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Assessment of red rock lobsters (*Jasus edwardsii*) in CRA 1 and CRA 2 in 2002

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EXECUTIVE SUMMARY

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A 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 1 and CRA 2 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 simulations were used to estimate the marginal posterior distributions of parameters and indicators. Sensitivity trials were based on both the modes of joint posterior distributions and the marginal posteriors for a more limited number of trials.

The model appeared to behave reasonably well in the assessment. For the CRA 1 assessment, iterative re-weighting was used successfully to find a base case, but for CRA 2 additional weight had to be applied to the CPUE data to obtain a satisfactory fit.

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 remain near the current level. For both stocks, but especially for CRA 2, these 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.

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. (2001) and Booth et al. (1994). Recent assessments were described by Bentley et al. (2001) and Breen et al. (2002).

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 this was introduced in 1990, the fishery was managed primarily 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) annually advises 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 (RLIC), which in turn was contracted by MFish, to provide an assessment for northern substock, NSN, comprising areas CRA 1 (Northland) and CRA 2 (Bay of Plenty) 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 et al. (2001a) 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 1 and CRA 2) and the combined CRA 4 and CRA 5 stock. The model was revised for the 2000 assessment as described by Bentley et al. (2001), and revised again for the 2001 assessment after an extensive review (Breen et al. 2002). 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 four data sets: standardised catch per unit of effort (CPUE), historical catch rates (CR), proportions-at-size from catch sampling and voluntary logbook programmes, and growth increments from tag-recapture programmes.

This report describes the revised size-based model, describes and lists the data used for the CRA 1 and CRA 2 assessments, and presents and discusses the assessment results.

2. ASSESSMENT MODEL

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

The 2002 assessment of CRA 1 and CRA 2 used a revision of the model described by Breen et al. (2002). 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. The revised model is described in general terms in this section, and full details are provided in Appendix A. Major changes made to the model were as follows.

- The coefficient of variation (c.v.) of the expected growth increment was changed to a sex-specific parameter (CV^g).
- The catch dynamics were changed to operate in two parts during each 6-month period so that proportions-at-length could be calculated from the mid-season length structure. The dynamics of the SL and NSL fisheries were improved in doing this.

The total fishery comprises four elements–the commercial and recreational sectors are governed by the minimum legal sizes (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 the regulations; together we call them the NSL fishery and estimate the catch as C^{SLB}.

2.1 Dynamics

Only the sections affected by changes are described here. For a detailed description of the model's operation, see Appendix A.

2.1.1 Growth

The moult-based growth model used in 2000 was retained. After experimentation with growth estimates based on the male and female tagging data sets alone, we made the c.v. of expected growth increments a different parameter for males and females.

2.1.2 Catch dynamics

The model now removes half the catch to obtain the mid-season length structure and then removes the other half. The steps involved in the catch dynamics are:

- calculating the biomass of fish in the SL fishery (males above the MLS, immature females above the MLS, and mature females above the MLS in the spring-summer season only),
- calculating the biomass of fish in the NSL fishery (males below the MLS, immature females below the MLS, and mature females above the MLS in the autumn-winter season only),
- calculating the proportion of NSL catch to be taken from each of the SL and NSL biomass components during the period,
- summing the catches from the SL and NSL biomass components,

- calculating provisional exploitation rates for the biomass components during the period,
- if necessary, reducing the exploitation rates and catches after considering the maximum allowable exploitation rate, U_{max},
- calculating handling mortality rate from the exploitation rate exerted by the SL fishery,
- removing half the catches from the population numbers vectors,
- re-calculating biomass and exploitation rates, and
- removing the second half of the catch.

Natural mortality, growth, recruitment, and maturation all occur (in that order) after the catch dynamics.

2.2 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, $\sigma_{j,k}$, the standard deviation of a common error component used in the likelihood component, was 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, was calculated with a revised normal function. This replaced the robust formulation proposed by Fournier et al. (1990), which was not a true likelihood and for which the standard deviation could not be estimated. We experimented with a mixture likelihood but settled on that described by Eq. 40. It has the desired property that the standard deviation of standardised residuals is 1.0 when only the length frequency data are fitted, and it gives most weight to the larger proportions and least to the smallest.

All other likelihoods and prior probabilities were described by Bentley et al (2001).

2.3 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). The posteriors were based on 4950 samples selected from one chain for CRA 1, based on 3 million simulations, and from 990 samples from each of five chains of 600 000 McMC simulations for CRA 2. The CRA 1 chain was started from the MPD. This was then split into five psuedo-chains for diagnostics. The five chains for CRA 2 were started from five different parameter vectors as follows. One chain was started from the MPD. A likelihood profile was run on the recruitment parameter, ln(*R0*), using the AD Model Builder function that saves parameter vectors at intervals along the profile. We chose the parameter vectors from plus and minus 1.5 and 3.0 standard deviations away from the best estimate of ln(*R0*) and started four chains from those parameter vectors. After diagnostics described in the results, we discarded the first 10 samples from each chain and combined the chains.

2.4 Projections

From each of the 5000 samples for each area, we made 5-year projections, encompassing the 2002–03 to 2006–07 fishing years, under the assumptions that commercial catches would equal the current TACC and that other catches would remain the same as their 2001 levels during the projection. For CRA 1 these catches were 178 t and 82 t for the SL and NSL catches respectively; for CRA 2 they were 354 t and 98 t. Projected recruitments for the years 1998–2007 were randomly re-sampled from the estimated model recruitments from the period 1988–97.

2.5 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 was 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 was defined as the biomass of all individuals above the MLS. We used the biomass as the start of the fishing year.

1. $BVULN_{02}/BVULN_{79\text{-}88}$
2. $BVULN_{07}/BVULN_{02}$
3. $BVULN_{07}/BVULN_{79\text{-}88}$
4. $UNSL_{02,AW}$
5. $USL_{02,AW}$
6. $UNSL_{06,AW}$
7. $USL_{06,AW}$

The period 1979–88 was chosen as a reference period after inspecting some early model fits. It was the earliest period where there were good data available from which to estimate biomass, and biomass was relatively stable despite increasing catches during this period. Although not ideal, this period is defensible as a period of relative stability in this fishery. Biomass in this reference period is neither a target nor a limit reference point, but is simply a useful reference level that history appears to have proven safe.

Current vulnerable biomass, $BVULN_{02}$, is defined as the beginning season vulnerable biomass on 1 April 2002, the beginning of the autumn-winter season for the 2002–03 fishing season. It is calculated from B^{SL}_{115} (see Appendix A), where period 115 is the AW season in 2002 (Table B1). Similarly, projected vulnerable biomass $BVULN_{07}$ is defined as the beginning season vulnerable biomass on 1 April 2007, the beginning of the autumn-winter season for the 2007–08 fishing season, and calculated as B^{SL}_{125}. The reference period biomass, $BVULN_{79\text{-}88}$, is calculated as the mean of the AW values (odd-numbered periods) for B^{SL}_{69} through B^{SL}_{87}.

$USL_{02,AW}$ is the exploitation rate for catch taken from the SL vulnerable biomass in the autumn-winter season of 2002–03, B^{SL}_{115}. It is calculated as U^{SL}_{115} (see Appendix A), and $USL_{06,AW}$ is the exploitation rate for catch taken from the SL vulnerable biomass in the autumn-winter season of 2006–07, the last year of projections, and calculated as U^{SL}_{123}. $UNSL_{02,AW}$ and $UNSL_{06,AW}$ are similarly defined except that they describe the exploitation rate for catch taken from the biomass vulnerable only to the NSL fishery, B^{NSL}_{115} and B^{NSL}_{123}, and are calculated as U^{NSL}_{115} and U^{NSL}_{123}.

2.6 Sensitivity trials

2.6.1 MPD sensitivity trials

Sensitivity of the MPD results were 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, obtaining alternative MPD results, by:

- re-weighting the four data sets – CPUE, CR, tags and proportions-at-length – one at a time;
- fitting to alternative series of assumed NSL catches;
- estimating the right-hand limb of the selectivity-at-length;
- assuming that maximum vulnerability occurs in AW for males, and estimating other sex-and season-specific vulnerabilities relative to that;
- using separate selectivity curves for the years before 1993; and
- estimating the power in the CPUE-biomass relation.

To make arbitrary alternative sets of catches, we assumed that illegal, Maori customary, and recreational catches were 1.5 and 2.0 times their agreed values: constant at 230 t after 1978 (high illegal), or 40 t (low illegal); and in one trial we changed the historical pattern of recreational catches.

2.6.2 McMC sensitivity trials

Three sensitivity trials were made, two in CRA 1 and one in CRA 2 , involving full McMC runs. These were made after examining the results of MPD sensitivity trials for each area and are described below in the results.

2.7 Retrospective analysis

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

For each area, we removed CPUE and proportions-at-length data, one year at a time, from the years 2000, 1999, 1998, 1997, 1996 and 1995. Tagging data were not removed - most of the tagging data are from before this period. In each trial, we estimated the MPD results and examined the trajectory of biomass.

3. ASSESSMENT MODEL INPUTS

A summary of all the data and the data sources used in the CRA 1 and CRA 2 stock assessments is provided in Table 1. A discussion of these data and their sources is provided below.

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 to 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 to 31 March 1997 is labelled as "1996").

3.2 Catches

The assessment model requires annual values of the catch taken under existing regulations (the MLS and protection of berried females) and the catch taken without reference to existing regulations. These two catch categories are referred to as SL and NSL catches respectively, C^{SL} and C^{NSL}. Five types of catch were considered when collating SL and NSL catch totals by season.

3.2.1 Reported commercial catch

From 1945 to 1978, reported annual commercial catches were obtained from Breen & Kendrick (1998). Beginning on 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 pertaining to 1 January 1979 to 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 to 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. Therefore, the 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 assigned to the SL catch category.

3.2.2 Unreported catch

Estimates of unrecorded commercial catch were made for the calendar years 1974–80 by comparing reported catches with export weights and assigning the discrepancy to stocks in proportion to the reported commercial catch (Breen 1991). These catches were assigned to the C^{NSL} and handled as described below.

Attempts to use more recent export data in this way were foiled because recent export data are available only in gross weight and include the packaging.

3.2.3 Recreational catch

As in previous assessments, the RLFAWG agreed to assume that the 1945 recreational catches were 20% of current levels and that they increased at a constant rate until 1980, then remained constant at current levels. Levels of recreational catch were estimated using the best estimate of mean weight available at the time of the survey. These catches were assigned to C^{SL}.

The method used to calculate the recreational catch weight used mean weights from the logbook or catch sampling data and the estimated number of lobsters caught by the recreational fishery. The best estimates of current catch are estimates of numbers taken from 1994 and 1996 (see Teirney et al. 1997). The values used for each area are shown in Table 2.

3.2.4 Maori customary catch

The Ministry of Fisheries provided an estimate of 20 t for the Maori customary catch in CRA 1 and CRA 2 combined. The stock assessment used a constant Maori customary catch of 10 t for each area. year. These catches were assigned to C^{NSL}.

3.2.5 *Illegal catch*

For the years 1974–80, the unreported catch estimates (Section 3.2.2) were used as estimates of illegal catch. By agreement with the RLFAWG we used the average relation between the commercial catches and the unreported catches to estimate illegal catches for 1945–73. MFish provided estimates of illegal catches for some years between 1979 and the present (Table 3). We interpolated the catches between these years.

There are two categories of illegal catch. The first is the catch taken without regard to the existing regulations but which is included in the legal catch totals. For instance, this category includes berried females held illegally in pots until they released their eggs. These catches were assigned to C^{SL}. The second category comprises unreported catch and is assigned to C^{NSL}. The first category must be subtracted from the reported legal catch to avoid double counting.

Estimates were partitioned by MFish between "reported" and "unreported" illegal catch only for the 1996–97 fishing year. These proportions were applied to all years. The RLFAWG members have very little confidence in the estimates of illegal catch. However, because these figures cannot be verified, the RLFAWG is not in a position to modify these estimates.

3.2.6 Seasonal division of catches

To divide 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 (CELR: held by the Ministry of Fisheries) data to the reported catches by fishing year. For the period 1973–78 the seasonal catch data were not available, and the mean seasonal proportions for 1 April 1979 to 31 March 1982 were applied. Monthly catch data from 1 January 1963 to 31 December 1973 were available for statistical areas specific to CRA 3. These data were summarised by year by Annala & King (1983) and used to calculate seasonal proportions for 1 April 1963 to 31 March 1973.

The recreational and Maori customary fisheries were split between the two seasons by assuming that 90% of these catches was taken during the spring-summer season. Illegal catches were divided using the same proportional split as the commercial fishery.

The SL and NSL catch data by season provided to the model are shown in Figure 1 and Figure 2 for CRA 1 and CRA 2 respectively. During the first few years' spring-summer 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 are 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 up to 1982, including the timing of the introduction of minimum size limit regulation changes. Booth et al. (1994) summarised the regulation changes after 1983. These regulations are summarised in Table 5; minimum legal sizes by period, as used by the model, are shown in Appendix B.

3.3.3 Escape gaps

Annala (1983) noted that, before June 1970, escape gaps were not used as a management measure in New Zealand. Street (1973) also discussed the introduction of escape gaps, but concluded, on the basis of limited sampling, that the escape gaps were not effective. Annala (1983) noted that the escape gap size was set at 54 x 305 mm in all New Zealand with the exception of Otago. Escape gap regulations were changed again in July 1993. We explored fitting separate selectivity functions for two epochs: 1945–92 and 1993 to the present, as for the 2001 CRA 3 assessment (Breen et al. 2002), but there are insufficient data from before 1993 to support this approach; we used a single epoch and we explored the change caused by a second epoch.

3.3.4 Prohibition on the taking of berried females

Historical information provided by Annala (1983) indicates that, from 1945 to the present, there is only a two-year period (1950 & 1951) during which the taking of berried females was allowed by regulation. This is a short period relative to the total model period, so 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 are available for CRA 1 and CRA 2: 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 1, standardised abundance indices were estimated from catch per potlift from statistical areas 901 to 904 plus 939 in the FSU and CELR databases. For CRA 2, areas 905 to 908 were used. The different CPUE trends in CRA 1 and CRA 2 led us to make separate stock assessments for these two areas, after discussion with the RLFAWG, rather than use combined data from the NSN. Seasonal relative indices of catch rates are generated by standardising for month and statistical area (Maunder & Starr 1995, Breen & Kendrick 1998).

These indices are made relative to a base season, which is defined as the season with the lowest standard deviation in the absolute index. The coefficients for categorical variables (including annual 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.

Full details were reported by Bentley et al. (2001). These indices are given in Appendix B.

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 unstandardised catch per day for each season from 1 April 1963 to 31 March 1973 using the former statistical areas 1, 2, and 12 for CRA 1 and former areas 3 and 4 for CRA 2. These results are reported in Appendix B.

3.5 Proportions-at-size

3.5.1 Structure of size frequency data

Tail width size frequency data from research sampling and from voluntary logbook programmes 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. Two-millimetre size classes were considered small enough to provide good resolution in the model. The voluntary logbook programme 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 data

Estimates of the proportions-at-size were obtained from data summarised, for the research sampling and logbooks separately, by area/month strata and weighted by the relative proportion of the commercial catch taken in that stratum, the number of days sampled and the number of lobsters measured (see Eq. 41–44).

3.5.3 Historical data

Some historical sampling data (from 1974 to 1978) were found for CRA 1 (K. George, NIWA, pers. comm.). Some of these sets were market sampling and others were catch sampling. No historical data were found from CRA 2. 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 Tagging data

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

Tag recovery data were handled as follows.

1. For the RLIC tag recoveries, multiple recaptures were treated as separate and independent release and recovery events.
2. Records were excluded in which a) dates were missing, b) the size at release or recapture was missing, and c) the recorded sex at recapture was not the same as the sex at release.
3. Records were automatically excluded if the apparent increment was less than -10 mm, but records with smaller negative increments were retained.

4. Recoveries made in the same period as the release were excluded. They 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 with only the tagging data suggested this parameter could be fixed.

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

Because numbers of recaptures were so small from CRA 1, we used the combined data from CRA 1 and CRA 2 for the CRA 1 assessment, and used only the CRA 2 data for the CRA 2 assessment.

3.7 Parameter priors

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

An informative prior was placed on *M*, based on the presumption that the mean of this distribution 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 the prior on deviations 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 Development of a base case

Structural and fixed values used in this assessment are shown in Table 8. For each estimated parameter, the phase in which it was estimated, upper and lower bounds, prior, c.v., and initial values are shown in Table 7.

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

For CRA 2 there was a tradeoff between the fits to CPUE and proportions-at-age. When the sdsdrs were close to 1, the fit to CPUE was unacceptable. We abandoned the attempt to produce sdsdrs close to 1, and adjusted the weights until we obtained an acceptable fit to the CPUE. Acceptability was judged on the ability of predicted CPUE to mimic the steep increase from 1993 to 1998 or so, and its subsequent decline. The weights used and sdsdrs obtained are shown in Table 9. Other weights were used in an exploration of the sensitivity of this procedure.

Recruitment deviations were estimated only for those years where information existed in the data - from 1960 onwards. Deviations in the early years were applied to more than one year, as shown in Appendix B.

An arbitrary standard deviation of 0.3 was used for all elements of the historical catch rate (CR) data set.

Some parameters were fixed in the base case 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.

The standard deviation of growth observation error was not estimated, but was fixed near the value obtained when the model was fitted to the tagging data only.

The second maturity parameter was fixed at a value obtained when fitting to the proportion-at-length data only. When other data sets were used, this parameter tended to become unreasonably large.

Parameters describing the right-hand limb of the selectivity curves were fixed at values that gave a nearly flat right-hand limb. This was to maintain conservatism: the model tendency was to estimate a steeply declining right-hand limb, especially for males. The biological interpretation of this would be that large lobsters are somehow behaviourally or spatially protected from the fishery. This interpretation is dangerous to accept without external evidence. The consequences of fixing the right-hand limb were explored in sensitivity trials.

4. ASSESSMENT RESULTS

4.1 CRA 1

4.1.1 CRA 1 base case MPD estimates

Results of the base case MPD estimation are shown in the first column of Table 10. The fit to standardised CPUE is shown in Figure 3 and the residuals in Figure 4. The model fitted reasonably well to the pattern of CPUE (Figure 3), but tended to underestimate AW and overestimate SS CPUE before 1990. In this fishery the difference between observed AW and SS CPUE is not nearly as great as in some others. However, the model structure assumes that no mature females are vulnerable in AW, while all are vulnerable in SS, so it is difficult to produce vulnerable biomass for AW that is the same as in SS. In trying to do so, the model made AW and SS vulnerabilities for males the same (Table 10).

Historical catch rates were not fitted tightly (Figure 5 and Figure 6) and residuals for the AW showed a trend. Fits to the tag-recapture data were generally good (Figure 7), suggesting that tagging data were consistent with the proportions-at-length data.

Fits to proportions-at-length (Figure 8, Figure 9, Figure 10 and Figure 11) were not tight, but the observed proportions show much variability from year to year, and the low weights reflect the small sample sizes and poor representativeness of these data.

Total biomass is compared with recruited biomass in Figure 12 for each sex. This comparison suggests that much of the total biomass is also recruited. Immature females show a zero contribution to recruited biomass because of their relatively early maturation, but their contribution to total biomass is greater than that of mature females. Males, with their faster growth and larger size, have the greatest contribution. These plots show a biomass nadir in 1973, another low point in the late 1980s, and relatively high biomass in recent years.

Vulnerable biomass (Figure 13) shows a pattern similar to that of recruited and total biomass, with a nadir near 1973, another low near 1990, and high biomass subsequently. Exploitation rate (Figure 14) shows a peak in the early 1970s near 30%, a decline in the 1990s, and a switch to higher exploitation rate in the AW season in the mid 1990s.

Recruitment estimates (Figure 15) show little trend except for a very low period near 1970 and a spike in 1993.

4.1.2 Sensitivity trials with the CRA 1 base case

Various sensitivity trials, based on MPD results, were made with the base case (Table 10). When two selectivity epochs were used, there was little effect on the results, either when the selectivity parameters were estimated or when they were fixed.

Different assumed non-commercial catches led to higher biomass estimates but left exploitation rates nearly the same (Table 10). When the shape of the biomass-abundance relation was estimated, it changed from 1.0 to 0.70, indicating a slight hyperstability; the fit was improved only slightly and other parameters and indicators changed little. Exploring increased weights for each of the data sets in turn also had a small effect except in the case of CPUE, where the *M* increased and the fit went to a different place.

To explore the model's ability to fit to the seasonal patterns of CPUE better, we reversed the usual assumption about relative vulnerability. In the base case we assumed that maximum vulnerability was experienced by males in the SS; in this trial we assumed that maximum vulnerability was experienced by males in the AW. The model estimated (Table 10) the SS vulnerability for males as 0.88 times that in the AW season. Other parameters and indicators were not substantially changed.

When the right-hand limbs of the selectivity curves were estimated rather than fixed, the limb declined for males (Table 10) but went to the upper bound for females. The model wanted to see all the females but wanted to allow cryptic males. Total and recruited biomass increased as a result, but other indicators did not change much.

These trials suggest the assessment is somewhat sensitive to the relative weighting for CPUE. The base case is defensible in that we found the weighting that made the sdsdrs nearly 1. The trials suggest little sensitivity to other modelling choices.

4.1.3 MPD retrospective analysis for CRA 1

Retrospective analyses were made by successively removing one year's CPUE and proportion-at length data back to 1997's data. Tag data were not removed. The estimates are compared in Table 11 and several estimates are illustrated–Figure 16 shows the vulnerable biomass estimates, Figure 17 shows the recruitment multipliers and Figure 18 shows the estimated CPUE.

There is a tendency for base recruitment and *M* to increase as data are removed, and for recent biomass estimates to decrease as data are removed. The three indicators illustrated show changes among the retrospective trials, but they are relatively small. No qualititative changes to the assessment conclusions result from these trials.

4.1.4 CRA 1 McMC simulations and Bayesian results

For CRA 1 we made the McMC in a single long chain. For diagnostics, we broke the single chain into five. We show the results of five tests: Heidelberger & Welsh (1983), Raftery & Lewis (1992), Geweke (1992), the single chain Gelman test, and the Brooks, Gelman and Rubin (see Brooks & Roberts 1998). The first four are single chain tests that examine for stationarity and convergence of single chains; the last is a multiple-chain test that examines the similarity among the five chains. We conducted the tests for all estimated parameters but we show only the derived parameter results.

Chains 2 and 3 were sensitive to the Geweke test for some parameters; chains 2 and 4 to the Heidelberger & Welsh tests (different parameters failed these two tests); most chains passed the other tests for most or all parameters (Table 12). There was no pattern to the indicators that tended to fail these diagnostic tests, and there were no substantial differences in the posterior means from the five chains.

After considering these results, we rejected the first 10 samples from each chain as a burn-in and we combined the remaining five chains to make one chain of 4950 samples. Posteriors for the function value, some estimated and some derived parameters from each of the five chains are shown in Figure 19. This illustrates the similarity of the chains for most parameters, and the differences among chains in some of the more poorly estimated parameters.

The sequence patterns ("traces") of some parameters and indicators from these 4950 samples are shown in Figure 20. Most traces look good, but the first two relative vulnerability parameters are somewhat suspect. We examined these further by plotting the parameters against other estimated and derived parameters (Figure 21): there was no relation, suggesting that there is no consequential problem from these parameters.

The posterior distributions were summarised by calculating the mean, median, and 5th and 95th percentiles (Table 13). The d_{80} growth parameters for both sexes were not tightly estimated, and the vulnerability of females in the AW season was extremely badly determined. Current estimated vulnerable biomass varied from 930 to 1790 t; recruited and total biomass estimates were similarly wide. Projections were, as usual, uncertain: vulnerable biomass in five years varied from 67% to 157% of current levels.

The posterior distributions of recruitment deviations (Figure 22) show that although most deviations are close to average, some are consistently high or low.

Biomass posterior trajectories (Figure 23, Figure 24, and Figure 25) show similar patterns in vulnerable, recruited, and total biomass. There was a divergence of projections, although this was not as great as seen in other assessments (Breen et al. 2002). Trajectories for SL and NSL exploitation rates differed from each other and between seasons (Figure 26, Figure 27). There was greater divergence of projections for exploitation rates than for biomass.

4.2 McMC sensitivities

Two additional sets of McMC simulations were made, one to test the effect of allowing greatest vulnerability in the AW season and the other to test the effect of estimating the right-hand limb of the selectivity curve. We made both McMCs in a single long chain. For diagnostics, we broke the single chain into five. We show the results of the five diagnostic tests we described for CRA 1 for both sensitivities.

Table 14 and Table 15 show the results of the five diagnostic tests for two sensitivities. Only the Geweke and Heidelberger & Welsh tests showed any problems, again for different parameters, and the five chains all passed the other tests (Table 14 and Table 15). There was no pattern to the indicators that tended to fail these diagnostic tests, and there were no substantial differences in the posterior means from the five chains.

After considering these results, we rejected the first 10 samples from each chain as a burn-in and we combined the remaining five chains to make one chain of 4950 samples for both sensitivities.

Posterior distributions from these two sets of runs are compared with the base case posteriors in Table 13. The trial on the effect of allowing greatest vulnerability in the AW season gave lower M and d_{80} for male parameter and estimated the male vulnerability in the SS season as 0.88 (0.82–0.95). The d_{80} growth parameters for both sexes were not tightly estimated, and the vulnerability of females in the AW season was extremely badly determined. Current estimated vulnerable biomass varied from 860 to 1720 t; recruited and total biomass estimates were also wide. Projections were, as usual, uncertain: recruited biomass in five years varied from 64% to 158% of current levels.

When the right-hand limb of selectivity was estimated, the model gave a smaller estimate, median of 25.29 (20.15–36.22) and 152.93 (50.53–240.69) for male and female respectively. Estimated *M* was lower than in the base case. The d_{80} growth parameters for both sexes were not tightly estimated. Biomasses for all animals and recruited animals were higher than in the base case, but the vulnerable biomass was lower. Although the biomass changed, the exploitation was similar to the base case. *Current estimated vulnerable biomass varied from 890 to 1800 t; recruited and total biomass estimated* were even wider. Projections were uncertain: vulnerable biomass in five years varied from 73% to 161% of current levels.

4.3 CRA 2

4.3.1 CRA 2 base case MPD estimates

Results of the base case MPD estimation are shown in the first column of Table 16. The fit to standardised CPUE is shown in Figure 28 and the residuals in Figure 29. There was some difficulty with the fit to CPUE: the model fitted reasonably well to the general pattern of observed CPUE, but tended to overestimate the SS CPUE in the early 1990s and underestimated the peak of CPUE in the AW after 1995. This created trends in the residuals (Figure 29).

As for CRA 1, historical catch rates were not fitted tightly (Figure 30) and residuals for the AW showed a trend (Figure 31). Fits to the tag-recapture data were generally good (Figure 32), suggesting that tagging data were consistent with the proportions-at-length data.

Fits to proportions-at-length (Figure 33, Figure 34, Figure 35, and Figure 36) were generally good. Poorer fits were often associated with samples with low weights (e.g., 1991/SS/CS). The predicted proportion-at-length of males mirrored the observed increase in mean length during the 1990s (Figure 33). Although the model fitted the proportions-at-length of immature females relatively well during the early 1990s, it overestimated those proportions during the late 1990s (Figure 33). There was a tendency for the model to underestimate the numbers of large mature females (Figure 33, Figure 35)

Total biomass is compared with recruited biomass in Figure 37 for each sex. As for CRA 1, this comparison suggests that much of the total biomass is also recruited. Immature females show a zero contribution to recruited biomass because of their relatively early maturation. Males, with their faster growth and larger size, have the greatest contribution.

Vulnerable biomass (Figure 38) showed a similar pattern to that of recruited and total biomass, with a nadir in the late 1970s, another low in the late 1980s, and a peak in the late 1990s. Exploitation rate (Figure 39) showed a peak in the 1980s of over 50%. There was a subsequent decline in the 1990s and a switch to higher exploitation rate in the AW season.

Recruitment estimates (Figure 40) show little trend except for a very low period near 1970 and high recruitment in the late 1970s and early 1990s.

4.3.2 Sensitivity trials with the CRA 2 base case

Various sensitivity trials, based on MPD results, were made with the base case (Table 16). When two selectivity epochs were used, there was little effect on the results, either when the selectivity parameters were estimated or when they were fixed.

Using different assumed non-commercial catches led to higher biomass estimates but left exploitation rates nearly the same (Table 16). When the shape of the biomass-abundance relation was estimated, it changed from 1.0 to 0.69, indicating a slight hyperstability; the fit was improved only slightly and other parameters and indicators changed little. Exploring increased weights for each of the data sets in turn also had a small effect, but it was clear that CPUE and the proportions-at-length acted in opposition to each other.

To explore the model's ability to fit to the seasonal patterns of CPUE better, we reversed the usual assumption about relative vulnerability. In the base case we assumed that maximum vulnerability was experienced by males during the SS; in this trial we assumed that maximum vulnerability was experienced by males in the AW. The model estimated (Table 16) the SS vulnerability for males as 0.72 times that in the AW season. Other parameters and indicators were not substantially changed.

When the right-hand limbs of the selectivity curves were estimated rather than fixed, the limb (Table 16) went to the upper bound for both males and females; thus other parameters were very similar to the base case.

These trials suggest the assessment was reasonably robust to the modelling choices examined.

4.3.3 MPD retrospective analysis for CRA 2

Retrospective analyses were made by successively removing one year's CPUE and proportion-at length data back to 1997's data. Tag data were not removed. The estimates are compared in Table 17 and several estimates are illustrated – Figure 41 shows the vulnerable biomass estimates, Figure 42 shows the recruitment multipliers, and Figure 43 shows the estimated CPUE.

There was a big change when the 1999 data are added. Estimated *M* decreased from the 1998 estimate, which is near the upper bound, towards more plausible values. Biomass also decreased between 1998 and 1999. Recruitment retained the same form but was much lower before 1989 when the 1999 data were not present. These trials indicate that the 1999 data caused a substantial change in the model's estimates. Fits to CPUE show that the SS CPUE didn't change much in the retrospective trials, but the decrease in CPUE in AW 1999 changed the way the model fitted the data.

Had we been making a base case from the data through 1998 only, we would have experimented with data set weights to obtain a different fit from that shown in these trials, because the *M* was very high from the trials with no data from 1999. The trials do show that a change took place that the model would not have predicted.

4.3.4 CRA 2 McMC simulations and Bayesian results

For CRA 2, we made the McMC in five chains started from five different locations of the likelihood profile for ln(*R0*). We show the results of the five diagnostic tests we described for CRA 1. We conducted the tests for all estimated parameters but we show only the derived parameter results.

One chain was sensitive to the Heidelberger & Welsh test; all chains passed the other tests (Table 18). There were only three failures, all in one chain in one test, out of 336 tests.

After considering these results, we rejected the first 10 samples from each chain as a burn-in and we combined the five chains to make one chain of 4950 samples. Posteriors for the function value, some estimated and some derived parameters from each of the five chains are shown in Figure 44. This illustrates the similarity of the chains for most parameters, and the differences among chains in some of the more poorly estimated parameters.

The traces of some parameters and indicators from these 4950 samples are shown in Figure 45. Most of these look good, and the three vulnerability estimates were tight. We plotted the traces for these parameters against other parameters and indicators and concluded that there no consequential problem was caused by these parameters.

The posterior distributions were summarised by calculating the mean, median, and 5th and 95th percentiles (Table 19). Most parameters appeared well determined, with some exceptions among the growth parameters. In the biomass indicators, vulnerable biomass was estimated more tightly than total biomass. Projections were very uncertain: the ratio of projected to current vulnerable biomass varied (5th to 95th percentiles) from 34 to168%.

The trajectories of recruitment posteriors (Figure 46) showed some structure (particular years have consistently high or low recruitment), and the later recruitment was estimated with less certainty than the earlier years. This is probably a result of the fewer data on recent recruitments for the model to use.

Biomass posterior trajectories (Figure 47, Figure 48 and Figure 49) showed little variation in estimates except for the years before the data and the projected years, which again showed very wide divergence; the median of projected vulnerable biomass was about the same as current biomass, but after five years the range was between half and double the current biomass.

Trajectories for SL and NSL exploitation rates differed from each other and between seasons (Figure 50, Figure 51). There was greater divergence of projections for exploitation rates than for biomass.

4.4 McMC sensitivities for CRA 2

Two additional sets of McMC simulations were made, one to test the effect of allowing greatest vulnerability in the AW season and the other to test the effect of using a different trajectory for the recreational catch. We made both McMCs in a single long chain. For diagnostics, we broke the single chain into five. We show the results of the five diagnostic tests we described for CRA 1 for both sensitivities.

Table 20 and Table 21 show the results of the five diagnostic tests for two sensitivities: chains were most sensitive to the Geweke and Heidelberger & Welsh tests. There was little pattern to the indicators that tended to fail these diagnostic tests, except that the reference biomass indicators had the highest failure rate, and there were no substantial differences in the posterior means from the five chains.

After considering these results, we rejected the first 10 samples from each chain as a burn-in and we combined the remaining five chains to make one chain of 4950 samples for both sensitivities.

Posterior distributions from these two sets of runs are compared with the base case posteriors in Table 19. The trial on the effect of allowing greatest vulnerability in the AW season gave higher M and female d_{50} parameter, and lower male d_{80} parameter estimates. The male vulnerability in the SS season was estimated as 0.72 with a tight range from 0.71 to 0.74. All the biomass indicators are slightly less than the base case with overlaps in range. Projections were more uncertain than the base case: the ratio of projected to current vulnerable biomass varied (5th to 95th percentiles) from 33-176%.

5. DISCUSSION

5.1 Model behaviour

Changes to the model for the 2002 assessment were relatively minor; their specific effects are unknown. The addition of one growth parameter should allow the model to fit male and female tag-recovery data more closely, by allowing the male and female c.v.s to be different. The revised catch dynamics appeared to have only a minor effect on base case results at the point where this change was made.

The model behaved generally well. For CRA 1 we were able to use iterative weighting to obtain an objective base case; this was the first time this had been done. In the CRA 3 assessment for 2001 (Breen et al. 2002) and in earlier assessments, we were forced to fix one of the selectivity parameters, but in this assessment we had no trouble. Nor were we forced to change any of the initial bounds or priors to obtain satisfactory MPD fits. A minor problem was that the low numbers of immature females gave poor estimates of the maturity parameter m_{95}, which we fixed.

Most minimisations had positive definite Hessian matrices, in contrast to the CRA 3 assessment in 2001. The McMC diagnostics were much better than for CRA 3 in 2001, and for CRA 2 the chains passed all but two tests. For CRA 1, some chains failed in one test and passed in another test: failures for the Geweke test were nearly all passes for the Heidelberger & Welsh test, and vice versa; most failures were for one of these two tests.

For both assessments the traces and posteriors appeared well formed. An exception was the trace for r_{AW}^{male}. This trace was "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: examining the relation between this parameter and other estimates showed no relation.

In both assessments the model estimated r_{AW}^{male} at the upper bound of 1. This is the vulnerability of males in AW relative to that for males in SS, which is assumed to be 1. Thus the model is making the seasonal vulnerability in AW equal to that in summer. For both assessments, the observed SS CPUE was only slightly higher than the AW CPUE. The model structure assumes that no mature females are available to the fishery in AW, and that a male moult injects new recruitment to the vulnerable stock at the beginning of SS. With these dynamics, the model naturally has trouble predicting a SS CPUE that is not substantially larger than AW CPUE. It is difficult to see what mis-specification is occurring, if any, to cause the problem. When the male AW and SS vulnerabilities were reversed, with 1 assumed for AW and SS estimated, the model fit was slightly better for both stocks but the indicators did not change much. An exception was current exploitation rate for SS in CRA 2, which was 50% higher in this trial. When this sensitivity was extended to a full McMC, the difference was not as great.

5.2 CRA 1 assessment

The model fitted comfortably to the CRA 1 data set – the base case was chosen from iterative re-weighting that made the standard deviation of standardised residuals for each data close to 1. *M* was slightly higher than the mean of the prior – 0.18 *vs* 0.12. The fit to the proportions-at-length was not tight, but this was likely more a function of data quality than actual model fit: relative weights for most records were low. Growth parameters were close to the values estimated from tagging data alone. Recruitment was relatively flat after 1972, with a single spike in 1993.

Sensitivity of the MPD fit to a variety of trials showed little sensitivity except when the weight on the CPUE data set was doubled. This caused the model to find a different solution, with very high *M* and recruitment.

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

The McMC results of the assessment suggest that the current vulnerable biomass at the beginning of AW was 1276 t (median of the posterior) with 5th and 95th percentiles 929 to 1792 t. Current exploitation rate was estimated to be 10.4% (7.4–14.3%). The current biomass was estimated at 156% that in the reference period (131–182%).

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, the model suggested that vulnerable biomass would remain near the current level (67–157%). These conclusions appeared to be robust to the sensitivity trials made with McMC: the trial described above in which male vulnerability was estimated for SS, and one in which the right-hand limb of selectivity was estimated.

These results suggest that current catch levels are sustainable. It is, however, a source of uncertainty that current levels and historical patterns of non-commercial catch levels are poorly determined.

5.3 CRA 2 assessment

The model did not fit as comfortably as it did to the CRA 1 data set: the base case could not be chosen from iterative re-weighting, because the fit to CPUE became unacceptably poor. There was clearly an antagonism between the proportion-at-length data sets and the CPUE, because the model was unable to fit both comfortably. This problem was not nearly as severe as in the 2001 assessment for CRA 3. We abandoned iterative re-weighting, and gave the CPUE data sufficient weight to allow the model to reproduce the sharp upward trend and subsequent decline.

In the MPD fit, M was at the mean of the prior – 0.12. The fit to the proportions-at-length was good. Growth parameters were close to the values estimated from tagging data alone. Recruitment was much more variable than in CRA 1, showing a series of strong peaks and two low points.

Sensitivity of the MPD fit to a variety of trials showed little sensitivity, except for SS exploitation rate when vulnerability for males in SS was estimated, causing this indicator to increase to 33% from the base case 24%.

The retrospective trials, based on MPD fits, showed a high sensitivity at the point between the 1998 and 1999 data sets. The addition of the 1999 data causes the biomass estimates to decrease, although the shape of the trajectory remains the same, and causes the model's predicted CPUE to start to drop, whereas in the 1998 retrospective CPUE showed little tendency to decline.

Combined with the antagonism between CPUE and proportions-at-length, this suggests that the model might be missing some process. Possibilities are:

- CPUE could be misleading,
- a high natural mortality may have occurred,
- growth rate may have declined,
- non-commercial removals may have been much higher than estimated, or
- emigration could have occurred.

Misleading CPUE seems unlikely, because the pattern in CPUE was widespread over several CRA areas and persistent for some years. The model could be programmed to estimate annual deviations in growth, mortality and emigration, but these would all be highly correlated.

The McMC results of the assessment suggested that the current vulnerable biomass at the beginning of AW was 619 t (526–715 t). This is a more precise estimate than for CRA 2. This was 150% (130–172%) of the reference period biomass. Current exploitation rate is estimated to be 25% (22–29%).

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, the model suggested that vulnerable biomass would increase to 149% of the current level, but with very high uncertainty (47–269%).

These conclusions appeared to be robust to the sensitivity trials made with McMC: the trial described above in which male vulnerability was estimated for SS, and one with an increasing trajectory for recreational catches. The latter did produce less optimistic projections.

These results suggest that current catch levels should be sustainable on average, but the high uncertainty must be noted: the future biomass could be halved or doubled. The uncertainty was higher than for CRA 1 because of the more volatile pattern of estimated recruitments. It was also a source of uncertainty that current levels and historical patterns of non-commercial catch levels are poorly determined.

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TABLES

Table 1: Data types and sources for the 2002 assessment of CRA 1 and CRA 2. Year codes apply to the first 9 months of each fishing year, *viz* 1998-99 is called 1998. RLIC – Rock Lobster Industry Council.

Data type	Data source	Begin year	End year
Historical catch rate	Annala & King (1983)	1963	1973
CPUE	FSU & CELR	1979	2001
Historical proportions-at-size	Various	1974	1978
Observer proportions-at-size	MFish	1990	2001
Logbook proportions-at-size	RLIC	1993	2001
Historical tag recovery data	MFish various	1975	1986
Current tag recovery data	RLIC & MFish	1996	2001
Historical MLS regulations	Annala (1983)	1945	1999
Escape gap regulation changes	Annala (1983)	1945	1999

Table 2. Recreational catch estimates used in the assessments.

	CRA 1	CRA 2
1994 numbers	56 000	142 000
1996 numbers	74 000	223 000
mean numbers	65 000	182 500
mean weight (kg)	0.726	0.672
catch in kg	47 190	122 640

Table 3: Estimates of illegal catches (t) for the 2001 assessment of CRA 1 and CRA 2. For the years not listed, the assessment used values interpolated linearly.

Year	CRA 1	CRA 2
1979	2.79	7.12
1987	13.72	34.54
1990	38.00	70.00
1992	11.00	37.00
1994	15.00	70.00
1995	15.00	60.00
1997	72.00	88.00
1998	72.00	88.00
1999	72.00	88.00
2000	72.00	88.00
2001	72.00	88.00

Table 4: Parameter estimates for the conversion of total length to tail length and from tail length to tail width. Conversion factors for total length to tail length (in inches) are taken from Sorensen (1970). Conversion factors for tail length to tail width (in mm) are taken from 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
Tail length (mm) to tail width (mm) CRA 1	0.383	-1.36	0.464	-10.64
Tail length (mm) to tail width (mm) CRA 2	0.404	-6.53	0.477	-13.09
Carapace length (mm) to tail width (mm) CRA 1	0.521	3.83	0.686	-7.19
Carapace length (mm) to tail width (mm) CRA 2	0.538	0.78	0.709	-8.03

Table 5: Summary of historical minimum size limit regulations for CRA1 and 2. Regulation changes through 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	56
1988	54 mm TW	58 mm TW	54	58
1992	54 mm TW	60 mm TW	54	60
1993	54 mm TW	60 mm TW	54	60

Table 6: Summary of the number and sources of tag recoveries from CRA 1 and CRA 2 used in the assessments.

	CRA 1		CRA 2		Total	
	Male	Female	Male	Female	Male	Female
Older data	189	173	68	120	257	293
Current data	117	145	927	609	1044	754
Total	306	318	995	729	1301	1047

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. Initial values in bold indicate a parameter that was held fixed in the base case. –, not applicable.

	Phase	Lower bound	Upper bound	Prior type	Mean	c.v.	Initial value
$\ln(R_0)$	1	1	50	U	–	–	15
χ	-1	0.0001	2	U	–	–	**1**
$\tilde{\sigma}$	1	0.01	20	U	–	–	0.3
ε_y	1	-2.3	2.3	N	0	0.4	0
M	4	0.01	0.35	L	0.12	0.4	0.12
d_{50}^{male}	2	1	8	U	–	–	3.8
d_{50}^{female}	2	1	8	U	–	–	4.4
d_{80}^{male}	2	-10	3	U	–	–	-0.15
d_{80}^{female}	2	-10	3	U	–	–	-1.03
$CV^{male,j}$	3	0.01	1	U	–	–	0.28
$CV^{female,j}$	3	0.01	1	U	–	–	0.61
$\varphi^{j,\min}$	4	0.01	5	U	–	–	1.68
$\sigma^{j,obs}$	-2	0.01	50	U	–	–	**2**
m_{50}	3	30	80	U	–	–	54
m_{95}	-4	0	60	U	–	–	**11**
r_{AW}^{male}	2	0	1	U	–	–	1
r_{AW}^{female}	2	0	1	U	–	–	1
r_{SS}^{female} or r_{SS}^{femmat}	2	0	1	U	–	–	1
r_{AW}^{femmat}	2	0	1	U	–	–	0.6
η^{male}	3	10	80	N	54	2	54
η^{female}	3	10	80	N	60	2	60
$v^{male,l}$	2	1	50	U	–	–	5
$v^{female,l}$	2	1	50	U	–	–	5
$w^{male,r}$	-4	1	250	U	–	–	**200**
$w^{female,r}$	-4	1	250	U	–	–	**200**

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	std. dev. of size of recruits	2
U^{max}	maximum exploitation rate per period	0.9
f_k^g	moult probability for sex g in season k	males: AW 1 SS 1 females: AW 0, SS 1
λ	shape parameter for mixing left and right halves of selectivity curves	5
w^g	shape parameter for the right hand limb of the selectivity curve for sex g	200 except in sensitivity trial
	handling mortality rate multiplier on SL fishery exploitation rate	0.1
$\sigma^{d,obs}$	std. dev. of increment observation error	2
χ	shape of biomass - CPUE relation	1
m_{95-50}	difference between sizes at 50% and 95% probability of maturing	11

Table 9. Weights and the resulting sdsdrs used for the base cases in CRA 1 and CRA 2 assessments; sdsdrs - standard deviation of the standardised residuals.

	CRA 1		CRA 2	
data	weight	sdsdr	weight	sdsdr
CPUE	1.0	1.07	2.0	3.89
CR	0.6	1.00	1.0	1.39
tags	0.5	0.99	1.0	0.93
LFs	50.0	0.96	18.0	0.83

Table 10: Data weights, MPD parameter estimates, negative log likelihoods and performance indicators for CRA 1. 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.

	Base case	2 epochs, estimate selectivity	2 epochs, fixed selectivity	1.5 times non-comm. catches	2 times non-comm. catches	different rec. catch trajectory	estimate χ	double CPUE wt	double LF wt	double tag wt	double CR wt	estimate male SS vulnest	VR
Weights													
ϖ^{I}	**1**	1	1	1	1	1	1	2	1	1	1	1	1
ϖ^{CR}	**0.6**	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.2	0.6	0.6
ϖ^{p}	**50**	50	50	50	50	50	50	50	100	50	50	50	50
ϖ^{TAG}	**0.5**	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5	0.5	0.5
Parameters													
χ	**1**	1	1	1	1	1	0.70	1	1	1	1	1	1
$\ln(R_0)$	**13.29**	13.36	13.35	13.38	13.47	13.41	13.22	16.56	13.42	13.27	13.35	13.18	13.20
M	**0.18**	0.19	0.19	0.17	0.17	0.18	0.18	0.35	0.20	0.18	0.21	0.17	0.14
d_{50}^{male}	**3.83**	3.82	3.82	3.84	3.84	3.83	3.84	3.75	4.01	3.92	3.85	3.83	3.89
d_{50}^{female}	**4.77**	4.81	4.81	4.78	4.79	4.82	4.81	5.33	5.46	4.67	4.88	4.80	4.57
d_{80}^{male}	**0.19**	0.22	0.22	0.19	0.18	0.20	0.18	0.27	0.19	-0.03	0.16	0.17	0.12
d_{80}^{female}	**-0.86**	-0.88	-0.88	-0.87	-0.88	-0.91	-0.85	-1.48	-0.95	-0.90	-0.93	-0.85	-0.73
CV^{male}	**0.28**	0.28	0.28	0.27	0.27	0.28	0.28	0.28	0.09	0.33	0.27	0.28	0.27
CV^{female}	**0.60**	0.59	0.59	0.59	0.59	0.59	0.60	0.53	0.06	0.76	0.59	0.59	0.62
$\varphi^{j,\min}$	**1.69**	1.69	1.69	1.69	1.69	1.69	1.70	1.67	0.57	2.13	1.68	1.70	1.68
$\sigma^{j,obs}$	**2**	2	2	2	2	2	2	2	2	2	2	2	2
m_{50}	**48.87**	43.35	46.07	48.94	48.99	49.04	49.43	49.47	47.75	49.29	49.48	49.18	48.51
m_{95-50}	**11**	11	11	11	11	11	11	11	11	11	11	11	11
r_{AW}^{male} (* r_{SS}^{male})	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.88*	1.00
r_{AW}^{female}	**1.00**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
r_{SS}^{female} or r_{SS}^{femmat}	**0.57**	0.59	0.58	0.56	0.55	0.58	0.60	0.87	0.64	0.58	0.64	0.55	0.47
r_{AW}^{femmat}	**0.73**	0.75	0.74	0.71	0.70	0.72	0.70	1.00	0.82	0.73	0.76	0.71	0.61
η_1^{male}		52.62	52.00										
η_1^{female}		60.95	60.00										
η_2^{male}	**53.38**	53.91	54.00	53.39	53.41	53.40	53.48	53.63	52.74	53.52	53.45	53.33	53.26
η_2^{female}	**55.16**	55.08	55.00	55.16	55.16	55.16	55.17	55.15	54.94	55.20	55.17	55.16	55.17
$v_1^{male,l}$		7.12	7.00										

	Base case	2 epochs, estimate selectivity	2 epochs, fixed selectivity	1.5 times non-comm. catches	2 times non-comm. catches	different rec. catch trajectory	estimate χ	double CPUE wt	double LF wt	double tag wt	double CR wt	estimate male SS vulnest	VR
$v_1^{female,l}$		5.82	5.00										
$v_2^{male,l}$	**7.01**	7.16	7.00	7.02	7.03	6.98	7.09	6.90	6.34	7.22	7.04	7.06	6.92
$v_2^{female,l}$	**3.06**	2.70	3.00	3.09	3.11	3.07	3.20	2.78	3.33	3.13	3.10	3.06	3.21
$w^{male,l}$	**200**	200	200	200	200	200	200	200	200	200	200	200	23.07
$w^{female,l}$	**200**	200	200	200	200	200	200	200	200	200	200	200	250.00
$\tilde{\sigma}$	**0.53**	0.53	0.53	0.53	0.53	0.53	0.52	0.54	0.91	0.57	0.53	0.53	0.52
λ	**5**	5	5	5	5	5	5	5	5	5	5	5	5
Likelihoods													
CPUE	**-22.4**	-22.7	-22.5	-22.1	-21.8	-22.2	-26.4	-11.3	-13.3	-21.6	-22.2	-28.0	-19.1
CR	**1.8**	1.6	1.6	1.9	2.0	2.1	2.2	2.8	6.6	1.6	10.8	4.9	0.0
LF	**-4263.1**	-4266.2	-4265.8	-4264.1	-4264.7	-4262.7	-4264.2	-4241.0	-4253.0	-4252.2	-4261.6	-4265.4	-4271.0
Tags	**5974.2**	5974.8	5974.8	5974.1	5974.0	5974.4	5974.9	5979.2	6104.7	6060.9	5974.8	5974.7	5972.9
Penalty on													
***M* Priors**	**6.7**	10.5	0.6	6.6	6.6	6.7	6.6	9.8	7.5	6.7	7.1	6.6	6.3
ε_y	**10.2**	10.2	10.1	10.3	10.5	11.2	10.8	21.8	11.4	10.2	11.7	10.2	11.6
Penalty on U	**0**	0	0	0	0	0	0	0	0	0	0	0	0
LikeTotal	**1707.4**	1708.3	1698.8	1706.9	1706.6	1709.5	1703.9	1761.3	1863.9	1805.6	1720.7	1702.9	1700.7
Std dev of Residuals													
CPUE	**1.07**	1.07	1.07	1.08	1.08	1.08	0.99	1.72	0.68	1.01	1.07	0.95	1.14
CR	***1.00***	*0.99*	*0.99*	*1.01*	*1.01*	*1.02*	*1.02*	*1.02*	*0.62*	*0.90*	*1.80*	*1.14*	*0.91*
Tags	**0.99**	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.86	1.06	0.99	0.99	0.99
LFs	**0.96**	0.96	0.96	0.96	0.96	0.96	0.96	0.94	1.10	0.88	0.95	0.96	0.96
Indicators													
$BALL_{79\text{-}88}$	**1819**	1900	1875	2042	2276	2111	1536	32822	1843	1745	1856	1694	2250
$BRECT_{79\text{-}88}$	**1080**	1132	1112	1229	1385	1303	862	21217	1061	1036	1074	1006	1519
$BVULN_{79\text{-}88}$	**690**	726	707	772	860	829	537	16230	701	663	715	637	694
$BALL_{02}$	**2493**	2649	2600	2788	3100	2910	2363	52146	2512	2354	2462	2361	3355
$BRECT_{02}$	**1728**	1815	1778	1935	2153	2015	1640	34342	1742	1636	1683	1647	2577
$BVULN_{02}$	**1048**	1124	1093	1159	1279	1217	973	25221	1087	988	1048	979	1039
$UNSL_{01,AW}$	**2.9%**	2.8%	2.8%	3.9%	4.7%	4.9%	3.1%	0.1%	2.7%	3.1%	2.9%	3.1%	2.8%
$USL_{01,AW}$	**12.4%**	11.8%	12.1%	12.6%	12.7%	13.1%	13.4%	0.5%	11.8%	13.1%	12.3%	13.4%	12.4%
$UNSL_{01,SS}$	**1.6%**	1.5%	1.6%	2.2%	2.6%	2.7%	1.7%	0.1%	1.5%	1.7%	1.6%	1.9%	1.6%
$USL_{01,SS}$	**7.1%**	6.6%	6.8%	8.4%	9.5%	8.7%	7.4%	0.3%	6.6%	7.4%	6.9%	8.3%	6.8%
$BVULN_{02}/BVULN_{79\text{-}88}$	**152.0%**	154.8%	154.6%	150.2%	148.7%	146.7%	181.3%	155.4%	155.1%	149.0%	146.6%	153.6%	149.7%
$BRECT_{02}/BRECT_{79\text{-}88}$	**159.9%**	160.3%	159.8%	157.4%	155.5%	154.7%	190.1%	161.9%	164.1%	158.0%	156.7%	163.7%	169.6%

Table 11: Parameter estimates from CRA 1 MPD retrospective analysis. Years are named for the last year of data that were used.

	last year of LF and CPUE data				
	2001 (base case)	2000	1999	1998	1997
Parameters					
$\ln(R_0)$	13.29	13.08	13.37	13.45	13.43
M	0.18	0.16	0.20	0.22	0.22
d_{50}^{male}	3.83	3.74	3.76	3.77	3.79
d_{50}^{female}	4.77	4.52	4.62	4.79	4.81
d_{80}^{male}	0.19	0.33	0.30	0.28	0.25
d_{80}^{female}	-0.86	-0.57	-0.88	-1.20	-1.21
CV^{male}	0.28	0.30	0.29	0.29	0.28
CV^{female}	0.60	0.63	0.62	0.57	0.56
$\varphi^{j,\min}$	1.69	1.77	1.73	1.71	1.68
m_{50}	48.87	64.46	64.36	63.47	63.09
m_{95-50}	11	11	11	11	11
$\ln(q)$	-6.87	-6.81	-6.94	-6.77	-6.58
r_{AW}^{male}	1.00	1.00	1.00	1.00	1.00
r_{AW}^{female}	1.00	0.34	0.39	0.51	0.56
r_{SS}^{female} or r_{SS}^{femmat}	0.57	0.70	0.91	0.96	0.94
r_{AW}^{femmat}	0.73	1.00	1.00	1.00	1.00
η^{male}	53.38	49.13	49.13	49.12	49.13
η^{female}	55.16	59.12	59.32	59.42	59.40
$\nu^{male,l}$	7.01	1.37	1.36	1.30	1.32
$\nu^{female,l}$	3.06	5.86	5.26	5.23	5.32
$\tilde{\sigma}$	0.53	0.50	0.51	0.52	0.53
Likelihoods					
CPUE	-22.4	-20.6	-19.4	-19.5	-18.4
CR	1.8	2.8	1.0	0.9	1.1
LF	-4263.1	-3780.1	-3279.3	-2971.7	-2738.9
Tags	5974.2	5979.1	5975.1	5973.3	5972.7
Penalty on M Prior	6.7	6.5	7.1	7.4	7.4
ε_y	10.2	10.1	9.6	8.6	8.1
Penalties on U	0.0	0.0	0.0	0.0	0.0
Total	1707.4	2197.8	2694.2	2999.0	3232.0
Std dev of Residuals					
CPUE	1.07	1.14	1.13	1.10	1.08
CR	1.00	1.10	1.00	0.98	0.96
Tags	0.99	1.00	1.00	1.00	1.00
LFs	0.96	0.95	0.94	0.94	0.94
Indicators					
$BALL_{79-88}$	1819	1626	1749	1585	1420
$BRECT_{79-88}$	1080	938	972	810	670
$BVULN_{79-88}$	690	655	746	641	537
$BALL_{02}$	2493	2006	2171	2117	1925
$BRECT_{02}$	1728	1397	1405	1286	1110
$BVULN_{02}$	1048	841	916	860	744
$UNSL_{01,AW}$	2.9%	3.3%	3.6%	3.9%	4.2%
$USL_{01,AW}$	12.4%	14.0%	14.6%	16.4%	18.1%
$UNSL_{01,SS}$	1.6%	2.1%	1.5%	1.5%	1.9%
$USL_{01,SS}$	7.1%	8.8%	6.8%	7.0%	9.0%
$BVULN_{02}/BVULN_{79-88}$	152.0%	128.3%	122.8%	134.1%	138.7%
$BRECT_{02}/BRECT_{79-88}$	159.9%	149.0%	144.5%	158.8%	165.6%

Table 12: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from CRA 1 (* indicates the test failed).

Quantity	Posterior means					Convergence statistic																				
						Raftery and Lewis					Geweke					Heidelberger and Welsh					Single chain Gelman					Brooks Gelman
Chain #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	Rubin
Indicators	mean	mean	mean	mean	mean																					
BALL$_{79-88}$	2080	2112	2070	2116	2076										*		*		*	*						
BRECT$_{79-88}$	1299	1321	1288	1319	1292										*		*		*							
BVULN$_{79-88}$	850	861	841	866	842										*		*		*							
BALL$_{02}$	3053	3126	3039	3120	3073								*		*		*		*							
BRECT$_{02}$	2078	2122	2055	2110	2080							*			*		*									
BVULN$_{02}$	1301	1329	1283	1325	1302							*			*		*									
BALL$_{07}$	3146	3251	3213	3235	3203								*		*											
BRECT$_{07}$	2119	2207	2170	2188	2165								*		*											
BVULN$_{07}$	1344	1406	1386	1398	1378								*		*											
UNSL$_{02}$	2.5%	2.5%	2.5%	2.5%	2.5%								*		*											
USL$_{02}$	10.7%	10.5%	10.8%	10.5%	10.6%				*			*	*		*											
UNSL$_{06}$	2.6%	2.5%	2.5%	2.5%	2.5%								*		*											
USL$_{06}$	11.1%	10.8%	11.0%	10.8%	10.9%								*		*											
BVULN$_{02}$/***BVULN***$_{79-88}$	153%	154%	153%	153%	154%						*		*		*											
BVULN$_{07}$/***BVULN***$_{02}$	103%	105%	108%	105%	105%								*													
BVULN$_{07}$/***BVULN***$_{79-88}$	158%	163%	165%	162%	163%								*		*											

Table 13: Summary statistics for performance indicators from posterior distributions from the CRA 1 base case.

	Base case				Estimate male SS vulnerability				Estimate descending limb variance of vulnerability ogive			
	0.05	median	mean	0.95	0.05	median	mean	0.95	0.05	median	mean	0.95
f	1724.4	1731.5	1731.9	1740.5	1720.3	1727.8	1728.1	1737.1	1719.5	1727.5	1727.9	1737.3
$\ln(R_0)$	13.09	13.34	13.35	13.66	12.96	13.24	13.25	13.58	13.01	13.29	13.30	13.65
M	0.16	0.19	0.19	0.22	0.14	0.17	0.17	0.21	0.12	0.15	0.15	0.19
$\tilde{\sigma}$	0.52	0.53	0.53	0.54	0.52	0.53	0.53	0.54	0.52	0.53	0.53	0.54
d_{50}^{male}	3.68	3.80	3.80	3.93	3.68	3.80	3.80	3.92	3.73	3.85	3.85	3.98
d_{50}^{female}	4.54	4.84	4.84	5.15	4.57	4.86	4.87	5.18	4.37	4.67	4.67	4.98
d_{80}^{male}	0.00	0.22	0.22	0.43	-0.03	0.19	0.19	0.41	-0.05	0.16	0.16	0.37
d_{80}^{female}	-1.31	-0.93	-0.94	-0.60	-1.28	-0.92	-0.92	-0.59	-1.17	-0.82	-0.82	-0.51
$CV^{male,j}$	0.03	0.20	0.20	0.39	0.03	0.20	0.21	0.39	0.03	0.19	0.20	0.38
$CV^{female,j}$	0.49	0.58	0.58	0.66	0.50	0.58	0.58	0.66	0.51	0.59	0.59	0.68
$\varphi^{j,\min}$	1.61	1.70	1.70	1.79	1.62	1.71	1.71	1.79	1.61	1.69	1.69	1.78
m_{50}	31.27	42.34	41.96	51.62	31.33	43.14	42.55	52.08	31.38	42.61	42.05	51.17
m_{95-50}	11	11	11	11	11	11	11	11	11	11	11	11
r_{AW}^{male} (* r_{SS}^{male})	0.99	1.00	1.00	1.00	0.82*	0.88*	0.88*	0.95*	0.96	0.97	0.98	1.00
r_{AW}^{female}	0.06	0.47	0.47	0.95	0.05	0.41	0.46	0.93	0.07	0.62	0.57	0.96
r_{SS}^{female} or r_{SS}^{femmat}	0.49	0.62	0.62	0.77	0.47	0.59	0.60	0.75	0.39	0.50	0.51	0.64
r_{AW}^{femmat}	0.64	0.77	0.77	0.91	0.63	0.75	0.76	0.90	0.53	0.64	0.65	0.78
$v_1^{male,l}$	3.96	6.84	6.72	9.03	4.00	6.87	6.76	9.14	3.30	6.53	6.36	8.74
$v_1^{female,l}$	1.54	2.78	2.90	4.68	1.52	2.83	2.99	4.95	1.58	2.98	3.18	5.39
η_1^{male}	50.24	53.00	52.84	55.01	50.16	52.92	52.76	54.94	49.98	52.71	52.51	54.62
η_1^{female}	53.94	55.06	55.03	56.10	53.90	55.12	55.10	56.27	53.81	55.10	55.10	56.38
$w^{male,l}$	200	200	200	200	200	200	200	200	20.15	25.29	26.34	36.22
$w^{female,l}$	200	200	200	200	200	200	200	200	50.53	152.93	149.47	240.69
$BALL_{79-88}$	1741	2057	2091	2542	1618	1903	1949	2414	2014	2560	2638	3534
$BRECT_{79-88}$	1029	1278	1304	1652	959	1190	1218	1570	1307	1775	1832	2558
$BVULN_{79-88}$	642	834	852	1121	593	768	793	1071	623	821	845	1153
$BALL_{02}$	2274	2995	3082	4155	2159	2788	2880	3905	2894	3981	4131	5844
$BRECT_{02}$	1594	2050	2089	2715	1514	1932	1980	2619	2144	2961	3067	4311
$BVULN_{02}$	929	1276	1308	1792	859	1182	1221	1720	891	1227	1272	1798
$BALL_{07}$	2007	3113	3209	4771	1840	2868	2969	4448	2686	4208	4361	6643
$BRECT_{07}$	1268	2087	2170	3355	1172	1944	2025	3171	1877	3099	3231	5040
$BVULN_{07}$	725	1320	1382	2269	646	1204	1266	2123	768	1305	1379	2242
$UNSL_{02}$ (%)	1.7	2.5	2.5	3.3	1.8	2.6	2.7	3.5	1.7	2.4	2.4	3.3
USL_{02} (%)	7.4	10.4	10.6	14.3	7.8	11.2	11.4	15.4	7.3	10.7	10.8	14.7
$UNSL_{06}$ (%)	1.5	2.4	2.5	3.8	1.6	2.6	2.7	4.2	1.4	2.3	2.4	3.6
USL_{06} (%)	6.2	10.3	10.9	17.4	6.6	11.3	11.9	19.3	6.2	10.3	10.8	16.8
$BVULN_{02}/BVULN_{79-88}$ (%)	131	152	153	182	131	152	154	184	128	149	151	183
$BVULN_{07}/BVULN_{02}$ (%)	67	101	105	157	64	98	103	158	73	102	108	161
$BVULN_{07}/BVULN_{79-88}$ (%)	94	156	162	250	91	152	160	250	103	156	163	249

Table 14: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from the sensitivity on estimating male SS vulnerability for CRA 1 (* indicates the test failed).

Quantity	Posterior means					Convergence statistic																				
						Raftery and Lewis					Geweke					Heidelberger and Welsh					Single chain Gelman					Brooks Gelman Rubin
Chain #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Indicators	mean	mean	mean	mean	mean																					
$BALL_{79-88}$	1956	1917	1958	1963	1945						*															
$BRECT_{79-88}$	1226	1196	1224	1227	1215						*															
$BVULN_{79-88}$	799	776	799	801	789						*															
$BALL_{02}$	2898	2832	2890	2901	2872						*															
$BRECT_{02}$	1996	1942	1990	1994	1975						*															
$BVULN_{02}$	1233	1191	1229	1233	1217						*															
$BALL_{07}$	3004	2937	2978	2991	2934																					
$BRECT_{07}$	2052	1997	2025	2045	2002																					
$BVULN_{07}$	1287	1242	1268	1283	1245																					
$UNSL_{02}$	2.6%	2.7%	2.6%	2.6%	2.7%						*															
USL_{02}	11.3%	11.6%	11.3%	11.3%	11.4%						*															
$UNSL_{06}$	2.7%	2.8%	2.7%	2.7%	2.7%																					
USL_{06}	11.8%	12.2%	11.9%	11.9%	12.0%																					
$BVULN_{02}/BVULN_{79-88}$	154%	154%	154%	154%	154%																					
$BVULN_{07}/BVULN_{02}$	104%	104%	103%	104%	102%																					
$BVULN_{07}/BVULN_{79-88}$	161%	160%	159%	160%	158%																					

Table 15: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from the sensitivity on estimating descending limb variance of vulnerability ogive for CRA 1 (* indicates the test failed).

Quantity	Posterior means					Convergence statistic																				
						Raftery and Lewis					Geweke					Heidelberger and Welsh					Single chain Gelman					Brooks Gelman Rubin
Chain #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Indicators	mean	mean	mean	mean	mean																					
$BALL_{79-88}$	2617	2616	2650	2657	2646													*								
$BRECT_{79-88}$	1822	1820	1839	1842	1839													*								
$BVULN_{79-88}$	847	844	851	846	839																					
$BALL_{02}$	4122	4115	4133	4153	4132													*								
$BRECT_{02}$	3073	3059	3064	3072	3069													*								
$BVULN_{02}$	1282	1276	1277	1270	1258																					
$BALL_{07}$	4320	4342	4397	4363	4382																					
$BRECT_{07}$	3209	3234	3252	3225	3234								*													
$BVULN_{07}$	1366	1388	1402	1370	1367																					
$UNSL_{02}$	2.4%	2.4%	2.4%	2.5%	2.5%																					
USL_{02}	10.7%	10.7%	10.8%	10.9%	10.9%									*												
$UNSL_{06}$	2.4%	2.4%	2.4%	2.4%	2.4%								*													
USL_{06}	10.8%	10.6%	10.6%	10.9%	10.9%								*													
$BVULN_{02}/BVULN_{79-88}$	152%	151%	150%	150%	150%									*												
$BVULN_{07}/BVULN_{02}$	107%	109%	110%	108%	108%																					
$BVULN_{07}/BVULN_{79-88}$	162%	165%	166%	162%	163%																					

Table 16: Data weights, MPD parameter estimates, negative log likelihoods and performance indicators for CRA 2. LF: Size frequency data; VR: $w^{g,r}$ estimated. Shading in the parameters indicates fixed values.

	Base case	2 epochs, estimate selectivity	2 epochs, fixed selectivity	1.5 times non-comm. catches	2 times non-comm. catches	different rec. catch trajectory	estimate χ	double CPUE wt	double LF wt	double tag wt	double CR wt	estimate male SS vulnest	VR
Weights													
ϖ^{I}	2	2	2	2	2	2	2	4	2	2	2	2	2
ϖ^{CR}	1	1	1	1	1	1	1	1	1	1	2	1	1
ϖ^{P}	18	18	18	18	18	18	18	18	36	18	18	18	18
ϖ^{TAG}	1	1	1	1	1	1	1	1	1	2	1	1	1
Parameters													
χ	1	1	1	1	1	1	0.69	1	1	1	1	1	1
$\ln(R_0)$	13.20	13.15	13.15	13.26	13.28	13.20	13.05	13.66	12.84	13.21	13.14	13.04	13.21
M	0.14	0.13	0.13	0.12	0.10	0.13	0.13	0.21	0.09	0.14	0.13	0.14	0.14
d_{50}^{male}	3.77	3.80	3.85	3.77	3.79	3.79	4.02	3.81	3.84	3.78	3.65	3.85	3.77
d_{50}^{female}	4.28	4.09	4.43	4.19	4.01	4.39	4.64	4.45	3.63	4.30	3.99	4.63	4.27
d_{80}^{male}	0.70	0.68	0.65	0.70	0.67	0.70	0.31	0.89	0.33	0.61	0.95	0.36	0.71
d_{80}^{female}	-0.72	-0.51	-0.82	-0.56	-0.33	-0.77	-0.86	-1.19	0.22	-0.77	-0.51	-0.57	-0.72
CV^{male}	0.43	0.42	0.42	0.43	0.41	0.43	0.19	0.43	0.36	0.43	0.45	0.42	0.43
CV^{female}	0.81	0.90	0.79	0.89	0.99	0.79	0.77	0.80	0.98	0.81	0.92	0.97	0.81
$\varphi^{I,\min}$	2.47	2.44	2.50	2.45	2.37	2.48	2.59	2.46	2.21	2.49	2.42	2.54	2.47
$\sigma^{I,obs}$	2	2	2	2	2	2	2	2	2	2	2	2	2
m_{50}	54.39	54.47	54.22	54.41	54.53	54.29	53.91	54.96	54.48	54.38	54.51	53.77	54.39
m_{95-50}	11	11	11	11	11	11	11	11	11	11	11	11	11
r_{AW}^{male} (* r_{SS}^{male})	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.72*	1.00
r_{AW}^{female}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
r_{SS}^{female} or r_{SS}^{femmat}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
r_{AW}^{femmat}	0.55	0.56	0.55	0.55	0.56	0.55	0.51	0.65	0.50	0.55	0.56	0.63	0.55
η_1^{male}		58.31	56.90										
η_1^{female}		57.35	59.75										
η_2^{male}	53.69	53.65	53.66	53.70	53.71	53.69	53.79	54.24	53.46	53.68	53.77	53.79	53.69
η_2^{female}	60.33	60.26	60.18	60.26	60.34	60.35	60.54	60.04	60.65	60.32	60.23	60.70	60.33
$v_1^{male,I}$		9.38	3.00										

	Base case	2 epochs, estimate selectivity	2 epochs, fixed selectivity	1.5 times non-comm. catches	2 times non-comm. catches	different rec. catch trajectory	estimate χ	double CPUE wt	double LF wt	double tag wt	double CR wt	estimate male SS vulnest	VR
$v_1^{female,l}$		3.56	5.00										
$v_2^{male,l}$	**3.03**	2.99	3.00	3.05	3.08	3.03	3.18	3.36	2.94	3.03	3.07	3.17	3.03
$v_2^{female,l}$	**5.10**	4.96	5.00	4.98	4.88	5.13	5.48	5.06	4.90	5.11	4.91	5.25	5.10
$w^{male,l}$	**200**	200	200	200	200	200	200	200	200	200	200	200	250
$w^{female,l}$	**200**	200	200	200	200	200	200	200	200	200	200	200	250
$\tilde{\sigma}$	**0.35**	0.35	0.35	0.35	0.35	0.35	0.34	0.44	0.59	0.37	0.36	0.31	0.35
λ	**5**	5	5	5	5	5	5	5	5	5	5	5	5
Likelihoods													
CPUE	**248.5**	246.6	230.5	242.6	239.9	244.2	221.8	318.8	141.7	218.5	226.7	110.6	248.7
CR	**-7.4**	-7.5	-7.4	-6.7	-5.5	-6.4	0.5	-13.3	-4.4	-7.7	22.1	-17.5	-7.4
LF	**-7354.7**	-7362.1	-7350.2	-7355.8	-7356.0	-7366.4	-7431.1	-6896.7	-7612.6	-7313.4	-7329.8	-7539.1	-7355.2
Tags	**4467.0**	4466.4	4471.8	4467.1	4465.9	4469.1	4482.1	4465.5	4428.8	4562.8	4470.0	4496.1	4467.0
Penalty on													
***M* Priors**	**3.3**	9.7	7.6	3.2	3.3	3.3	3.3	4.2	3.7	3.3	3.3	3.4	3.3
ε_y	**19.8**	21.4	19.9	21.6	24.6	21.8	24.6	17.5	23.7	19.1	24.6	23.6	19.8
Penalty on U	**0.00**	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
LikeTotal	**-2623.5**	-2625.5	-2628.0	-2628.0	-2627.8	-2634.4	-2698.8	-2104.0	-3019.1	-2517.4	-2583.1	-2922.9	-2623.7
Std dev of Residuals													
CPUE	**3.89**	3.88	3.79	3.86	3.85	3.87	3.75	4.38	3.08	3.71	3.77	3.07	3.90
CR	**1.39**	1.39	1.40	1.42	1.46	1.43	1.67	0.97	1.10	1.35	2.47	1.12	1.39
Tags	**0.93**	0.94	0.93	0.94	0.95	0.93	0.90	0.92	0.94	1.01	0.95	0.90	0.94
LFs	**0.83**	0.83	0.84	0.83	0.83	0.83	0.83	0.79	0.91	0.79	0.82	0.89	0.83
Indicators													
$BALL_{79\text{-}88}$	**1625**	1623	1560	1846	2069	1668	1375	1787	1563	1617	1675	1450	1626
$BRECT_{79\text{-}88}$	**543**	540	568	623	694	590	379	594	501	543	552	470	543
$BVULN_{79\text{-}88}$	**404**	394	386	460	513	431	282	460	375	403	415	360	404
$BALL_{02}$	**1777**	1776	1743	2002	2251	1845	1586	1781	1814	1776	1820	1617	1779
$BRECT_{02}$	**1056**	1047	1033	1183	1313	1095	924	1024	1030	1055	1083	905	1057
$BVULN_{02}$	**550**	541	532	614	676	570	448	596	477	549	569	502	551
$UNSL_{01,AW}$	**4.3%**	4.4%	4.4%	5.7%	6.7%	4.0%	5.0%	3.8%	4.9%	4.3%	4.2%	4.7%	4.3%
$USL_{01,AW}$	**25.9%**	26.5%	26.9%	25.4%	25.2%	25.3%	31.3%	22.1%	31.4%	26.0%	25.2%	29.1%	25.9%
$UNSL_{01,SS}$	**3.9%**	3.9%	4.0%	5.1%	6.0%	3.6%	4.3%	3.9%	4.0%	3.9%	3.8%	5.3%	3.9%
$USL_{01,SS}$	**23.6%**	23.9%	24.2%	26.6%	29.0%	27.0%	26.7%	23.5%	24.8%	23.6%	23.1%	32.8%	23.5%
$BVULN_{07}/BVULN_{79\text{-}88}$	**136.2%**	137.1%	137.8%	133.6%	131.9%	132.0%	158.9%	129.7%	127.1%	136.1%	137.2%	139.5%	136.3%
$BRECT_{07}/BRECT_{79\text{-}88}$	**194.6%**	194.0%	181.8%	190.1%	189.1%	185.6%	244.0%	172.4%	205.5%	194.2%	196.1%	192.4%	194.7%

Table 17. Parameter estimates from CRA 2 MPD retrospective analysis. Years are named for the last year of data that were used.

	last year of LF and CPUE data				
	2001 (base case)	2000	1999	1998	1997
Parameters					
$\ln(R_0)$	13.20	13.09	13.21	15.33	15.59
M	0.14	0.11	0.13	0.30	0.32
d_{50}^{male}	3.77	3.62	3.59	3.19	3.23
d_{50}^{female}	4.28	4.02	4.32	5.79	5.92
d_{80}^{male}	0.70	0.71	0.65	1.07	1.03
d_{80}^{female}	-0.72	-0.51	-1.03	-3.17	-3.64
CV^{male}	0.43	0.43	0.43	0.49	0.51
CV^{female}	0.81	0.88	0.76	0.55	0.54
$\varphi^{j,\min}$	2.47	2.34	2.32	2.35	2.34
m_{50}	54.39	54.65	54.65	53.67	53.50
m_{95-50}	11	11	11	11	11
$\ln(q)$	-6.92	-7.01	-7.13	-8.97	-9.31
r_{AW}^{male}	1.00	1.00	1.00	1.00	1.00
r_{AW}^{female}	1.00	1.00	0.95	0.88	0.90
r_{SS}^{female} or r_{SS}^{femmat}	1.00	1.00	1.00	1.00	0.97
r_{AW}^{femmat}	0.55	0.58	0.59	0.61	0.56
η^{male}	3.03	3.06	3.14	2.74	2.74
η^{female}	5.10	5.10	5.72	6.12	6.14
$v^{male,l}$	53.69	53.68	53.70	53.52	53.46
$v^{female,l}$	60.33	60.26	60.55	60.78	60.51
$\tilde{\sigma}$	0.35	0.36	0.36	0.32	0.32
Likelihoods					
CPUE	248.5	208.0	169.3	115.8	98.9
CR	-7.4	-6.1	-7.5	-6.6	-7.0
LF	-7354.7	-6257.7	-5104.6	-4315.8	-3759.6
Tags	4467.0	4452.2	4444.3	4484.8	4485.5
Penalty on M Prior	3.3	3.3	3.3	6.0	6.3
ε_y	19.8	24.0	19.4	25.0	26.0
Penalties on U	0.00	0.00	0.00	0.00	0.00
Total	-2623.5	-1576.4	-475.9	309.2	850.0
Std dev of Residuals					
CPUE	3.89	3.71	3.52	3.21	3.12
CR	1.39	1.43	1.37	1.49	1.47
Tags	0.93	0.97	0.99	1.01	1.02
LFs	0.83	0.82	0.80	0.79	0.77
Indicators					
$BALL_{79\text{-}88}$	1625	1683	1749	6842	9295
$BRECT_{79\text{-}88}$	543	598	670	4052	5662
$BVULN_{79\text{-}88}$	404	439	483	2771	3889
$BALL_{02}$	1777	2359	2138	14261	17393
$BRECT_{02}$	1056	1494	1350	9495	11313
$BVULN_{02}$	550	823	652	6233	7464
$UNSL_{01,AW}$	4.3%	3.5%	4.8%	0.8%	0.7%
$USL_{01,AW}$	25.9%	21.4%	29.3%	4.0%	3.4%
$UNSL_{01,SS}$	3.9%	2.7%	1.9%	0.2%	0.1%
$USL_{01,SS}$	23.6%	17.3%	14.4%	1.7%	1.4%
$BVULN_{02}/BVULN_{79\text{-}88}$	136.2%	187.6%	135.0%	224.9%	191.9%
$BRECT_{02}/BRECT_{79\text{-}88}$	194.6%	250.0%	201.3%	234.3%	199.8%

Table 18: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from CRA 2 (* indicates the test failed).

Quantity	Posterior means				
Chain #	1	2	3	4	5
Indicators	mean	mean	mean	mean	mean
$BALL_{79-88}$	1658	1660	1653	1655	1657
$BRECT_{79-88}$	556	558	555	555	556
$BVULN_{79-88}$	413	414	412	412	413
$BALL_{02}$	2168	2174	2164	2169	2183
$BRECT_{02}$	1149	1151	1146	1153	1148
$BVULN_{02}$	621	622	618	621	621
$BALL_{07}$	2084	2092	2082	2083	2186
$BRECT_{07}$	1008	1013	1010	1014	1071
$BVULN_{07}$	604	608	605	608	651
$UNSL_{02}$	4.2%	4.2%	4.3%	4.2%	4.3%
USL_{02}	25.1%	25.0%	25.2%	25.1%	25.1%
$UNSL_{06}$	5.0%	5.0%	5.0%	5.0%	5.0%
USL_{06}	30.9%	30.8%	30.9%	30.9%	31.2%
$BVULN_{02}/BVULN_{79-88}$	150%	150%	150%	151%	150%
$BVULN_{07}/BVULN_{02}$	96%	96%	97%	97%	96%
$BVULN_{07}/BVULN_{79-88}$	146%	147%	147%	147%	146%

Convergence statistic	Raftery and Lewis					Geweke					Heidelberger and Welsh					Single chain Gelman					Brooks Gelman Rubin
Chain #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
$BALL_{79-88}$															*						
$BRECT_{79-88}$															*						
$BVULN_{79-88}$															*						
$BALL_{02}$																					
$BRECT_{02}$																					
$BVULN_{02}$																					
$BALL_{07}$																					
$BRECT_{07}$																					
$BVULN_{07}$																					
$UNSL_{02}$																					
USL_{02}																					
$UNSL_{06}$																					
USL_{06}																					
$BVULN_{02}/BVULN_{79-88}$																					
$BVULN_{07}/BVULN_{02}$																					
$BVULN_{07}/BVULN_{79-88}$																					

Table 19: Summary statistics for performance indicators from posterior distributions from the CRA 2 base case.

	Base case				Estimate male SS vulnerability				Different recreational catch trajectories			
	0.05	median	mean	0.95	0.05	median	mean	0.95	0.05	median	mean	0.95
f	-2610.2	-2603.9	-2603.6	-2595.7	-2911.6	-2905.3	-2905.0	-2897.1	-2621.2	-2614.8	-2614.4	-2606.7
$\ln(R_0)$	13.08	13.21	13.21	13.34	13.07	13.22	13.22	13.36	13.08	13.21	13.21	13.34
M	0.12	0.13	0.13	0.15	0.14	0.16	0.16	0.17	0.12	0.13	0.13	0.14
$\tilde{\sigma}$	0.35	0.36	0.36	0.36	0.30	0.31	0.31	0.32	0.34	0.35	0.35	0.36
d_{50}^{male}	3.53	3.69	3.69	3.85	3.60	3.74	3.74	3.89	3.55	3.71	3.71	3.88
d_{50}^{female}	3.99	4.19	4.19	4.38	4.76	5.02	5.02	5.26	4.08	4.30	4.30	4.50
d_{80}^{male}	0.53	0.79	0.78	1.02	0.18	0.40	0.40	0.63	0.52	0.78	0.78	1.02
d_{80}^{female}	-0.95	-0.69	-0.69	-0.44	-1.28	-1.00	-1.00	-0.72	-0.98	-0.73	-0.73	-0.46
$CV^{male,j}$	0.04	0.28	0.27	0.52	0.04	0.28	0.28	0.53	0.04	0.29	0.30	0.58
$CV^{female,j}$	0.78	0.84	0.84	0.89	0.73	0.80	0.80	0.90	0.75	0.81	0.82	0.90
$\varphi^{j,\min}$	2.39	2.47	2.47	2.56	2.59	2.69	2.69	2.79	2.39	2.48	2.48	2.57
m_{50}	54.01	54.45	54.44	54.86	53.27	53.64	53.64	54.00	53.94	54.39	54.38	54.78
m_{95-50}	11	11	11	11	11	11	11	11	11	11	11	11
r_{AW}^{male} (* r_{SS}^{male})	1.00	1.00	1.00	1.00	0.71*	0.72*	0.72*	0.74*	1.00	1.00	1.00	1.00
r_{AW}^{female}	0.95	0.98	0.98	1.00	0.98	0.99	0.99	1.00	0.93	0.97	0.97	1.00
r_{SS}^{female} or r_{SS}^{femmat}	0.99	1.00	1.00	1.00	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00
r_{AW}^{femmat}	0.53	0.55	0.55	0.57	0.59	0.61	0.61	0.64	0.53	0.55	0.55	0.57
$v_1^{male,l}$	2.76	3.04	3.04	3.32	2.86	3.09	3.10	3.34	2.76	3.03	3.04	3.32
$v_1^{female,l}$	4.68	5.07	5.08	5.49	5.07	5.45	5.45	5.84	4.72	5.11	5.12	5.55
η_1^{male}	53.43	53.71	53.72	53.99	53.50	53.74	53.74	53.99	53.42	53.70	53.71	54.00
η_1^{female}	59.93	60.30	60.31	60.70	60.32	60.69	60.70	61.09	59.95	60.33	60.33	60.72
$BALL_{79\text{-}88}$	1592	1656	1657	1723	1443	1499	1499	1561	1625	1699	1699	1773
$BRECT_{79\text{-}88}$	525	555	556	589	479	504	505	532	565	603	603	640
$BVULN_{79\text{-}88}$	391	412	413	435	362	380	381	400	414	440	440	465
$BALL_{02}$	1807	2170	2176	2571	1578	1997	1997	2428	1886	2292	2296	2723
$BRECT_{02}$	1025	1150	1150	1275	889	1027	1028	1169	1064	1198	1197	1330
$BVULN_{02}$	527	619	621	716	485	588	589	696	547	647	648	750
$BALL_{07}$	1284	2122	2135	3037	1144	2004	2017	2911	1264	2190	2202	3191
$BRECT_{07}$	372	1033	1047	1757	291	1001	1006	1733	264	1028	1040	1822
$BVULN_{07}$	199	614	631	1117	173	612	621	1101	153	604	621	1142
$UNSL_{02}$ (%)	3.7	4.2	4.2	4.9	3.7	4.4	4.5	5.3	3.5	4.0	4.0	4.7
USL_{02} (%)	21.6	25.0	25.1	29.2	22.2	26.2	26.5	31.8	21.4	24.9	25.0	29.3
$UNSL_{06}$ (%)	2.8	4.4	4.8	8.4	2.8	4.4	5.1	9.9	2.7	4.3	4.9	9.3
USL_{06} (%)	15.2	25.7	30.0	59.3	15.4	26.2	31.8	73.1	15.2	26.2	31.8	72.1
$BVULN_{02}/BVULN_{79\text{-}88}$ (%)	130	150	150	171	129	154	155	181	127	146	147	169
$BVULN_{07}/BVULN_{02}$ (%)	34	99	101	170	33	104	104	176	26	93	94	167
$BVULN_{07}/BVULN_{79\text{-}88}$ (%)	48	149	153	271	46	161	163	290	35	137	141	258

Table 20: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from the sensitivity estimating male SS vulnerability for CRA 2 (* indicates the test failed).

Quantity	Posterior means					Convergence statistic																				
						Raftery and Lewis					Geweke					Heidelberger and Welsh					Single chain Gelman					Brooks Gelman
Chain #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	Rubin
Indicators	mean	mean	mean	mean	mean																					
$BALL_{79-88}$	1504	1491	1510	1508	1484									*	*		*	*	*			*	*		*	
$BRECT_{79-88}$	506	501	509	508	500								*	*	*	*	*	*	*			*			*	
$BVULN_{79-88}$	382	378	384	383	376									*	*	*	*	*	*			*			*	
$BALL_{02}$	2000	1989	2003	2015	1975										*	*	*									
$BRECT_{02}$	1030	1023	1033	1036	1019										*	*	*									
$BVULN_{02}$	591	587	592	594	583										*	*	*									
$BALL_{07}$	2020	2022	2023	2026	1984												*									
$BRECT_{07}$	1006	1009	1005	1013	988											*	*									
$BVULN_{07}$	623	624	622	625	609											*	*									
$UNSL_{02}$	4.5%	4.5%	4.4%	4.4%	4.5%									*	*	*										
USL_{02}	26.5%	26.6%	26.4%	26.3%	26.8%									*	*	*										
$UNSL_{06}$	5.2%	5.1%	5.0%	5.0%	5.2%										*											
USL_{06}	32.2%	31.6%	31.5%	31.5%	32.6%										*	*										
$BVULN_{02}/BVULN_{79-88}$	155%	155%	154%	155%	155%										*											
$BVULN_{07}/BVULN_{02}$	104%	105%	104%	104%	103%																					
$BVULN_{07}/BVULN_{79-88}$	163%	165%	162%	163%	162%																					

Table 21: Means and convergence diagnostics for each of several indicators for each part of the McMC chain from the sensitivity on using different recreational catch trajectories for CRA 2 (* indicates the test failed).

Quantity	Posterior means					Convergence statistic																				
						Raftery and Lewis					Geweke					Heidelberger and Welsh					Single chain Gelman					Brooks Gelman Rubin
Chain #	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
Indicators	mean	mean	mean	mean	mean																					
$BALL_{79-88}$	1702	1701	1703	1700	1688								*		*					*					*	
$BRECT_{79-88}$	604	604	604	604	598										*					*					*	
$BVULN_{79-88}$	441	441	441	441	436										*					*					*	
$BALL_{02}$	2294	2304	2294	2305	2283								*		*					*						
$BRECT_{02}$	1199	1203	1196	1201	1185								*		*					*					*	
$BVULN_{02}$	650	652	646	649	643								*		*					*						
$BALL_{07}$	2162	2222	2229	2204	2198								*													
$BRECT_{07}$	1009	1056	1053	1047	1034								*													
$BVULN_{07}$	600	633	631	624	619								*													
$UNSL_{02}$	4.0%	4.0%	4.1%	4.0%	4.1%								*		*					*					*	
USL_{02}	25.0%	24.9%	25.1%	25.0%	25.3%								*		*					*						
$UNSL_{08}$	5.0%	4.9%	4.8%	4.8%	5.0%										*					*						
USL_{08}	32.4%	31.6%	31.0%	31.0%	33.0%										*					*						
$BVULN_{02}/BVULN_{79-88}$	147%	148%	147%	147%	148%																					
$BVULN_{07}/BVULN_{02}$	91%	96%	96%	95%	94%								*													
$BVULN_{07}/BVULN_{79-88}$	136%	144%	143%	142%	142%								*													

FIGURES

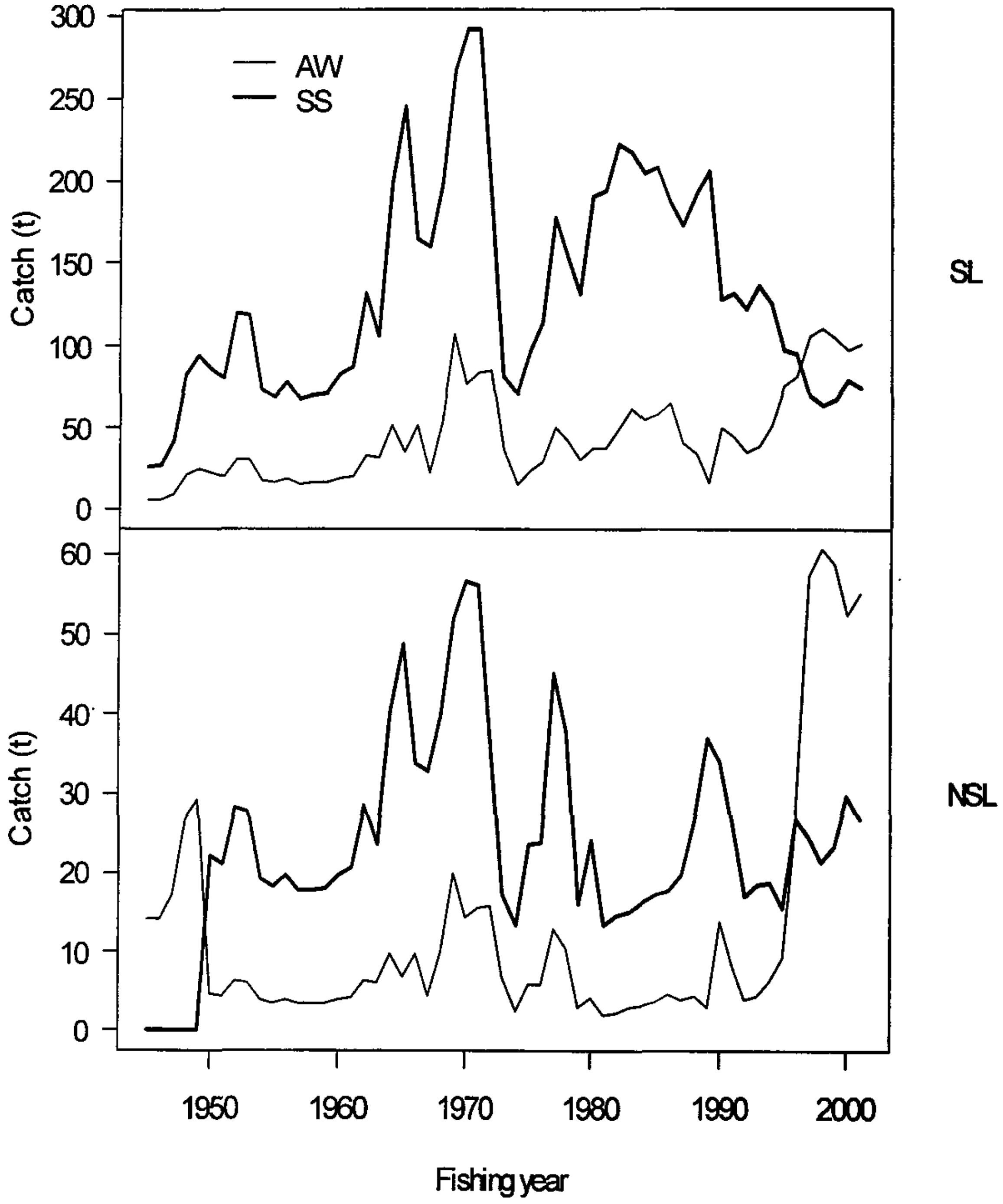


Figure 1: CRA 1: SL and NSL catch by season. SL catch is that taken with respect to the size limit and protection on berried females (commercial and recreational catches).

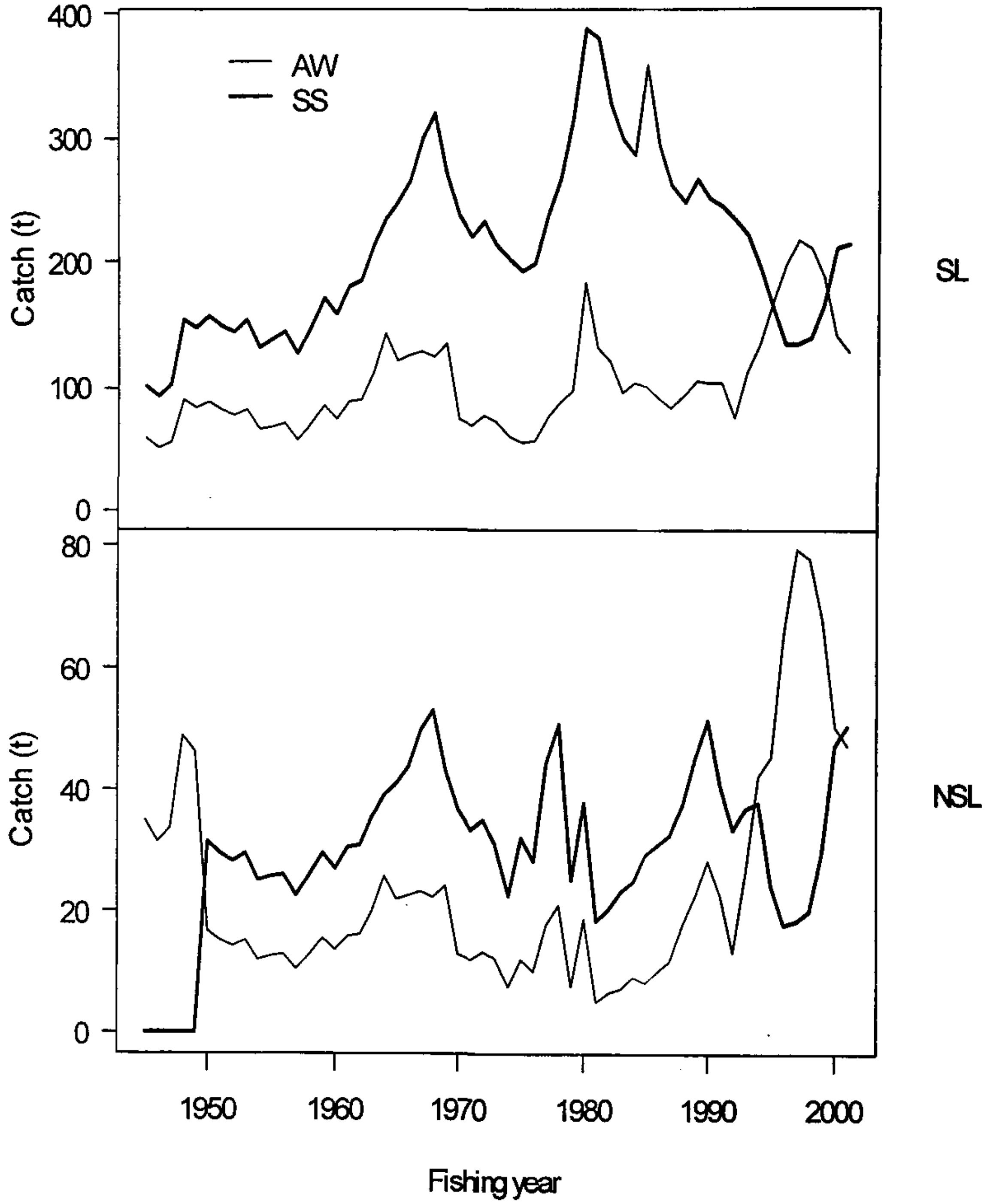


Figure 2: CRA2: SL and NSL catch by season.

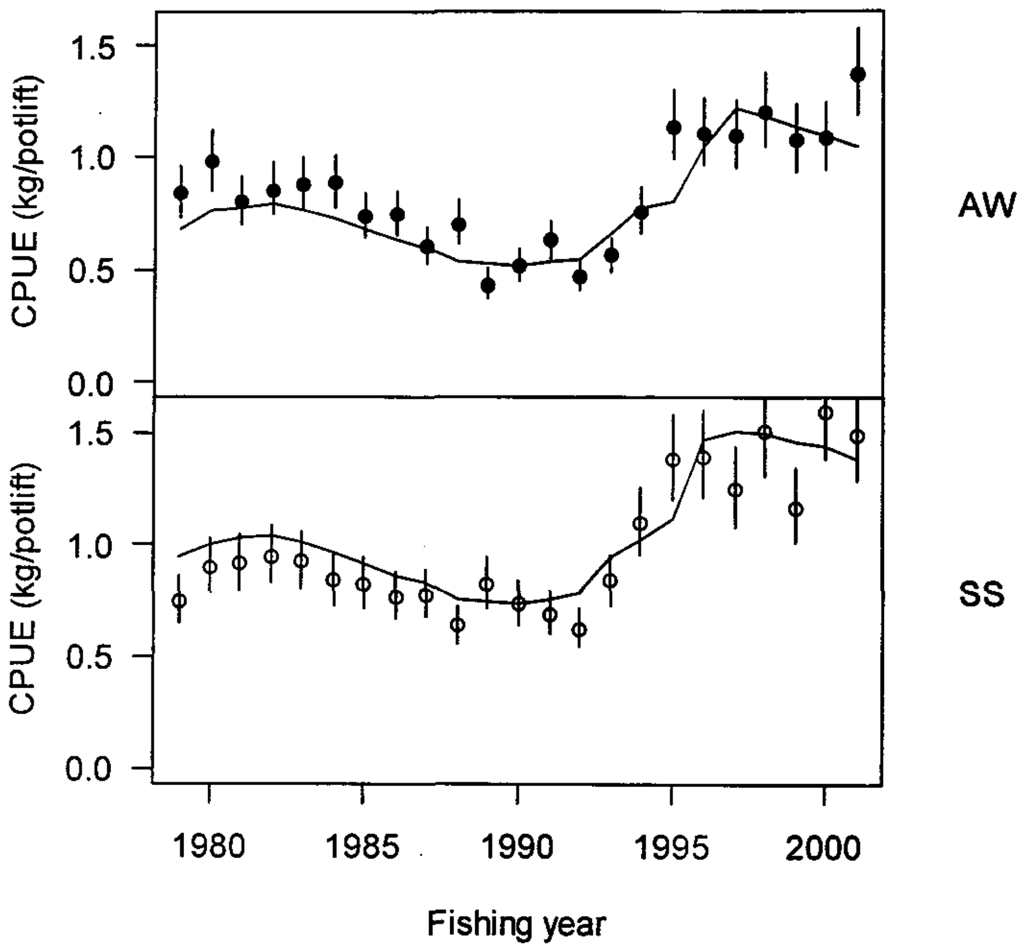


Figure 3: CRA 1: predicted (line) and observed (circles with one standard error) standardised CPUE index by season from the base case MPD results: upper, autumn-winter (AW) season; lower, spring-summer (SS) season.

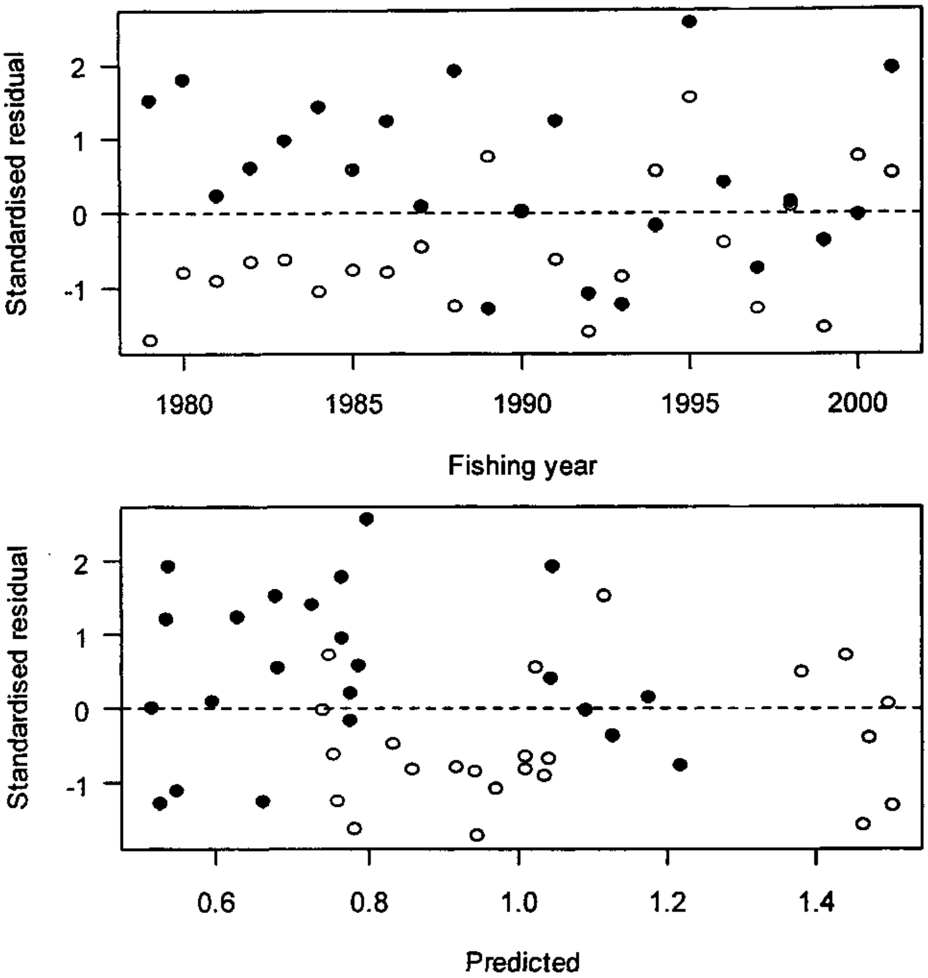


Figure 4: CRA 1: standardised residuals of predicted CPUE index from the base case MPD results, plotted by fishing year [upper panel] and by predicted CPUE index [lower panel]. Closed circles, autumn-winter (AW) season; open circles, spring-summer (SS) season.

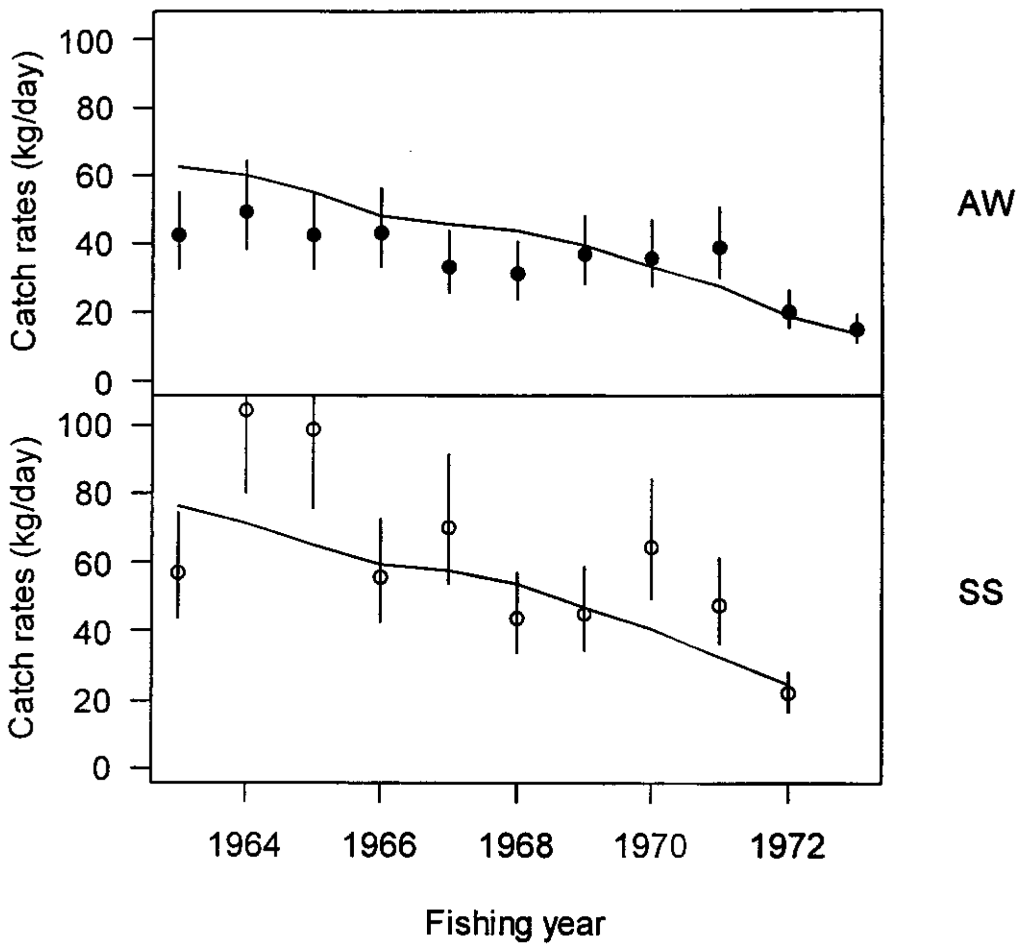


Figure 5: CRA 1: predicted (solid line) and observed (circles with one standard error) catch rate (CR) by season from the base case MPD results: upper, autumn-winter (AW) season, lower, spring-summer (SS) season.

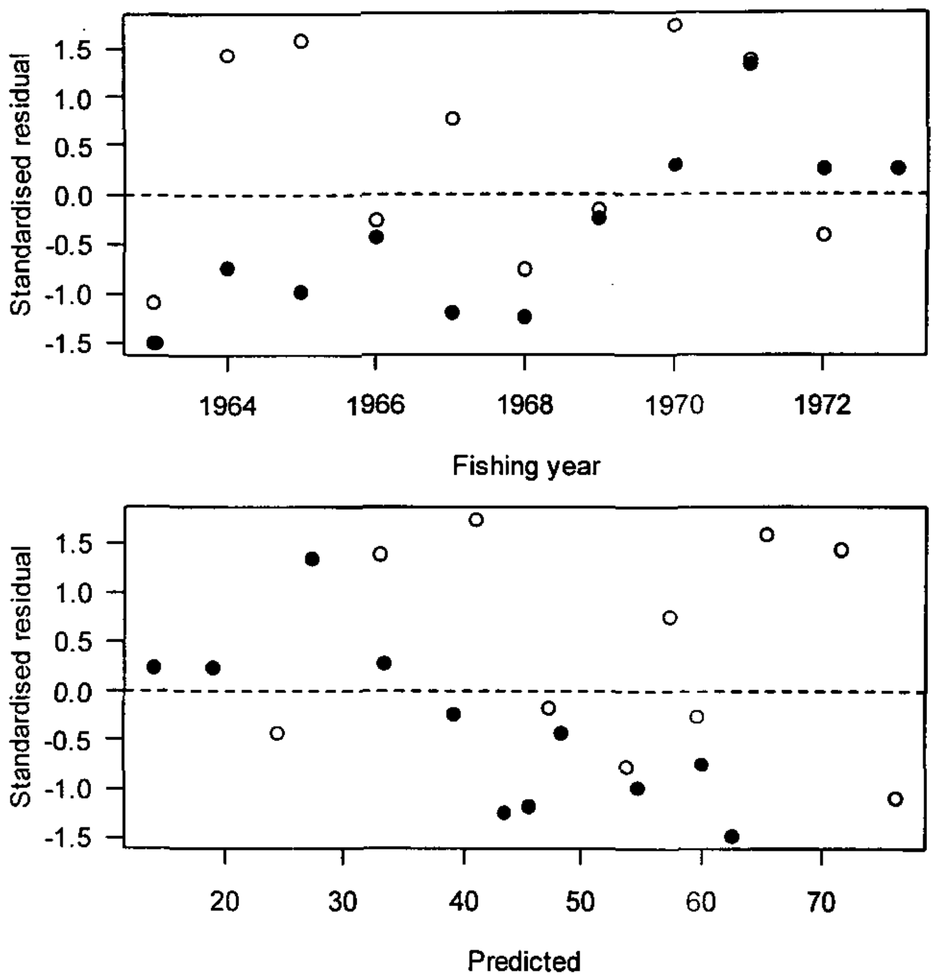


Figure 6: ***CRA 1:*** **standardised residuals of catch rate from the base case MPD results, plotted by fishing year [upper panel] and by predicted catch rate [lower panel]. Closed circles, autumn-winter (AW) season; open circles, spring-summer (SS) season.**

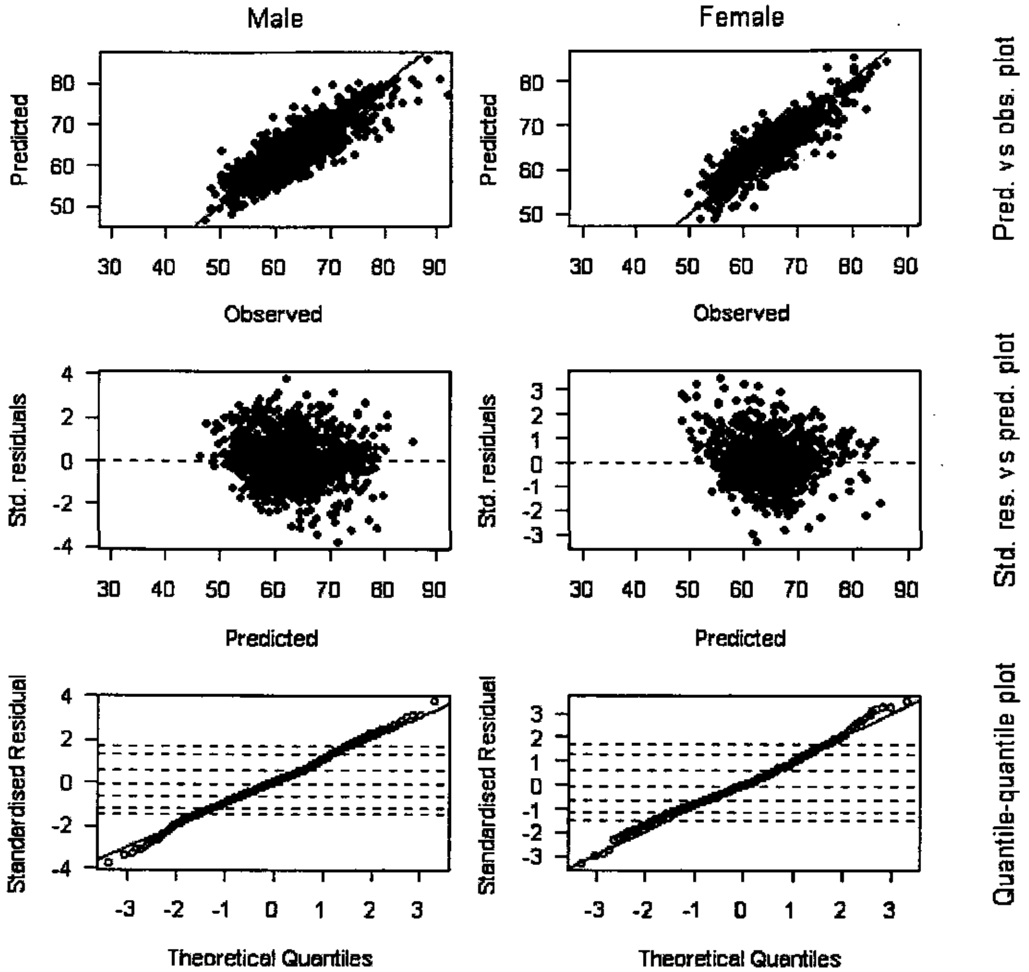


Figure 7: CRA 1: predicted and observed size at recapture from the base case model MPD fit from the tagging data (top panels); standardised residuals versus predicted size at recapture (middle panels); Q-Q plots of the standardised residuals (bottom panels). For all plots left panels are males and right panels are females.

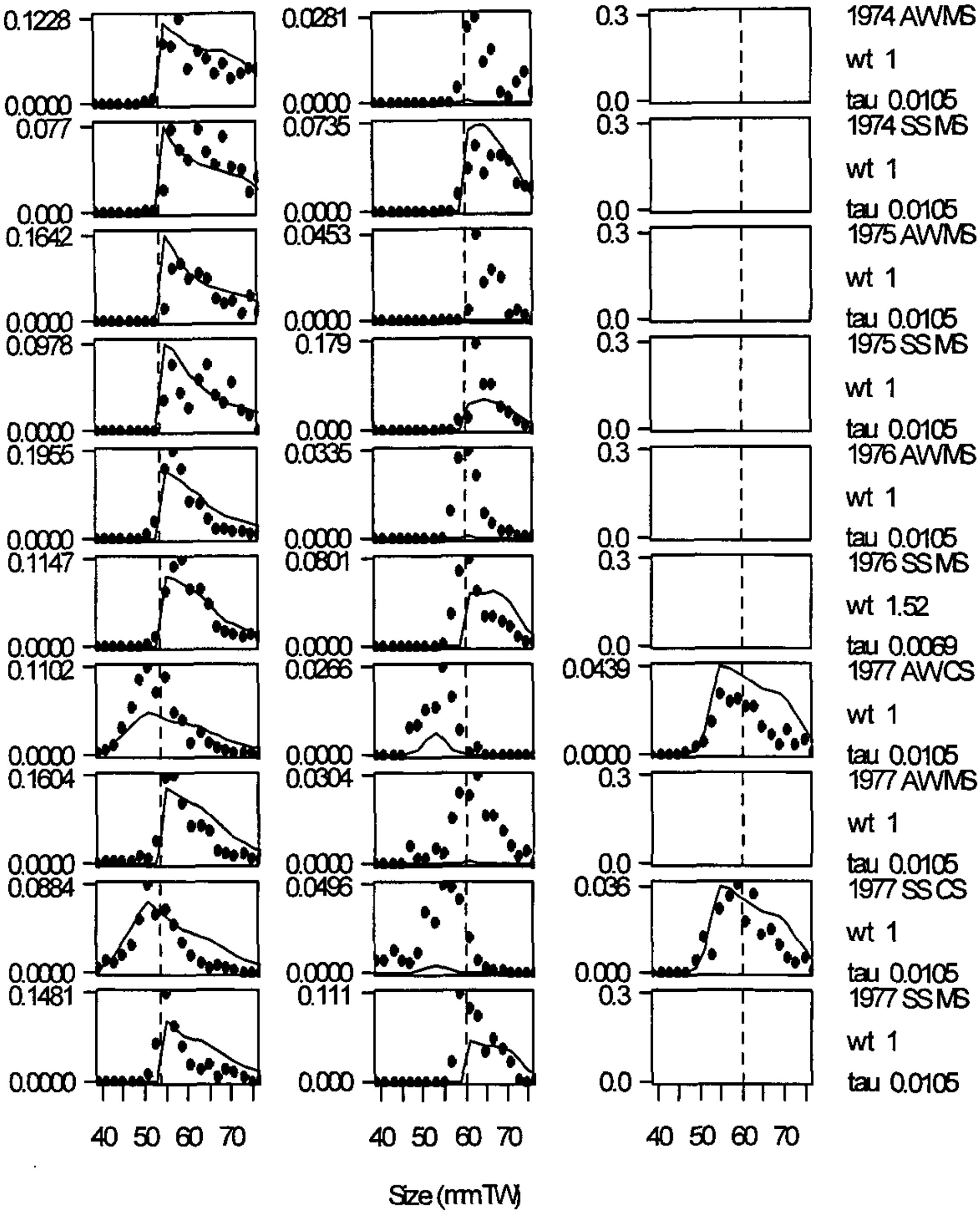


Figure 8: CRA 1: the base case MPD fit to the proportion-at-length data, plotted by year and season (AW, autumn-winter; SS, spring-summer), sex category, and data source type. The left column shows males, the centre immature females, and the right mature females. LB, log book data; CS, catch sampling data; HS, historical data; MS, market sampling data; wt ($=\kappa_t$), relative weight given to each data set; tau ($=\kappa_t\tilde{\sigma}/\varpi^p$), scaling factor relative to sigma. For HS and MS data, where females were not graded by maturity, the centre column is all females. The dotted vertical line is the current summer MLS.

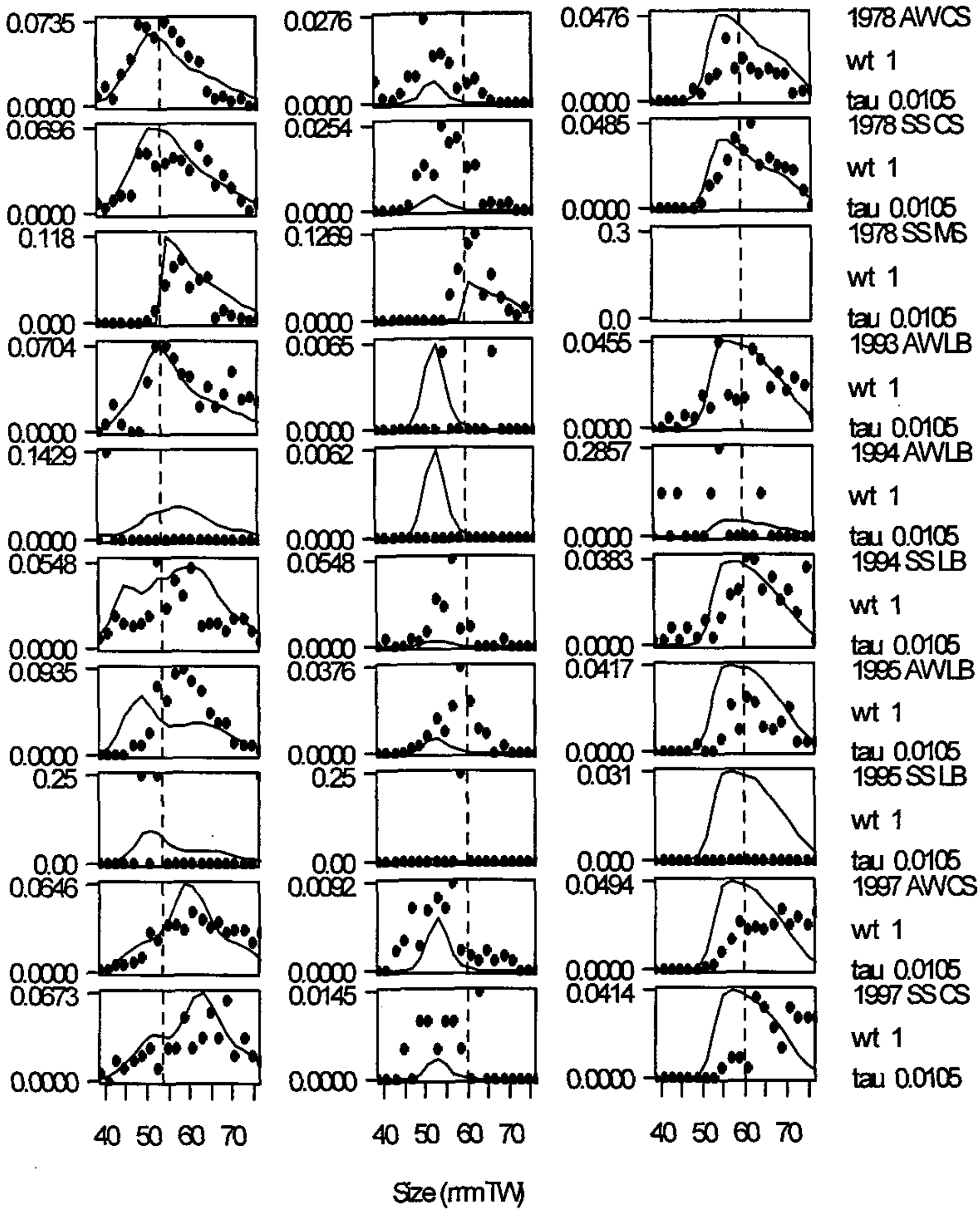


Figure 8: continued.

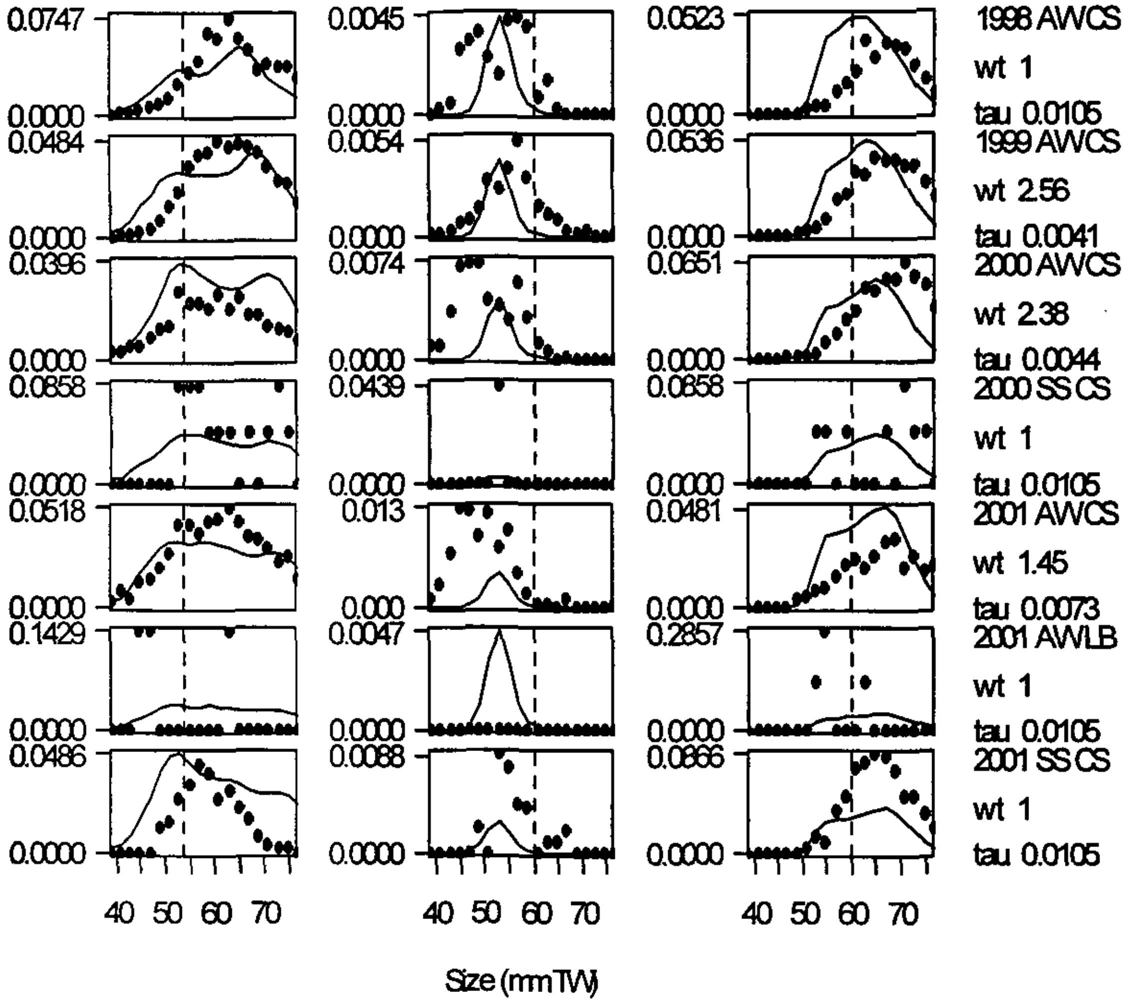


Figure 8: continued.

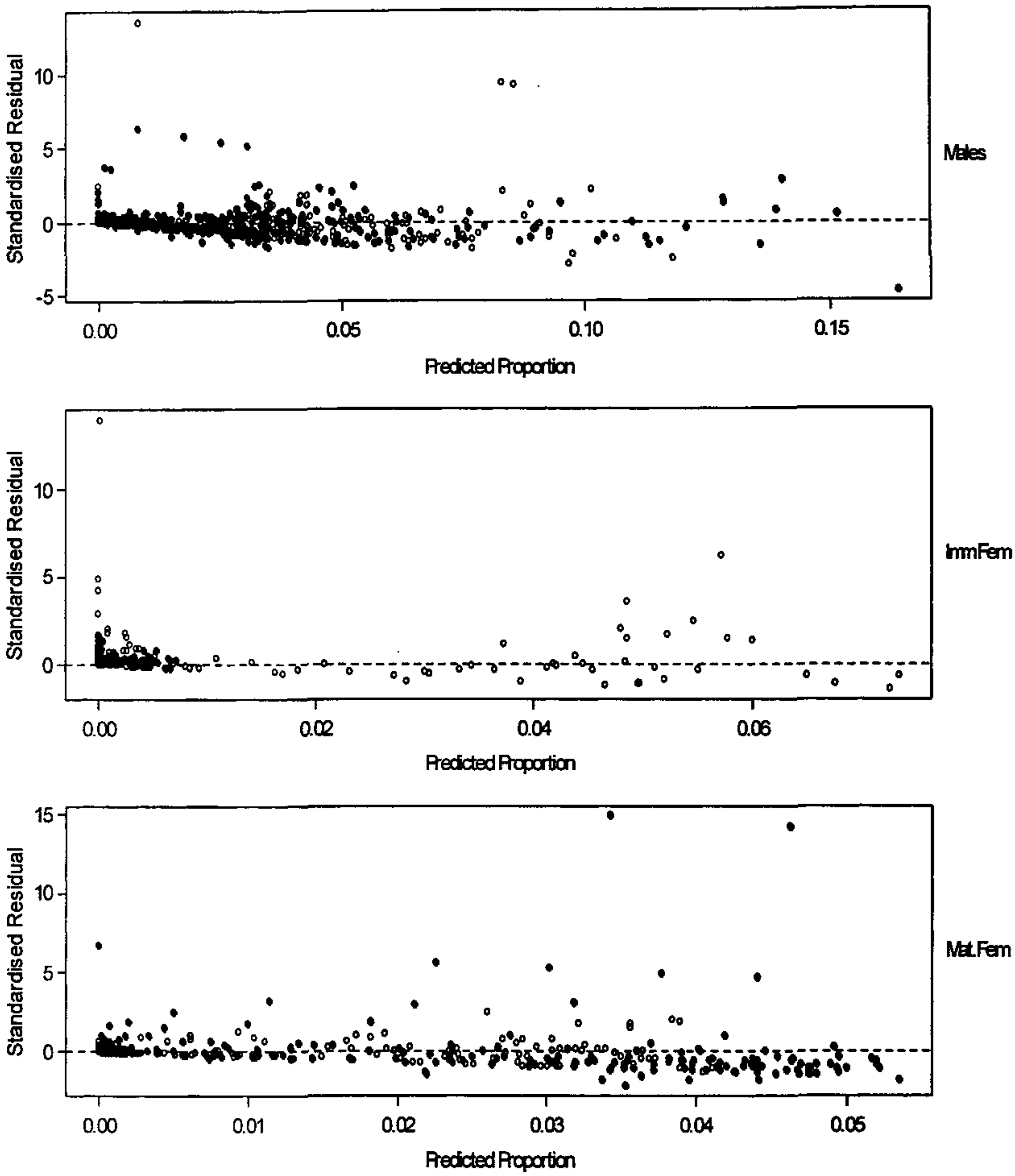


Figure 9: CRA 1: standardised residuals from the fits to proportions-at-length (Figure 8), plotted against predicted proportions-at-length for the three sex categories indicated.

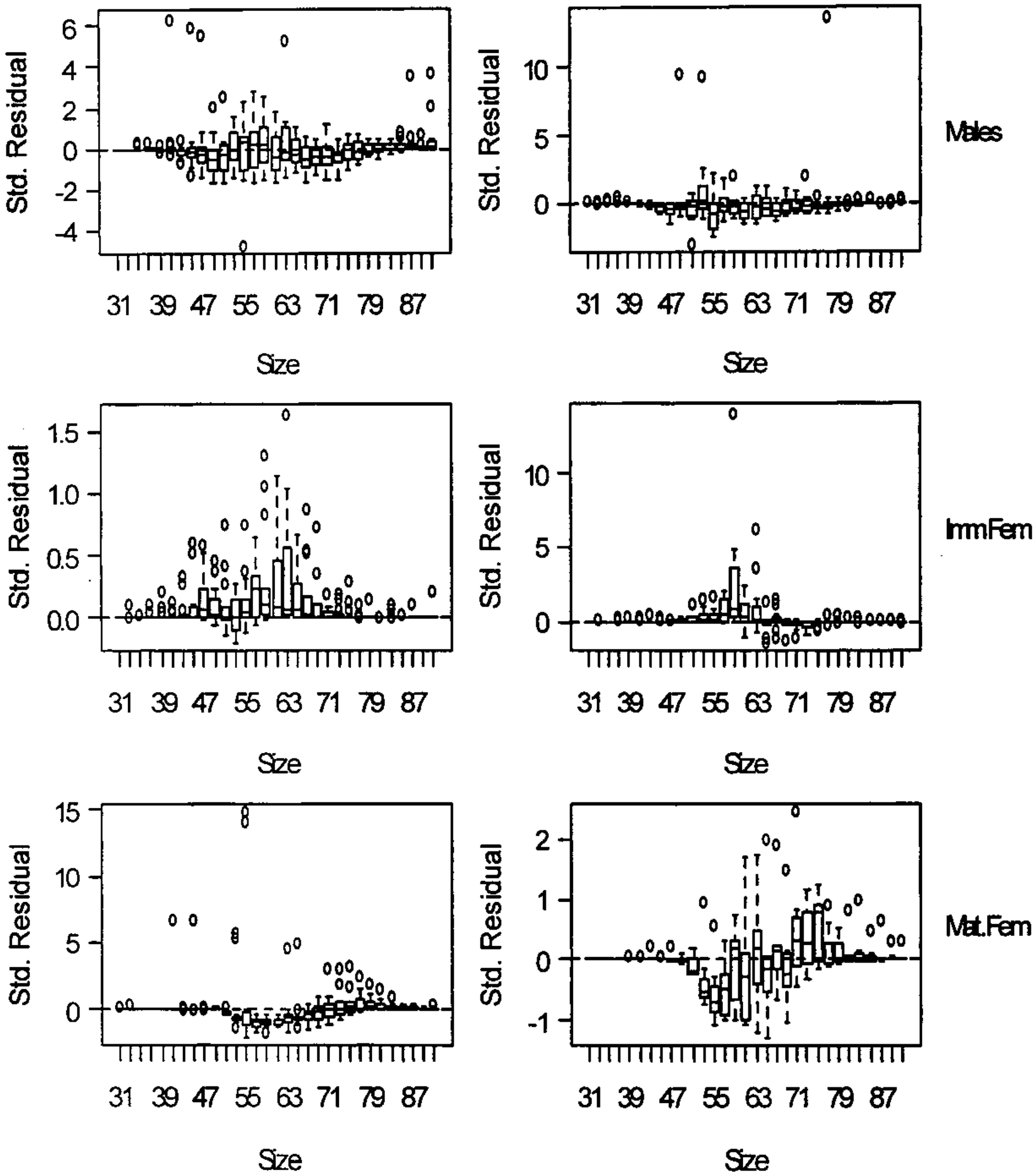


Figure 10: CRA 1: **standardised residuals from the fits to proportions-at-length (Figure 8), plotted against length and by season for the three sex categories indicated. Left panels are the autumn-winter season and the right panels for the spring-summer season. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.**

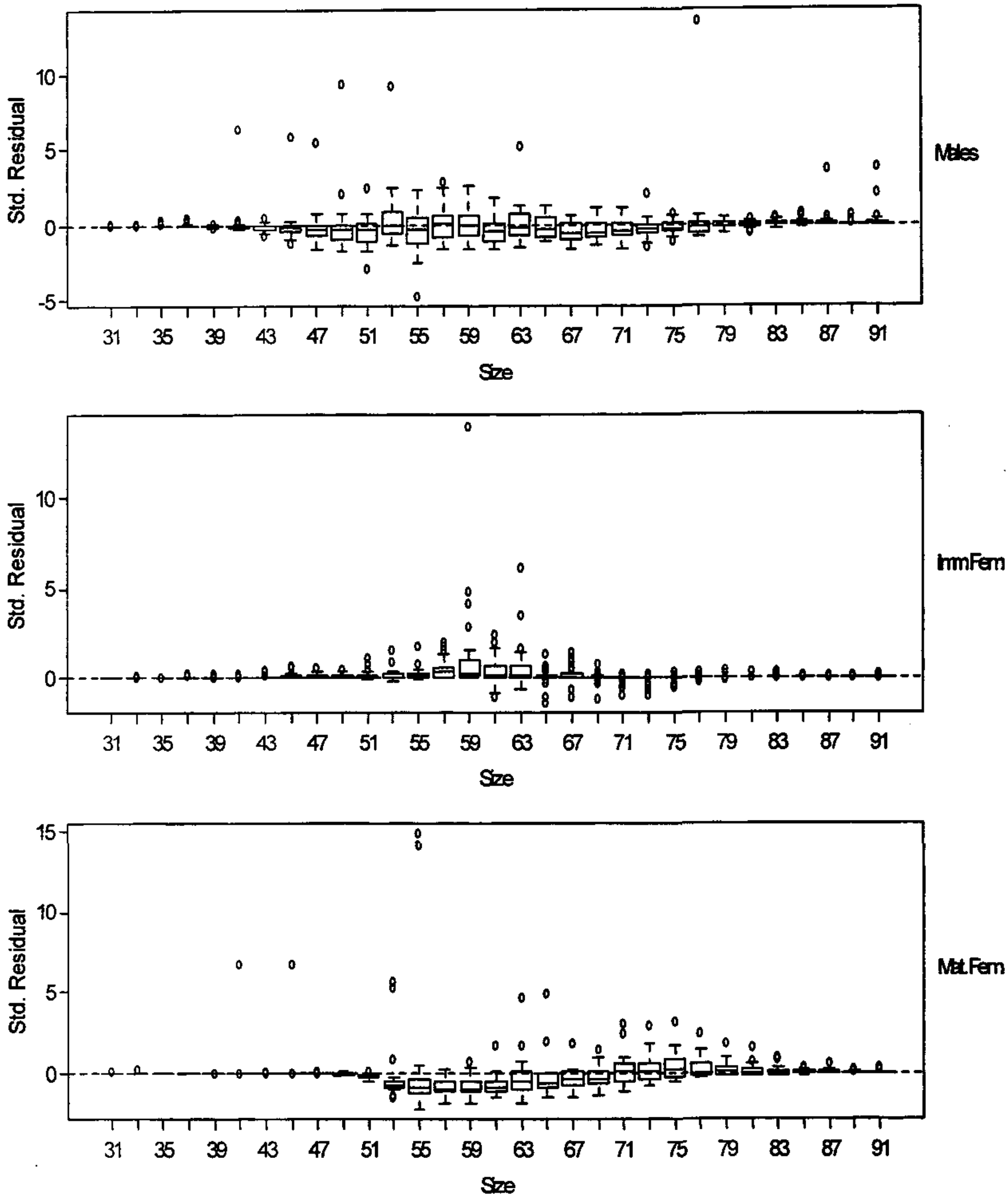


Figure 11: CRA 1: standardised residuals from the fits to proportions-at-length (Figure 8), plotted against length for the three sex categories indicated. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.

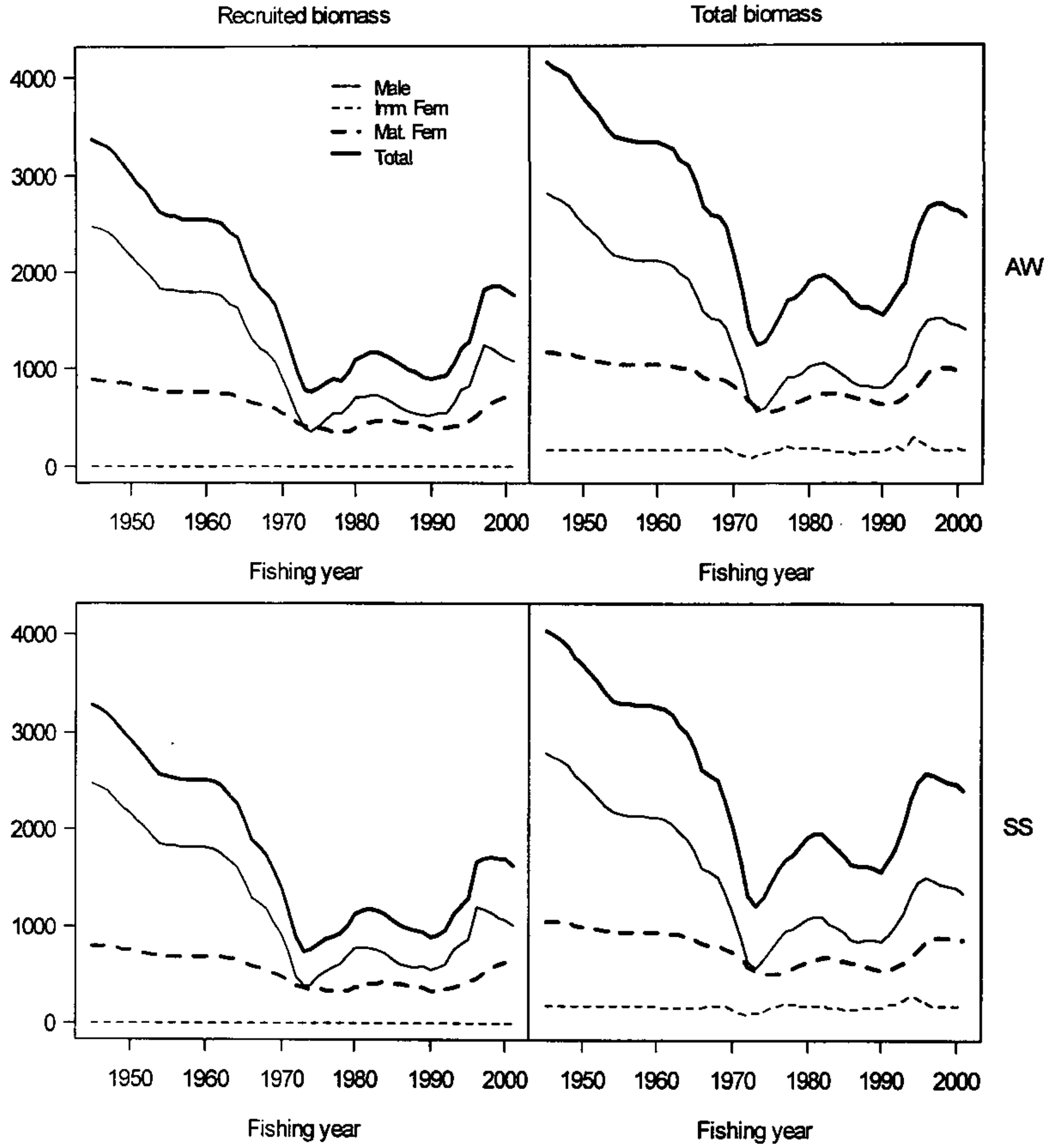


Figure 12: CRA 1: recruited (left panels) and total biomass (right panels) from the MPD fit by sex (as indicated in the legend) and season: upper panels, autumn-winter season; lower panels, spring-summer season.

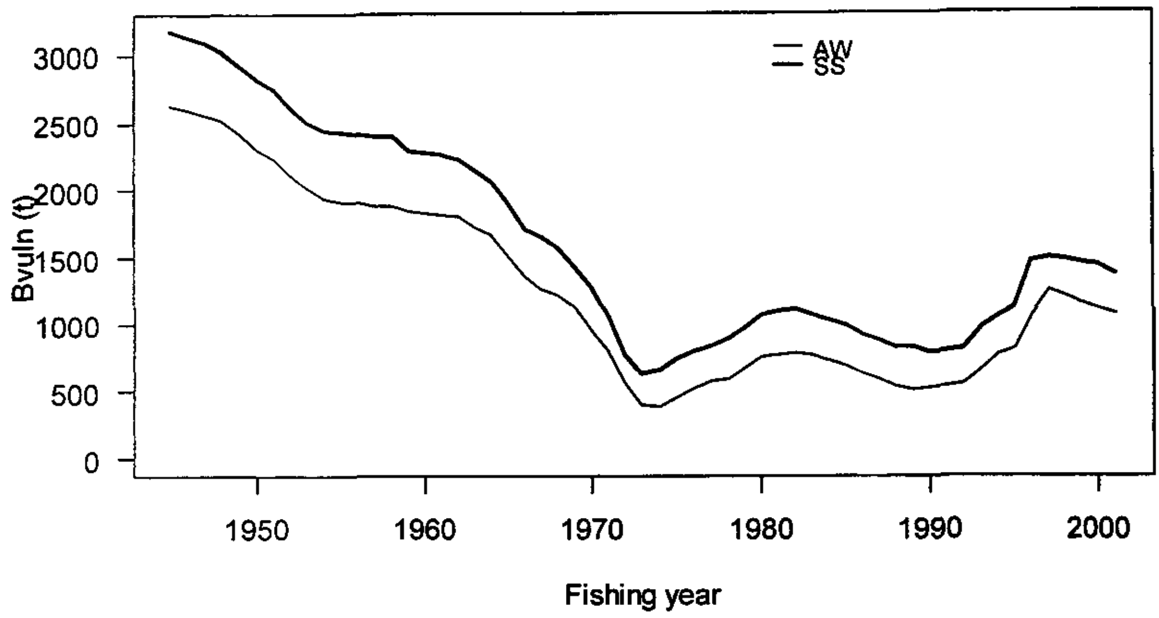


Figure 13: CRA 1: the base case model's predicted vulnerable biomass from the MPD fit: heavy line, spring-summer season; light line, autumn-winter season.

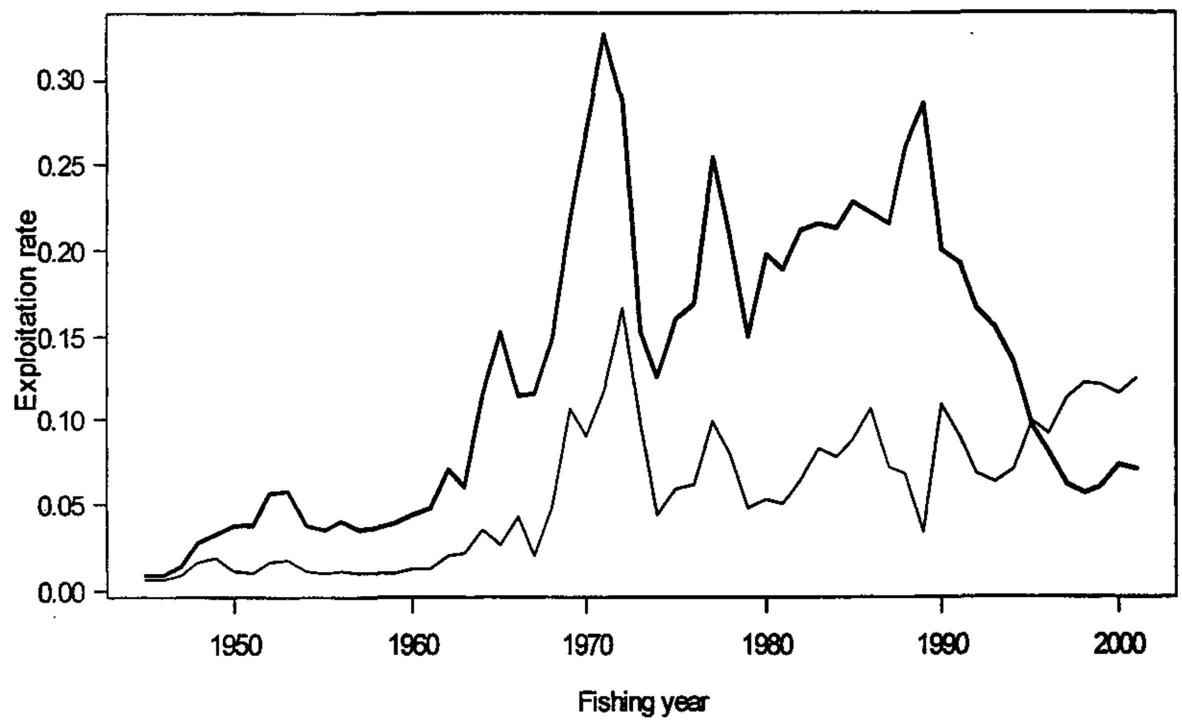


Figure 14: CRA 1: exploitation rate trajectories from the base case model MPD fit: heavy line, spring-summer season; light line, autumn-winter season.

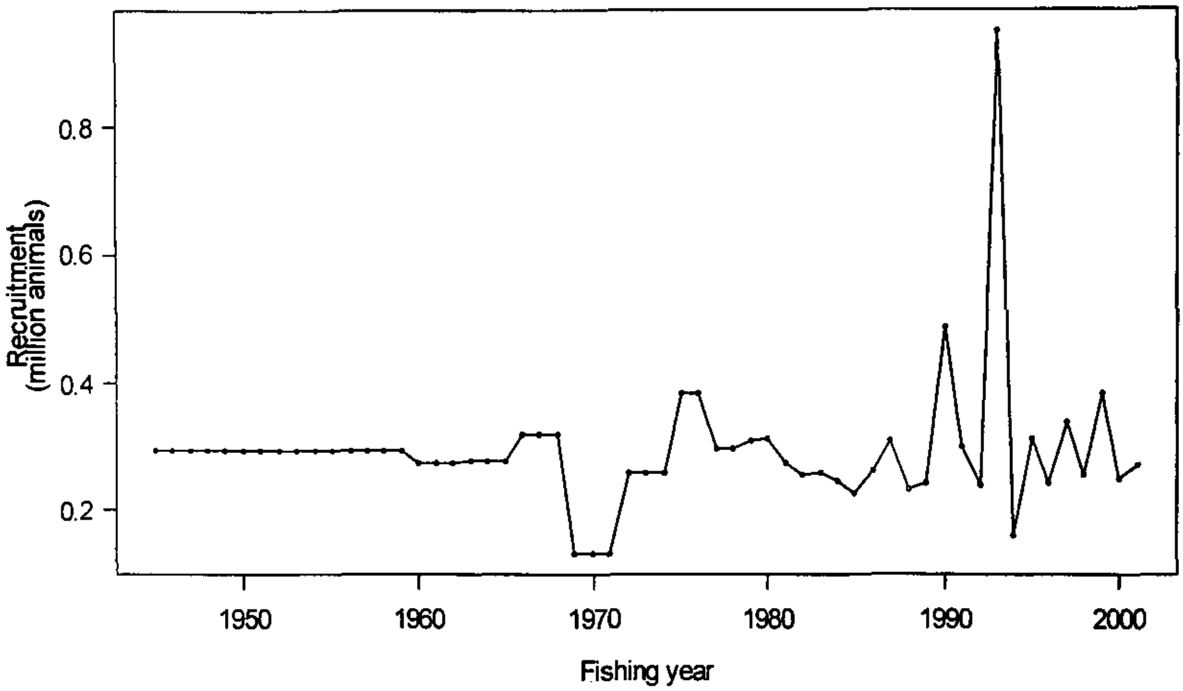
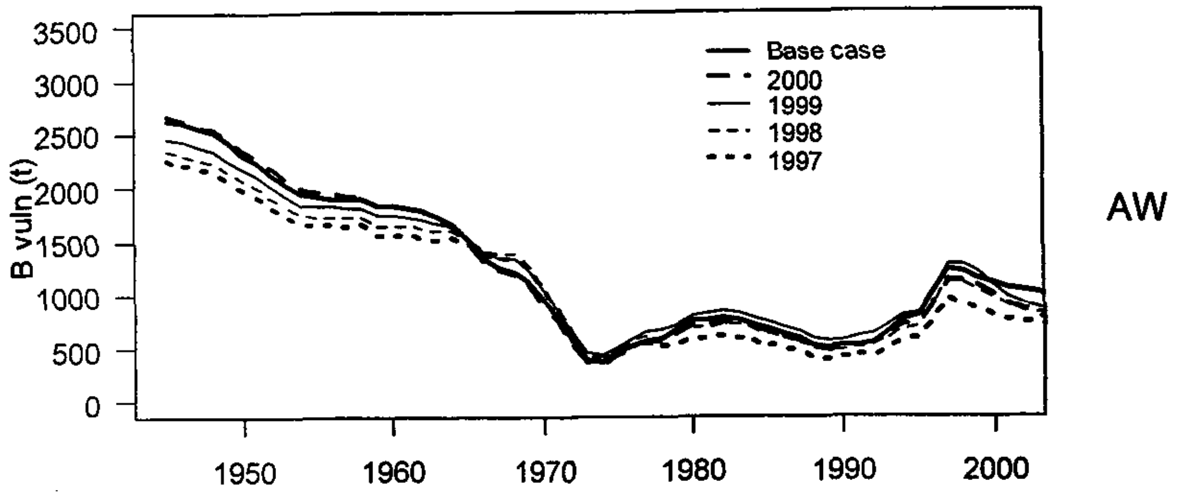


Figure 15: CRA 1: recruitment trajectory (millions) from the base case model MPD fit.



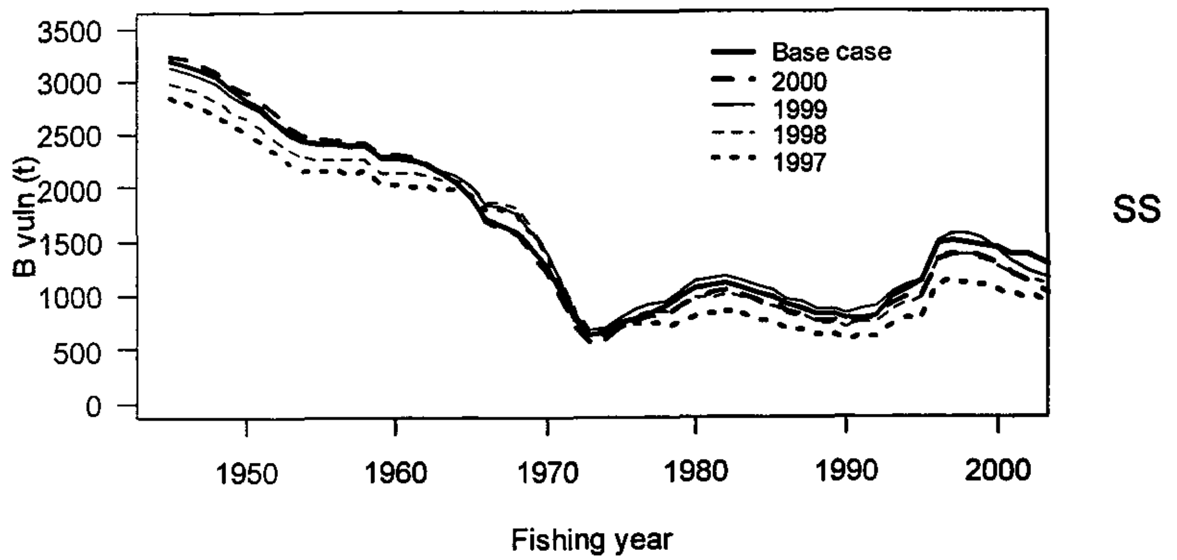


Figure 16: Vulnerable biomass trajectories from the MPD retrospectives for CRA 1, plotted by season; upper panel - SS, lower panel - AW. Each line connects the predicted biomass for each year in the MPD fit. Data sets are named by the last year of data they were fit to.

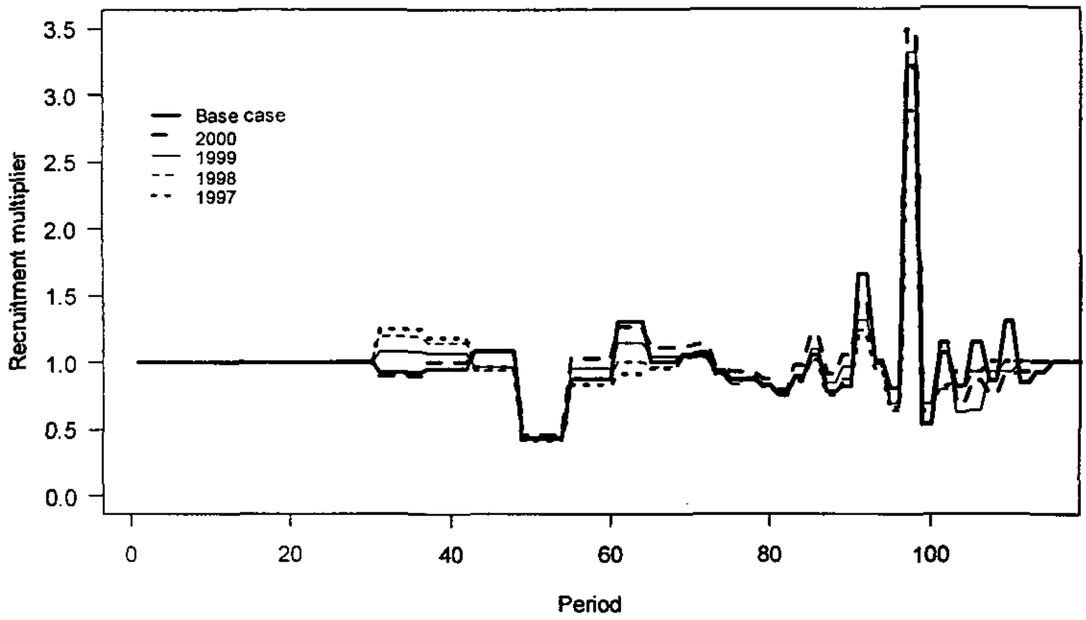


Figure 17: Estimated recruitment multipliers from the MPD retrospectives for CRA 1. Each line connects the predicted recruitment for each year in the MPD fit. Data sets are named by the last year of data they were fitted to.

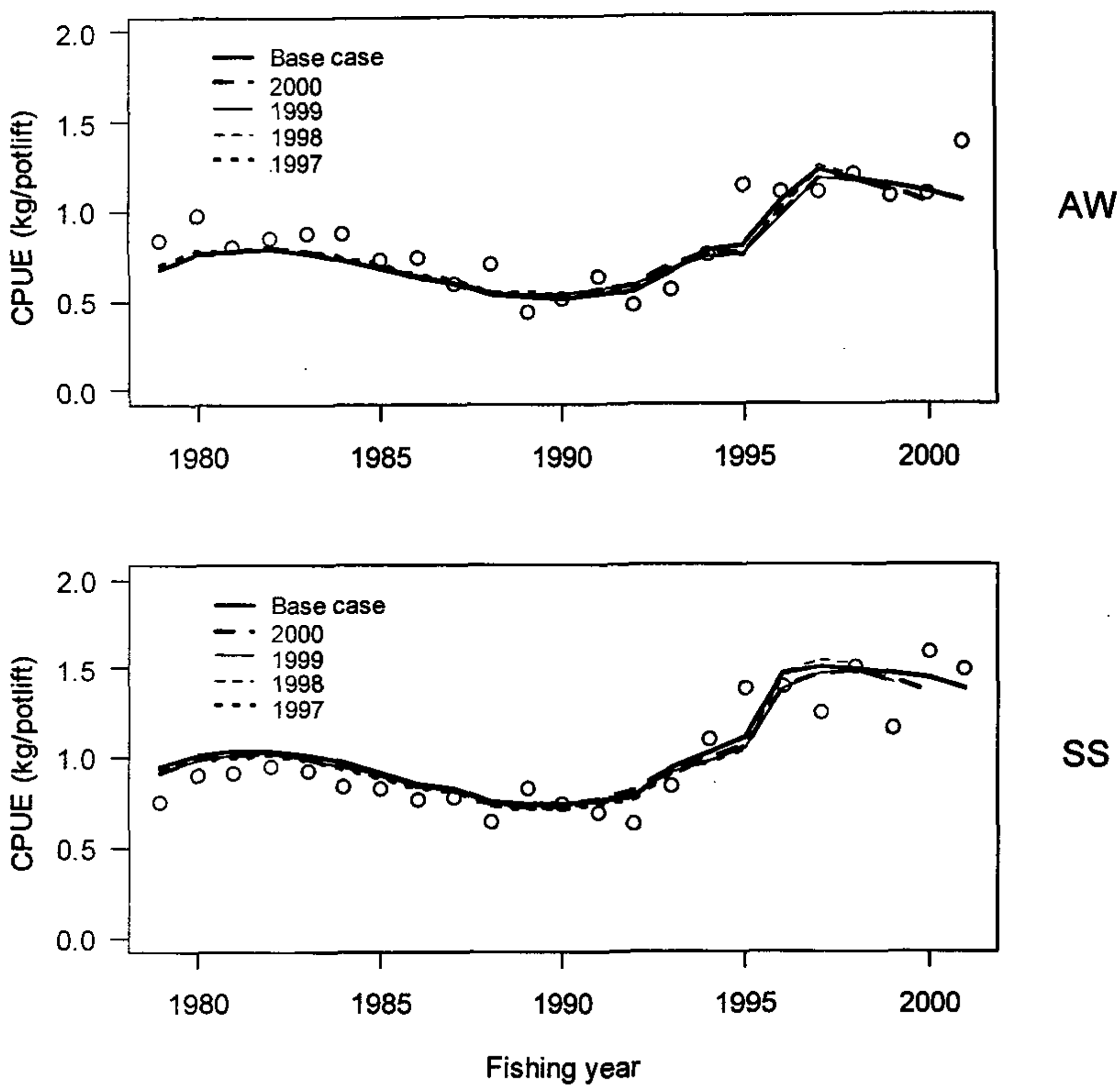


Figure 18: CPUE trajectories **from the MPD retrospectives for CRA 1, plotted by season; upper panel -** AW, lower panel - SS. **Each line connects the predicted biomass for each year in the MPD fit. Data sets are named** by the last year of data they were fitted to. **Points are the observed CPUE.**

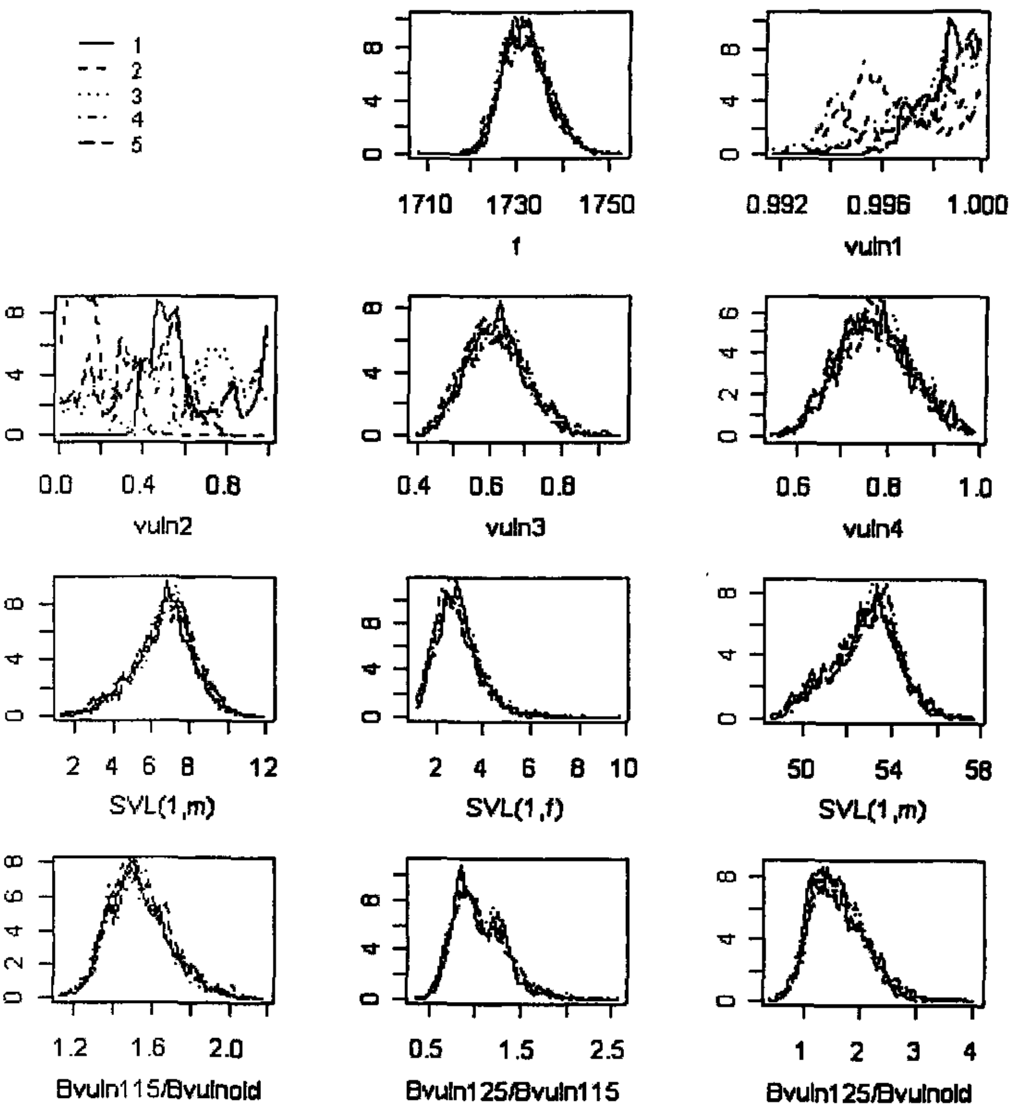


Figure 19: Marginal posterior distributions of some parameters and performance indicators for the CRA 1 base case assessment from each of the five parts of the chain.

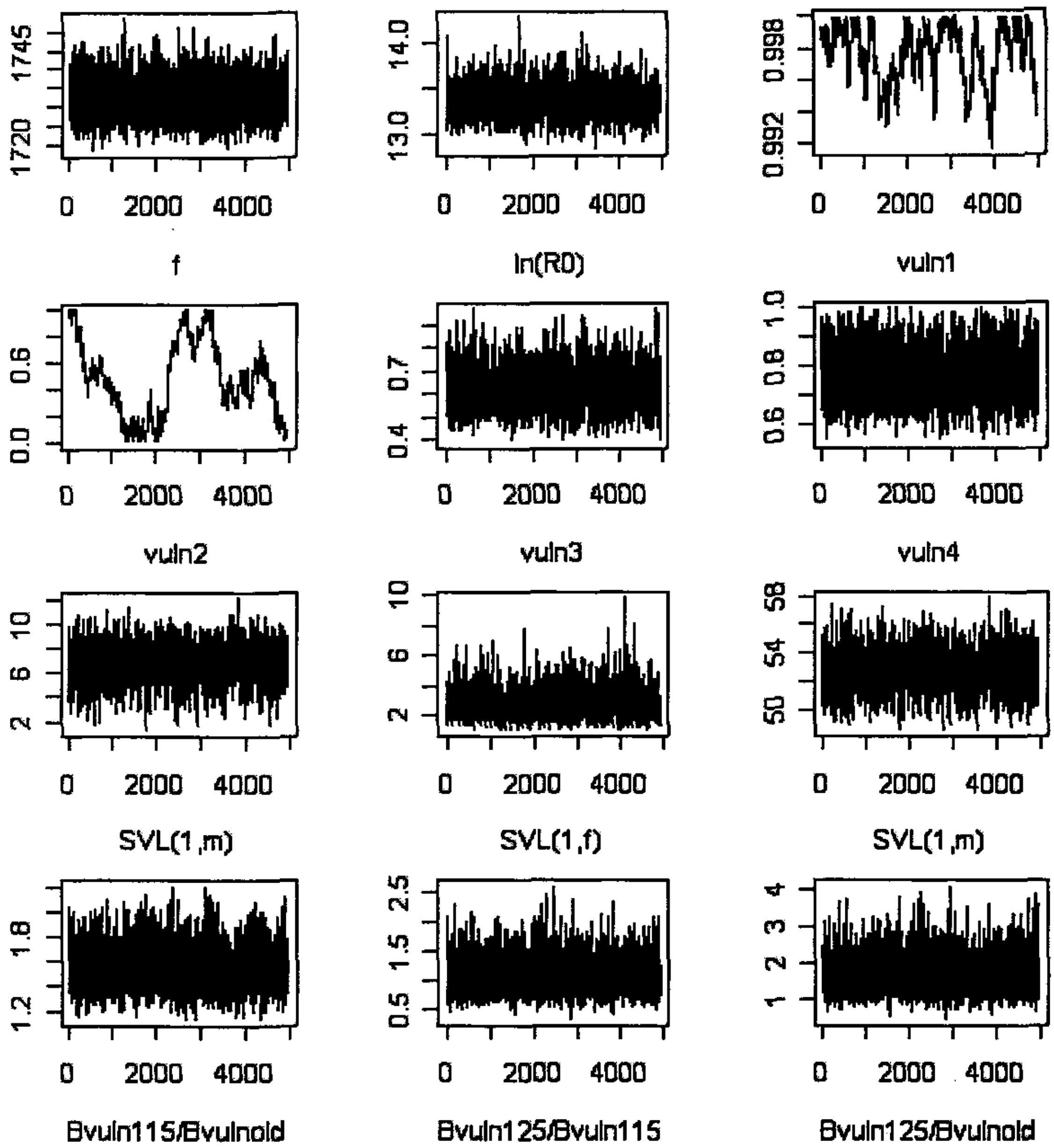


Figure 20: Examples of traces from the base case McMC simulations for the CRA 1 assessment.

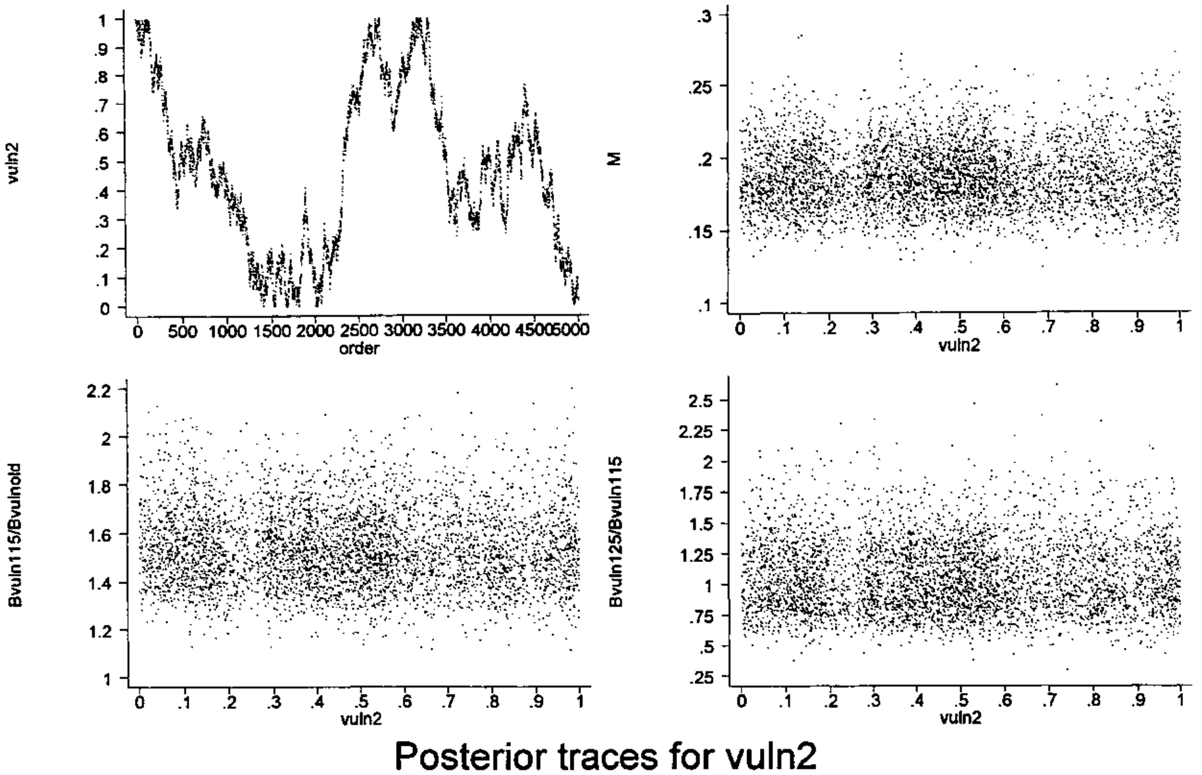


Figure 21: Posterior traces for vuln2 from the CRA 1 base case McMC for CRA 1. The complete posterior trace for vulnest2 is shown in the upper left graph and then concurrent values for vuln2 with *M* and two derived parameters are shown (Bvuln$_{02}$/Bvuln$_{79\text{-}88}$ and Bvuln$_{07}$/Bvuln$_{02}$).

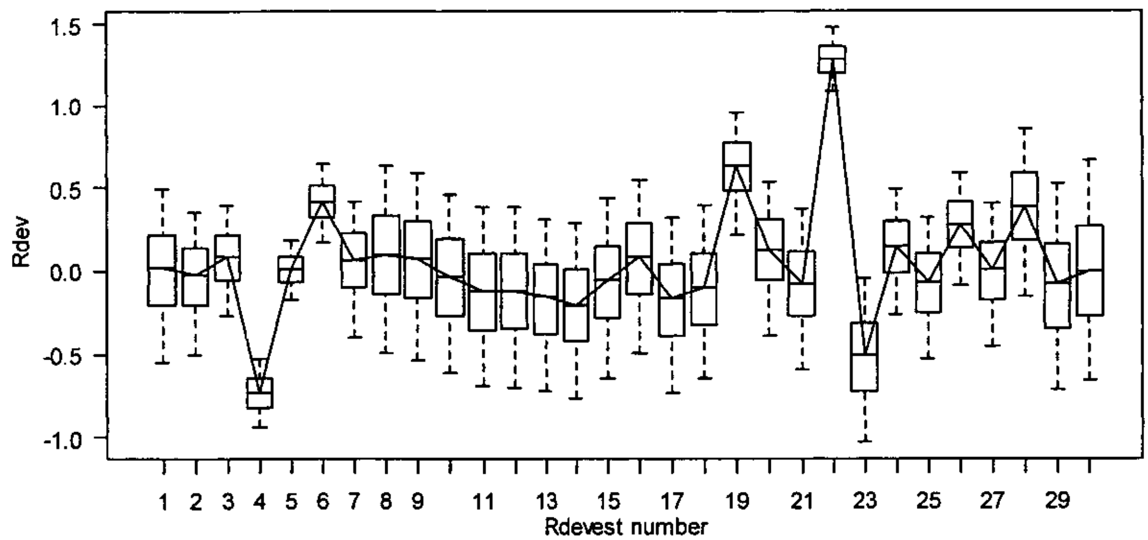
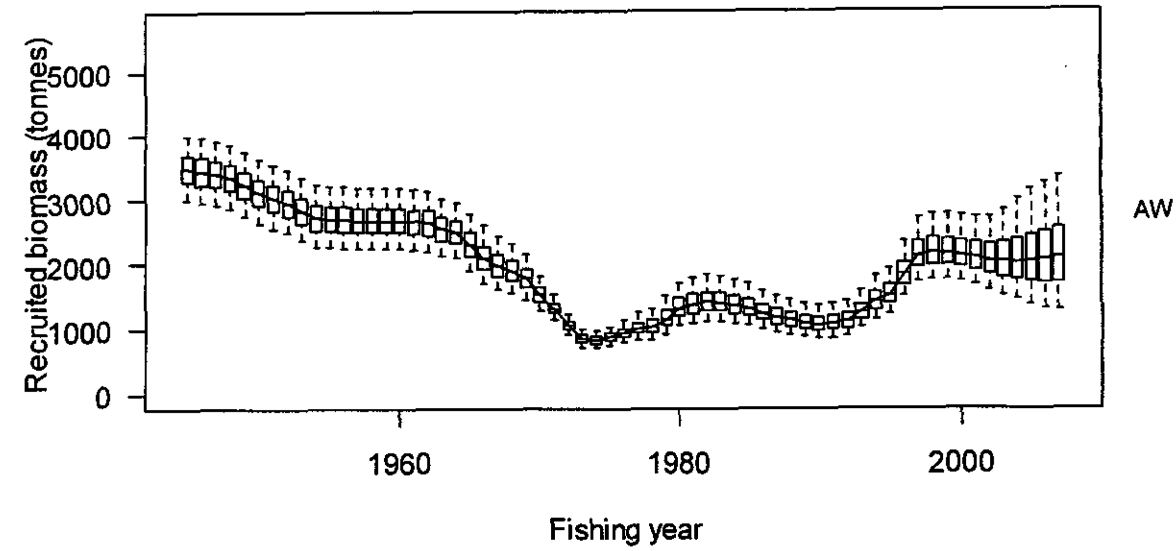


Figure 22: CRA 1: posterior trajectories of recruitment deviations from the base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



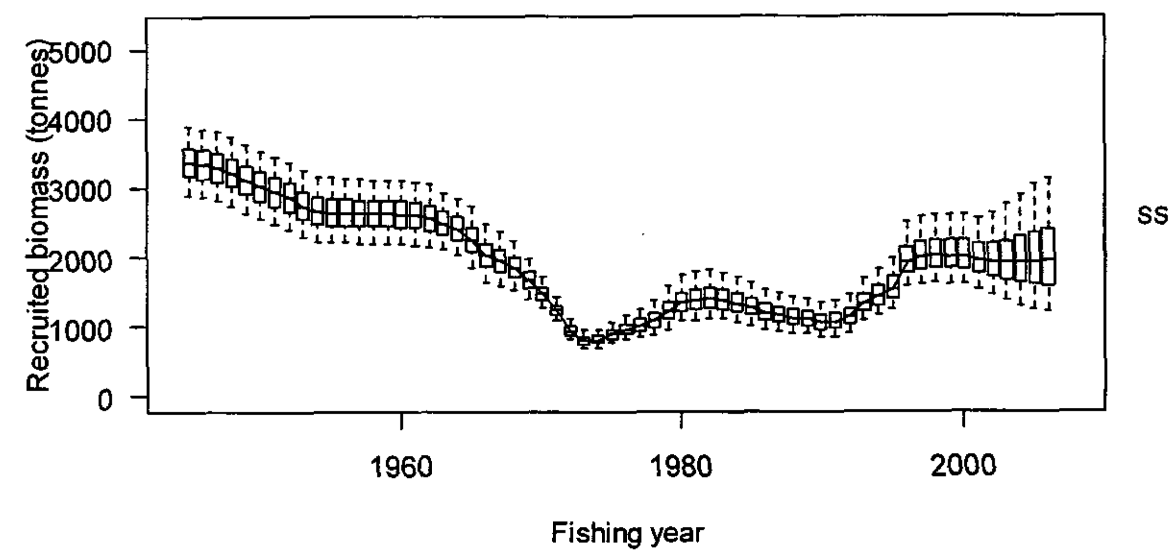


Figure 23: CRA 1: posterior trajectories of recruited biomass, for the AW (top) and SS (bottom) seasons, from the CRA 1 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

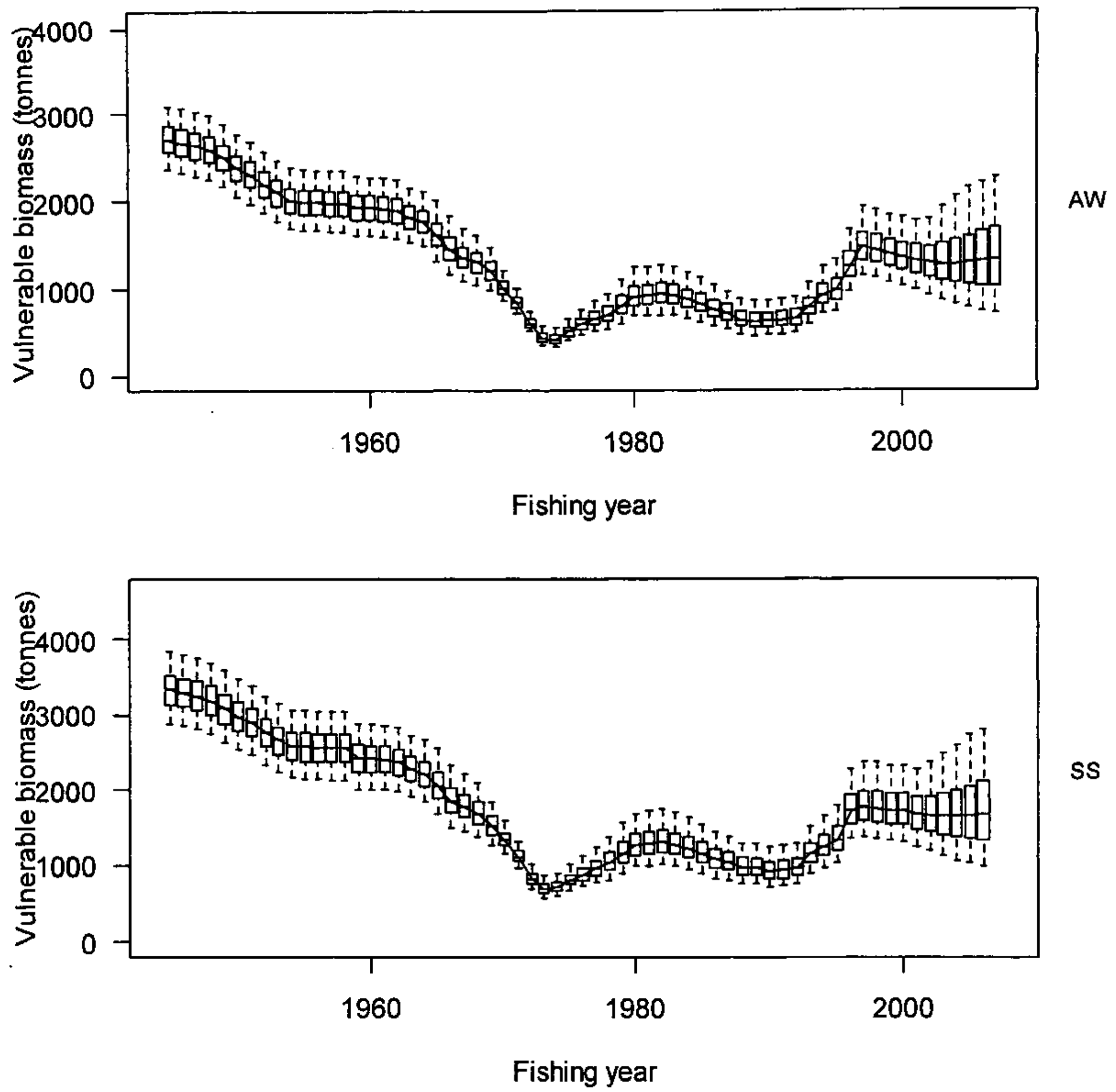


Figure 24: CRA 1: posterior trajectories of vulnerable biomass, for the AW (top) and SS (bottom) seasons, from the CRA 1 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

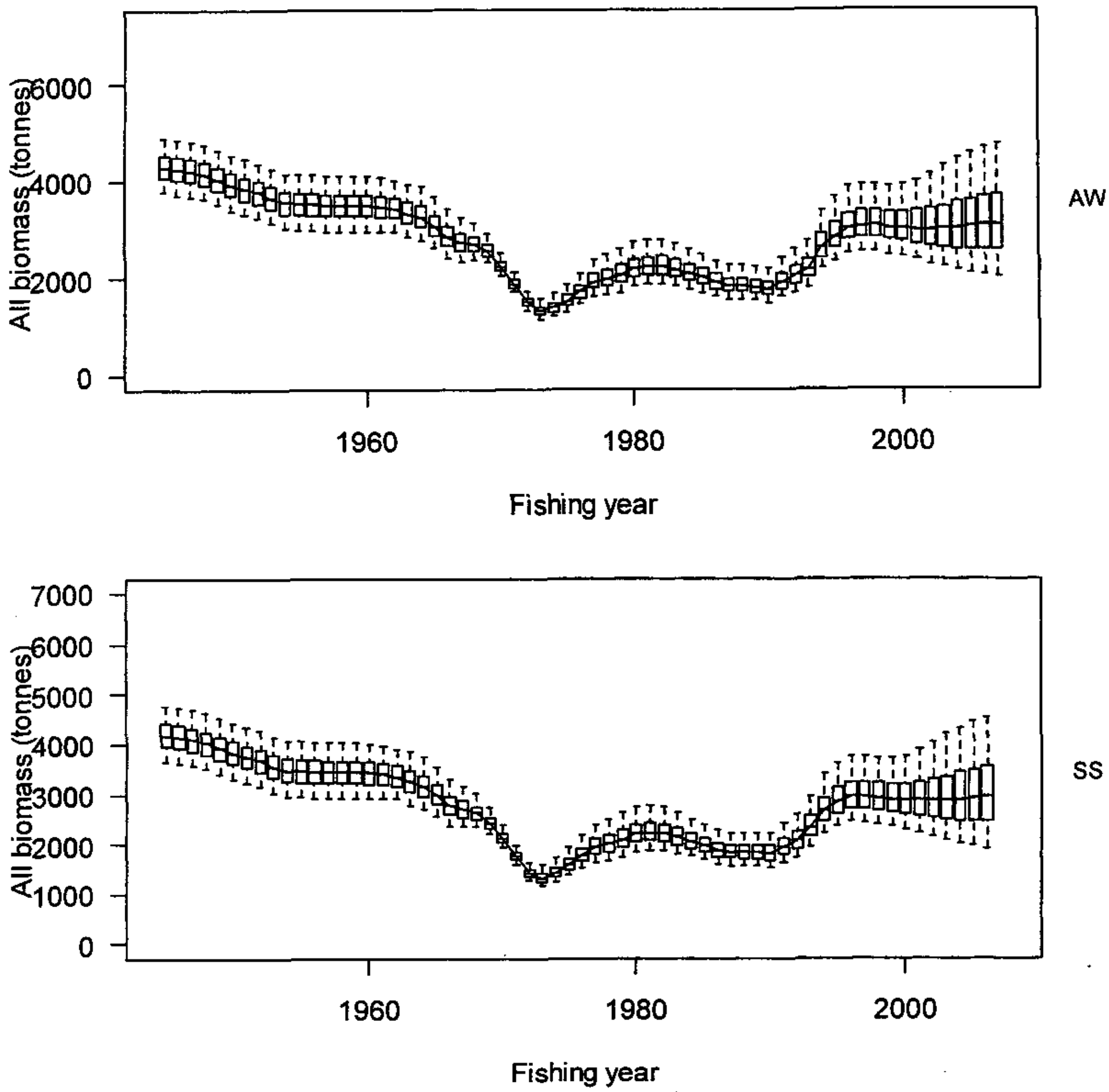


Figure 25: CRA 1: posterior trajectories of total biomass, for the AW (top) and SS (bottom) seasons, from the CRA 1 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

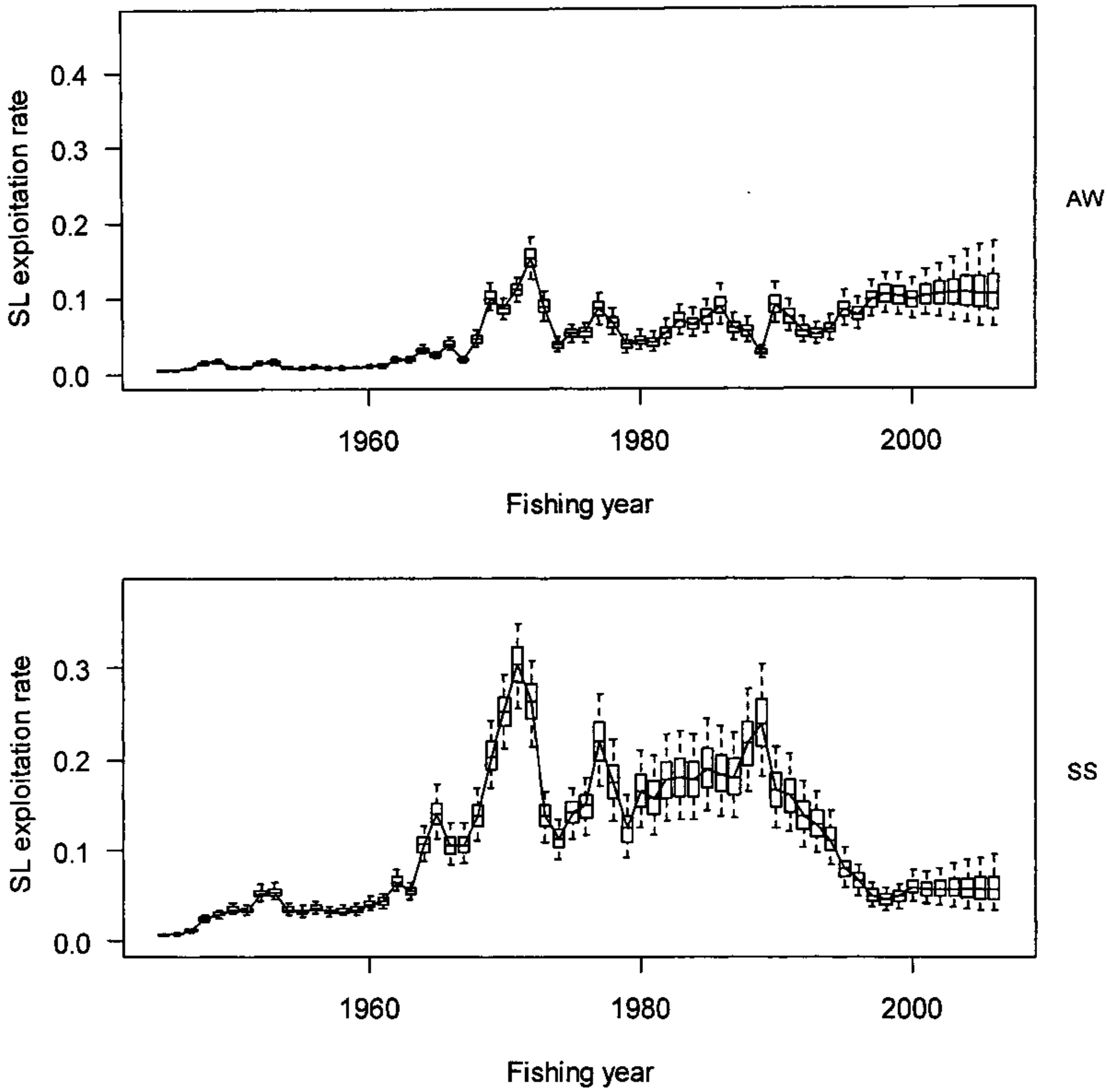


Figure 26: CRA 1: posterior trajectories of SL exploitation rate, for the AW (top) and SS (bottom) seasons, from the CRA 1 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

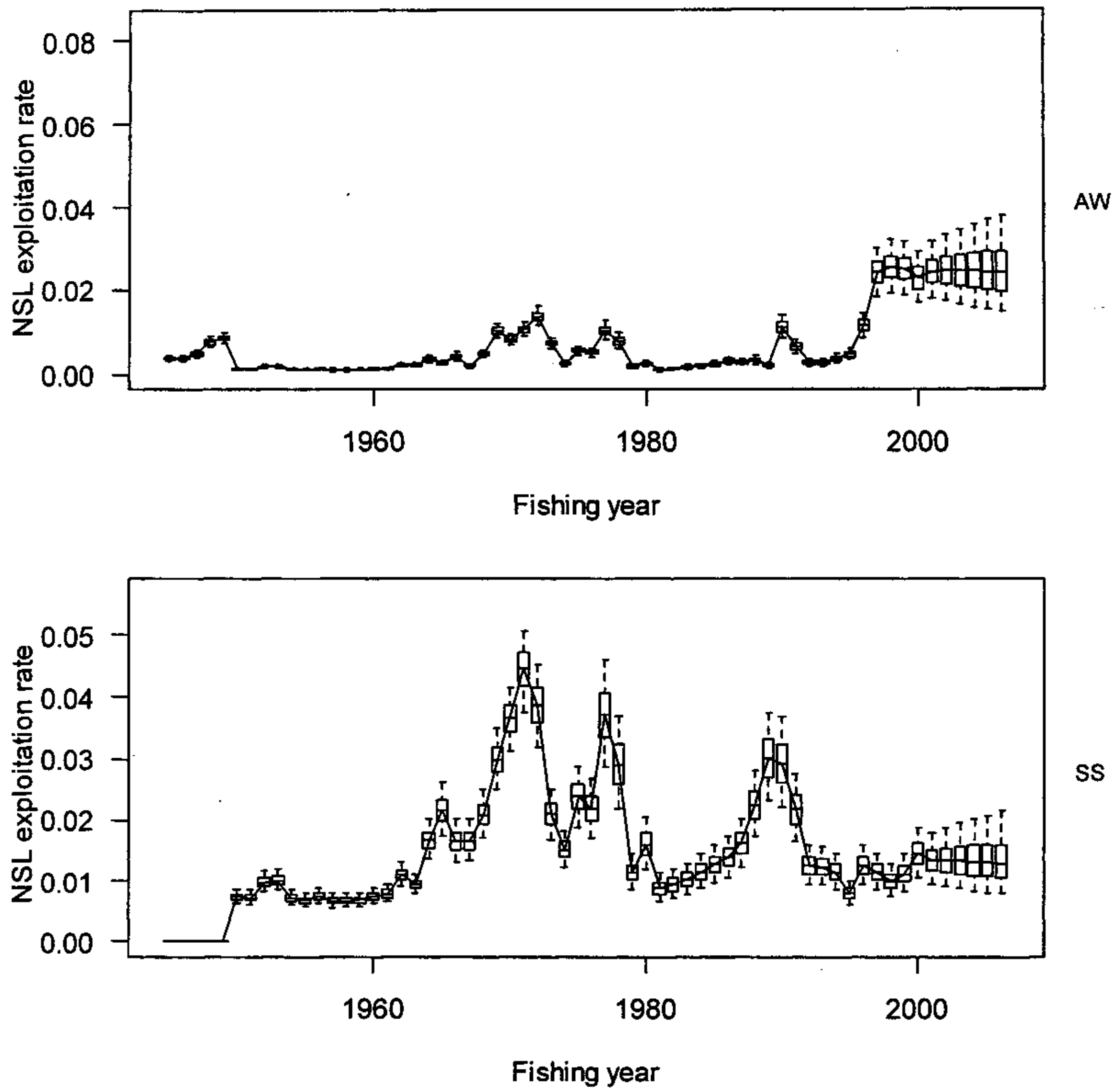


Figure 27: CRA 1: posterior trajectories of NSL exploitation rate, for the AW (top) and SS (bottom) seasons, from the CRA 1 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

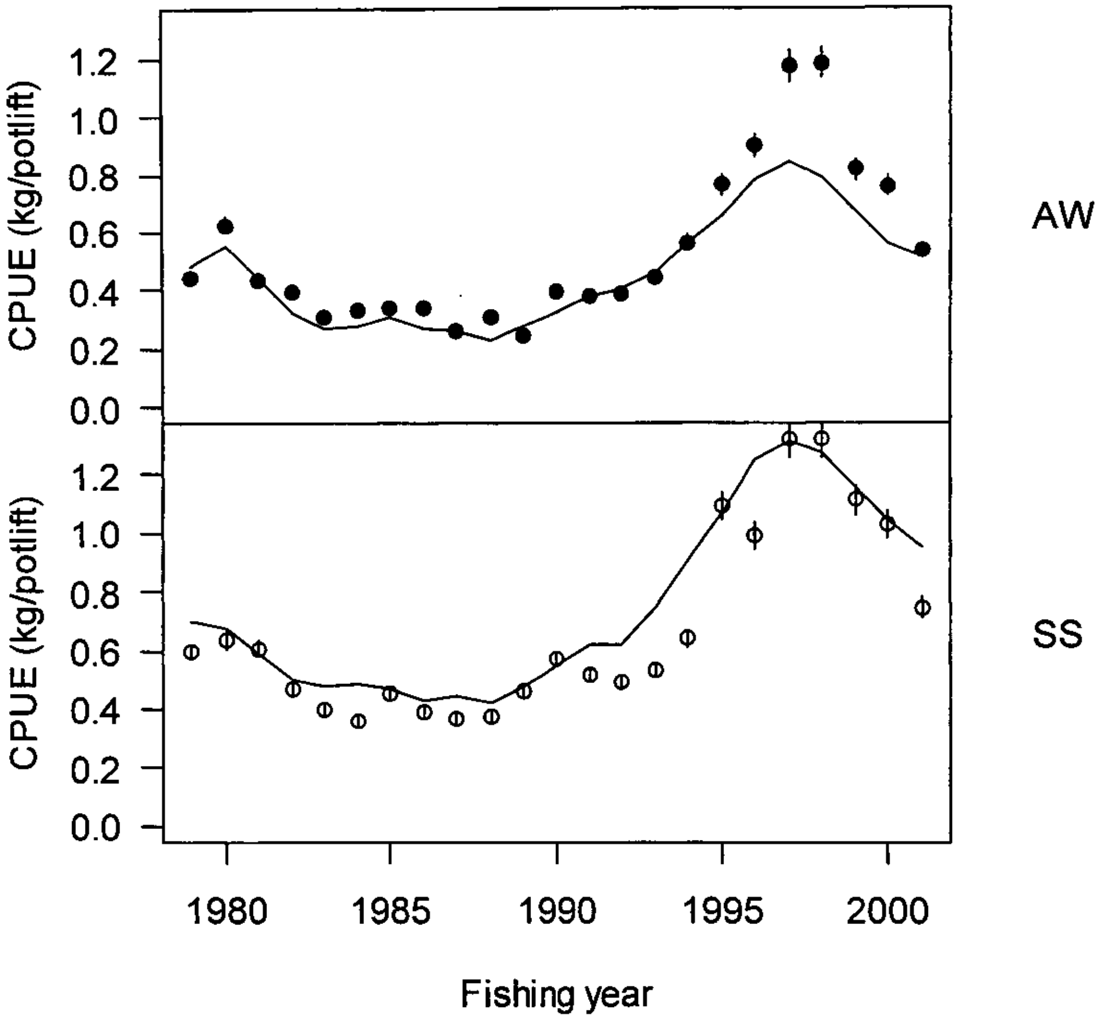


Figure 28: CRA 2: predicted (line) and observed (circles with one standard error) standardised CPUE index by season from the base case MPD results: upper, autumn-winter (AW) season; lower, spring-summer (SS) season.

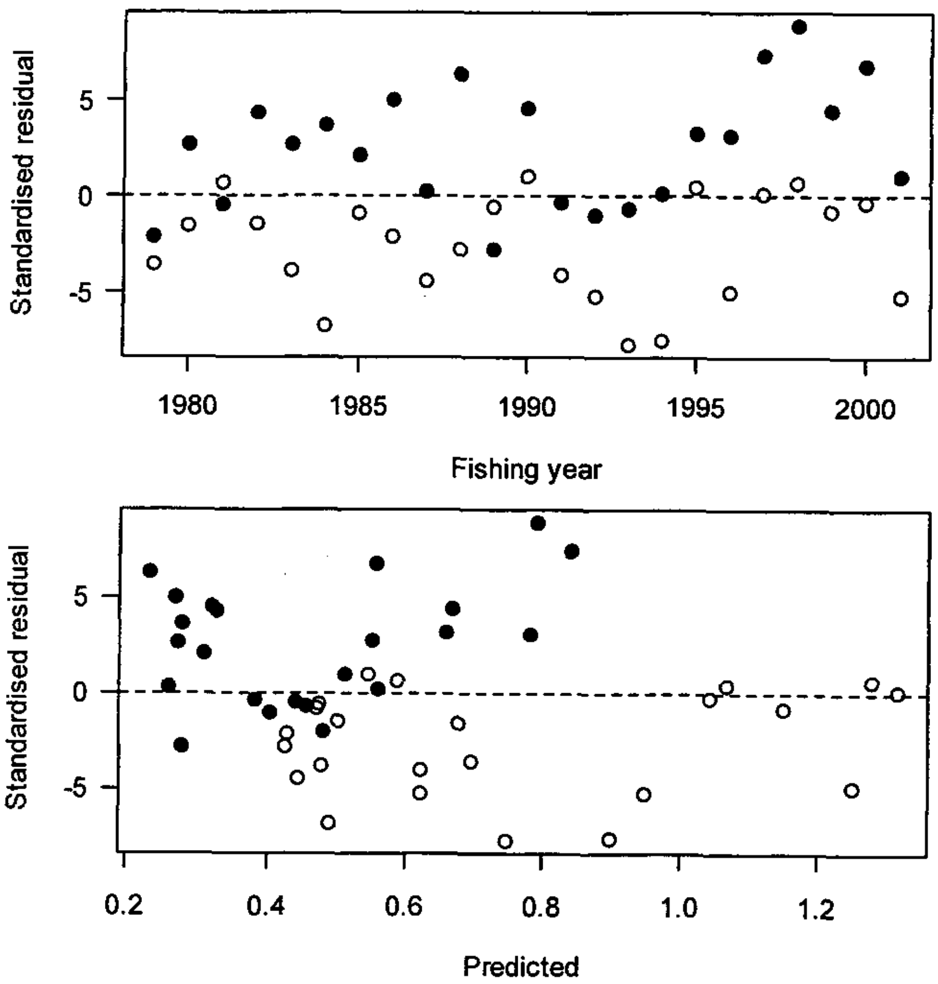


Figure 29: CRA 2: standardised residuals of predicted CPUE index from the base case MPD results, plotted by fishing year [upper panel] and by predicted CPUE index [middle panel]. Closed circles, autumn-winter (AW) season; open circles, spring-summer (SS) season. The bottom panel shows a quantile-quantile plot of the CPUE standardised residuals.

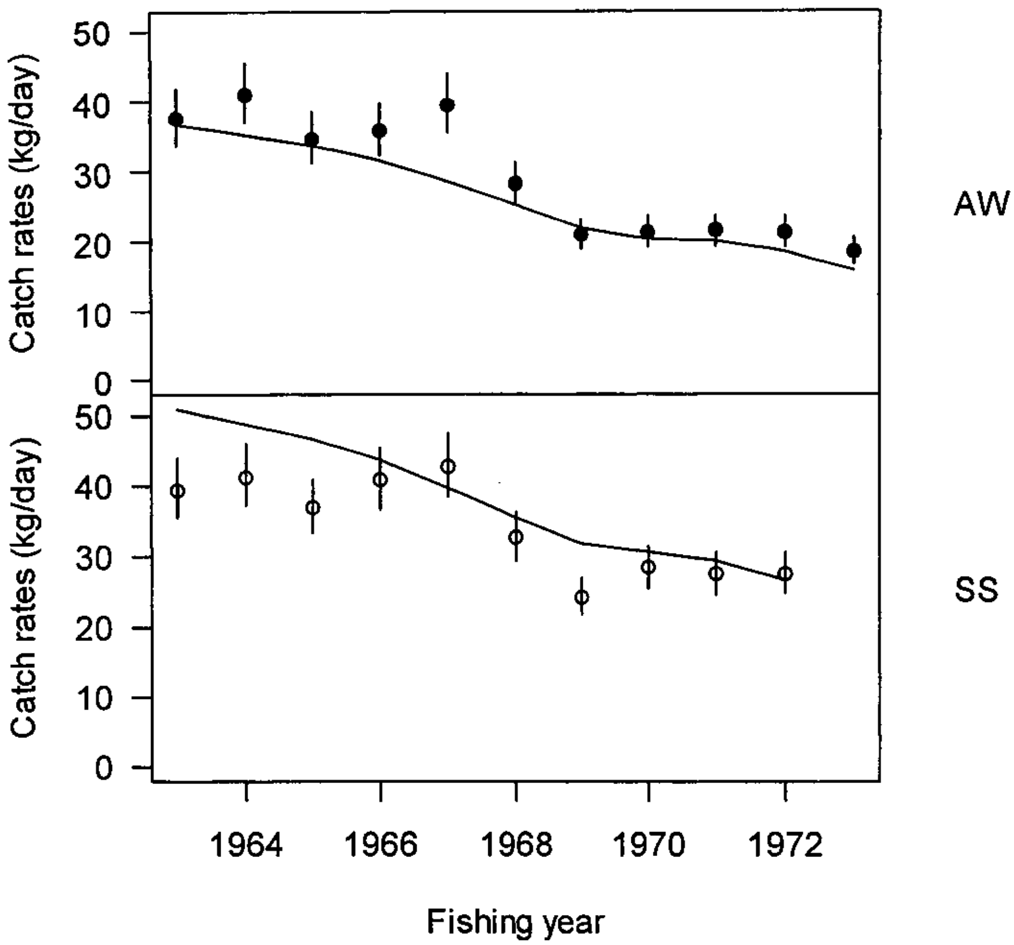


Figure 30: CRA 2: predicted (solid line) and observed (circles with one standard error) catch rate (CR) by season from the base case MPD results: upper, autumn-winter (AW) season, lower, spring-summer (SS) season.

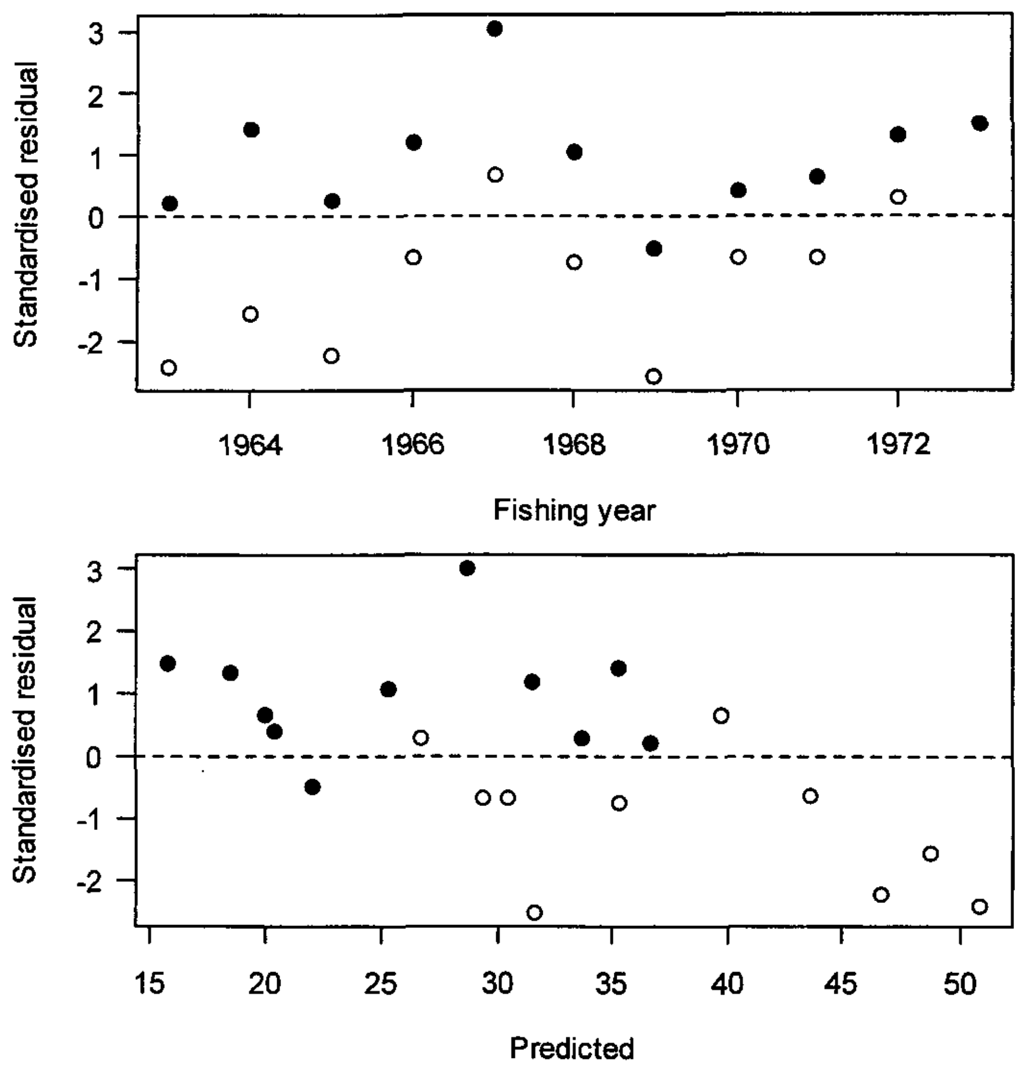


Figure 31: CRA 2: standardised residuals of catch rate from the base case MPD results, plotted by fishing year [upper panel] and by predicted catch rate [lower panel]. Closed circles, autumn-winter (AW) season; open circles, spring-summer (SS) season.

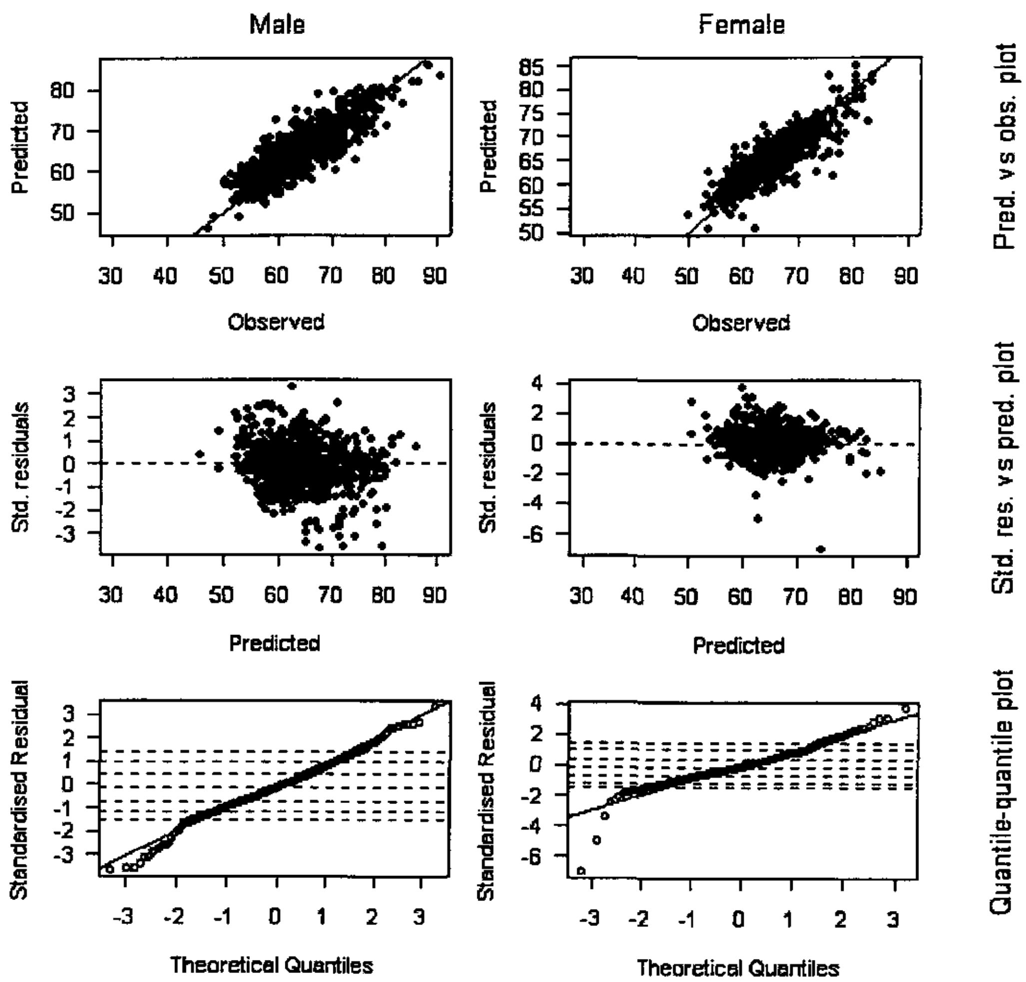


Figure 32: CRA 2: predicted and observed size at recapture from the base case model MPD fit from the tagging data (top panels); standardised residuals versus predicted size at recapture (middle panels); Q-Q plots of the standardised residuals (bottom panels). For all plots left panels are males and right panels are females.

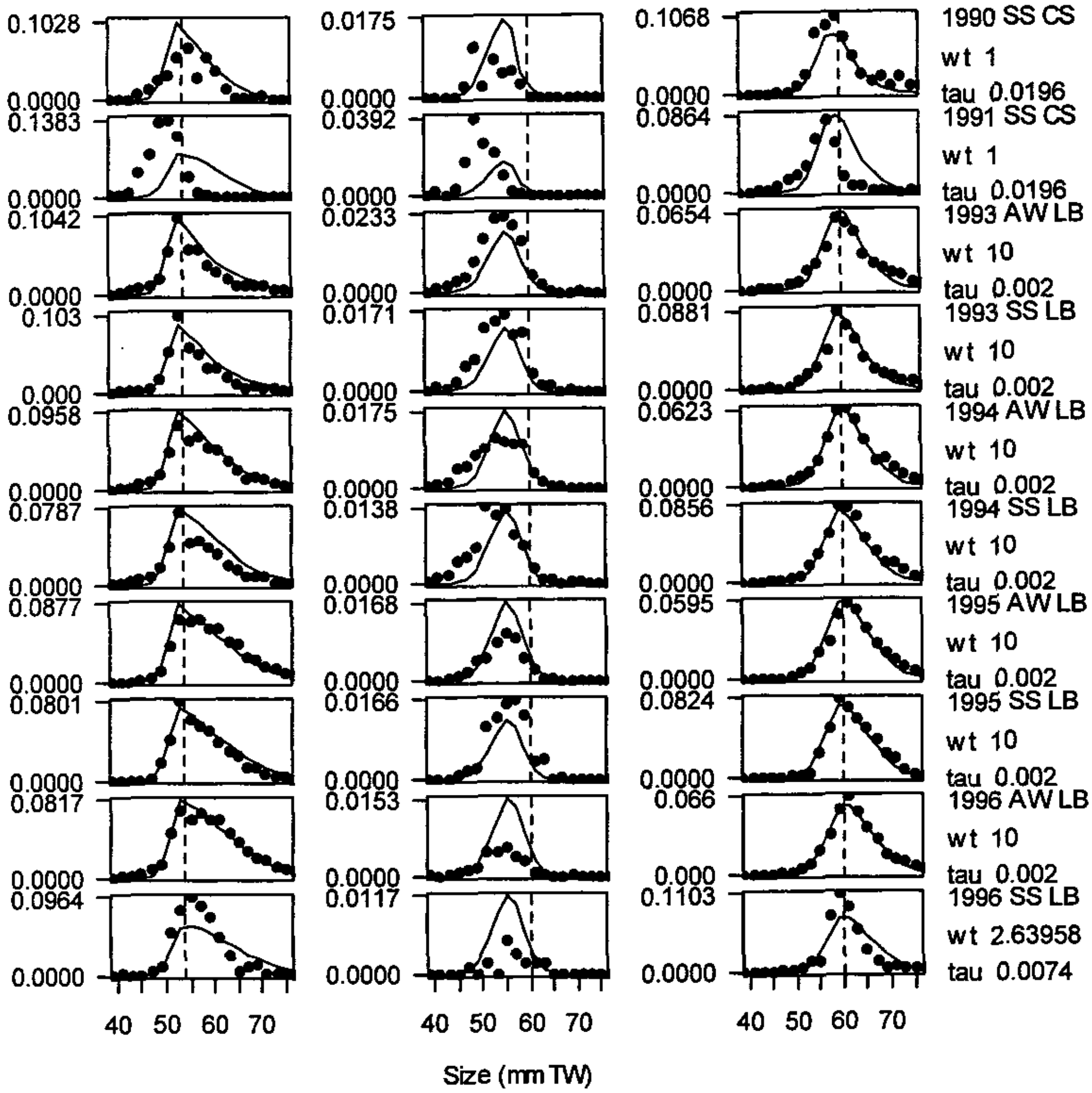


Figure 33: CRA 2: the base case MPD fit to the proportion-at-length data, plotted by year and season (AW, autumn-winter; SS, spring-summer), sex category, and data source type. The left column shows males, the centre immature females and the right mature females. LB, log book data; CS, catch sampling data; HS, historical data; MS, market sampling data; wt, relative weight given to each data set; tau, scaling factor relative to sigma. For HS and MS data, where females were not graded by maturity, the centre column is all females. The dotted vertical line is the current summer MLS.

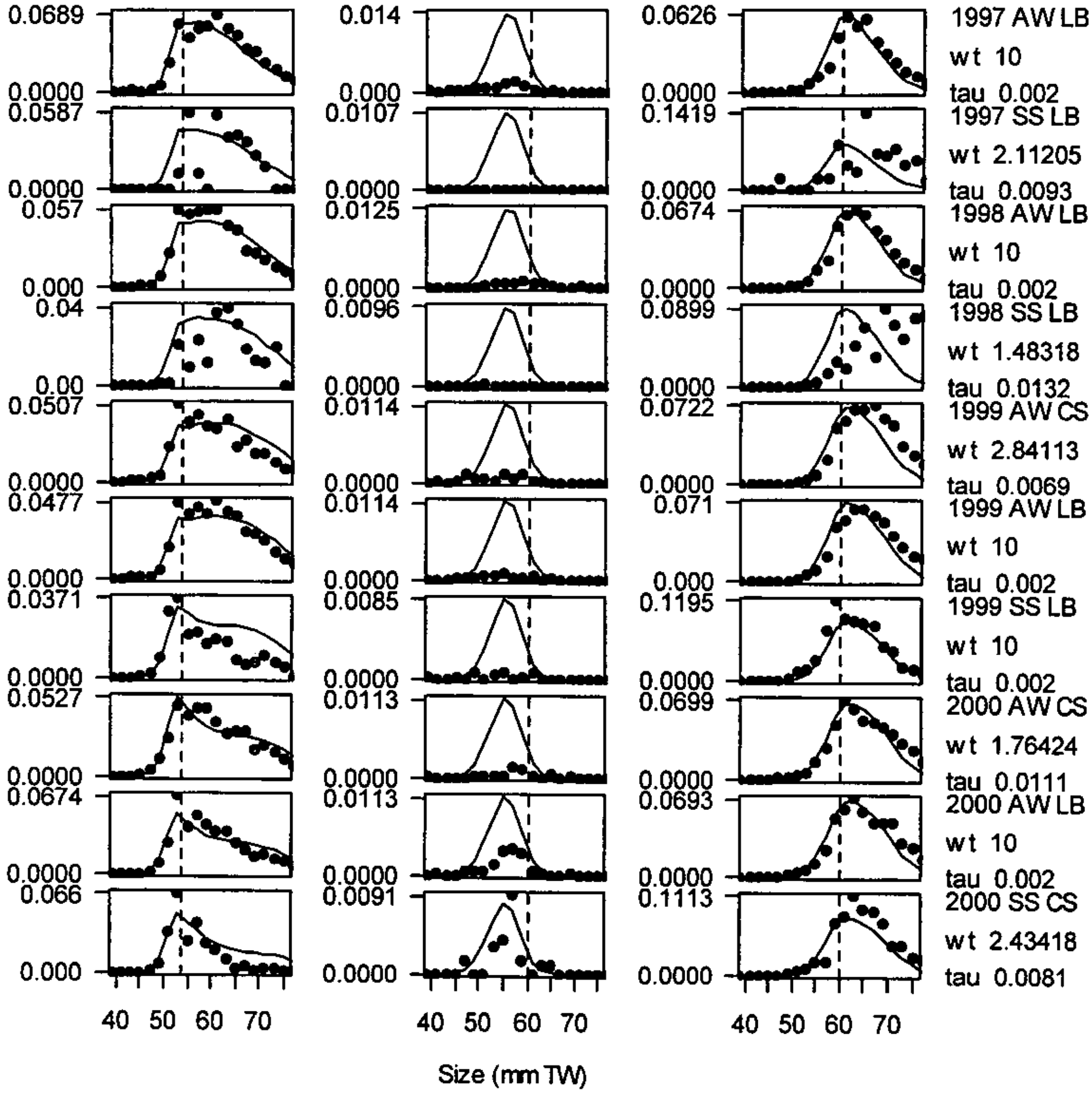


Figure 33: continued.

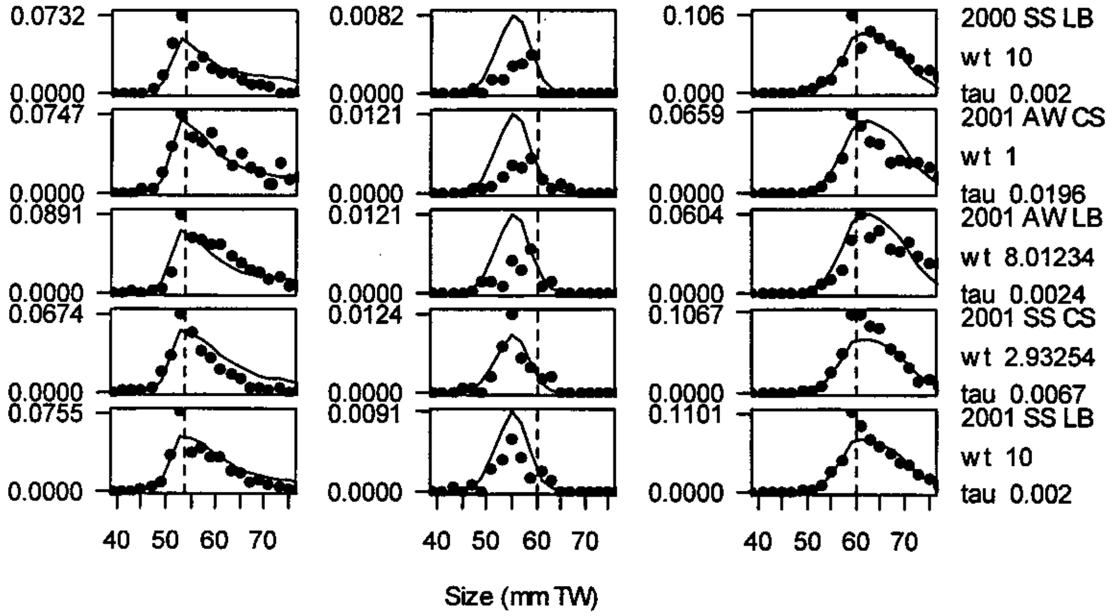


Figure 33: continued.

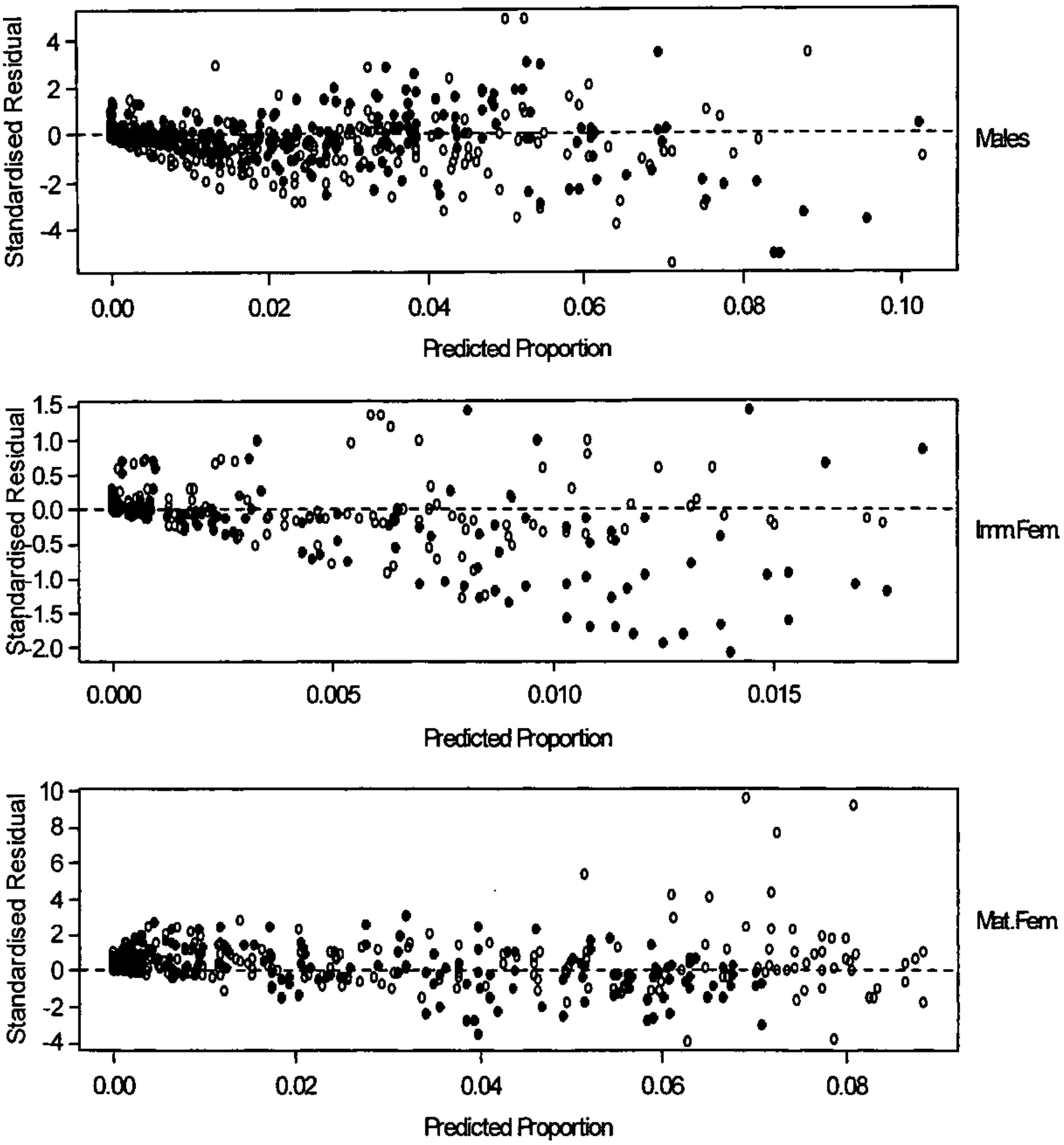


Figure 34: CRA 2: standardised residuals from the fits to proportions-at-length (Figure 33), plotted against predicted proportions-at-length for the three sex categories indicated.

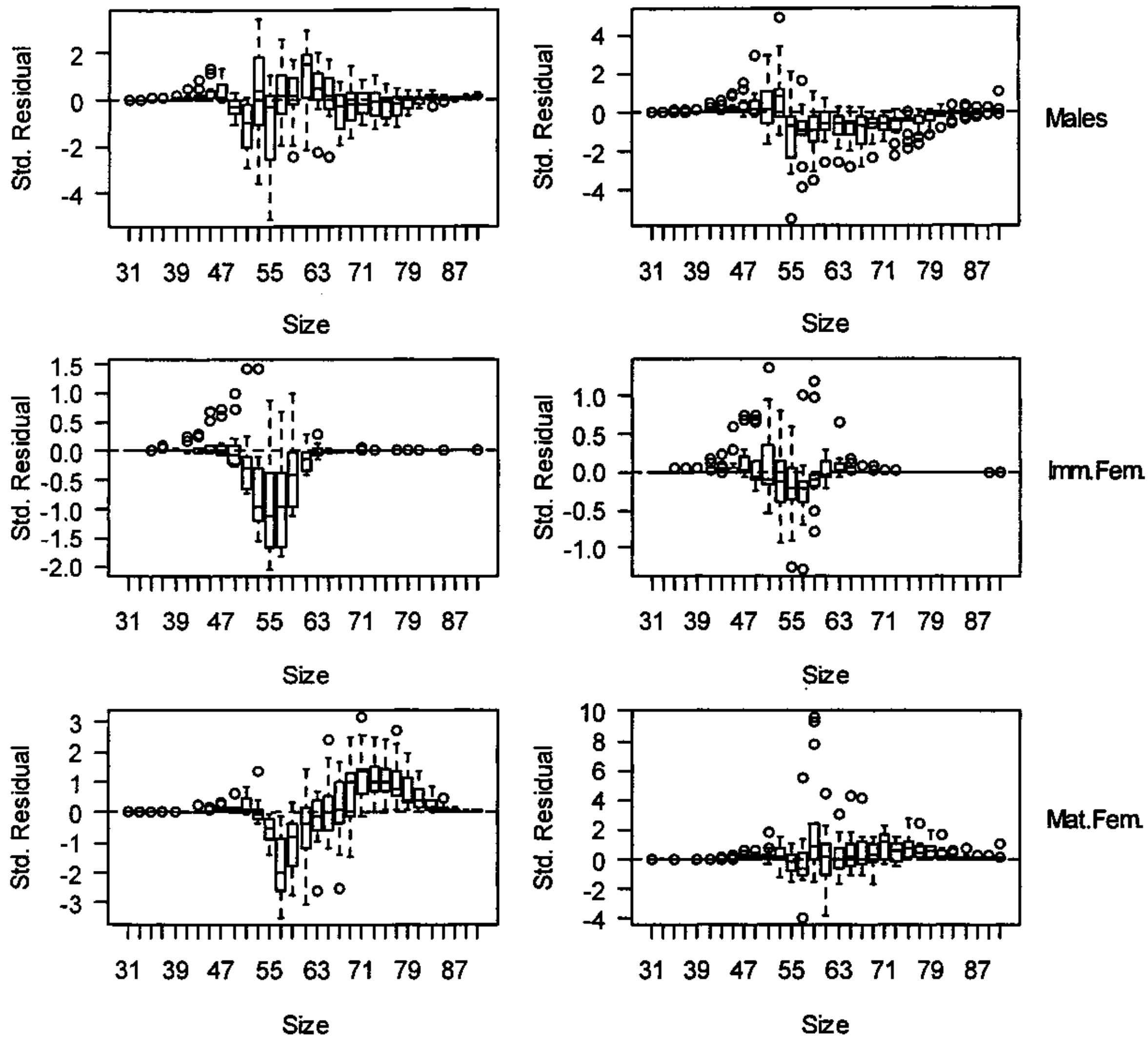


Figure 35: CRA 2: standardised residuals from the fits to proportions-at-length (Figure 33), plotted against length and by season for the three sex categories indicated. Left panels are the autumn-winter season and the right panels for the spring-summer season. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.

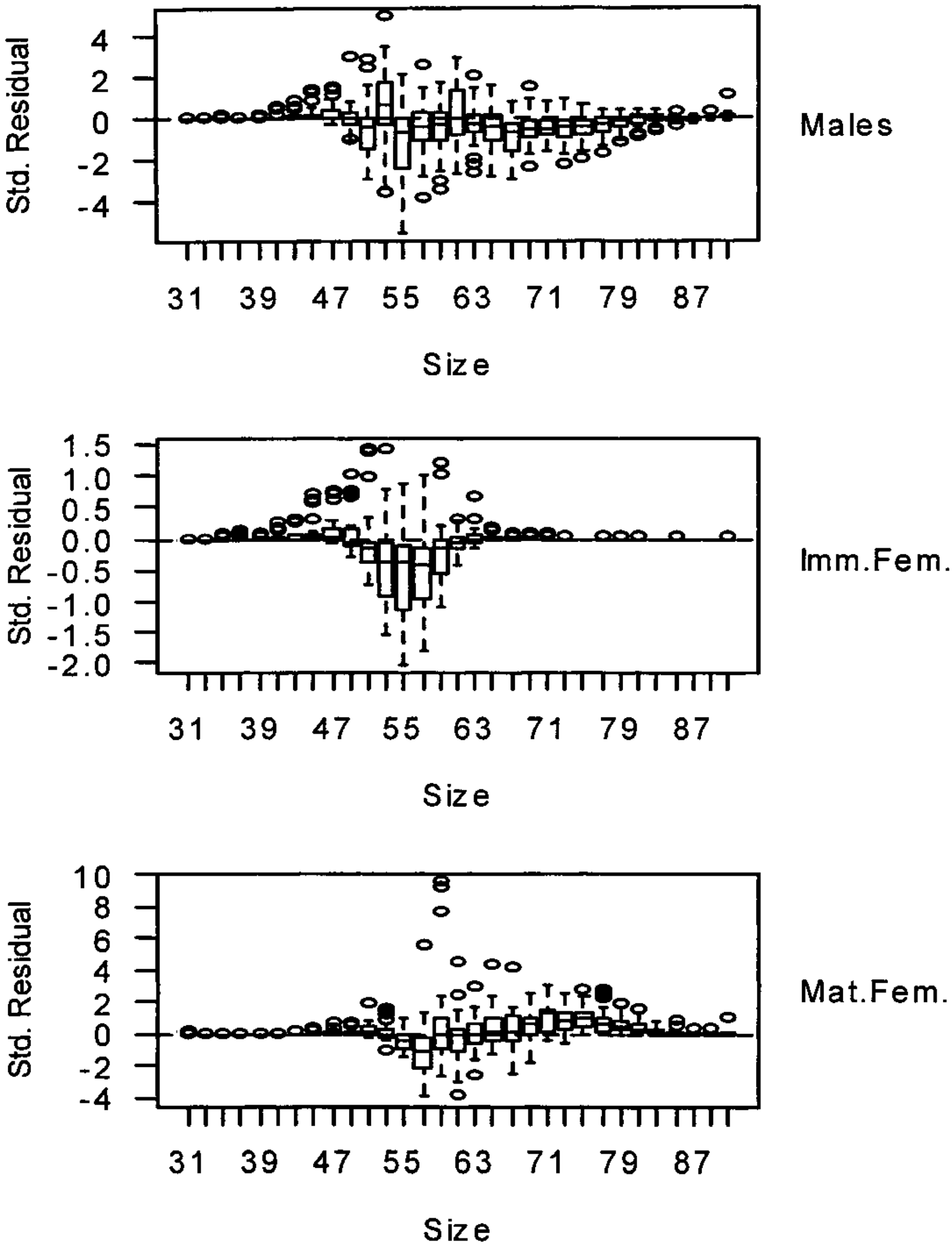


Figure 36: CRA 2: standardised residuals from the fits to proportions-at-length (Figure 33), plotted against length for the three sex categories indicated. The box plots show the median as a horizontal line; the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles, other points indicate outliers.

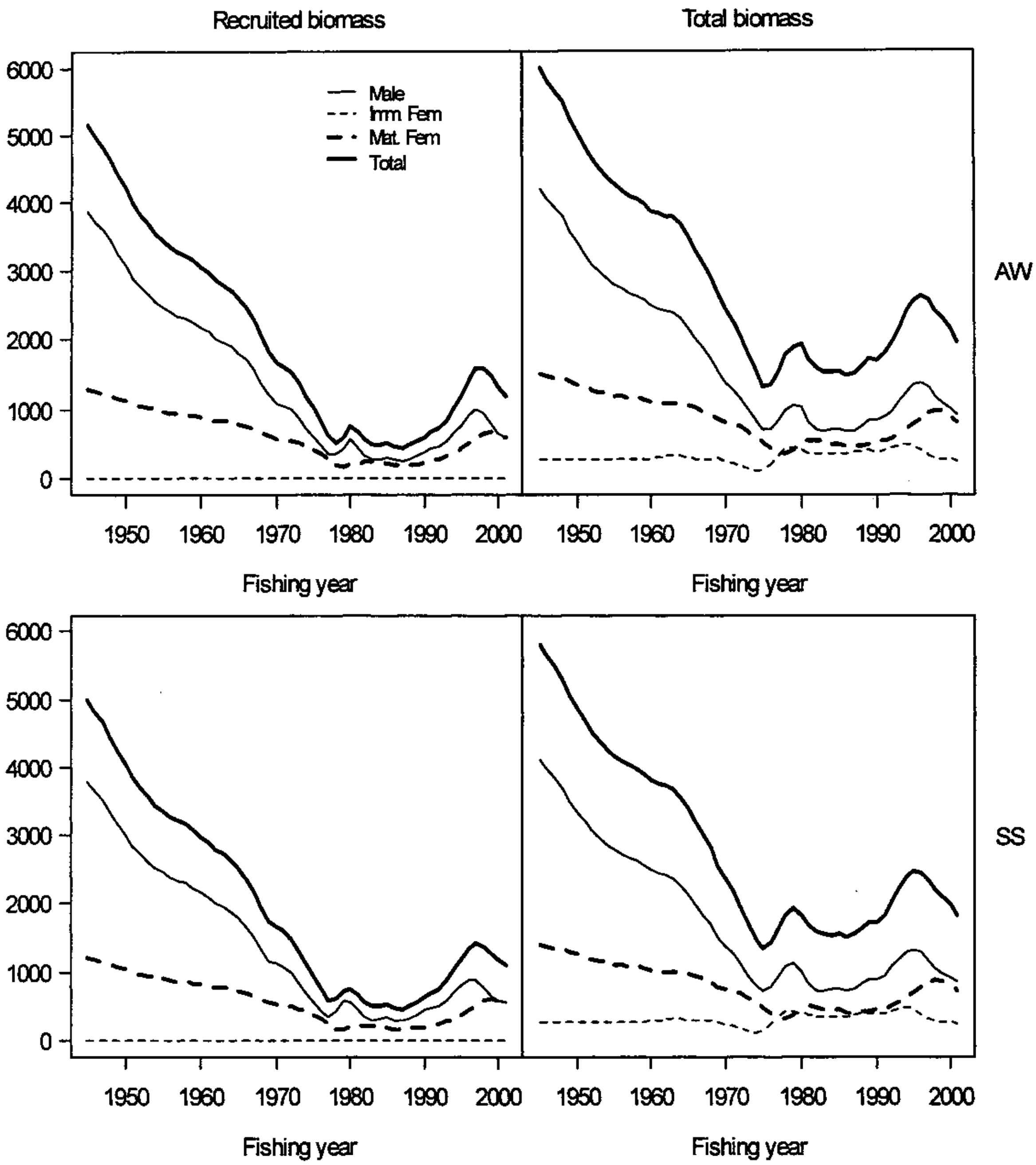


Figure 37: CRA 2: recruited (left panels) and total biomass (right panels) from the MPD fit by sex (as indicated in the legend) and season: upper panels, autumn-winter season; lower panels, spring-summer season.

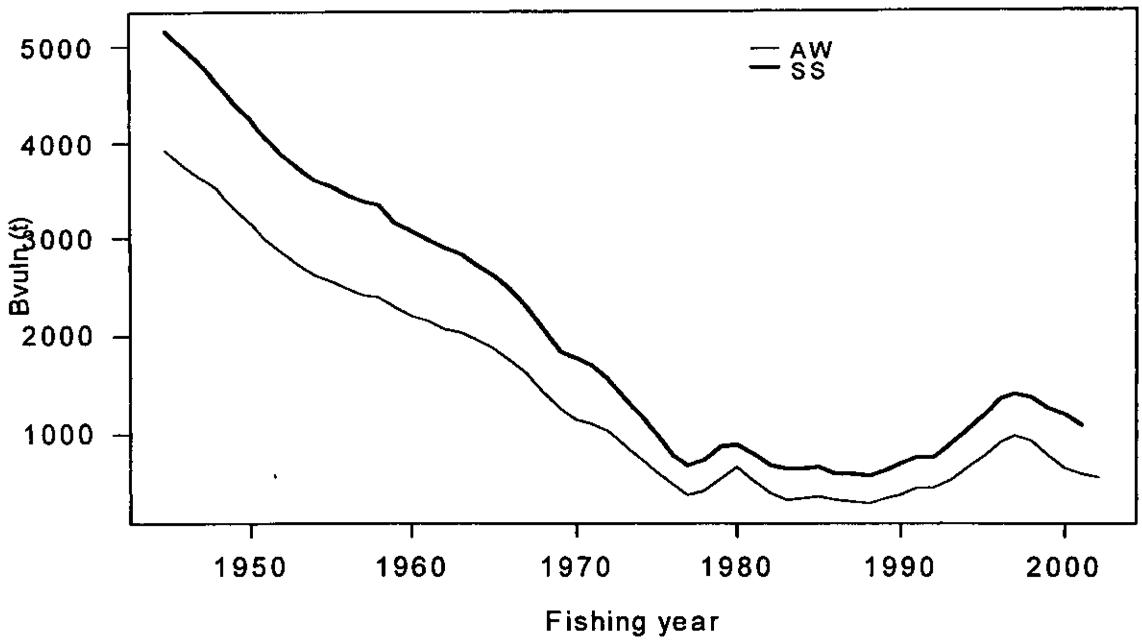


Figure 38: CRA 2: the base case model's predicted vulnerable biomass from the MPD fit: heavy line, spring-summer season; light line, autumn-winter season.

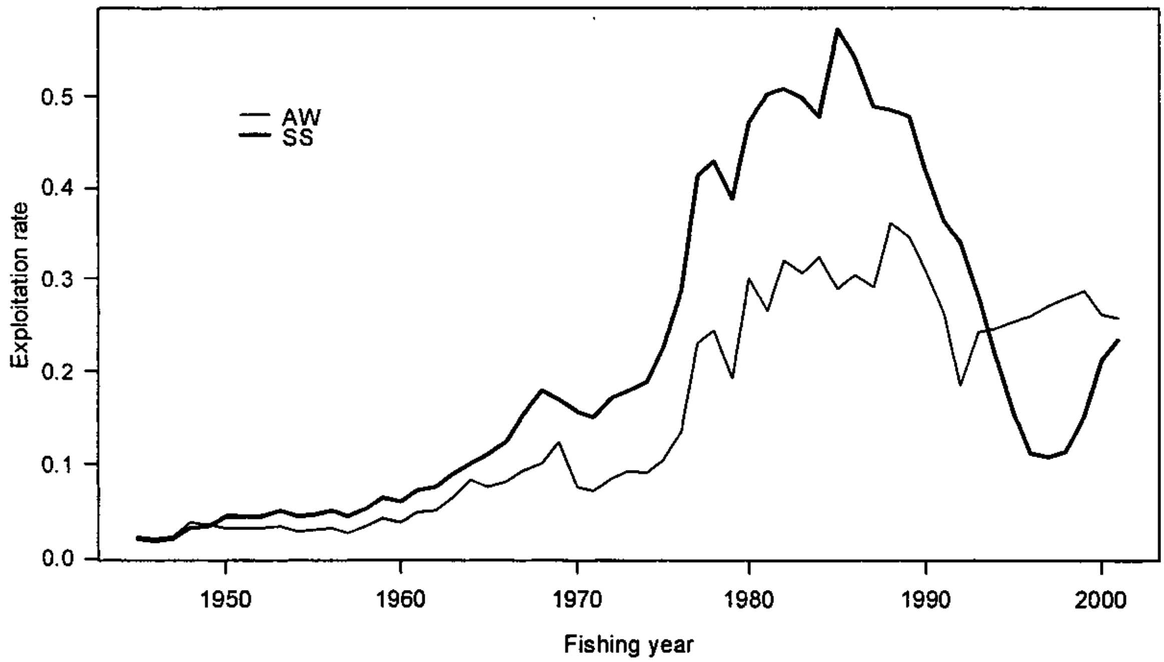


Figure 39: CRA 2: exploitation rate trajectories from the base case model MPD fit: heavy line, spring-summer season; light line, autumn-winter season.

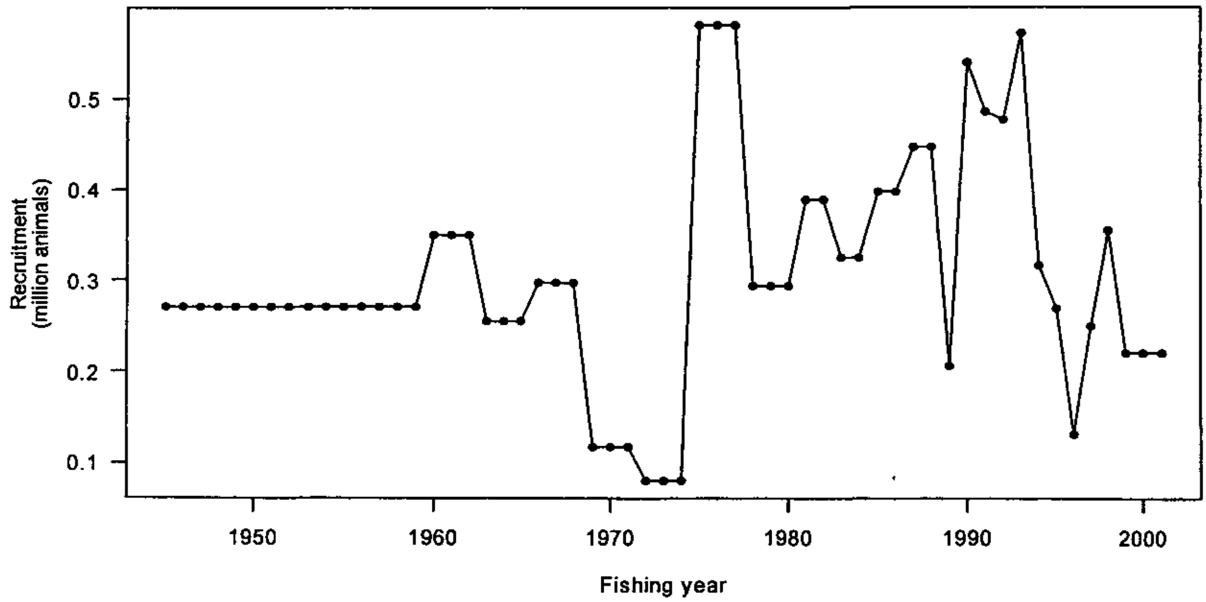
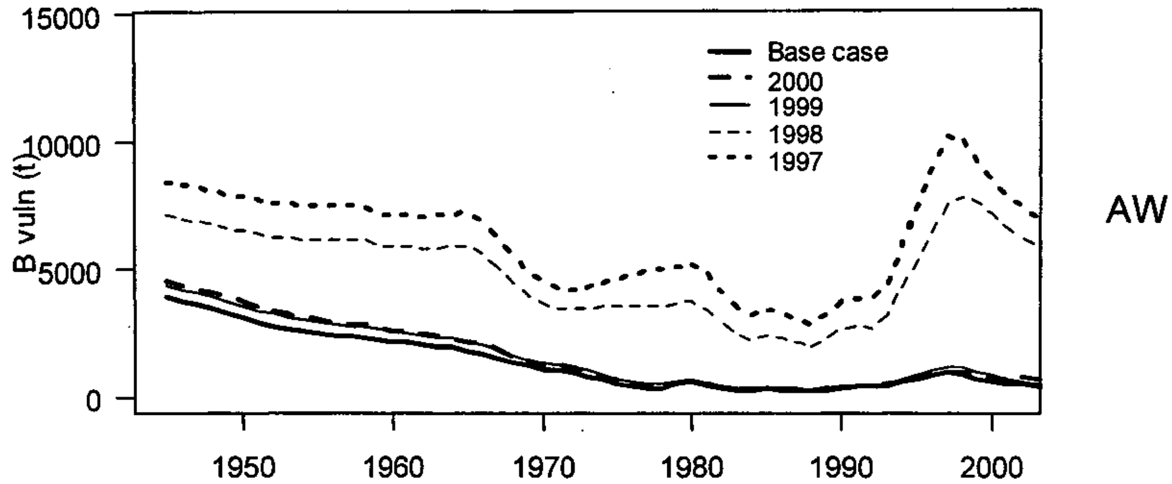


Figure 40: CRA 2: recruitment trajectory (millions) from the base case model MPD fit.



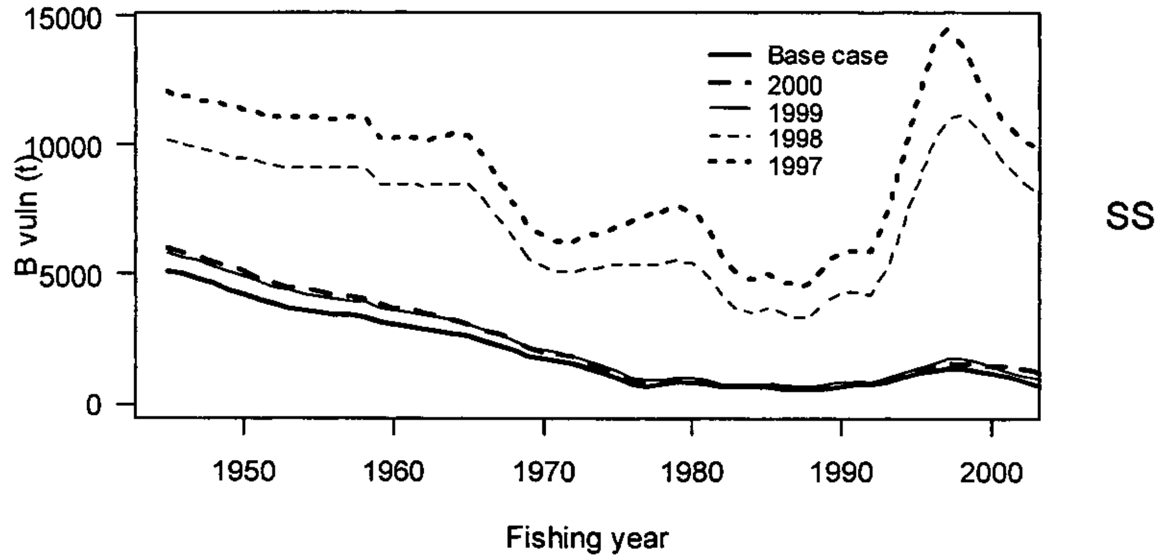


Figure 41: Vulnerable biomass trajectories from the MPD retrospectives for CRA 2, plotted by season; upper panel - SS, lower panel - AW. Each line connects the predicted biomass for each year in the MPD fit. Data sets are named by the last year of data they were fitted to.

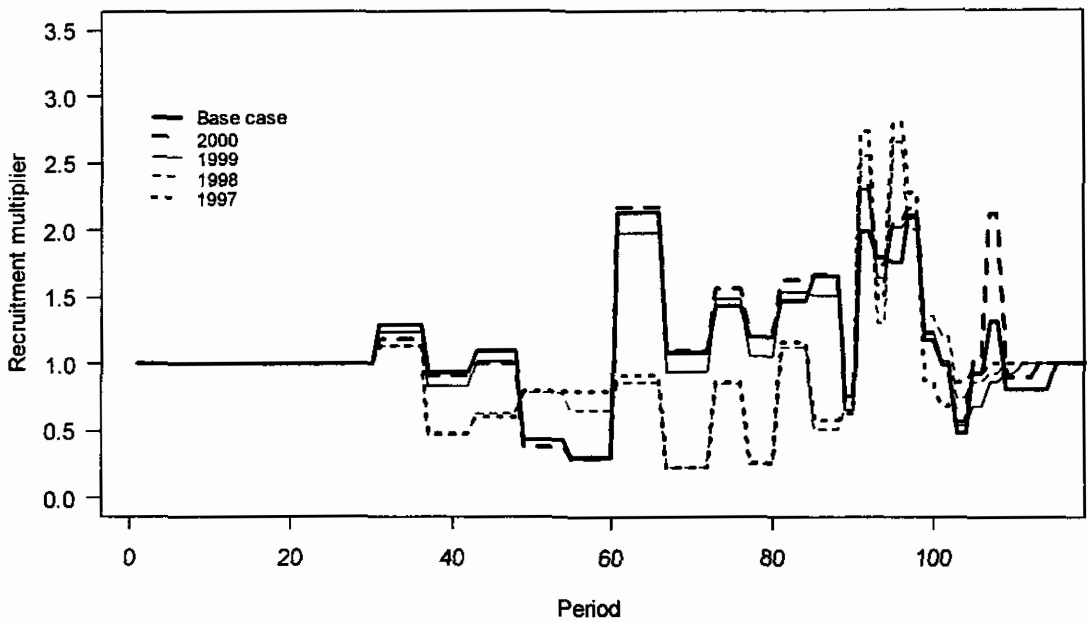


Figure 42: Estimated recruitments from the MPD retrospectives for CRA 2. Each line connects the *predicted recruitment for each year in the MPD fit.* Data sets are named by the last year of data they were fit to. Note that the 1998 and 1997 retrospectives have much larger estimates of R0 and are thus off the scale of the graph.

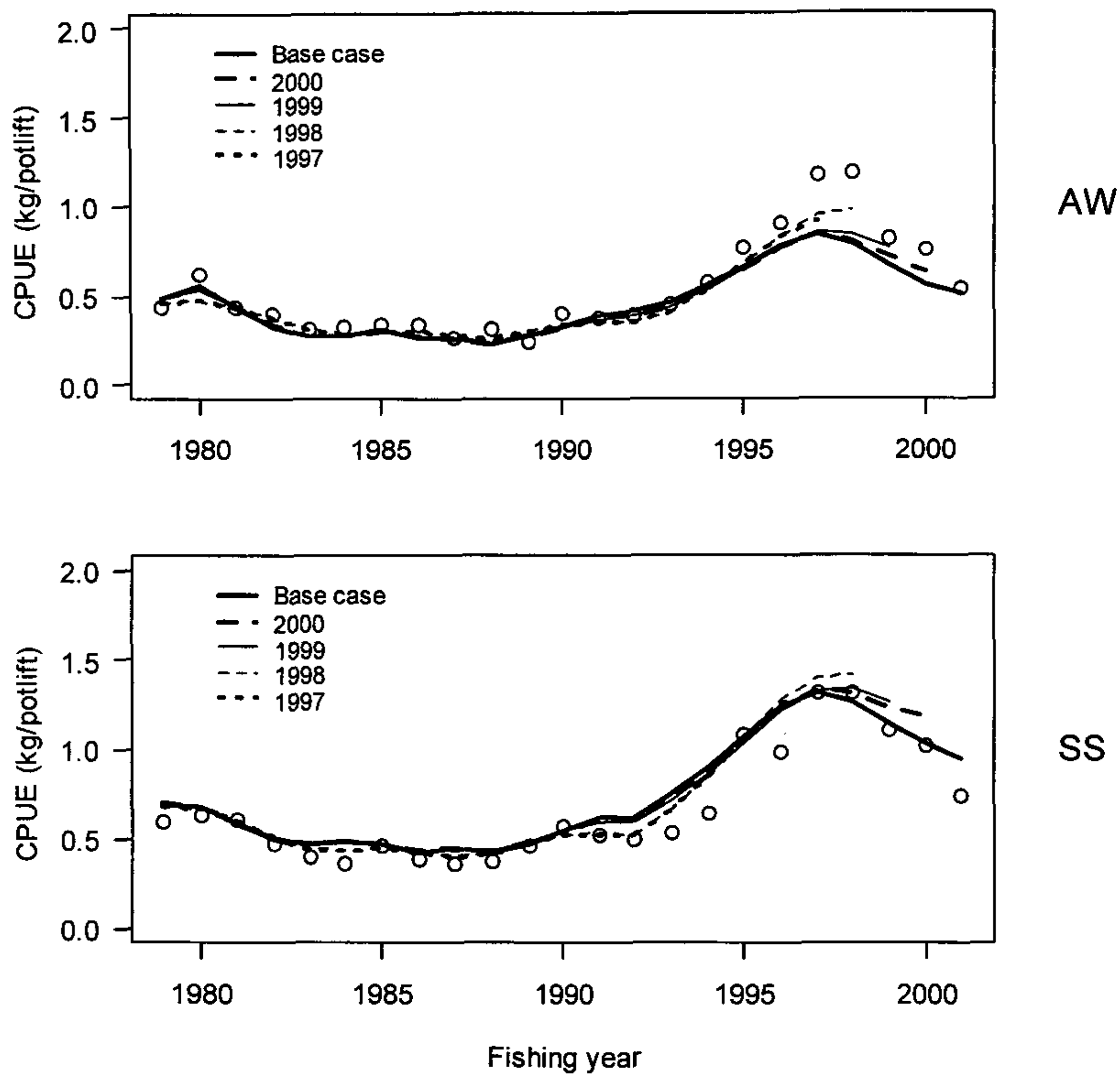


Figure 43: CPUE trajectories from the MPD retrospectives for CRA 2, plotted by season; upper panel - AW, lower panel - SS. Each line connects the predicted biomass for each year in the MPD fit. Data sets are named by the last year of data they were fit to. Points are the observed CPUE.

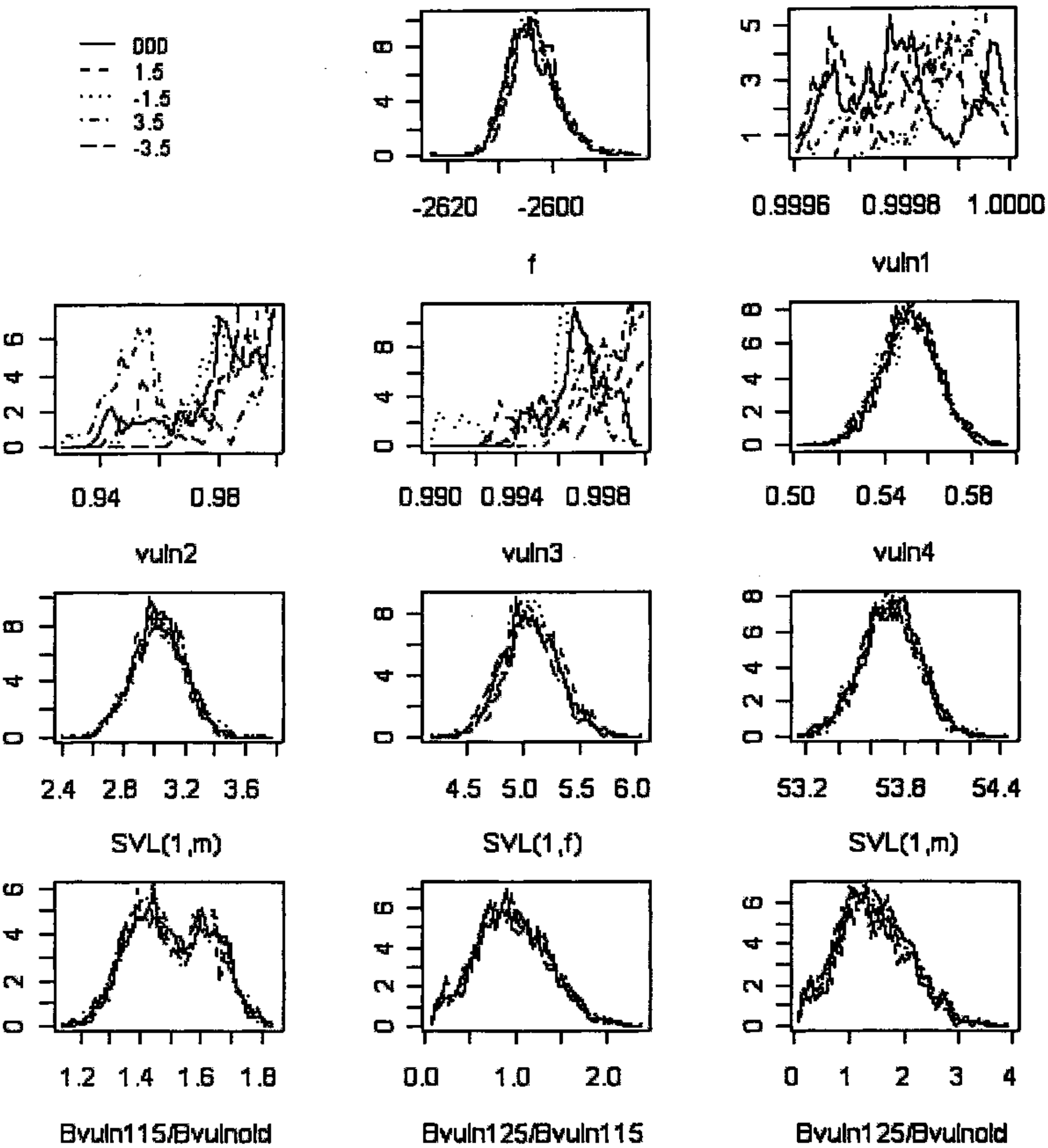


Figure 44: Marginal posterior distributions of some parameters and performance indicators from the five McMC chains for the CRA 2 base case assessment.

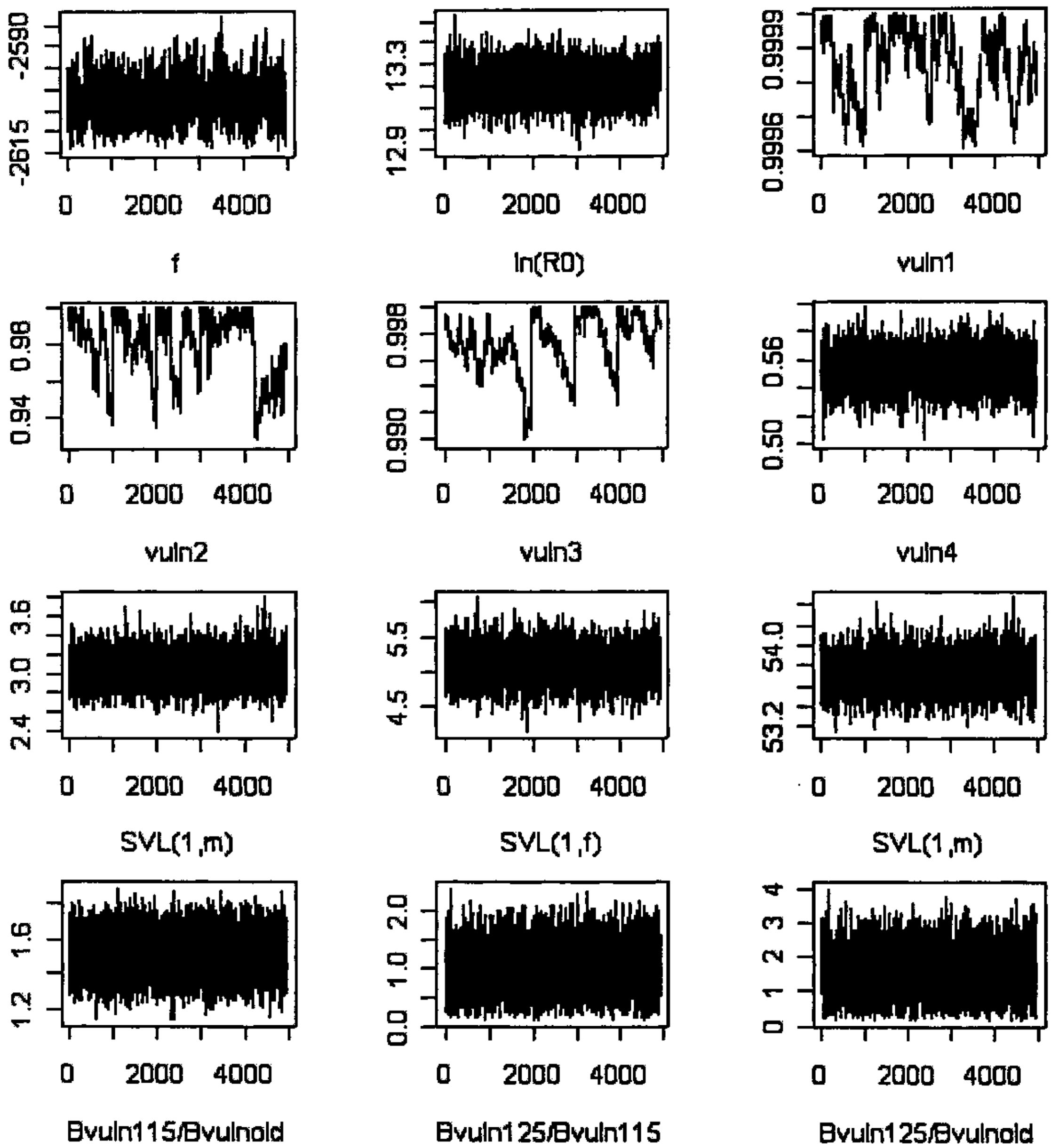


Figure 45: Examples of traces from the base case McMC simulations for the CRA 2 assessment.

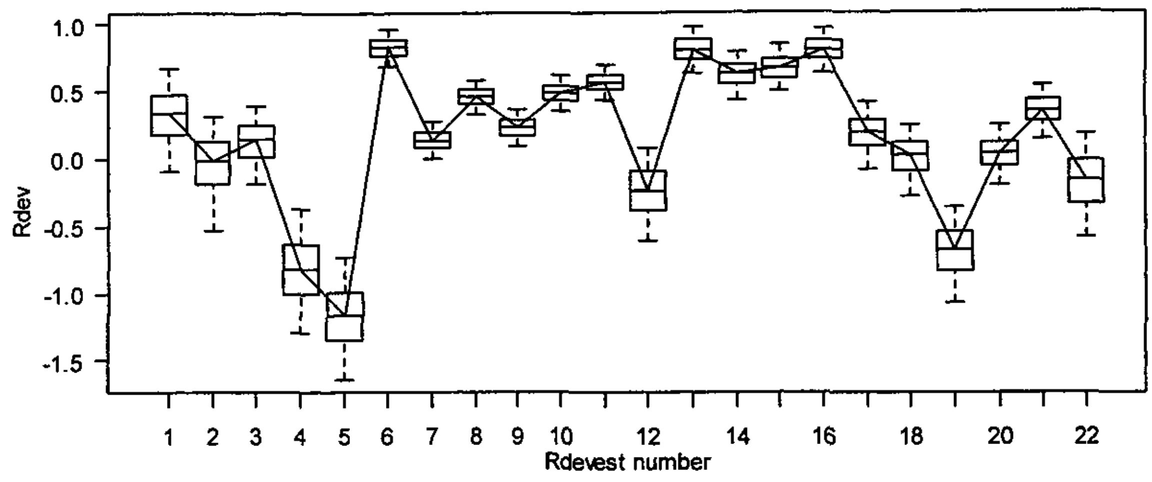
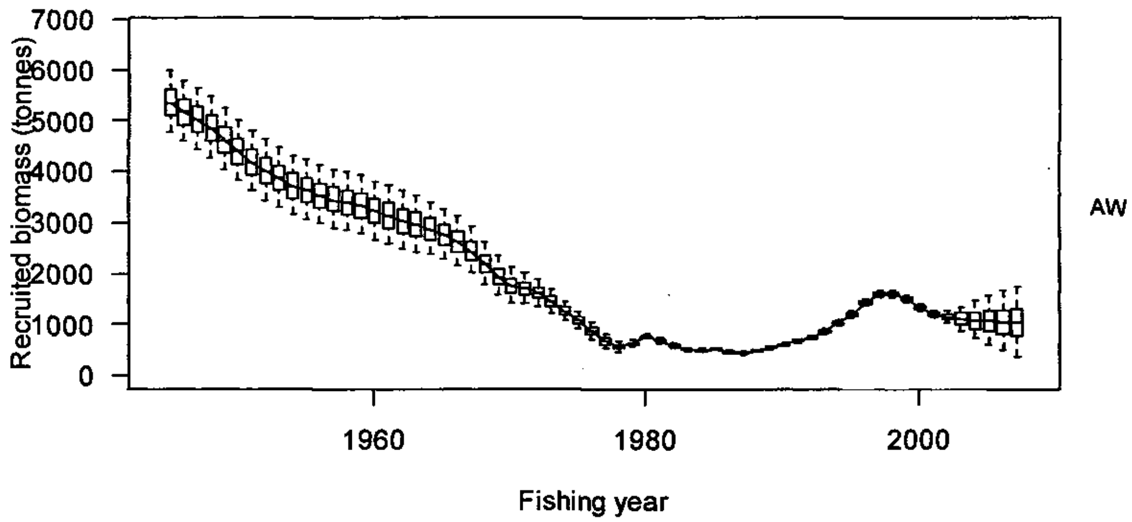


Figure 46: CRA 2: posterior trajectories of recruitment deviations from the base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



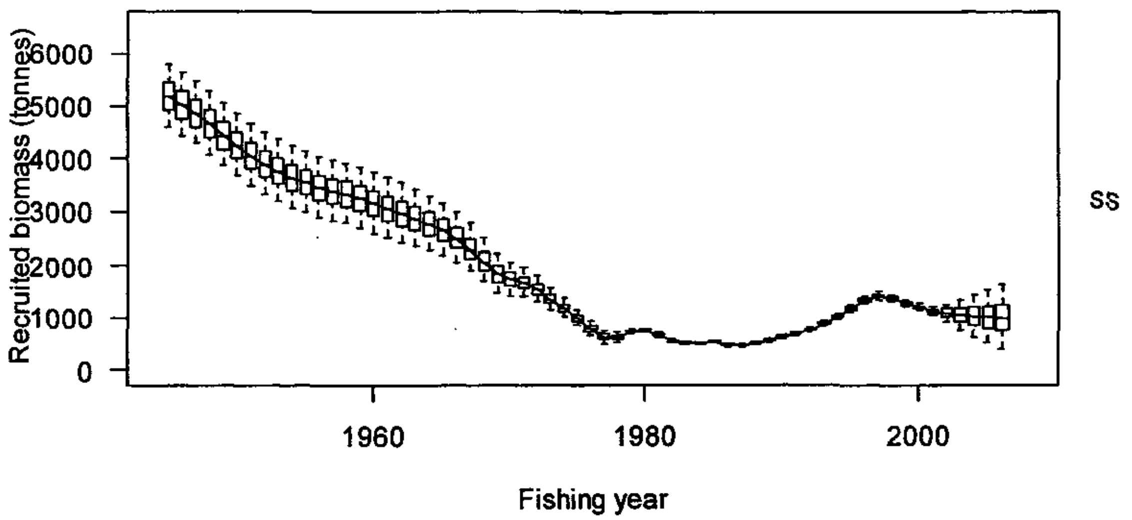
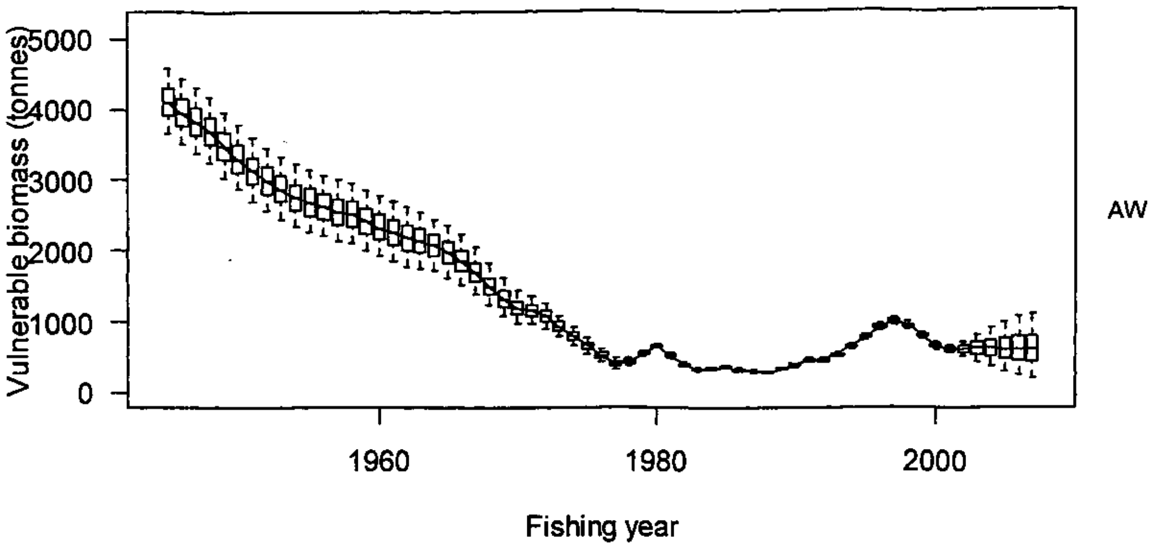


Figure 47: CRA 2: posterior trajectories of recruited biomass, for the AW (top) and SS (bottom) seasons, from the CRA 2 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



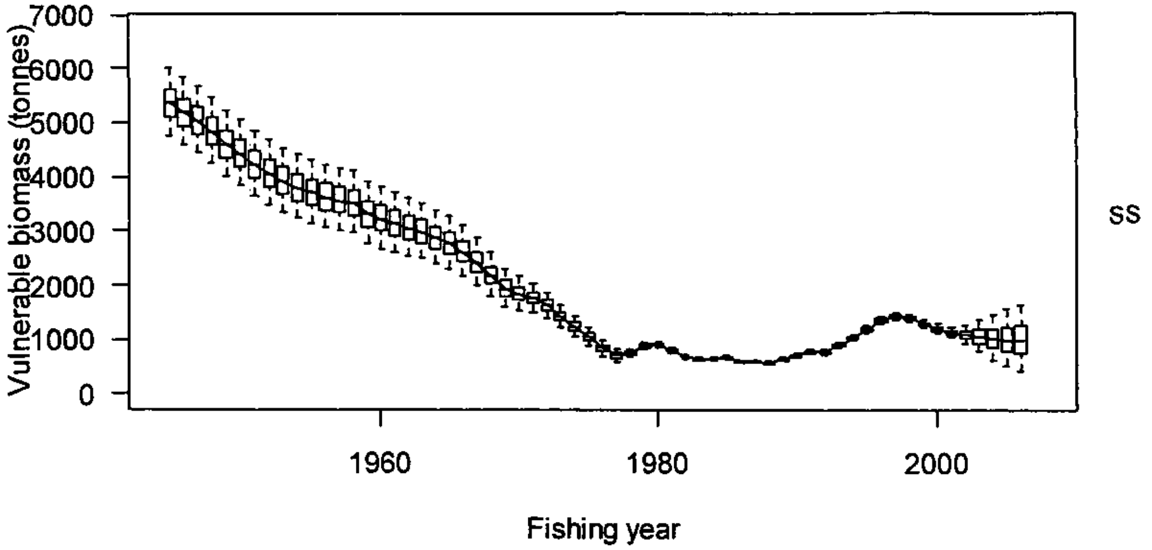


Figure 48: CRA 2: posterior trajectories of vulnerable biomass, for the AW (top) and SS (bottom) seasons, from the CRA 2 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

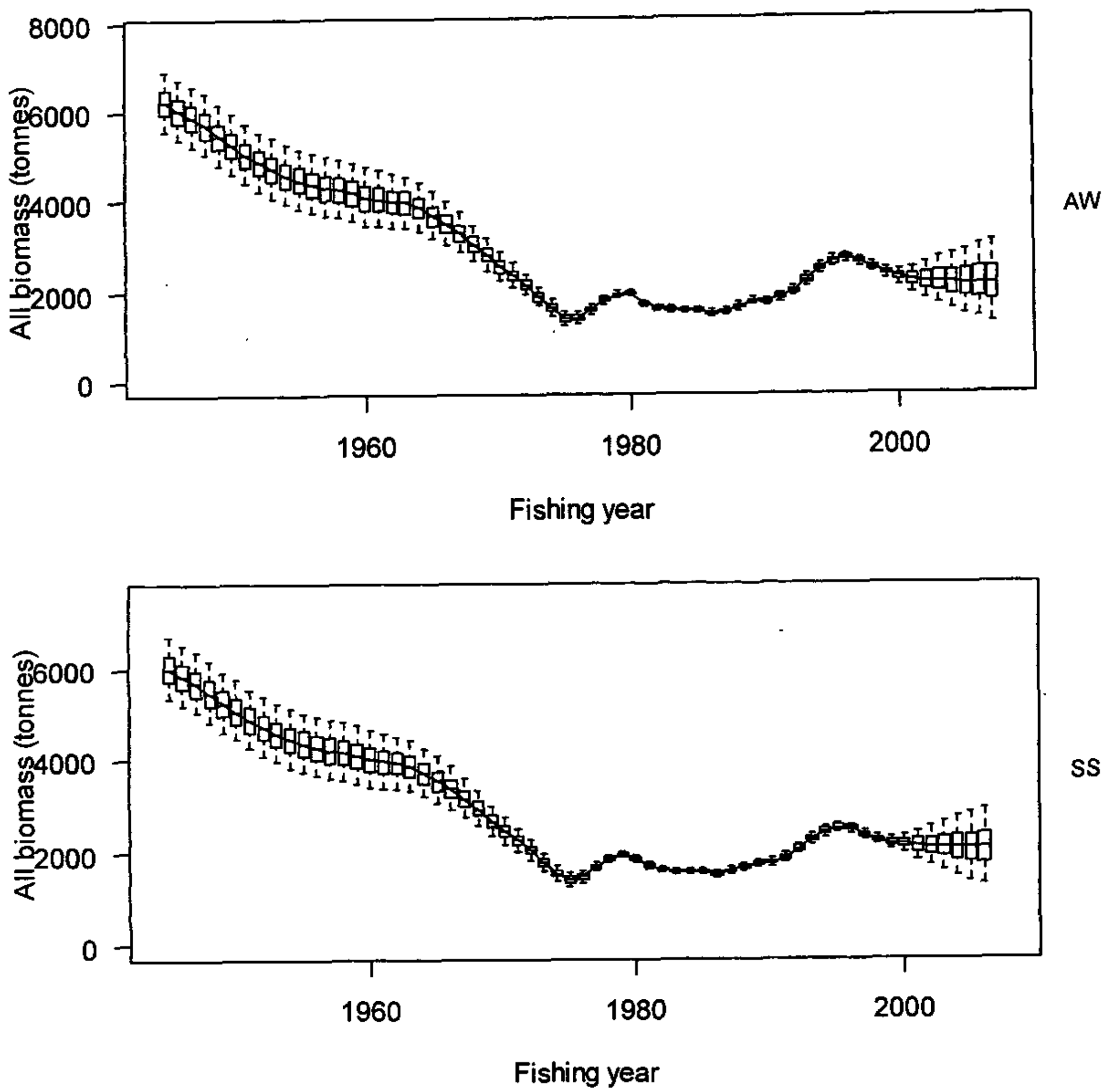


Figure 49: CRA 2: posterior trajectories of total biomass, for the AW (top) and SS (bottom) seasons, from the CRA 2 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

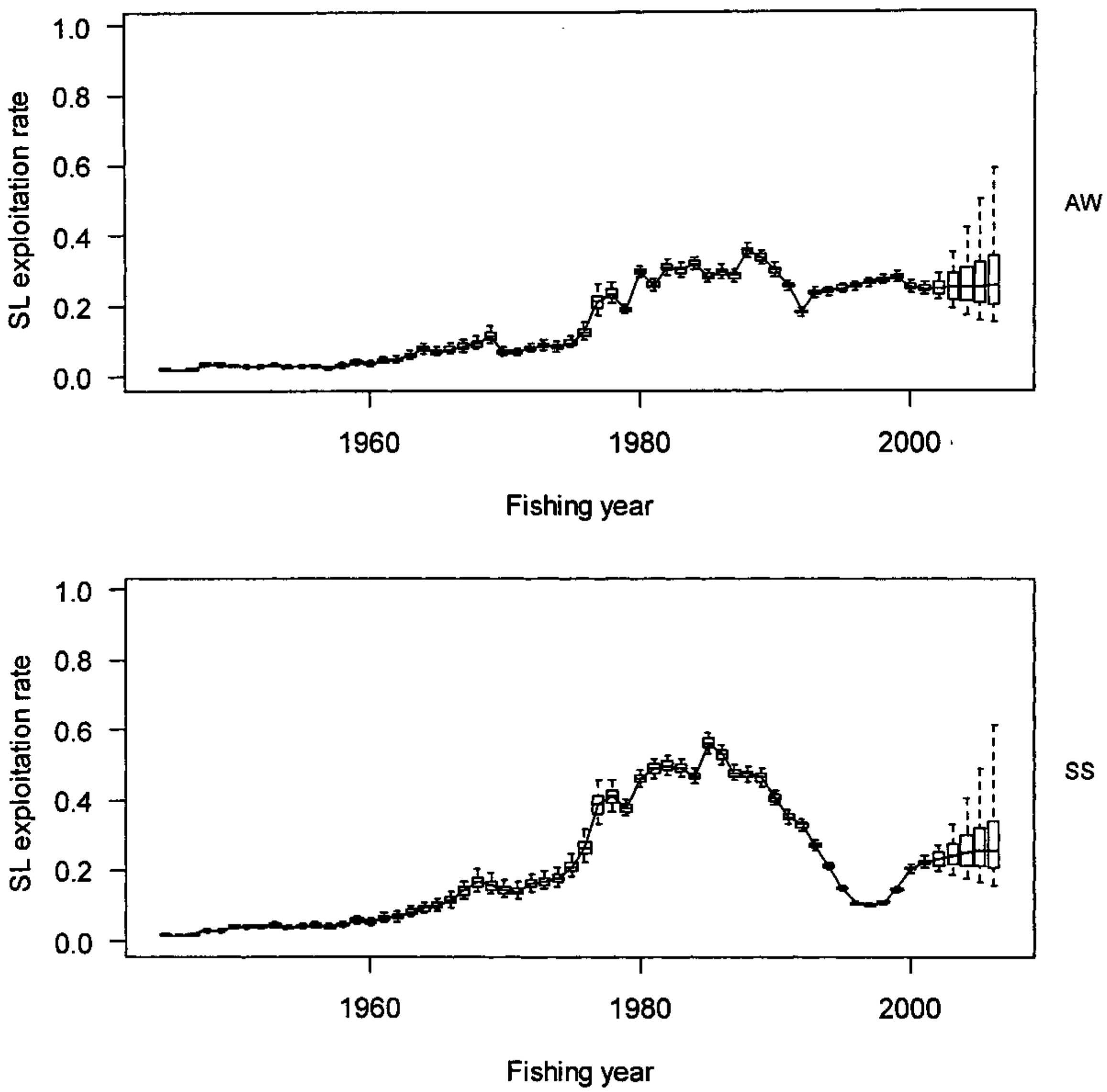


Figure 50: CRA 2: posterior trajectories of SL exploitation rate, for the AW (top) and SS (bottom) seasons, from the CRA 2 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

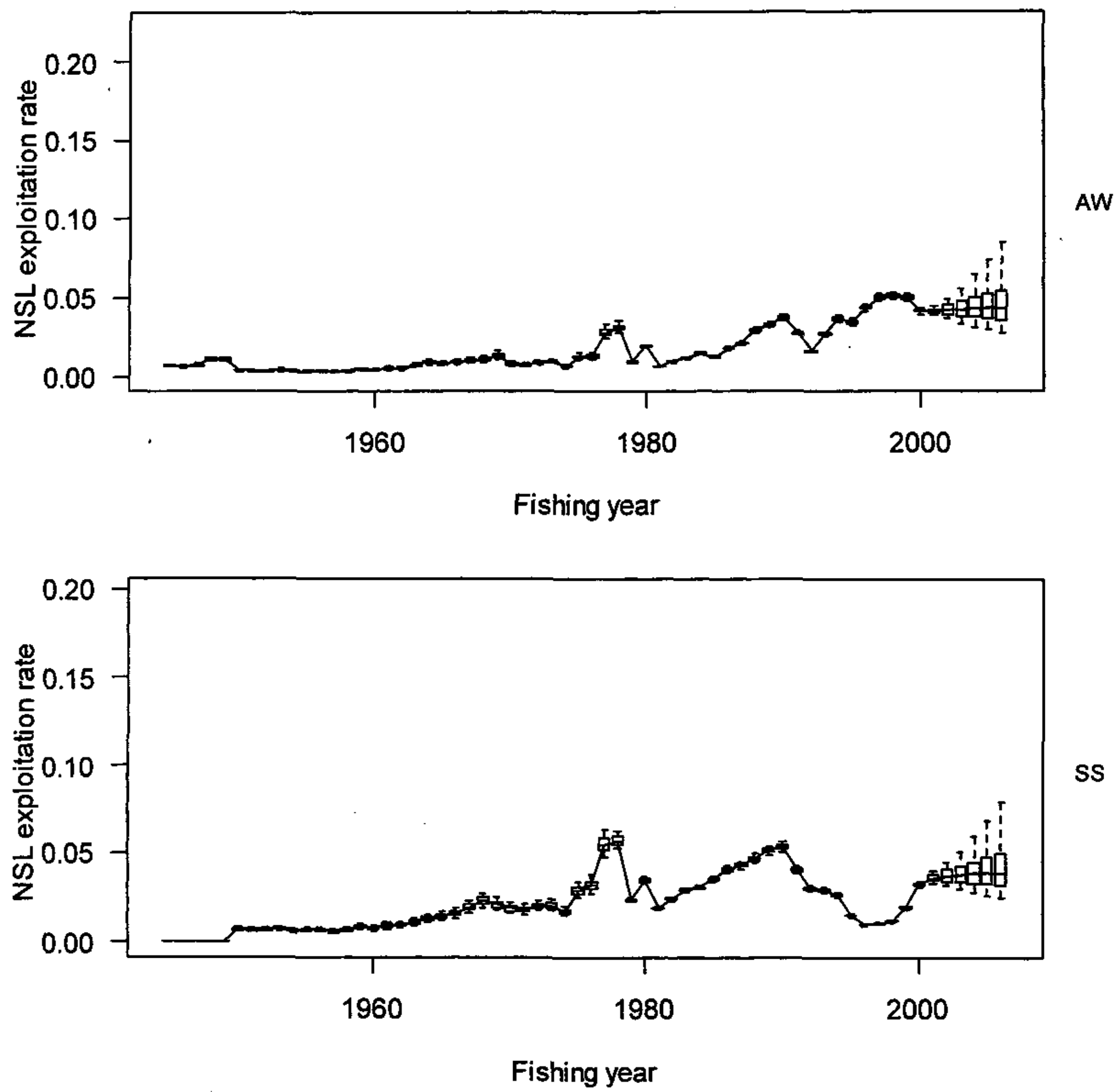


Figure 51: CRA 2: posterior trajectories of NSL exploitation rate, for the AW (top) and SS (bottom) seasons, from the CRA 2 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

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 through 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 y, and tag return records by i. In describing how length frequency records are handled, month is indexed by m and area by a. In discussing how growth of tagged lobsters is predicted, the number of moults is indexed by q. The subscript used to index the selectivity function parameters is z.

Table A1: Major variables and parameters of the assessment model

Structural and fixed variables	
$\overleftarrow{S}_s$	Smallest size modelled in size class s
$\overrightarrow{S}_s$	Largest size modelled in size class s
$\bar{S}_s$	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
$D_{m,a}$	Numbers of days sampled in month m and area a

$C_{m,a}$	Catch in month m and area a within a period
$c_{m,a}$	Calculated weight for length frequencies from month m and area a
$n^g_{m,a,s}$	Number of lobsters sampled in month m, area a and size s within a period
$p^g_{m,a,s}$	Proportion of lobsters sampled in month m, area a 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_y	Recruitment deviation for year y
M	Instantaneous rate of natural mortality (per year)
r_k^g	Relative seasonal vulnerability for sex g and season k
η_z^g	Size of maximum selectivity of sex g for selectivity function z
v_z^g	Shape parameter for the left hand limb of the selectivity curve for sex g and selectivity function in epoch z
w^g	Shape parameter for the right hand limb of the selectivity curve for sex g in all epochs
d_{50}^g	Mean expected moult increment for a lobster of size 50 mm TW and sex g
d_{80}^g	Mean expected moult increment for a lobster of size 80 mm TW and sex g
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
$L_{s,t}^g$	Legal status flag (zero or one) for individuals of sex g and size s in period t. Mature females are assumed to be berried and are therefore not legal in *AW*.
$\mathbf{R}_0$	Vector of average recruitment-at-size
$\mathbf{N}_0^g$	Vector of numbers-at-size for sex g in the unexploited population at equilibrium
b^g	Slope of the growth increment-at-size relation for sex g
y^g	y-intercept of the growth increment-at-size relation for sex g
d_s^g	Expected growth increment of an individual of size s and sex g
φ_s^g	Standard deviation of the growth increment for an animal of sex g and size s
$\mathbf{X}_k^g$	Growth transition matrix for sex g in season k
$X_{s,s',k}^g$	One cell of $\mathbf{X}_k^g$: the proportion of individuals of sex g that grow from size-class s to size-class s' in season k

$\hat{S}^g_{s,t+1}$	Expected size of an individual of size s and sex g after moulting
$V^g_{s,k,z}$	Total vulnerability, incorporating selectivity and seasonal vulnerability, of an individual of sex g and size s in epoch z
$T^g_{s,z}$	Intermediate term used in calculating $V^g_{s,k,z}$
$\mathbf{Q}$	Vector of the probability of females maturing-at-size
Q_s	Probability that an immature female at size s will become mature during period

State variables

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

Model predictions

$\hat{I}_t$	Predicted CPUE for period t
$\hat{CR}_t$	Predicted historical catch rate for period t
$\hat{p}^g_{s,t}$	Predicted proportion-at-size for size g and sex s in period t
$\hat{S}^{g,recap}_i$	Predicted size at recapture for the ith tagged lobster
φ^g_i	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^I_t	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
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, although in this study only one was 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. It is assumed that the maximum relative seasonal vulnerability is for males in spring-summer, i.e., $r_{SS}^{male} = 1$. It is also 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.

A.4 Vulnerable biomass

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

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

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

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

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

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

Eq. 5 $$L_{s,t}^g = \begin{cases} 0 & \bar{S}_s \le l_t^g \\ 1 & \bar{S}_s > l_t^g \end{cases}$$

and $L_{s,t}^g$ is zero for all mature females in the autumn-winter season. The SL biomass is

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

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

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

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

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

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_{50}^{g} and d_{80}^{g}, the expected increments for lobsters of 50 and 80 mm TW for sex g. From those, the mean expected increment j_{s}^{g} can be calculated for each size s for each sex g:

Eq. 17 $$d_{s}^{g} = y^{g} + h^{g}\,\overline{S}_{s}$$

but is constrained with the AD Model Builder™ "posfun" function to be positive. The slope is determined from

Eq. 18 $$h^{g} = \left(d_{80}^{g} - d_{50}^{g}\right)/30$$

and the intercept from

Eq. 19 $$y^{g} = d_{50}^{g} - 50h^{g}$$

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 $$\varphi_{s}^{g} = \left(j_{s}^{g}CV^{g} - \varphi^{d,\min}\right)\left(\frac{1}{\pi}\times\tan^{-1}\left(\left(d_{s}^{g}CV^{g} - \varphi^{d,\min}\right)\times10^{6}\right)+0.5\right)+\varphi^{d,\min}$$

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, $\bar{S}_{s'}$ to ∞. With the sex index, g, and the season index, k, suppressed this is:

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

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

Eq. 23 $$\dddot{N}_{s',t}^g = \sum_s \left(X_{s,s'}^g \ddot{N}_{s,t}^g \right) + R_{s',t+1}$$

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

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

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

where it is assumed that the recruitment deviations ε_y 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 $$R_{s,t} = R_t \frac{\exp\left(-(\bar{S}_s - \phi)^2 \Big/ 2\gamma^2\right)}{\sum_s \exp\left(-(\bar{S}_s - \phi)^2 \Big/ 2\gamma^2\right)}$$

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

A.10 Maturation

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

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

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

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

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

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

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

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

A.11 Predictions and likelihoods for abundance indices

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

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

where χ determines the shape of the relationship and the scaling coefficient q^I is calculated from:

Eq. 32 $$q^I = \exp\left[\frac{\sum_t \frac{(\varpi^I)^2}{(\sigma_t^I \tilde{\sigma})^2} \ln\left(\frac{I_t}{(B_{t+0.5}^{SL})^{\chi}}\right)}{\sum_t \frac{(\varpi^I)^2}{(\sigma_t^I \tilde{\sigma})^2}}\right]$$

where the standard deviation σ_t^I for each period is obtained from the standardisation process, ϖ^I is the relative weight applied to the standardised CPUE index data set and $\tilde{\sigma}$ is the estimated common error component.

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

Eq. 33 $$L(\hat{I}_t \mid \theta) = \frac{\varpi^I}{\sigma_t^I \tilde{\sigma}\sqrt{2\pi}} \exp\left[\frac{-(\ln(I_t) - \ln(\hat{I}_t))^2}{2(\sigma_t^I \tilde{\sigma} / \varpi^I)^2}\right].$$

The normalised residual is:

Eq. 34 $$residual = \frac{\ln(I_t) - \ln(\hat{I}_t)}{(\sigma_t^I \tilde{\sigma} / \varpi^I)}$$

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

Eq. 35 $$C\hat{R}_t = q^{CR} B_{t+0.5}^{SL}$$

where the scaling coefficient q^{CR} is calculated from:

Eq. 36 $$q^{CR} = \exp\left[\frac{\sum_t \frac{(\varpi^{CR})^2}{(\sigma_t^{CR} \tilde{\sigma})^2} \ln\left(\frac{CR_t}{B_{t+0.5}^{SL}}\right)}{\sum_t \frac{(\varpi^{CR})^2}{(\sigma_t^{CR} \tilde{\sigma})^2}}\right]$$

where the standard deviation σ_t^{CR}, constant for all observations, is assumed to be 0.3 and ϖ^{CR} is the relative weight applied to the catch rate index data set.

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

Eq. 37 $$L(C\hat{R}_t \mid \theta) = \frac{\varpi^{CR}}{\sigma_t^{CR} \tilde{\sigma}\sqrt{2\pi}} \exp\left[\frac{-(\ln(CR_t) - \ln(C\hat{R}_t))^2}{2(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR})^2}\right].$$

The normalised residual is

Eq. 38 $residual = \frac{\ln(CR_t) - \ln(\hat{CR}_t)}{\left(\sigma_t^{CR}\tilde{\sigma} / \varpi^{CR}\right)}$

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

The observed relative proportions-at-size $p^g_{s,t}$ 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. 39 $$\hat{p}^g_{s,t} = \frac{V^g_{s,k,z} N^g_{s,t+0.5}}{\sum_g \sum_s V^g_{s,k,z} N^g_{s,t+0.5}}$$

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

Eq. 40 $$L(\hat{p}^g_{s,t} \mid \theta) = \frac{\kappa_t \varpi^p \sqrt{\left(p^g_{s,t} + 0.1\right)}}{\tilde{\sigma}\sqrt{2\pi}} \exp\left(\frac{-\left(p^g_{s,t} + 0.1\right)\left(\hat{p}^g_{s,t} - p^g_{s,t}\right)^2}{2\left(\tilde{\sigma} / \kappa_t \varpi^p\right)^2} \right)$$

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 1 or CRA 2). If m indexes month and a indexes statistical area, the proportion of lobsters in sex g at size s, aggregated within the area x month cell, $p^g_{m,a,s}$, can be expressed as

Eq. 41 $$p^g_{m,a,s} = n^g_{m,a,s} \Big/ \sum_g \sum_s n^g_{m,a,s}$$

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

Eq. 42 $$c_{m,a} = \frac{\sqrt[3]{\sum_g \sum_s N^g_{m,a,s}} \sqrt[3]{D_{m,a}}\, C_{m,a}}{\sum_m \sum_a C_{m,a}}$$

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

Eq. 43 $$p^g_{s,t} = \frac{c_{m,a} p^g_{m,a,s}}{\sum_m \sum_a \sum_s \sum_g \left(c_{m,a} p^g_{m,a,s}\right)}$$

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

Eq. 44 $\kappa_t = \sum_m \sum_a c_{m,a}$.

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. 45 $$residual = \frac{\sqrt{p_{s,t}^g + 0.1}\left(\hat{p}_{s,t}^g - p_{s,t}^g\right)}{\left(\tilde{\sigma} / \kappa_t \varpi^p\right)}$$

A.13 Likelihood of tag size increments

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

Eq. 46 $$\hat{S}_i^{g,recap} = S_i^{g,tag} + y^g + h^g \, S_i^{g,tag}$$

If the animal was at liberty for more than one moulting period for that sex, then the resulting size is calculated as above, replacing $S_{i,q}^{g,tag}$ with the result of Eq. 46, and so on.

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

Eq. 47 $$L\left(\hat{S}_i^{g,recap} \mid \theta\right) = \frac{1}{\sqrt{2\pi}\varphi_i^g} \exp\left(-\frac{\left(S_i^{g,recap} - \hat{S}_i^{g,recap}\right)^2}{2\left(\varphi_i^g\right)^2} \right)$$

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. 48

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

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. 49 $$\left(\varphi_s^g\right)^2 = \sum_q \left(\varphi_{s,q}^g\right)^2 + \left(\sigma^{d,obs} \tilde{\sigma} / \varpi^{TAG}\right)^2$$

where

Eq. 50

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

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

The normalised residual is:

Eq. 51 $$residual = \frac{S_{i}^{g,recap} - \hat{S}_{i}^{g,recap}}{\varphi_{i}^{g}}$$

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. 52 $$L\left(\varepsilon_{y} \mid \theta\right) = \frac{1}{\sigma^{\varepsilon}\sqrt{2\pi}}\exp\left[\frac{-\sum\left(\varepsilon_{y}\right)^{2}}{2\left(\sigma^{\varepsilon}\right)^{2}}\right]$$

APPENDIX B. DATA USED IN THE ASSESSMENT

B.1 CRA 1 data

Table B1: Catch data in kilograms used for the CRA 1 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]	Export discrepancy unreported[3]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1945	1	1	4 815	0	944	0	884	1945
1945	2	2	17 285	0	8 494	0	3 173	1945
1946	1	3	4 959	0	1 055	0	910	1946
1946	2	4	17 801	0	9 494	0	3 267	1946
1947	1	5	8 711	0	1 166	0	1 599	1947
1947	2	6	31 271	0	10 493	0	5 740	1947
1948	1	7	19 769	0	1 277	0	3 629	1948
1948	2	8	70 965	0	11 492	0	13 026	1948
1949	1	9	22 702	0	1 388	0	4 167	1949
1949	2	10	81 495	0	12 491	0	14 959	1949
1950	1	11	20 134	0	1 499	0	3 696	1950
1950	2	12	72 277	0	13 491	0	13 267	1950
1951	1	13	18 518	0	1 610	0	3 399	1951
1951	2	14	66 475	0	14 490	0	12 202	1951
1952	1	15	29 122	0	1 721	0	5 346	1952
1952	2	16	104 541	0	15 489	0	19 189	1952
1953	1	17	28 591	0	1 832	0	5 248	1953
1953	2	18	102 634	0	16 489	0	18 839	1953
1954	1	19	15 685	0	1 943	0	2 879	1954
1954	2	20	56 303	0	17 488	0	10 335	1954
1955	1	21	13 936	0	2 054	0	2 558	1955
1955	2	22	50 025	0	18 487	0	9 183	1955
1956	1	23	16 393	0	2 165	0	3 009	1956
1956	2	24	58 846	0	19 487	0	10 802	1956
1957	1	25	13 216	0	2 276	0	2 426	1957
1957	2	26	47 443	0	20 486	0	8 709	1957
1958	1	27	13 515	0	2 387	0	2 481	1958
1958	2	28	48 516	0	21 485	0	8 906	1958
1959	1	29	13 559	0	2 498	0	2 489	1959
1959	2	30	48 674	0	22 485	0	8 935	1959
1960	1	31	16 364	0	2 609	0	3 004	1960
1960	2	32	58 742	0	23 484	0	10 783	1960
1961	1	33	17 644	0	2 720	0	3 239	1961
1961	2	34	63 337	0	24 483	0	11 626	1961
1962	1	35	29 532	0	2 831	0	5 421	1962
1962	2	36	106 011	0	25 483	0	19 459	1962
1963	1	37	28 470	0	2 942	0	5 226	1963
1963	2	38	79 530	0	26 482	0	14 599	1963
1964	1	39	47 841	0	3 053	0	8 782	1964
1964	2	40	171 159	0	27 481	0	31 418	1964

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Export discrepancy unreported[3]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1965	1	41	32 362	0	3 165	0	5 940	1 000
1965	2	42	216 638	0	28 481	0	39 766	9 000
1966	1	43	47 487	0	3 276	0	8 717	1 000
1966	2	44	135 513	0	29 480	0	24 875	9 000
1967	1	45	19 120	0	3 387	0	3 510	1 000
1967	2	46	129 880	0	30 479	0	23 841	9 000
1968	1	47	49 605	0	3 498	0	9 105	1 000
1968	2	48	167 395	0	31 479	0	30 727	9 000
1969	1	49	103 853	0	3 609	0	19 063	1 000
1969	2	50	234 147	0	32 478	0	42 980	9 000
1970	1	51	73 277	0	3 720	0	13 451	1 000
1970	2	52	258 723	0	33 477	0	47 491	9 000
1971	1	53	80 173	0	3 831	0	14 716	1 000
1971	2	54	256 827	0	34 476	0	47 143	9 000
1972	1	55	80 767	0	3 942	0	14 826	1 000
1972	2	56	151 233	0	35 476	0	27 760	9 000
1973	1	57	32 054	0	4 053	0	5 884	1 000
1973	2	58	44 946	0	36 475	0	8 250	9 000
1974	1	59	11 241	5 926	4 164	0	1 480	1 000
1974	2	60	33 759	19 458	37 474	0	4 446	9 000
1975	1	61	19 484	19 762	4 275	0	4 861	1 000
1975	2	62	58 516	48 094	38 474	0	14 598	9 000
1976	1	63	24 730	38 544	4 386	0	4 936	1 000
1976	2	64	74 270	9 049	39 473	0	14 825	9 000
1977	1	65	45 463	18 504	4 497	0	12 014	1 000
1977	2	66	136 537	0	40 472	0	36 081	9 000
1978	1	67	37 274	0	4 608	0	9 628	1 000
1978	2	68	111 941	0	41 472	0	28 915	9 000
1979	1	69	25 361	0	4 719	0	1 995	1 000
1979	2	70	89 675	0	42 471	0	7 054	9 000
1980	1	71	32 391	0	4 719	0	3 334	1 000
1980	2	72	147 394	0	42 471	0	15 170	9 000
1981	1	73	32 565	0	4 719	0	978	1 000
1981	2	74	151 325	0	42 471	0	4 546	9 000
1982	1	75	44 074	0	4 719	0	1 362	1 000
1982	2	76	178 940	0	42 471	0	5 529	9 000
1983	1	77	57 012	0	4 719	0	2 032	1 000
1983	2	78	174 690	0	42 471	0	6 225	9 000
1984	1	79	49 523	0	4 719	0	2 252	1 000
1984	2	80	162 036	0	42 471	0	7 370	9 000
1985	1	81	53 555	0	4 719	0	2 690	1 000
1985	2	82	165 202	0	42 471	0	8 298	9 000
1986	1	83	60 978	0	4 719	0	3 677	1 000
1986	2	84	143 870	0	42 471	0	8 677	9 000
1987	1	85	35 630	0	4 719	0	2 949	1 000
1987	2	86	130 153	0	42 471	0	10 771	9 000
1988	1	87	28 877	0	4 719	0	3 528	1 000
1988	2	88	149 683	0	42 471	0	18 286	9 000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Export discrepancy unreported[3]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1989	1	89	11 455	0	4 719	0	1 969	1 000
1989	2	90	162 559	0	42 471	0	27 938	9 000
1990	1	91	44 978	0	4 719	0	13 040	1 000
1990	2	92	86 090	0	42 471	0	24 960	9 000
1991	1	93	39 026	0	4 719	0	7 454	1 000
1991	2	94	89 238	0	42 471	0	17 046	9 000
1992	1	95	30 196	0	4 719	0	3 007	1 000
1992	2	96	80 266	0	42 471	0	7 993	9 000
1993	1	97	33 815	0	4 719	0	3 451	1 000
1993	2	98	93 570	0	42 471	0	9 549	9 000
1994	1	99	46 091	0	4 719	0	5 319	1 000
1994	2	100	83 886	0	42 471	0	9 681	9 000
1995	1	101	71 199	0	4 719	0	8 428	1 000
1995	2	102	55 525	0	42 471	0	6 572	9 000
1996	1	103	76 602	0	4 719	0	25 751	1 000
1996	2	104	52 801	0	42 471	0	17 749	9 000
1997	1	105	101 278	0	4 719	0	56 393	1 000
1997	2	106	28 030	0	42 471	0	15 607	9 000
1998	1	107	106 634	0	4 719	0	59 674	1 000
1998	2	108	22 026	0	42 471	0	12 326	9 000
1999	1	109	100 799	0	4 719	0	57 718	1 000
1999	2	110	24 943	0	42 471	0	14 282	9 000
2000	1	111	93 528	0	4 719	0	51 437	1 000
2000	2	112	37 389	0	42 471	0	20 563	9 000
2001	1	113	97 233	0	4 719	0	54 162	1 000
2001	2	114	32 023	0	42 471	0	17 838	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 only been estimated 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 1 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]	Recruitment period[7]
1945	1	1	0	0	0	0	0	0	0
1945	2	2	0	0	0	0	0	0	0
1946	1	3	0	0	0	0	0	0	0
1946	2	4	0	0	0	0	0	0	0
1947	1	5	0	0	0	0	0	0	0
1947	2	6	0	0	0	0	0	0	0
1948	1	7	0	0	0	0	0	0	0
1948	2	8	0	0	0	0	0	0	0
1949	1	9	0	0	0	0	0	0	0
1949	2	10	0	0	0	0	0	0	0
1950	1	11	0	0	0	0	47	49	0
1950	2	12	0	0	0	0	47	49	0
1951	1	13	0	0	0	0	47	49	0
1951	2	14	0	0	0	0	47	49	0
1952	1	15	0	0	0	0	51	53	0
1952	2	16	0	0	0	0	51	53	0
1953	1	17	0	0	0	0	51	53	0
1953	2	18	0	0	0	0	51	53	0
1954	1	19	0	0	0	0	51	53	0
1954	2	20	0	0	0	0	51	53	0
1955	1	21	0	0	0	0	51	53	0
1955	2	22	0	0	0	0	51	53	0
1956	1	23	0	0	0	0	51	53	0
1956	2	24	0	0	0	0	51	53	0
1957	1	25	0	0	0	0	51	53	0
1957	2	26	0	0	0	0	51	53	0
1958	1	27	0	0	0	0	51	53	0
1958	2	28	0	0	0	0	51	53	0
1959	1	29	0	0	0	0	53	58	0
1959	2	30	0	0	0	0	53	58	0
1960	1	31	0	0	0	0	53	58	1
1960	2	32	0	0	0	0	53	58	1
1961	1	33	0	0	0	0	53	58	1
1961	2	34	0	0	0	0	53	58	1
1962	1	35	0	0	0	0	53	58	1
1962	2	36	0	0	0	0	53	58	1
1963	1	37	0	0	42.2	0	53	58	2
1963	2	38	0	0	57.2	0	53	58	2
1964	1	39	0	0	49.4	0	53	58	2
1964	2	40	0	0	104.5	0	53	58	2
1965	1	41	0	0	42.2	0	53	58	2
1965	2	42	0	0	98.9	0	53	58	2
1966	1	43	0	0	43.2	0	53	58	3
1966	2	44	0	0	55.7	0	53	58	3
1967	1	45	0	0	33.4	0	53	58	3

Fishing year	Season[1]	Sequential season number	CPUE biomass indices[2]	σ^{1} [3]	Historical CPUE [4]	Settlement indices [5]	Male size limit [6]	Female size limit [6]	Recruitment period[7]
1967	2	46	0	0	70.3	0	53	58	3
1968	1	47	0	0	31.3	0	53	58	3
1968	2	48	0	0	44.0	0	53	58	3
1969	1	49	0	0	36.8	0	53	58	4
1969	2	50	0	0	45.2	0	53	58	4
1970	1	51	0	0	35.9	0	53	58	4
1970	2	52	0	0	64.6	0	53	58	4
1971	1	53	0	0	38.9	0	53	58	4
1971	2	54	0	0	47.4	0	53	58	4
1972	1	55	0	0	20.2	0	53	58	5
1972	2	56	0	0	21.9	0	53	58	5
1973	1	57	0	0	14.9	0	53	58	5
1973	2	58	0	0	0	0	53	58	5
1974	1	59	0	0	0	0	53	58	5
1974	2	60	0	0	0	0	53	58	5
1975	1	61	0	0	0	0	53	58	6
1975	2	62	0	0	0	0	53	58	6
1976	1	63	0	0	0	0	53	58	6
1976	2	64	0	0	0	0	53	58	6
1977	1	65	0	0	0	0	53	58	7
1977	2	66	0	0	0	0	53	58	7
1978	1	67	0	0	0	0	53	58	7
1978	2	68	0	0	0	0	53	58	7
1979	1	69	0.836	0.262	0	0	53	58	8
1979	2	70	0.751	0.256	0	0	53	58	8
1980	1	71	0.978	0.262	0	0	53	58	9
1980	2	72	0.903	0.257	0	0	53	58	9
1981	1	73	0.799	0.264	0	0	53	58	10
1981	2	74	0.915	0.258	0	0	53	58	10
1982	1	75	0.852	0.262	0	0	53	58	11
1982	2	76	0.951	0.257	0	0	53	58	11
1983	1	77	0.872	0.263	0	0	53	58	12
1983	2	78	0.926	0.257	0	0	53	58	12
1984	1	79	0.882	0.263	0	0	53	58	13
1984	2	80	0.839	0.257	0	0	53	58	13
1985	1	81	0.734	0.260	0	0	53	58	14
1985	2	82	0.824	0.257	0	0	53	58	14
1986	1	83	0.741	0.261	0	0	53	58	15
1986	2	84	0.769	0.256	0	0	53	58	15
1987	1	85	0.599	0.261	0	0	53	58	16
1987	2	86	0.780	0.257	0	0	53	58	16
1988	1	87	0.700	0.267	0	0	54	58	17
1988	2	88	0.640	0.258	0	0	54	58	17
1989	1	89	0.432	0.282	0	0	54	58	18
1989	2	90	0.826	0.258	0	0	54	58	18
1990	1	91	0.511	0.262	0	0	54	58	19
1990	2	92	0.739	0.258	0	0	54	58	19
1991	1	93	0.626	0.260	0	0	54	58	20

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]	Recruitment period[7]
1991	2	94	0.691	0.257	0	0	54	58	20
1992	1	95	0.469	0.261	0	0	54	60	21
1992	2	96	0.629	0.257	0	0	54	60	21
1993	1	97	0.558	0.261	0	0	54	60	22
1993	2	98	0.839	0.258	0	0	54	60	22
1994	1	99	0.757	0.262	0	0	54	60	23
1994	2	100	1.101	0.259	0	0	54	60	23
1995	1	101	1.136	0.262	0	0	54	60	24
1995	2	102	1.381	0.264	0	0	54	60	24
1996	1	103	1.103	0.262	0	0	54	60	25
1996	2	104	1.390	0.265	0	0	54	60	25
1997	1	105	1.097	0.262	0	0	54	60	26
1997	2	106	1.247	0.274	0	0	54	60	26
1998	1	107	1.200	0.264	0	0	54	60	27
1998	2	108	1.509	0.276	0	0	54	60	27
1999	1	109	1.072	0.264	0	0	54	60	28
1999	2	110	1.166	0.275	0	0	54	60	28
2000	1	111	1.087	0.264	0	0	54	60	29
2000	2	112	1.595	0.271	0	0	54	60	29
2001	1	113	1.369	0.265	0	0	54	60	30
2001	2	114	1.487	0.276	0	0	54	60	30

[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 2 data

Table B3: Catch data in kilograms used for the CRA 2 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]	Export discrepancy unreported[3]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1945	1	1	56 374	0	2 453	588	9 760	1 000
1945	2	2	80 388	0	22 075	838	13 918	9 000
1946	1	3	48 186	0	2 741	503	8 342	1 000
1946	2	4	68 712	0	24 672	717	11 896	9 000
1947	1	5	53 463	0	3 030	558	9 256	1 000
1947	2	6	76 238	0	27 269	795	13 199	9 000
1948	1	7	87 492	0	3 318	912	15 147	1 000
1948	2	8	124 763	0	29 866	1 301	21 600	9 000
1949	1	9	81 713	0	3 607	852	14 147	1 000
1949	2	10	116 522	0	32 464	1 215	20 173	9 000
1950	1	11	86 194	0	3 896	899	14 923	1 000
1950	2	12	122 912	0	35 061	1 282	21 280	9 000
1951	1	13	78 823	0	4 184	822	13 647	1 000
1951	2	14	112 401	0	37 658	1 172	19 460	9 000
1952	1	15	73 734	0	4 473	769	12 766	1 000
1952	2	16	105 144	0	40 255	1 097	18 204	9 000
1953	1	17	78 697	0	4 761	821	13 625	1 000
1953	2	18	112 222	0	42 852	1 170	19 429	9 000
1954	1	19	61 797	0	5 050	645	10 699	1 000
1954	2	20	88 123	0	45 449	919	15 257	9 000
1955	1	21	63 954	0	5 338	667	11 072	1 000
1955	2	22	91 198	0	48 046	951	15 789	9 000
1956	1	23	65 923	0	5 627	688	11 413	1 000
1956	2	24	94 005	0	50 643	980	16 275	9 000
1957	1	25	51 945	0	5 916	542	8 993	1 000
1957	2	26	74 074	0	53 240	773	12 824	9 000
1958	1	27	63 891	0	6 204	666	11 061	1 000
1958	2	28	91 109	0	55 837	950	15 774	9 000
1959	1	29	79 283	0	6 493	827	13 726	1 000
1959	2	30	113 058	0	58 434	1 179	19 574	9 000
1960	1	31	68 855	0	6 781	718	11 921	1 000
1960	2	32	98 187	0	61 031	1 024	16 999	9 000
1961	1	33	81 985	0	7 070	855	14 194	1 000
1961	2	34	116 910	0	63 629	1 219	20 240	9 000
1962	1	35	83 744	0	7 358	873	14 499	1 000
1962	2	36	119 418	0	66 226	1 245	20 675	9 000
1963	1	37	105 017	0	7 647	1 095	18 182	1 000
1963	2	38	145 983	0	68 823	1 523	25 274	9 000
1964	1	39	135 770	0	7 936	1 416	23 506	1 000
1964	2	40	164 230	0	71 420	1 713	28 433	9 000
1965	1	41	114 642	0	8 224	1 196	19 848	1 000
1965	2	42	175 358	0	74 017	1 829	30 360	9 000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Export discrepancy unreported[3]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1966	1	43	117 819	0	8 513	1 229	20 398	1 000
1966	2	44	190 181	0	76 614	1 983	32 926	9 000
1967	1	45	121 558	0	8 801	1 268	21 045	1 000
1967	2	46	222 442	0	79 211	2 320	38 511	9 000
1968	1	47	116 035	0	9 090	1 210	20 089	1 000
1968	2	48	240 965	0	81 808	2 513	41 718	9 000
1969	1	49	126 891	0	9 378	1 323	21 969	1 000
1969	2	50	187 109	0	84 405	1 951	32 394	9 000
1970	1	51	65 798	0	9 667	686	11 391	1 000
1970	2	52	152 202	0	87 002	1 587	26 351	9 000
1971	1	53	60 323	0	9 955	629	10 444	1 000
1971	2	54	132 677	0	89 599	1 384	22 970	9 000
1972	1	55	67 730	0	10 244	706	11 726	1 000
1972	2	56	142 270	0	92 196	1 484	24 631	9 000
1973	1	57	62 943	0	10 533	656	10 897	1 000
1973	2	58	121 057	0	94 794	1 263	20 958	9 000
1974	1	59	50 351	0	10 821	377	6 254	1 000
1974	2	60	104 649	0	97 391	783	12 998	9 000
1975	1	61	44 829	0	11 110	635	10 548	1 000
1975	2	62	93 171	0	99 988	1 321	21 922	9 000
1976	1	63	46 778	0	11 398	531	8 807	1 000
1976	2	64	97 222	0	102 585	1 103	18 304	9 000
1977	1	65	64 645	0	11 687	971	16 112	1 000
1977	2	66	134 355	0	105 182	2 017	33 487	9 000
1978	1	67	77 928	0	11 975	1 144	18 986	1 000
1978	2	68	161 964	0	107 779	2 377	39 460	9 000
1979	1	69	86 524	0	12 264	387	6 420	1 000
1979	2	70	206 662	0	110 376	924	15 333	9 000
1980	1	71	172 593	0	12 264	1 009	16 754	1 000
1980	2	72	280 036	0	110 376	1 638	27 184	9 000
1981	1	73	120 608	0	12 264	245	4 061	1 000
1981	2	74	270 797	0	110 376	549	9 118	9 000
1982	1	75	109 676	0	12 264	331	5 502	1 000
1982	2	76	217 493	0	110 376	657	10 911	9 000
1983	1	77	83 995	0	12 264	362	6 009	1 000
1983	2	78	190 626	0	110 376	822	13 637	9 000
1984	1	79	92 134	0	12 264	470	7 800	1 000
1984	2	80	178 128	0	110 376	908	15 080	9 000
1985	1	81	88 535	0	12 264	412	6 846	1 000
1985	2	82	249 149	0	110 376	1 161	19 266	9 000
1986	1	83	79 815	0	12 264	530	8 795	1 000
1986	2	84	186 503	0	110 376	1 238	20 551	9 000
1987	1	85	71 569	0	12 264	625	10 378	1 000
1987	2	86	153 105	0	110 376	1 337	22 201	9 000
1988	1	87	83 233	0	12 264	987	16 381	1 000
1988	2	88	138 948	0	110 376	1 647	27 346	9 000
1989	1	89	94 371	0	12 264	1 234	20 492	1 000
1989	2	90	158 339	0	110 376	2 071	34 383	9 000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Export discrepancy unreported[3]	Recreational[4]	Reported illegal[5]	Unreported illegal[6]	Maori customary[7]
1990	1	91	93 404	0	12 264	1 563	25 951	1 000
1990	2	92	144 231	0	110 376	2 414	40 072	9 000
1991	1	93	93 145	0	12 264	1 233	20 466	1 000
1991	2	94	136 511	0	110 376	1 807	29 994	9 000
1992	1	95	64 616	0	12 264	714	11 852	1 000
1992	2	96	125 641	0	110 376	1 388	23 046	9 000
1993	1	97	102 494	0	12 264	1 450	24 063	1 000
1993	2	98	112 435	0	110 376	1 590	26 397	9 000
1994	1	99	125 391	0	12 264	2 343	38 900	1 000
1994	2	100	87 428	0	110 376	1 634	27 123	9 000
1995	1	101	158 157	0	12 264	2 538	42 127	1 000
1995	2	102	54 300	0	110 376	871	14 464	9 000
1996	1	103	187 848	0	12 264	3 705	61 507	1 000
1996	2	104	25 313	0	110 376	499	8 288	9 000
1997	1	105	209 052	0	12 264	4 459	74 019	1 000
1997	2	106	25 364	0	110 376	541	8 981	9 000
1998	1	107	203 103	0	12 264	4 371	72 561	1 000
1998	2	108	29 220	0	110 376	629	10 439	9 000
1999	1	109	178 856	0	12 264	3 804	63 146	1 000
1999	2	110	56 236	0	110 376	1 196	19 854	9 000
2000	1	111	132 420	0	12 264	2 812	46 685	1 000
2000	2	112	103 005	0	110 376	2 188	36 315	9 000
2001	1	113	118 733	0	12 264	2 639	43 806	1 000
2001	2	114	106 232	0	110 376	2 361	39 194	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 only been estimated 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 2 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]	Recruitment period[7]
1945	1	1	0	0	0	0	0	0	0
1945	2	2	0	0	0	0	0	0	0
1946	1	3	0	0	0	0	0	0	0
1946	2	4	0	0	0	0	0	0	0
1947	1	5	0	0	0	0	0	0	0
1947	2	6	0	0	0	0	0	0	0
1948	1	7	0	0	0	0	0	0	0
1948	2	8	0	0	0	0	0	0	0
1949	1	9	0	0	0	0	0	0	0
1949	2	10	0	0	0	0	0	0	0
1950	1	11	0	0	0	0	47	49	0
1950	2	12	0	0	0	0	47	49	0
1951	1	13	0	0	0	0	47	49	0
1951	2	14	0	0	0	0	47	49	0
1952	1	15	0	0	0	0	51	53	0
1952	2	16	0	0	0	0	51	53	0
1953	1	17	0	0	0	0	51	53	0
1953	2	18	0	0	0	0	51	53	0
1954	1	19	0	0	0	0	51	53	0
1954	2	20	0	0	0	0	51	53	0
1955	1	21	0	0	0	0	51	53	0
1955	2	22	0	0	0	0	51	53	0
1956	1	23	0	0	0	0	51	53	0
1956	2	24	0	0	0	0	51	53	0
1957	1	25	0	0	0	0	51	53	0
1957	2	26	0	0	0	0	51	53	0
1958	1	27	0	0	0	0	51	53	0
1958	2	28	0	0	0	0	51	53	0
1959	1	29	0	0	0	0	53	58	0
1959	2	30	0	0	0	0	53	58	0
1960	1	31	0	0	0	0	53	58	1
1960	2	32	0	0	0	0	53	58	1
1961	1	33	0	0	0	0	53	58	1
1961	2	34	0	0	0	0	53	58	1
1962	1	35	0	0	0	0	53	58	1
1962	2	36	0	0	0	0	53	58	1
1963	1	37	0	0	37.61	0	53	58	2
1963	2	38	0	0	39.40	0	53	58	2
1964	1	39	0	0	41.00	0	53	58	2
1964	2	40	0	0	41.24	0	53	58	2
1965	1	41	0	0	34.72	0	53	58	2
1965	2	42	0	0	36.78	0	53	58	2
1966	1	43	0	0	35.79	0	53	58	3
1966	2	44	0	0	40.66	0	53	58	3
1967	1	45	0	0	39.43	0	53	58	3

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]	Recruitment period[7]
1967	2	46	0	0	42.63	0	53	58	3
1968	1	47	0	0	28.25	0	53	58	3
1968	2	48	0	0	32.66	0	53	58	3
1969	1	49	0	0	20.83	0	53	58	4
1969	2	50	0	0	24.11	0	53	58	4
1970	1	51	0	0	21.31	0	53	58	4
1970	2	52	0	0	28.35	0	53	58	4
1971	1	53	0	0	21.44	0	53	58	4
1971	2	54	0	0	27.33	0	53	58	4
1972	1	55	0	0	21.27	0	53	58	5
1972	2	56	0	0	27.51	0	53	58	5
1973	1	57	0	0	18.47	0	53	58	5
1973	2	58	0	0	0	0	53	58	5
1974	1	59	0	0	0	0	53	58	5
1974	2	60	0	0	0	0	53	58	5
1975	1	61	0	0	0	0	53	58	6
1975	2	62	0	0	0	0	53	58	6
1976	1	63	0	0	0	0	53	58	6
1976	2	64	0	0	0	0	53	58	6
1977	1	65	0	0	0	0	53	58	6
1977	2	66	0	0	0	0	53	58	6
1978	1	67	0	0	0	0	53	58	7
1978	2	68	0	0	0	0	53	58	7
1979	1	69	0.441	0.253	0	0	53	58	7
1979	2	70	0.596	0.252	0	0	53	58	7
1980	1	71	0.624	0.252	0	0	53	58	7
1980	2	72	0.635	0.252	0	0	53	58	7
1981	1	73	0.432	0.253	0	0	53	58	8
1981	2	74	0.607	0.252	0	0	53	58	8
1982	1	75	0.397	0.253	0	0	53	58	8
1982	2	76	0.471	0.252	0	0	53	58	8
1983	1	77	0.307	0.253	0	0	53	58	9
1983	2	78	0.403	0.252	0	0	53	58	9
1984	1	79	0.330	0.253	0	0	53	58	9
1984	2	80	0.362	0.252	0	0	53	58	9
1985	1	81	0.339	0.253	0	0	53	58	10
1985	2	82	0.456	0.252	0	0	53	58	10
1986	1	83	0.337	0.253	0	0	53	58	10
1986	2	84	0.390	0.252	0	0	53	58	10
1987	1	85	0.264	0.253	0	0	53	58	11
1987	2	86	0.365	0.252	0	0	53	58	11
1988	1	87	0.308	0.254	0	0	54	58	11
1988	2	88	0.377	0.253	0	0	54	58	11
1989	1	89	0.245	0.257	0	0	54	58	12
1989	2	90	0.464	0.258	0	0	54	58	12
1990	1	91	0.396	0.254	0	0	54	58	13
1990	2	92	0.571	0.253	0	0	54	58	13
1991	1	93	0.379	0.254	0	0	54	58	14

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]	Recruitment period[7]
1991	2	94	0.520	0.253	0	0	54	58	14
1992	1	95	0.388	0.255	0	0	54	60	15
1992	2	96	0.494	0.254	0	0	54	60	15
1993	1	97	0.445	0.254	0	0	54	60	16
1993	2	98	0.531	0.254	0	0	54	60	16
1994	1	99	0.565	0.255	0	0	54	60	17
1994	2	100	0.640	0.256	0	0	54	60	17
1995	1	101	0.764	0.255	0	0	54	60	18
1995	2	102	1.091	0.260	0	0	54	60	18
1996	1	103	0.899	0.255	0	0	54	60	19
1996	2	104	0.989	0.268	0	0	54	60	19
1997	1	105	1.175	0.255	0	0	54	60	20
1997	2	106	1.323	0.271	0	0	54	60	20
1998	1	107	1.185	0.256	0	0	54	60	21
1998	2	108	1.319	0.265	0	0	54	60	21
1999	1	109	0.818	0.255	0	0	54	60	22
1999	2	110	1.113	0.263	0	0	54	60	22
2000	1	111	0.760	0.256	0	0	54	60	22
2000	2	112	1.031	0.258	0	0	54	60	22
2001	1	113	0.537	0.256	0	0	54	60	22
2001	2	114	0.749	0.257	0	0	54	60	22

[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