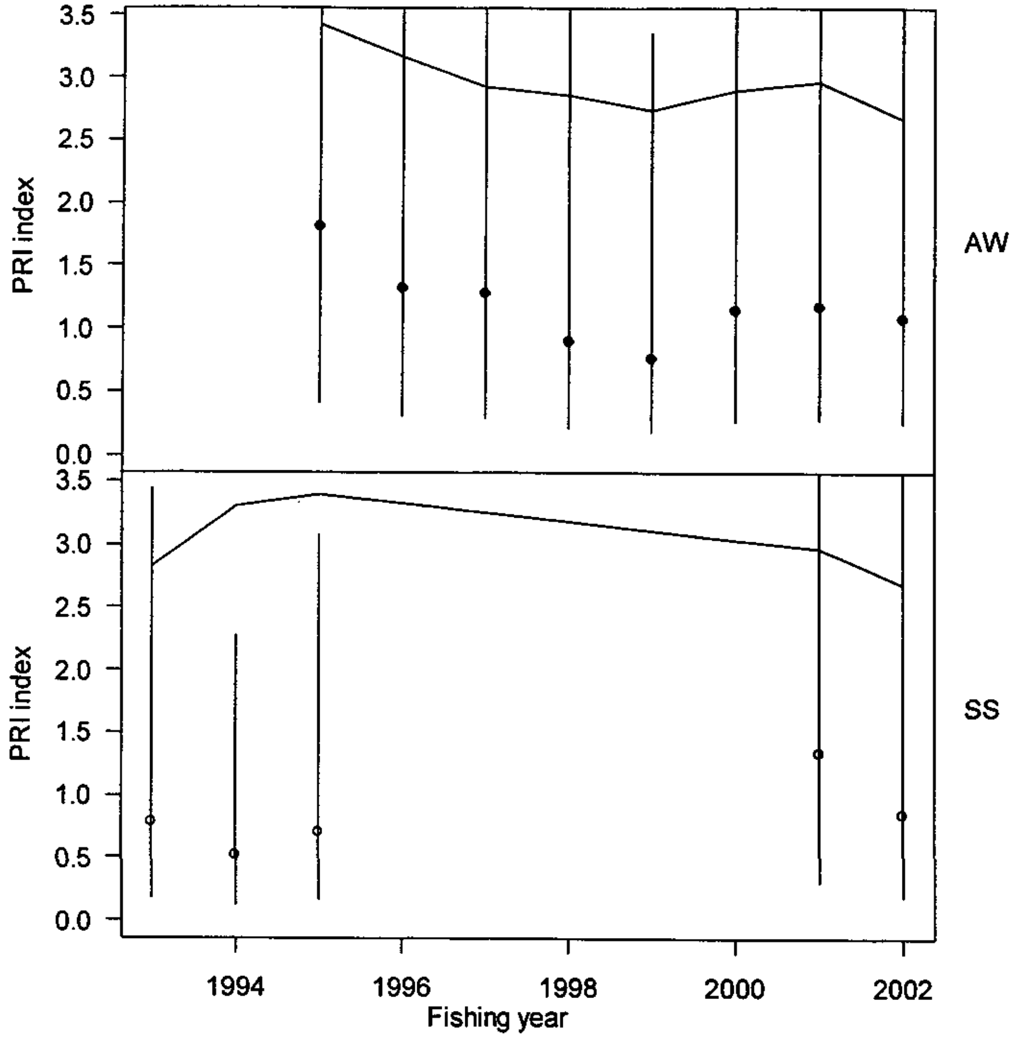


Figure 17: CRA 4: Predicted (solid line) and observed (circles with one standard error, taking all sources of variability into account) pre-recruit index (PRI) by season from the base case MPD results: upper, autumn-winter (AW) season, lower, spring-summer (SS) season.

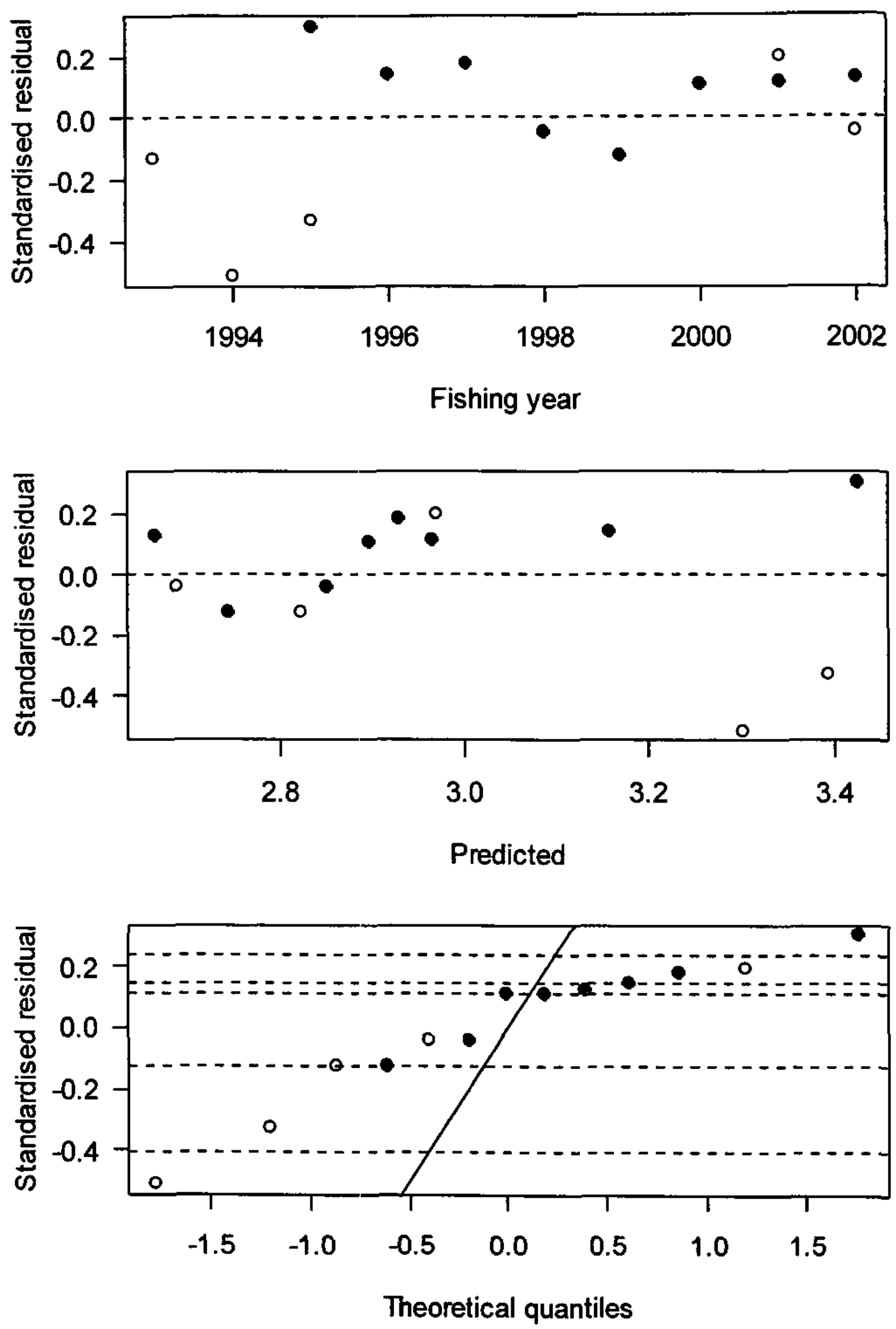


Figure 18: CRA 4: Standardised residuals of PRI from the base case MPD results, plotted by fishing year [upper panel] and by predicted catch rate [middle panel]; q-q plot of residuals [lower panel]. Closed circles, autumn-winter (AW) season; open circles, spring-summer (SS) season.

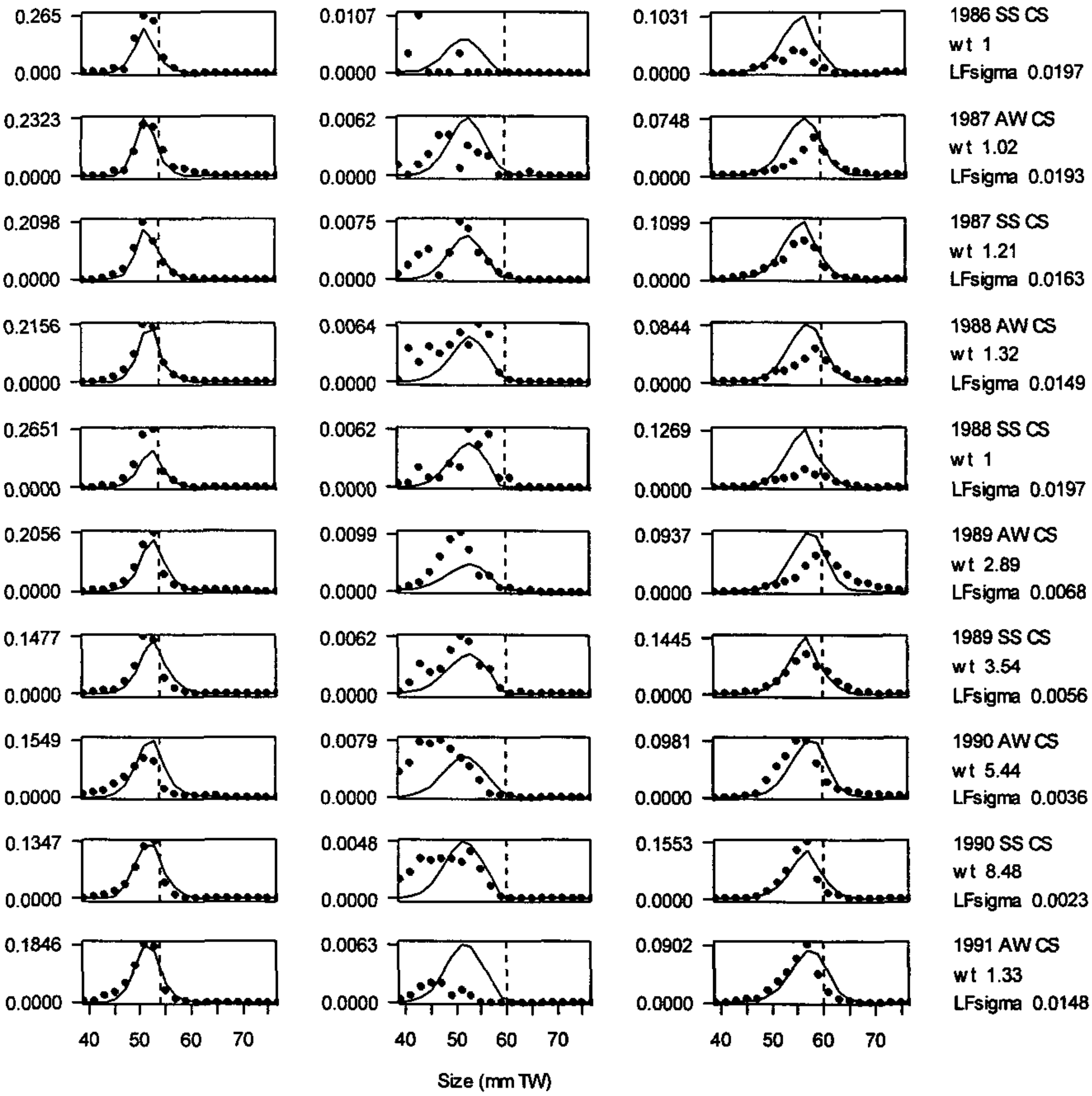


Figure 19: CRA 4: The base case MPD fit to the proportion-at-length data, plotted by year and season, sex category and data source type. The left column shows males, the centre immature females, and the right mature females. LB, log book data; CS, catch sampling data; wt ($=\kappa_l$), relative weight given to each data set. The dotted vertical line is the current summer MLS.

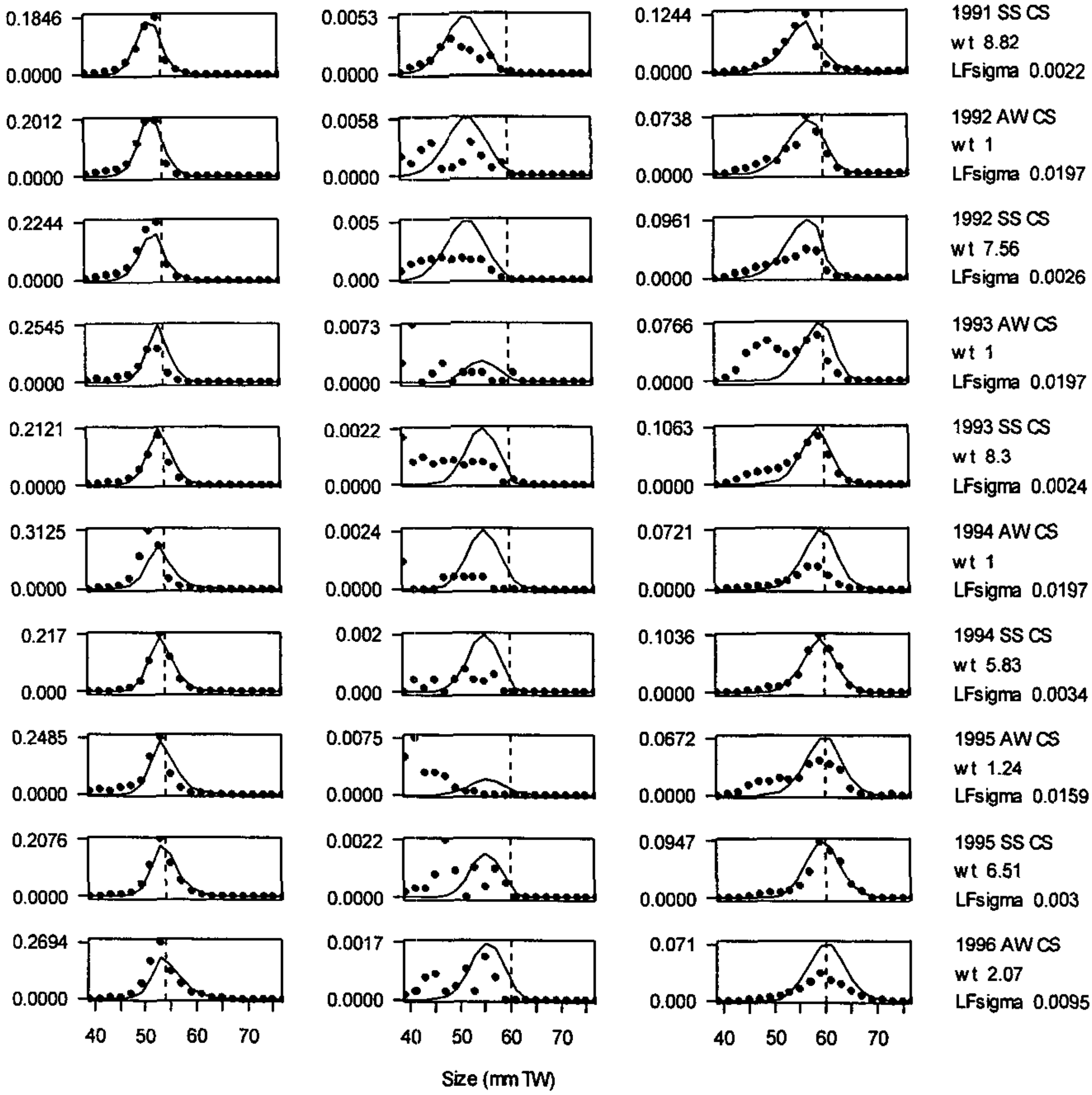


Figure 19 continued.

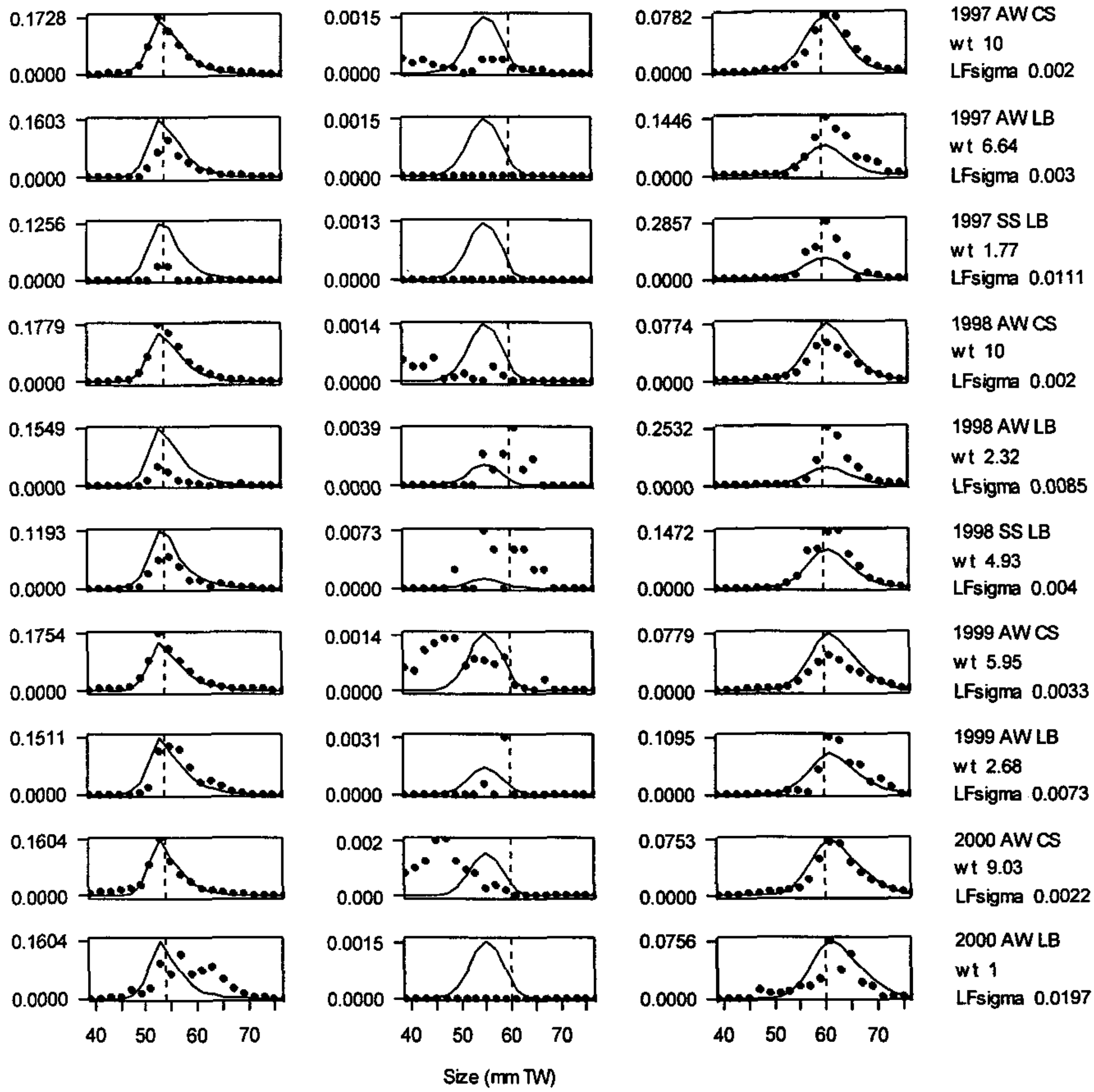


Figure 19 continued.

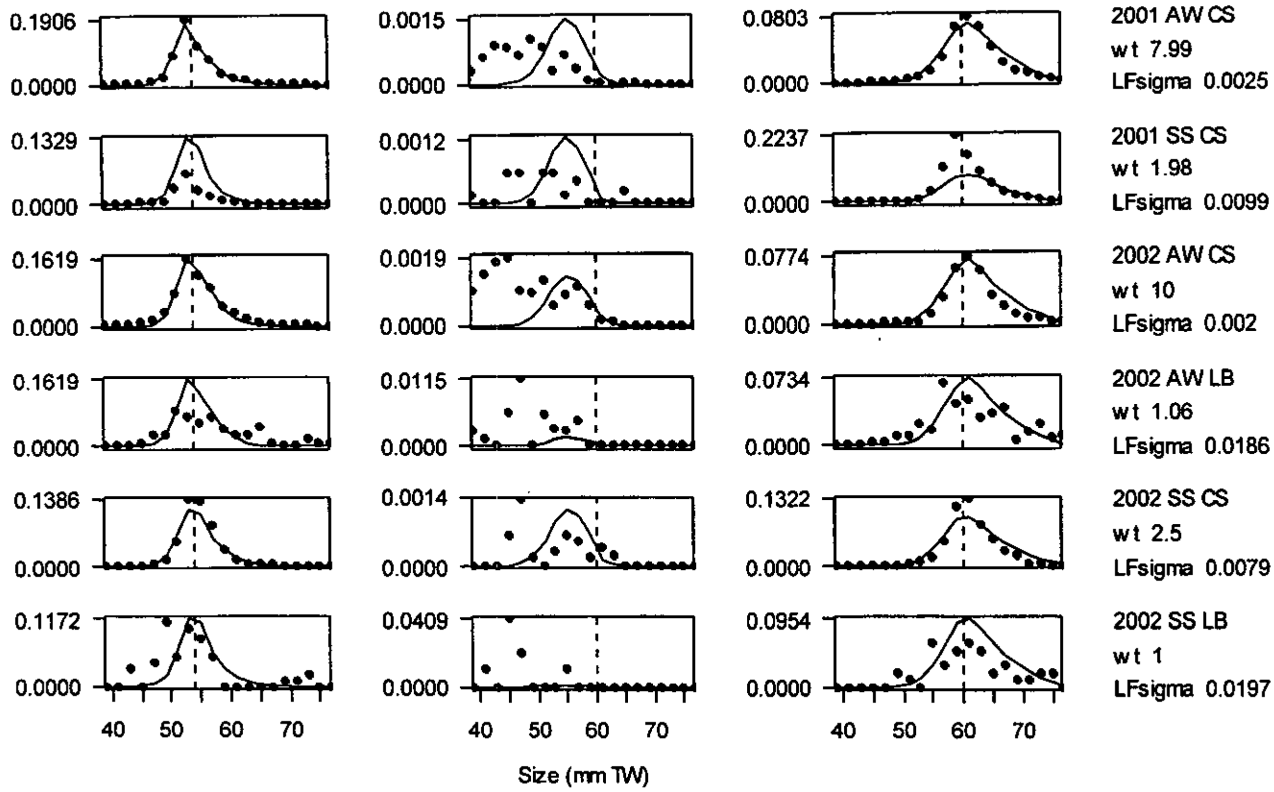
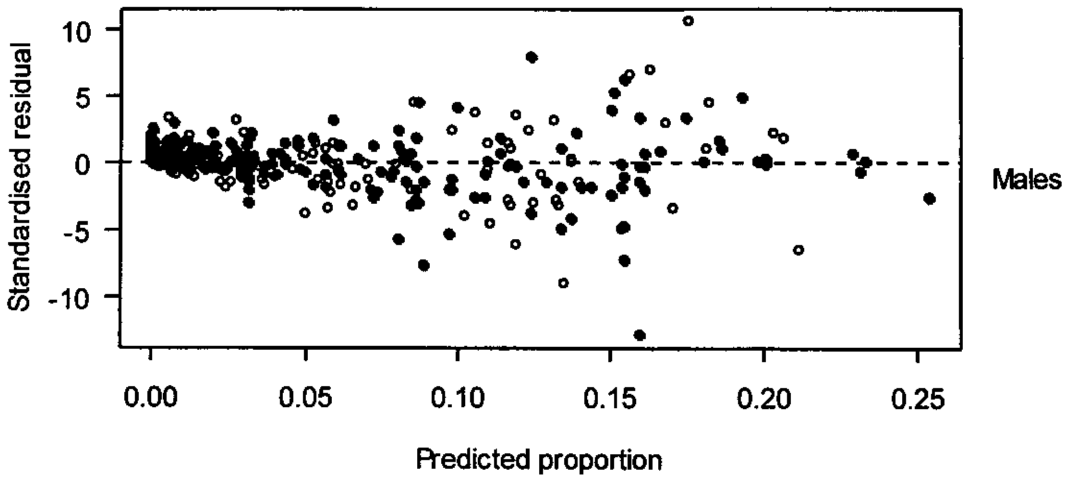
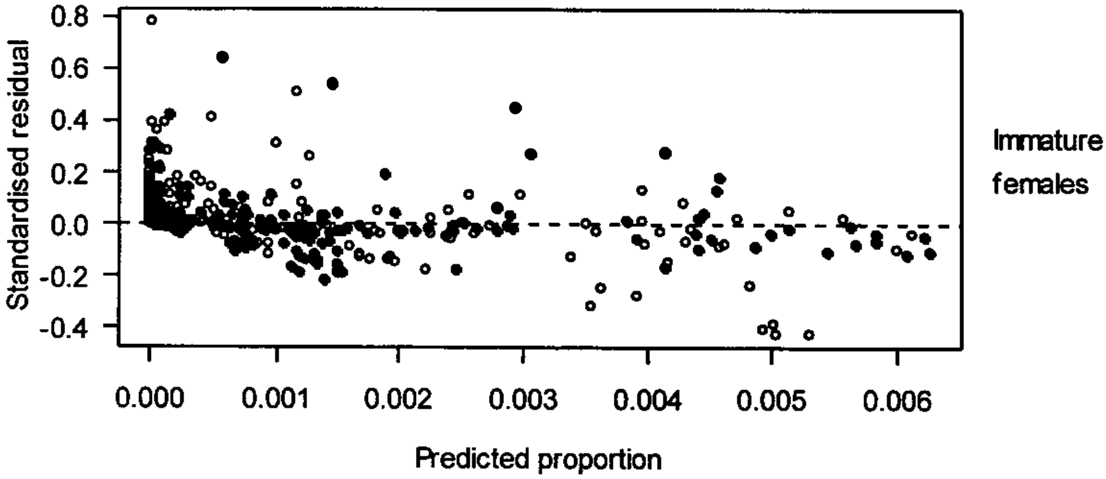


Figure 19 continued.





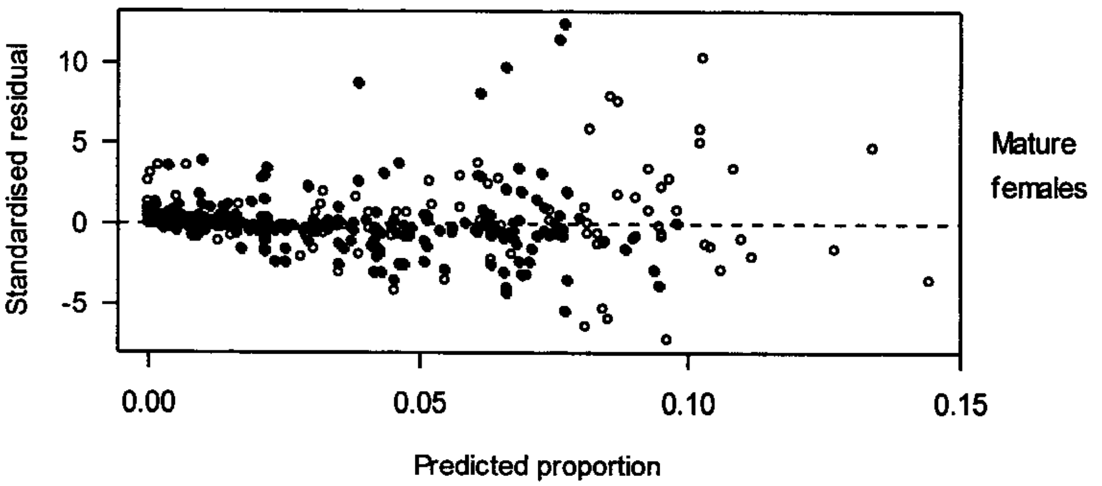


Figure 20: CRA 4: Standardised residuals from the fits to proportions-at-length plotted against predicted proportions-at-length for the three sex categories.

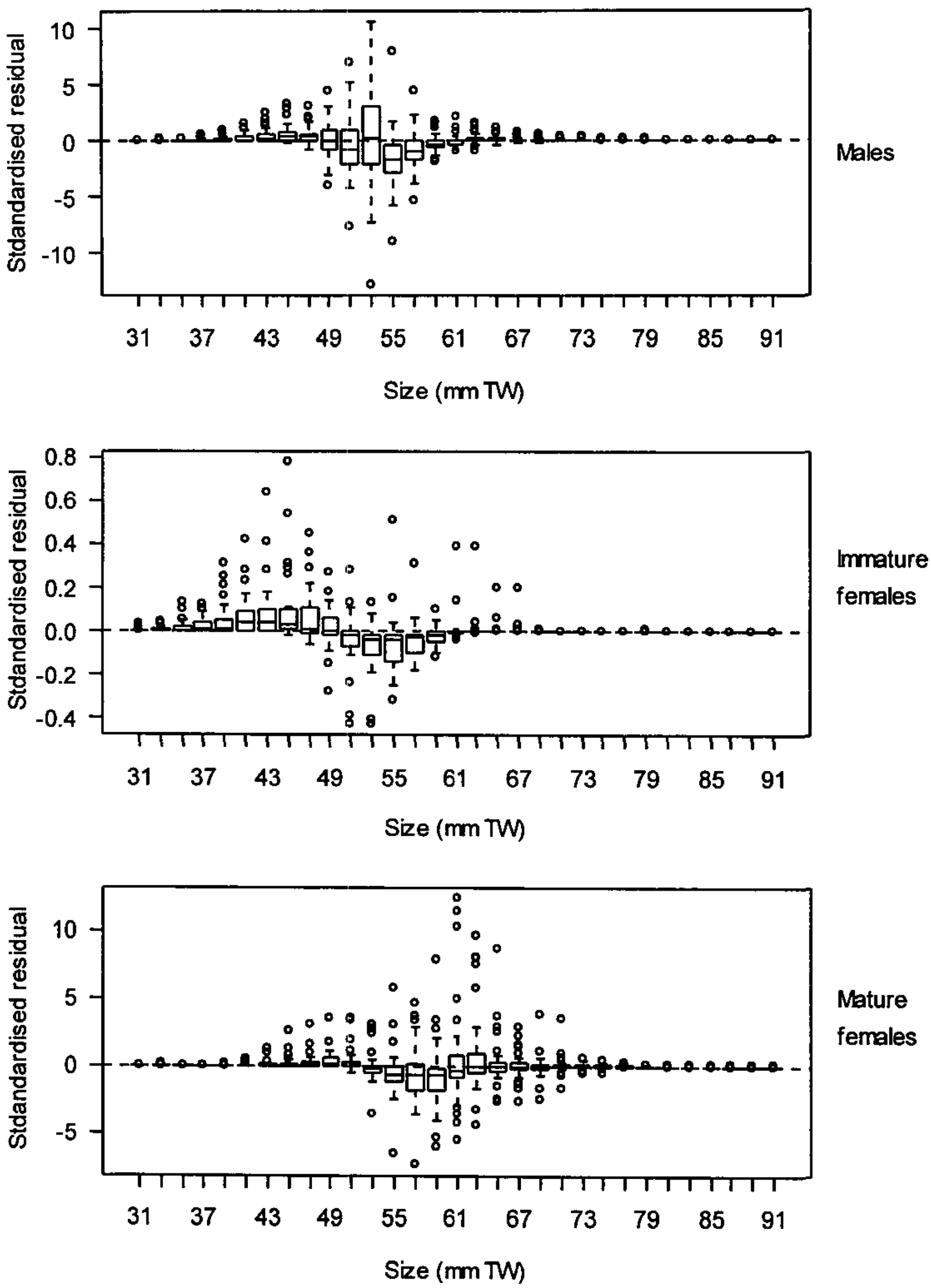


Figure 21: CRA 4: Standardised residuals from the fits to proportions-at-length plotted against length for the three sex categories indicated. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.

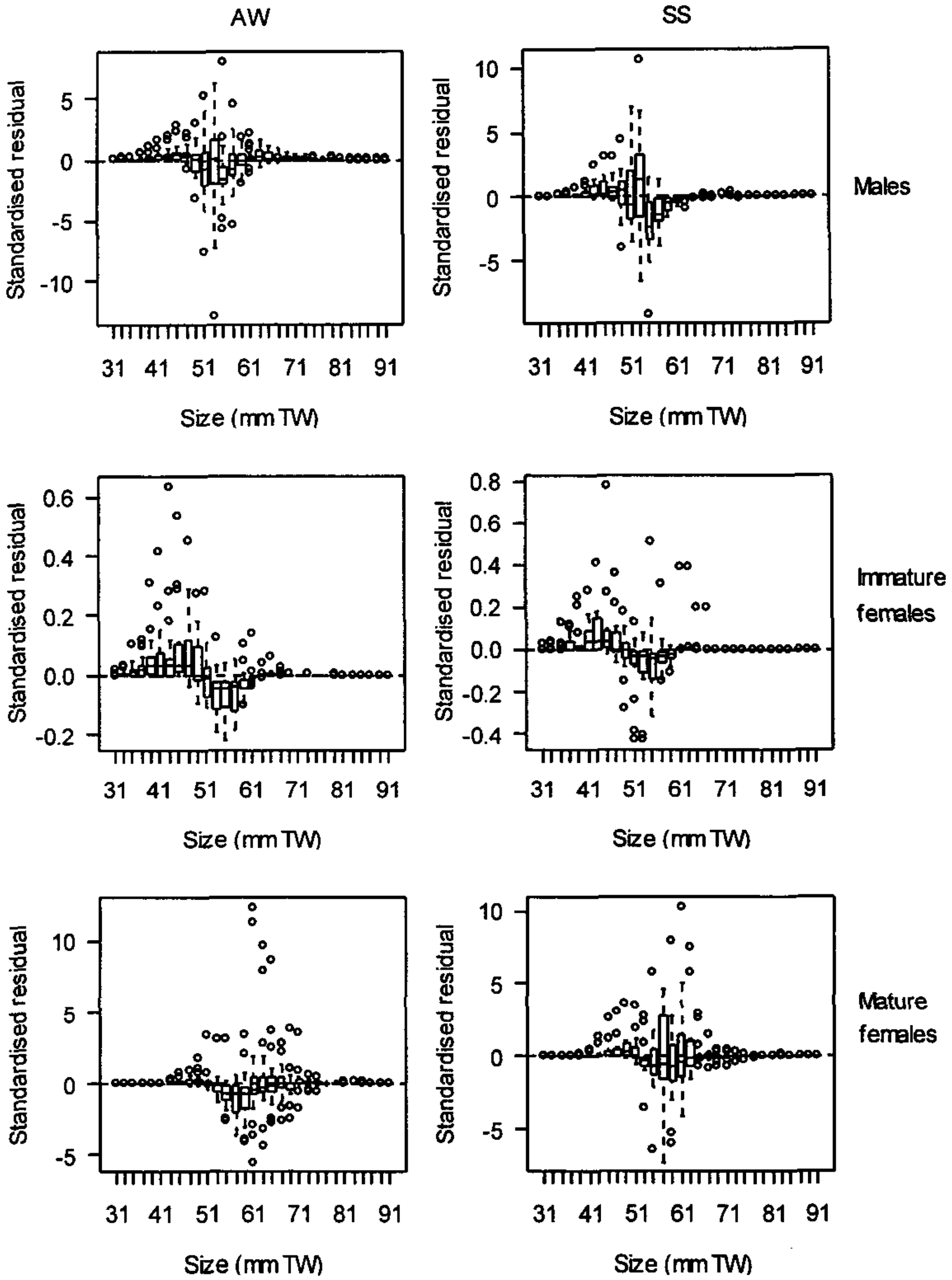


Figure 22: CRA 4: Standardised residuals from the fits to proportions-at-length plotted against length by season for the three sex categories indicated. Left panels are the autumn-winter season and the right panels for the spring-summer season. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.

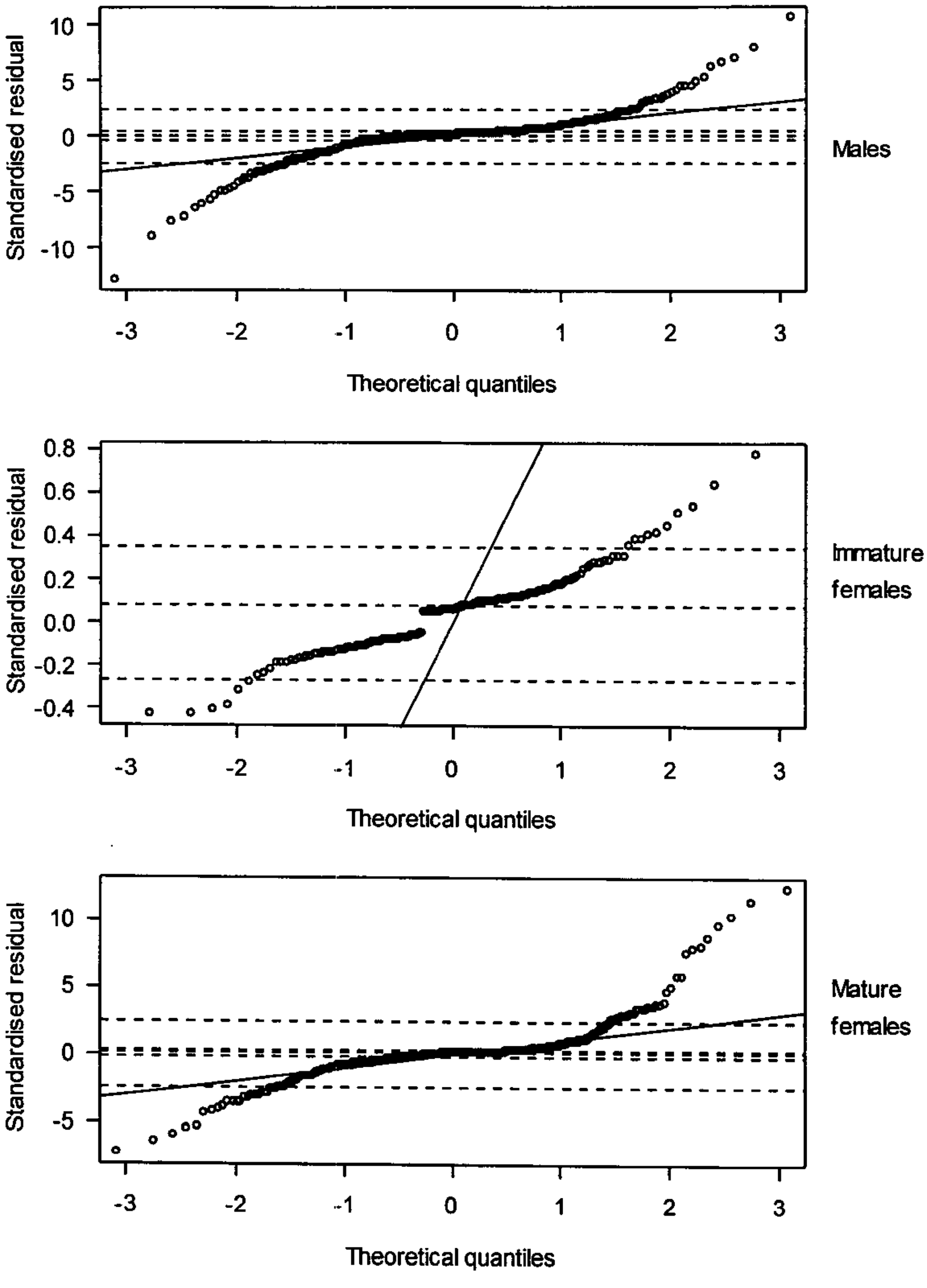


Figure 23: CRA 4: Quantile-quantile plot of standard residuals from the fits to proportions-at-length for the three sex categories indicated.

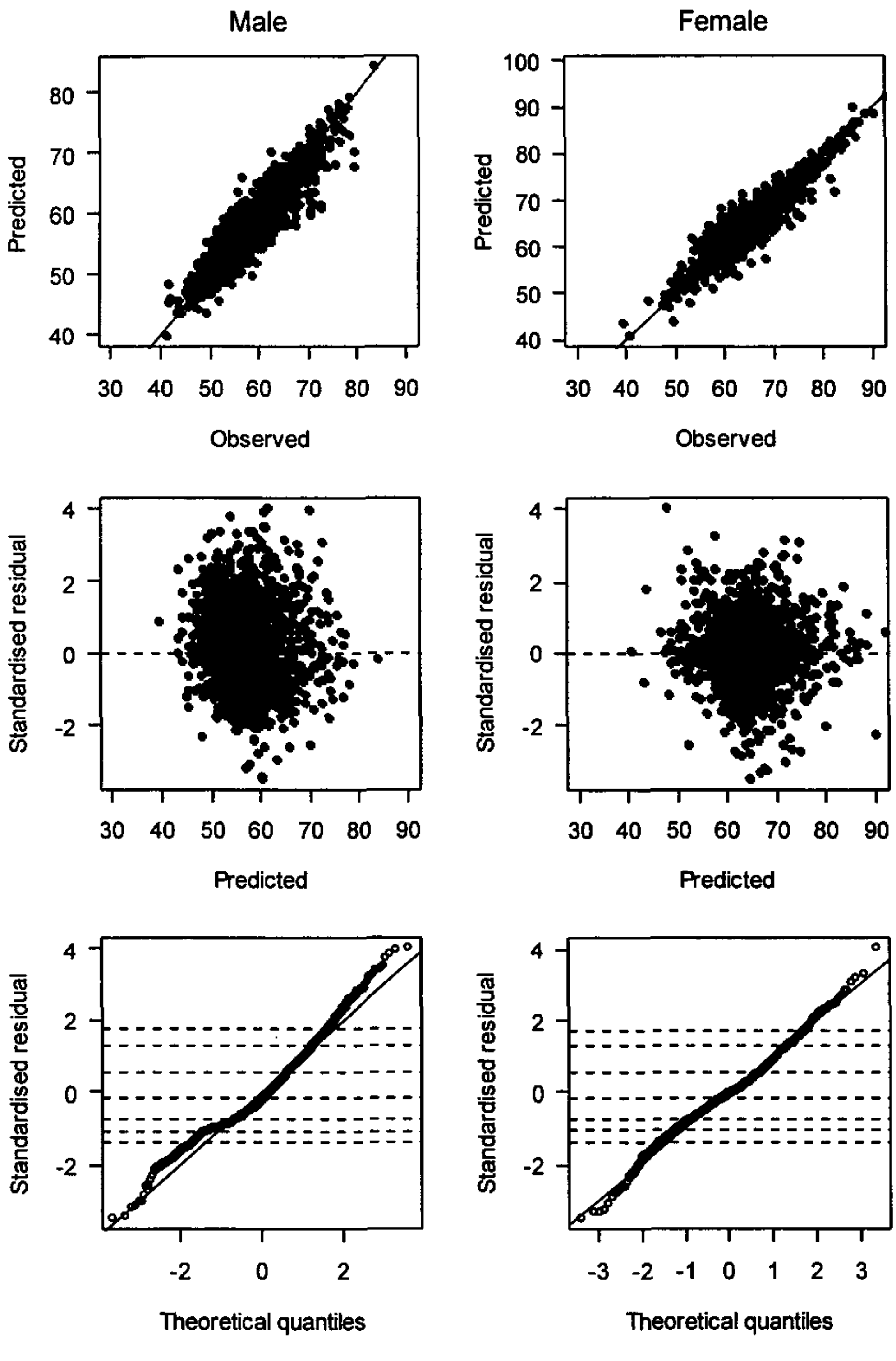


Figure 24: CRA 4: Predicted and observed size at recapture from the base case model MPD fit from the tagging data (top panels); standardised residuals versus predicted size at recapture (middle panels); q-q plots of the standardised residuals (bottom panels). For all plots, left panels are males and right panels are females.

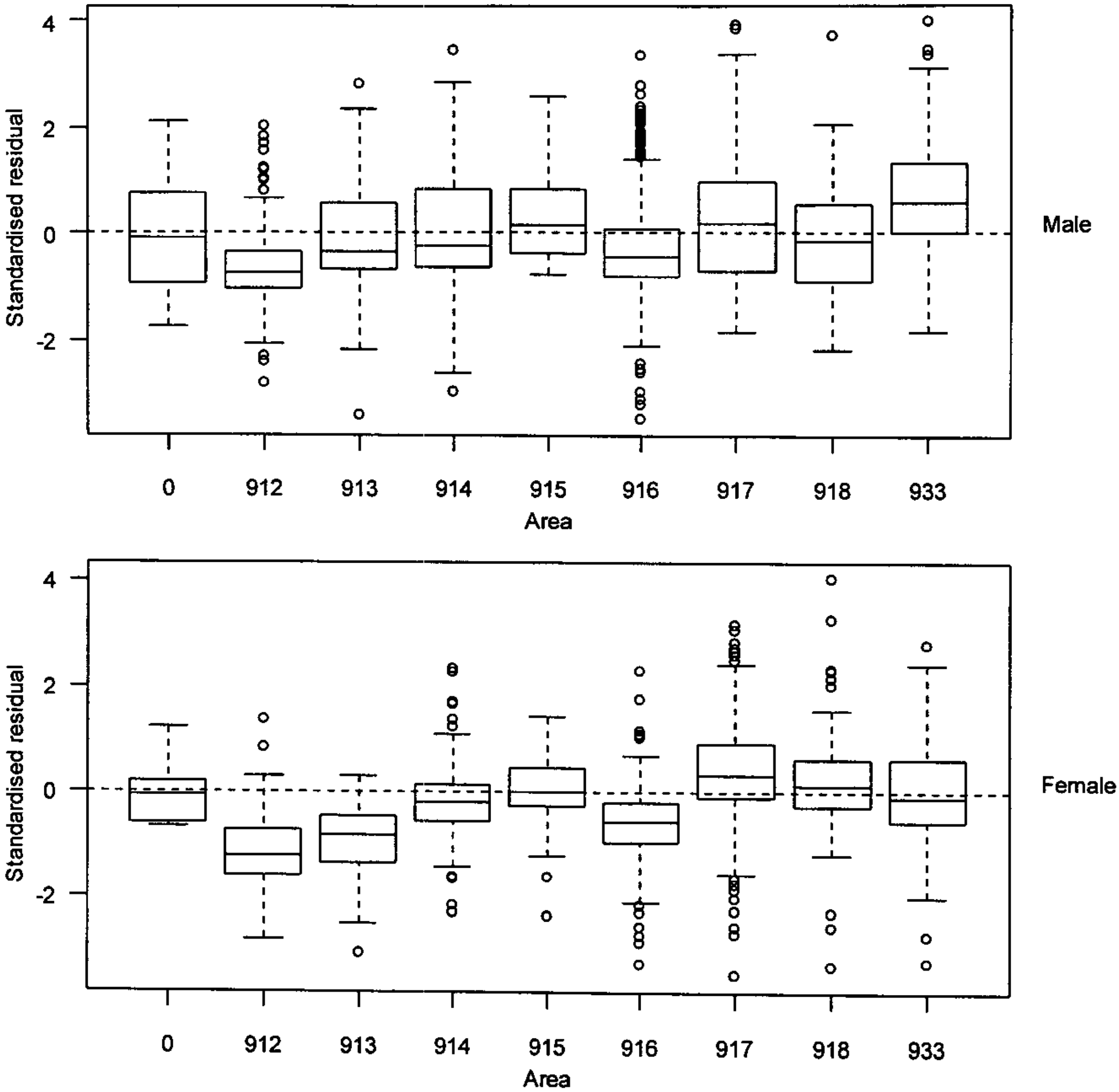


Figure 25: CRA 4: Box plots of the residuals from tag-recapture data by area of release; "0" indicates that no area was recorded.

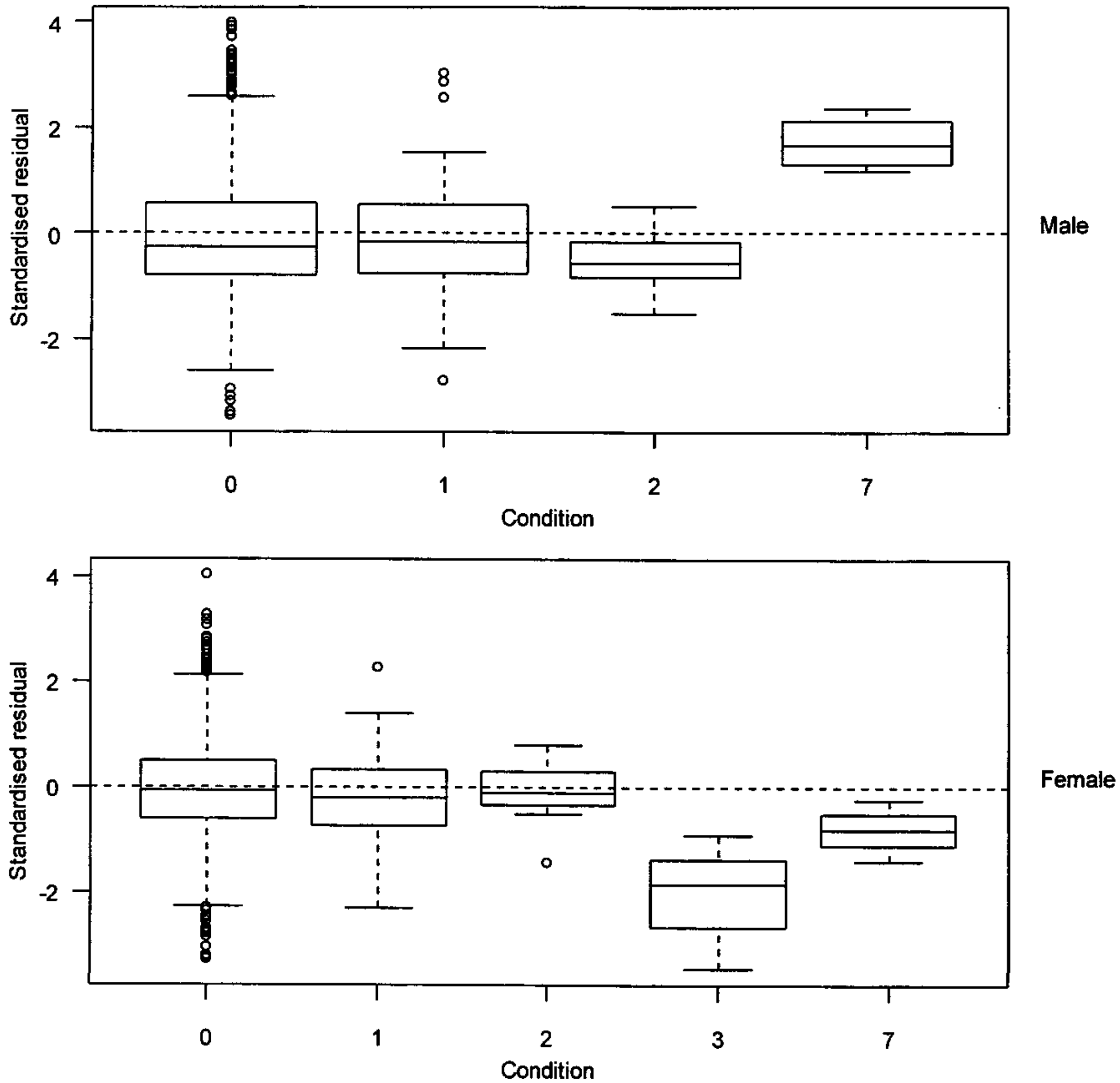


Figure 26: CRA 4: Box plots of the residuals from tag-recapture data plotted by injury index: 0, no injury; 1, one leg missing; 2, two legs missing; 7, severe injuries.

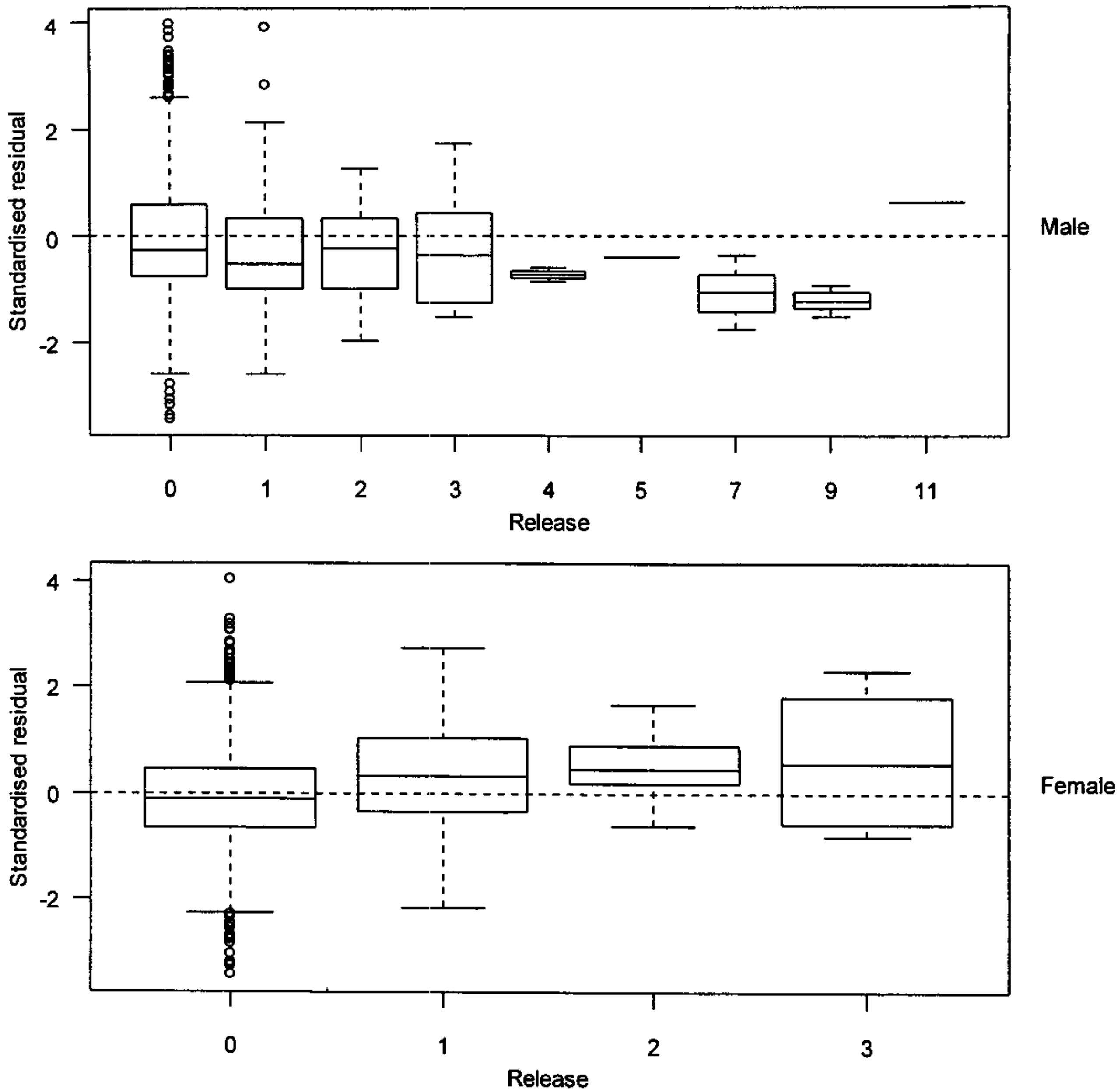


Figure 27: CRA 4: Box plots of residuals from tag-recapture data plotted by the number of re-releases.

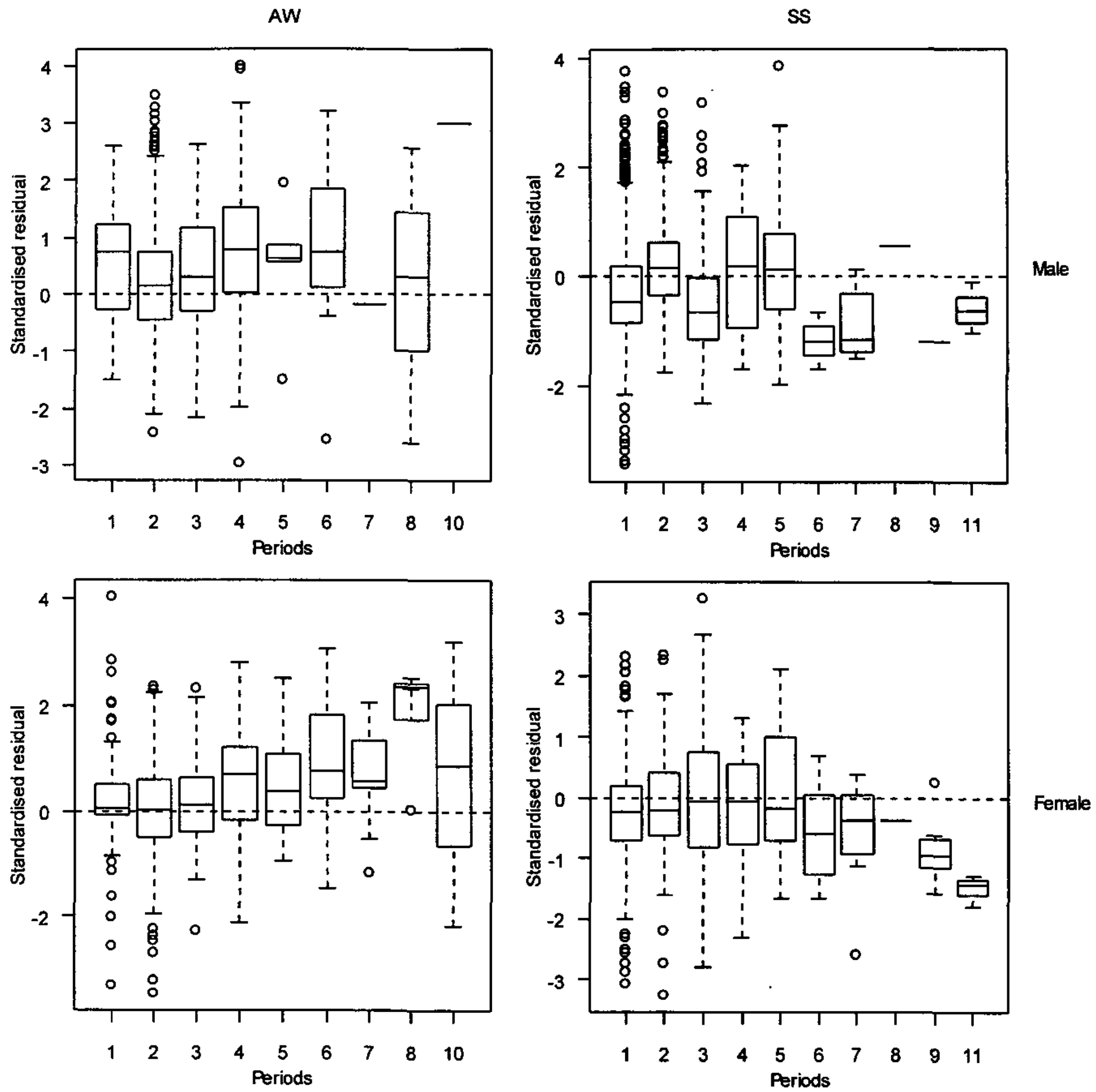


Figure 28: CRA 4: Box plots of residuals from tag-recapture data plotted by the number of periods at liberty and by season of release.

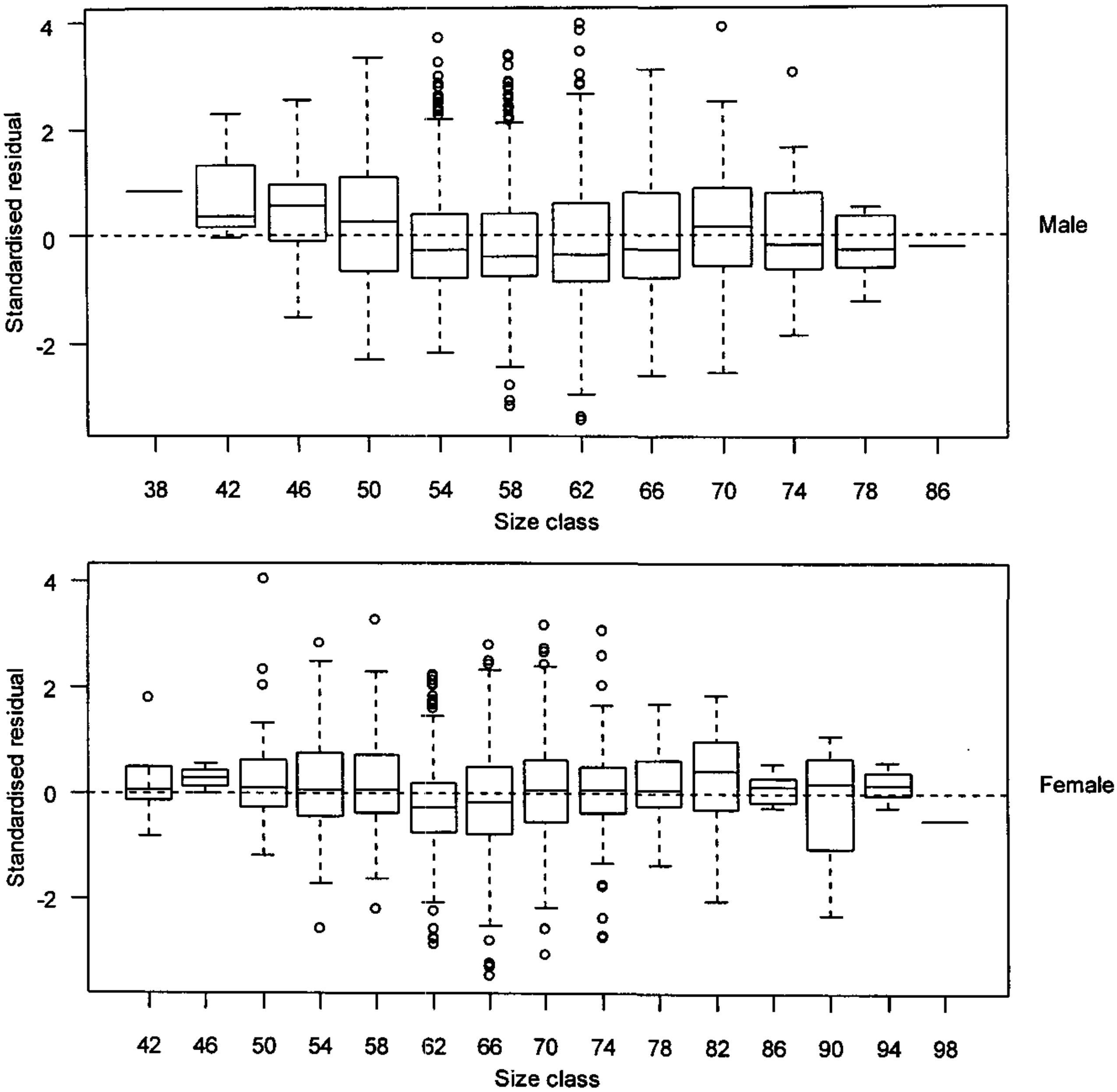


Figure 29: CRA 4: Box plots of residuals from tag-recapture data plotted by initial size.

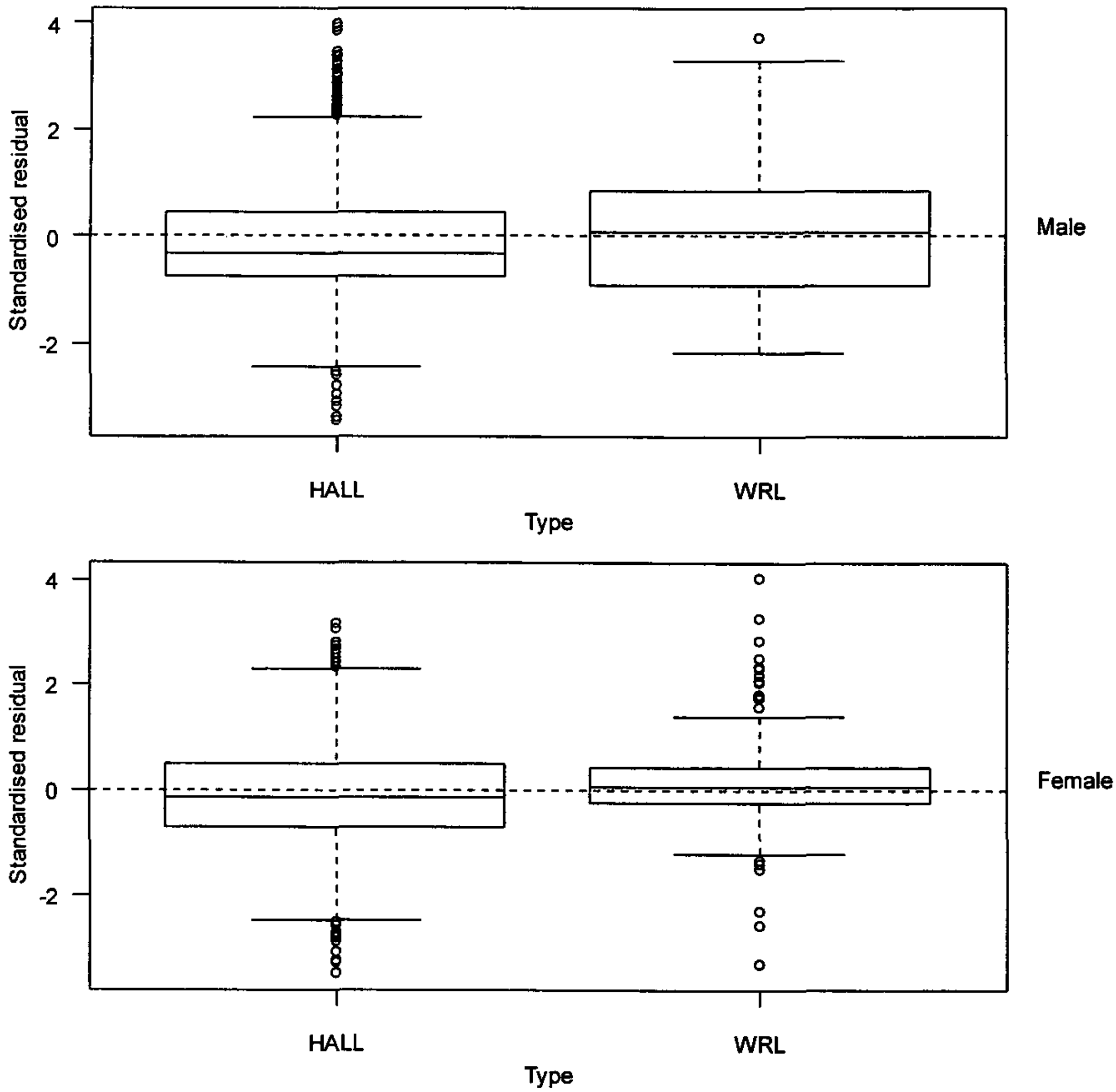


Figure 30: CRA 4: Box plots of residuals from tag-recapture data plotted by tag type: Hall, plastic dart tag from HallPrint; WRL, western rock lobster tag.

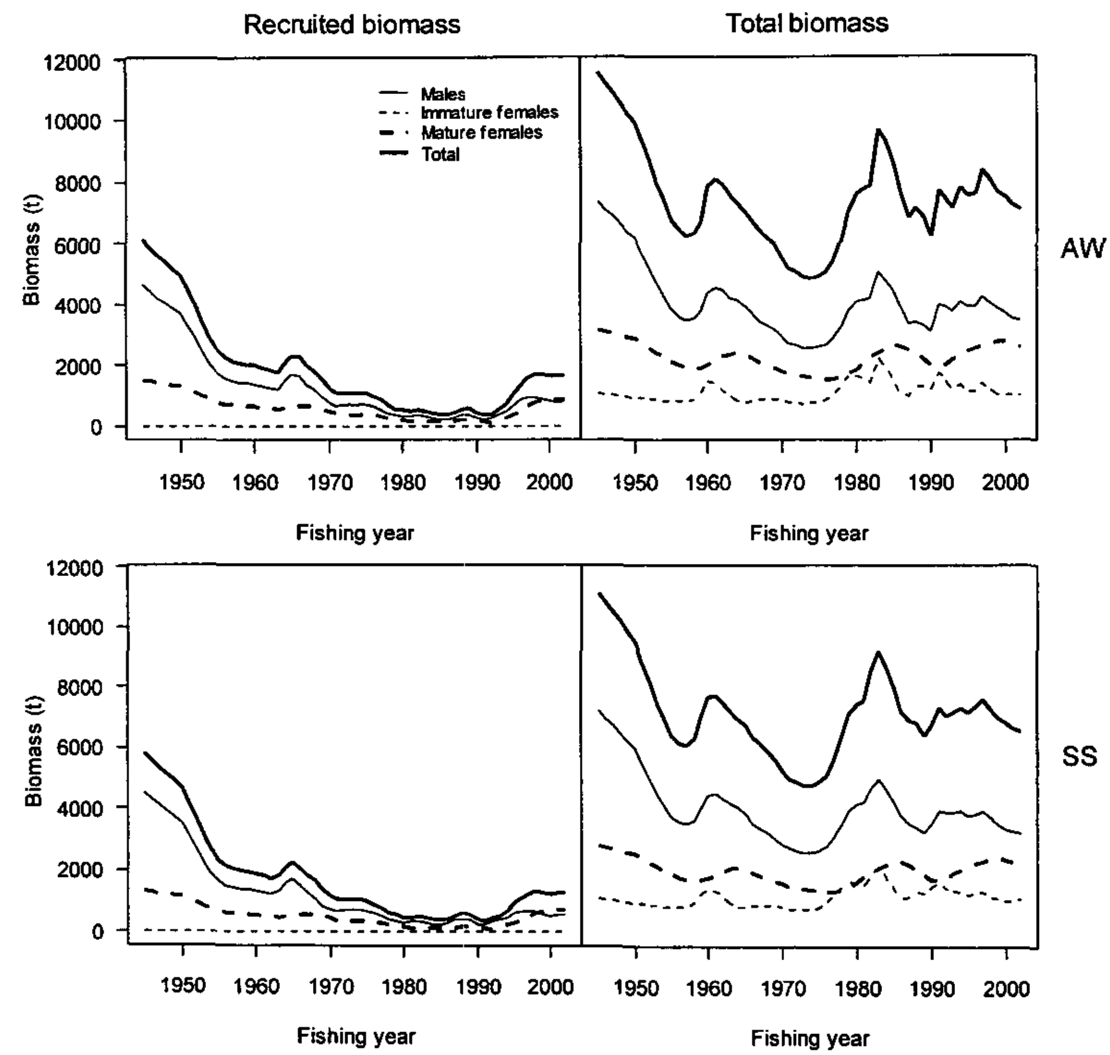


Figure 31: CRA 4: Recruited (left panels) and total biomass (right panels) from the MPD fit by sex and season: upper panels, AW season; lower panels, SS season.

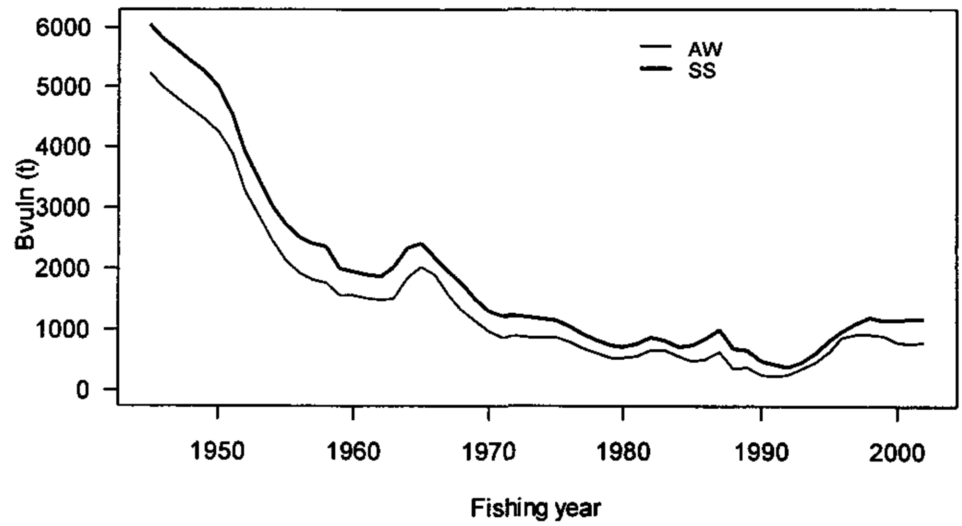


Figure 32: CRA 4: Predicted vulnerable biomass from the base case MPD fit: heavy line.

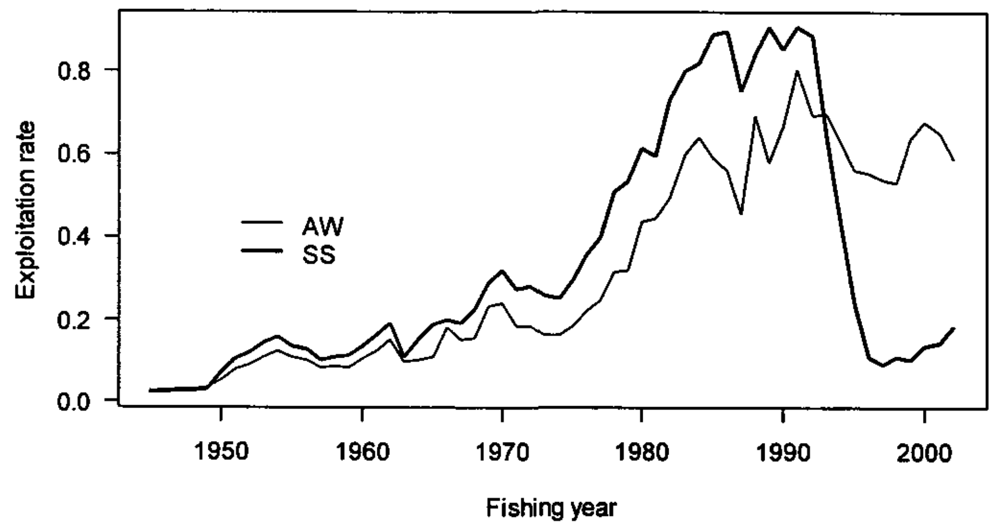


Figure 33: CRA 4: Exploitation rate trajectories from the base case MPD fit.

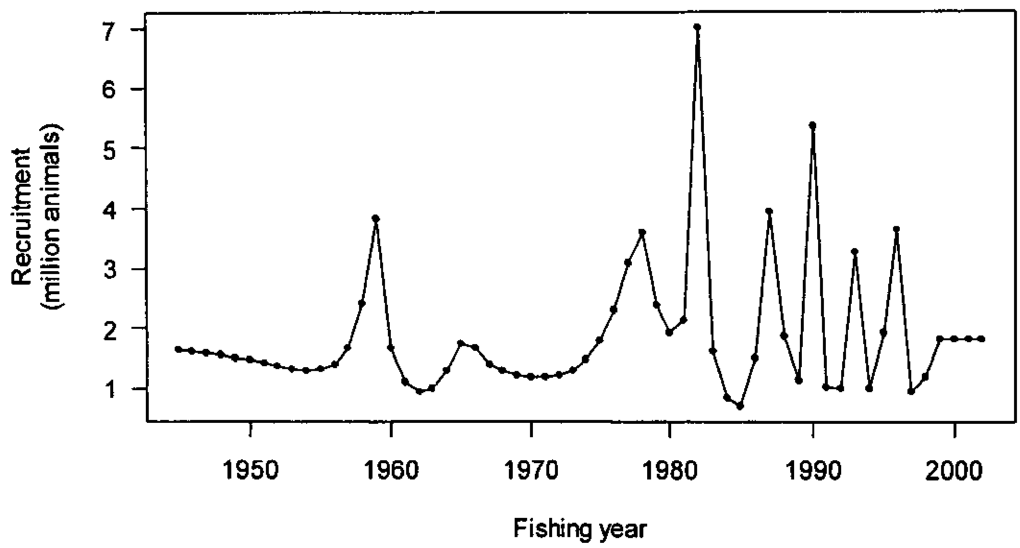


Figure 34: CRA 4: Recruitment trajectory (millions) from the base case MPD fit.

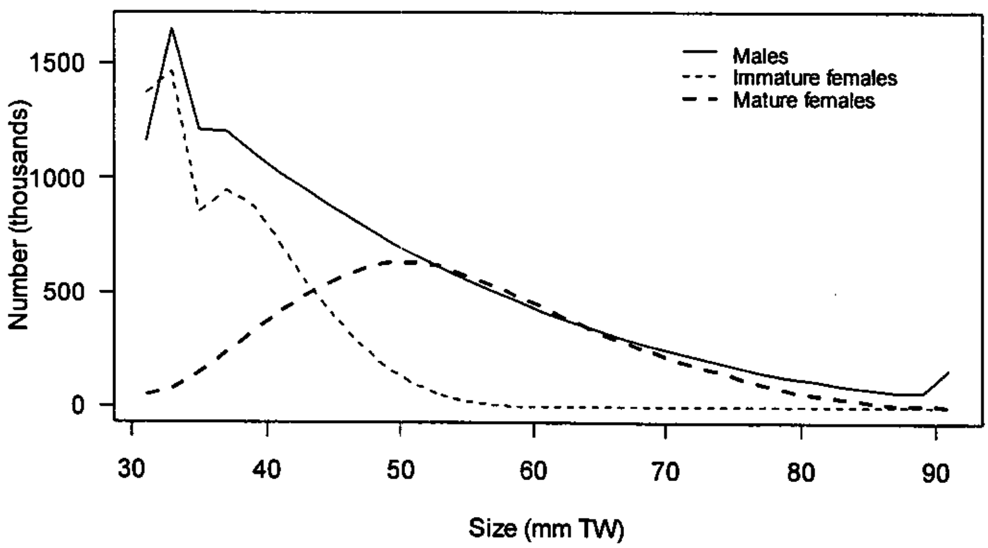


Figure 35: CRA 4: Initial length structure from the base case MPD fit for each sex.

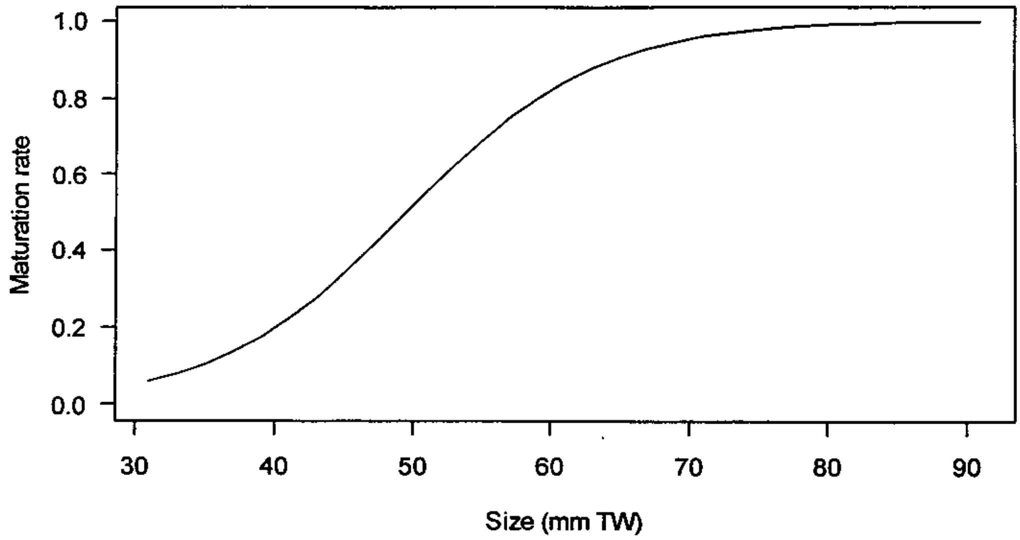


Figure 36: CRA 4: Maturation rate from the base case MPD fit.

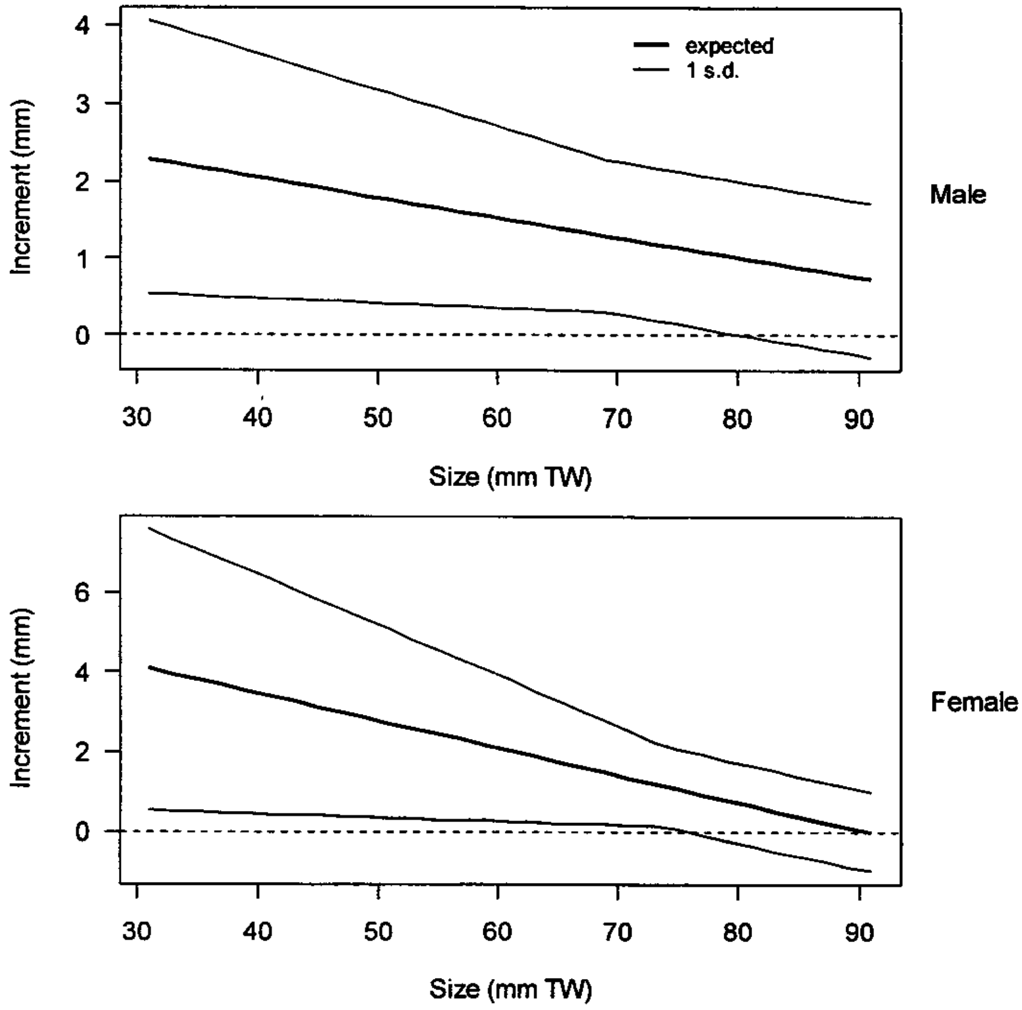


Figure 37: CRA 4: Predicted annual growth increment (thick line) *vs* initial size of rock lobster, shown with one standard deviation around the increment (thin line).

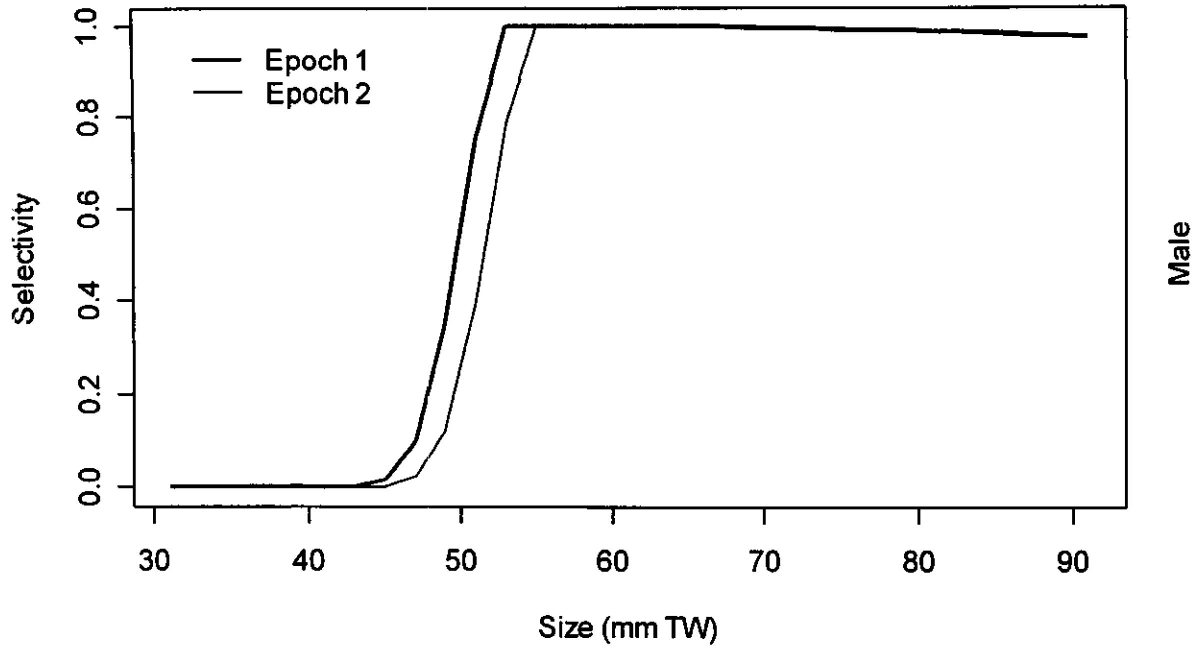


Figure 38: CRA 4: Selectivity for males in each epoch: epoch 1 extends from 1945 to 1992, epoch 2 from 1993 onwards.

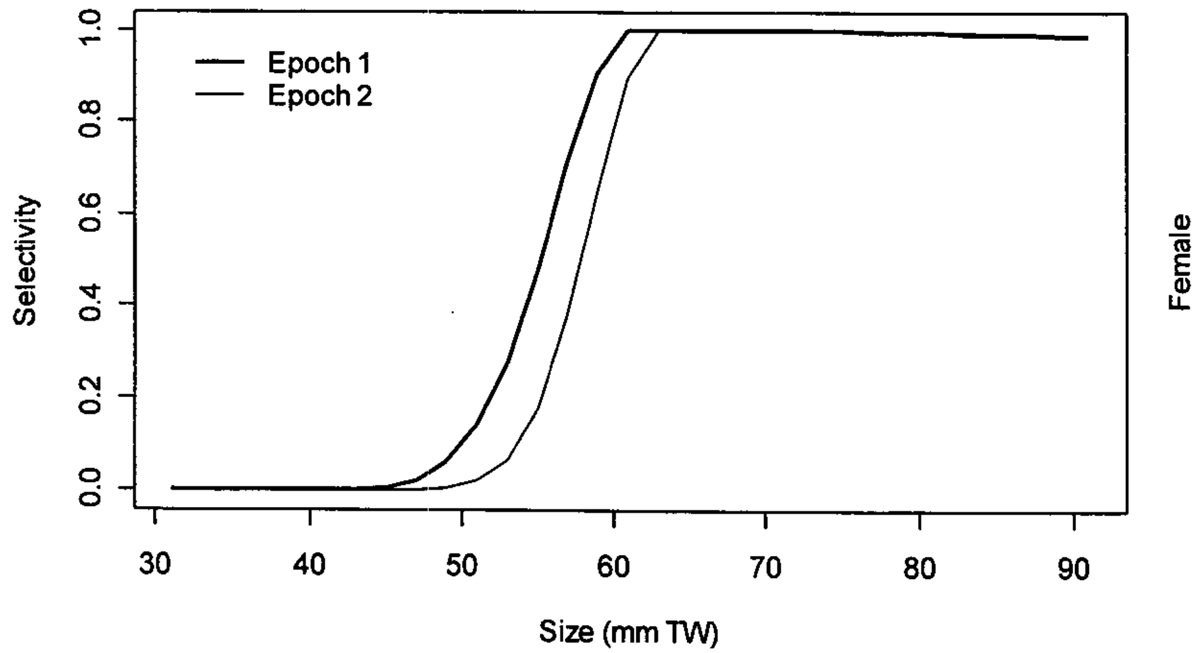


Figure 39: CRA 4: Selectivity for females in each epoch.

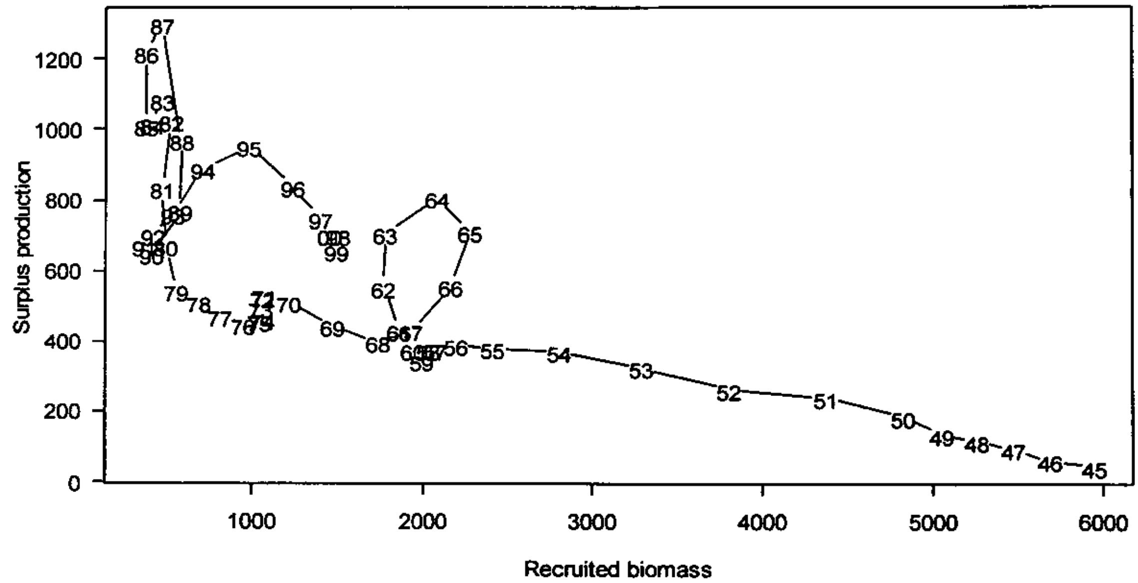


Figure 40: CRA 4: Surplus production plotted against recruited biomass. The labels indicate the last two digits of the fishing year.

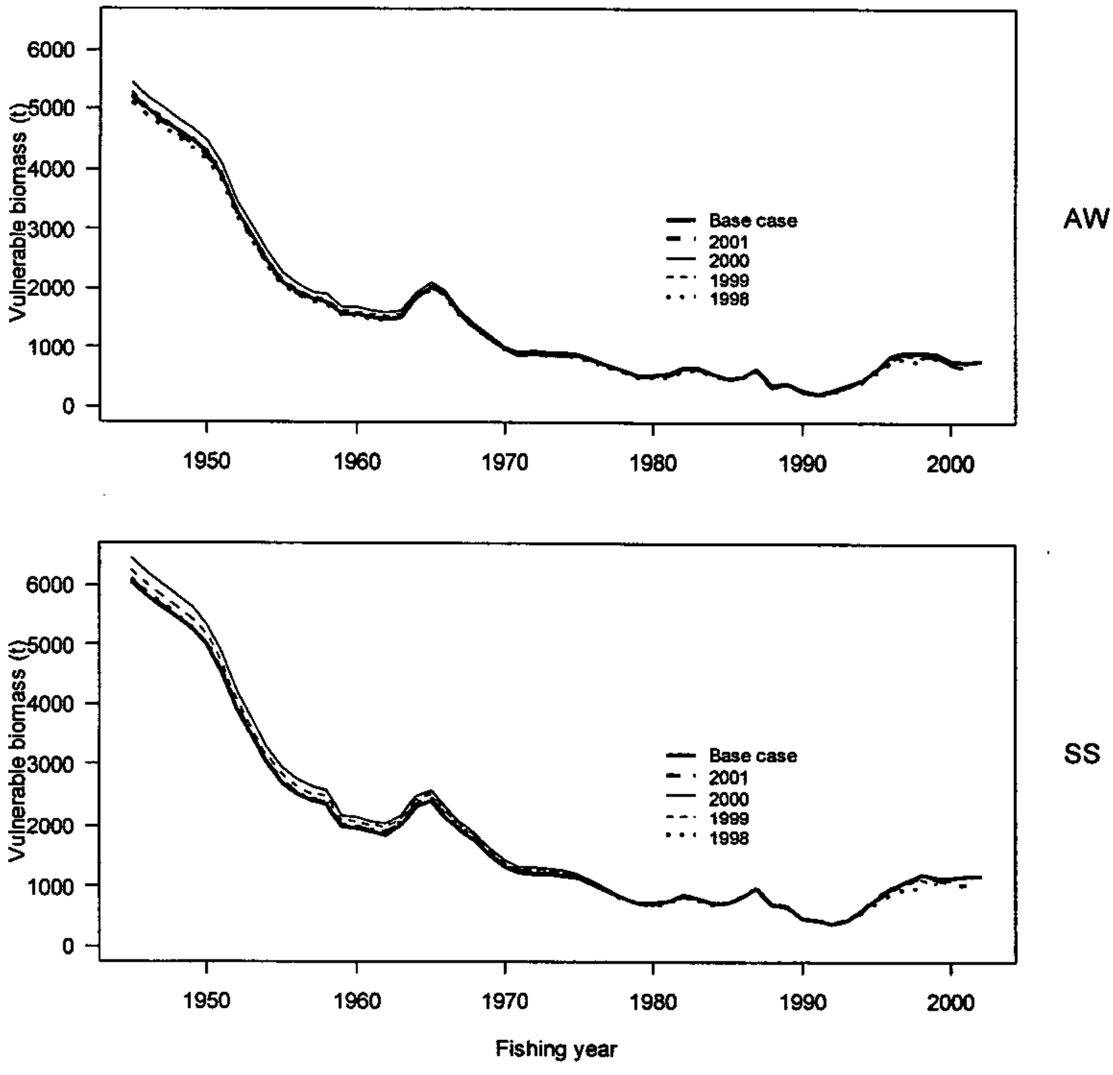


Figure 41: CRA 4: Vulnerable biomass trajectories from the MPD estimates in a retrospective analysis. The key refers to datasets labelled by the last year of data they include. The base case includes 2002 data.

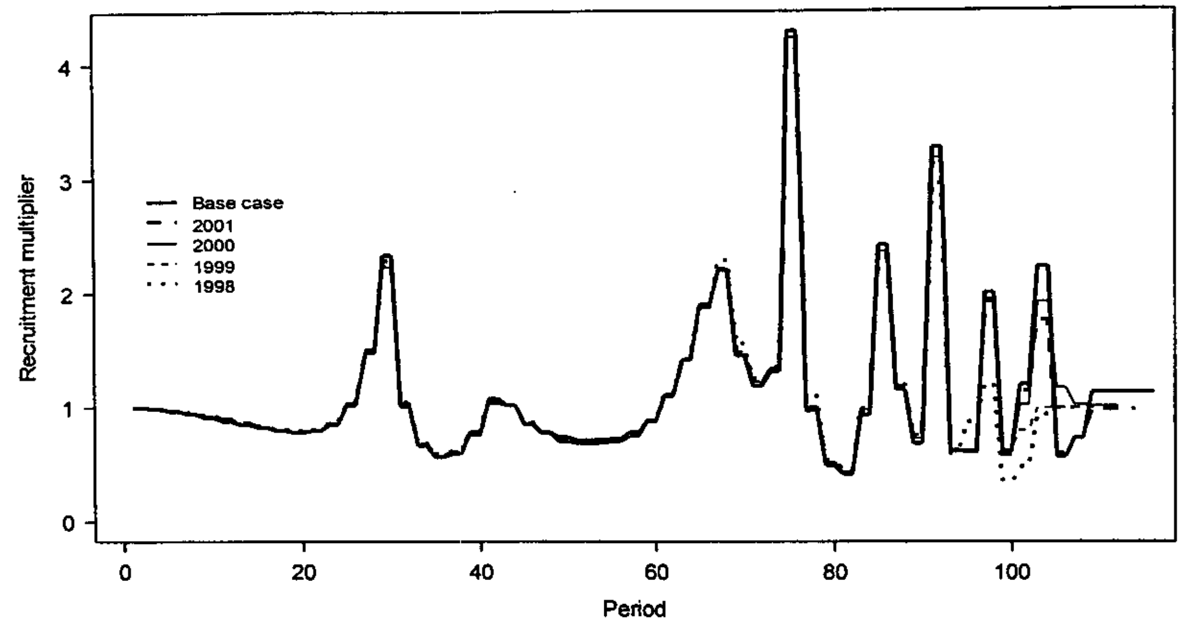


Figure 42: CRA 4: Recruitment multiplier trajectories from the MPD estimates in a retrospective analysis. The key refers to datasets labelled by the last of data they include. The base case includes 2002 data.

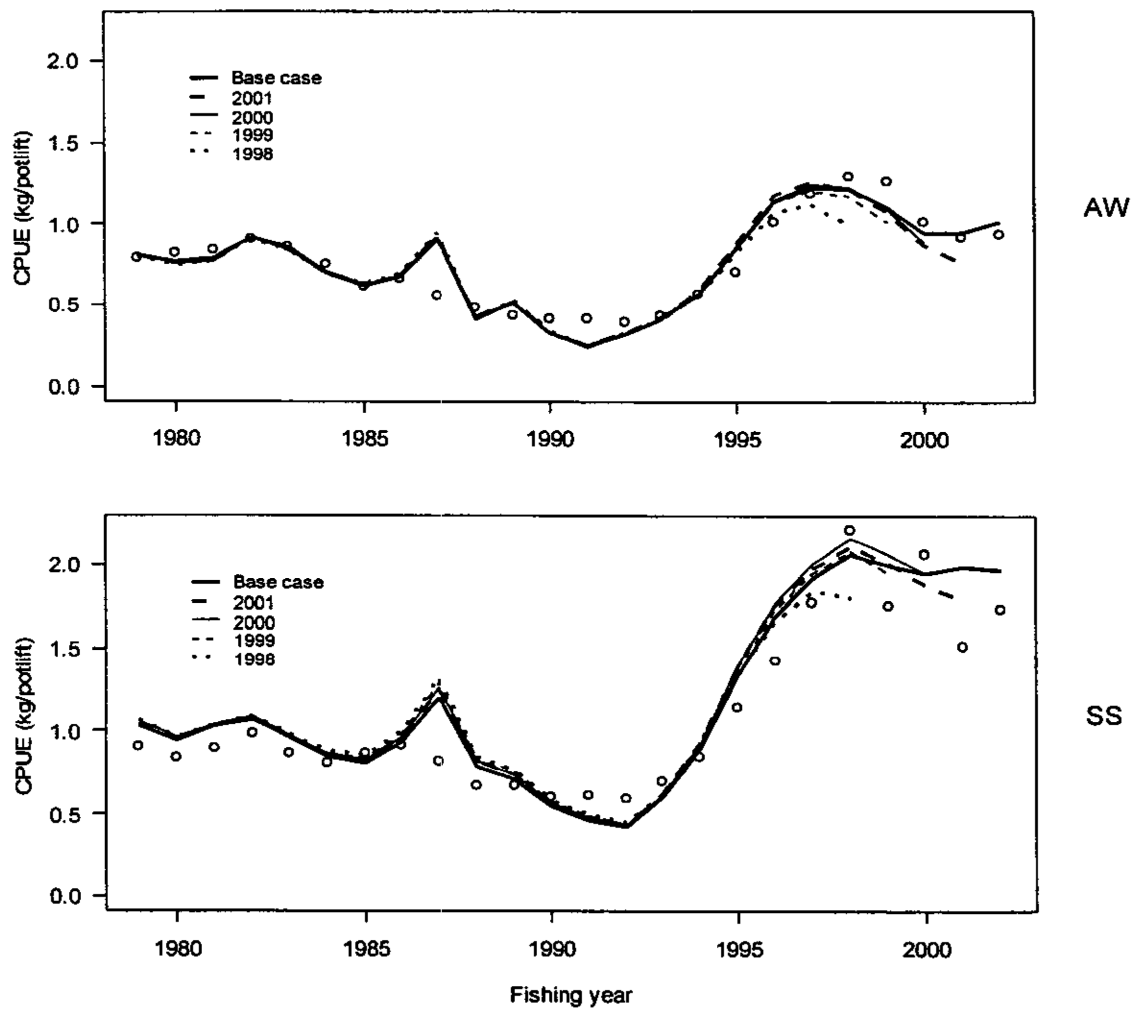


Figure 43: CRA4: CPUE trajectories from the MPD estimates in a retrospective analysis. The key refers to datasets labelled by the last of data they include. The base case includes 2002 data.

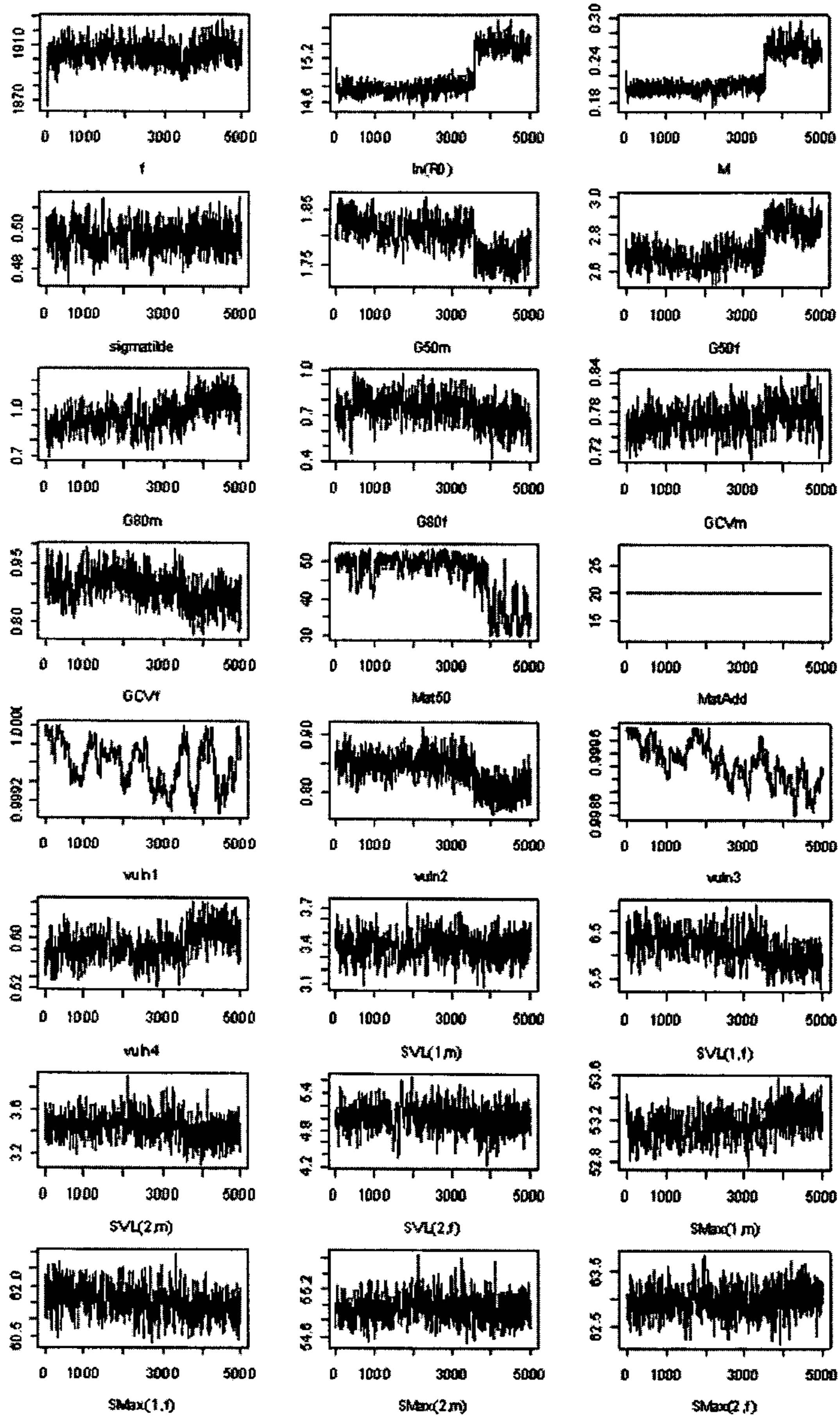


Figure 44: CRA 4: Traces of parameters and indicators from the base case McMC simulations.

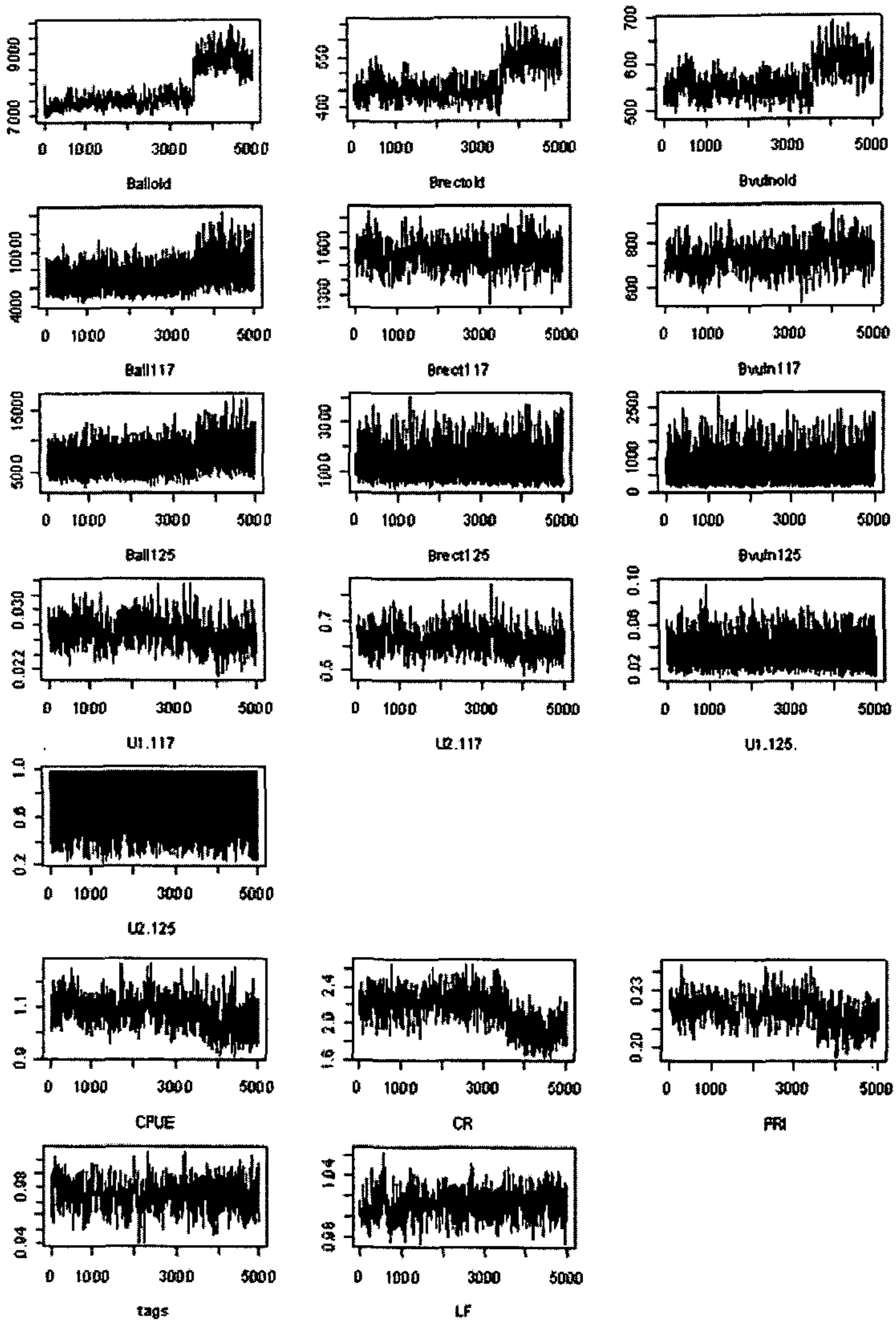


Figure 44 continued.

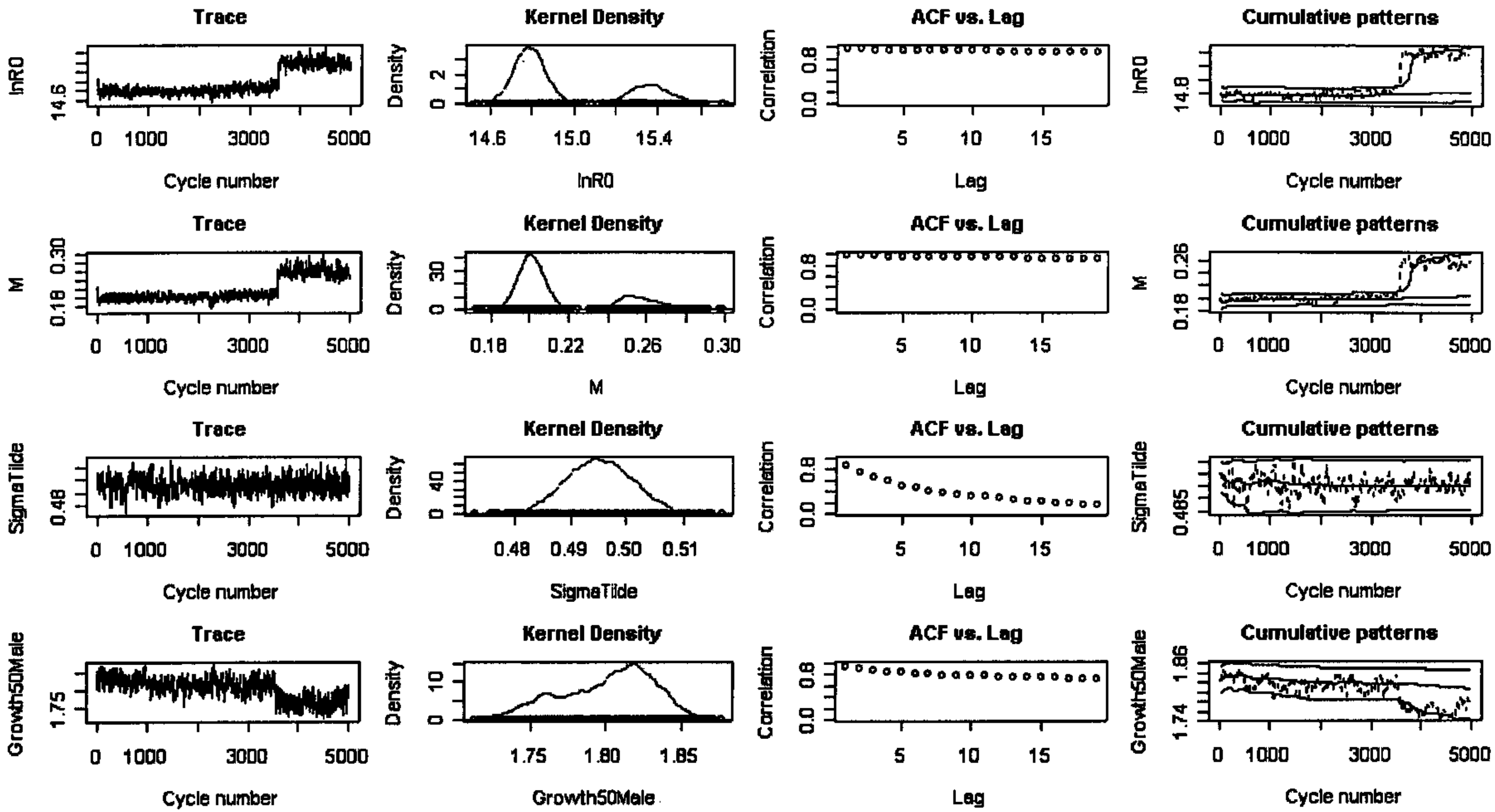


Figure 45: CRA 4: Diagnostics from single chain for different parameters. Left: traces; second from left: posterior distribution; second from right: serial autocorrelation; right: the cumulative fifth and 95th percentiles of the traces, the cumulative median and the running mean over 40 samples.

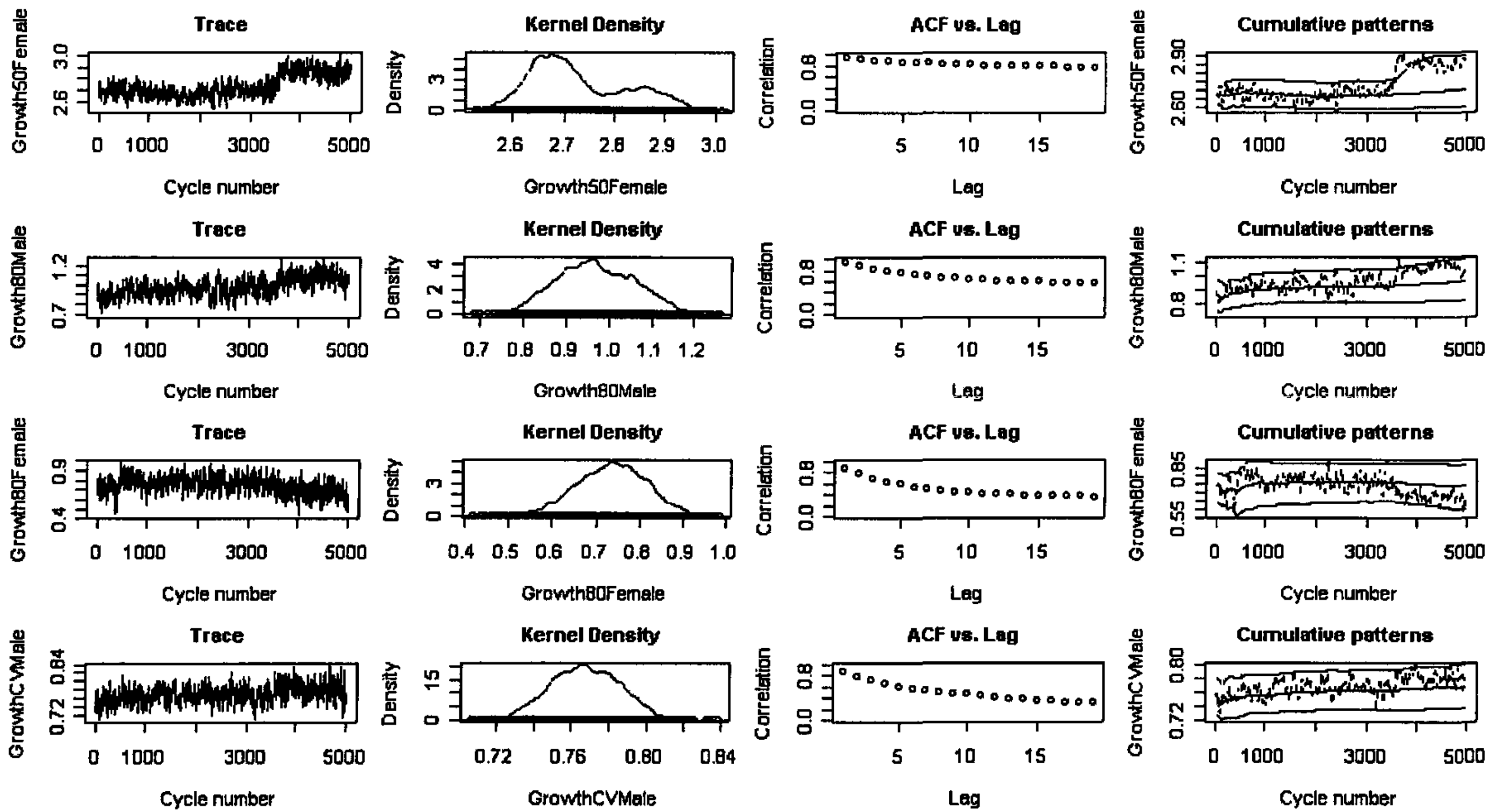


Figure 45 continued.

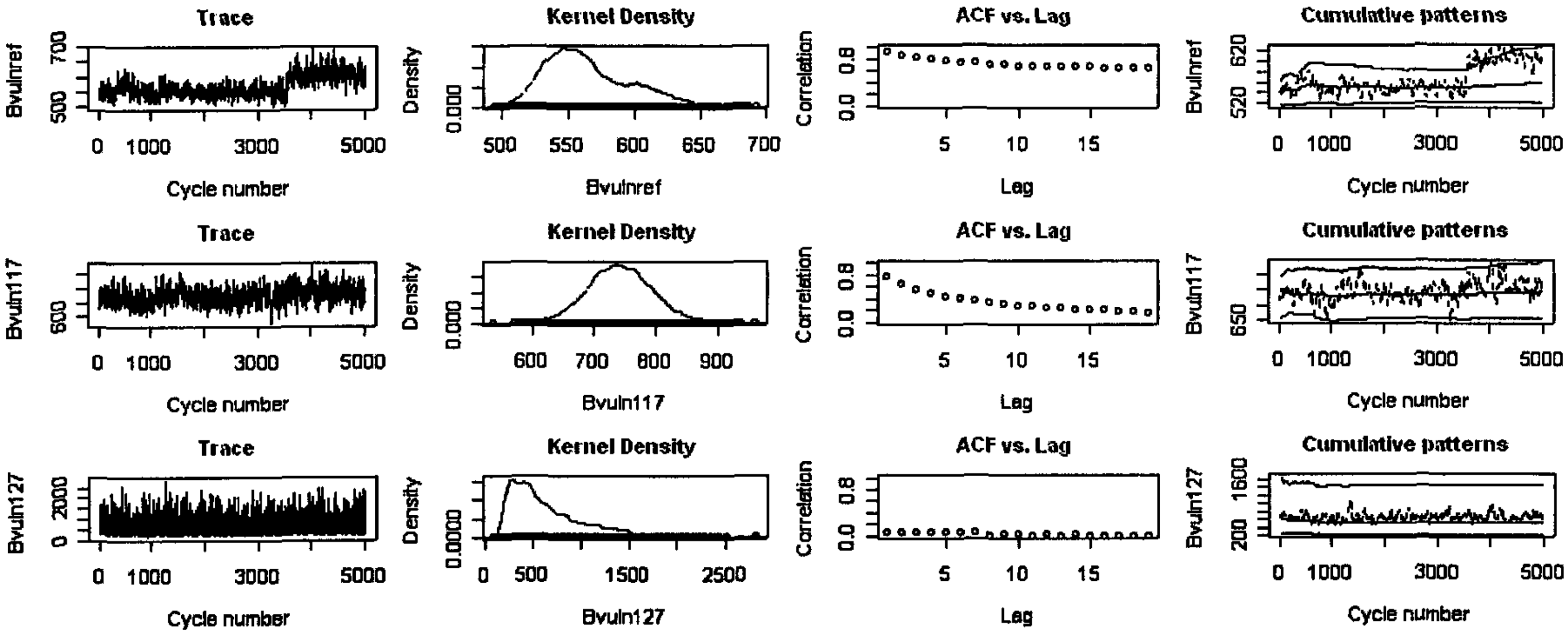


Figure 45 continued.

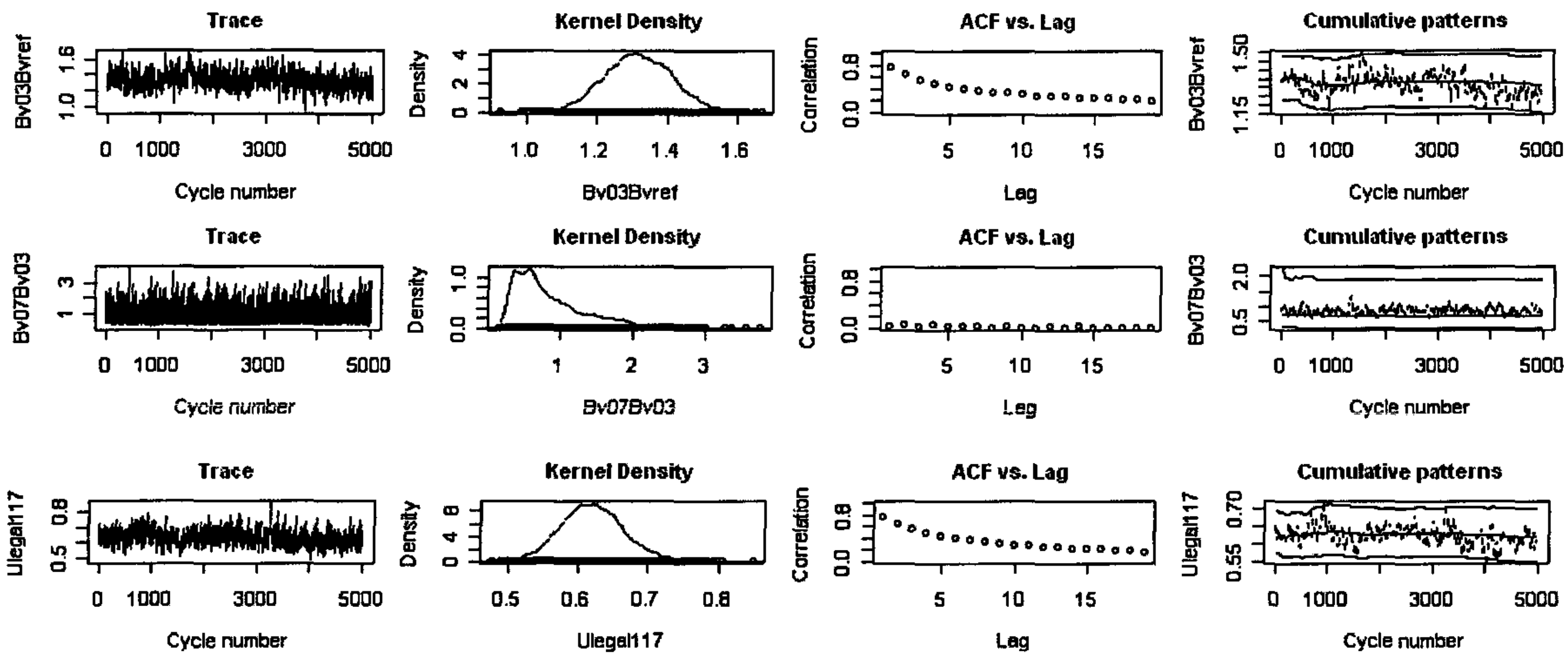


Figure 45 continued.

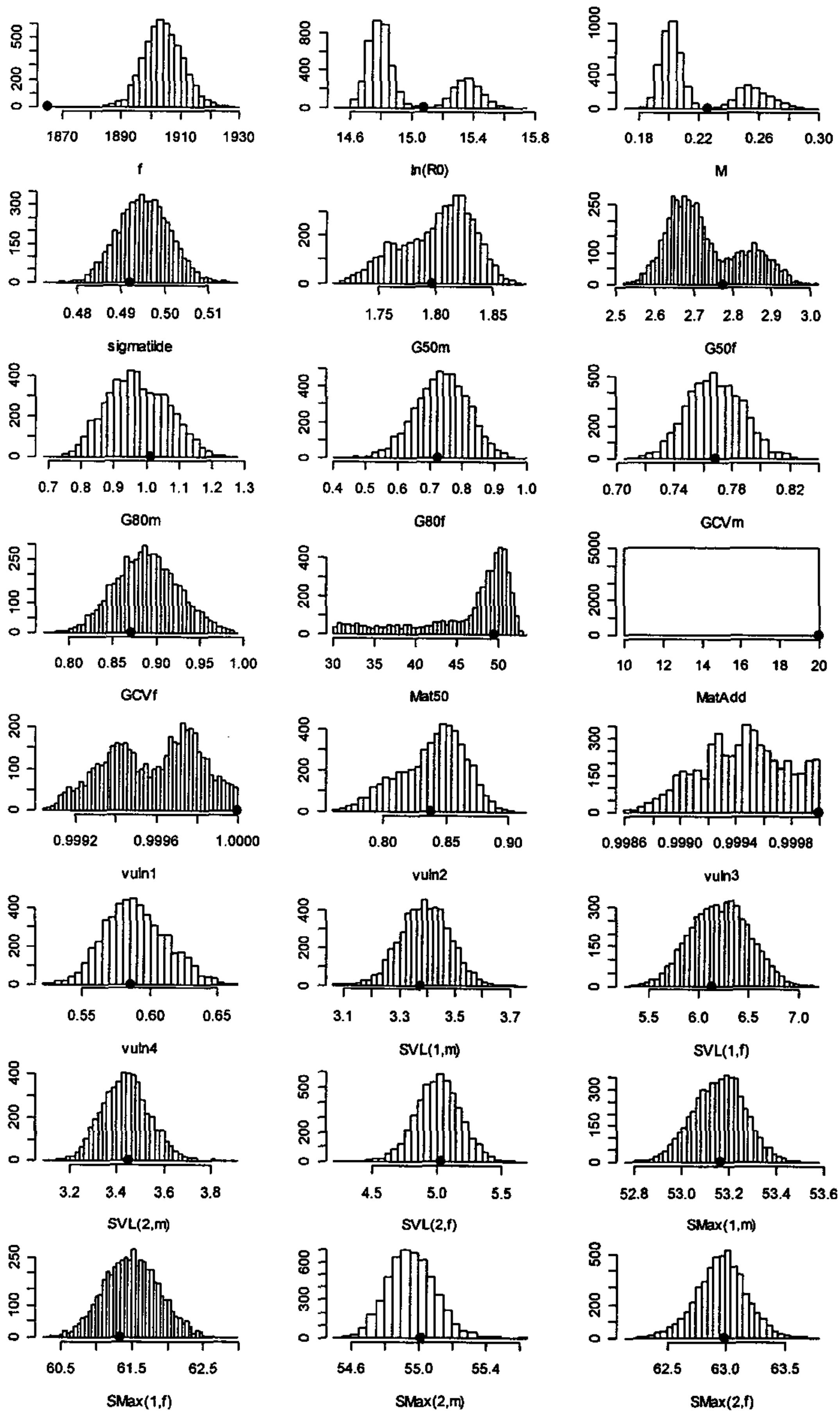


Figure 46: CRA 4: Marginal posterior distributions.

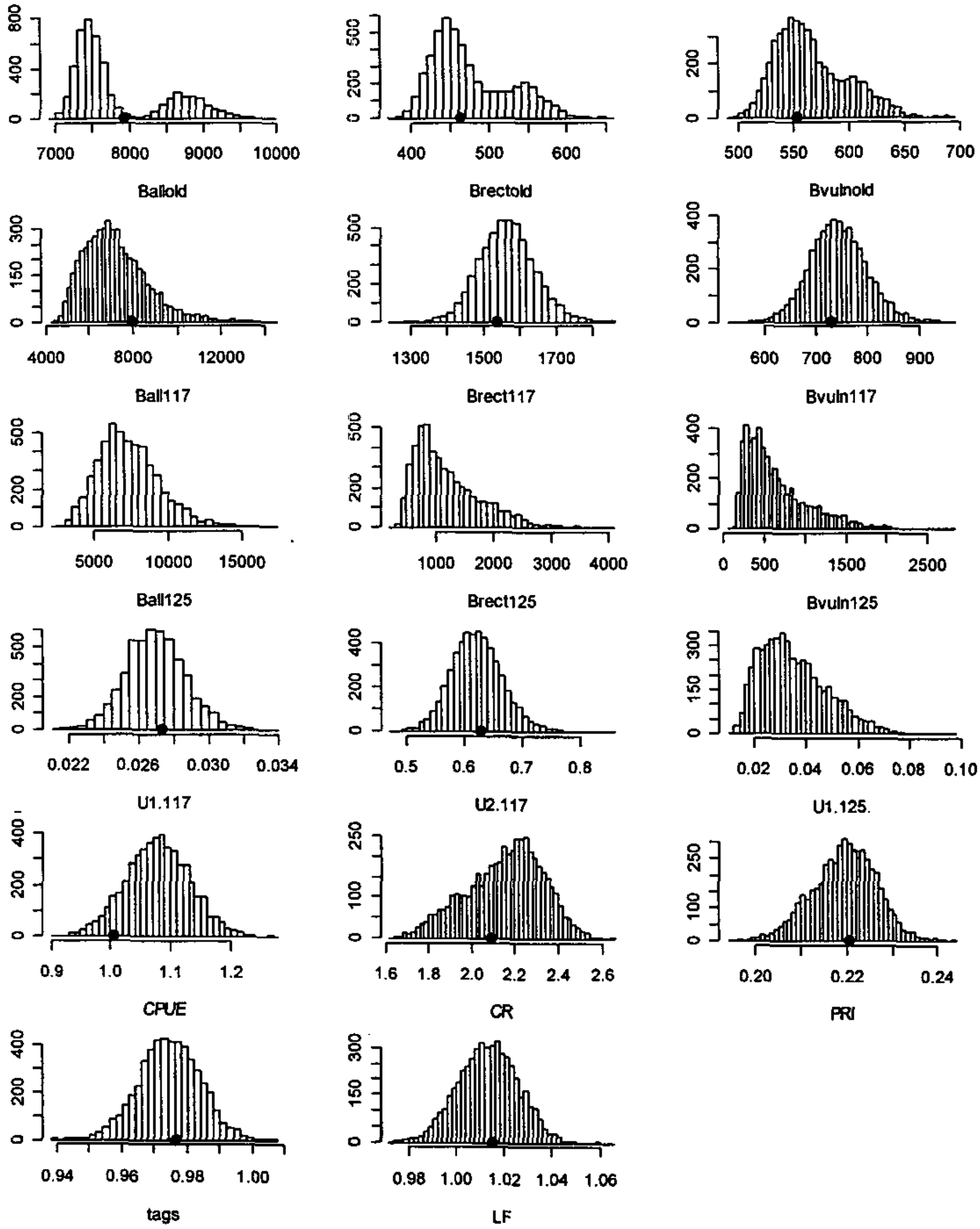


Figure 46 continued.

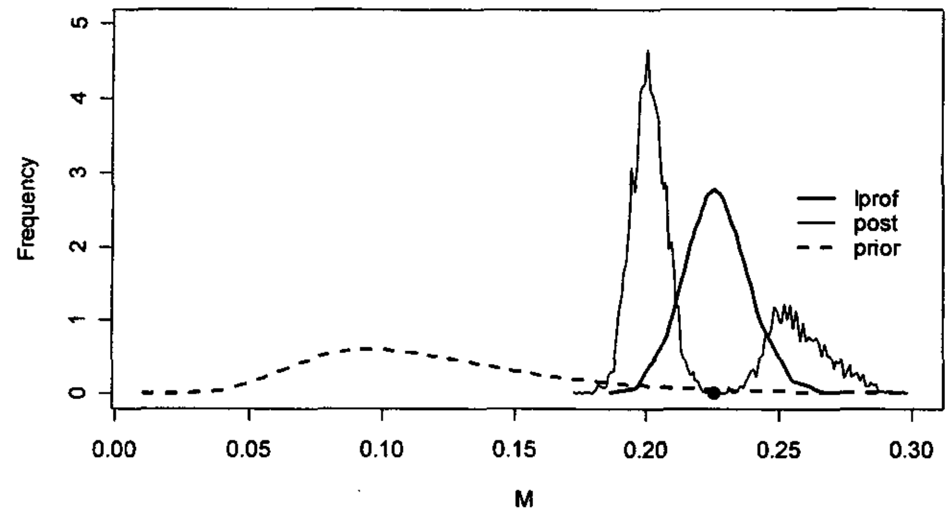


Figure 47: CRA 4: Comparison of the prior distribution (prior) of *M*, the likelihood profile (lprof), and the posterior (post). The dot is the MPD estimate.

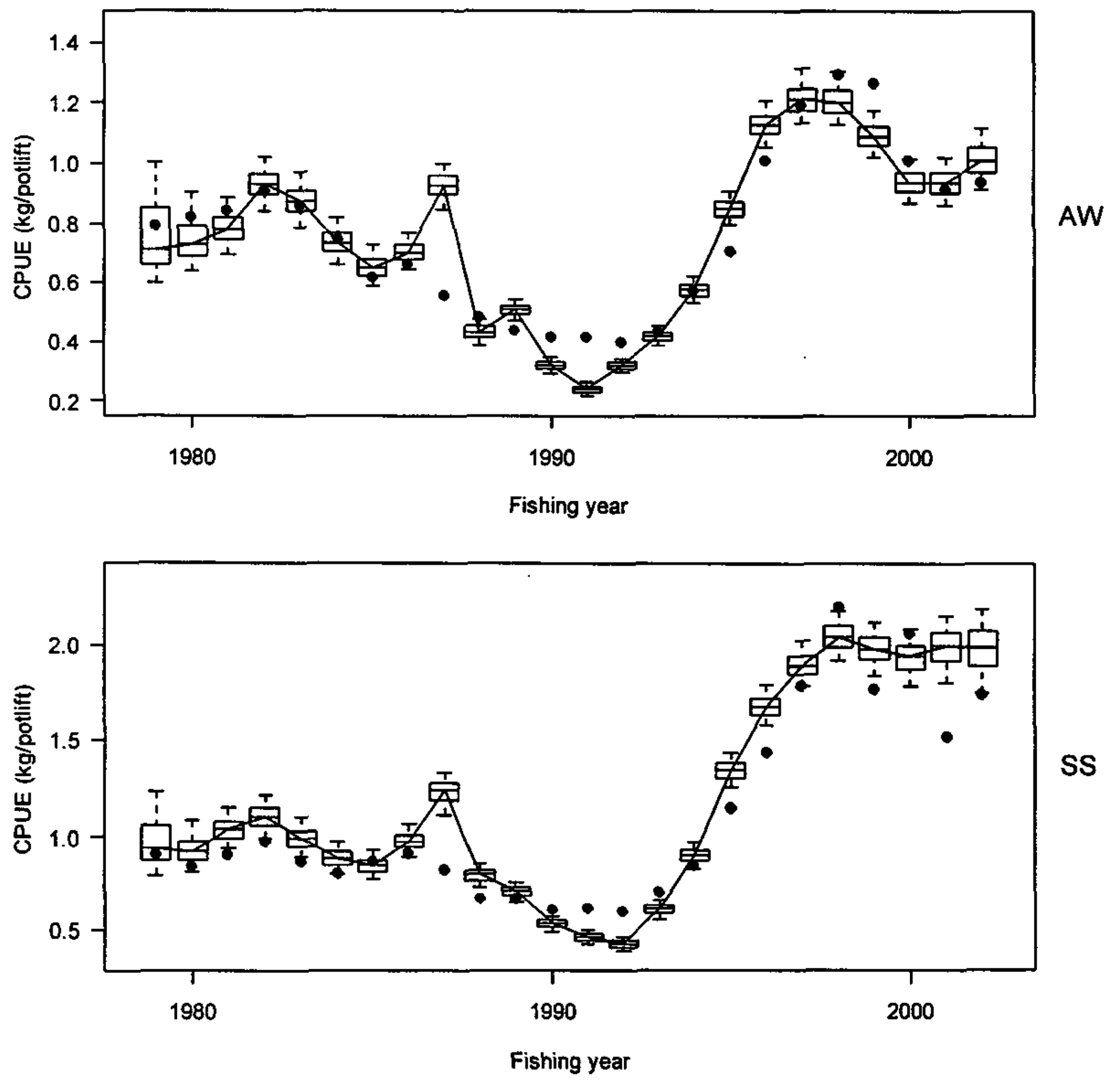


Figure 48: CRA 4: The posterior distributions of the fits to CPUE data.

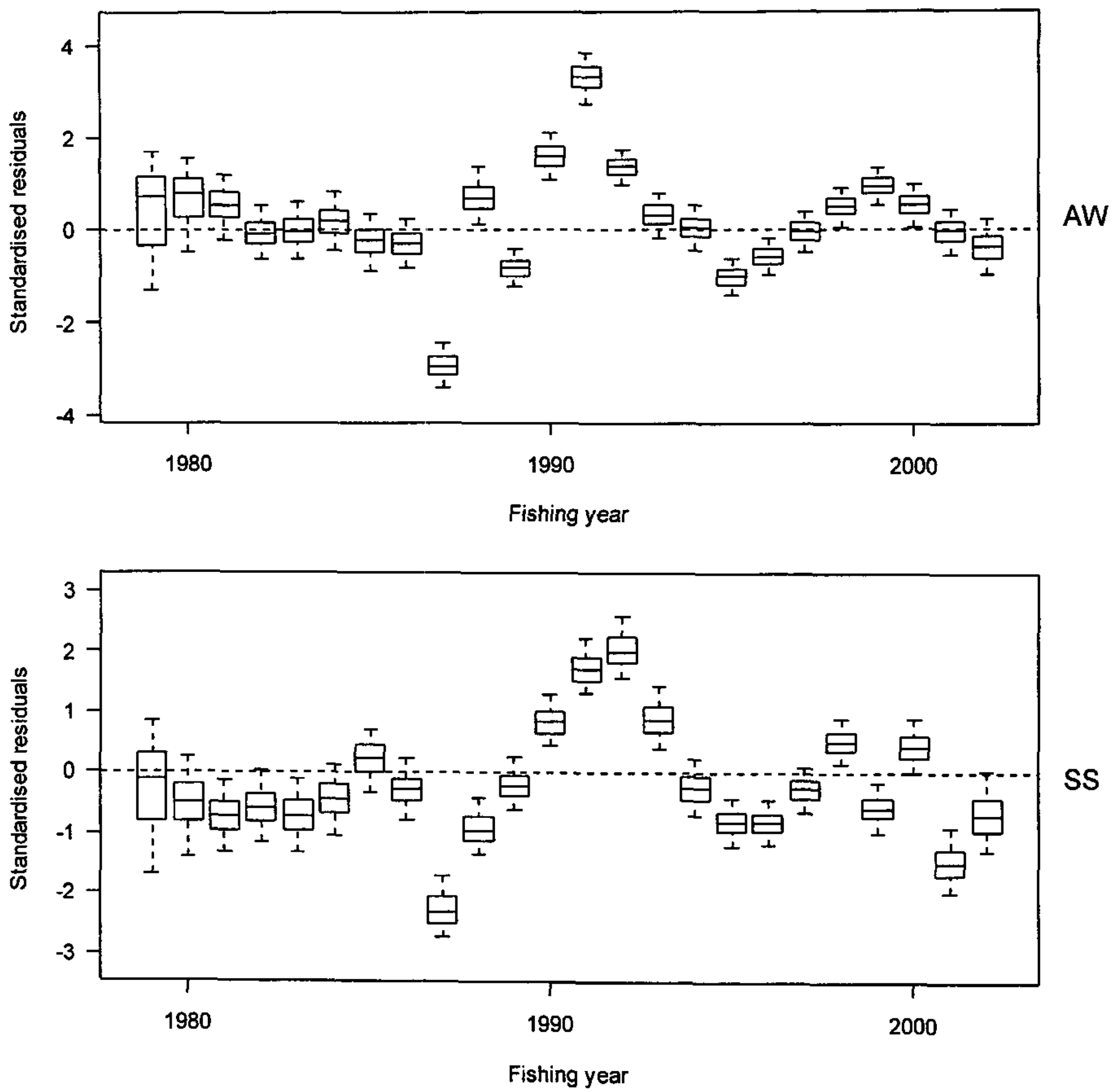


Figure 49: CRA 4: The posterior distributions of the normalised residuals from the CPUE fit.

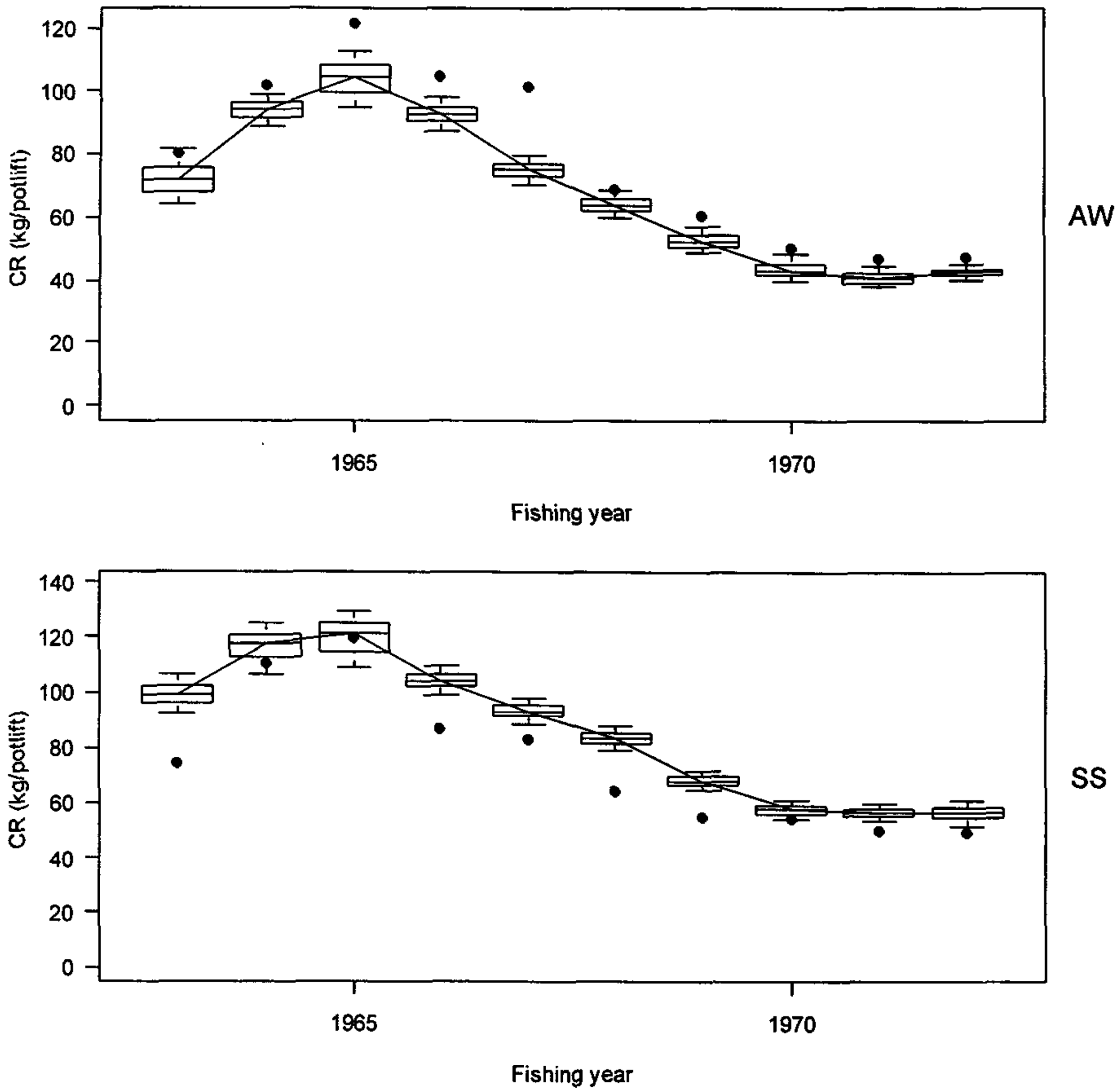


Figure 50: CRA 4: The posterior distributions of the fits to CR data.

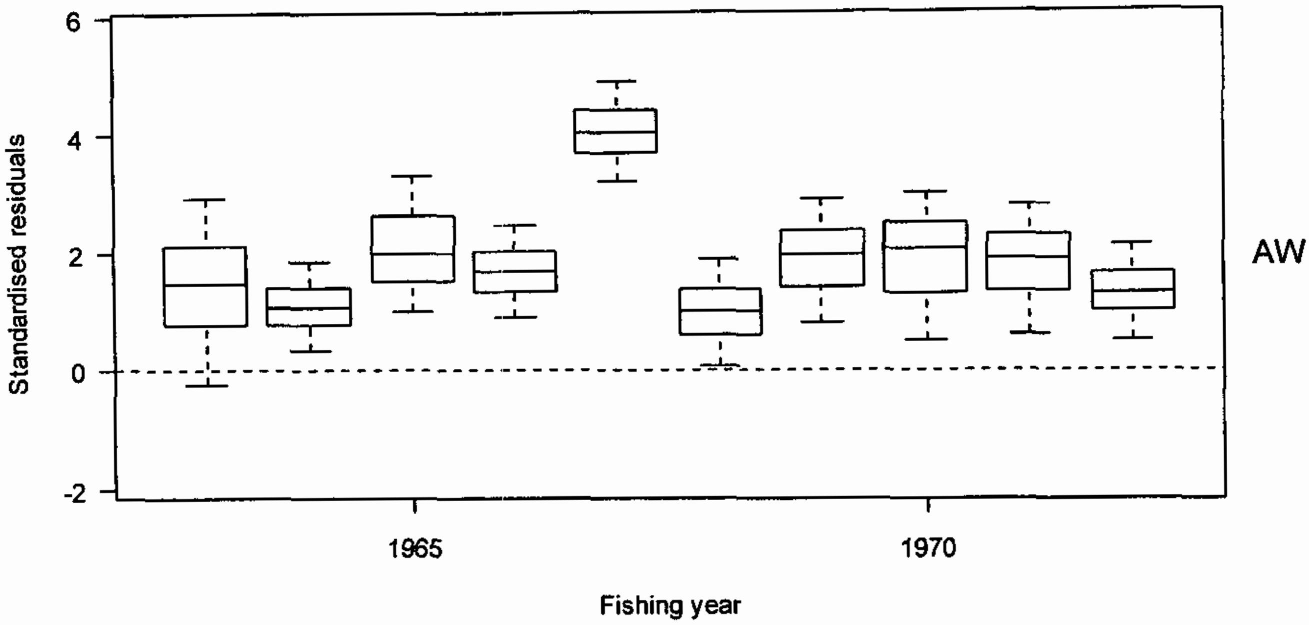


Figure 51: CRA 4: The posterior distributions of the normalised residuals from the CR fit.

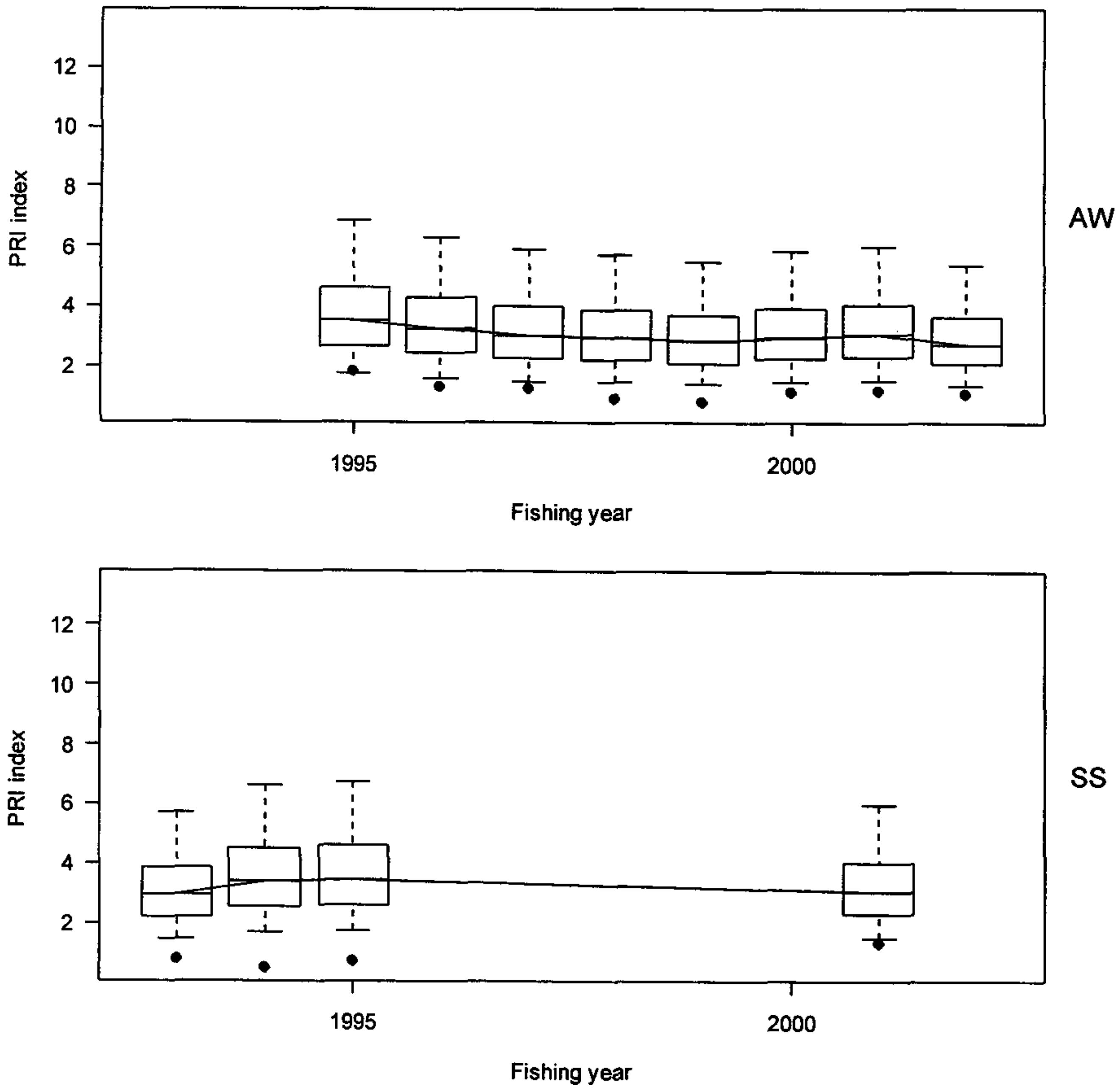
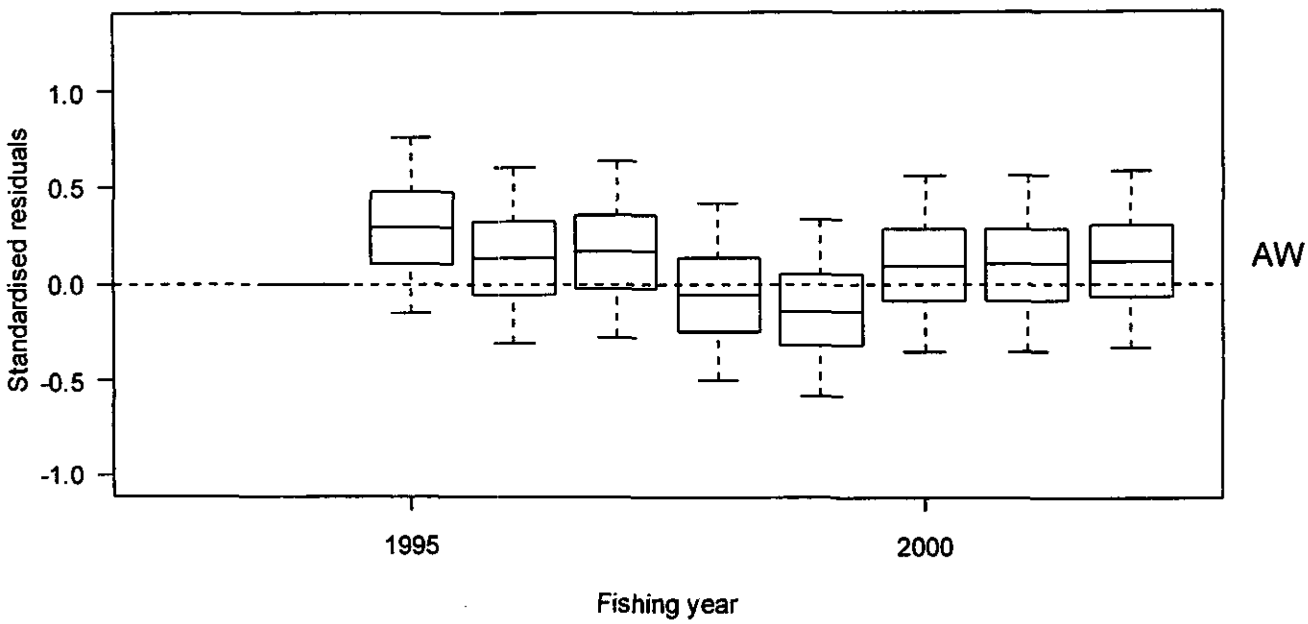


Figure 52: CRA 4: The posterior distributions of the fits to PRI data.



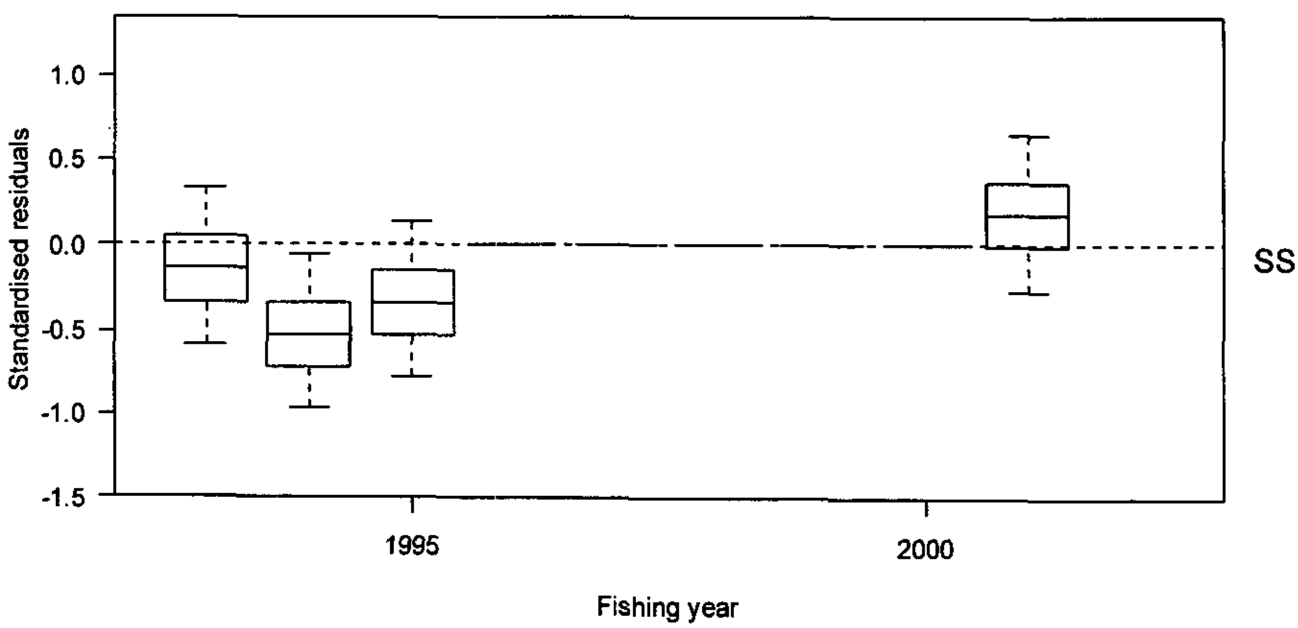


Figure 53: CRA 4: The posterior distributions of the normalised residuals from the PRI fit.

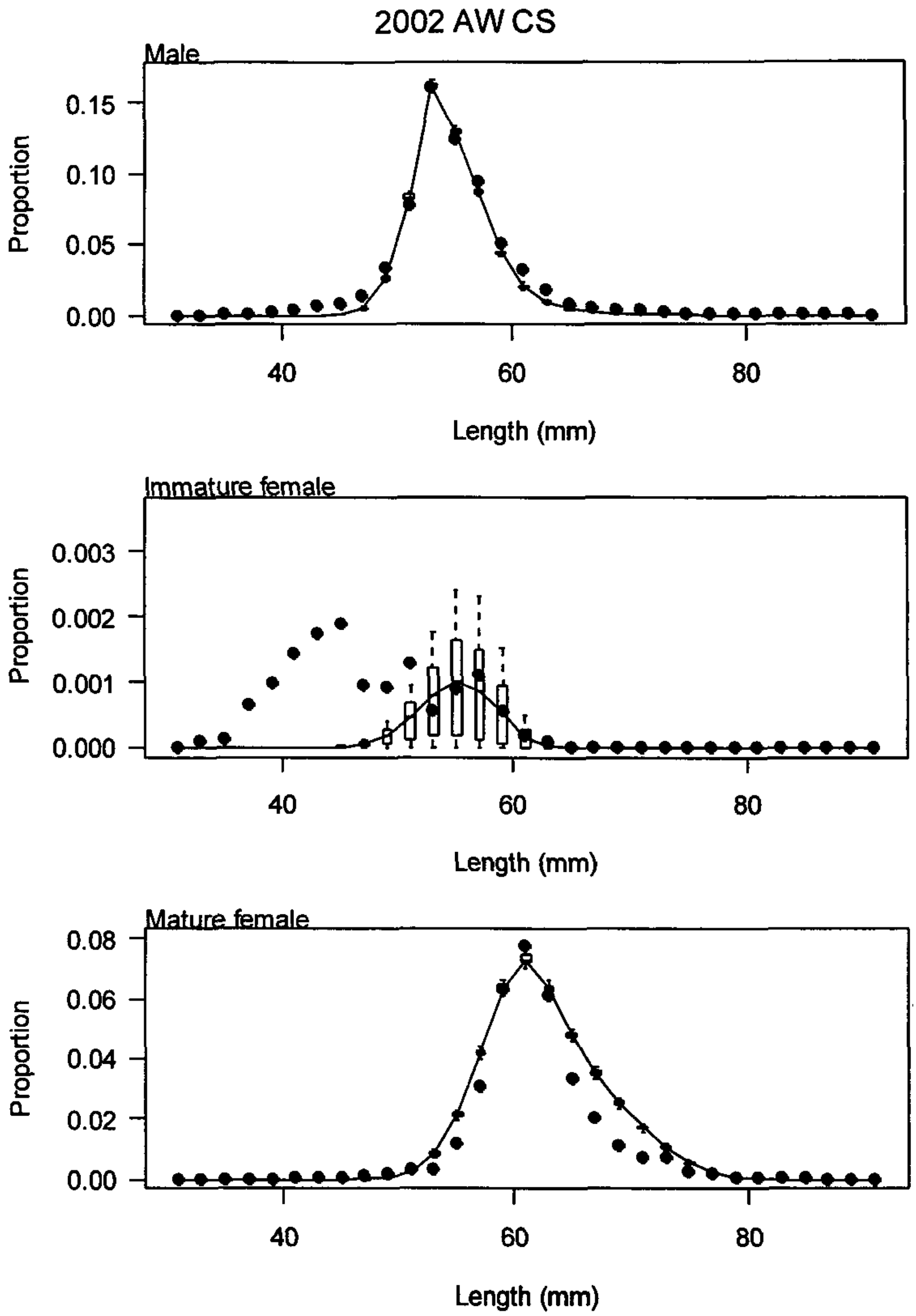


Figure 54: CRA 4: The posterior distributions of the fits to proportions-at-length from 2002 AW catch sampling.

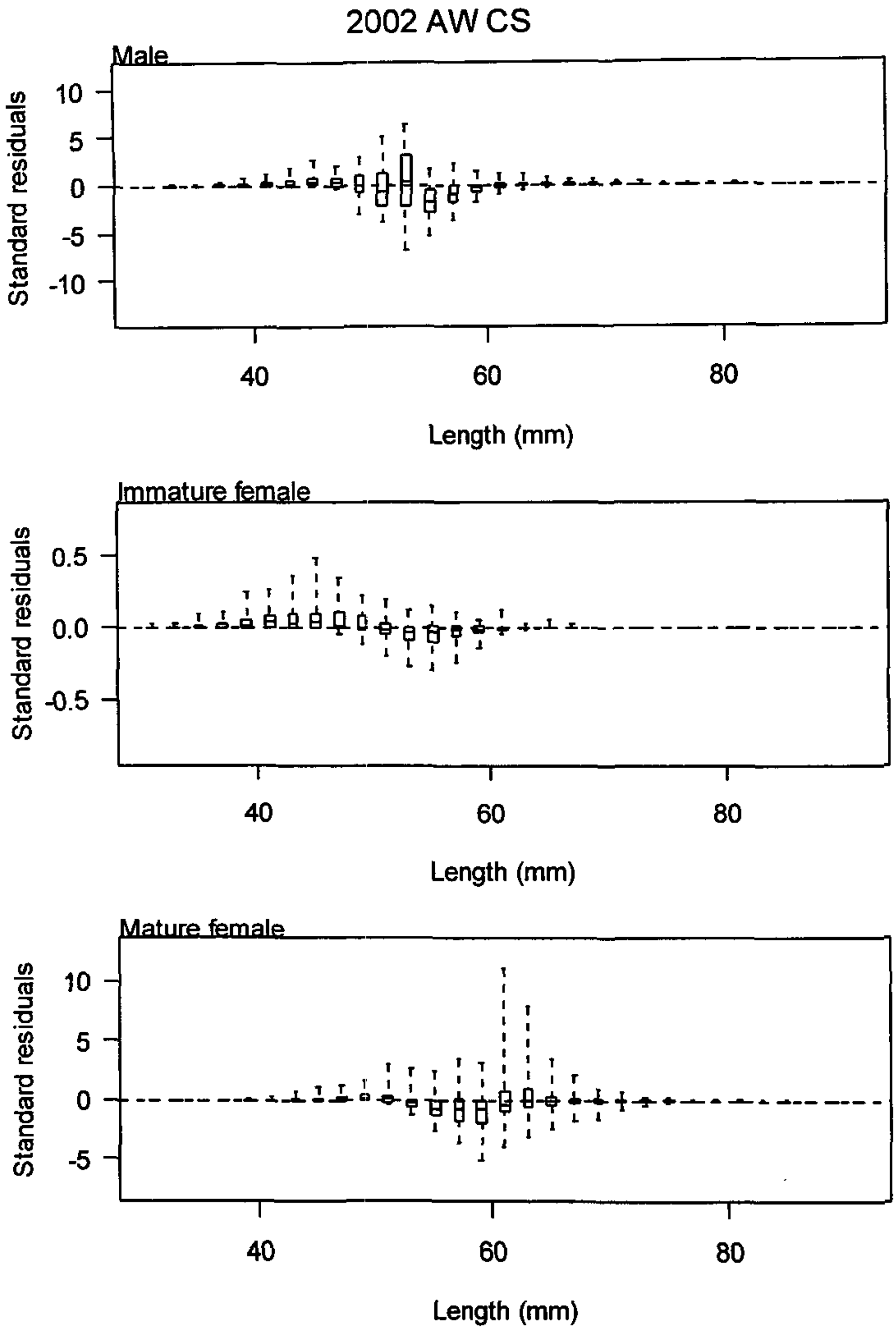
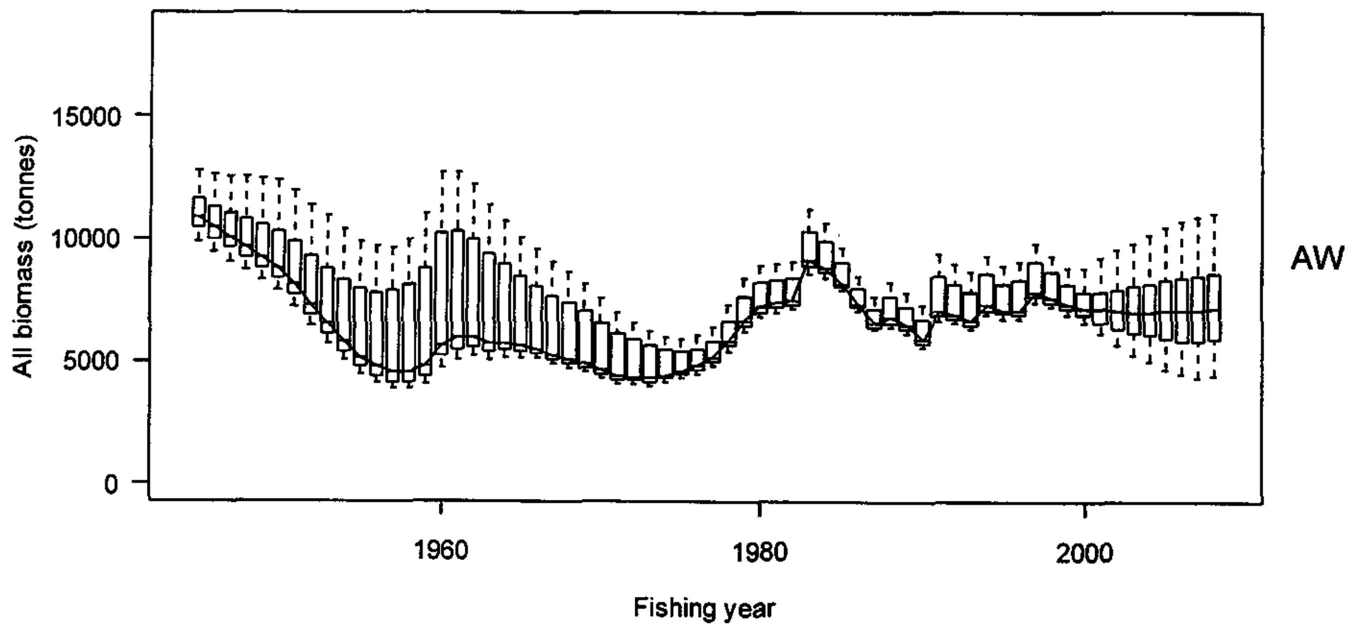


Figure 55: CRA 4: The posterior distributions of the normalised residuals from the fits to proportions-at-length from 2002 AW catch sampling.



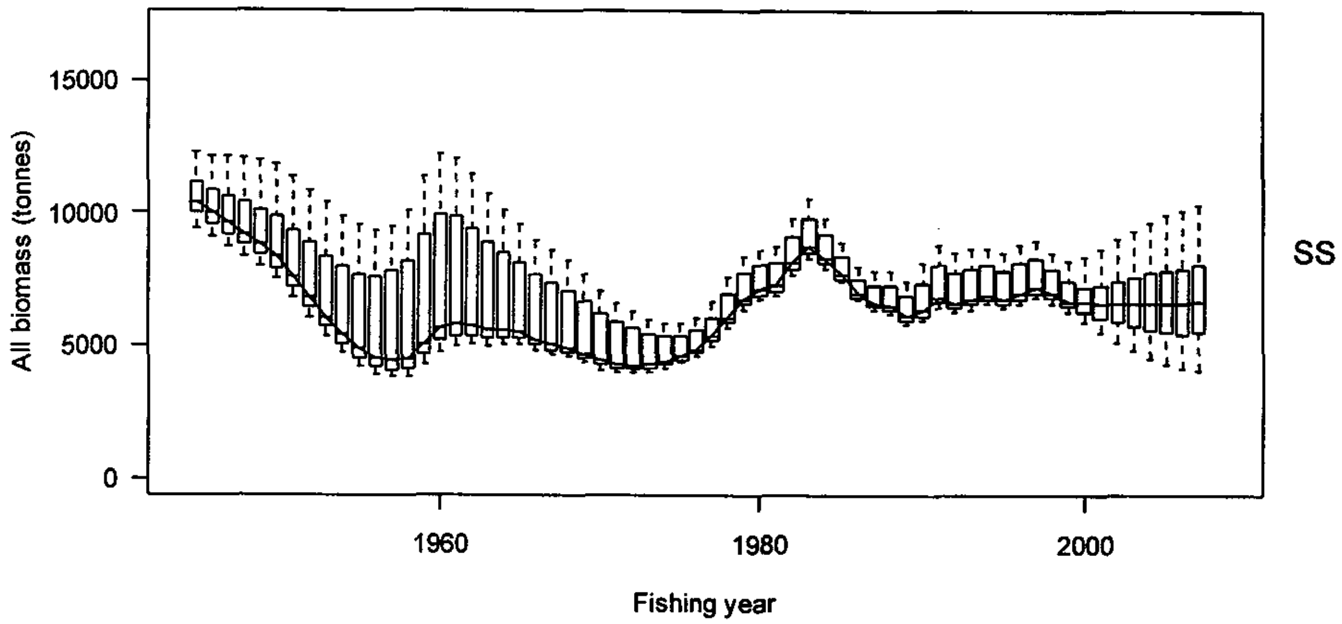
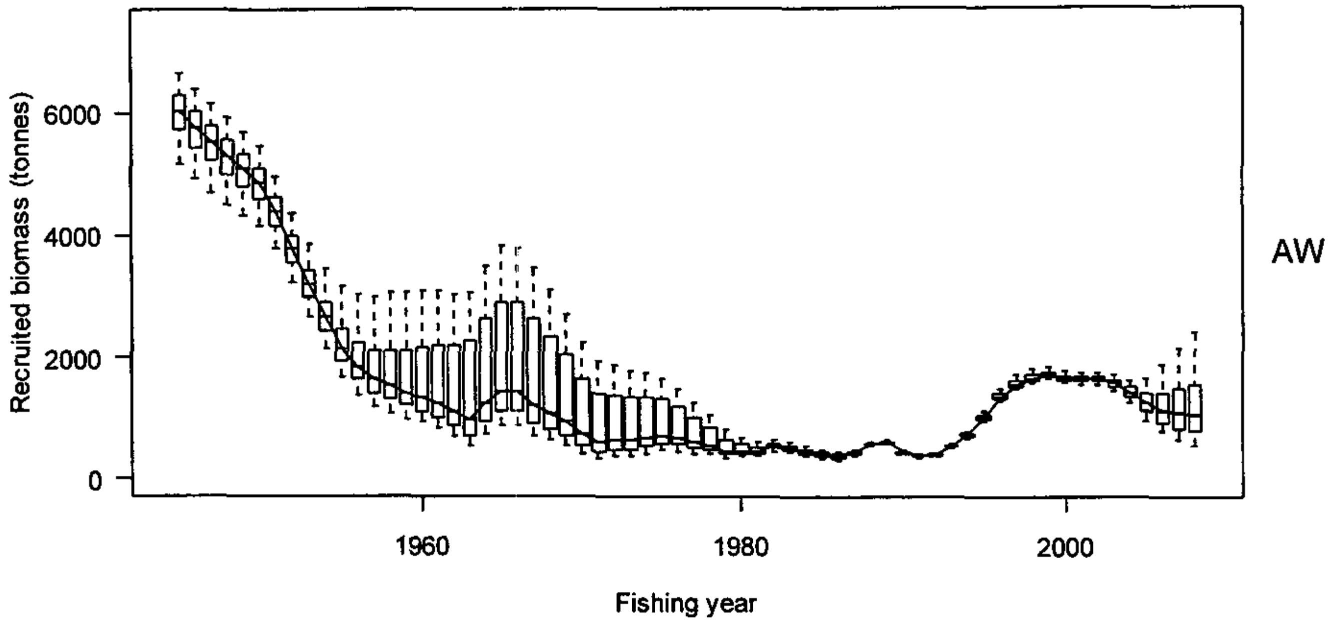


Figure 56: CRA 4: posterior trajectories of total biomass, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



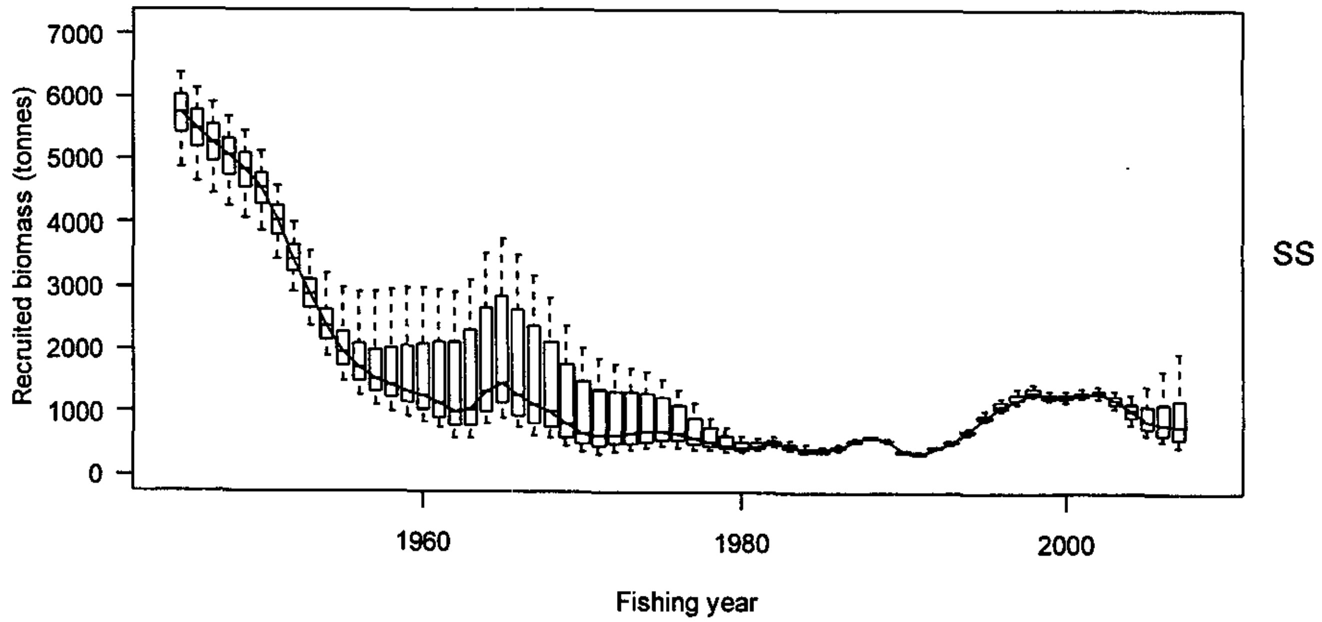


Figure 57: CRA 4: posterior trajectories of recruited biomass, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

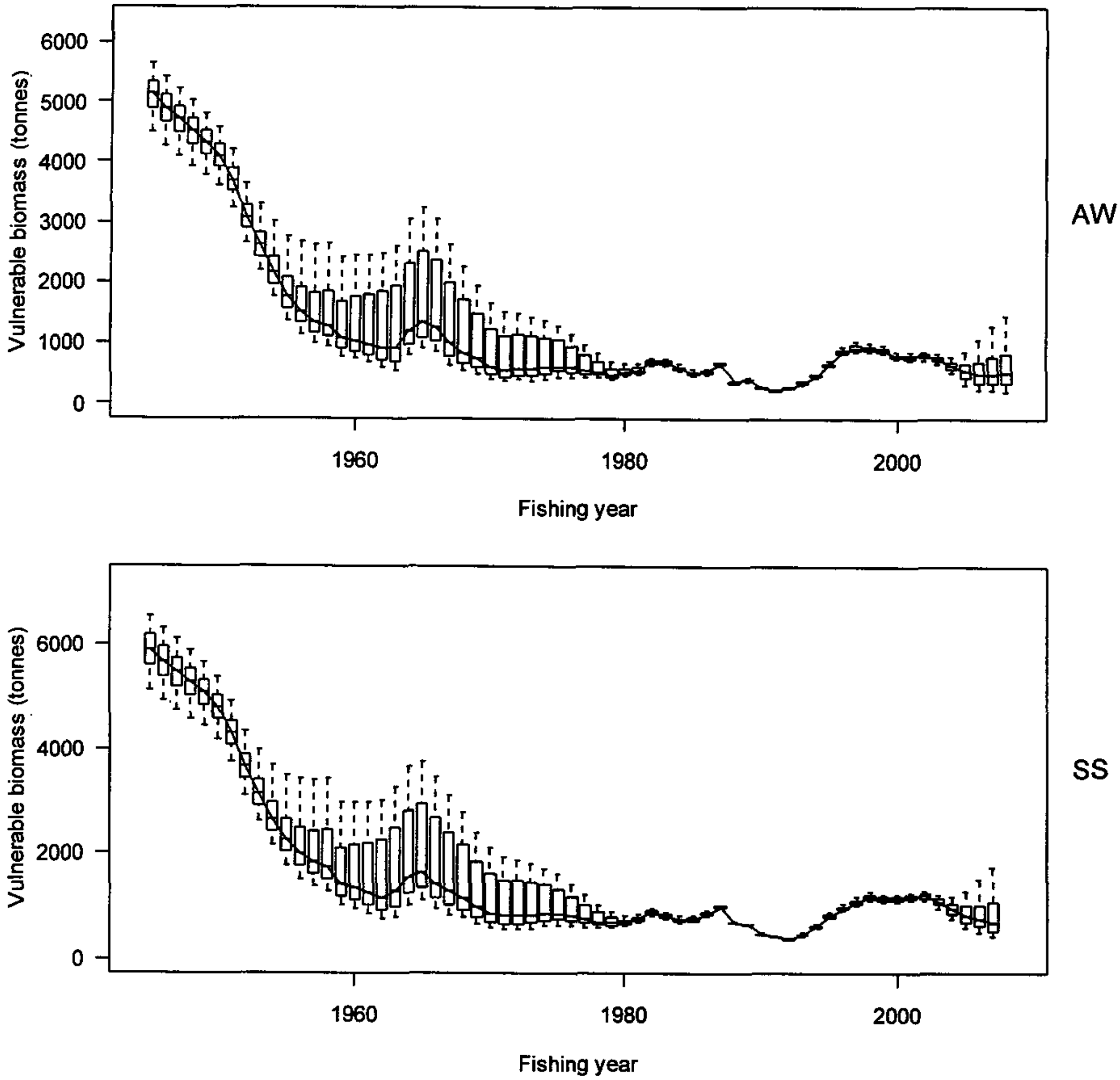
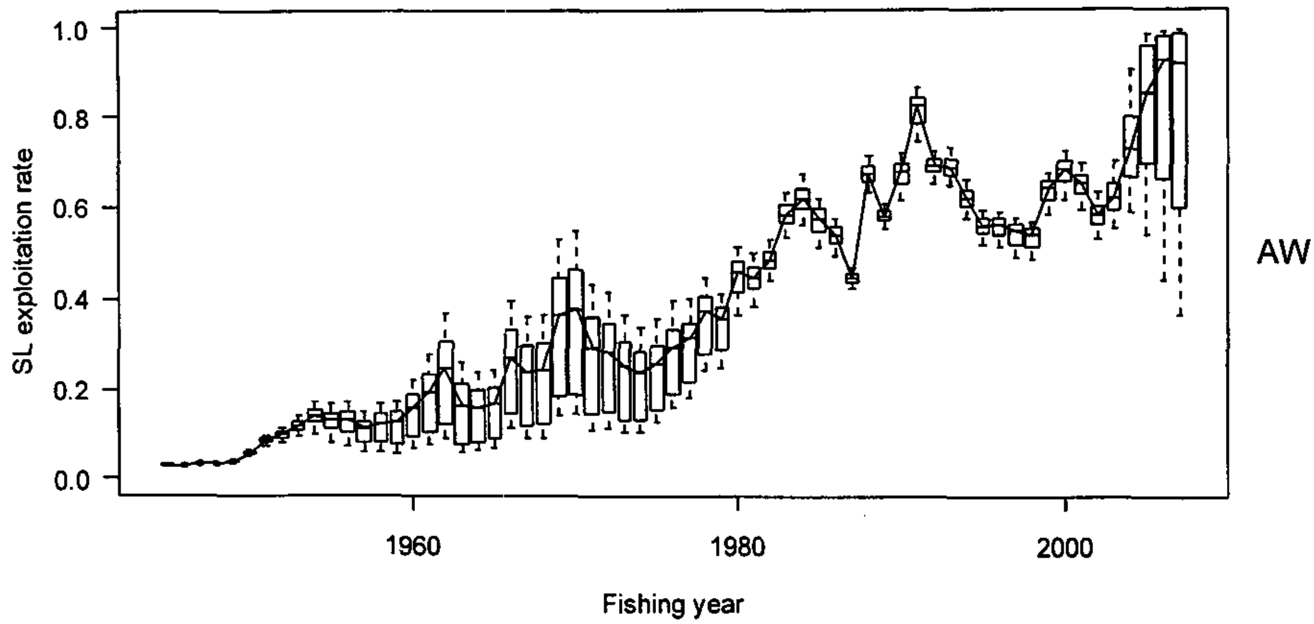


Figure 58: CRA 4: posterior trajectories of vulnerable biomass, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



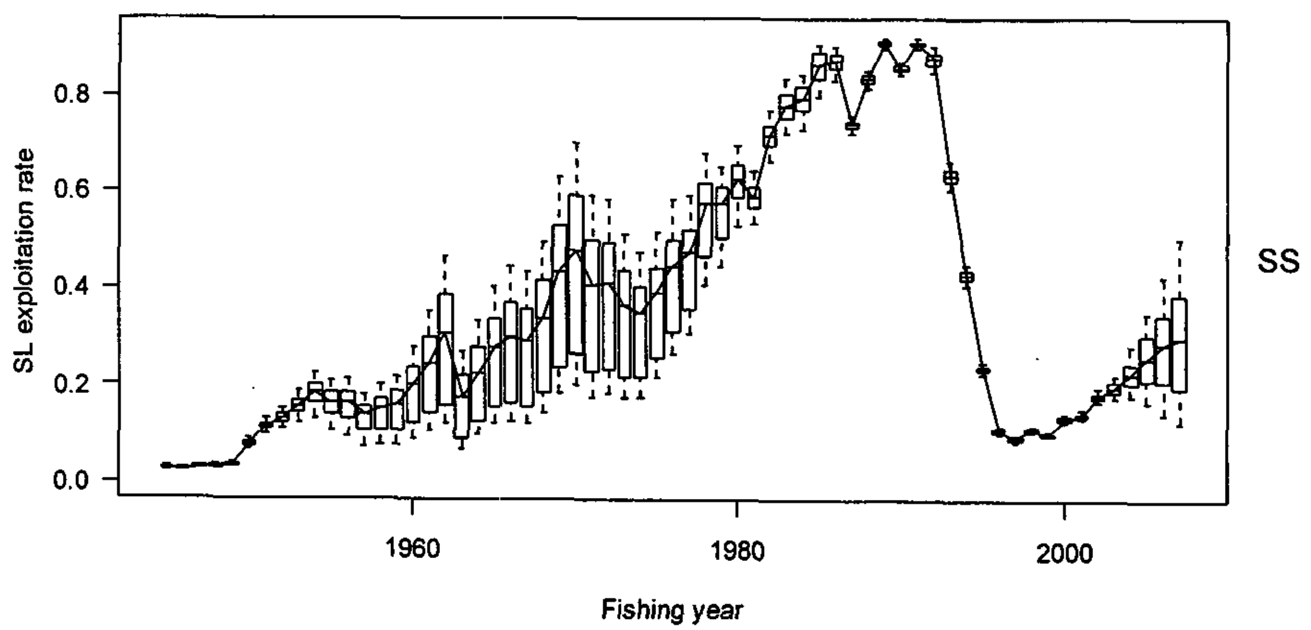


Figure 59: CRA 4: posterior trajectories of SL exploitation rate, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

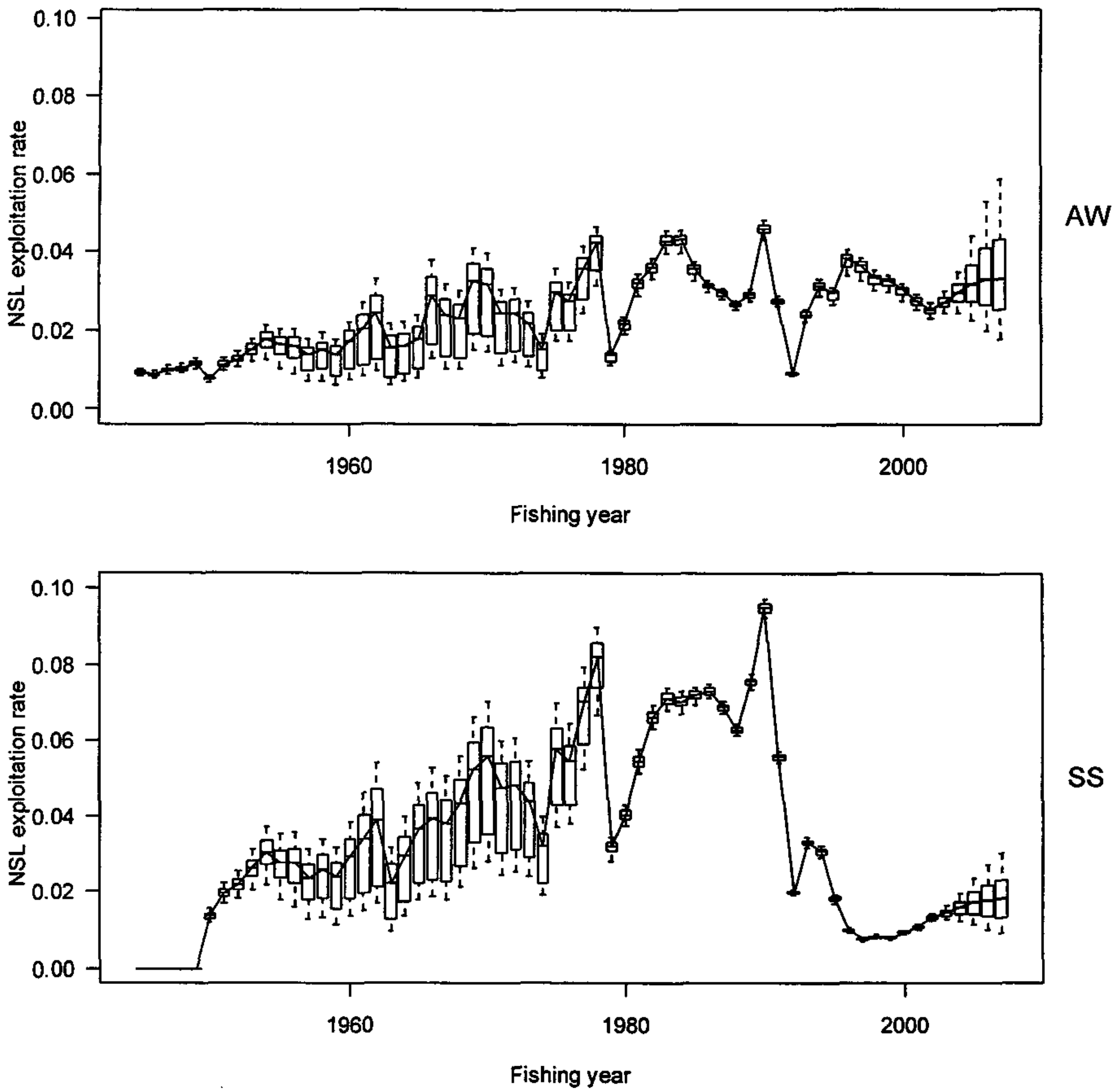


Figure 60: CRA 4: posterior trajectories of NSL exploitation rate, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

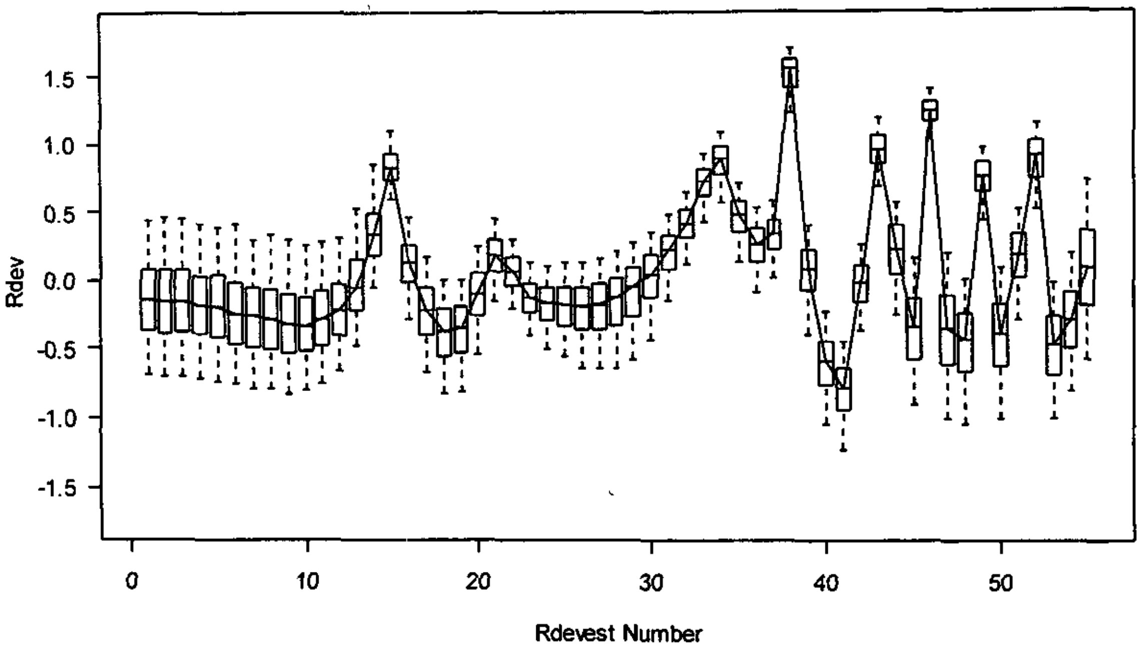


Figure 61: ***CRA 4: posterior trajectories of recruitment deviations from the base case McMC simulations.*** **For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.**

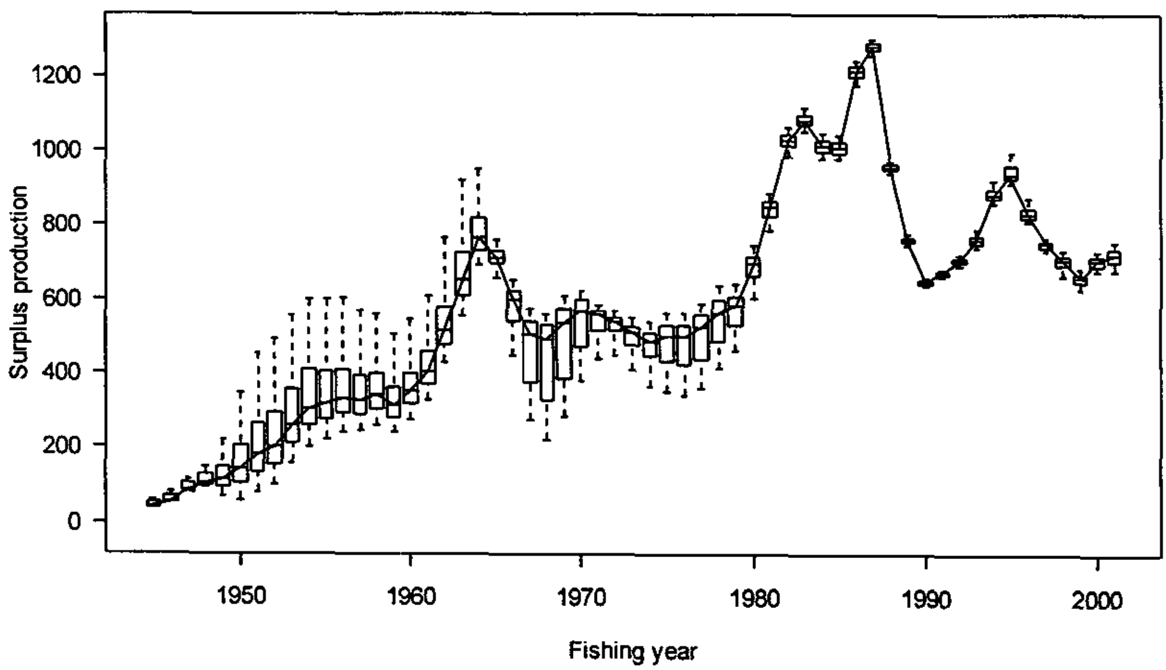


Figure 62: CRA 4: posterior trajectories of surplus production from the base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

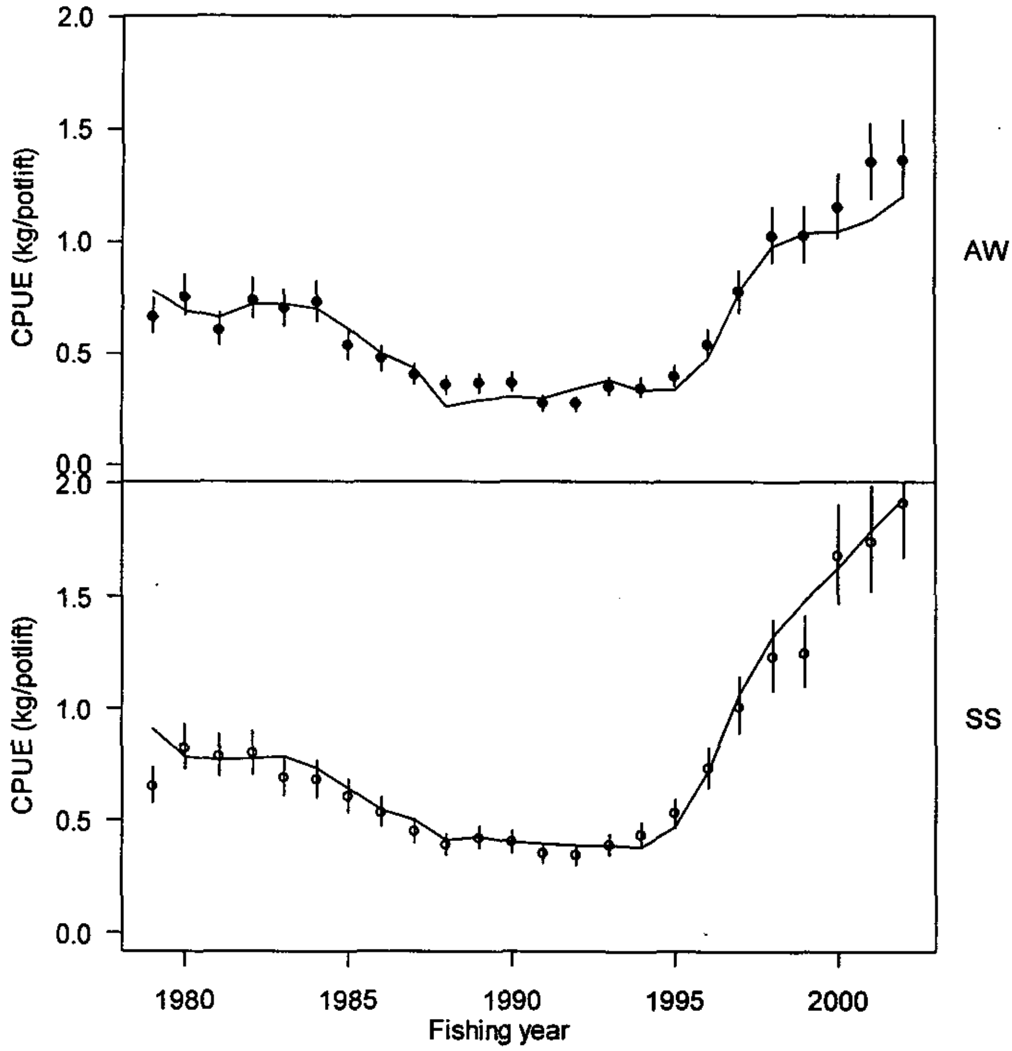


Figure 63: CRA 5: predicted (line) and observed (circles with one standard error, taking all sources of variation into account) standardised CPUE index by season from the base case MPD results.

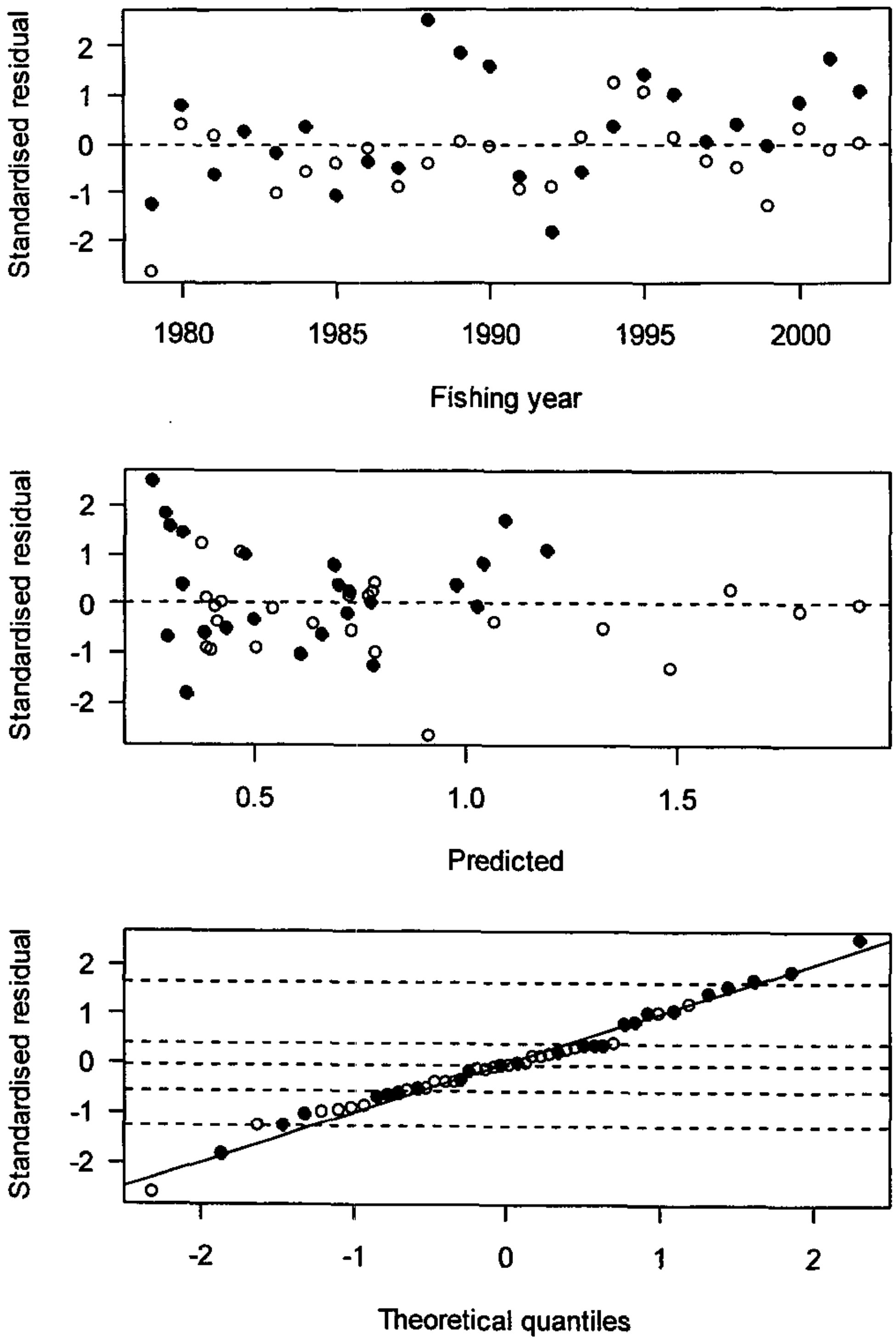


Figure 64: CRA 5: standardised residuals of predicted CPUE index from the base case MPD results, plotted by fishing year [upper panel] and by predicted CPUE index [middle panel]; q-q plot of residuals [lower panel]. Closed circles, AW; open circles, SS.

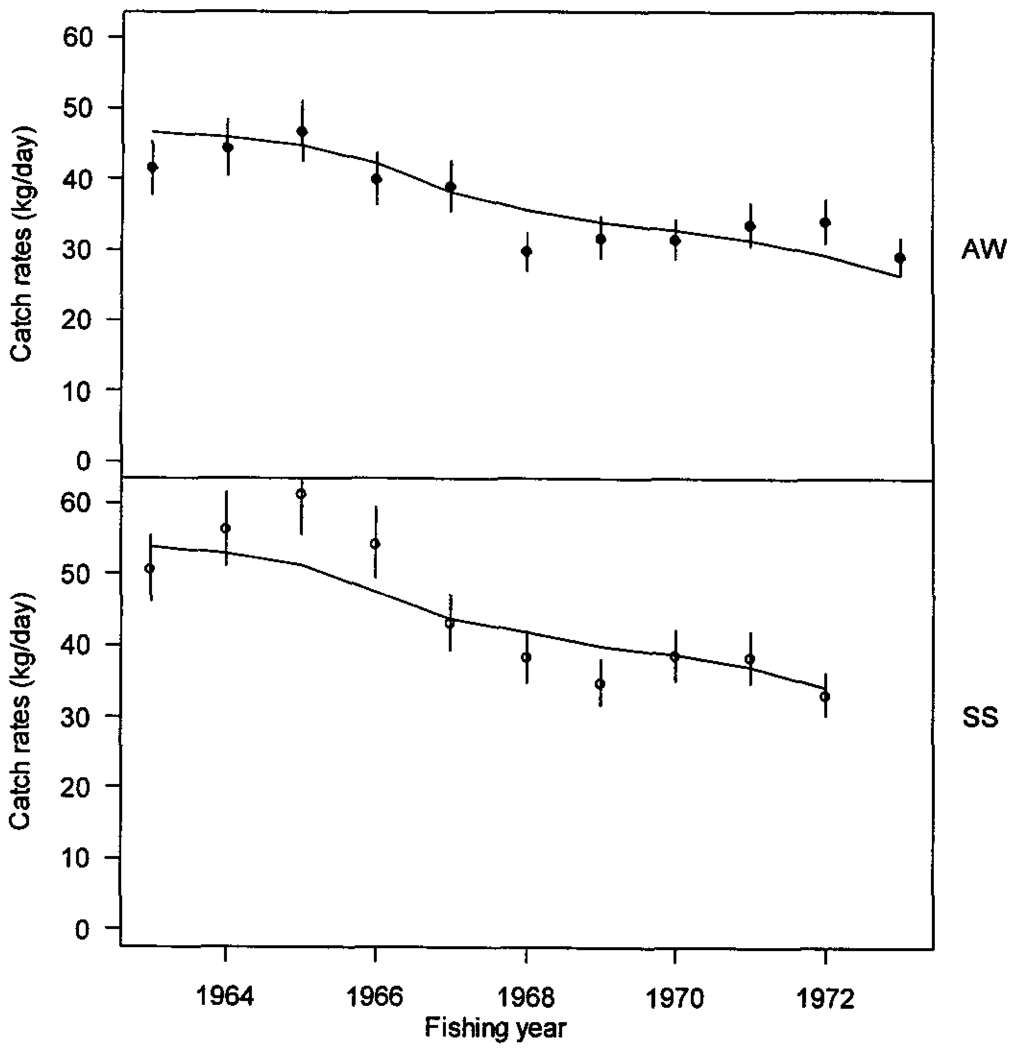


Figure 65: CRA 5: predicted (solid line) and observed (circles with one standard error, taking all sources of variation into account) catch rate (CR) by season from the base case MPD results.

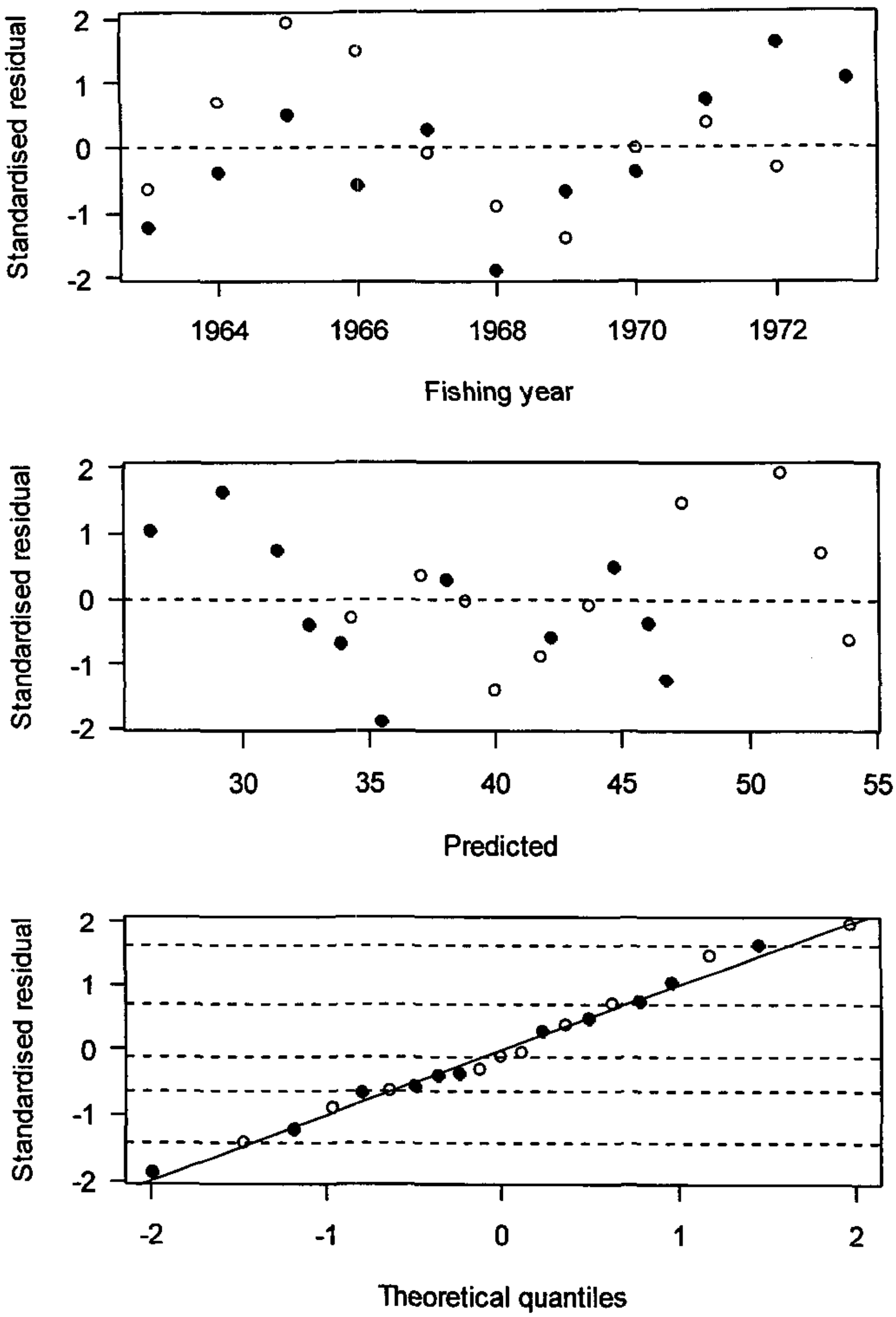


Figure 66: CRA 5: standardised residuals of catch rate from the base case MPD results, plotted by fishing year [upper panel] and by predicted catch rate [lower panel]; q-q plot of residuals [lower panel]. Closed circles, AW; open circles, SS.

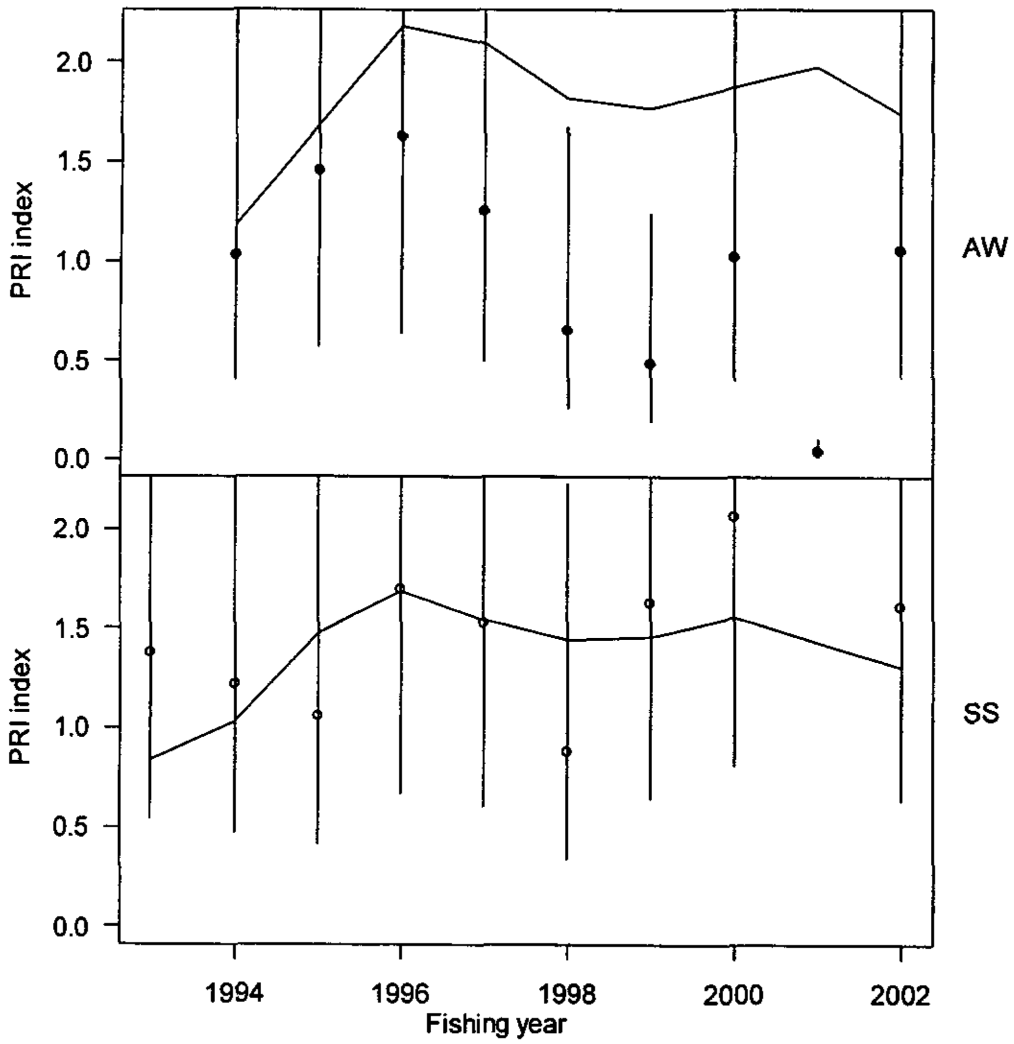


Figure 67: CRA 5: : predicted (solid line) and observed (circles with one standard error, taking all sources of variation into account) pre-recruit index (PRI) by season from the base case MPD results.

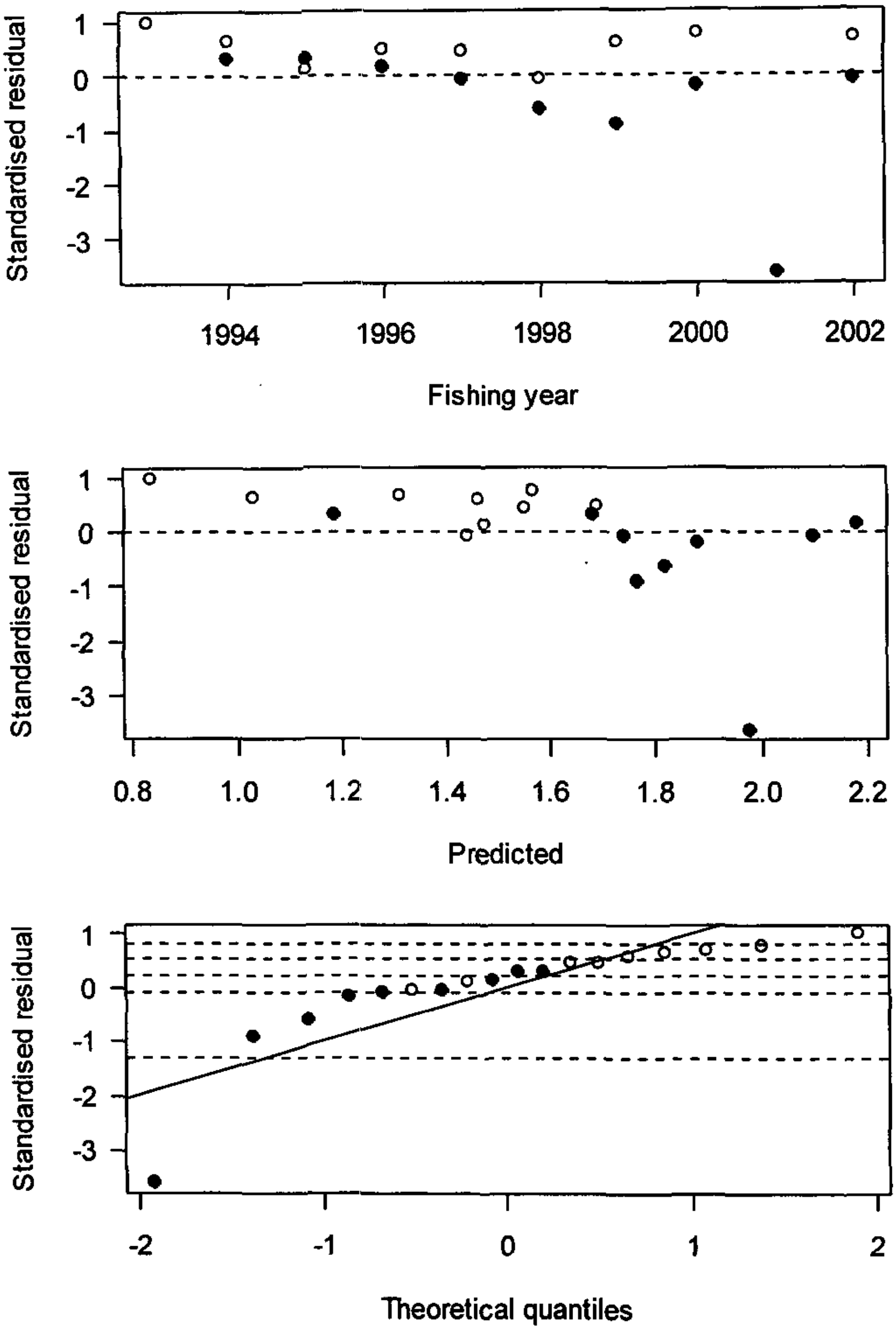


Figure 68: CRA 5: standardised residuals of PRI from the base case MPD results, plotted by fishing year [upper panel] and by predicted catch rate [middle panel]; q-q plot of residuals [lower panel]. Closed circles, AW; open circles, SS.

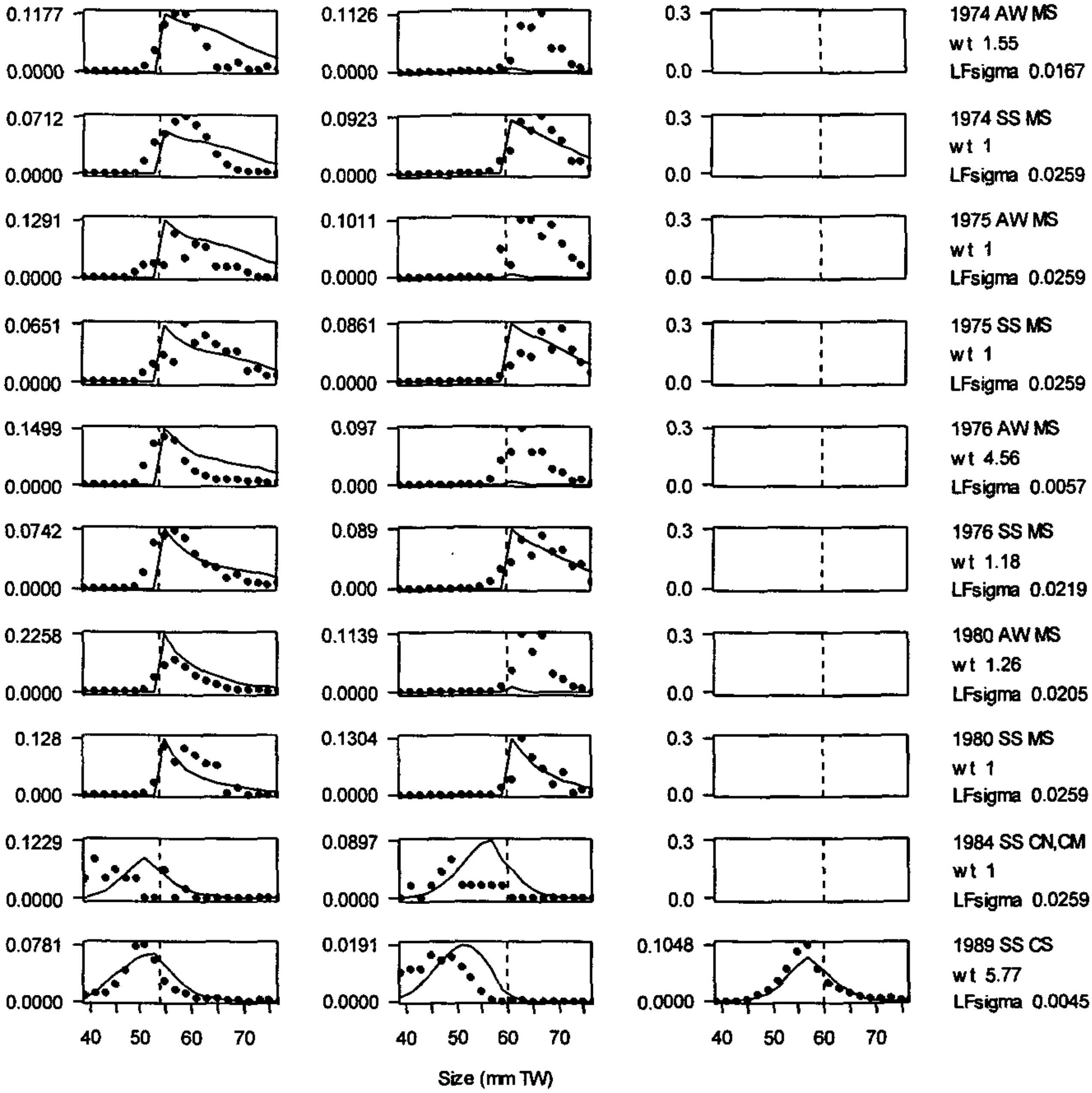


Figure 69: CRA 5: the base case MPD fit to the proportions-at-length, plotted by year and season, sex category and data source. The left column shows males, the centre immature females, and the right mature females. LB, log book data; CS and CN, catch sampling data; MS, market sampling data; wt ($=\kappa_l$). For MS and CN/CM data, where females were not graded by maturity, the centre column is all females. The dotted vertical line is the current summer MLS.

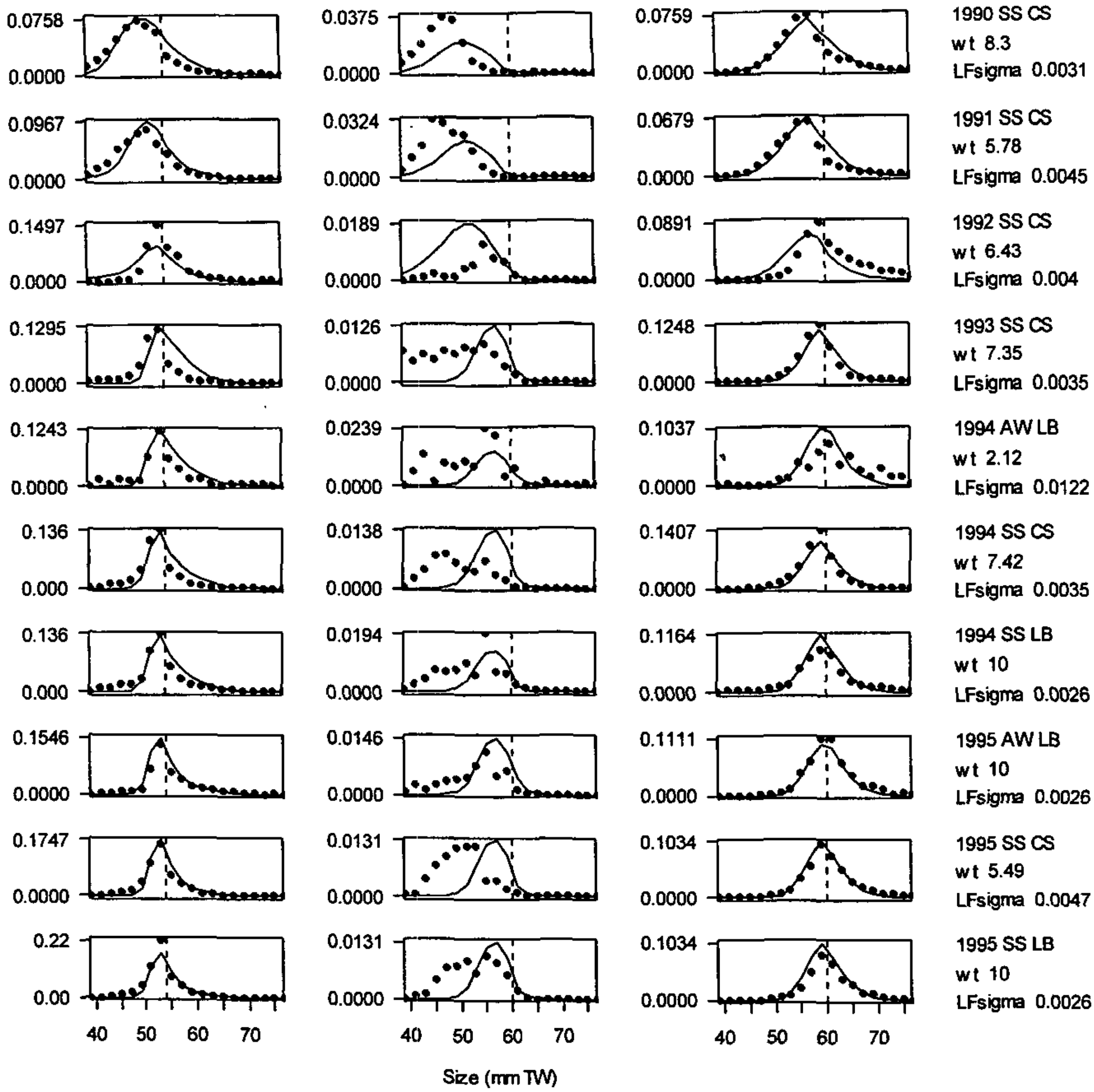


Figure 69 continued.

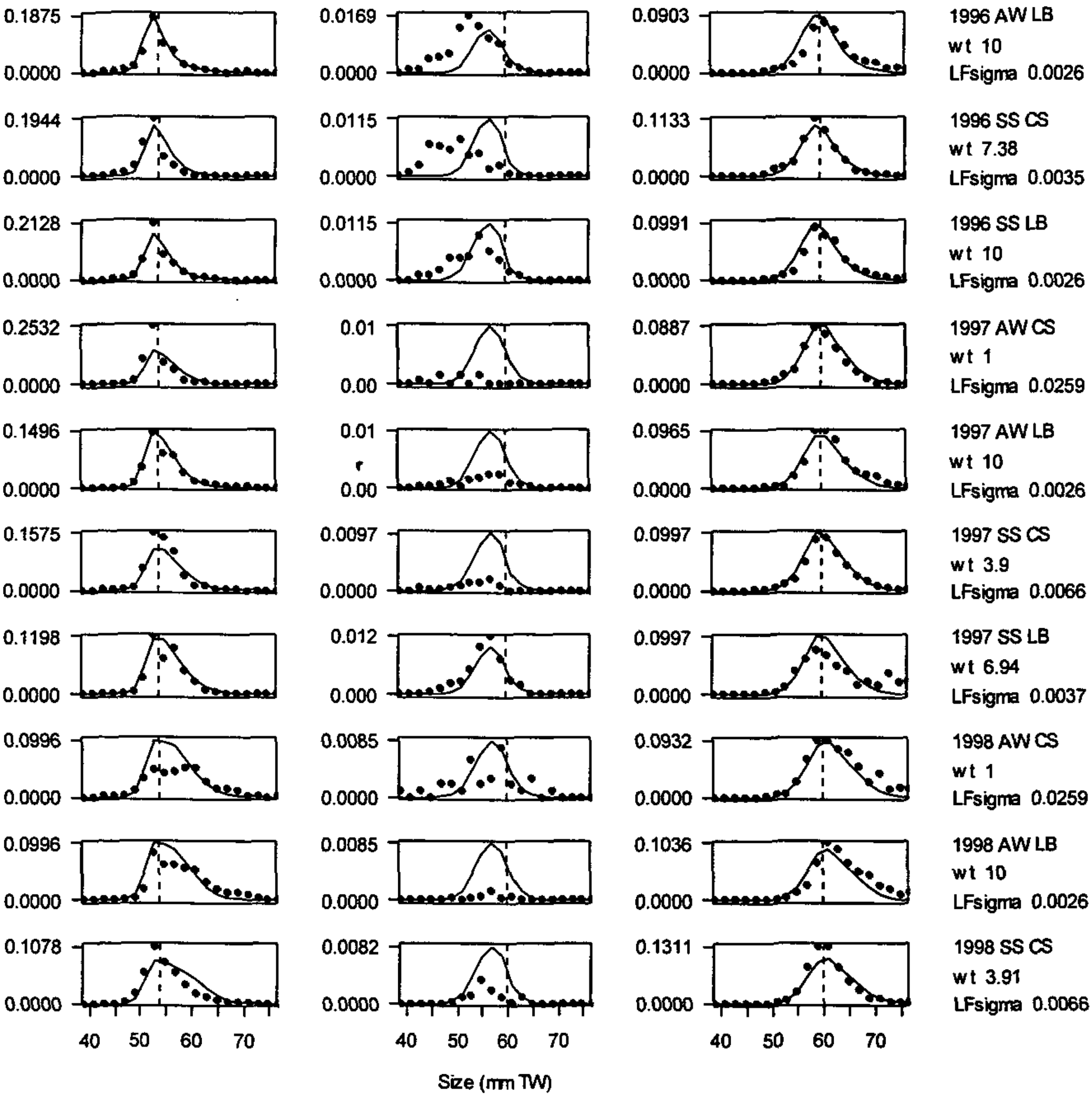


Figure 69 continued.

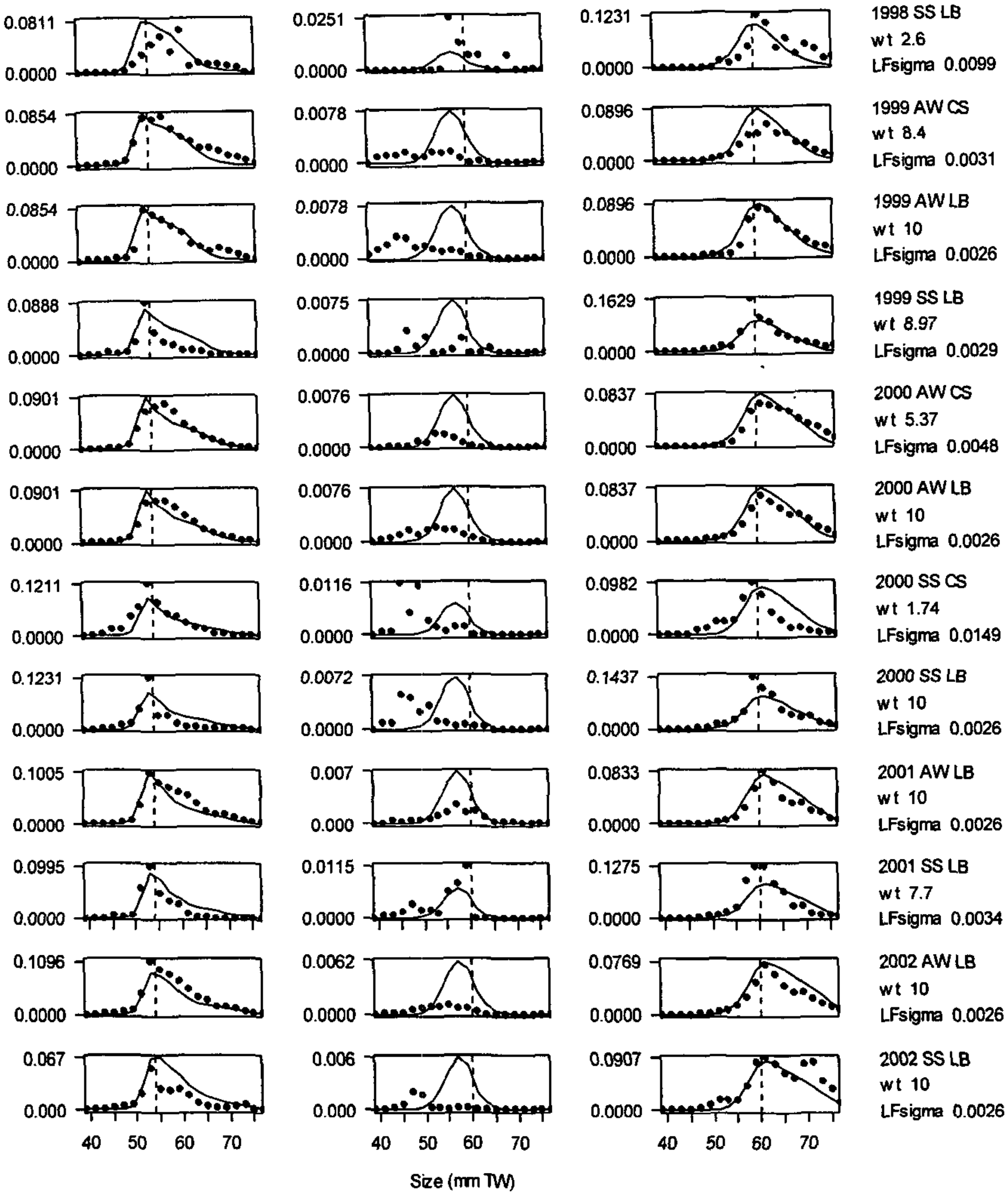


Figure 69 continued.

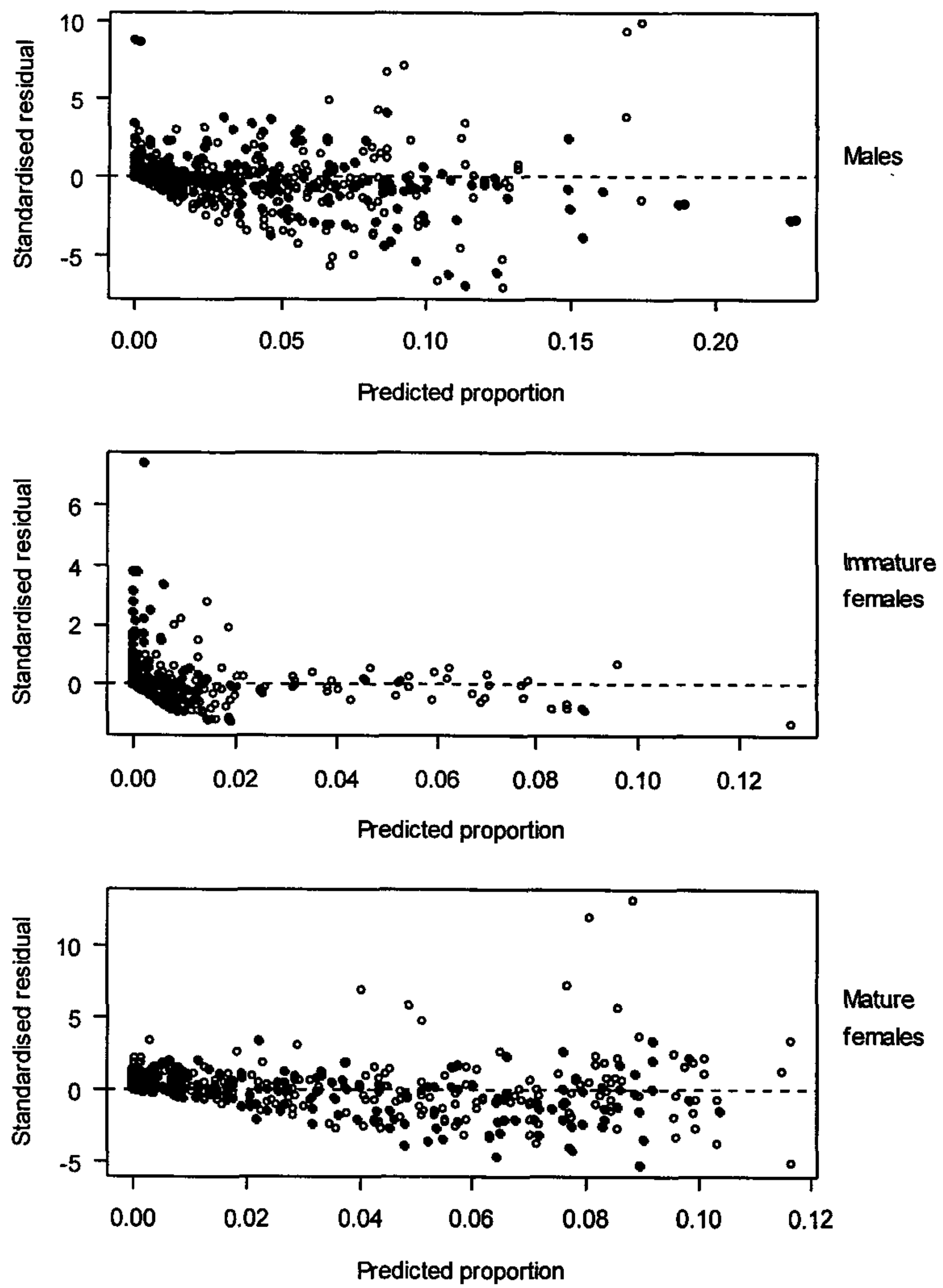


Figure 70: CRA 5: Standardised residuals from the fits to proportions-at-length, plotted against predicted proportions-at-length for the three sex categories.

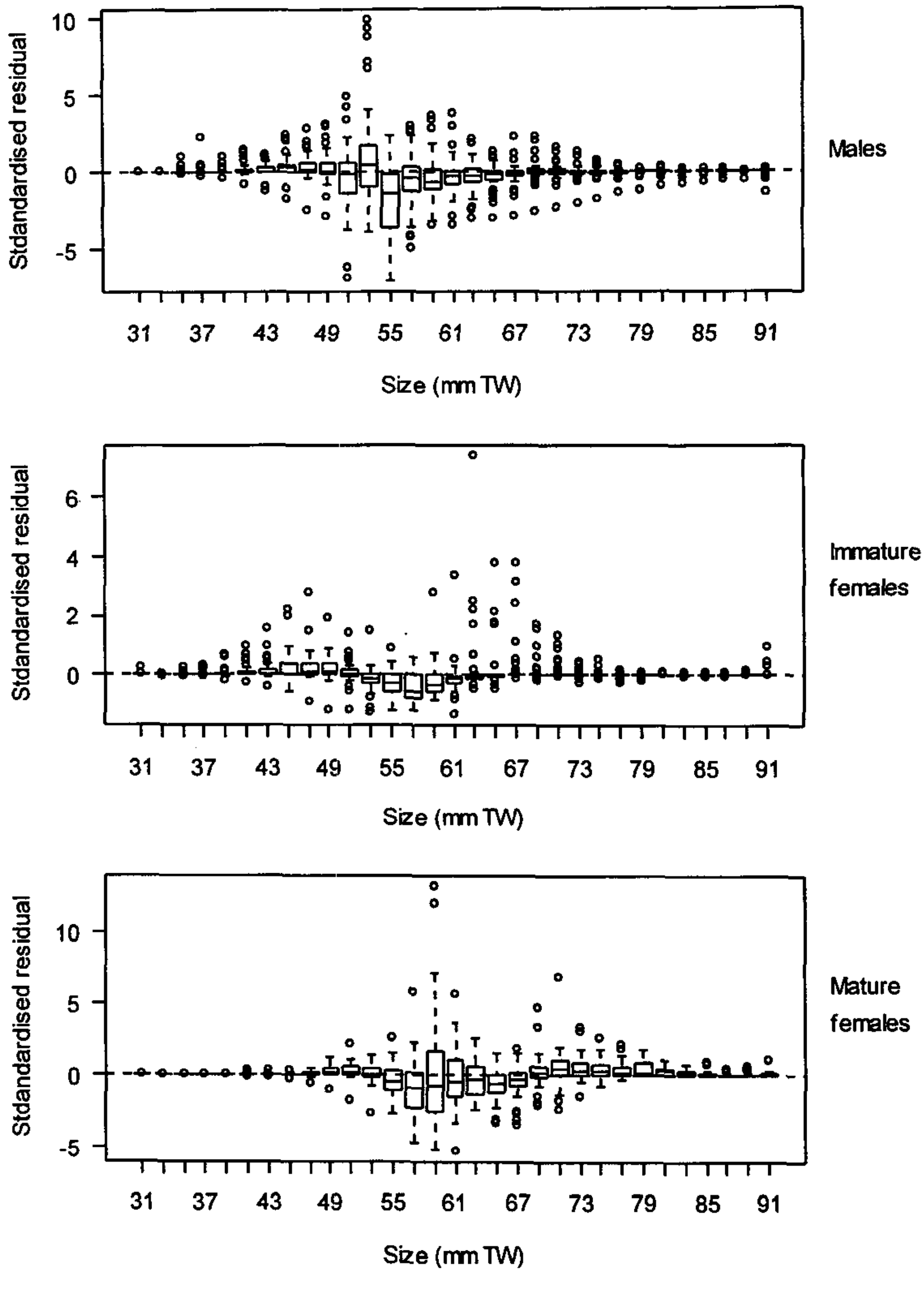


Figure 71: CRA 5: Standardised residuals from the fits to proportions-at-length, plotted against length for the three sex categories indicated. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.

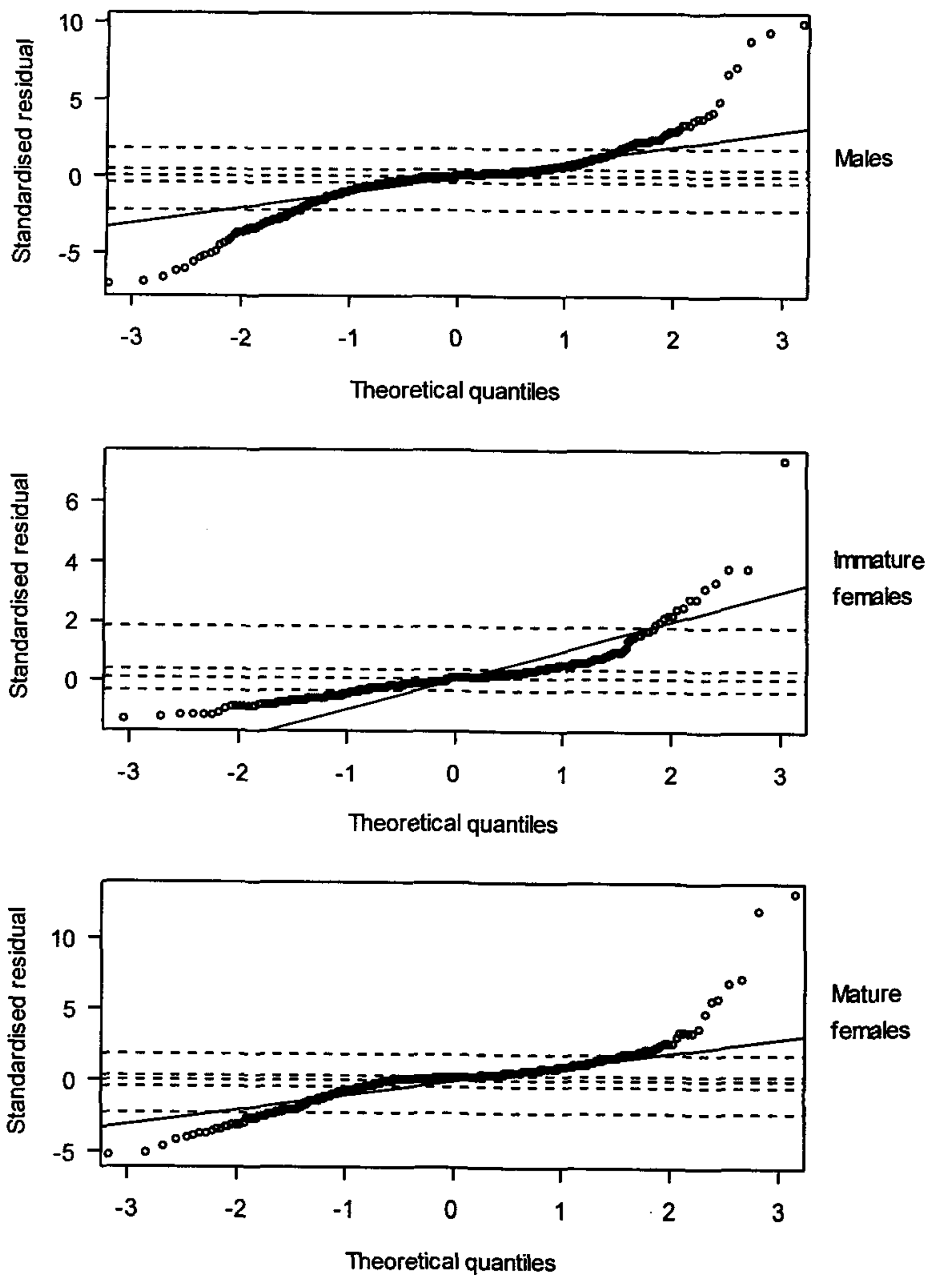


Figure 72: CRA 5: Quantile-quantile plots of standard residuals from the fits to proportions-at-length for the three sex categories indicated.

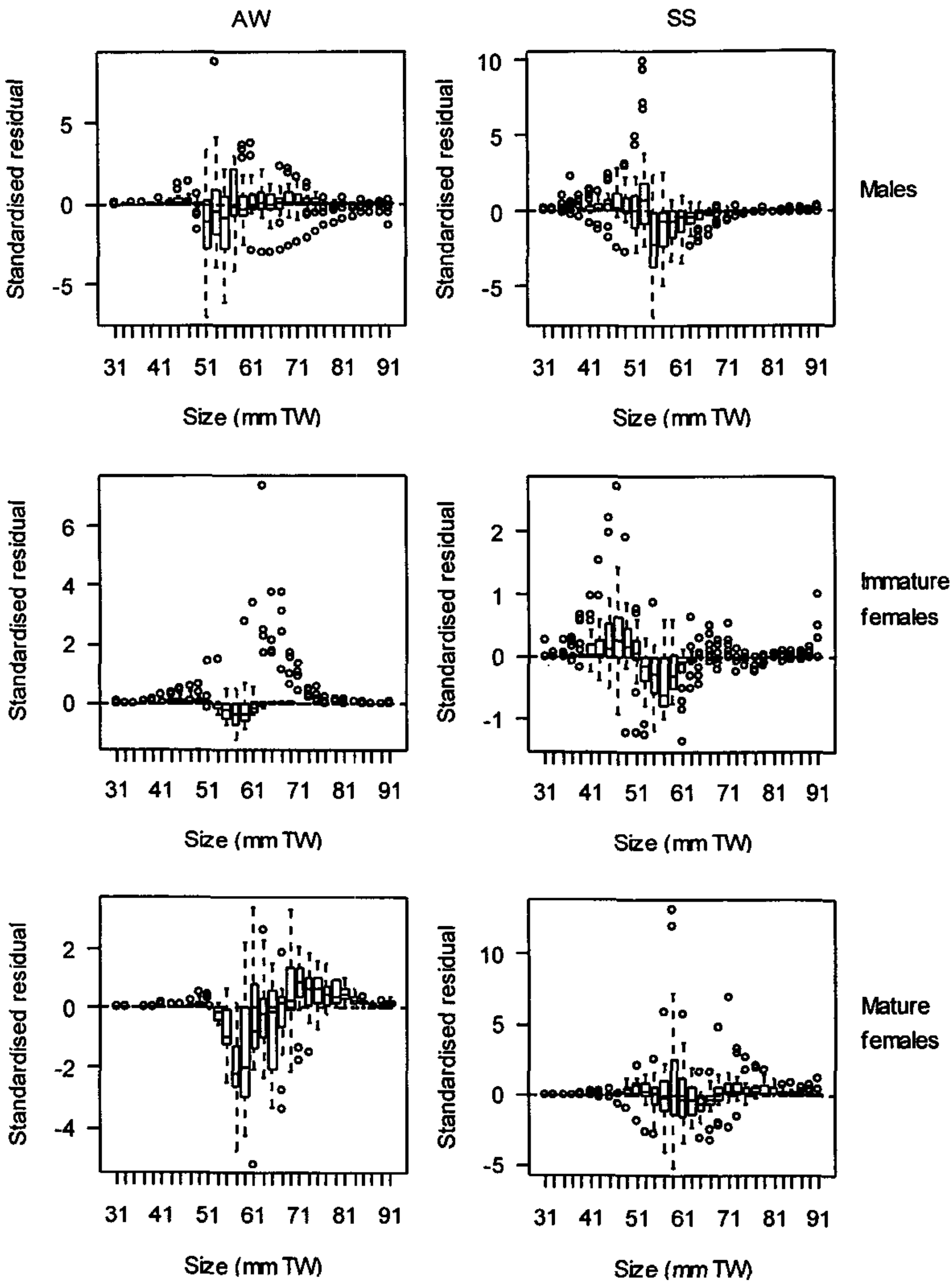


Figure 73: CRA 5: Standardised residuals from the fits to proportions-at-length, plotted against length and by season for the three sex categories indicated. Left panels are the AW and the right panels are the SS. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.

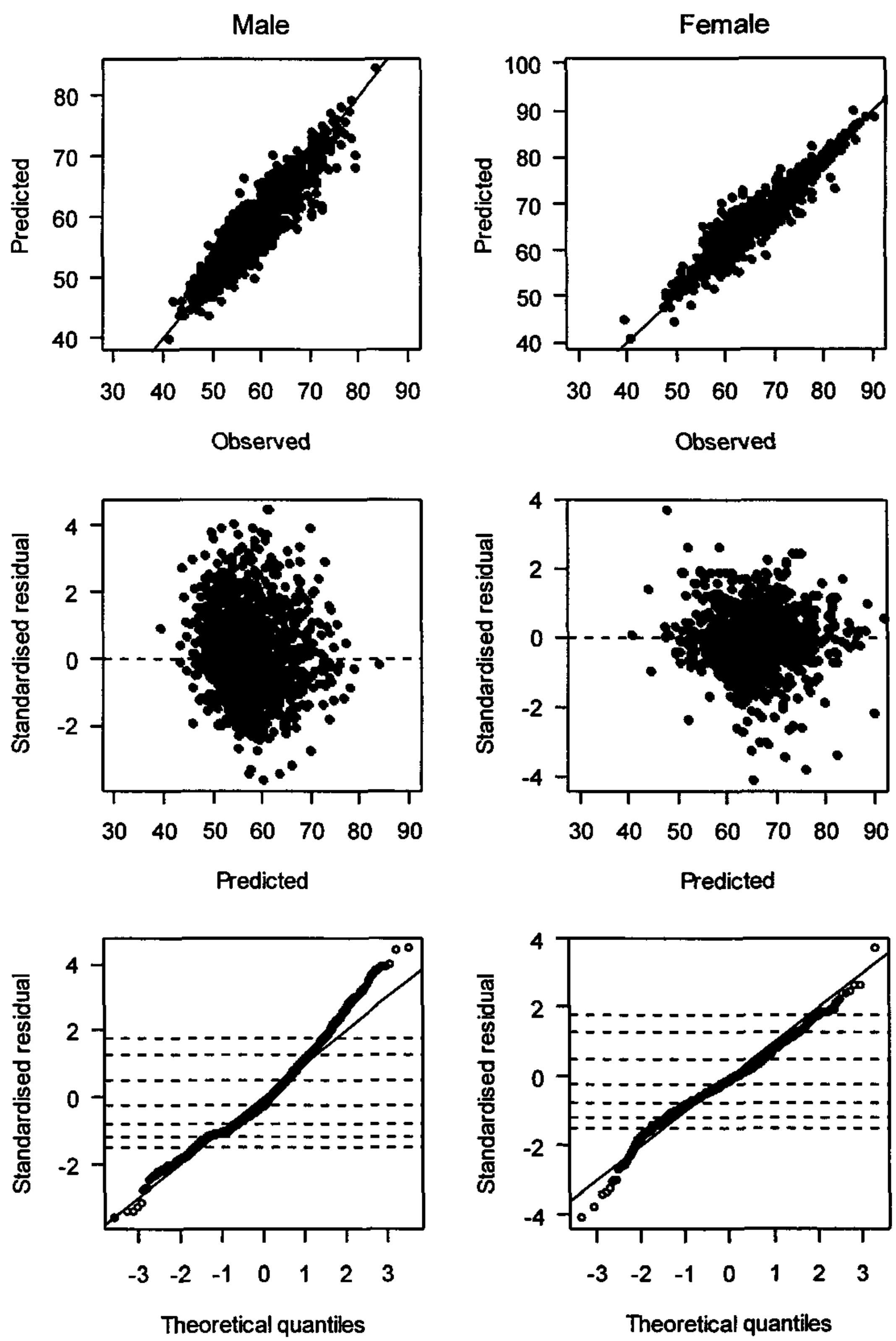


Figure 74: CRA 5: Predicted and observed size at recapture from the base case model MPD fit from the tagging data (top panels); standardised residuals versus predicted size at recapture (middle panels); q-q plots of the standardised residuals (bottom panels). For all plots left panels are males and right panels are females.

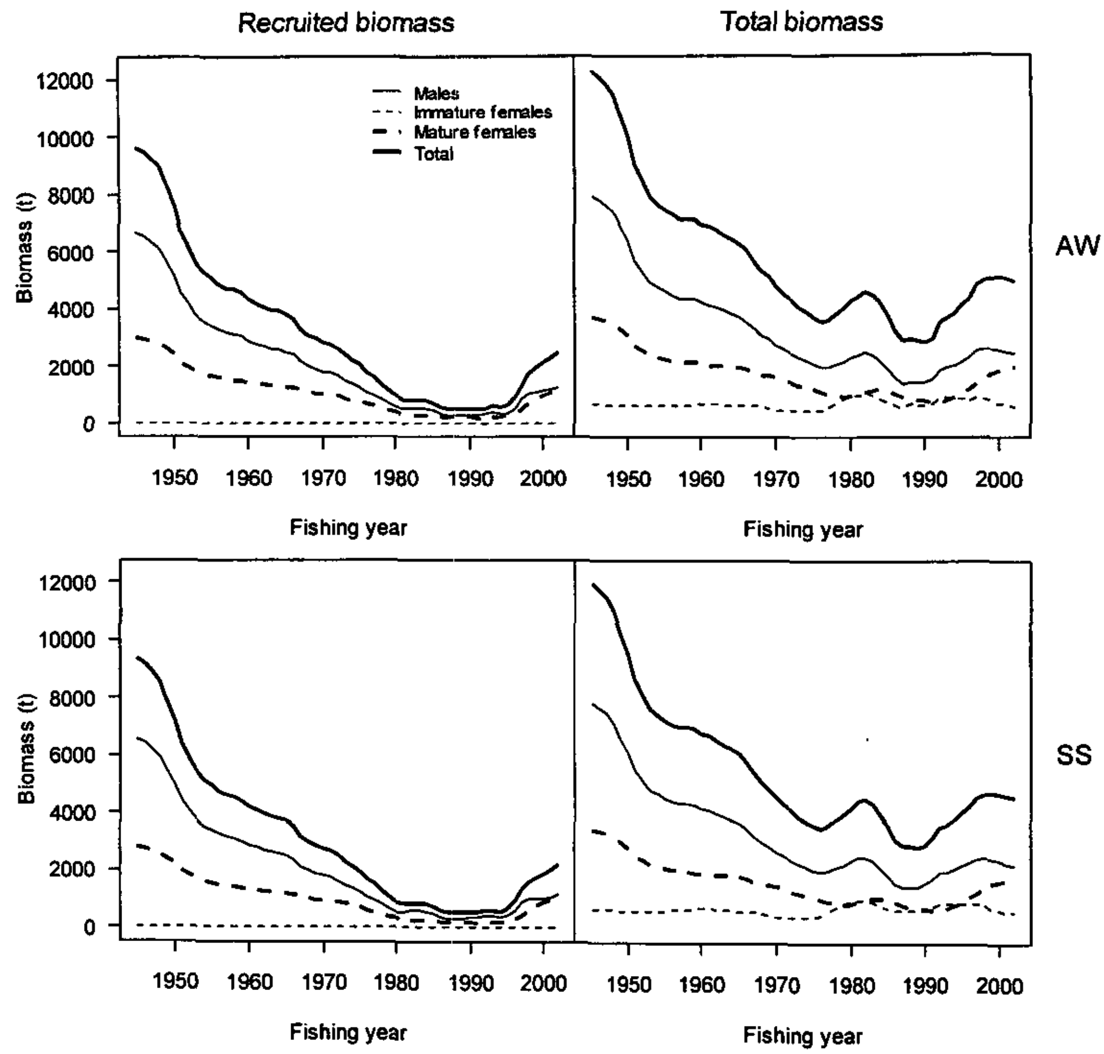


Figure 75: CRA 5: Recruited (left panels) and total biomass (right panels) from the MPD fit by sex (as indicated in the legend) and season.

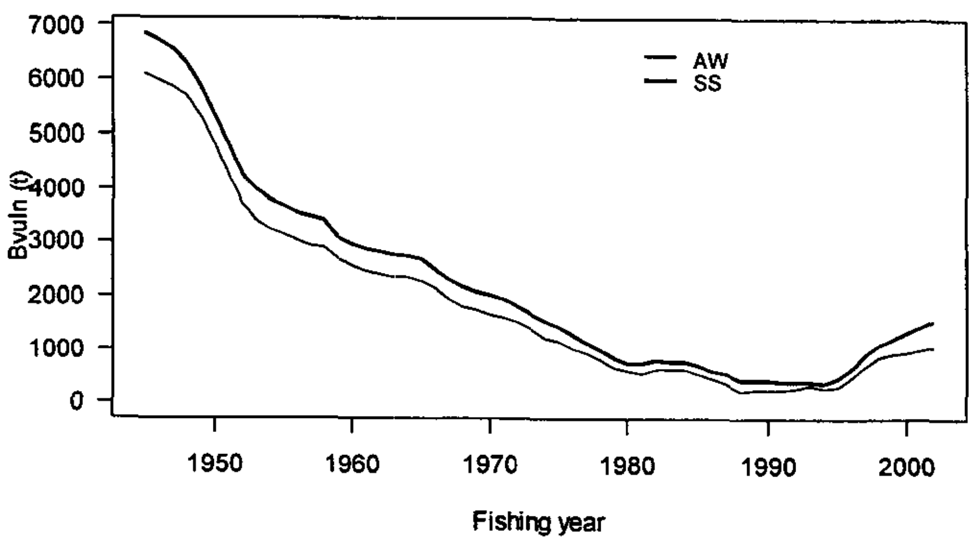


Figure 76: CRA 5: The base case predicted vulnerable biomass from the MPD fit.

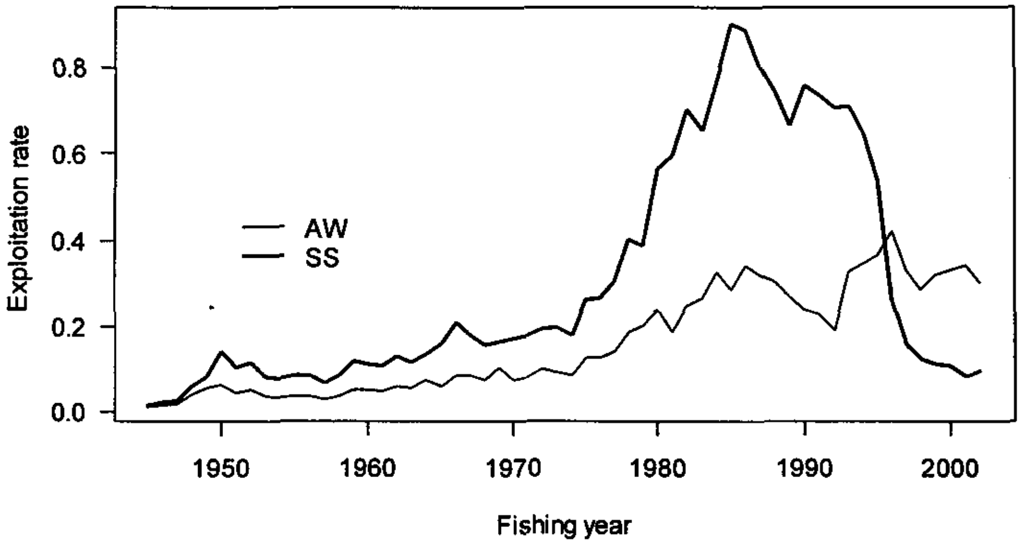


Figure 77: CRA 5: Exploitation rate trajectories from the base case model MPD fit.

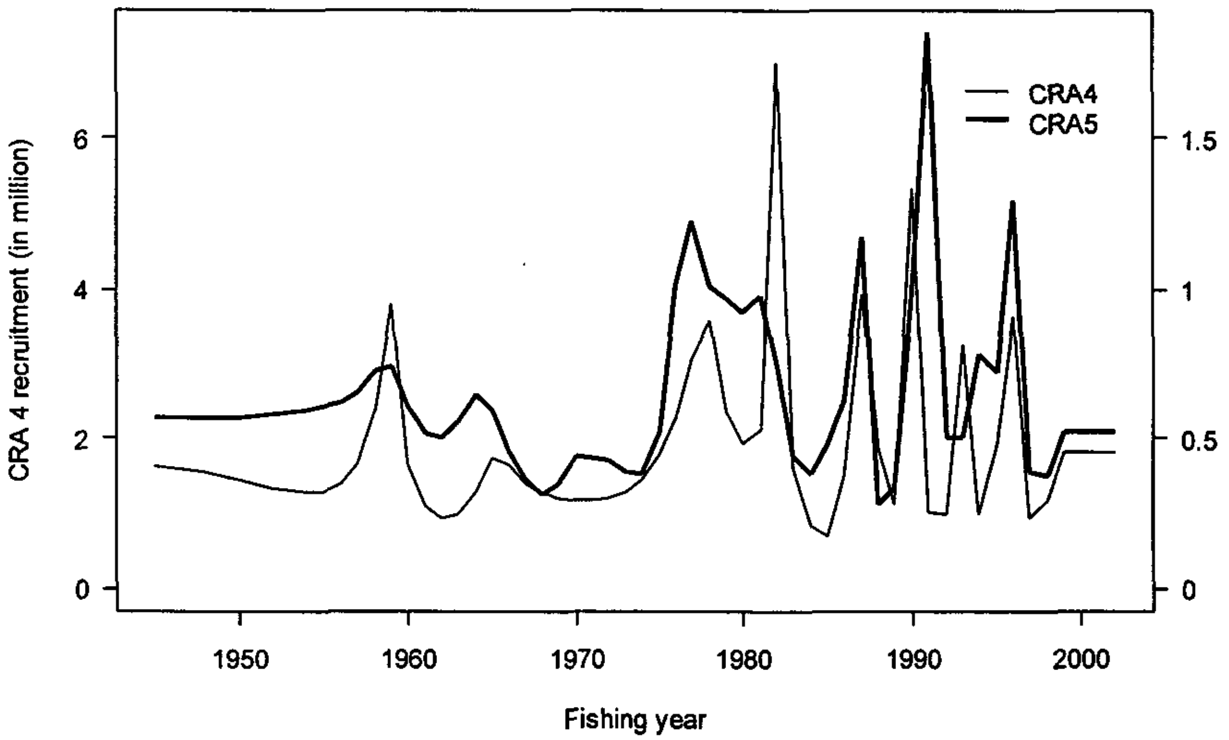


Figure 78: Comparison of recruitment (in millions) between CRA 4 and CRA 5.

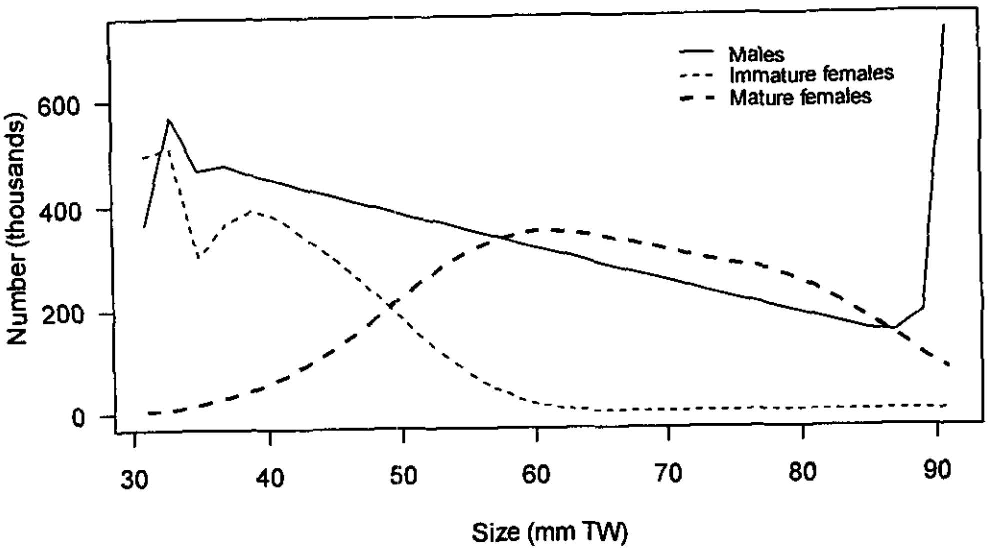


Figure 79: CRA 5: Initial length structure from the base case MPD fit for each sex.

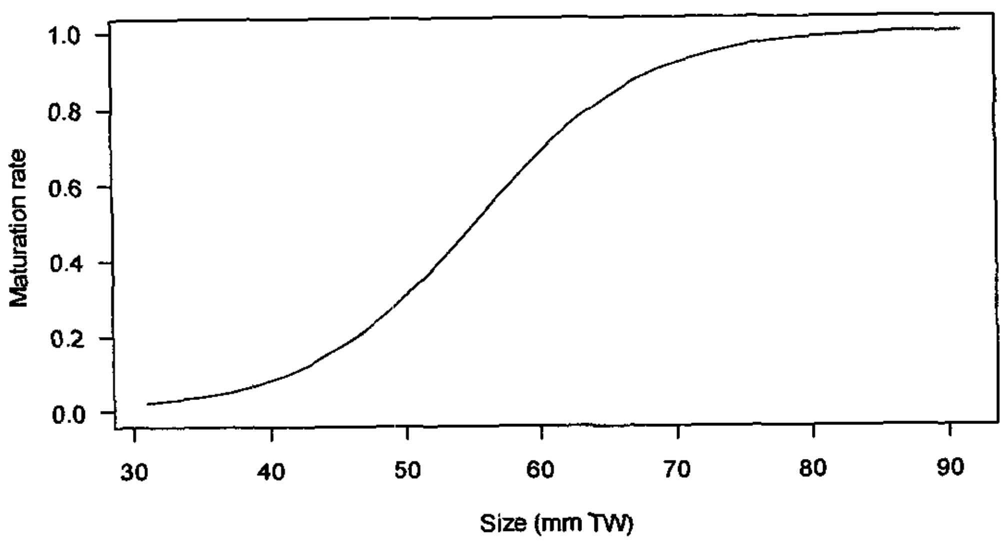


Figure 80: CRA 5: Maturation rate from the base case MPD fit.

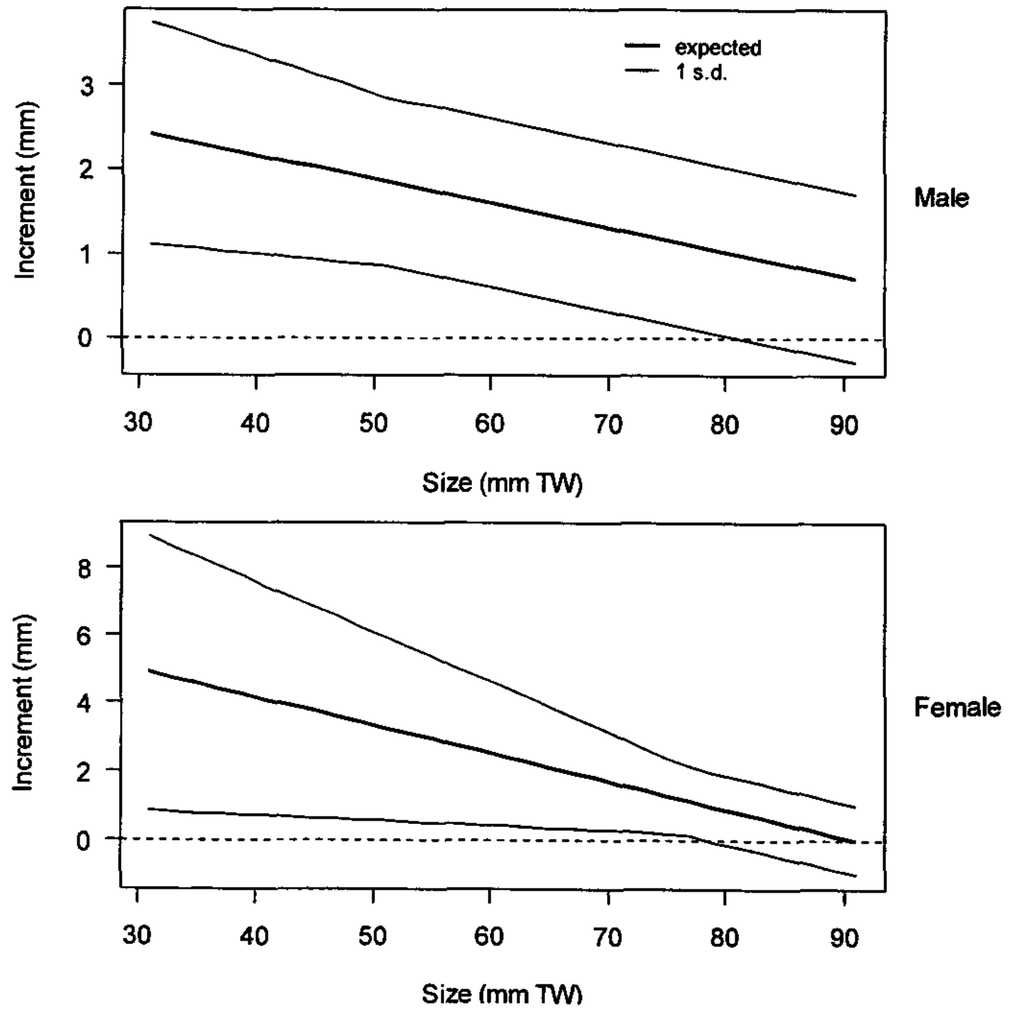


Figure 81: CRA 5: Predicted annual growth increment (thick line) plotted against initial size, shown with one standard deviation around the increment (thin line).

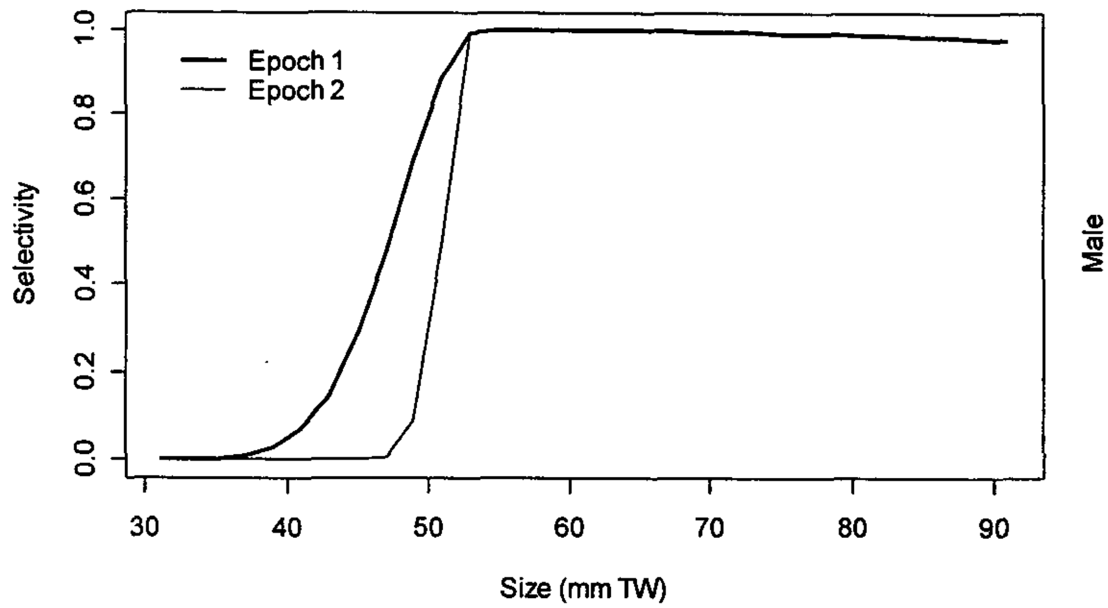


Figure 82: CRA 5: Selectivity for males in each epoch. Epoch 1 runs from 1945 through 1992; epoch 2 from 1993.

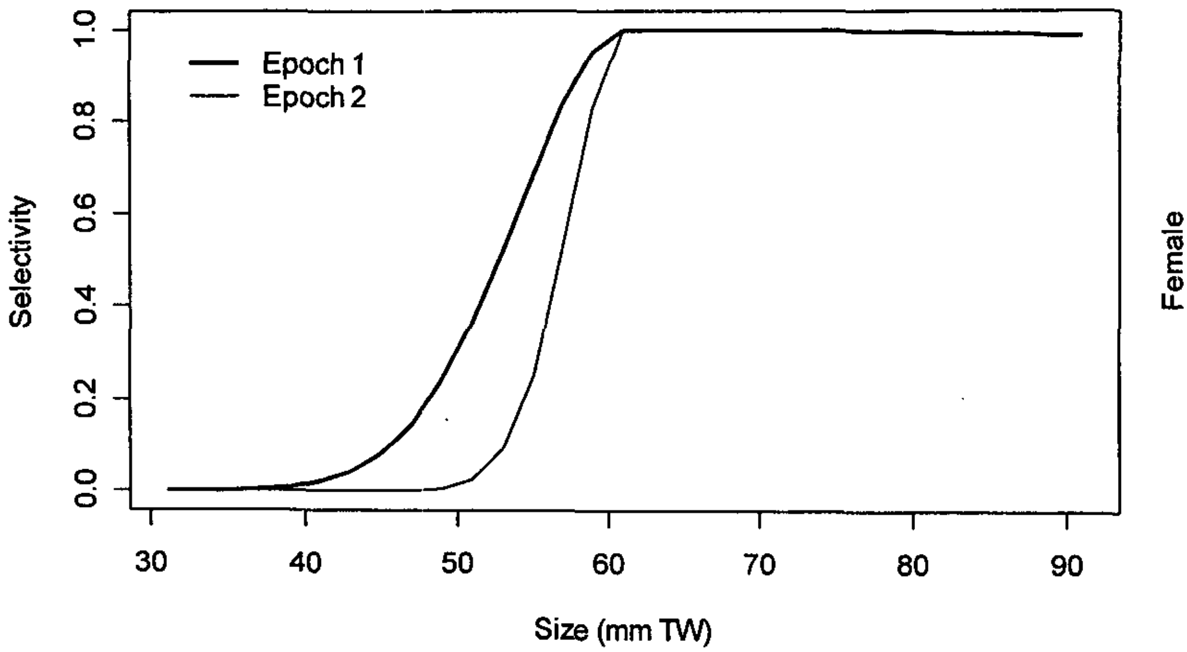


Figure 83: CRA 5: Selectivity for females in each epoch.

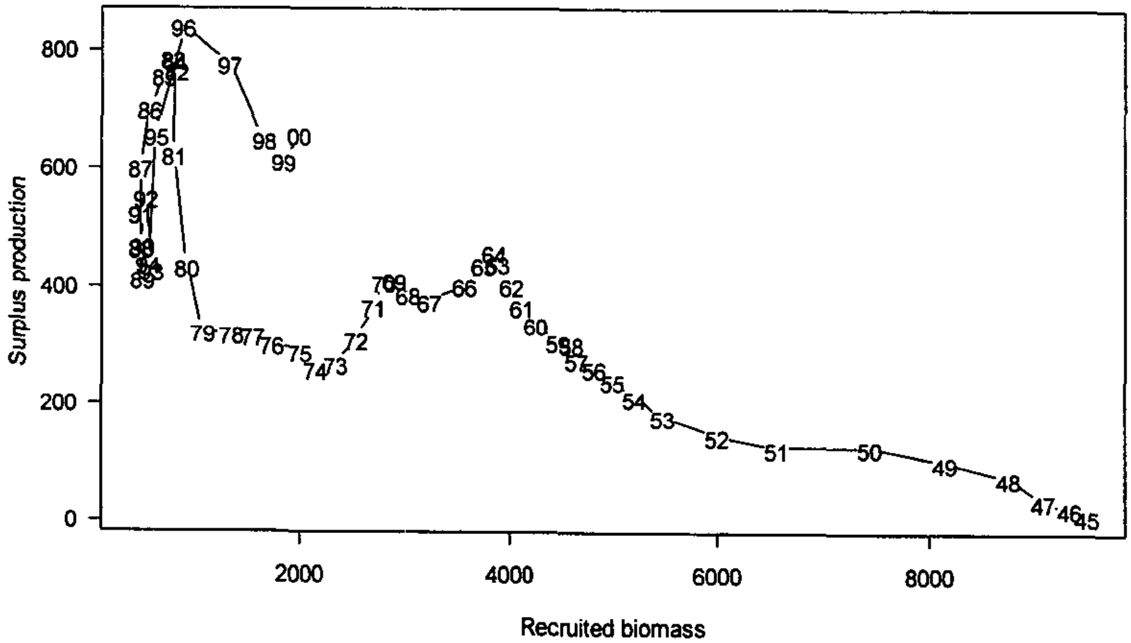


Figure 84: CRA 5: Surplus production plotted against recruited biomass. Labels indicate last the two digits of the fishing year.

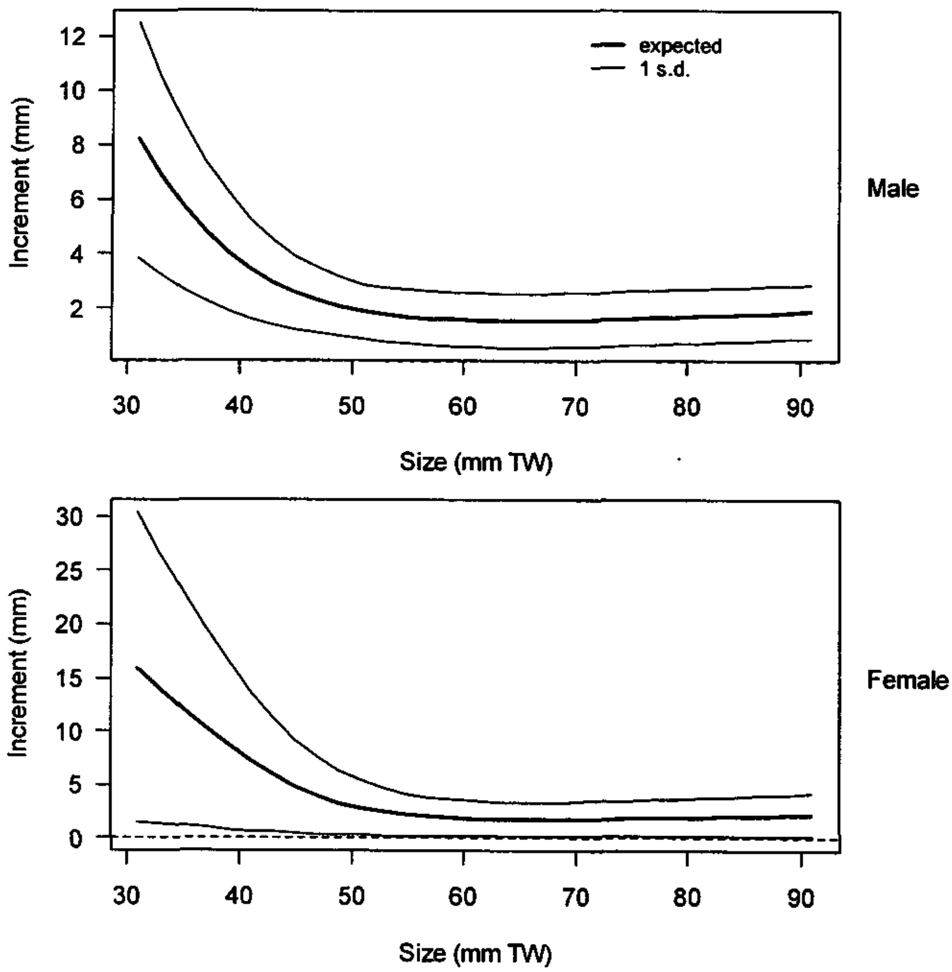


Figure 85: Predicted growth increments when the shape parameter is estimated.

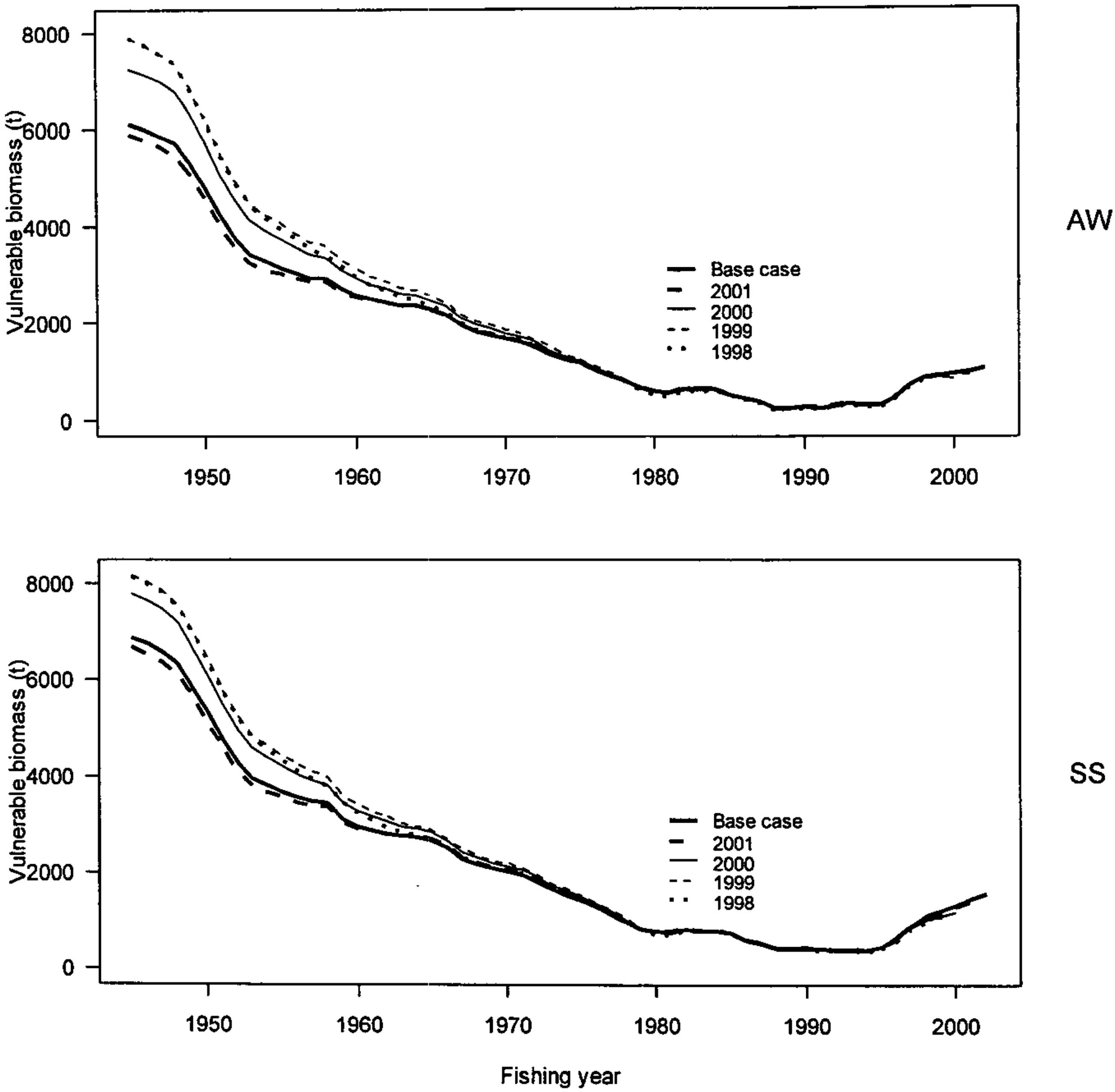


Figure 86: CRA 5: Vulnerable biomass trajectories from the MPD estimates in a retrospective analysis. The key refers to datasets labelled by the last of data they include. The base case includes 2002 data.

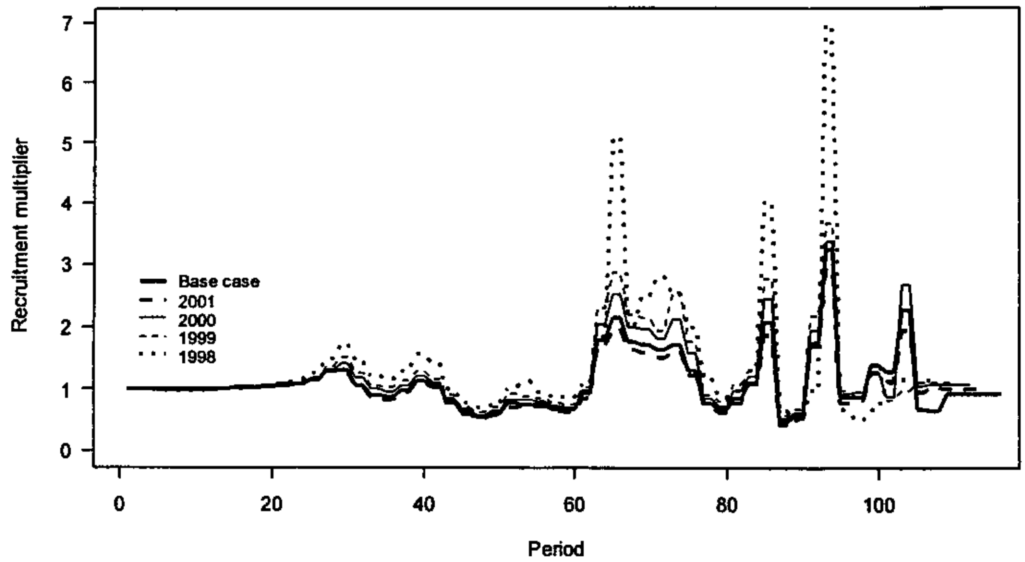


Figure 87: CRA 5: Recruitment multiplier trajectories from the MPD estimates in a retrospective analysis. The key refers to datasets labelled by the last of data they include. The base case includes 2002 data.

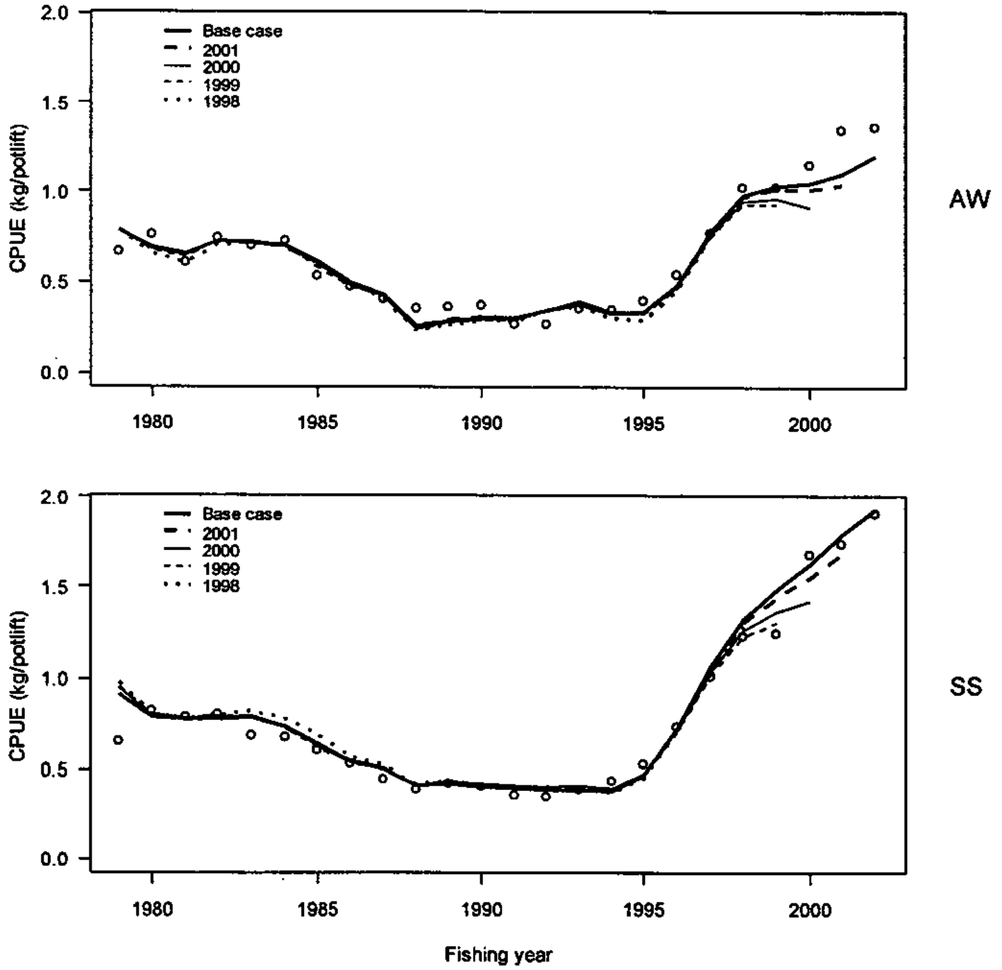


Figure 88: CRA 5: CPUE trajectories from the MPD estimates in a retrospective analysis. The key refers to datasets labelled by the last of data they include. The base case includes 2002 data.

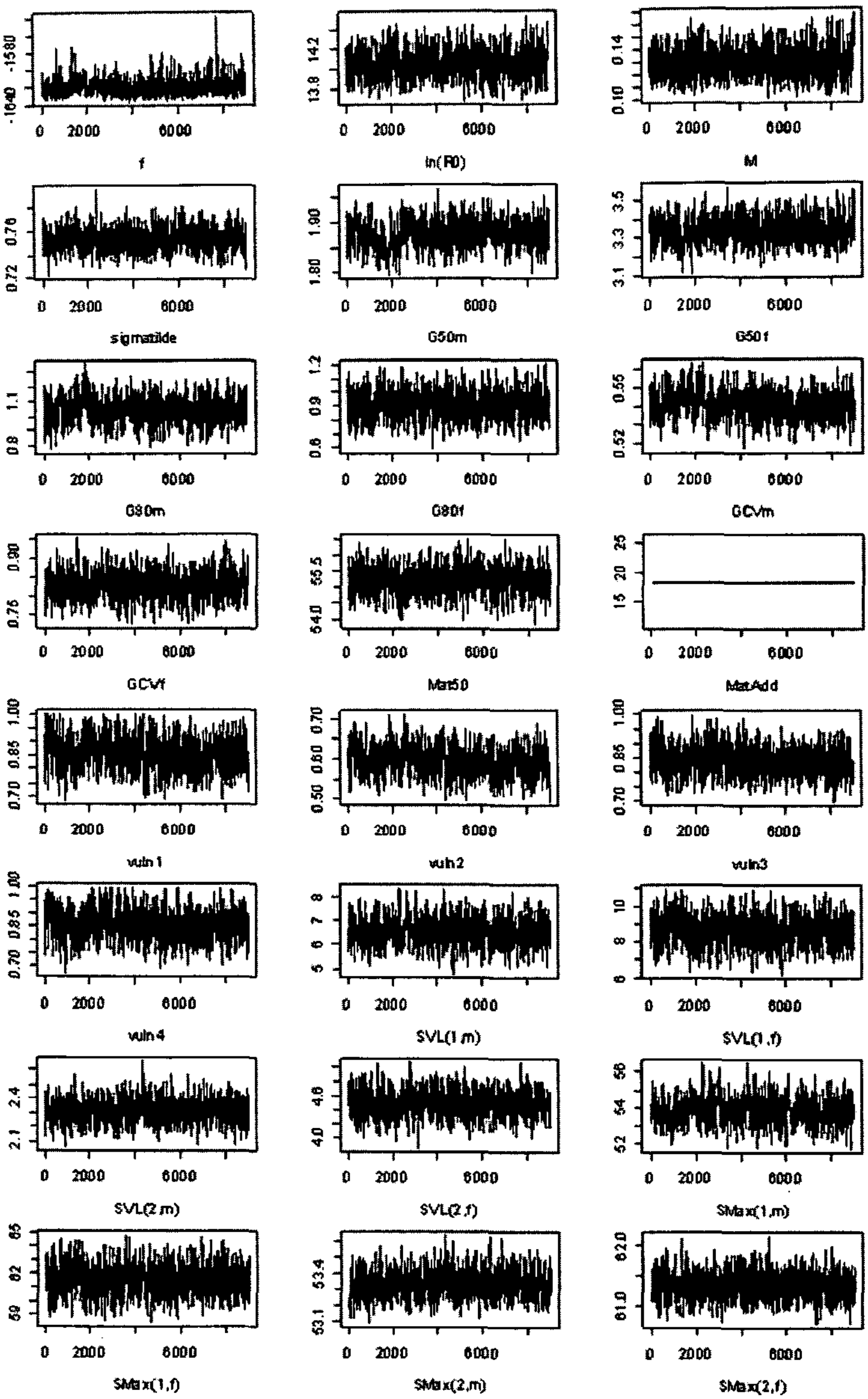


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Figure 89: CRA 5: Traces of parameters and indicators from the base case McMC simulations.

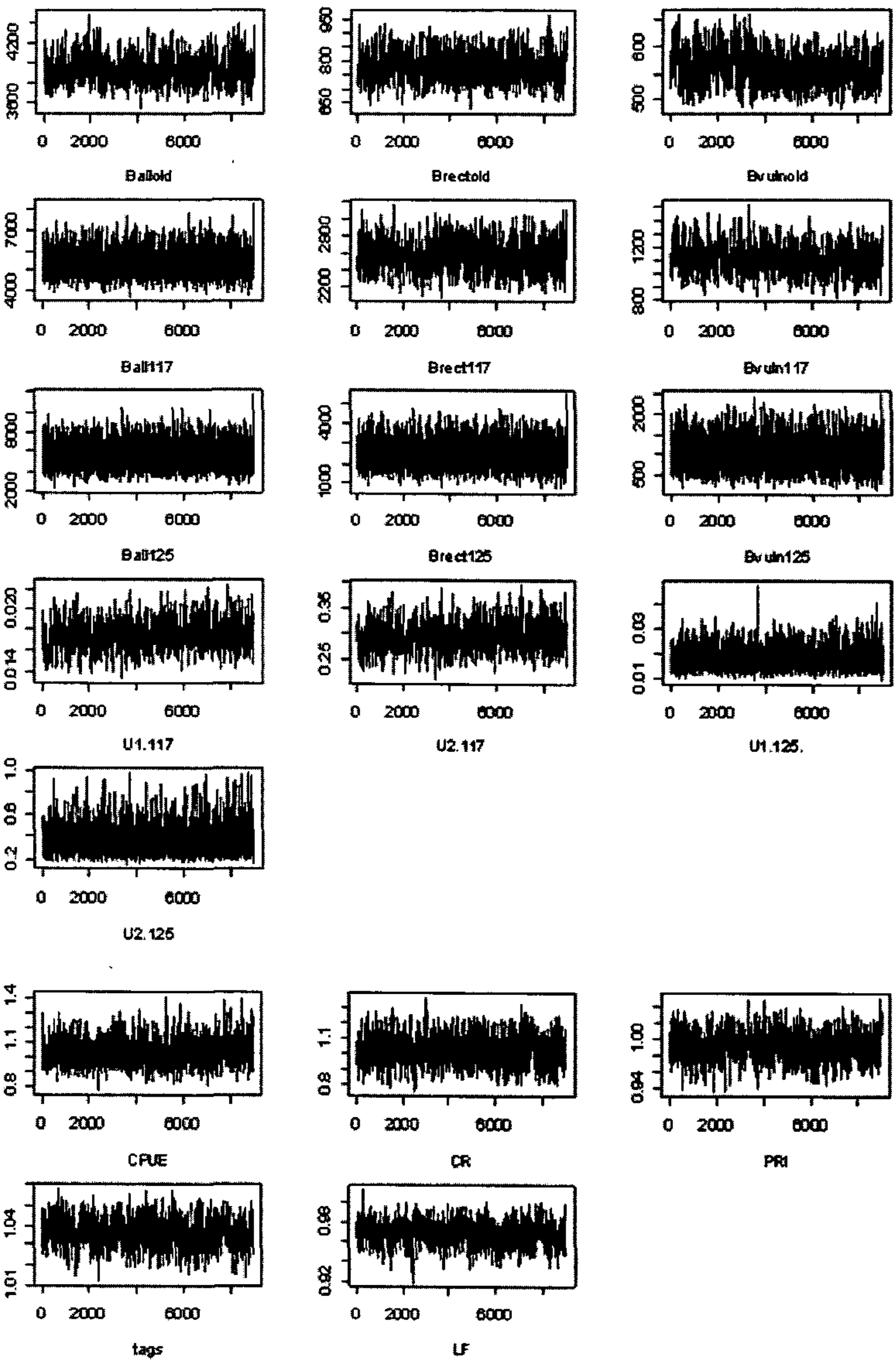


Figure 89 continued.

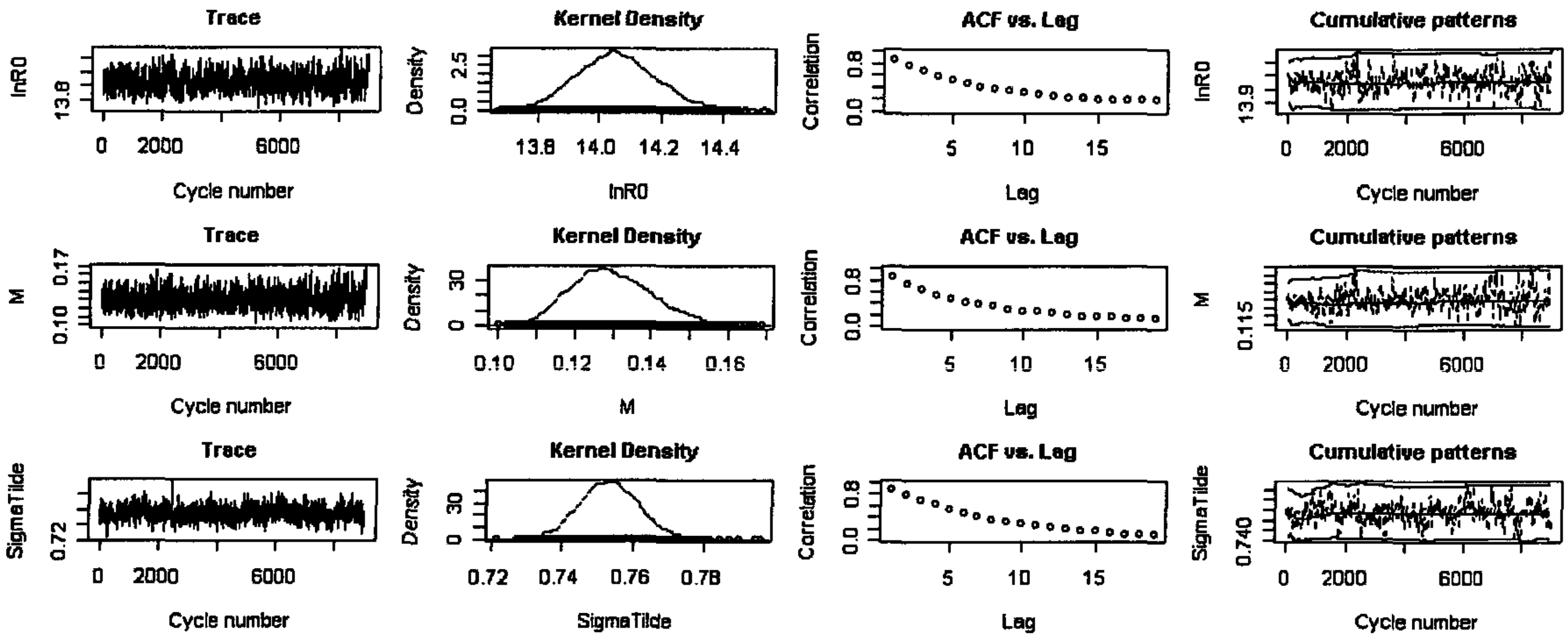


Figure 90: CRA 5: Diagnostics from single chain for different parameters. Left: traces; second from left: posterior distribution; second from right: serial autocorrelation; right: the cumulative fifth and 95th percentiles of the traces, the cumulative median and the running mean over 40 samples.

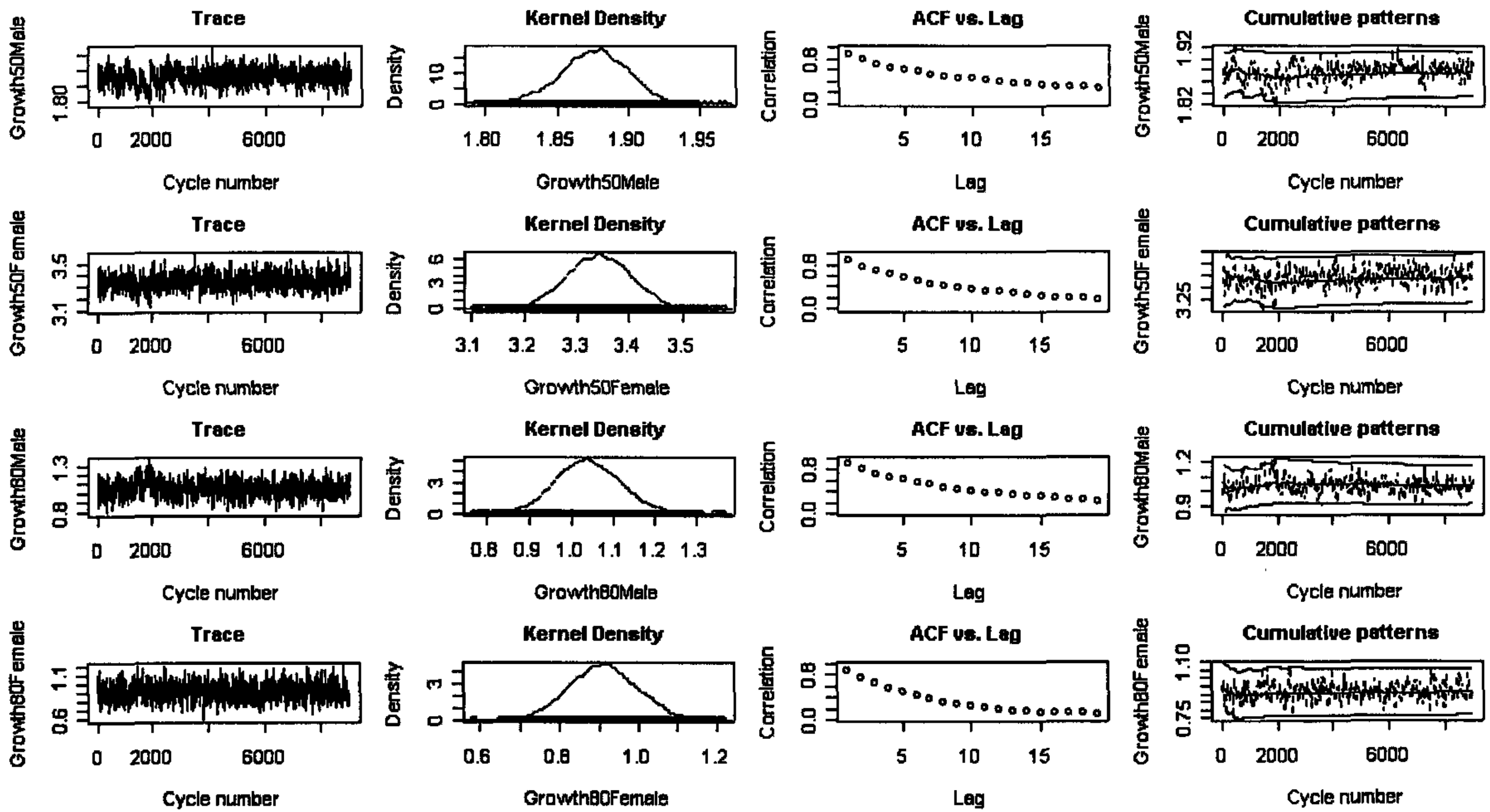


Figure 90 continued.

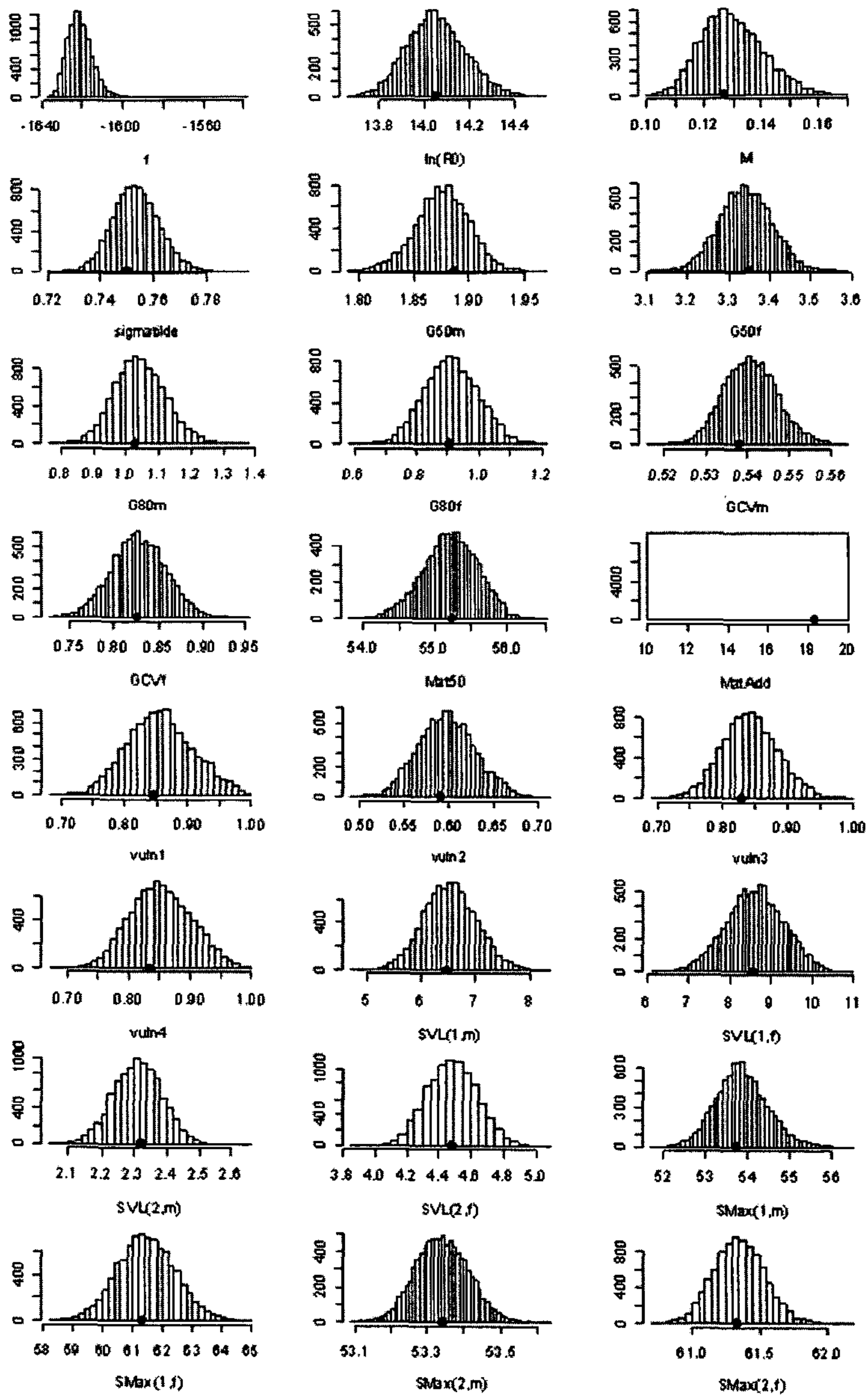


Figure 91: CRA 5: Marginal posterior distributions.

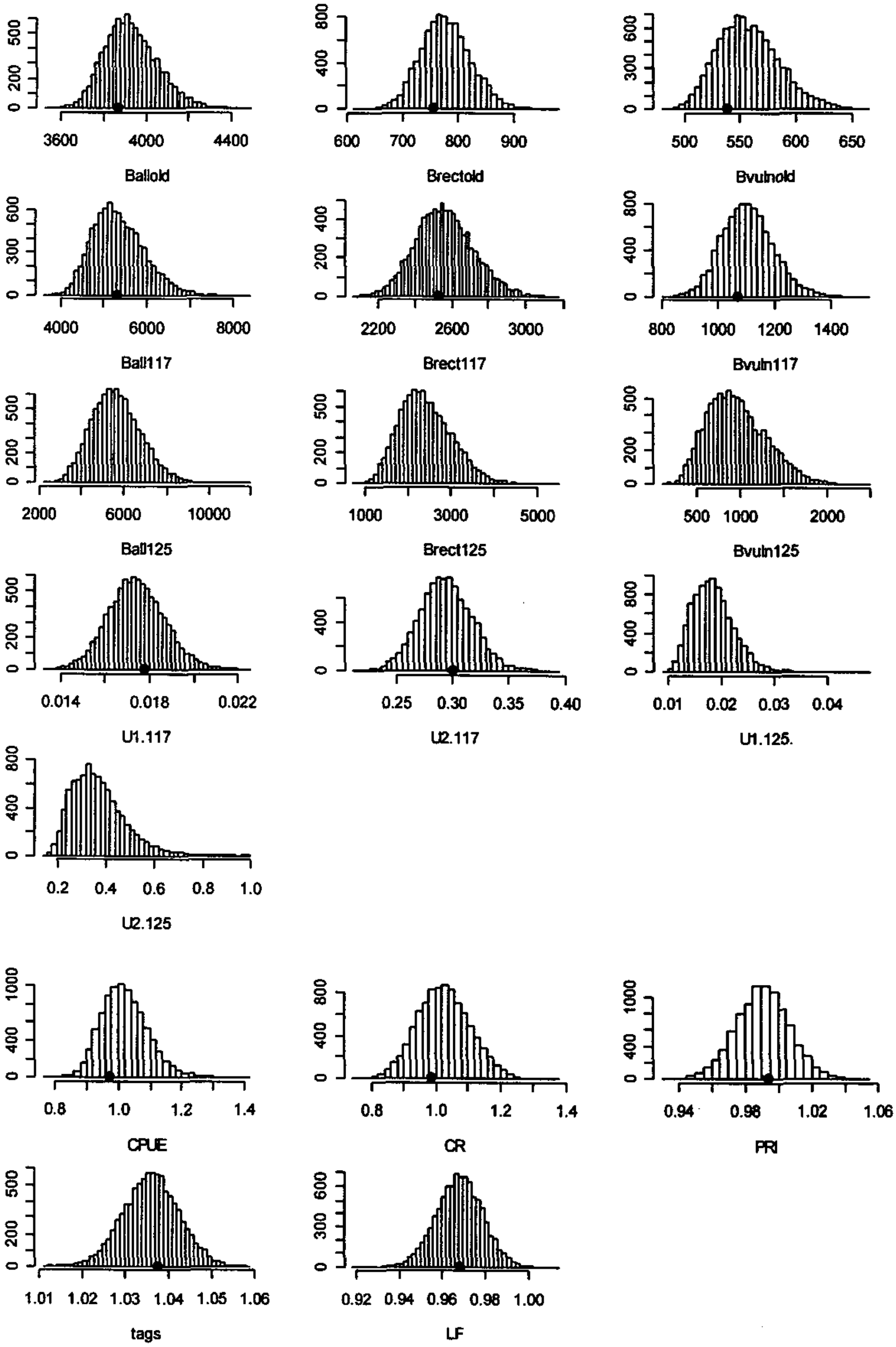


Figure 91 continued.

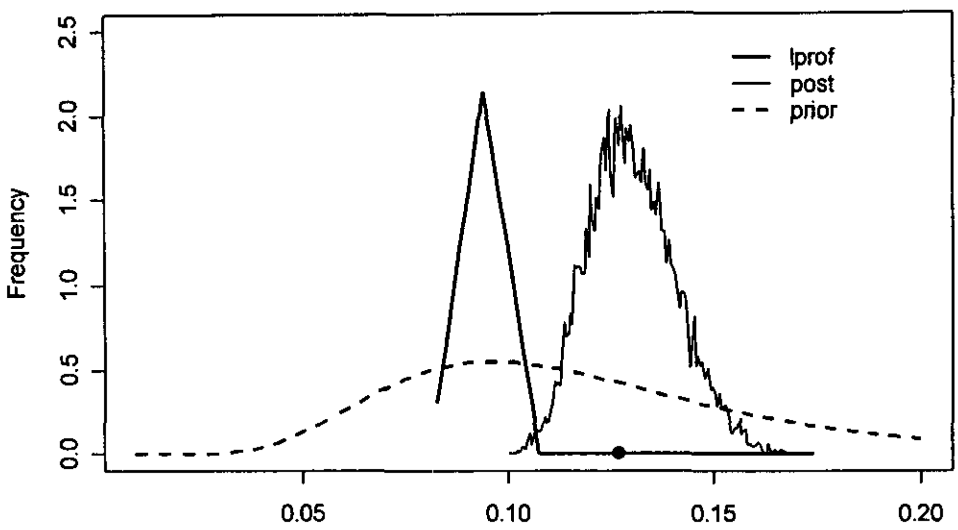


Figure 92: CRA 5: Comparison of the prior distribution (prior) of *M*, the likelihood profile (lprof), and the posterior (post).

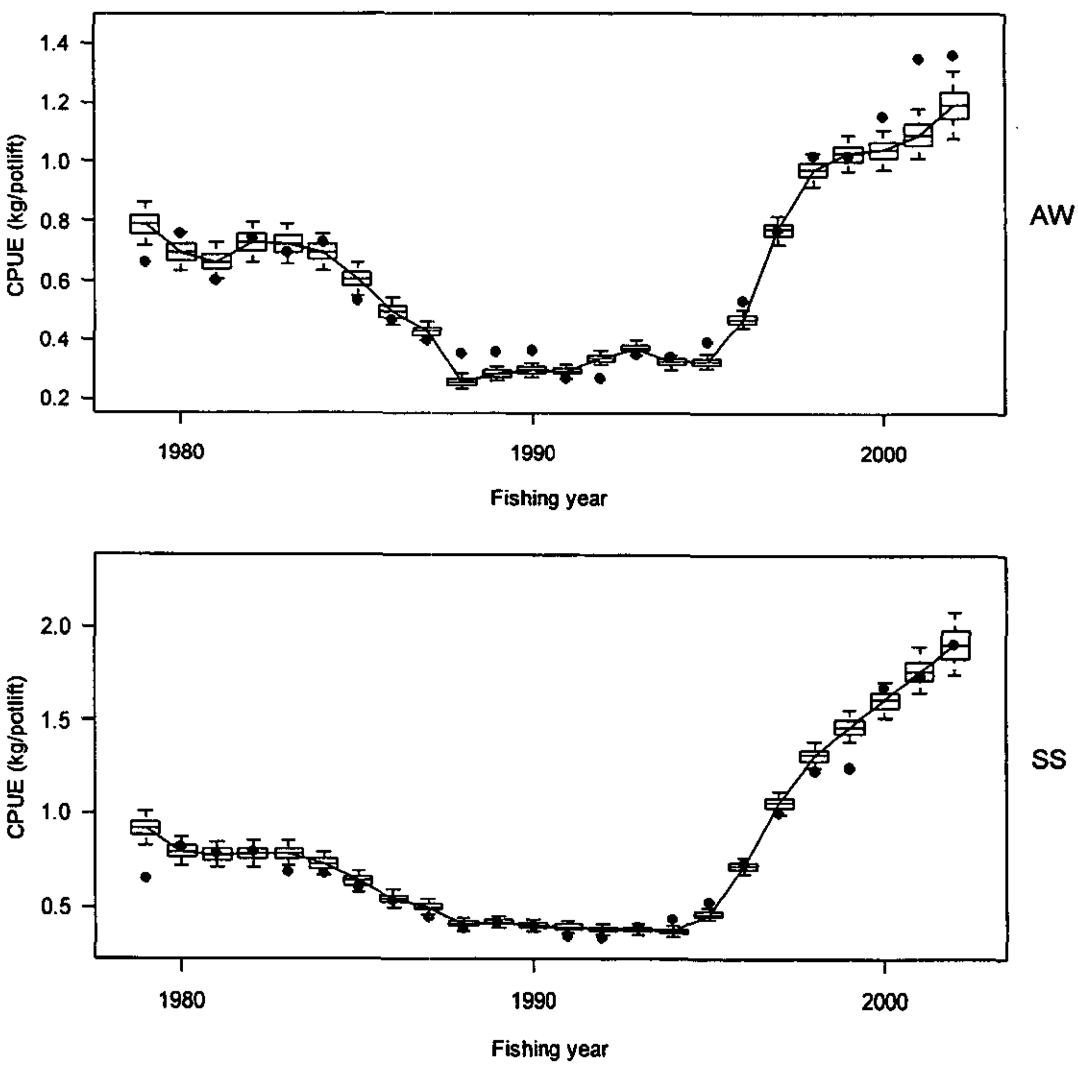


Figure 93: CRA 5: The posterior distributions of the fits to CPUE data.

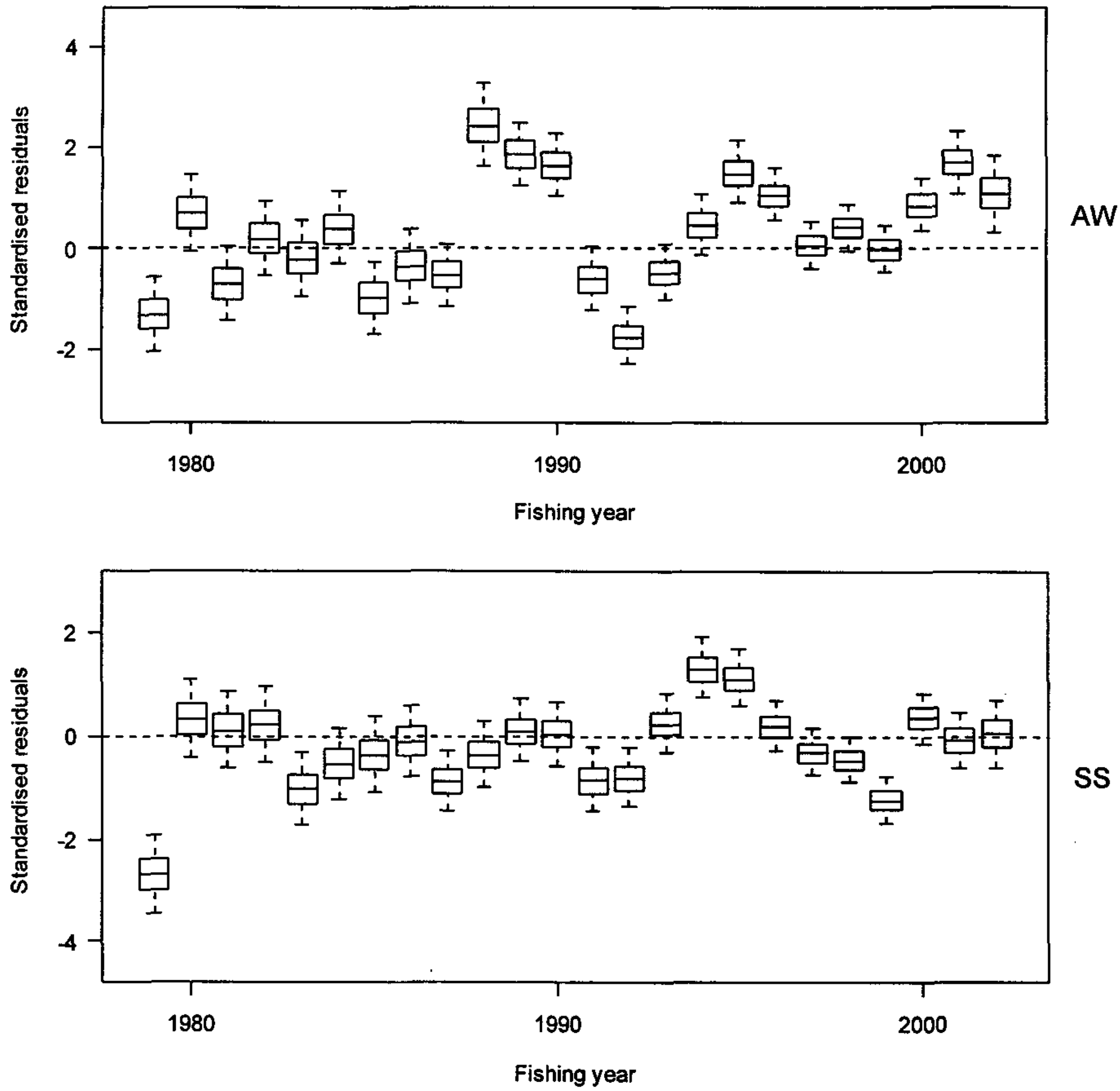


Figure 94: CRA 5: The posterior distributions of the normalised residuals from the CPUE fit.

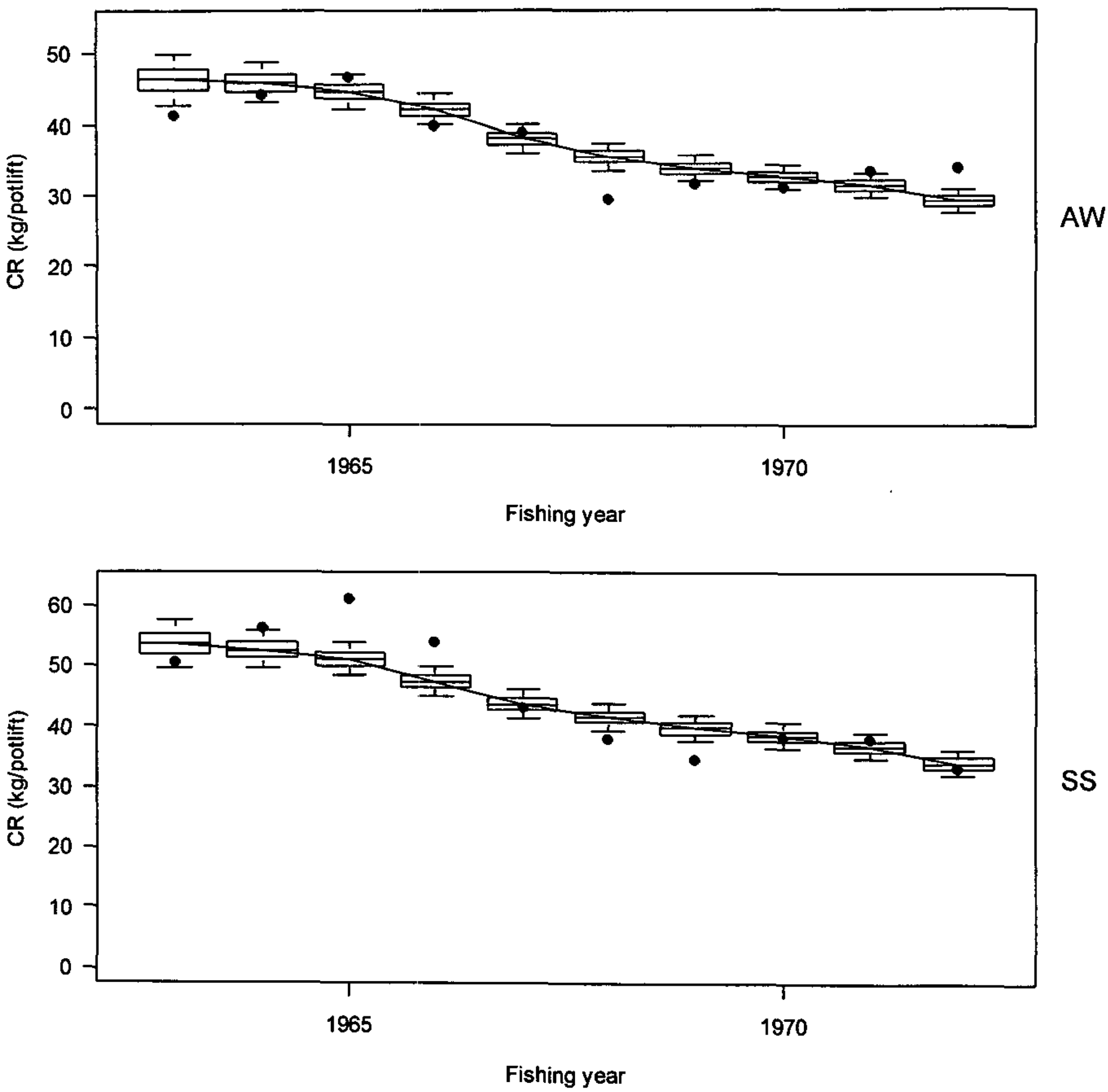


Figure 95: CRA 5: The posterior distributions of the fits to the CR data.

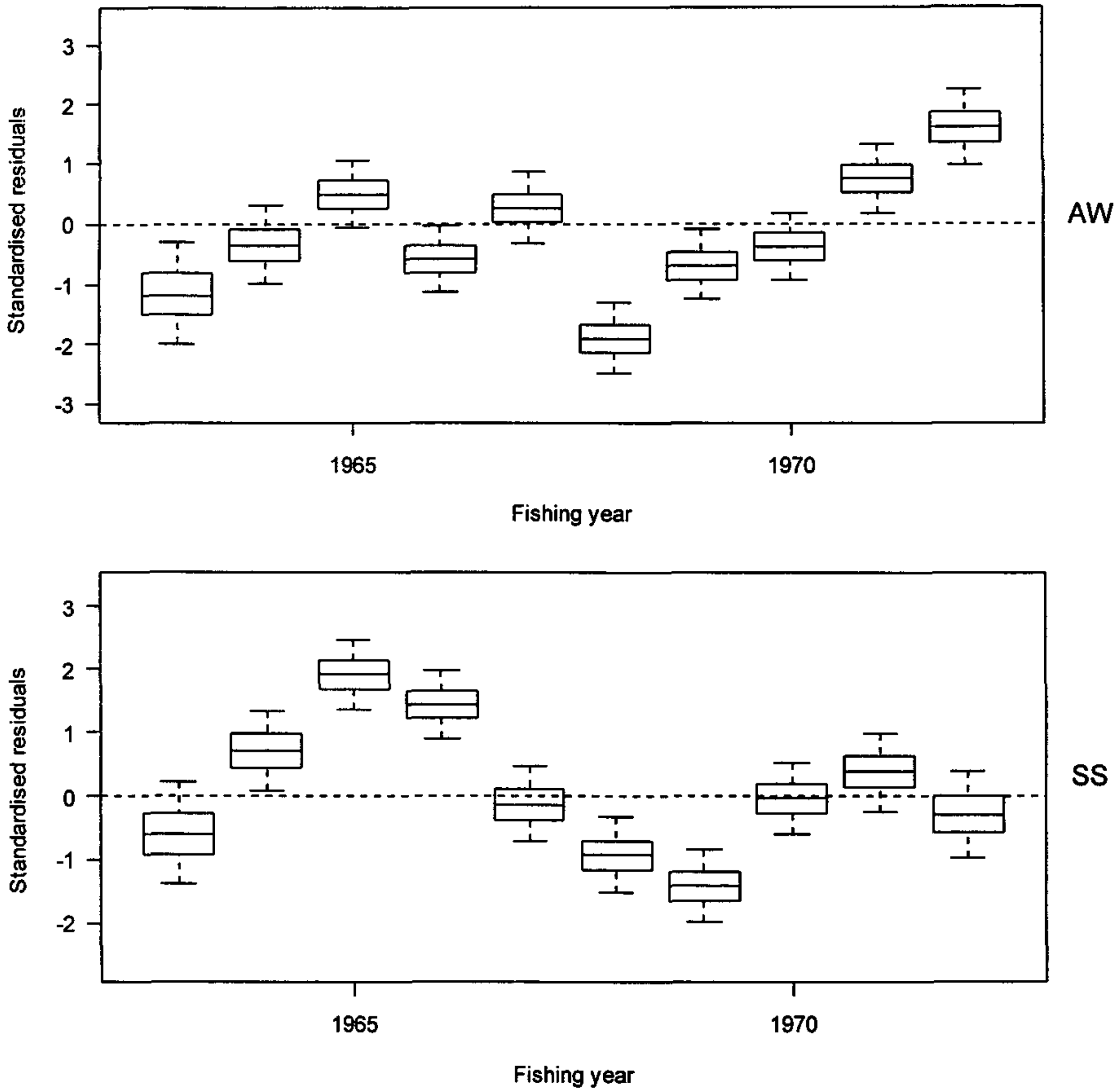
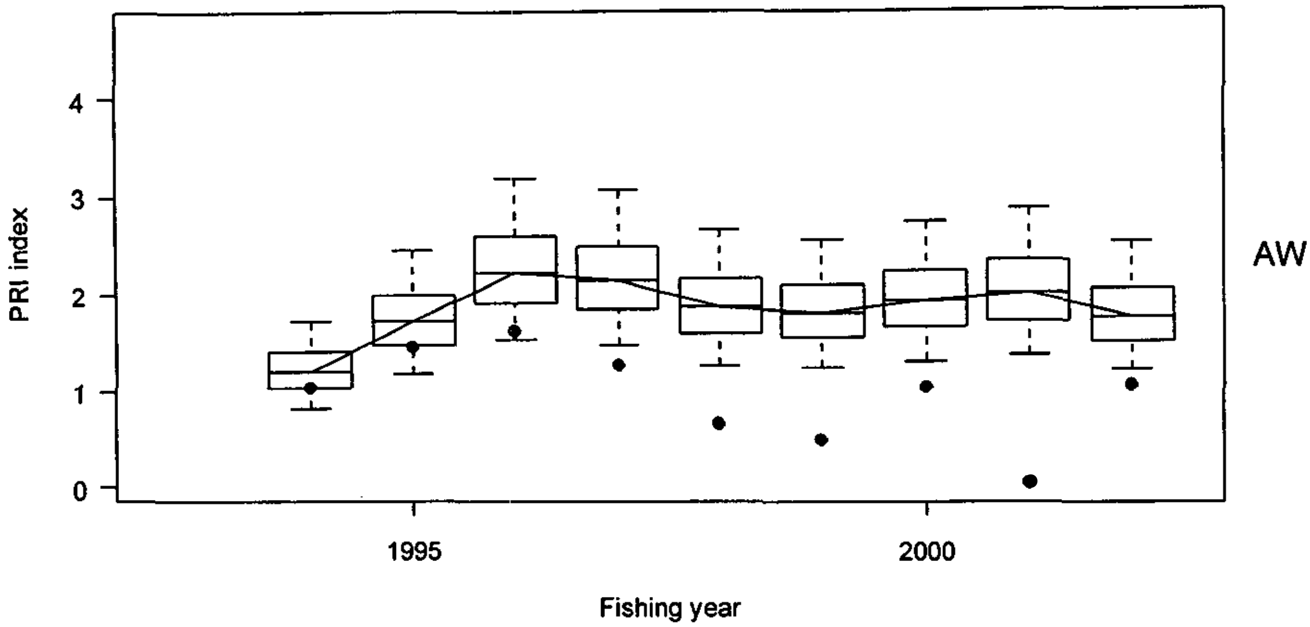


Figure 96: CRA 5: The posterior distributions of the normalised residuals from the CR fit.



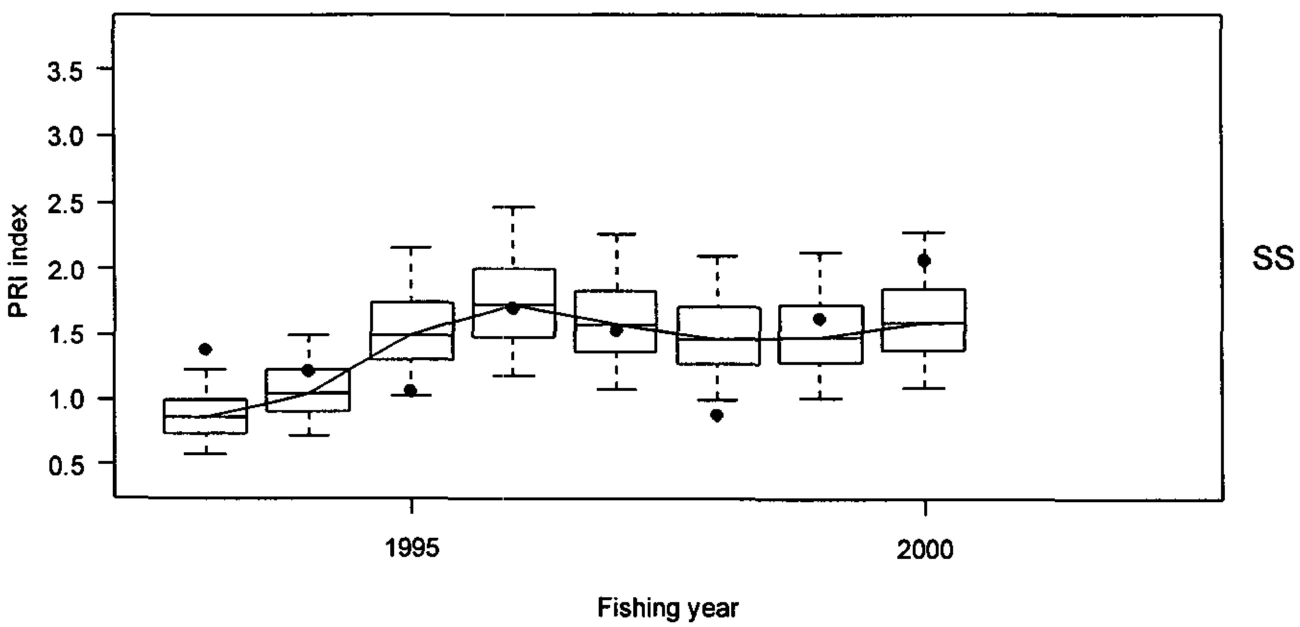


Figure 97: CRA 5: The posterior distributions of the fits to PRI data.

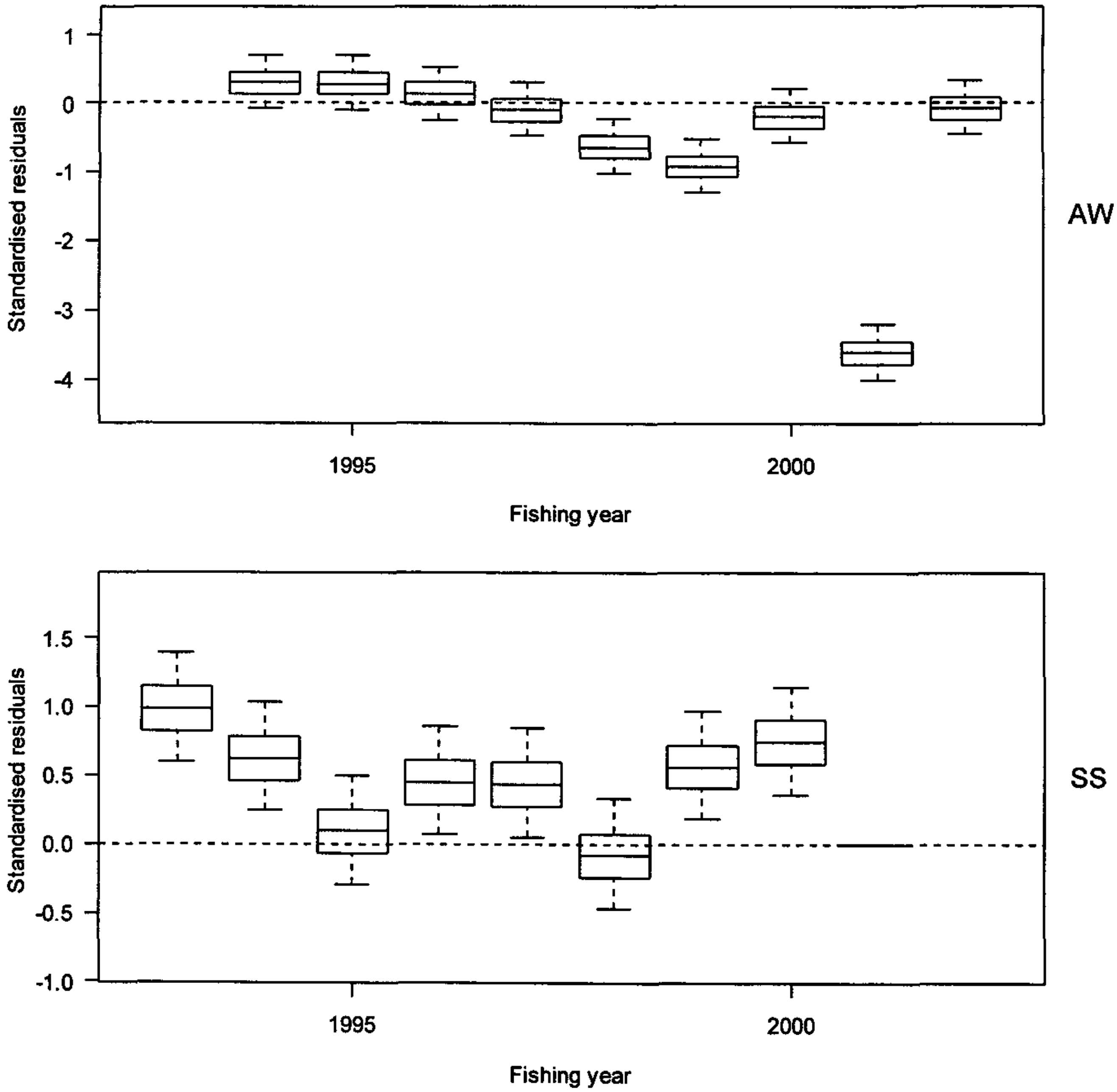


Figure 98: CRA 5: The posterior distributions of the normalised residuals from the PRI fit.

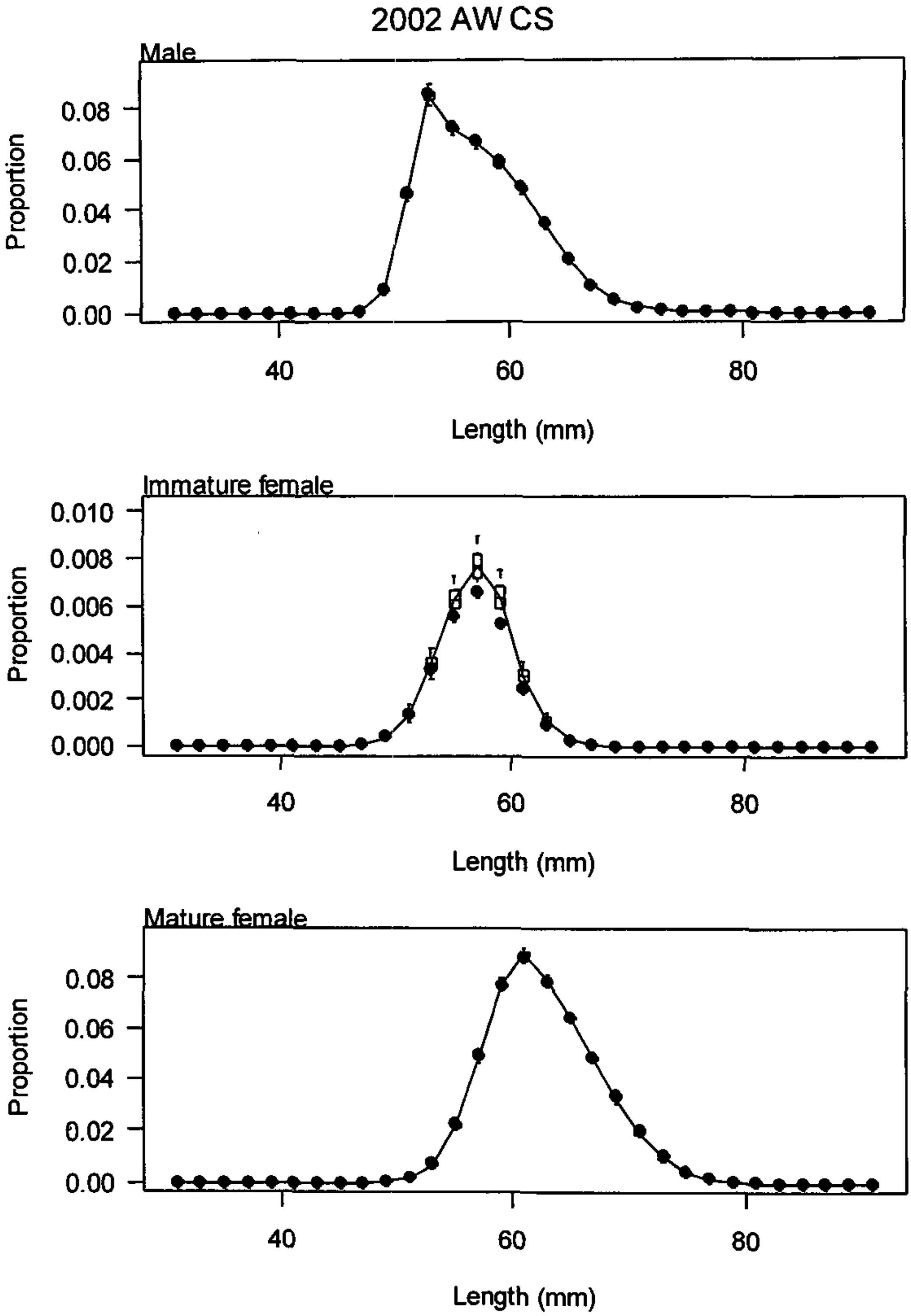


Figure 99: CRA 5: The posterior distributions of the fits to proportions-at-length from 2002 AW catch sampling.

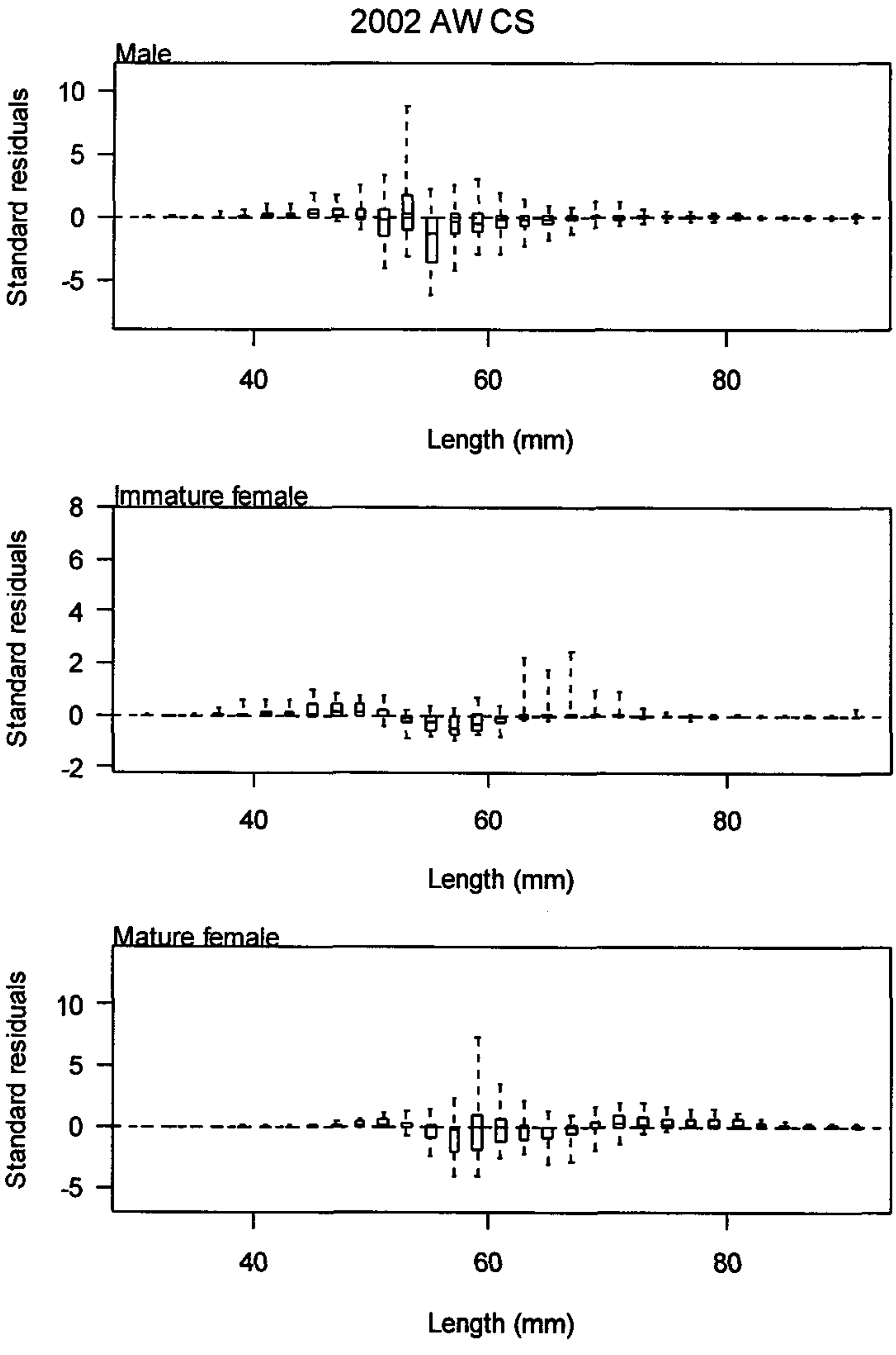
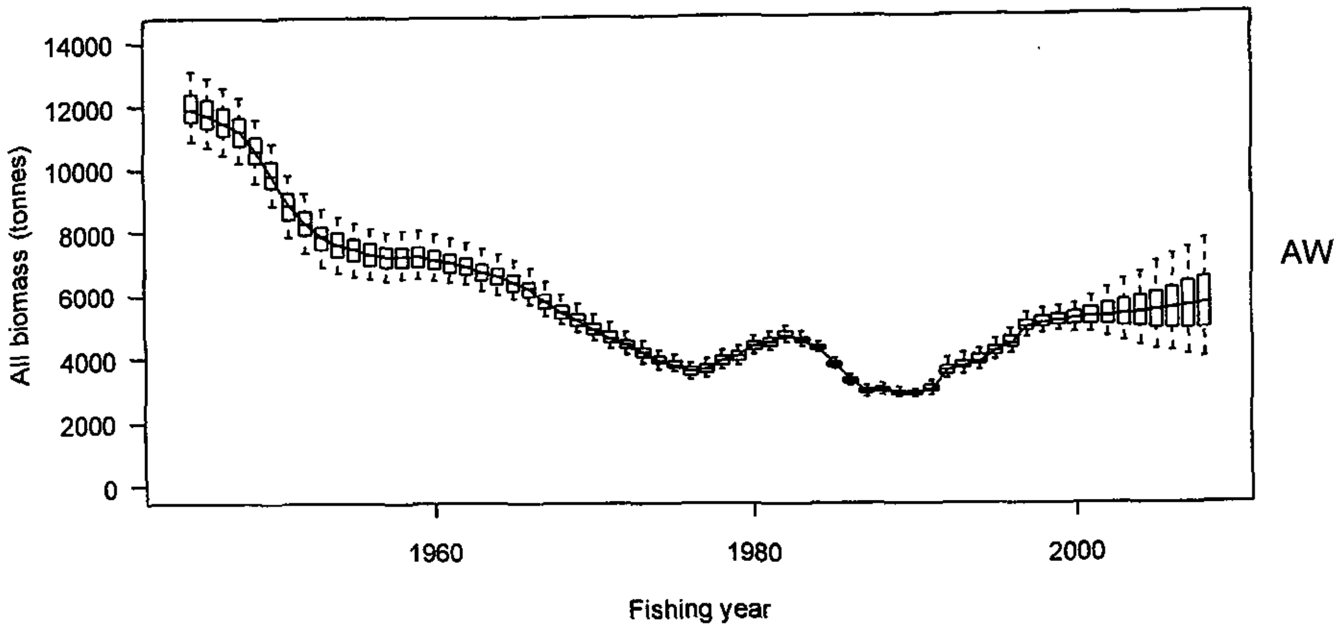


Figure 100: CRA 5: The posterior distributions of normalised residuals from the fits to proportions-at-length from 2002 AW catch sampling.



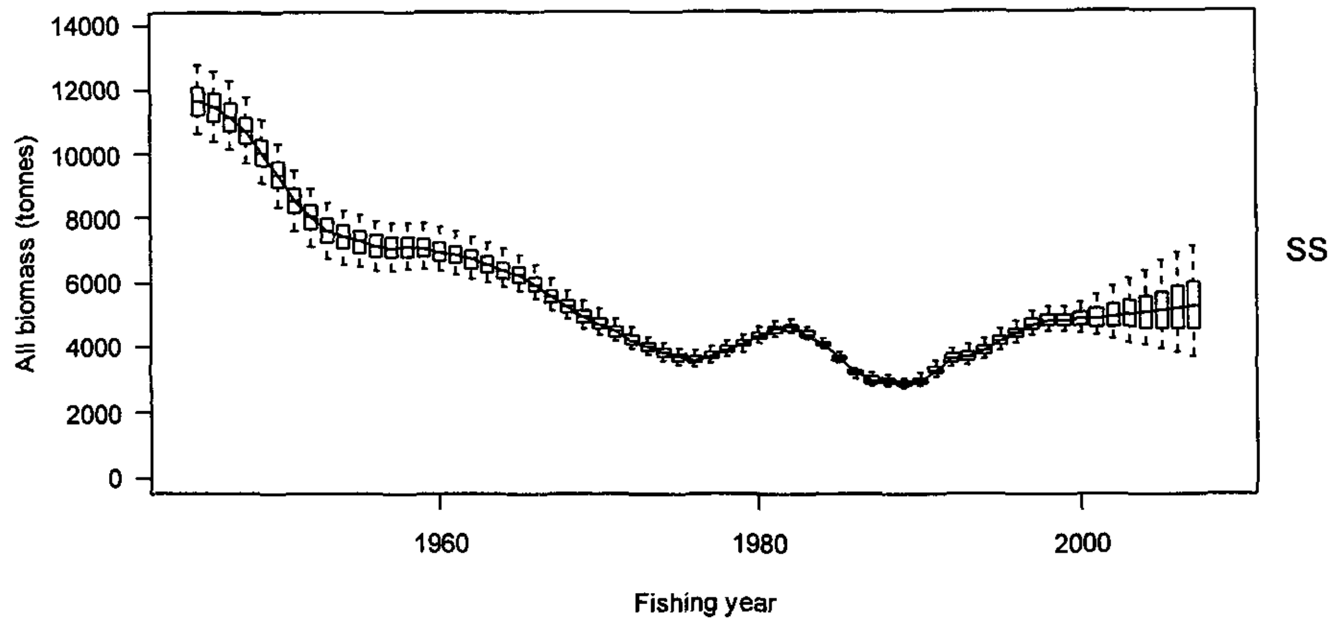
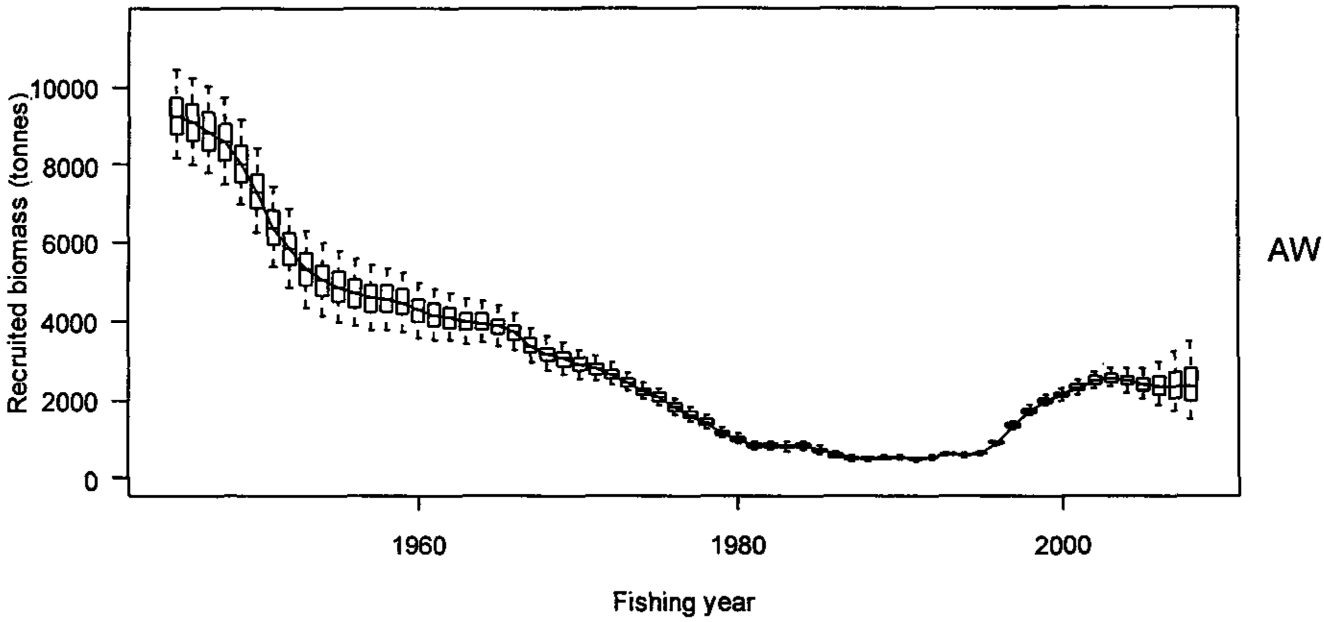


Figure 101: CRA 5: posterior trajectories of total biomass, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



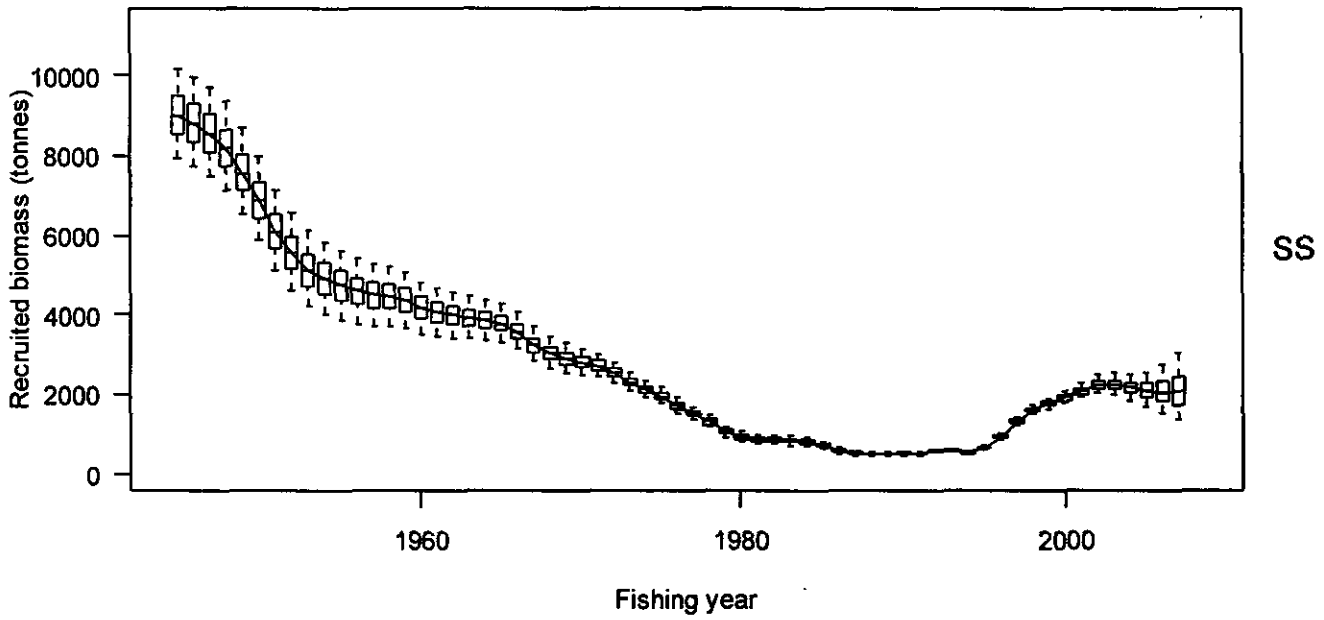
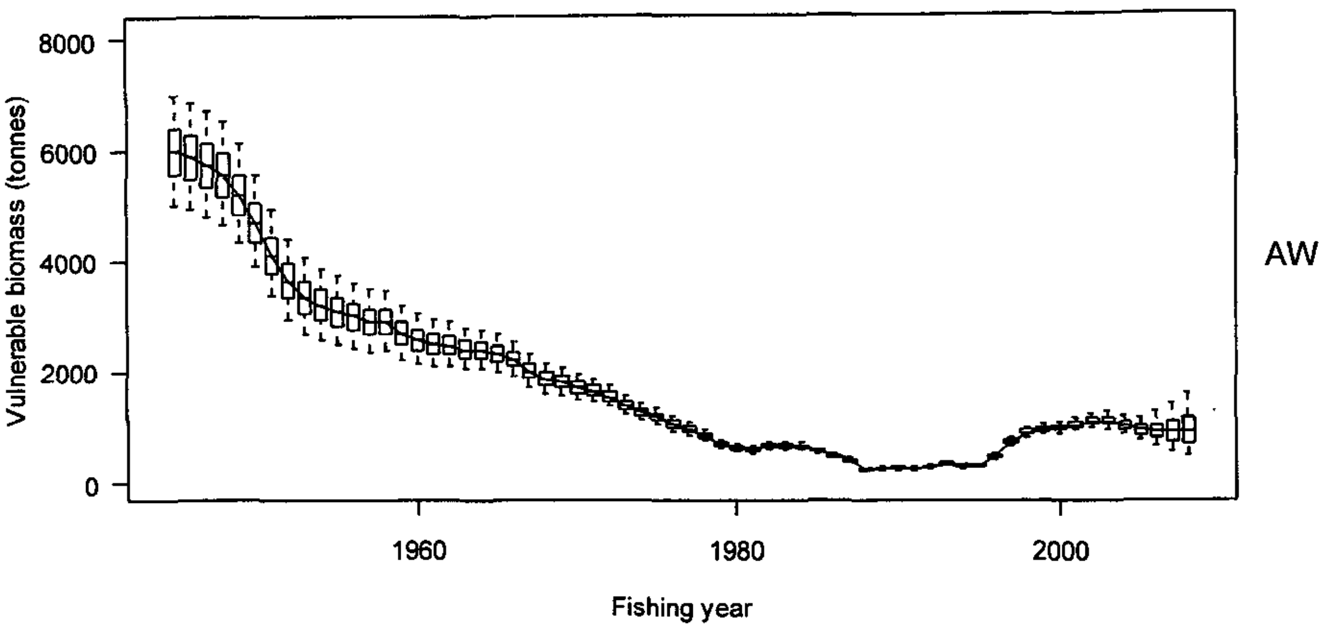


Figure 102: CRA 5: posterior trajectories of recruited biomass, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



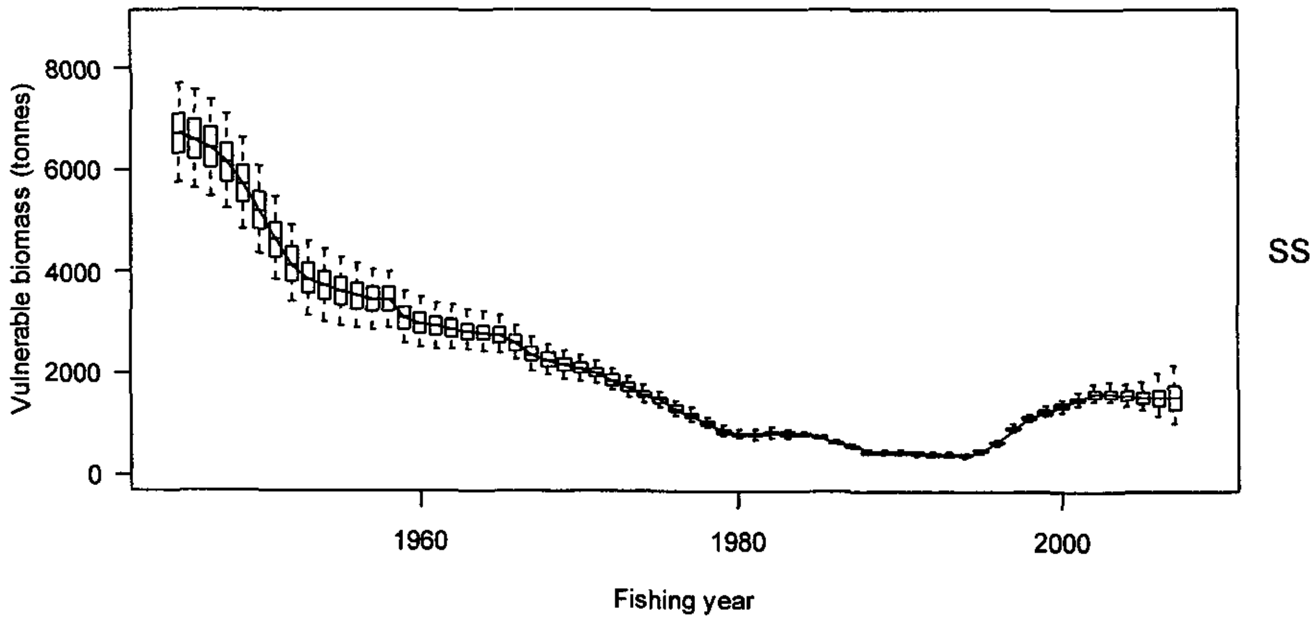


Figure 103: CRA 5: posterior trajectories of vulnerable biomass, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

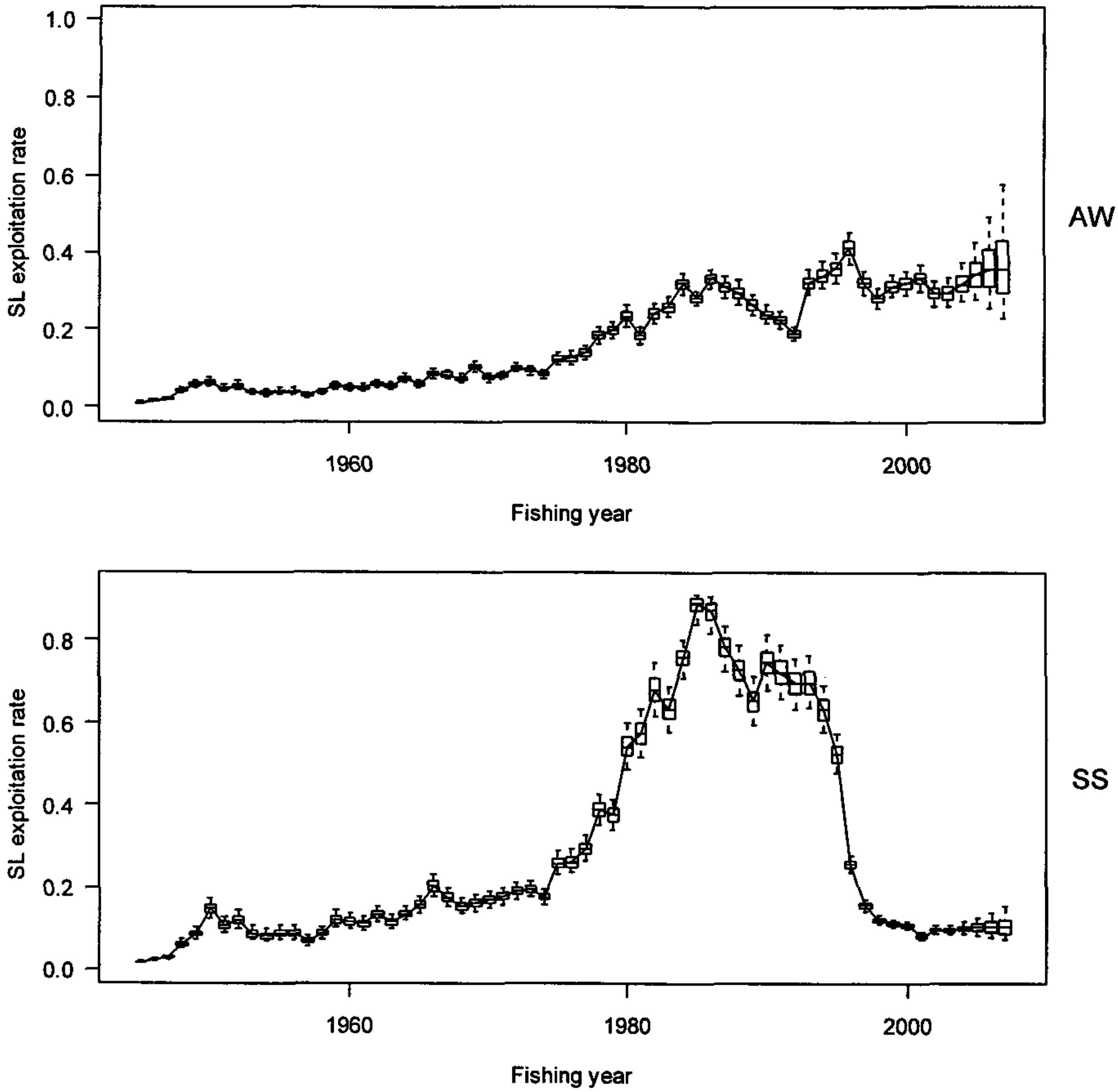
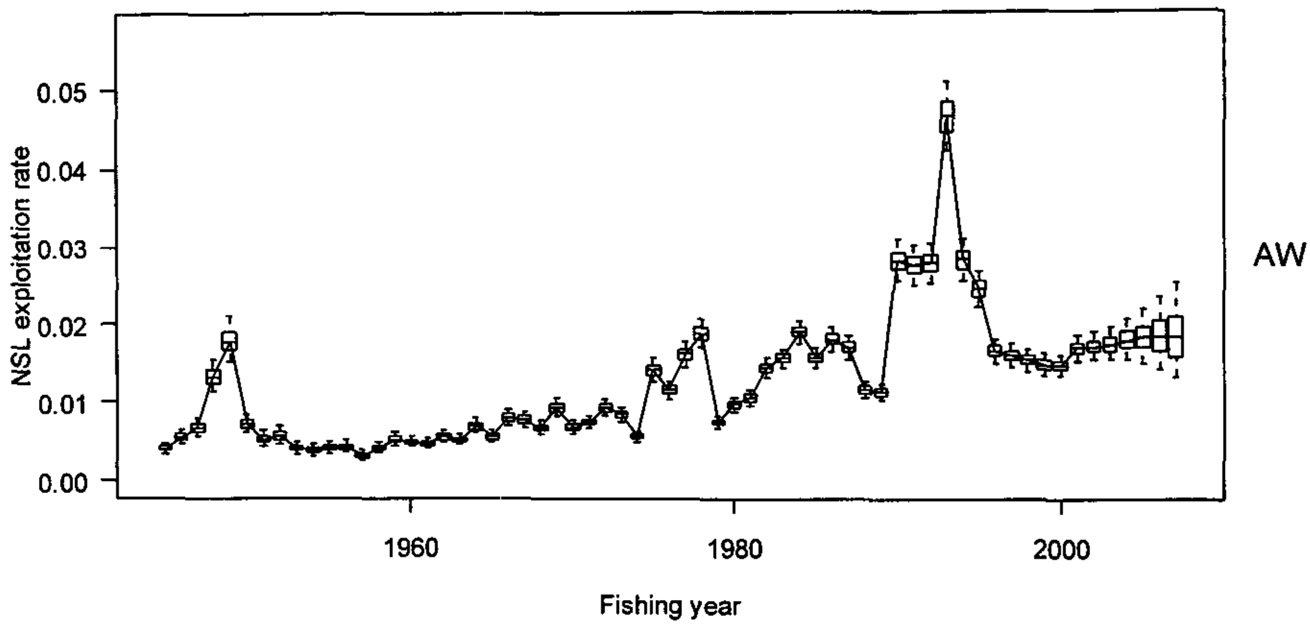


Figure 104: CRA 5: posterior trajectories of SL exploitation rate, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



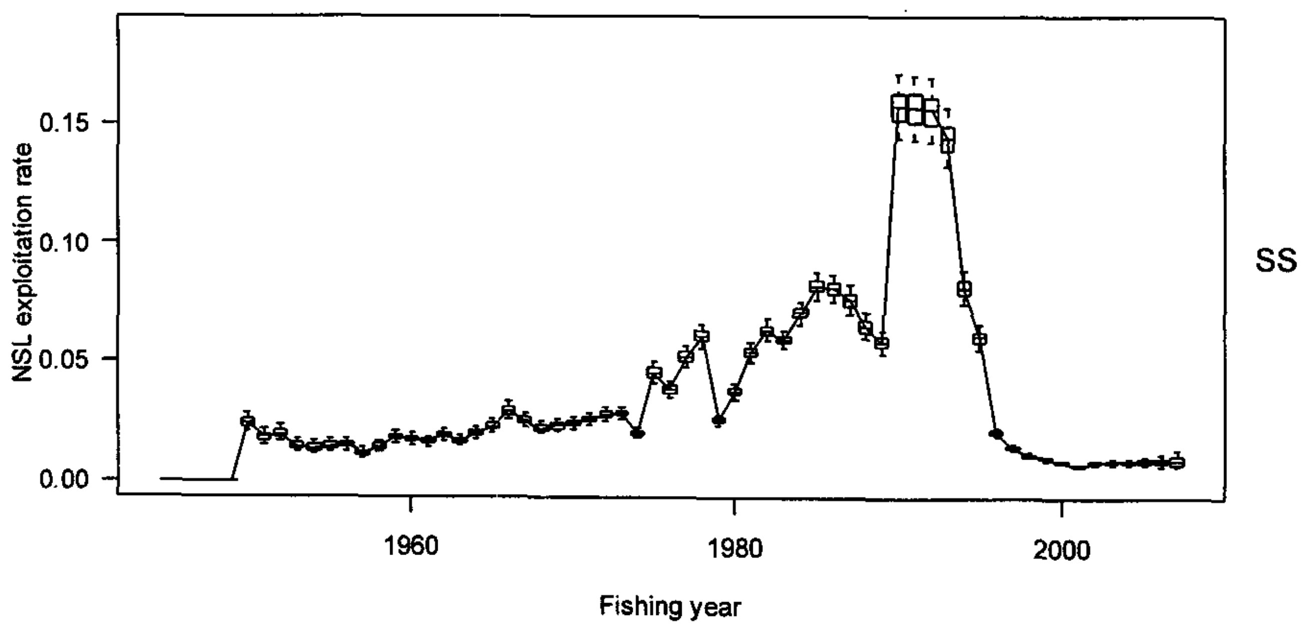


Figure 105: CRA 5: posterior trajectories of NSL exploitation rate, for the AW (top) and SS (bottom) seasons, from the base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

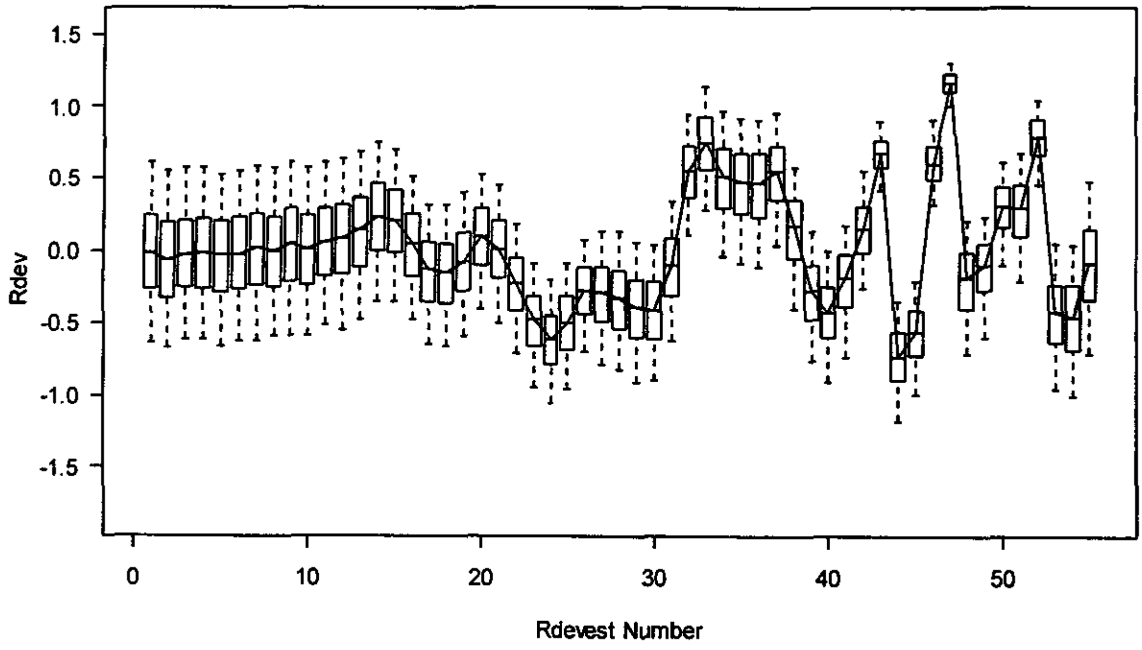


Figure 106: CRA 5: posterior trajectories of recruitment deviations from the base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

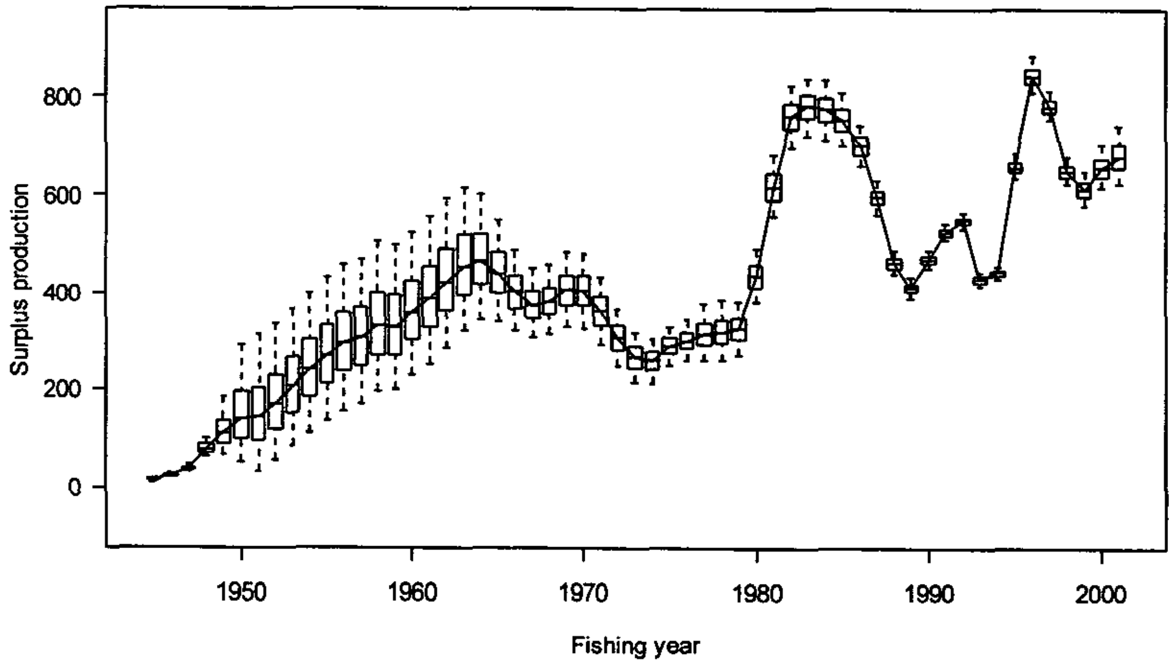


Figure 107: CRA 5: posterior trajectories of surplus production from the base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

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, that 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	
$\bar{S}_s$	Smallest size modelled in size class s
$\vec{S}_s$	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
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
$n^g_{m,o,s}$	Number of lobsters sampled in month m, area o and size s within a period
$p^g_{m,o,s}$	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^g_k	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^g_z	Size of maximum selectivity of sex g in selectivity epoch z
v^g_z	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^g_{50}	Mean expected moult increment for a lobster of size 50 mm TW and sex g
d^g_{80}	Mean expected moult increment for a lobster of size 80 mm TW and 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
$F^g_{s,t}$	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
$\mathbf{N}^g_0$	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^g_s	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
$\mathrm{R}_{s,t}$	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 spring-summer and autumn-winter 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 the autumn-winter, i.e. $r_{SS}^{femmat} = r_{SS}^{female}$; this was examined in sensitivity trials in this study (Table A2).

Table A2: Vulnerability that is fixed at 1 with their switch.

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

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

and $F_{s,t}^g$ is zero for all mature females in the autumn-winter season. 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 re-calculates vulnerable biomass in each category, re-calculates 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. The estimated 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. 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 the AW season. 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 $\hat{S}_{s,t+1}^g$; some move into smaller or larger size classes, depending on φ_s^g. 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 $\hat{S}_{s,t+1}^g$ and standard deviation φ_s^g. 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, $\underline{S}_{s'}$ to ∞. With the sex index, g, and the season index, k, suppressed this is:

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

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, $\dot{N}_{s,t}^g$:

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

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

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

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

where it is assumed that the recruitment deviations ε_t are normally distributed with mean zero and standard deviation σ^ε. The term $-\frac{(\sigma^\varepsilon)^2}{2}$ 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 $$R_{s,t} = R_t \frac{\exp\left({-(\bar{S}_s - \phi)^2} \middle/ {2\gamma^2} \right)}{\sum_s \exp\left({-(\bar{S}_s - \phi)^2} \middle/ {2\gamma^2} \right)}$$

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

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

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

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

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

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

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

A.11 Predictions and likelihoods for abundance indices

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

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

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

The normalised residual is:

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

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

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

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

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

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

The normalised residual is

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

The predicted pre-recruit index is calculated as:

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

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 $$p^{g}_{m,o,s} = n^{g}_{m,o,s} \Big/ \sum_{g}\sum_{s} n^{g}_{m,o,s}$$

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

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

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

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

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, $\hat{S}^{g,recap}_{i}$, is

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

If the animal was at liberty for more than one moulting period for that sex, then the resulting size is calculated as above, replacing $S^{g,tag}_{i,j}$ 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

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

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

A.15 Surplus production

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

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

where t indexes period.

APPENDIX B. DATA USED IN THE ASSESSMENT

B.1 CRA 4 data

Table B1: Catch data in kilograms used for the CRA 4 assessment. Catches are reported by calendar year through 1978, then are reported by fishing year (1 April to 31 March, named by the April-December year).

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1945	1	1	102 946	742	1 290	18 062	1 000
1945	2	2	151 781	6 679	1 902	26 630	9 000
1946	1	3	91 079	829	1 141	15 980	1 000
1946	2	4	134 284	7 465	1 683	23 560	9 000
1947	1	5	102 515	917	1 285	17 986	1 000
1947	2	6	151 146	8 251	1 894	26 519	9 000
1948	1	7	102 310	1 004	1 282	17 950	1 000
1948	2	8	150 843	9 037	1 890	26 466	9 000
1949	1	9	110 707	1 091	1 387	19 424	1 000
1949	2	10	163 223	9 823	2 046	28 638	9 000
1950	1	11	203 491	1 179	2 550	35 703	1 000
1950	2	12	300 020	10 608	3 760	52 639	9 000
1951	1	13	272 252	1 266	3 412	47 767	1 000
1951	2	14	401 399	11 394	5 030	70 426	9 000
1952	1	15	264 244	1 353	3 312	46 362	1 000
1952	2	16	389 593	12 180	4 882	68 355	9 000
1953	1	17	274 325	1 441	3 438	48 131	1 000
1953	2	18	404 456	12 966	5 069	70 962	9 000
1954	1	19	269 418	1 528	3 376	47 270	1 000
1954	2	20	397 222	13 752	4 978	69 693	9 000
1955	1	21	203 593	1 615	2 551	35 721	1 000
1955	2	22	300 172	14 538	3 762	52 665	9 000
1956	1	23	175 382	1 703	2 198	30 771	1 000
1956	2	24	258 578	15 323	3 241	45 368	9 000
1957	1	25	132 450	1 790	1 660	23 239	1 000
1957	2	26	195 281	16 109	2 447	34 262	9 000
1958	1	27	137 645	1 877	1 725	24 150	1 000
1958	2	28	202 939	16 895	2 543	35 606	9 000
1959	1	29	118 838	1 965	1 489	20 850	1 000
1959	2	30	175 211	17 681	2 196	30 741	9 000
1960	1	31	146 269	2 052	1 833	25 663	1 000
1960	2	32	215 654	18 467	2 703	37 837	9 000
1961	1	33	169 675	2 139	2 126	29 770	1 000
1961	2	34	250 163	19 252	3 135	43 891	9 000
1962	1	35	202 628	2 226	2 539	35 551	1 000
1962	2	36	298 749	20 038	3 744	52 416	9 000
1963	1	37	134 094	2 314	1 680	23 527	1 000
1963	2	38	176 204	20 824	2 208	30 915	9 000
1964	1	39	172 091	2 401	2 157	30 194	1 000
1964	2	40	287 831	21 610	3 607	50 500	9 000
1965	1	41	201 451	2 488	2 525	35 345	1 000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1965	2	42	379 960	22 396	4 762	66 664	9 000
1966	1	43	307 700	2 576	3 856	53 986	1 000
1966	2	44	355 781	23 181	4 459	62 422	9 000
1967	1	45	211 129	2 663	2 646	37 043	1 000
1967	2	46	301 509	23 967	3 779	52 900	9 000
1968	1	47	184 032	2 750	2 306	32 289	1 000
1968	2	48	325 523	24 753	4 080	57 113	9 000
1969	1	49	245 779	2 838	3 080	43 122	1 000
1969	2	50	360 969	25 539	4 524	63 332	9 000
1970	1	51	211 455	2 925	2 650	37 100	1 000
1970	2	52	347 504	26 325	4 355	60 970	9 000
1971	1	53	145 665	3 012	1 826	25 557	1 000
1971	2	54	273 673	27 110	3 430	48 016	9 000
1972	1	55	149 010	3 100	1 867	26 144	1 000
1972	2	56	277 321	27 896	3 475	48 656	9 000
1973	1	57	129 074	3 187	1 618	22 646	1 000
1973	2	58	244 745	28 682	3 067	42 941	9 000
1974	1	59	129 482	3 274	1 137	15 914	1 000
1974	2	60	245 518	29 468	2 155	30 175	9 000
1975	1	61	139 495	3 362	2 320	32 479	1 000
1975	2	62	264 505	30 254	4 399	61 586	9 000
1976	1	63	157 450	3 449	2 095	29 334	1 000
1976	2	64	298 550	31 040	3 973	55 621	9 000
1977	1	65	151 234	3 536	2 664	37 300	1 000
1977	2	66	286 766	31 825	5 052	70 727	9 000
1978	1	67	171 376	3 623	3 085	43 188	1 000
1978	2	68	324 958	32 611	5 849	81 891	9 000
1979	1	69	159 214	3 711	921	12 899	1 000
1979	2	70	344 443	33 397	1 993	27 906	9 000
1980	1	71	223 720	3 421	1 701	23 816	1 000
1980	2	72	383 993	30 793	2 920	40 878	9 000
1981	1	73	229 068	3 683	2 871	40 190	1 000
1981	2	74	385 167	33 149	4 827	67 578	9 000
1982	1	75	306 571	4 000	3 842	53 788	1 000
1982	2	76	546 931	36 003	6 854	95 960	9 000
1983	1	77	372 421	3 531	4 667	65 342	1 000
1983	2	78	567 969	31 781	7 118	99 651	9 000
1984	1	79	341 258	3 297	4 277	59 874	1 000
1984	2	80	522 011	29 671	6 542	91 587	9 000
1985	1	81	271 059	3 551	3 397	47 558	1 000
1985	2	82	576 895	31 957	7 230	101 217	9 000
1986	1	83	270 780	3 744	3 393	47 509	1 000
1986	2	84	676 685	33 692	8 480	118 725	9 000
1987	1	85	275 466	3 346	3 452	48 331	1 000
1987	2	86	653 840	30 114	8 194	114 717	9 000
1988	1	87	234 890	2 747	2 944	41 212	1 000
1988	2	88	530 424	24 722	6 647	93 064	9 000
1989	1	89	219 254	2 754	2 748	38 468	1 000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1989	2	90	539 188	24 787	6 757	94 601	9 000
1990	1	91	168 382	2 487	3 436	48 103	1 000
1990	2	92	354 817	22 383	7 240	101 364	9 000
1991	1	93	176 262	2 503	2 106	29 482	1 000
1991	2	94	354 244	22 529	4 232	59 252	9 000
1992	1	95	183 120	2 444	739	10 343	1 000
1992	2	96	312 618	21 999	1 261	17 657	9 000
1993	1	97	233 692	2 870	1 583	22 164	1 000
1993	2	98	258 350	25 832	1 750	24 503	9 000
1994	1	99	271 306	3 487	2 582	36 147	1 000
1994	2	100	219 060	31 382	2 085	29 186	9 000
1995	1	101	343 853	4 698	3 011	42 157	1 000
1995	2	102	143 363	42 279	1 255	17 576	9 000
1996	1	103	446 454	5 852	4 523	63 316	1 000
1996	2	104	47 130	52 667	477	6 684	9 000
1997	1	105	460 931	7 266	4 527	63 379	1 000
1997	2	106	29 489	65 395	290	4 055	9 000
1998	1	107	450 468	9 023	4 231	59 240	1 000
1998	2	108	42 789	81 209	402	5 627	9 000
1999	1	109	532 443	7 193	4 110	57 542	1 000
1999	2	110	44 030	64 735	340	4 758	9 000
2000	1	111	503 900	8 418	3 747	52 457	1 000
2000	2	112	69 901	75 762	520	7 277	9 000
2001	1	113	474 554	6 203	3 417	47 836	1 000
2001	2	114	99 514	55 827	717	10 031	9 000
2002	1	115	436 090	7 091	3 033	42 455	1 000
2002	2	116	139 129	63 823	967	13 545	9 000

[1] 1=autumn/winter season; 2=spring/summer season

[2] These are the total reported commercial catches from catch statistics. Seasonal splits calculated as reported in Section 3.2.6. The size limits are applied to this catch category.

[3] The 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 for 1945 was set to 20% of the best estimate in 1979. This value is then increased linearly to 100% which is assumed to be reached in 1980. The best estimate of recreational catch estimate is the mean of all available recreational catch estimates in numbers of lobster. The conversion to catch in weight is based on 1993-96 commercial logbook data. The seasonal split was obtained by assuming a 90%:10% split between the spring/summer and autumn/winter fisheries. Size limits were applied to this category.

[5] This is the fraction of illegal catch which is thought to have been processed through normal legal channels by the Ministry of Fisheries Compliance Unit. This value 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 been estimated only in the most recent years (1996) and this fraction has been applied retrospectively to the period of illegal catch estimates. Size limits were applied to this catch.

[6] This is the remaining fraction of illegal catch which is thought to have been processed through other channels by the Ministry of Fisheries Compliance Unit. No size limit is applied to this catch category. The total illegal catch is the sum of these two illegal components.

[7] Maori customary catches have been set to a constant level of 10 t per year, estimated by the Ministry of Fisheries. No size limits are applied to this category and a 10%:90% (autumn/winter – spring/summer) seasonal split has been used.

Table B2: Recent CPUE biomass indices and associated standard errors, historical CPUE biomass indices, settlement indices and male and female size limits used for the CRA 4 assessment.

Fishing year	Season[1]	Sequential season number	CPUE biomass indices[2]	σ^{I} [3]	Historical CPUE [4]	Settlement indices [5]	Male size limit [6]	Female size limit [6]	Select Flag	Recruitment period[7]
1945	1	1	0	0	0	0	0	0	1	1
1945	2	2	0	0	0	0	0	0	1	1
1946	1	3	0	0	0	0	0	0	1	2
1946	2	4	0	0	0	0	0	0	1	2
1947	1	5	0	0	0	0	0	0	1	3
1947	2	6	0	0	0	0	0	0	1	3
1948	1	7	0	0	0	0	0	0	1	4
1948	2	8	0	0	0	0	0	0	1	4
1949	1	9	0	0	0	0	0	0	1	5
1949	2	10	0	0	0	0	0	0	1	5
1950	1	11	0	0	0	0	47	49	1	6
1950	2	12	0	0	0	0	47	49	1	6
1951	1	13	0	0	0	0	47	49	1	7
1951	2	14	0	0	0	0	47	49	1	7
1952	1	15	0	0	0	0	51	53	1	8
1952	2	16	0	0	0	0	51	53	1	8
1953	1	17	0	0	0	0	51	53	1	9
1953	2	18	0	0	0	0	51	53	1	9
1954	1	19	0	0	0	0	51	53	1	10
1954	2	20	0	0	0	0	51	53	1	10
1955	1	21	0	0	0	0	51	53	1	11
1955	2	22	0	0	0	0	51	53	1	11
1956	1	23	0	0	0	0	51	53	1	12
1956	2	24	0	0	0	0	51	53	1	12
1957	1	25	0	0	0	0	51	53	1	13
1957	2	26	0	0	0	0	51	53	1	13
1958	1	27	0	0	0	0	51	53	1	14
1958	2	28	0	0	0	0	51	53	1	14
1959	1	29	0	0	0	0	53	58	1	15
1959	2	30	0	0	0	0	53	58	1	15
1960	1	31	0	0	0	0	53	58	1	16
1960	2	32	0	0	0	0	53	58	1	16
1961	1	33	0	0	0	0	53	58	1	17
1961	2	34	0	0	0	0	53	58	1	17
1962	1	35	0	0	0	0	53	58	1	18
1962	2	36	0	0	0	0	53	58	1	18
1963	1	37	0	0	79.97	0	53	58	1	19
1963	2	38	0	0	74.12	0	53	58	1	19
1964	1	39	0	0	101.60	0	53	58	1	20
1964	2	40	0	0	110.17	0	53	58	1	20
1965	1	41	0	0	121.27	0	53	58	1	21
1965	2	42	0	0	119.91	0	53	58	1	21
1966	1	43	0	0	104.71	0	53	58	1	22
1966	2	44	0	0	86.56	0	53	58	1	22
1967	1	45	0	0	101.05	0	53	58	1	23

Fishing year	Season[1]	Sequential season number	CPUE biomass indices[2]	σ' [3]	Historical CPUE [4]	Settlement indices [5]	Male size limit [6]	Female size limit [6]	Select Flag	Recruitment period[7]
1967	2	46	0	0	82.74	0	53	58	1	23
1968	1	47	0	0	68.69	0	53	58	1	24
1968	2	48	0	0	64.51	0	53	58	1	24
1969	1	49	0	0	60.55	0	53	58	1	25
1969	2	50	0	0	55.32	0	53	58	1	25
1970	1	51	0	0	50.13	0	53	58	1	26
1970	2	52	0	0	54.18	0	53	58	1	26
1971	1	53	0	0	46.79	0	53	58	1	27
1971	2	54	0	0	49.92	0	53	58	1	27
1972	1	55	0	0	47.20	0	53	58	1	28
1972	2	56	0	0	49.49	0	53	58	1	28
1973	1	57	0	0	43.99	0	53	58	1	29
1973	2	58	0	0	0	0	53	58	1	29
1974	1	59	0	0	0	0	53	58	1	30
1974	2	60	0	0	0	0	53	58	1	30
1975	1	61	0	0	0	0	53	58	1	31
1975	2	62	0	0	0	0	53	58	1	31
1976	1	63	0	0	0	0	53	58	1	32
1976	2	64	0	0	0	0	53	58	1	32
1977	1	65	0	0	0	0	53	58	1	33
1977	2	66	0	0	0	0	53	58	1	33
1978	1	67	0	0	0	0	53	58	1	34
1978	2	68	0	0	0	0	53	58	1	34
1979	1	69	0.793	0.035	0	0	53	58	1	35
1979	2	70	0.909	0.030	0	0	53	58	1	35
1980	1	71	0.821	0.034	0	0	53	58	1	36
1980	2	72	0.838	0.029	0	0	53	58	1	36
1981	1	73	0.842	0.034	0	0	53	58	1	37
1981	2	74	0.902	0.031	0	0	53	58	1	37
1982	1	75	0.909	0.033	0	0	53	58	1	38
1982	2	76	0.980	0.029	0	0	53	58	1	38
1983	1	77	0.860	0.032	0	0	53	58	1	39
1983	2	78	0.865	0.029	0	0	53	58	1	39
1984	1	79	0.748	0.032	0	0	53	58	1	40
1984	2	80	0.808	0.030	0	0	53	58	1	40
1985	1	81	0.618	0.032	0	0	53	58	1	41
1985	2	82	0.870	0.030	0	0	53	58	1	41
1986	1	83	0.662	0.032	0	0	53	58	1	42
1986	2	84	0.917	0.030	0	0	53	58	1	42
1987	1	85	0.555	0.033	0	0	53	58	1	43
1987	2	86	0.820	0.030	0	0	53	58	1	43
1988	1	87	0.481	0.034	0	0	54	58	1	44
1988	2	88	0.673	0.031	0	0	54	58	1	44
1989	1	89	0.437	0.033	0	0	54	58	1	45
1989	2	90	0.675	0.030	0	0	54	58	1	45
1990	1	91	0.413	0.034	0	0	54	58	1	46
1990	2	92	0.609	0.031	0	0	54	58	1	46
1991	1	93	0.415	0.031	0	0	54	58	1	47

Fishing year	Season[1]	Sequential season number	CPUE biomass indices[2]	σ^{I} [3]	Historical CPUE [4]	Settlement indices [5]	Male size limit [6]	Female size limit [6]	Select Flag	Recruitment period[7]
1991	2	94	0.613	0.030	0	0	54	58	1	47
1992	1	95	0.397	0.031	0	0	54	60	1	48
1992	2	96	0.599	0.030	0	0	54	60	1	48
1993	1	97	0.435	0.030	0	0	54	60	2	49
1993	2	98	0.703	0.034	0	0.787	54	60	2	49
1994	1	99	0.572	0.030	0	0.000	54	60	2	50
1994	2	100	0.854	0.039	0	0.520	54	60	2	50
1995	1	101	0.708	0.032	0	1.804	54	60	2	51
1995	2	102	1.151	0.047	0	0.702	54	60	2	51
1996	1	103	1.009	0.032	0	1.314	54	60	2	52
1996	2	104	1.433	0.068	0	0.000	54	60	2	52
1997	1	105	1.189	0.034	0	1.284	54	60	2	53
1997	2	106	1.780	0.082	0	0.000	54	60	2	53
1998	1	107	1.293	0.034	0	0.898	54	60	2	54
1998	2	108	2.210	0.074	0	0.000	54	60	2	54
1999	1	109	1.263	0.033	0	0.768	54	60	2	55
1999	2	110	1.762	0.076	0	0.000	54	60	2	55
2000	1	111	1.010	0.035	0	1.144	54	60	2	55
2000	2	112	2.062	0.067	0	0.000	54	60	2	55
2001	1	113	0.916	0.033	0	1.180	54	60	2	55
2001	2	114	1.519	0.058	0	1.338	54	60	2	55
2002	1	115	0.937	0.034	0	1.083	54	60	2	55
2002	2	116	1.737	0.051	0	0.847	54	60	2	55

[1] 1=autumn/winter season; 2=spring/summer season

[2] These CPUE indices are standardised CPUE indices calculated from commercial catch and effort data scaled to *the geometric mean of the raw indices to preserve the units of kg per potlift*

[3] Standard error of the CPUE estimates for each period after process error has been added

[4] Unstandardised CPUE indices in kg per day from Annala & King (1983)

[5] No settlement indices from this area

[6] In units of TW (mm) converted using parameters provided in Table 4.

[7] Recruitment deviations were calculated as an average over a specified number of periods. This flag shows the periods over which average recruitment deviation parameters were calculated

B.2 CRA 5 data

Table B3: Catch data in kilograms used for the CRA 5 assessment. Catches are reported by calendar year through 1978, then are reported by fishing year (1 April to 31 March, named by the April-December year).

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1945	1	1	41544	679	429	7 199	1 000
1945	2	2	97047	6 112	1 001	16 817	9 000
1946	1	3	60976	759	629	10 567	1 000
1946	2	4	142440	6 831	1 469	24 684	9 000
1947	1	5	75854	839	782	13 145	1 000
1947	2	6	177197	7 550	1 828	30 707	9 000
1948	1	7	159826	919	1 649	27 696	1 000
1948	2	8	373353	8 269	3 851	64 699	9 000
1949	1	9	206730	999	2 132	35 825	1 000
1949	2	10	482923	8 988	4 981	83 686	9 000
1950	1	11	270234	1 079	2 787	46 829	1 000
1950	2	12	631269	9 707	6 512	109 393	9 000
1951	1	13	174095	1 158	1 796	30 169	1 000
1951	2	14	406688	10 426	4 195	70 475	9 000
1952	1	15	173547	1 238	1 790	30 074	1 000
1952	2	16	405407	11 145	4 182	70 254	9 000
1953	1	17	114276	1 318	1 179	19 803	1 000
1953	2	18	266951	11 864	2 754	46 260	9 000
1954	1	19	101789	1 398	1 050	17 639	1 000
1954	2	20	237779	12 583	2 453	41 205	9 000
1955	1	21	106936	1 478	1 103	18 531	1 000
1955	2	22	249804	13 302	2 577	43 289	9 000
1956	1	23	105200	1 558	1 085	18 230	1 000
1956	2	24	245749	14 021	2 535	42 586	9 000
1957	1	25	77621	1 638	801	13 451	1 000
1957	2	26	181323	14 740	1 870	31 422	9 000
1958	1	27	100967	1 718	1 041	17 497	1 000
1958	2	28	235858	15 459	2 433	40 872	9 000
1959	1	29	128850	1 798	1 329	22 329	1 000
1959	2	30	300996	16 178	3 105	52 160	9 000
1960	1	31	117398	1 877	1 211	20 344	1 000
1960	2	32	274244	16 897	2 829	47 524	9 000
1961	1	33	109647	1 957	1 131	19 001	1 000
1961	2	34	256136	17 616	2 642	44 386	9 000
1962	1	35	130647	2 037	1 348	22 640	1 000
1962	2	36	305193	18 335	3 148	52 887	9 000
1963	1	37	119111	2 117	1 229	20 641	1 000
1963	2	38	256815	19 055	2 649	44 504	9 000
1964	1	39	158237	2 197	1 632	27 421	1 000
1964	2	40	303273	19 774	3 128	52 555	9 000
1965	1	41	121804	2 277	1 256	21 108	1 000
1965	2	42	350479	20 493	3 615	60 735	9 000
1966	1	43	169601	2 357	1 749	29 390	1 000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1966	2	44	433060	21 212	4 467	75 046	9 000
1967	1	45	149661	2 437	1 544	25 935	1 000
1967	2	46	333704	21 931	3 442	57 828	9 000
1968	1	47	122652	2 517	1 265	21 255	1 000
1968	2	48	272958	22 650	2 816	47 301	9 000
1969	1	49	167249	2 597	1 725	28 983	1 000
1969	2	50	272421	23 369	2 810	47 208	9 000
1970	1	51	114608	2 676	1 182	19 861	1 000
1970	2	52	279850	24 088	2 887	48 496	9 000
1971	1	53	119515	2 756	1 233	20 711	1 000
1971	2	54	278331	24 807	2 871	48 232	9 000
1972	1	55	139336	2 836	1 437	24 146	1 000
1972	2	56	278375	25 526	2 871	48 240	9 000
1973	1	57	115666	2 916	1 193	20 044	1 000
1973	2	58	261144	26 245	2 694	45 254	9 000
1974	1	59	97000	2 996	718	12 056	1 000
1974	2	60	219000	26 964	1 620	27 219	9 000
1975	1	61	128003	3 076	1 794	30 138	1 000
1975	2	62	288997	27 683	4 050	68 044	9 000
1976	1	63	117259	3 156	1 315	22 091	1 000
1976	2	64	264741	28 402	2 969	49 877	9 000
1977	1	65	115110	3 236	1 709	28 710	1 000
1977	2	66	259890	29 121	3 858	64 819	9 000
1978	1	67	137325	3 316	1 847	31 024	1 000
1978	2	68	310045	29 840	4 169	70 045	9 000
1979	1	69	129887	3 395	633	10 641	1 000
1979	2	70	272108	30 559	1 327	22 293	9 000
1980	1	71	136763	4 280	876	14 723	1 000
1980	2	72	368341	38 518	2 360	39 652	9 000
1981	1	73	96585	4 080	996	16 737	1 000
1981	2	74	379434	36 722	3 914	65 753	9 000
1982	1	75	145971	4 161	1 506	25 296	1 000
1982	2	76	479540	37 450	4 946	83 100	9 000
1983	1	77	157276	3 573	1 622	27 255	1 000
1983	2	78	441814	32 160	4 557	76 563	9 000
1984	1	79	194715	3 529	2 008	33 742	1 000
1984	2	80	527219	31 758	5 438	91 362	9 000
1985	1	81	146877	3 154	1 515	25 453	1 000
1985	2	82	577699	28 389	5 959	100 110	9 000
1986	1	83	146496	2 785	1 511	25 386	1 000
1986	2	84	479647	25 063	4 948	83 119	9 000
1987	1	85	116860	2 324	1 205	20 251	1 000
1987	2	86	379677	20 917	3 916	65 795	9 000
1988	1	87	67822	2 022	700	11 753	1 000
1988	2	88	283903	18 196	2 928	49 198	9 000
1989	1	89	64721	2 190	668	11 216	1 000
1989	2	90	247638	19 707	2 554	42 914	9 000
1990	1	91	56254	2 089	1 823	30 621	1 000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1990	2	92	252379	18 803	8 177	137 379	9 000
1991	1	93	52098	1 827	1 823	30 624	1 000
1991	2	94	235314	16 439	8 233	138 320	9 000
1992	1	95	48049	1 778	1 878	31 543	1 000
1992	2	96	210741	16 000	8 235	138 345	9 000
1993	1	97	97169	2 043	2 194	36 859	1 000
1993	2	98	213849	18 384	4 828	81 119	9 000
1994	1	99	95900	2 274	1 283	21 559	1 000
1994	2	100	197987	20 468	2 649	44 509	9 000
1995	1	101	104077	2 757	1 375	23 105	1 000
1995	2	102	193530	24 815	2 557	42 963	9 000
1996	1	103	182612	3 809	1 264	21 236	1 000
1996	2	104	117681	34 282	815	13 685	9 000
1997	1	105	218485	5 273	1 547	25 984	1 000
1997	2	106	81103	47 455	574	9 645	9 000
1998	1	107	233365	6 426	1 693	28 440	1 000
1998	2	108	64799	57 833	470	7 897	9 000
1999	1	109	281986	6 511	1 779	29 890	1 000
1999	2	110	67506	58 602	426	7 155	9 000
2000	1	111	293212	8 740	1 897	31 863	1 000
2000	2	112	54198	78 661	351	5 890	9 000
2001	1	113	320069	9 060	2 370	39 808	1 000
2001	2	114	29009	81 543	215	3 608	9 000
2002	1	115	297091	9 949	2 489	41 810	1 000
2002	2	116	51645	89 537	433	7 268	9 000

[1] *1=autumn/winter season; 2=spring/summer season*

[2] These are the total reported commercial catches from catch statistics. Seasonal splits calculated as reported in Section 3.2.6. The size limits are applied to this catch category.

[3] The 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 for 1945 was set to 20% of the best estimate for 1979. This value is then increased linearly to 100% which is assumed to be reached in 1980. The best estimate of recreational catch estimate is the mean of all available recreational catch estimates in numbers of lobster. The conversion to catch in weight is based on 1993-96 commercial logbook data. The seasonal split was obtained by assuming a 90%:10% split between the spring/summer and autumn/winter fisheries. Size limits were applied to this category.

[5] This is the fraction of illegal catch which is thought to have been processed through normal legal channels by the Ministry of Fisheries Compliance Unit. This value 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 been estimated only in the most recent years (1996) and this fraction has been applied retrospectively to the period of illegal catch estimates. Size limits were applied to this catch.

[6] This is the remaining fraction of illegal catch which is thought to have been processed through other channels by the Ministry of Fisheries Compliance Unit. No size limit is applied to this catch category. The total illegal catch is the sum of these two illegal components.

[7] Maori customary catches have been set to a constant level of 10 t per year, estimated by the Ministry of Fisheries. No size limits are applied to this category and a 10%:90% (autumn/winter – spring/summer) seasonal split has been used.

Table B4: Recent CPUE biomass indices and associated standard errors, historical CPUE biomass indices, settlement indices and male and female size limits used for the CRA 5 assessment.

Fishing year	Season[1]	Sequential season number	CPUE biomass indices[2]	σ^{I} [3]	Historical CPUE [4]	Settlement indices [5]	Male size limit [6]	Female size limit [6]	Select Flag	Recruitment period[7]
1945	1	1	0	0	0	0	0	0	1	1
1945	2	2	0	0	0	0	0	0	1	1
1946	1	3	0	0	0	0	0	0	1	2
1946	2	4	0	0	0	0	0	0	1	2
1947	1	5	0	0	0	0	0	0	1	3
1947	2	6	0	0	0	0	0	0	1	3
1948	1	7	0	0	0	0	0	0	1	4
1948	2	8	0	0	0	0	0	0	1	4
1949	1	9	0	0	0	0	0	0	1	5
1949	2	10	0	0	0	0	0	0	1	5
1950	1	11	0	0	0	0	47	49	1	6
1950	2	12	0	0	0	0	47	49	1	6
1951	1	13	0	0	0	0	47	49	1	7
1951	2	14	0	0	0	0	47	49	1	7
1952	1	15	0	0	0	0	51	53	1	8
1952	2	16	0	0	0	0	51	53	1	8
1953	1	17	0	0	0	0	51	53	1	9
1953	2	18	0	0	0	0	51	53	1	9
1954	1	19	0	0	0	0	51	53	1	10
1954	2	20	0	0	0	0	51	53	1	10
1955	1	21	0	0	0	0	51	53	1	11
1955	2	22	0	0	0	0	51	53	1	11
1956	1	23	0	0	0	0	51	53	1	12
1956	2	24	0	0	0	0	51	53	1	12
1957	1	25	0	0	0	0	51	53	1	13
1957	2	26	0	0	0	0	51	53	1	13
1958	1	27	0	0	0	0	51	53	1	14
1958	2	28	0	0	0	0	51	53	1	14
1959	1	29	0	0	0	0	53	58	1	15
1959	2	30	0	0	0	0	53	58	1	15
1960	1	31	0	0	0	0	53	58	1	16
1960	2	32	0	0	0	0	53	58	1	16
1961	1	33	0	0	0	0	53	58	1	17
1961	2	34	0	0	0	0	53	58	1	17
1962	1	35	0	0	0	0	53	58	1	18
1962	2	36	0	0	0	0	53	58	1	18
1963	1	37	0	0	41.43	0	53	58	1	19
1963	2	38	0	0	50.60	0	53	58	1	19
1964	1	39	0	0	44.28	0	53	58	1	20
1964	2	40	0	0	56.15	0	53	58	1	20
1965	1	41	0	0	46.59	0	53	58	1	21
1965	2	42	0	0	61.11	0	53	58	1	21
1966	1	43	0	0	39.81	0	53	58	1	22
1966	2	44	0	0	54.15	0	53	58	1	22
1967	1	45	0	0	38.87	0	53	58	1	23

Fishing year	Season[1]	Sequential season number	CPUE biomass indices[2]	σ^{I} [3]	Historical CPUE [4]	Settlement indices [5]	Male size limit [6]	Female size limit [6]	Select Flag	Recruitment period[7]
1967	2	46	0	0	43.11	0	53	58	1	23
1968	1	47	0	0	29.60	0	53	58	1	24
1968	2	48	0	0	38.23	0	53	58	1	24
1969	1	49	0	0	31.65	0	53	58	1	25
1969	2	50	0	0	34.86	0	53	58	1	25
1970	1	51	0	0	31.33	0	53	58	1	26
1970	2	52	0	0	38.53	0	53	58	1	26
1971	1	53	0	0	33.49	0	53	58	1	27
1971	2	54	0	0	38.21	0	53	58	1	27
1972	1	55	0	0	33.83	0	53	58	1	28
1972	2	56	0	0	33.19	0	53	58	1	28
1973	1	57	0	0	28.97	0	53	58	1	29
1973	2	58	0	0	0	0	53	58	1	29
1974	1	59	0	0	0	0	53	58	1	30
1974	2	60	0	0	0	0	53	58	1	30
1975	1	61	0	0	0	0	53	58	1	31
1975	2	62	0	0	0	0	53	58	1	31
1976	1	63	0	0	0	0	53	58	1	32
1976	2	64	0	0	0	0	53	58	1	32
1977	1	65	0	0	0	0	53	58	1	33
1977	2	66	0	0	0	0	53	58	1	33
1978	1	67	0	0	0	0	53	58	1	34
1978	2	68	0	0	0	0	53	58	1	34
1979	1	69	0.665	0.039	0	0	53	58	1	35
1979	2	70	0.652	0.033	0	0	53	58	1	35
1980	1	71	0.755	0.041	0	0	53	58	1	36
1980	2	72	0.822	0.037	0	0	53	58	1	36
1981	1	73	0.603	0.045	0	0	53	58	1	37
1981	2	74	0.784	0.036	0	0	53	58	1	37
1982	1	75	0.740	0.041	0	0	53	58	1	38
1982	2	76	0.799	0.035	0	0	53	58	1	38
1983	1	77	0.697	0.041	0	0	53	58	1	39
1983	2	78	0.687	0.036	0	0	53	58	1	39
1984	1	79	0.727	0.041	0	0	53	58	1	40
1984	2	80	0.678	0.036	0	0	53	58	1	40
1985	1	81	0.532	0.042	0	0	53	58	1	41
1985	2	82	0.606	0.035	0	0	53	58	1	41
1986	1	83	0.474	0.042	0	0	53	58	1	42
1986	2	84	0.535	0.037	0	0	53	58	1	42
1987	1	85	0.401	0.042	0	0	53	58	1	43
1987	2	86	0.447	0.037	0	0	53	58	1	43
1988	1	87	0.355	0.046	0	0	54	58	1	44
1988	2	88	0.388	0.040	0	0	54	58	1	44
1989	1	89	0.362	0.053	0	0	54	58	1	45
1989	2	90	0.421	0.039	0	0	54	58	1	45
1990	1	91	0.367	0.051	0	0	54	58	1	46
1990	2	92	0.401	0.038	0	0	54	58	1	46
1991	1	93	0.272	0.045	0	0	54	58	1	47

Fishing year	Season[1]	Sequential season number	CPUE biomass indices[2]	σ' [3]	Historical CPUE [4]	Settlement indices [5]	Male size limit [6]	Female size limit [6]	Select Flag	Recruitment period[7]
1991	2	94	0.351	0.036	0	0	54	58	1	47
1992	1	95	0.271	0.046	0	0	54	60	1	48
1992	2	96	0.342	0.039	0	0	54	60	1	48
1993	1	97	0.350	0.045	0	0	54	60	2	49
1993	2	98	0.392	0.043	0	1.378	54	60	2	49
1994	1	99	0.344	0.047	0	1.033	54	60	2	50
1994	2	100	0.437	0.046	0	1.214	54	60	2	50
1995	1	101	0.394	0.049	0	1.458	54	60	2	51
1995	2	102	0.530	0.047	0	1.055	54	60	2	51
1996	1	103	0.537	0.047	0	1.623	54	60	2	52
1996	2	104	0.732	0.056	0	1.695	54	60	2	52
1997	1	105	0.771	0.050	0	1.254	54	60	2	53
1997	2	106	1.013	0.061	0	1.528	54	60	2	53
1998	1	107	1.019	0.053	0	0.656	54	60	2	54
1998	2	108	1.235	0.068	0	0.875	54	60	2	54
1999	1	109	1.018	0.052	0	0.486	54	60	2	55
1999	2	110	1.251	0.069	0	1.630	54	60	2	55
2000	1	111	1.151	0.057	0	1.024	54	60	2	55
2000	2	112	1.679	0.082	0	2.068	54	60	2	55
2001	1	113	1.346	0.059	0	0.043	54	60	2	55
2001	2	114	1.741	0.110	0	0.000	54	60	2	55
2002	1	115	1.358	0.061	0	1.060	54	60	2	55
2002	2	116	1.911	0.091	0	1.612	54	60	2	55

[1] 1=autumn/winter season; 2=spring/summer season
[2] These CPUE indices are standardised CPUE indices calculated from commercial catch and effort data scaled to the geometric mean of the raw indices to preserve the units of kg per potlift
[3] Standard error of the CPUE estimates for each period after process error has been added.
[4] Unstandardised CPUE indices in kg per day from Annala & King (1983)
[5] No settlement indices from this area
[6] In units of TW (mm) converted using parameters provided in Table 4.
[7] Recruitment deviations were calculated as an average over a specified number of periods. This flag shows the periods over which average recruitment deviation parameters were calculated