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The 2013 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2 and development of management procedures

New Zealand Fisheries Assessment Report 2014/19

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This document describes a new stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2 and evaluations of operational management procedures. The work was conducted by a stock assessment team contracted by the New Zealand Rock Lobster Industry Council Ltd.

The stock assessment was made using the length-based multi-stock model MSLM. The Rock Lobster Fishery Assessment Working Group oversaw this work, and all technical decisions were agreed beforehand or subsequently approved (and sometimes changed) by that group. The model was fitted to CPUE, size frequency data and tag-recapture data. This document describes the procedures used to find an acceptable base case and shows the model fits. The assessment was based on Markov chain-Monte Carlo (McMC) simulations, and the document describes the diagnostics for these and shows the results of the McMC sensitivity trials. Short-term projections were made at the current assumed levels of catch.

The assessment showed that current vulnerable biomass is below *Bref* (the mean vulnerable biomass at the start of the autumn-winter seasons for 1979–81), but is well above *Bmsy* and *Bmin* reference levels. Current fishing intensity is below *Fmsy*. At current catch levels, biomass was projected to stay about the same based on recent recruitments.

The assessment model was used as the basis for an operating model to test management procedures for CRA 2, which has not previously been managed in this way. At MPI request, the rules tested determined annual TACC as a function of offset-year CPUE. These rules were all “plateau” rules with a series of increasing steps above the right-hand edge of the plateau; this rule type imparts high catch stability. Each rule was tested with 1000 20-year simulations, based on the McMC posteriors, to address parameter uncertainty, and with stochastic variation in CPUE observation error and in recruitment. Rule behaviour under alternative operating model assumptions was tested using six robustness trials. The document illustrates model productivity and the major trade-offs among indicators. Final management procedure candidates were presented to the National Rock Lobster Management Group.

This document also provides a glossary of terms used in the stock assessment and management procedure evaluations to make it accessible to the non-specialist.

1. INTRODUCTION

This work addressed Objective 4 and part of Objective 5 of the Ministry for Primary Industries (MPI) contract CRA2012-01A. This three-year contract, which began in April 2013, was awarded to New Zealand Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contract Objectives 4 and 5 to the authors of this report.

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

Objective 5 - Decision rules: To evaluate new management procedures for rock lobster fisheries

The most recent previous assessment of CRA 2 was in 2002 (Starr et al. 2003). For 2013, the National Rock Lobster Management Group (NRLMG) agreed that Objective 4 should be addressed with a stock assessment for CRA 2, and that Objective 5 should be addressed by development of management procedures for CRA 2 and CRA 9. The CRA 9 work is described by Breen (2014). This document describes the CRA 2 work, using the data described by Starr et al. (2014).

The stock assessment used the length-based Bayesian model MSLM described by Haist et al. (2009) and followed the pattern of recent lobster stock assessments (e.g. Haist et al. 2013). Decisions on modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).

CRA 2 extends from the Waipu River through the Hauraki Gulf and Bay of Plenty to East Cape (see Figure 1). The current 452.6 tonnes TAC for the fishery was set in 1997. The TAC includes allowances for 140 tonnes of amateur catch, 16.5 tonnes of customary harvest and 60 tonnes of illegal removals. The current TACC has been 236.1 tonnes since 1997, and since 1993 the TACC has been more than 85% caught, except for 2002–04.

In 2010 the TACC was distributed amongst 43 quota share owners (NRLMG 2010), and in 2012–13 there were 35 vessels reporting commercial catches that exceeded 1 t (Starr 2013). The main operating period for commercial vessels generally extends from June to January. The estimated landed value of the CRA 2 catch was $13.1 million in 2010 (NRLMG 2010), based on the average port price. The industry sustains a number of processing and export companies in Tauranga, Whitianga and Auckland.

This study also developed management procedures for CRA 2. Management procedures are extensively simulation-tested decision rules: see Johnston & Butterworth (2005) for discussion of a management procedure used to manage rock lobsters in South Africa. Management procedures are now a major part of New Zealand rock lobster management (Bentley et al. 2003b; Breen et al. 2009b). They were used to rebuild the depleted CRA 8 stock in New Zealand and to manage the volatile CRA 7 stock (Starr et al. 1997; Bentley et al. 2003a; Breen et al. 2008; Haist et al. 2013); a voluntary management procedure was used to govern ACE shelving in CRA 4 to rebuild a badly depleted stock (Breen et al. 2009c) and was revised by Breen et al. (2012); a management procedure was adopted for CRA 5 for the 2012–13 season, after using a voluntary management procedure designed to maintain high abundance (Breen 2009a); a management procedure was adopted for CRA 3 in 2010 (see Breen et al. 2009a). Management procedures were explored with a surplus-production model for CRA 9 (Breen 2011, 2014) and CRA 6 (Breen 2009b).

This document describes the base case stock assessment, both MPD and McMC sensitivity trials, the projection model, management procedure evaluations and the final harvest control rules that were submitted to the NRLMG.

Technical terms used here are defined in the Glossary.

2. BASE CASE MPD AND SENSITIVITY TRIALS

2.1 Model parameters

The model is described by Haist et al. (2009). The descriptions and tables below refer to some of the model parameters, and the list below provides a description of the estimated parameters:

- ln(*R0*): the natural logarithm of average recruitment
- ln(*qCPUE*) and ln(*qCR*): the natural logarithms of catchability coefficients for the CPUE and CR abundance indices
- *M*: the instantaneous rate of fishing mortality
- *Rdev*s: annual recruitment deviations that allow annual recruitment to be less than or greater than average
- *sigmaR*: the standard deviation of *Rdev*s in ln space
- *CPUEpow*: a parameter that determines the shape of the relation between CPUE and abundance (1 implies linear)
- *Mat50*: size at which 50% of immature females become mature at a moult
- *Mat95add*: the difference between *mat50* and *mat95*
- *Galpha*: annual increment at 50 mm TW
- *Gdiff*: the estimated difference between *Galpha* and *GBeta*

- *GBeta*: : annual increment at 80 mm TW
- *GrowthCV*: the relation between expected increment and its standard deviation
- *Gshape*: a shape parameter: 1 gives a linear relation between increment and initial size while greater than 1 gives a curve concave upwards
- *GrowthDD*: a density-dependent growth parameter (described below)
- *StdObs*: standard deviation of observation error
- *StdMin*: the minimum standard deviation of growth
- *Vulns*: a set of four parameters that estimate the vulnerability of a sex class in a season relative to that of specified sex and season
- *Sel_L*: the shape of the left-hand side of the selectivity-at-length curve
- *Sel_Max*: the size at which selectivity-at-length is maximum
- *Sel_R*: the shape of the right-hand side of the selectivity-at-length curve
- *Gmax*: maximum growth increment for the inverse logistic growth model
- *L50*: the size at growth is 50% of maximum for the inverse logistic growth model
- *L95*: the size at which growth is 95% of maximum for the inverse logistic growth model.

The *GrowthDD* parameter can take values between 0 and 1. When it is active, the predicted growth increment is multiplied by the factor

$$1 - GrowthDD\left(B_t / B0\right)$$

where B_t is the total biomass in period *t* and $B0$ is the initial total biomass.

2.2 Stock assessment indicators

Indicators requested by MPI and subsequently agreed by the RLFAWG for this assessment were:

- *Bmin*: the minimum value of AW vulnerable biomass; for this and other biomass indicators, vulnerable biomass was calculated with the 2012 selectivity and MLS so that changes over time would not affect the vulnerable biomass estimate
- *Bcurr:* current biomass, taken as the beginning AW 2013 vulnerable biomass
- *Bproj:* projected biomass, taken as AW 2016 biomass; these projections were made using the 2012 catches and using stochastic recruitment based on the mean and standard deviation of recruitment deviations estimated from 2001–10
- *Bref:* reference biomass, taken as the mean of AW vulnerable biomass in 1979–81, with the vulnerable biomass defined as for *Bmin*
- *Bmsy:* the equilibrium AW vulnerable biomass associated with *MSY*, determined with a 50-year projection using the mean recruitment from 2000–09, using 2011 non-commercial catches and fishing patterns (AW/SS catch split, MLS, selectivity), using mean movement rates and full retention, and running a set of projections with multiples of the 2012 size-limited instantaneous fishing mortality rate *F*; the multiplier that gave maximum SL catch (*MSY*) was called *Fmult*, with the vulnerable biomass as for *Bmin*
- *SSBcurr, SSBproj, SSBmsy:* indicators using spawning stock biomass, taken as the weight of mature females at the beginning of the AW season
- *CPUEcurr, CPUEproj* and *CPUEmsy:* CPUE associated with the biomass indicators described above, determined with the estimated *qCPUE*
- *USLcurr and USLproj:* exploitation rate in AW 2011 and 2015, taken as SL catch divided by AW vulnerable biomass
- various ratios of these quantities
- the “soft limit” discussed by the Harvest Strategy Standard (MFish 2011) was agreed by theRLFAWG to be SSB equal to or less than 20% *SSB0*, and the hard limit was defined as SSB equal to or less than 10% *SSB0.*

Bref is meant to be the biomass in a time when the stock was stable, catch and CPUE were considered good, and the stock subsequently declined and recovered, indicating that the *Bref* was a safe place to be. The previous assessment used 1979–88, based on the biomass trajectory that was available at the time. The 2013 RLFAWG chose the period 1979–81 based on inspection of the vulnerable biomass trajectory (see Figure 19); this is shorter because the previously used period contained *Bmin*, which was thought to be inappropriate. *Bref* is calculated with the current (2012–13) regulations instead of the regulations that applied during 1979–81.

2.3 Model options

The multi-stock length-based model (MSLM) (Haist et al. 2009) has many options for alternative ways of fitting to data. This section describes those options and the choices made for the CRA 2 stock assessment.

Starting year: catch data for New Zealand rock lobster fisheries are available from 1945 (Annala & Esterman 1986), but the model can be started in any year. In some recent assessments, the model has been started in the 1970s to resolve fitting problems. For CRA 2, no problems were encountered in preliminary fits and the model was started in 1945.

Last year: was the last year of data, 2012–13[1].

Seasons: the model has a user-specified time step, and allows a change of time step size within the years being modelled; we used an annual step for 1945–78 and a 6-monthly time step for 1979–2012. An unavoidable over-simplification is that berried females are allowed to be caught in the model until 1979; there is no ability to divide earlier catches into 6-month seasons before 1979 without major arbitrary assumptions.

Size structure: the model size bins are flexible. As in previous assessments, we used 31 bins for each sex, each 2-mm wide with left-hand edges from 30 to 90 mm.

Model recruitment size: this is also flexible, and as in previous assessments we specified recruitment to the model with a mean of 32 mm tail width (TW) and a standard deviation of 2 mm.

Data switches: were turned on for length frequencies (LFs), catch per unit of effort (CPUE), the historical abundance index CR and tag data; were turned off for the pre-recruit index and puerulus (no pre-recruit or puerulus settlement indices are available for CRA 2).

Likelihoods: data sets can be fitted with a variety of likelihood options. For length frequencies, the model has used the multinomial in all recent assessments (but see below for a discussion of two alternative fitting approaches); for abundance indices, all recent assessments have used the lognormal; for tag-recapture increments all recent assessments have used robustified normal (see Bull et al. 2012).

(In 2012, the implementation of a robust normal likelihood for tag-recapture data was changed so that the dataset weight was not used in calculating the variance term for each record, instead, it was applied to the likelihood values after calculation. The reason for the change was that the dataset weight affected the operation of the robustification, but the change prevented us from using the standard deviation of normalised residuals (sdnr) as a diagnostic. For this assessment, we reverted to the robust normal likelihood as used in assessments before 2012.)

Dataset weights: were determined iteratively as discussed below.

Fishing mortality dynamics: the model uses instantaneous rate dynamics, and the choices are:

- using Newton-Raphson iteration to determine F from biomass, catch and M,
- estimating Fs as model parameters.

[1] which by convention and long usage is called “2012”

As in the past two stock assessments (Haist et al. 2013, Breen et al. 2012), we used the first option. The number of Newton-Raphson iterations is a sub-option, and we used four iterations but made an MPD sensitivity trial with three iterations.

Growth model: the model can use either a version of the Schnute-Francis model (Francis 1995) or the inverse logistic model (Haddon et al. 2008). We experimented with both: we chose the Schnute-Francis model for the base case based on a better fit when fitting only to tags and (to a lesser extent) better diagnostics.

Density-dependent growth: was used for the base case, and we conducted an MPD sensitivity trial with no density-dependence.

Stock-recruit function: we chose not to use this option; it is unlikely that recruitment originates within the stock (Chiswell & Booth 2008).

Movements: when fitting to data from multiple stocks, the model can estimate movements between stocks; CRA 2 was assessed as a single stock so this option was not used.

Recruitment deviations: can be estimated for all years or a subset of years; we estimated them from the first model year, 1945, through 2010.

Initial exploitation rate: this can be estimated, but, with a start in 1945 before any significant fishing mortality, we fixed it at zero, assuming a stock in equilibrium with average recruitment.

Selectivity epochs: the model can estimate different selectivity patterns in different periods called epochs; we specified two epochs with the second beginning in 1993, when escape gap and female minimum legal size (MLS) regulations changed.

Selectivity type: the model options are logistic or double normal; we chose double normal and forced the right-hand limb to be nearly asymptotic; an MPD sensitivity trial using logistic selectivity.

Year with sex/seasonal vulnerability equal to 1: the model estimates four sex/seasonal vulnerability parameters relative to a specified sex and season; we specified that males in AW should be 1. We used *vulnest1* for males in SS, *vulnest2* for immature females in AW, *vulnest3* for both types of female in SS and *vulnest4* for mature females in AW. Preliminary fits is gave estimated values for the four relative sex/seasonal parameters that were all less than 1.

2.4 Fitting to length frequencies

For this assessment, the model had two options for fitting the length frequencies (LFs). The option used in previous assessments compared observations and predictions that were normalised across all three sex groups; thus the model was estimating both the relative proportions of males by size and the relative proportion of males against females at the same time. The sdnr used to balance the dataset weight was based on predicted and observed mean lengths of fish for each record: the model did not fit to these but it calculated the sdnr. Under this option, the model uses one dataset weight for the LFs.

In the new option, the model fits to each sex class separately, so within a record, each sex class is normalised independently of the others. The model independently fits to the proportions-at-sex using multinomial likelihood. Under this option, the model uses three weights for the proportions-at-size in the three sex classes and a fourth for the overall sex proportions.

We chose to use the second approach in the base case, and ran an MPD sensitivity trial with the option used in previous assessments.

2.5 Modification to tag-recapture data

A second change from previous practice was made after examining diagnostics, in exploratory fitting, for the tag residuals as a function of the number of re-releases (Figure 2; diagnostics from the inverse logistic model were similar). Fish that had been re-released tended to have smaller than predicted increments. This is known as “Punt’s phenomenon”, and may be caused by slower-growing fish being less likely to be above the MLS and thus more likely to be returned to the sea. Because the inclusion of re-released tags may bias the growth estimates, we removed them from the data set. This reduced the tag-recapture dataset by 24%, from 3207 to 2451 records.

Most of the fish removed from the data set were large males (Figure 3). This is not consistent with the usual explanation for Punt’s phenomenon, which would predict that the smaller lobsters would be implicated in re-releases. The growth parameters estimated from fitting the two growth models to each of the datasets, independently of other data, are compared in Table 1. The likelihood value was smaller for the Schnute-Francis model, indicating a better fit to the data.

Based on this exploration, we used the reduced dataset in the base case.

2.6 Initial explorations

Exploring for a base case involved:

- experimenting with dataset weights
- experimenting with estimated or fixed (based on Table 1) *GrowthCV* parameters
- experimenting initially with the tag likelihood method
- experimenting with the LF estimation method and the growth model
- experimenting with other model options.

A constraint when finding a base case was the need for the estimated Hessian matrix to be positive definite (pdH) so that a Markov chain – Monte Carlo (McMC) simulation could be performed. This is a limitation of the ADMB software used to implement this model.

When estimating the *GrowthCVs* as free parameters, there were associated undesirable effects with the overall model fit:

- estimated *GrowthCV* values lower than for the tag-only fit
- a very high estimated growth shape parameter for females compared with the estimates from the tag-only fit
- a low value for the *mat95add* parameter, leading to a knife-edged maturity ogive
- a tendency not to be pdH.

GrowthCV was therefore fixed at 0.27 based on the values in Table 1. Unlike other assessments, the weights and *GrowthCV* appeared to be the only consequential options; we did not encounter sensitivities or problems with the other parameters.

2.7 Base case: MPD results

The specifications for parameter estimation in the base case are shown in Table 2. Most priors were uniform with wide bounds, with informed priors only for M (the same prior used in previous assessments, based on a literature search) and the recruitment deviations (normal in natural log space with a mean of zero and standard deviation of 0.4). The dataset weights and other fixed values are shown in Table 3.

As in previous assessments, we fixed the *Sel_R* parameters to 200, which allows some limited decreased selectivity with increased size. When this parameter is estimated, it generally becomes small, implying a strong decrease in selectivity with increased size. This seems unrealistic: in CRA 9, for example, with low exploitation rates, the mode for males is at a large size, which probably could not occur at low selectivity for large males (Breen 2014). In any case, allowing decreased selectivity at larger sizes creates "cryptic fish" in the model, which could distort the indicators in an unsafe way.

The MPD fit to CPUE (Figure 4) was good and the residuals (Figure 5) showed no obvious trends; the fit to CR (Figure 6) was excellent. The CPUE fit was obtained by overweighting the CPUE observations; without this, the predicted values rose and declined in advance of the observations.

The MPD fit to tag-recaptures is hard to explore in the same way because of the differing times at liberty. Figure 7 compares the predictions and observations; Figure 8 shows that residuals tended to fit the theoretical distribution. Residuals for both sexes showed a trend (Figure 9), with positive residuals at small sizes and negative at large sizes: this tendency was also seen in the tag-only fits and so does not result from fitting to LF data as well as tags. It reflects a problem that the growth model has in fitting to the observed tagging data.

The MPD fits to LF data (examples are shown in Figure 10) were generally good, especially for the logbook data, which had higher weights resulting from the greater number of samples. Residuals from the fits are shown in Figure 11. Fits to the seasonal sex proportions are shown in Figure 12 and Figure 13, and the residuals in Figure 14.

The fits to mean length by sex are shown in Figure 15 through Figure 17 and the residuals by season in Figure 18. These are diagnostic fits that were not used in the objective function: the sdnr was used to weight the LF data fit (see Francis 2011).

The MPD vulnerable biomass trajectory (Figure 19) showed a long biomass decline from the start of the fishery until the late 1980s, a strong increase in the 1990s due to a recruitment pulse and then a decline to levels near the early 1990s when the QMS was introduced. Recruitment (Figure 20) showed much variability after 1979, when the modern data first become available; a spike in the 1960s was related to the pattern seen in the CR data.

Recruited biomass, shown seasonally in Figure 21, had trends similar to vulnerable biomass. Exploitation rates were low for the non-size-limited (NSL) fishery (Figure 22), and the trends in the size-limited (SL) fishery tended to be the inverse of the biomass trends, with a peak in SS in the mid-1980s near 80%.

The change in escape gaps and female MLS regulations was reflected in a change in selectivity curves (Figure 23). Maturation (Figure 24) showed that most females had matured by the time they reached the MLS of 60 mm.

Predicted increments-at-size are shown in Figure 25 for the base case and in Figure 26 for the sensitivity run where the whole tag dataset was included. The initial size structure of the population is shown in Figure 27 and the effect of estimated density-dependence in Figure 28.Base case results are shown in the first data column of Table 4. The tag sdnr was near one, indicating that the relative weight on this data set was appropritate; the CR sdnr was well below one but the fit could scarcely be improved (Figure 6); as mentioned above, CPUE was over-weighted intentionally (sdnr of 1.46) to obtain an acceptable fit. The LF sdnr should not be interpreted because it is not the basis for weighting these data, but the sdnrs for the fit to proportions-by-sex were near one.

The MPD estimate for M was slightly higher than the mean of the prior. Growth estimates for males tended to be slightly higher than those from the tag-only fit (see Table 1), reflecting the effect of estimating density-dependence and possibly the fit to the LF data. The parameter for density-dependence was 0.43, reflecting a moderate influence (Figure 28). The *vuln*s were all less than one, suggesting that the relative vulnerabilities were parameterised appropriately.

Bref was estimated at 436 t (vulnerable biomass in AW), using the period 1979–81. The base case MPD results suggested that the start-of-2013 biomass was 18% below *Bref* and 37% above *Bmsy*.

2.8 MPD sensitivity trials

We ran 14 MPD sensitivity trials, some at the request of the RLFAWG and some of our own, to explore the sensitivity to data and modelling choices. These trials were:
sens1: “LF wt”: with the weight on each of the 70 LF records set at its raw value (see Starr et al. 2014) instead of being truncated to lie between 1 and 10; no attempt was made to re-weight the dataset from its base case values
sens2: “N-R 3”: with three Newton-Raphson iterations to estimate *F*s instead of four
sens3: “No d-d”: with no density-dependence estimated
sens4: “Old LFs”: using the original fitting procedure based on normalisation across all sex categories; for this trial the dataset weight was iteratively adjusted until the sdnr was just above 1 (lower values failed to achieve pdH)
sens5: “Lo Rec”: with half the base case recreational catch vector (see Starr et al. 2014 and Figure 29)
sens6: “Hi Rec”: with twice the base case recreational catch vector (Starr et al. 2014 and Figure 29)
sens7: “Lo Ill”: with an altered (lower) illegal catch vector (see Figure 29)
sens8: “Log Sel”: logistic selectivity ogive instead of double-normal
sens9: “All Tags”: with the complete tag dataset including re-released fish
sens10: “CPUEpow”: estimating a possible non-linear relation between biomass and CPUE
sens11: “No CPUE”: estimated without using CPUE
sens12: “No CR”: estimated without using CR
sens13: “No LFs”: estimated without using the LFs
sens14: “No Tags”: estimated without using the tag-recapture data

Results are compared with the base case in Table 4. In trials sens1 through sens10, *Bref* varied only from 406 to 504 t and start-of-2013 biomass varied only from 0.75 to 0.88 *Bref*. *Bmsy* varied from 213 to 353 and *MSY* from 244 to 318 t.

Using the raw LF weights (sens1) increased the likelihood and function values because of the higher weight (many logbook weights were well over 10), and CPUE was fitted better. Estimated M increased to 0.19, *Bref* increased, *Bmsy* decreased by 12–15% and the ratio *Bcurr/Bmsy* increased by 32%, but other values changed little.

Using fewer Newton-Raphson iterations (sens2) gave practically the same results, suggesting that McMCs could be run more quickly using only three iterations.

When no density-dependence was estimated (sens3), the growth parameters decreased: with density dependence invoked, the estimated growth parameters are relevant to small biomass only, and are larger than the increments expected from the tag-recapture data. *Bref* and *Bmsy* both increased, by 9% and 17% respectively, but other indicators changed little.

When LFs were fit using the older procedure (sens4), growth and the density-dependent parameters changed, but other indicators did not change much.

The low and high recreational catch trials (sens5 and sens6) had opposite effects from each other: the model fitted slightly better with lower recreational catch and slightly worse with higher recreational catch. *Bref* and *Bmsy* were smaller with lower catch and larger with higher catch. The ratio *Bcurr/Bmsy* increased by 13% for low recreational catch and decreased by 14% for high recreational catch, while the ratio *Bcurr/Bref* showed almost no change. Using lower illegal catch (sens7) had generally small effects except that *MSY* was 14% higher than in the base case.

Logistic selectivity (sens8) yielded ogives very similar to the base case (Figure 30) and did not lead to a noticeable change in estimated status of the stock.

Including all the tag data (sens9) led to smaller *GBeta* for both sexes and less density-dependence. This seems to confirm that the re-releases had slower growth than the fish that were caught only once. However, the estimates of stock status relative to *Bref* and *Bmsy* were unchanged compared to the base case.

CPUEpow, when estimated, (sens10) was 1.34, implying hyperdepletion. The fit to CPUE was better in this trial, *Bref* was 8% larger, and *Bcurrent/Bmsy* was 16% higher than in the base case.

When CPUE was not estimated (sens11), fits to other datasets were affected, as would be expected. Growth and density-dependence parameters increased; *vulnest1* and *vulnest3* went to very small values. Estimated *Bref* doubled, but *Bmsy* remained about the same. Figure 31 compares the NoCPUE recruited biomass trajectory with the base case: the LFs contain enough information that the model was able to reconstruct major trends in the stock, particularly the strong decline in abundance in early 2000s, without the CPUE abundance index.

When the CR abundance index was not estimated (sens12), the effects were small.

When LFs were not estimated (sens13), *M* went to its upper bound of 0.35, the *mat95add* parameter went to its lower bound (giving knife-edged maturation), growth and *vulnest* parameters decreased, and selectivity parameters were widely different. *Bref* and *Bmsy* both decreased substantially.

Without the tag data (sens14), the *Galpha* parameters for both sexes were similar to the base case, but the *Gbeta* parameters increased (more growth at larger sizes). Early growth for males was much faster, with 1 year between recruitment to the model and MLS, compared with 2 years in all other trials. The density-dependence parameter became small (no information). *Bref* decreased by 20% and *Bmsy* doubled.

These final four trials, sens11 through sens14, suggest that the model results are sensitive to all the data sets except CR. Of the indicators, *Bmsy* and *Fmult* are most sensitive to dropping datasets, but these sensitivities are not great.

3. BASE CASE MCMC

The CRA 2 base case was run as a set of five million McMC simulations, starting at the base case MPD, saving one thousand posterior samples.

Posterior distributions of parameter estimates are summarised in Table 5 and compared with the MPD estimates. Most medians of estimated parameters were close to the MPD values: exceptions were *mat95add*, which increased by 23%, and the parameter for the left-hand selectivity for both sexes in the first epoch, which doubled.

Traces for the main model parameters and the derived parameters are shown in Figure 32, with diagnostics in Figure 33 and the posteriors in Figure 34. The traces show good mixing and no obvious problems. Diagnostics suggest good convergence, with only *mat95add* showing signs of shaky convergence. Posterior distributions seem well-formed and most parameters appear well determined, exceptions being *mat95add* and the left-hand selectivity parameters.

Posterior distributions of derived parameters are summarised in Table 6. Their traces are also shown in Figure 32, diagnostic plots in Figure 33 and posteriors in Figure 34.

The indicators (Table 6) suggest that start-of-2013 biomass was 42% above *Bmin* (5th to 9th quantiles 25% to 62%), and above *Bmin* with 100% probability. It was 36% above *Bmsy* (11% to 66%), and above *Bmsy* with 99.5% probability; 20% below *Bref* (11% to 30%), and below *Bref* with nearly 100% probability. *Bref* was based on the years 1979–81 as agreed by the RLFAWG (see above).

Short-term projections (three years) were made using the 2012 catches and seasonal catch splits, and based on resampling with replacement the most recent 10 years of estimated recruitment. Projected biomass was a trifle above current biomass, with 53% of runs increasing, so projected biomass had roughly the same relation to the reference levels as current biomass did. Projected biomass was above

Bmin with 90% probability, above *Bmsy* with 87% probability, but above *Bref* with only 15% probability. There was almost no probability that current or projected spawning biomass was below 20%*SSB0*.

The posterior of the fit to CPUE (Figure 35) was similar to the MPD fit, with predicted values showing small ranges; similarly the fit to CR (Figure 36).

Recruitment deviations appeared well determined (Figure 37). The vulnerable biomass trajectory (Figure 38) showed a decline from 1945 through the mid-1980s, an increase from 1990 to the late 1990s and then a decline, with a mostly flat trajectory to the present. The model's surplus production trajectory (Figure 39) tended to mimic the recruitment trajectory (Figure 37).

AW SL exploitation rate was reasonably flat near 30% over its history (Figure 40), while SS exploitation rate peaked at more than 70% in the mid-1980s, fell as abundance increased in the 1990s (and the fishery shifted to the winter months), and rose steadily towards its peak in 2010. The NSL exploitation rates showed similar trends, but at much lower values.

The "snail trail" is a phase plot developed by the Stock Assessment Methods Working Group. It plots the estimated history of fishing intensity against spawning stock biomass, based on the stock assessment's McMC estimates. The snail trail for CRA 2 is shown in Figure 41.

The phase space in the plot is spawning biomass on the x-axis and fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery would be likely to go. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock, *SSB0*. *SSB0* is constant for all years of a run, but varies through the 1000 samples from the posterior distribution.

The y-axis is fishing intensity as a proportion of the fishing intensity that would have given *MSY* (*Fmsy*) under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. *Fmsy* varies every year because the fishing patterns change. It was calculated with a 50-year projection for each year in each run, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually *F*s for two seasons) that gave *MSY* was *Fmsy*, and the multiplier was *Fmult*.

Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2012. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

This figure suggests that fishing intensity exceeded *Fmsy* only from 1980–89 and that *SSB* was below *SSBmsy* only from 1986–88. The current position of the stock is near the 1979 position, with fishing intensity just below *Fmsy* and with biomass just above *SSBmsy*.

3.1 Stock assessment

The base case indicators (Table 6) suggest i) that the stock is comfortably above *Bmin* and *Bmsy* reference levels, but is below *Bref*; ii) that the stock is likely to stay near its current level under current levels of catch; and iii) that the stock is well above the MPI default hard and soft thresholds of 10% and 20% *SSB0*. The snail trial shows that the spawning stock is above the *SSBmsy* level, although not as far above as during the reference years 1979–81, with fishing intensity below *Fmsy*, a little below that in 1979.

3.2 McMC sensitivity trials

We conducted several sensitivity trials:

- "CPUEpow3": estimating the *CPUEpow* parameter with three Newton-Raphson iterations (the base case MPD sensitivity trial was not pdH with four iterations)
- "OldLFs: estimating the LF fits in the way that was used in previous stock assessments, fitting to proportions-at-size and proportions-at-sex simultaneously; this continued from the MPD sensitivity trial in which the weights had been adjusted iteratively
- "LF wt": fitting to LFs records that had the raw record weights (in the base case, weights were truncated to lie between 1 and 10); the dataset weight was not adjusted
- "No d-d": with the density-dependence parameter for growth turned off
- "HiRec": using the doubled recreational catch vector.

All but "CPUEpow3" and"CPUEpow5" were reported above as MPD sensitivities. Each of these was run, starting at the MPD values, for five million McMC simulations, saving 1000 samples of the joint posterior distribution, in the same way as for the base case. The traces and diagnostic plots (not shown) showed no pathology in the McMC simulations.

The estimated parameters are compared in Table 7 and the indicators in Table 8. In the estimated parameters, the median of estimated *CPUEpow* was 1.24 for both the 3- and 5-iteration trials. This changed the values of catchability but had little effect on other parameters.

The OldLFs trial had some differences in median growth and maturation parameters, less density-dependence and some changes in selectivity in the first epoch only. The untruncated LFs weight (LF wt) trial caused the most change to parameter estimates: median *M* went to 0.19 from 0.16, median growth parameters for males and the density-dependence parameter were changed, *vuln*s and the left-hand selectivity in the first epoch were all somewhat different. This trial has effectively more weight on the LFs than the other trials. In the no density-dependence trial, growth parameters decreased (because their interpretation in the model was changed).

The effects of these trials on the indicators (Table 8) were not very great: the largest change was a 43% increase in *Fmult* in the untruncated LF trial. In the HiRec trial, all the biomass indicators were increased, but the biomass ratio indicators did not change much. None of these trials would change the qualitative conclusions from the base case about the state of the stock: current biomass is higher than *Bmin* and *Bmsy*, and 80–85% *Bref*.

4. MANAGEMENT PROCEDURE DEVELOPMENT

4.1 Projection model

Projections were made using procedures agreed by the RLFAWG:

- recruitment was sampled from a distribution having the mean and standard deviation defined by estimated recruitments from 2001–10
- CPUE observation error deviations were simulated from observed distributions of CPUE residuals and their autocorrelations
- no recruitment autocorrelation was simulated (the autocorrelation was found to be very sensitive to the range of years chosen)
- projections were made for 20 years, assuming the 2013 TACC and starting in 2014
- TACC was determined from projected offset-year CPUE and the harvest control rule being evaluated
- the seasonal split of commercial catch was determined as described below
- offset-year CPUE was calculated as described below
- recreational catch was calculated from the 1979–2012 average recreational exploitation rate estimated in the McMC phase, applied to the appropriate biomass

- other non-commercial catches were fixed at their 2012 estimates: 10 t for customary and 88 t for illegal
- recreational and customary catches were assumed to be taken 90% in SS, and the split for illegal catch was assumed to follow the commercial catch split.

The fishery tends to take a higher proportion of catch in AW when abundance, as measured by CPUE, is higher. The projected seasonal commercial catch split was estimated from the observed historical relation between proportion taken in AW and the previous year AW CPUE. These values were determined from a regression of the AW catch proportion against standardised AW CPUE in the previous year (Table 9, Figure 42).

The projections used the most recent offset-year CPUE to drive the harvest control rule; this is the procedure that will be used after the rule is adopted. The offset-year is from 1 October through 30 September in the following year, and this determines the TACC in the next fishing year, beginning in April. Thus the offset-year incorporates information from the year immediately preceding the year to which the TACC applies. Because, the model tracks only seasonal CPUE, and must combine these to simulate the offset-year CPUE, projected offset-year CPUE was based on the relation between observed standardised offset-year CPUE and the mean of standardised AW and SS CPUE (Figure 43 and Table 10).

4.2 Harvest control rules

The harvest control rules tested were variants of a generalised rule used for CRA 4 in 2011 (Breen et al. 2012) (see Figure 44). These rules have a plateau, on which the TACC is constant when CPUE remains within a specified range, and a series of steps above the plateau. Specific members of this rule family are determined by the parameters that specify when the TACC becomes zero, the right and left edges of the plateau, plateau height, the width and height of steps above the plateau; and minimum and maximum change thresholds and a latent year switch.

Rule parameters:

- *par1*: rule type (in this work, type 4)
- *par2*: plateau height (t TACC)
- *par3*: CPUE at the left side of the plateau (kg/potlift)
- *par4*: CPUE at the right side of the plateau (kg/potlift)
- *par5*: CPUE at which TACC becomes zero (kg/potlift)
- *par6*: step width (kg/potlift)
- *par7*: increase of each step, as a proportion of the TACC in the preceding step (dimensionless).

These parameters define the relation between offset-year CPUE in a given year and the TACC in the following fishing year (see Figure 44). The rule family also has three potential buffering parameters:

- *par8*: the minimum change threshold
- *par9*: the maximum change threshold
- *par10*: a switch for an asymmetric latent year.

If a minimum change threshold is specified, the TACC cannot be changed by less than this; similarly with the maximum change threshold. If an asymmetric latent year is specified, then TACC cannot increase if there has been a TACC change in the preceding year. Explorations showed that there were but trifling differences, for all but the stability indicators, between rules with no minimum change threshold and the same rules with a threshold of 5%. All the runs presented here had a minimum change threshold of 5%, no maximum threshold and no latent year.

4.3 Indicators

Indicators for MPEs were as agreed by the RLFAWG in 2012; these are described in Table 11. Biomass is beginning AW biomass; CPUE is offset-year CPUE calculated from seasonal mid-season CPUEs using the relation described above.

To control the stability indicator when TACC became zero or very low, average annual variation in TACC (%AAVH) was calculated as the change divided by the mean TACC:

$$AAVH = \frac{\displaystyle\sum_{y=2014}^{y=2033} 100 \frac{\left|TACC_y - TACC_{y-1}\right|}{0.5\left(TACC_y + TACC_{y-1}\right)}}{20}$$

Indicators were calculated for each run (a run is a 20-year projection from one sample of the joint posterior distribution of parameters). Except for indicators defined as “proportion of years in which...”, indicators were summarised for the whole set of 1000 runs by the 5th and 95th quantiles and medians of their posterior distributions.

4.4 Guidance from stakeholders

MPI (unpublished data) held a CRA 2 stakeholder meeting in Tauranga in May 2013 to obtain advice on management goals from stakeholders, including the commercial industry, tangata whenua and recreational fishers. The CRA 2 data were described; stock assessment and management procedures were also described in non-technical presentations. Stakeholder concerns included:

- uncertainties in non-commercial catch estimates
- movement of lobsters
- other factors than abundance possibly affecting CPUE
- concerns about management procedures and their reliance on CPUE
- uncertainty about what the target should be for CRA 2.

Stakeholder groups then discussed amongst themselves two questions:

1) How is the CRA 2 fishery currently performing?
2) How would you like the CRA 2 fishery to perform in the future?

MPI considered their responses to have the following common aspirations:

- higher abundance (including a wide size distribution of rock lobsters)
- improved stability
- improved CPUE
- improved information on non-commercial catches and recruitment dynamics.

4.5 Finding rules to present

A wide variety of rules were explored by the assessment team, working independently in a loosely structured way. Close to 600 rules were evaluated in several phases. Rules were also suggested by stakeholders after the RLFAWG meeting in October 2013 and after an industry meeting in Tauranga in November 2013.

Rules could be developed that were conservative: these produced low average catches and rebuilt the stock to well above *Bref*; other rules were very aggressive and caused the stock to decrease from its current level. The rules explored were limited to the range between rebuilding the stock to *Bref* or just over, at the conservative end, and rules that maintained the stock close to its current level at the aggressive end.

Table 12 shows the ranges of parameter values used in the exploratory runs and Table 13 shows the ranges of indicators seen in the exploratory rule evaluations. Average[2] commercial catch varied from 176 to 250 t and average recreational catch varied from 52 to 85 t. The *Bmin* safety indicator varied from zero to 44% of years with stock abundance less than *Bmin*, and the *Bmsy* safety indicator was similar. No rules went below 20% *SSB0* in more than 2.8% of years. Average total catch varied from 261 to 301 t, which is 86–99% of *MSY*.

A major trade-off in management procedures is between average catch and average stock abundance, illustrated for CRA 2 in Figure 45. At a given level of average catch, all the rules that produced this average catch, which varied considerably in form, nevertheless produced nearly the same average CPUE.

Because the recreational catch is assumed to be proportional to abundance, and in the model is determined by an exploitation rate, recreational catch increased as commercial catch decreased: this is a second major trade-off (Figure 46). The trade-off was not one to one for CRA 2: a decrease in commercial catch was divided nearly equally between the recreational catch and rebuilding of the stock (results in Figure 45 suggested that 43% of the decrease became increased recreational catch).

A third trade-off was between the average commercial catch and the safety indicator P(B<*Bmin*): the frequency of years with stock lower than *Bmin* increased sharply as commercial catch increased (Figure 45).

Stability, as measured by the AAVH indicator, tended to be better at higher abundance (Figure 47), but showed considerable contrast among rules that gave the same average commercial catch. Minimum commercial catch tended to have a dome-shaped relation with abundance (Figure 48), and showed very high contrast among rules with the same catch and abundance.

The most important rule parameter was plateau height, with higher values tending to give higher commercial catch, lower stock biomass and CPUE and worse safety indicators (Figure 49 and Figure 50). The left-hand side of the plateau was relatively unimportant over the range of exploratory values. We constrained the right-hand side of the plateau to values between 0.5 and 0.65 kg/pot-lift in the later runs, because the CPUE associated with *Bref* was roughly 0.6 kg/potlift. The intercept (*par5*) seemed relatively unimportant in rule results. In later evaluations, step widths were limited to between 0.1 and 0.2 kg/potlift. The parameters for the steps above the plateau did not have much effect on indicators, because CPUE in the evaluations tended to lie mostly on the plateau or below it.

4.6 Nine example rules

The assessment team chose ten rules from the range explored and discussed them with the RLFAWG. Two each were chosen with plateau heights of 180, 200, 210, 220 and 236 t. From the rules available, rules were chosen that had less than 5% of years with stock less than *Bmin* if possible, and with a high choice for minimum commercial catch if there was a range.

Discussion in the RLFAWG and in the NRLMG, and subsequent discussion among the commercial sector, resulted in a "final" set of nine rules. Important considerations in choosing a set of final rules were the safety indicators, the TACCnow and the minimum TACC.

Parameters for the final rule set considered by the NRLMG are shown in Table 14 and the rules are illustrated in Figure 51 through Figure 59. Base case results of the rules are compared in Table 15. Using the 2013 offset-year CPUE of 0.367 kg/potlift (Starr et al. 2014), the rules would set a TACC for 2014 ranging from 200 to 236 t. The rebuilding was greater and average commercial catch was smaller in the rules with lower plateau heights. Average commercial catch ranged from 203 to 229 t.

[2] "Average" is used to refer to the median of the posterior distributions of the mean values (across all years in a run) from the 1000 posterior samples.

As shown above, recreational catch was higher when commercial catch was lower, and the range of the average in these rules was from 62 to 74 t.

4.7 MPE robustness trials

The nine final rule candidates were evaluated with the base case operating model and also a set of robustness trial models. The trials agreed by the RLFAWG were:

- "CPUE_pow": used the *CPUEpow* McMC posterior from the *CPUEpow3* sensitivity run to inform the operating model
- "Lo_rect": recruitment was arbitrarily decreased; where the amount of decrease was chosen by examining the 10-year moving average of estimated recruitment and comparing the lowest period with the period used as the basis for projections (Figure 60); the median was 85% of the 2001–10 mean recruitment, so for this trial the recruitment was decreased by 15%
- "Hi_Obs": CPUE observation error was arbitrarily doubled
- "Inc_q": catchability was arbitrarily increased by 1% per year, which could happen as a result of technology changes (although it would likely not be gradual)
- "Hi_SigR": projections used a standard deviation for *Rdev*s of 0.4 instead of the standard deviation of the estimated *Rdev*s, which had a median of 0.24.

Results for each of the nine rules for the base case and the above six robustness trials are presented in Table 16 to Table 24.

5. DISCUSSION

The MSLM model fitted the data much more easily than in previous stock assessments. Common problems previously encountered included: difficulty in finding runs that were pdH, implausibly high or low estimated *M* values, datasets that worked against each other, problems in obtaining acceptable fits to one of the datasets, usually CPUE. In this assessment, we encountered few of these problems. In the range of weightings we used, there was no problem with pdH (but, strangely, the result was non-pdH when we tried to estimate the *CPUEpow* parameter, but this disappeared when the Newton-Raphson iterations were changed from four to either three or five). Fixing the *GrowthCV* parameter increased the chance of a run being pdH, and this corrected problems with a growth shape parameter and one of the maturity parameters.

The MPD sensitivity trials that involved removing datasets one at a time showed that the CR dataset had little influence on the results, but that all the other data sets were important. Without CPUE, vulnerable biomass showed the same basic trends as in the base case (see Figure 31), suggesting that the length frequency data, combined with the catch data, contained much information about trends in abundance. Without the LF data, *M* went to its upper bound.

Both MPD and McMC sensitivity trials suggested that the results were robust to modelling choices. In particular, how to fit the LFs, whether to use density-dependence and whether to estimate *CPUEpow* all seem major decisions, but their effects on the conclusions about state of the stock were relatively small.

As always, the RLFAWG identified the lack of information on non-commercial catches and their trends as being a major source of uncertainty. Illegal catches especially are poorly known. The recent large-scale multi-species recreational survey has increased the confidence in the current level of recreational catch estimates, although the charter fleet was not included and remains poorly documented at the time of writing. Our assumption that recreational catch is proportional to abundance is controversial. The recreational fishery is partly constrained by the bag limit, but daily catches are commonly less than the bag limit and bags can be easily distributed across participants, so bag limits are only a weak constraint, and both fishers and fishing trips can increase as abundance increases. Assuming that catch is proportional to abundance implies constant effort, but it is possible that recreational effort may be increasing over time because of increasing interest; if this is true, catch may be increasing faster than abundance. In any case, the effects of changing the illegal and recreational catch assumptions on these stock assessment conclusions were predictable but also were relatively small, especially when using *Bref* as a reference level.

This stock assessment suggests that CRA 2 has no probability of being below the default hard and soft limits of 10% and 20% spawning stock biomass and is also above *Bmsy*. However, the stock is only 36% above *Bmsy* (base case median level), and fishing intensity is about 17% below that associated with *Bmsy*. Current catches would keep the stock near its current state if recruitment were near its recent levels.

The stock is 21% below *Bref*, and likely to rebuild to *Bref* (given recent recruitment patterns) only with substantial reductions in catch. The significance of this depends on how *Bref* is interpreted. If it is a target, then the stock is below its target. The RLFAWG did not resolve whether *Bref* is intended as a target. It is based on a short period and was chosen somewhat arbitrarily.

The model was easily converted to an operating model for management procedure evaluations (MPEs). We explored plateau rules of the same form as those used in CRA 4 and CRA 5: the plateau and the steps above the plateau impart high TACC stability compared with simpler rules. The choices for rule parameters were constrained by the situation: we did not develop and test rules that would rebuild the stock to higher than *Bref* or that would, on average, allow the stock to decrease from its current state; the left-hand edge of the plateau needed to be only slightly less than the current CPUE while the right-hand edge was constrained to be near the CPUE at *Bref*; plateau heights could not be higher than the current TACC.

At the time of writing, the NRLMG has gone to consultation on rules 4 and 6.

6. ACKNOWLEDGEMENTS

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Table 1: Tag-only fits of the MSLM model with two growth models and two datasets: the inverse logistic and Schnute-Francis models, and the full dataset (3207 records) and the reduced dataset (2451 records after removing the re-released tagged fish); "-LL" denotes negative log-likelihood value, "sdnr" is the standard deviation of the normalised residuals, "MAR" is the median of absolute normalised residuals; *M* and *F* on the growth parameters indicate male and female estimates. Shaded cells were fixed at the values given.

Model	Logistic		Schnute-Francis	
Tags	3207	2451	3207	2451
Tags-weight	0.66	0.66	0.66	0.66
Tags-sdnr	1.071	1.092	1.075	1.098
Tags-MAR	0.608	0.634	0.625	0.653
Tags-LL	4690.2	3796.0	4632.6	3737.2
function value	4625.2	3731.0	4567.6	3672.1
GalphaM	13.38	13.33	7.65	7.65
GbetaM	1.05	1.18	1.35	1.42
GdiffM	-12.34	-12.15	0.18	0.19
GshapeM			4.511	4.090
GrowthCVM	0.263	0.263	0.214	0.213
GalphaF	6.88	8.21	7.77	7.79
GbetaF	0.46	0.40	0.66	0.50
GdiffF	-6.42	-7.81	0.09	0.06
GshapeF			9.085	8.603
GrowthCVF	0.469	0.463	0.319	0.315
StdMin	1.6	1.6	1.6	1.6
StdObs	0.6	0.6	0.6	0.6
GmaxM	15.88	15.73		
GmaxF	31.42	18.41		
L50M	47.99	47.95		
L50F	33.17	42.00		
L95M	82.64	84.44		
L95F	65.80	71.17		

Table 2: Specifications for the provisional base case. Estimation phase is the phase at which parameter estimation is turned on (negative indicates a fixed value), prior type 0 = uniform, 1 = normal, 2 = lognormal.

parameter	Estimation phase	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV	Initial value
ln(*R0*)	1	1	25	0	n.a.	n.a.	18
M	4	0.01	0.35	2	0.12	0.4	0.1
Rdevs	2	-2.3	2.3	1	0	0.4	0
ln(*qCPUE*)	1	-25	0	0	n.a.	n.a.	-6
ln(*qCR*)	1	-25	2	0	n.a.	n.a.	-3
CPUEpow	-1	0.001	2	0	n.a.	n.a.	1
Mat_50	3	30	80	0	n.a.	n.a.	60
Mat_95add	3	3	60	0	n.a.	n.a.	10
Galpha	2	1	20	0	n.a.	n.a.	7.5
Gdiff	2	0.001	1	0	n.a.	n.a.	0.12
Gshape	3	0.1	15	0	n.a.	n.a.	4
GrowthCV	-3	0.01	2	0	n.a.	n.a.	0.27
GrowthDD	5	0	1	0	n.a.	n.a.	0
StdMin	-5	0.01	5	0	n.a.	n.a.	1.6
StdObs	-5	0.00001	10	0	n.a.	n.a.	0.6
Sel_L_male	4	1	50	0	n.a.	n.a.	5
Sel_L_female	4	1	50	0	n.a.	n.a.	5
Sel_R_male	-3	1	250	0	n.a.	n.a.	200
Sel_R_female	-3	1	250	0	n.a.	n.a.	200
Sel_Max_male	5	30	70	0	n.a.	n.a.	50
Sel_Max_female	5	30	70	0	n.a.	n.a.	50
vuln1	3	0.01	1	0	n.a.	n.a.	0.8
vuln2	3	0.01	1	0	n.a.	n.a.	0.8
vuln3	3	0.01	1	0	n.a.	n.a.	0.8
vuln4	3	0.01	1	0	n.a.	n.a.	0.8

Table 3: Fixed quantities in the provisional base case.

Quantity	Value	
LFs - sex proportion dataset weight	10.0	
LFs - male dataset weight	2.383	
LFs - immature female dataset weight	2.308	
LFs - mature female dataset weight	2.976	
CPUE dataset weight	5.0	
CR dataset weight	7.0	
Tag dataset weight	0.6	
Length-weight parameters	a	b
Male	4.16E-06	2.935
Female	1.30E-05	2.545
CPUE added process error	0.25	
CR relative sigma	0.3	
Newton-Raphson iterations	4	
Handling mortality	0.1	
Minimum survival	0.02	

Table 4: Base case MPD results and results from MPD sensitivity trials. Grey indicates quantities not estimated. For selectivity parameters, the numeral suffix indicates the first or second epoch and the letter suffix indicates male or female; for sens8 (logistic selectivity ogive), parameters *Sel_L* and *Sel_Max* refer to the length at 50% selected and the difference between lengths at 95% and 50% selected respectively.

	base	sens1 LF wt	sens2 N-R 3	sens3 No d-d	sens4 Old LF	sens5 Lo Rec	sens6 Hi Rec	sens7 Lo Ill	sens8 Log Sel	sens9 All Tags	sens10 CPUE pow	sens11 No CPUE	sens12 No CR	sens13 No LFs	sens14 No Tags
LFs-wt-M	2.383	2.383	2.383	2.383	3.2	2.383	2.383	2.383	2.383	2.383	2.383	2.383	2.383	2.383	2.383
LFs-wt-IF	2.308	2.308	2.308	2.308		2.308	2.308	2.308	2.308	2.308	2.308	2.308	2.308	2.308	2.308
LFs-wt-MF	2.876	2.876	2.876	2.876		2.876	2.876	2.876	2.876	2.876	2.876	2.876	2.876	2.876	2.876
LFs-sdnr	0.551	0.706	0.551	0.571	0.389	0.555	0.547	0.556	0.537	0.581	0.531	0.488	0.549		0.489
LFs-MAR	0.199	0.235	0.199	0.200	0.127	0.200	0.198	0.200	0.199	0.202	0.197	0.188	0.199		0.194
LFs-LL	450.4	922.6	450.4	460.9	154.9	450.4	452.8	452.8	444.7	458.0	451.4	401.4	449.2		434.8
Tags-sdnr	0.989	0.997	0.989	0.997	0.986	0.989	0.989	0.989	0.991	0.974	0.992	0.978	0.990	0.982	
Tags-MAR	0.593	0.592	0.593	0.597	0.594	0.592	0.596	0.593	0.597	0.579	0.595	0.573	0.593	0.589	
Tags-LL	3797.5	3813.6	3797.5	3804.6	3791.9	3797.4	3797.8	3797.7	3800.3	4722.0	3797.5	3772.9	3797.6	3784.0	
CPUE-sdnr	1.460	1.677	1.460	1.469	1.351	1.452	1.480	1.451	1.445	1.471	1.403		1.463	1.157	1.427
CPUE-MAR	0.932	0.934	0.932	0.944	0.880	0.978	0.942	0.956	0.954	0.951	1.031		0.943	0.611	0.946
CPUE-LL	-129.7	-106.6	-129.7	-128.8	-140.2	-130.4	-127.7	-130.6	-131.2	-128.6	-135.3		-129.4	-156.6	-132.9
CR-sdnr	0.689	0.679	0.689	0.818	0.647	0.603	0.867	0.683	0.656	0.744	0.708	0.905		0.235	0.729
CR-MAR	0.384	0.348	0.384	0.516	0.311	0.300	0.358	0.363	0.379	0.397	0.396	0.500		0.137	0.437
CR-LL	-32.0	-32.1	-32.0	-31.0	-32.3	-32.6	-30.5	-32.1	-32.3	-31.6	-31.9	-30.1		-34.3	-31.7
Sex propns -sdnr	0.929	1.714	0.929	0.954		0.923	0.948	0.932	0.927	0.935	0.965	0.936	0.926	9.469	0.958
Sex propns -MAR	0.666	1.002	0.666	0.669		0.671	0.664	0.672	0.670	0.670	0.681	0.648	0.665	5.368	0.642
Function value	4048.1	4558.4	4048.0	4067.1	3735.0	4045.7	4055.9	4049.3	4043.1	4981.2	4040.4	4094.8	4073.5	3548.7	232.0
ln(*R0*)	13.20	13.35	13.20	13.20	13.27	13.18	13.27	13.19	13.24	13.20	13.24	13.28	13.19	14.00	13.02
M	0.161	0.191	0.161	0.163	0.174	0.176	0.143	0.162	0.168	0.159	0.165	0.151	0.150	0.350	0.174
ln(*qCPUE*)	-6.512	-6.650	-6.512	-6.620	-6.541	-6.422	-6.688	-6.495	-6.493	-6.578	-8.646	-6	-6.491	-5.793	-6.078
ln(*qCR*)	-2.957	-3.013	-2.956	-3.149	-2.915	-2.772	-3.277	-2.948	-2.936	-3.035	-2.980	-2.617	-3	-2.012	-2.791
CPUEpow	1	1	1	1	1	1	1	1	1	1	1.344	1	1	1	1
Mat50	45.7	48.6	45.7	46.3	45.2	45.7	45.7	45.7	46.2	45.9	45.7	45.8	45.7	56.6	45.2
Mat95add	7.8	11.7	7.8	8.7	9.0	7.7	8.0	8.2	7.7	8.2	8.2	8.4	8.1	3.0	4.4
GalphaM	8.817	8.618	8.816	7.179	8.530	8.878	8.705	8.702	8.852	8.256	8.693	9.627	8.780	8.178	11.426
GbetaM	3.139	3.694	3.139	2.342	2.643	3.171	3.069	3.118	3.222	2.387	3.065	3.325	3.170	1.383	9.440
GdiffM	0.356	0.429	0.356	0.326	0.310	0.357	0.353	0.358	0.364	0.289	0.353	0.345	0.361	0.169	0.826
GshapeM	3.216	3.678	3.215	3.692	3.080	3.233	3.182	3.289	3.124	3.323	3.339	3.283	3.272	2.509	7.198
GalphaF	7.987	7.498	7.987	6.672	7.987	8.030	7.916	7.879	7.945	7.576	7.962	8.800	7.942	7.945	7.963
GbetaF	1.417	1.633	1.417	1.034	1.162	1.410	1.424	1.403	1.484	1.269	1.372	1.291	1.394	0.310	2.884
GdiffF	0.177	0.218	0.177	0.155	0.145	0.176	0.180	0.178	0.187	0.167	0.172	0.147	0.176	0.039	0.362

	base	sens1 LF wt	sens2 N-R 3	sens3 No d-d	sens4 Old LF	sens5 Lo Rec	sens6 Hi Rec	sens7 Lo Ill	sens8 Log Sel	sens9 All Tags	sens10 CPUE pow	sens11 No CPUE	sens12 No CR	sens13 No LFs	sens14 No Tags
GshapeF	7.575	8.237	7.574	7.175	7.538	7.646	7.476	7.533	7.371	7.616	7.652	7.685	7.626	6.609	7.560
GrowthDD	0.430	0.331	0.430	0	0.351	0.417	0.438	0.410	0.430	0.335	0.413	0.611	0.458	0.191	0.449
vuln1	0.631	0.727	0.631	0.644	0.651	0.627	0.644	0.629	0.635	0.634	0.608	0.019	0.624	0.510	0.701
vuln2	0.532	0.414	0.532	0.517	0.477	0.528	0.534	0.532	0.585	0.531	0.539	0.527	0.525	0.010	0.539
vuln3	0.463	0.385	0.463	0.473	0.437	0.456	0.471	0.466	0.494	0.471	0.452	0.014	0.456	0.292	0.473
vuln4	0.438	0.617	0.438	0.453	0.414	0.433	0.445	0.440	0.467	0.447	0.453	0.433	0.432	0.163	0.441
Sel_L1M	3.48	4.67	3.48	3.54	3.49	3.44	3.55	3.51	45.31	3.51	3.49	3.44	3.50	1.00	1.00
Sel_Max1M	49.2	51.9	49.2	49.5	49.9	49.4	49.0	49.0	3.1	49.1	49.4	47.3	49.0	41.2	35.7
Sel_L1F	3.08	2.96	3.08	3.10	1.00	3.09	3.07	3.09	46.74	3.09	3.15	3.21	3.10	50.00	3.17
Sel_Max1F	49.5	48.2	49.5	49.5	31.9	49.5	49.5	49.6	3.4	49.4	49.4	50.0	49.5	53.4	49.6
Sel_L2M	4.04	4.27	4.04	4.06	4.12	4.04	4.05	4.04	50.99	4.03	4.00	4.00	4.04	22.35	4.35
Sel_Max2M	54.8	55.1	54.8	54.8	55.0	54.9	54.8	54.8	4.3	54.7	54.7	54.7	54.8	59.3	54.8
Sel_L2F	9.01	9.92	9.01	9.24	7.73	8.97	9.03	9.01	55.65	9.14	8.99	8.69	9.03	1.00	9.22
Sel_Max2F	63.8	64.5	63.8	63.8	62.0	63.8	63.8	63.8	9.5	63.7	63.6	63.1	63.7	60.6	65.0
Bcurr/Bref	0.815	0.787	0.815	0.798	0.751	0.811	0.821	0.823	0.841	0.811	0.876	0.630	0.817	0.547	0.846
Bref	436.2	495.2	435.9	475.7	448.7	406.1	504.3	430.6	422.6	459.8	472.0	711.6	428.4	272.6	324.7
Bmsy	259.4	216.1	259.2	304.5	233.1	212.9	353.0	262.6	246.1	270.3	258.9	267.0	285.6	126.8	390.5
Bcurr/Bmsy	1.371	1.803	1.371	1.246	1.445	1.547	1.173	1.350	1.443	1.379	1.597	1.680	1.226	1.176	0.704
MSY	267.3	277.4	267.1	249.3	276.5	243.6	318.4	303.6	271.1	263.4	275.1	315.5	274.2	302.3	259.0
Fmult	1.190	1.710	1.190	1.000	1.440	1.410	0.980	1.300	1.270	1.180	1.470	1.710	1.070	1.590	0.490

Table 5: Summaries of estimated parameter posteriors from the provisional base case McMC.

		Parameter	Min.	0.05	Median	0.95	Max.	MPD
		function value	3251.2	3287.0	3298.2	3311.8	3330.0	3251.2
		ln(*R0*)	12.96	13.08	13.19	13.32	13.44	13.20
		M	0.133	0.145	0.161	0.179	0.199	0.161
		ln(*qCPUE*)	-6.730	-6.674	-6.570	-6.482	-6.397	-6.512
		ln(*qCR*)	-3.532	-3.380	-3.156	-2.903	-2.640	-2.957
		Mat50	30.5	38.2	44.8	47.1	49.2	45.7
		Mat95add	3.01	4.07	9.66	19.21	35.69	7.84
	male	*Galpha*	7.897	8.251	8.769	9.221	9.659	8.817
	male	*GBeta*	2.133	2.618	3.166	3.695	4.348	3.139
	male	*Gdiff*	0.254	0.299	0.362	0.421	0.484	0.356
	male	*Gshape*	2.479	2.869	3.427	3.975	4.482	3.216
	female	*Galpha*	7.018	7.514	7.916	8.290	8.673	7.987
	female	*Gbeta*	0.892	1.180	1.436	1.702	2.017	1.417
	female	*Gdiff*	0.113	0.149	0.182	0.216	0.254	0.177
	female	*Gshape*	6.674	7.007	7.643	8.269	9.006	7.575
		GrowthDD	0.259	0.324	0.421	0.500	0.580	0.430
		vuln1	0.596	0.611	0.635	0.660	0.688	0.631
		vuln2	0.365	0.444	0.576	0.742	0.936	0.532
		vuln3	0.385	0.435	0.491	0.550	0.606	0.463
		vuln4	0.352	0.407	0.461	0.521	0.580	0.438
epoch 1	male	*Sel_L*	1.007	1.793	6.944	22.787	34.208	3.481
epoch 1	male	*Sel_Max*	35.75	42.14	51.09	63.78	70.00	49.18
epoch 1	female	*Sel_L*	1.01	1.67	6.60	18.15	34.98	3.08
epoch 1	female	*Sel_Max*	34.40	41.96	52.00	63.18	69.97	49.48
epoch 2	male	*Sel_L*	3.13	3.54	4.06	4.66	5.24	4.04
epoch 2	male	*Sel_Max*	53.51	54.00	54.76	55.59	56.43	54.85
epoch 2	female	*Sel_L*	7.90	8.47	9.18	10.08	10.88	9.01
epoch 2	female	*Sel_Max*	61.82	62.71	64.05	65.54	66.94	63.82

Table 6: Summaries of indicator posteriors (median, 5th and 95th quantiles) from the base case McMC; the second part of the table shows the probability (proportion of McMC samples) for which the proposition was true.

CRA2	Median	5%	95%
Bmin	255.2	232.8	282.1
Bcurr	365.8	312.7	417.3
Bref	459.6	424.7	502.6
Bproj	369.7	231.1	523.9
Bmsy	268.2	233.9	304.8
MSY	265.8	237.9	297.5
Fmult	1.2	0.96	1.51
SSBcurr	528.8	484.0	580.7
SSBproj	564.5	415.3	713.5
SSBmsy	442.8	398.9	488.9
CPUEcurrent	0.361	0.340	0.383
CPUEproj	0.416	0.228	0.625
CPUEmsy	0.283	0.230	0.341
Bcurr/Bmin	1.429	1.257	1.618
Bcurr/Bref	0.793	0.699	0.895
Bcurr/Bmsy	1.361	1.114	1.659
Bproj/Bcurr	1.014	0.674	1.343
Bproj/Bref	0.805	0.500	1.128
Bproj/Bmsy	1.377	0.840	2.004
SSBcurr/SSB0	0.368	0.330	0.415
SSBproj/SSB0	0.390	0.289	0.505
SSBcurr/SSBmsy	1.194	1.061	1.375
SSBproj/SSBmsy	1.266	0.927	1.643
SSBproj/SSBcurr	1.064	0.811	1.319
USLcurrent	0.276	0.251	0.303
USLproj	0.246	0.174	0.394
USLproj/USLcurrent	0.885	0.633	1.414
P(*Bcurr*>*Bmin*)	100.0%		
P(*Bcurr*>*Bref*)	0.1%		
P(*Bcurr*>*Bmsy*)	99.5%		
P(*Bproj*>*Bmin*)	91.8%		
P(*Bproj*>*Bref*)	15.0%		
P(*Bproj*>*Bmsy*)	87.1%		
P(*Bproj*>*Bcurr*)	53.0%		
P(*SSBcurr*>*SSBmsy*)	99.0%		
P(*SSBproj*>*SSBmsy*)	90.8%		
P(*USLproj*>*USLcurr*)	32.3%		
P(*SSBcurr*<*0.2SSB0*)	0.0%		
P(*SSBproj*<*0.2SSB0*)	0.1%		
P(*SSBcurr*<*0.1SSB0*)	0.0%		
P(*SSBproj*<*0.1SSB0*)	0.0%		

Table 7: Median parameter estimates from the base case and McMC sensitivity trials; shaded cells indicate parameters not estimated; in the selectivity parameters the numeral suffixes indicate first or second epoch and the letter suffixes indicate male or female.

Quantity	Base	CPUE pow3	Old LFs	LF wt	No d-d	Hi Rec
function value	3298.2	3290.1	2983.4	3807.8	3317.6	3304.5
ln(R0)	13.19	13.22	13.26	13.34	13.20	13.27
M	0.161	0.165	0.176	0.192	0.164	0.144
ln(*qCPUE*)	-6.570	-8.113	-6.633	-6.687	-6.687	-6.750
ln(*qCR*)	-3.156	-3.152	-3.142	-3.221	-3.339	-3.439
CPUEpow	1	1.244	1	1	1	1
Mat50	44.8	44.7	39.3	48.5	45.6	45.1
Mat95-50	9.66	10.16	15.57	11.88	9.66	9.55
GalphaM	8.77	8.63	8.44	8.56	7.13	8.59
GBetaM	3.17	3.06	2.63	3.72	2.34	3.04
GdiffM	0.362	0.356	0.312	0.434	0.329	0.354
GshapeM	3.427	3.499	3.276	3.882	3.888	3.371
GalphaF	7.92	7.88	7.91	7.47	6.64	7.81
GBetaF	1.44	1.39	1.18	1.65	1.05	1.43
GdiffF	0.182	0.178	0.149	0.220	0.158	0.183
GshapeF	7.643	7.678	7.576	8.284	7.231	7.497
GrowthDD	0.421	0.400	0.327	0.323	0.000	0.418
vuln1	0.635	0.618	0.652	0.731	0.648	0.649
vuln2	0.576	0.584	0.552	0.433	0.555	0.581
vuln3	0.491	0.485	0.473	0.398	0.501	0.496
vuln4	0.461	0.477	0.448	0.639	0.478	0.465
Sel_L1M	6.94	6.87	7.77	10.03	7.03	6.41
Sel_Max1M	51.09	51.33	54.20	55.77	51.47	50.86
Sel_L1F	6.60	6.98	1.36	8.77	7.68	7.31
Sel_Max1F	52.00	51.72	40.05	48.67	52.54	52.38
Sel_L2M	4.06	4.03	4.13	4.29	4.07	4.10
Sel_Max2M	54.76	54.61	54.88	55.03	54.67	54.78
Sel_L2F	9.18	9.20	7.96	9.97	9.37	9.20
Sel_Max2F	64.05	63.93	62.41	64.54	63.91	63.95

Table 8: CRA2: median indicator values, and probability indicators, from the base case and McMC sensitivity trials.

Quantity	Base	CPUE pow3	CPUE pow5	Old LFs	LF wt	No d-d	Hi Rec
Bmin	255.2	303.4	304.5	274.1	282.3	281.5	297.3
Bcurr	365.8	417.2	419.5	368.6	386.4	389.6	425.9
Bref	459.6	493.4	495.4	487.2	518.9	506.0	532.9
Bproj	369.7	424.1	428.0	362.8	388.3	396.3	526.3
Bmsy	268.2	269.0	268.6	241.9	219.1	307.3	364.3
MSY	265.8	272.5	273.1	273.3	277.7	247.8	316.2
Fmult	1.200	1.430	1.440	1.480	1.720	1.030	0.980
SSBcurr	528.8	572.6	574.1	554.1	604.4	568.3	609.0
SSBproj	564.5	607.7	611.5	571.4	634.1	601.4	708.6
SSBmsy	442.8	438.6	438.6	426.5	429.7	494.2	566.1
CPUEcurrent	0.361	0.368	0.368	0.369	0.342	0.359	0.356
CPUEproj	0.416	0.435	0.440	0.379	0.391	0.402	0.529
CPUEmsy	0.283	0.220	0.219	0.232	0.191	0.302	0.343
Bcurr/Bmin	1.429	1.371	1.372	1.347	1.367	1.386	1.429
Bcurr/Bref	0.793	0.847	0.845	0.759	0.743	0.770	0.798
Bcurr/Bmsy	1.361	1.557	1.571	1.519	1.767	1.281	1.169
Bproj/Bcurr	1.014	1.017	1.024	0.991	1.014	1.005	1.239
Bproj/Bref	0.805	0.854	0.864	0.739	0.748	0.784	0.985
Bproj/Bmsy	1.377	1.583	1.595	1.507	1.777	1.295	1.437
SSBcurr/SSB0	0.368	0.395	0.395	0.376	0.449	0.317	0.332
SSBproj/SSB0	0.390	0.418	0.421	0.388	0.472	0.333	0.389
SSBcurr/SSBmsy	1.194	1.305	1.307	1.306	1.411	1.156	1.077
SSBproj/SSBmsy	1.266	1.389	1.385	1.345	1.479	1.217	1.260
SSBproj/SSBcurr	1.064	1.062	1.069	1.024	1.049	1.055	1.177
USLcurrent	0.276	0.240	0.240	0.257	0.261	0.252	0.256

Quantity	Base	CPUE pow3	CPUE pow5	Old LFs	LF wt	No d-d	Hi Rec
USLproj	0.246	0.215	0.213	0.251	0.234	0.230	0.153
USLproj/USLcurrent	0.885	0.895	0.889	0.975	0.899	0.913	0.607
P(Bcurr>Bmin)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P(Bcurr>Bref)	0.001	0.007	0.006	0.000	0.000	0.001	0.000
P(Bcurr>Bmsy)	0.995	1.000	1.000	1.000	1.000	0.965	0.889
P(Bproj>Bmin)	0.918	0.947	0.936	0.845	0.935	0.884	0.987
P(Bproj>Bref)	0.150	0.217	0.222	0.091	0.072	0.130	0.474
P(Bproj>Bmsy)	0.871	0.974	0.976	0.892	0.994	0.798	0.931
P(Bproj>Bcurr)	0.530	0.528	0.556	0.481	0.526	0.511	0.854
P(SSBcurr>SSBmsy)	0.990	1.000	1.000	0.999	1.000	0.955	0.817
P(SSBproj>SSBmsy)	0.908	0.974	0.977	0.914	0.998	0.869	0.920
P(USLproj>USLcurr)	0.323	0.284	0.274	0.466	0.313	0.358	0.019
P(SSBcurr<0.2SSB0)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P(SSBproj<0.2SSB0	0.001	0.000	0.000	0.003	0.000	0.004	0.000
P(SSBcurr<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P(SSBproj<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 9: Observed and predicted CRA 2 AW proportional seasonal split, based on the observed standardised AW CPUE from the previous fishing year.

Fishing Year	Standardised AW CPUE	Obs. AW proportion	Pred. AW proportion
1992	0.3639	–	–
1993	0.4037	0.4738	0.3870
1994	0.4790	0.5934	0.4161
1995	0.6777	0.7638	0.4714
1996	0.8311	0.8900	0.6171
1997	1.0151	0.8899	0.7296
1998	1.0428	0.8707	0.8645
1999	0.7219	0.7570	0.8848
2000	0.6758	0.5680	0.6495
2001	0.4875	0.5300	0.6157
2002	0.3286	0.3543	0.4776
2003	0.3973	0.3508	0.3610
2004	0.4602	0.3900	0.4114
2005	0.4133	0.3659	0.4576
2006	0.4642	0.3999	0.4232
2007	0.5056	0.3863	0.4605
2008	0.4649	0.3784	0.4909
2009	0.4006	0.3650	0.4610
2010	0.3453	0.3293	0.4139
2011	0.2923	0.2713	0.3733
2012	–	0.3725	0.3344

Table 10: CRA 2: Observed and predicted offset year CPUE, based on the observed standardised AW CPUE in year *y* and SS CPUE in year *y*-1.

Fishing year	AW CPUE	SS CPUE	Mean CPUE	Offset CPUE	Pred Offset
1979	0.460	–	–	–	–
1980	0.650	0.576	0.613	0.598	0.608
1981	0.450	0.613	0.532	0.529	0.526
1982	0.414	0.587	0.500	0.499	0.495
1983	0.321	0.456	0.388	0.387	0.382
1984	0.345	0.389	0.367	0.363	0.361
1985	0.354	0.350	0.352	0.343	0.345
1986	0.351	0.440	0.395	0.394	0.389
1987	0.275	0.377	0.326	0.325	0.319
1988	0.320	0.352	0.336	0.330	0.329
1989	0.277	0.364	0.321	0.321	0.314

Fishing year	AW CPUE	SS CPUE	Mean CPUE	Offset CPUE	Pred Offset
1990	0.425	0.553	0.489	0.476	0.483
1991	0.372	0.526	0.449	0.446	0.443
1992	0.364	0.467	0.416	0.414	0.410
1993	0.404	0.421	0.412	0.408	0.406
1994	0.479	0.461	0.470	0.465	0.464
1995	0.678	0.559	0.618	0.632	0.613
1996	0.831	0.754	0.793	0.839	0.788
1997	1.015	1.146	1.080	1.108	1.078
1998	1.043	1.037	1.040	1.107	1.037
1999	0.722	1.064	0.893	0.837	0.889
2000	0.676	1.137	0.907	0.809	0.903
2001	0.488	0.846	0.667	0.618	0.662
2002	0.329	0.613	0.471	0.445	0.465
2003	0.397	0.542	0.470	0.466	0.464
2004	0.460	0.477	0.469	0.459	0.463
2005	0.413	0.566	0.490	0.485	0.484
2006	0.464	0.538	0.501	0.497	0.495
2007	0.506	0.651	0.578	0.574	0.573
2008	0.465	0.610	0.537	0.535	0.532
2009	0.401	0.564	0.482	0.475	0.477
2010	0.345	0.489	0.417	0.417	0.411
2011	0.292	0.446	0.369	0.371	0.363
2012	0.394	0.455	0.425	0.420	0.419

Table 11: MPE indicators.

Code	Definition
B/*Bref*	mean biomass during the 20-year run, scaled as a proportion of *Bref*
TB/*Bref*	terminal biomass, scaled as a proportion of *Bref*
minComm	minimum commercial catch during the run
meanComm	mean commercial catch during the run
mean5-yrComm	mean commercial catch during the first five years of the run
minRec	minimum recreational catch during the run
meanRec	mean recreational catch during the run
minCPUE	minimum observed fishing year CPUE during the run
meanCPUE	mean observed fishing year CPUE during the run
%AAVH	average annual variation in TACC during the run (AAVH)
B/*Bmsy*	projected biomass as a proportion of *Bmsy*
B<*Bref*	proportion of years in which biomass was less than *Bref*
B<*Bmin*	proportion of years in which biomass was less than *Bmin*
B< *Bmsy*	proportion of years in which biomass was less than *Bmsy*
nchanges	proportion of years in which TACC changed
B<20%*SSB01*	proportion of years in which SSB was less than 20% *SSB0*
B<10%*SSB01*	proportion of years in which SSB was less than 10% *SSB0*
B<50%*Bref*	proportion of years in which biomass was less than 50% *Bref*
B<25%*Bref*	proportion of years in which biomass was less than 20% *Bref*
left of plateau	proportion of years in which the TACC was to the left of the plateau
right of plateau	proportion of years in which the TACC was to the right of the plateau
on plateau	proportion of years in which the TACC was on the plateau
totalCatch	sum of meanComm and meanRec
TACCnow	the TACC generated by a rule, given the best current estimate of offset-year CPUE

Table 12: Ranges of values used for each rule parameter in exploratory runs.

Function	Par	Min.	Max.
plateau height	*par2*	180	250
plateau left	*par3*	0.1	0.5
plateau right	*par4*	0.4	4.0
intercept	*par5*	0.0	0.2
step width	*par6*	0.1	1.0
step height	*par7*	0.05	0.20
min threshold	*par8*	0.00	0.05

Table 13: The range of indicator values seen in the rules evaluated.

Indicator	Min.	Max.
B/*Bref*	0.589	1.046
TB/*Bref*	0.562	1.098
minComm	45.4	235.5
meanComm	175.9	250.3
meanRec	51.8	85.4
minCPUE	0.190	0.436
meanCPUE	0.311	0.599
%AAVH	0.0	21.5
B/*Bmsy*	1.007	1.792
B<*Bref*	0.402	0.990
B<*Bmin*	0.000	0.444
B<*Bmsy*	0.002	0.503
nchanges	0.050	0.861
B<*SSB20%*	0.000	0.028
left of plateau	0.000	0.678
right of plateau	0.000	0.650
on plateau	0.271	1.000
totalCatch	261.3	302.1

Table 14: CRA 2: parameters for the nine final rule candidates, and the TACC generated by each rule from a CPUE of 0.3668 kg/potlift.

Finalists	Rule type par1	Plateau height par2	Plateau left par3	Plateau right par4	Intercept par5	Step width par6	Step height par7	Min par8	2014–15 TACC
3	4	200	0.35	0.6	0.1	0.1	0.15	0.05	200.00
4	4	200	0.30	0.5	0	0.1	0.1	0.05	200.00
5	4	210	0.35	0.65	0.1	0.1	0.15	0.05	210.00
6	4	210	0.30	0.5	0.1	0.15	0.1	0.05	210.00
7	4	220	0.35	0.6	0.1	0.2	0.1	0.05	220.00
9	4	236	0.35	0.6	0	0.2	0.1	0.05	236.00
12	4	215	0.35	0.65	0.1	0.2	0.15	0.05	215.00
13	4	210	0.35	0.55	0.1	0.1	0.1	0.05	210.00
16	4	215	0.35	0.55	0.1	0.15	0.1	0.05	215.00

Table 15: Comparison of the base case MPE indicators for the nine final rules presented to the NRLMG.

	3	4	5	6	7	9	12	13	16
TACC @ 0.3668	200	200	210	210	220	236	215	210	215
B/Bref	0.892	0.859	0.850	0.818	0.797	0.727	0.823	0.838	0.816
TB/Bref	0.903	0.863	0.860	0.817	0.804	0.722	0.830	0.842	0.817
minComm	199.9	199.9	209.8	209.8	199.8	190.4	214.8	209.8	214.7
meanComm	202.9	208.1	209.9	215.1	219.0	229.4	214.9	212.0	215.0
meanRec	74.2	72.0	71.2	69.2	67.6	62.2	69.4	70.4	68.8
minCPUE	0.379	0.369	0.353	0.344	0.323	0.279	0.340	0.349	0.336
meanCPUE	0.501	0.482	0.476	0.457	0.445	0.399	0.461	0.469	0.455
%AAVH	2.79	3.01	1.47	2.51	2.00	3.01	1.47	2.63	2.51
B/Bmsy	1.519	1.468	1.455	1.399	1.372	1.255	1.415	1.433	1.395
B<Bref	0.766	0.831	0.816	0.877	0.882	0.942	0.849	0.850	0.874
B<Bmin	0.013	0.021	0.026	0.045	0.049	0.121	0.036	0.027	0.038
B<Bmsy	0.029	0.042	0.051	0.073	0.082	0.174	0.065	0.053	0.068
nchanges	0.230	0.349	0.179	0.287	0.234	0.293	0.189	0.289	0.277
left of plateau	0.049	0.018	0.086	0.037	0.140	0.281	0.111	0.089	0.115
right of plateau	0.143	0.395	0.047	0.302	0.063	0.026	0.037	0.181	0.150

Table 16: Rule 3: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.892	0.918	0.658	0.886	0.868	0.946
TB/Bref	0.903	0.926	0.651	0.900	0.847	0.955
minComm	199.9	199.9	129.6	199.9	199.9	199.8
meanComm	202.9	204.4	185.3	203.1	207.6	209.3
meanRec	74.2	74.8	56.0	73.8	72.5	78.7
minCPUE	0.379	0.379	0.260	0.355	0.404	0.346
meanCPUE	0.501	0.511	0.365	0.502	0.545	0.535
%AAVH	2.79	2.94	7.06	4.39	3.67	5.87
B/Bmsy	1.519	1.682	1.138	1.513	1.479	1.620
B<Bref	0.766	0.735	0.982	0.777	0.822	0.617
B<Bmin	0.013	0.013	0.216	0.012	0.019	0.049
B<Bmsy	0.029	0.006	0.290	0.028	0.037	0.067
nchanges	0.230	0.253	0.424	0.316	0.301	0.398
left of plateau	0.049	0.046	0.424	0.062	0.025	0.090
right of plateau	0.143	0.173	0.007	0.161	0.274	0.298

Table 17: Rule 4: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.859	0.888	0.617	0.854	0.832	0.914
TB/Bref	0.863	0.889	0.592	0.856	0.803	0.915
minComm	199.9	199.9	152.0	199.9	199.8	199.8
meanComm	208.1	209.9	192.6	209.1	214.1	215.5
meanRec	72.0	72.7	53.0	71.5	70.0	76.2
minCPUE	0.369	0.367	0.226	0.344	0.391	0.333
meanCPUE	0.482	0.489	0.339	0.480	0.518	0.512
%AAVH	3.01	3.51	3.98	4.73	4.01	5.01
B/Bmsy	1.468	1.628	1.061	1.456	1.422	1.562
B<Bref	0.831	0.803	0.988	0.836	0.872	0.666
B<Bmin	0.021	0.023	0.344	0.023	0.030	0.070
B<Bmsy	0.042	0.011	0.413	0.044	0.055	0.092
nchanges	0.349	0.371	0.347	0.452	0.413	0.472
left of plateau	0.018	0.017	0.321	0.026	0.009	0.056
right of plateau	0.395	0.422	0.041	0.394	0.550	0.507

Table 18: Rule 5: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.850	0.883	0.634	0.848	0.841	0.926
TB/Bref	0.860	0.888	0.626	0.864	0.824	0.929
minComm	209.8	209.9	124.5	195.5	209.8	193.2
meanComm	209.9	209.9	189.2	209.9	211.5	213.1
meanRec	71.2	72.5	54.2	71.2	70.4	77.2
minCPUE	0.353	0.356	0.246	0.332	0.387	0.325
meanCPUE	0.476	0.485	0.349	0.478	0.524	0.521
%AAVH	1.47	1.47	9.03	2.94	2.20	5.13
B/Bmsy	1.455	1.629	1.092	1.455	1.432	1.589
B<Bref	0.816	0.785	0.987	0.821	0.849	0.642
B<Bmin	0.026	0.025	0.278	0.023	0.036	0.065
B<Bmsy	0.051	0.013	0.355	0.048	0.063	0.085
nchanges	0.179	0.193	0.497	0.245	0.211	0.338
left of plateau	0.086	0.080	0.510	0.100	0.047	0.115
right of plateau	0.047	0.064	0.002	0.063	0.123	0.181

Table 19: Rule 6: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.818	0.853	0.598	0.814	0.798	0.883
TB/Bref	0.817	0.847	0.579	0.817	0.773	0.890
minComm	209.8	209.9	125.2	209.8	209.8	209.8
meanComm	215.1	216.2	194.4	215.2	219.3	220.4
meanRec	69.2	70.3	51.5	68.8	67.6	74.2
minCPUE	0.344	0.341	0.217	0.320	0.370	0.311
meanCPUE	0.457	0.462	0.327	0.455	0.494	0.495
%AAVH	2.51	2.51	8.15	4.01	3.01	4.51
B/Bmsy	1.399	1.569	1.032	1.394	1.362	1.521
B<Bref	0.877	0.851	0.991	0.880	0.903	0.693
B<Bmin	0.045	0.042	0.392	0.044	0.059	0.087
B<Bmsy	0.073	0.021	0.459	0.074	0.091	0.112
nchanges	0.287	0.298	0.426	0.393	0.328	0.419
left of plateau	0.037	0.037	0.373	0.047	0.020	0.074
right of plateau	0.302	0.328	0.029	0.312	0.451	0.461

Table 20: Rule 7: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.797	0.839	0.613	0.801	0.788	0.886
TB/Bref	0.804	0.835	0.600	0.810	0.770	0.893
minComm	199.8	198.8	118.9	185.1	219.8	182.1
meanComm	219.0	219.5	192.1	218.1	220.9	220.4
meanRec	67.6	69.2	52.6	67.8	66.7	74.4
minCPUE	0.323	0.322	0.233	0.307	0.355	0.302
meanCPUE	0.445	0.452	0.336	0.448	0.487	0.496
%AAVH	2.00	2.19	11.25	3.30	2.00	4.01
B/Bmsy	1.372	1.554	1.056	1.376	1.345	1.522
B<Bref	0.882	0.856	0.991	0.883	0.900	0.685
B<Bmin	0.049	0.048	0.343	0.046	0.068	0.085
B<Bmsy	0.082	0.024	0.419	0.078	0.105	0.112
nchanges	0.234	0.243	0.566	0.308	0.234	0.353
left of plateau	0.140	0.134	0.586	0.151	0.085	0.150
right of plateau	0.063	0.081	0.003	0.081	0.147	0.234

Table 21: Rule 9: Comparison of base case and robustness trial MPE indicators.

	base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.727	0.773	0.562	0.732	0.712	0.819
TB/Bref	0.722	0.763	0.541	0.727	0.681	0.813
minComm	190.4	190.4	137.7	183.5	205.4	179.9
meanComm	229.4	229.9	199.8	228.7	233.4	231.7
meanRec	62.2	64.7	48.8	62.6	61.2	69.3
minCPUE	0.279	0.279	0.202	0.269	0.300	0.263
meanCPUE	0.399	0.405	0.304	0.404	0.434	0.452
%AAVH	3.01	3.04	9.54	4.34	2.36	4.49
B/Bmsy	1.255	1.444	0.969	1.261	1.226	1.411
B<Bref	0.942	0.925	0.995	0.942	0.951	0.766
B<Bmin	0.121	0.117	0.515	0.113	0.158	0.144
B<Bmsy	0.174	0.059	0.574	0.166	0.213	0.175
nchanges	0.293	0.300	0.617	0.362	0.264	0.377
left of plateau	0.281	0.277	0.748	0.285	0.192	0.236
right of plateau	0.026	0.037	0.001	0.038	0.067	0.159

Table 22: Rule 12: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.823	0.863	0.622	0.825	0.817	0.907
TB/Bref	0.830	0.865	0.614	0.839	0.802	0.917
minComm	214.8	214.8	121.6	191.3	214.8	188.4
meanComm	214.9	214.9	190.5	214.1	214.9	216.3
meanRec	69.4	70.8	53.3	69.6	68.8	75.9
minCPUE	0.340	0.339	0.239	0.319	0.372	0.315
meanCPUE	0.461	0.469	0.343	0.463	0.508	0.510
%AAVH	1.47	1.47	9.93	2.94	1.47	4.32
B/Bmsy	1.415	1.593	1.074	1.418	1.391	1.563
B<Bref	0.849	0.818	0.990	0.851	0.871	0.658
B<Bmin	0.036	0.035	0.310	0.033	0.050	0.074
B<Bmsy	0.065	0.017	0.387	0.062	0.082	0.097
nchanges	0.189	0.195	0.530	0.250	0.191	0.309
left of plateau	0.111	0.103	0.549	0.122	0.062	0.130
right of plateau	0.037	0.051	0.001	0.052	0.101	0.175

Table 23: Rule 13: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.838	0.871	0.634	0.836	0.818	0.905
TB/Bref	0.842	0.870	0.625	0.842	0.793	0.909
minComm	209.8	209.9	124.4	192.3	209.8	186.8
meanComm	212.0	213.0	189.2	212.0	216.2	217.3
meanRec	70.4	71.5	54.2	70.3	68.9	75.6
minCPUE	0.349	0.347	0.246	0.328	0.377	0.318
meanCPUE	0.469	0.476	0.349	0.469	0.508	0.507
%AAVH	2.63	3.01	9.20	4.56	3.01	5.65
B/Bmsy	1.433	1.606	1.090	1.427	1.396	1.555
B<Bref	0.850	0.824	0.988	0.855	0.884	0.674
B<Bmin	0.027	0.027	0.279	0.026	0.041	0.070
B<Bmsy	0.053	0.014	0.357	0.052	0.070	0.092
nchanges	0.289	0.310	0.511	0.395	0.342	0.463
left of plateau	0.089	0.086	0.512	0.106	0.051	0.123
right of plateau	0.181	0.211	0.012	0.201	0.319	0.358

Table 24: Rule 16: Comparison of base case and robustness trial MPE indicators.

	Base	CPUEpow	Lo_rect	Hi_obs	Inc_q	Hi_sigR
B/Bref	0.816	0.852	0.622	0.816	0.798	0.892
TB/Bref	0.817	0.849	0.614	0.825	0.780	0.897
minComm	214.7	203.2	121.6	187.4	214.8	183.0
meanComm	215.0	216.0	190.6	215.3	219.2	219.2
meanRec	68.8	70.1	53.3	68.8	67.6	74.8
minCPUE	0.336	0.334	0.239	0.317	0.364	0.308
meanCPUE	0.455	0.462	0.343	0.457	0.495	0.499
%AAVH	2.51	2.75	10.14	4.01	2.51	4.74
B/Bmsy	1.395	1.573	1.073	1.394	1.366	1.529
B<Bref	0.874	0.848	0.990	0.876	0.897	0.683
B<Bmin	0.038	0.037	0.311	0.036	0.055	0.079
B<Bmsy	0.068	0.018	0.389	0.066	0.089	0.104
nchanges	0.277	0.291	0.542	0.375	0.300	0.423
left of plateau	0.115	0.109	0.549	0.128	0.066	0.137
right of plateau	0.150	0.179	0.010	0.173	0.280	0.341

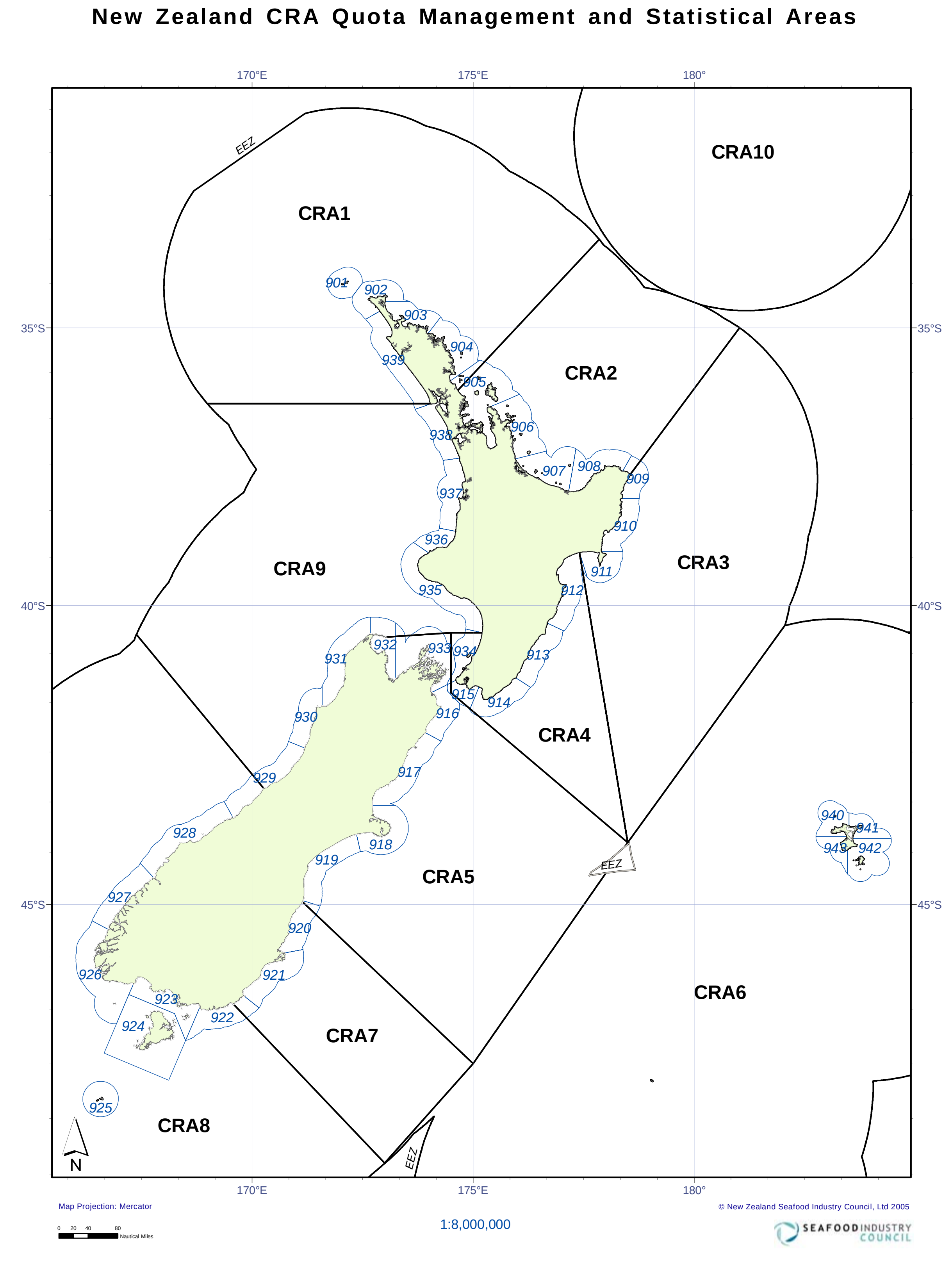

Figure 1: Rock lobster statistical areas (light blue) and Quota Management Areas.

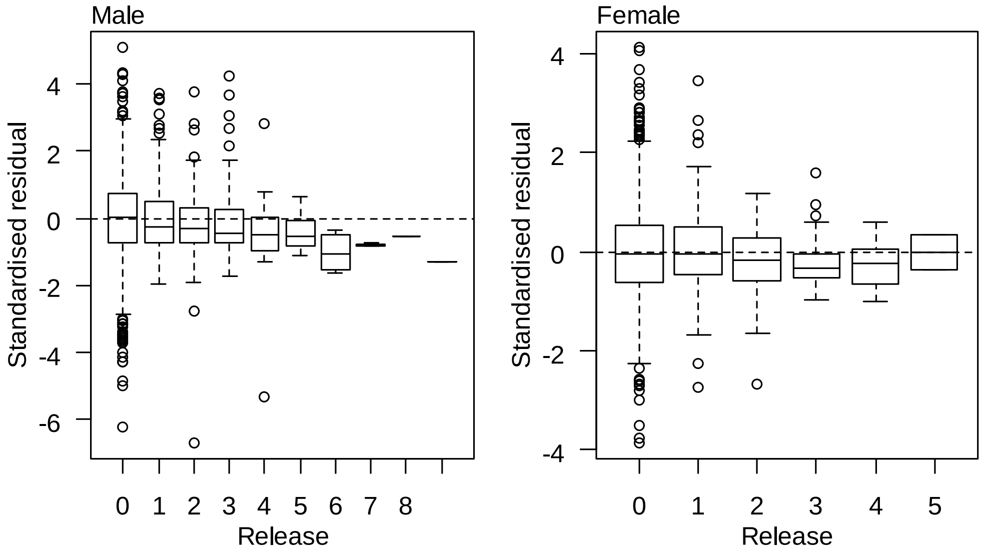

Figure 2: Residuals from the tag-recapture data in a preliminary fit using the Schnute-Francis growth model and the full tag dataset; males on left and females on right; the y-axis is the number of re-releases, *viz.* zero means that the tagged fish was recaptured and retained; 1 indicates that the tagged fished was recaptured twice, etc.

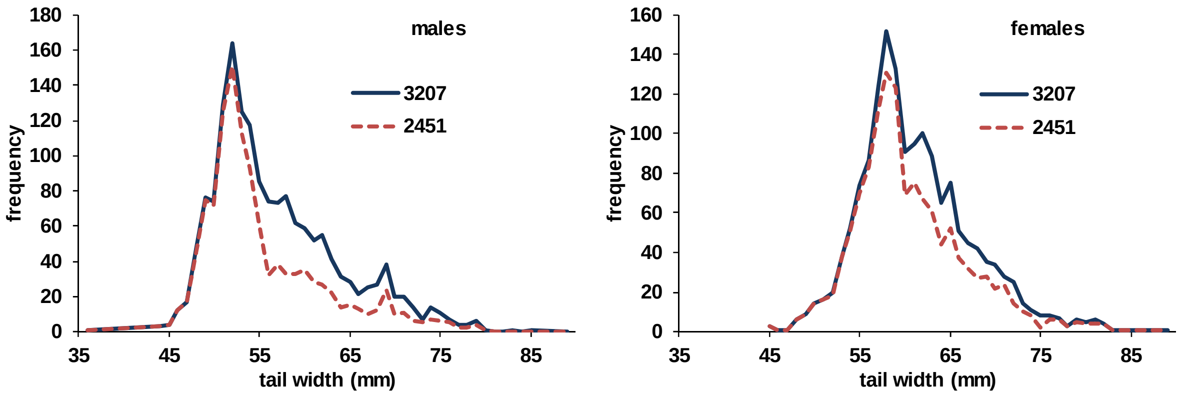

Figure 3: Sizes at release for the full (n=3207) and reduced (n=2451) tag data sets, where the re-released fish were removed; males on left and females on right.

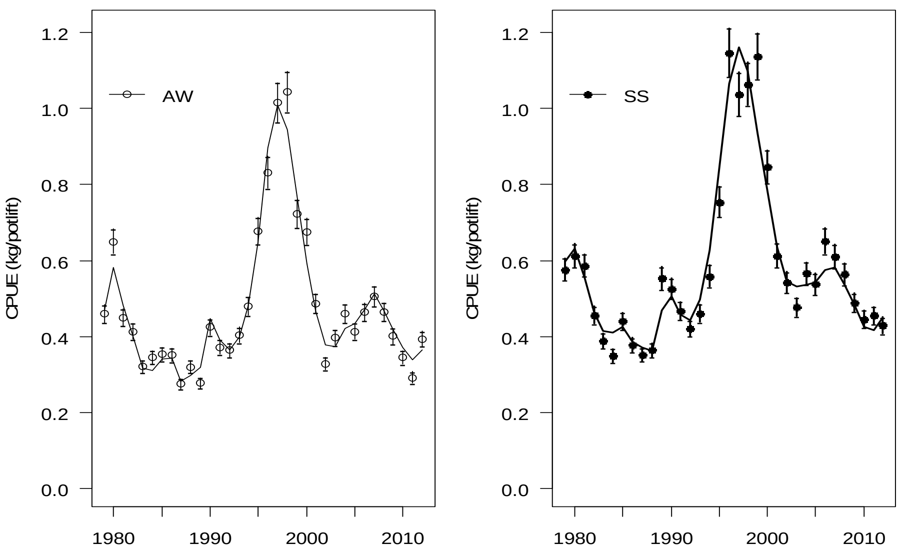

Figure 4: CRA 2 MPD base case fit: CPUE by year and season: circles show observed values, bars show one standard deviation; lines show predicted values; AW on left and SS on right.

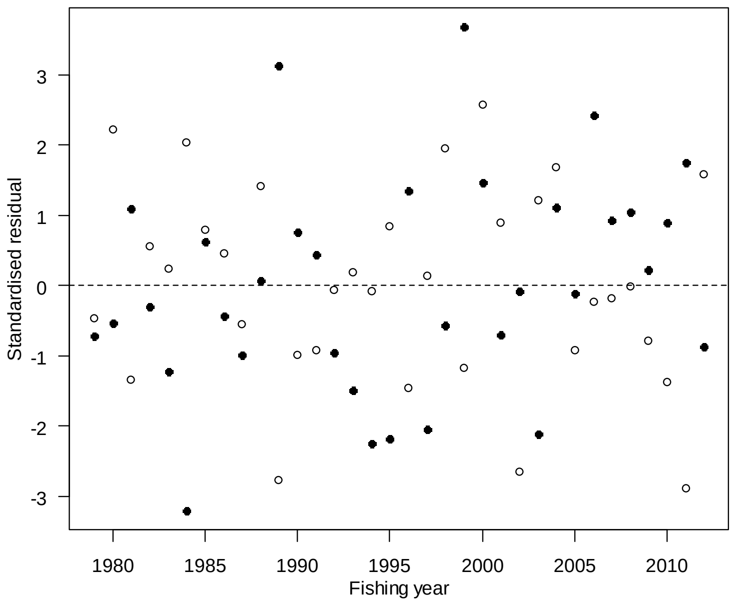

Figure 5: CRA 2 MPD base case fit: residuals from the fit to CPUE: open circles are AW, closed are SS.

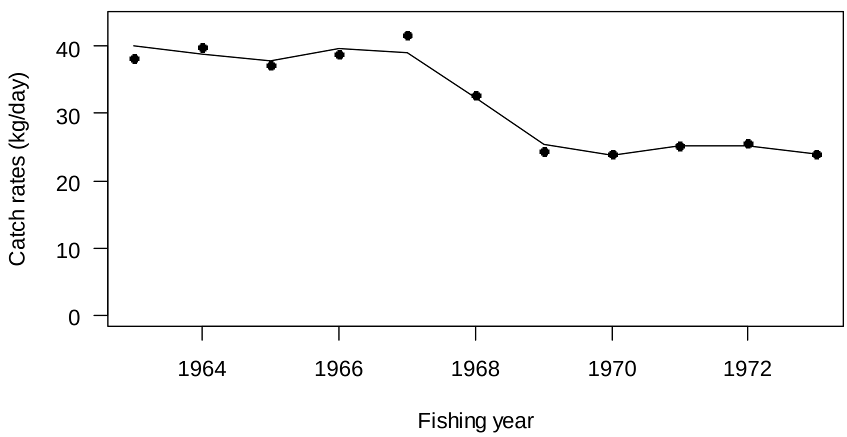

Figure 6: CRA 2 MPD base case fit: CR (historical catch rate) by year.

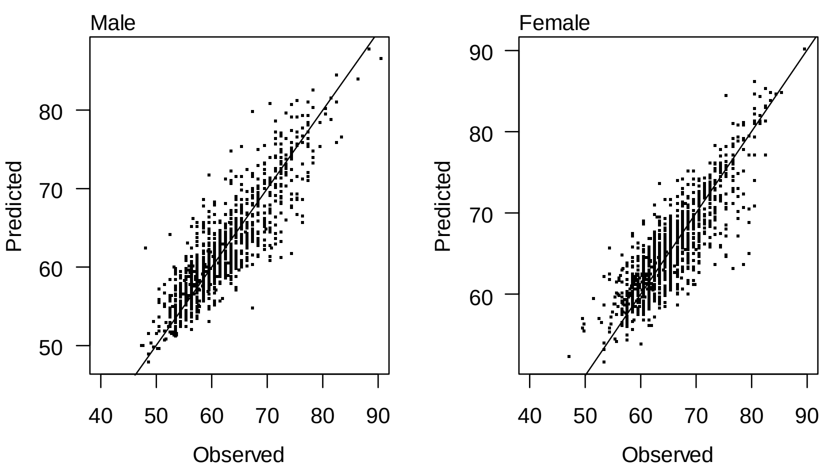

Figure 7: CRA 2 MPD base case fit: predicted versus observed increments in the tag-recapture data; males on left and females on right.

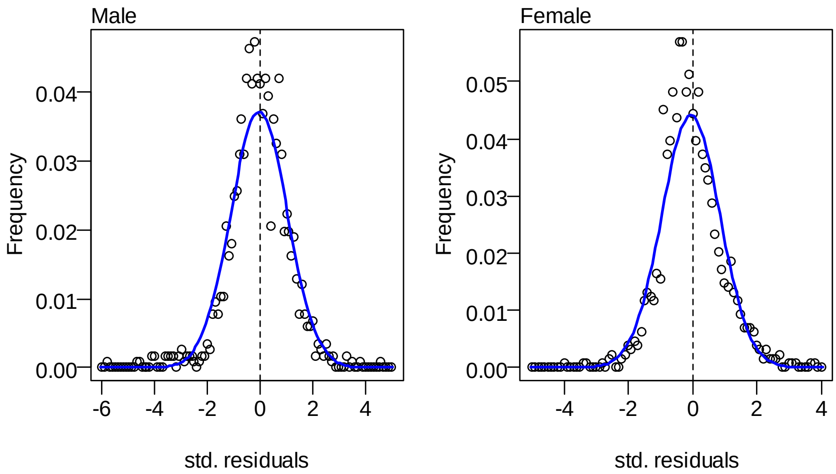

Figure 8: CRA 2 MPD base case fit: distributions of normalised residuals from the fit to tag-recapture data, but note that the likelihood uses robustified calculations; males on left and females on right.

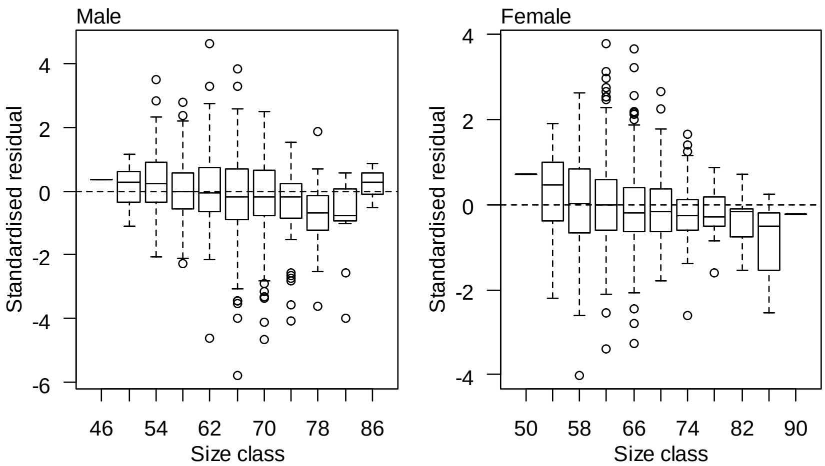

Figure 9: CRA 2 MPD base case fit: distributions of residuals from tag-recapture data by sex and size; males on left and females on right.

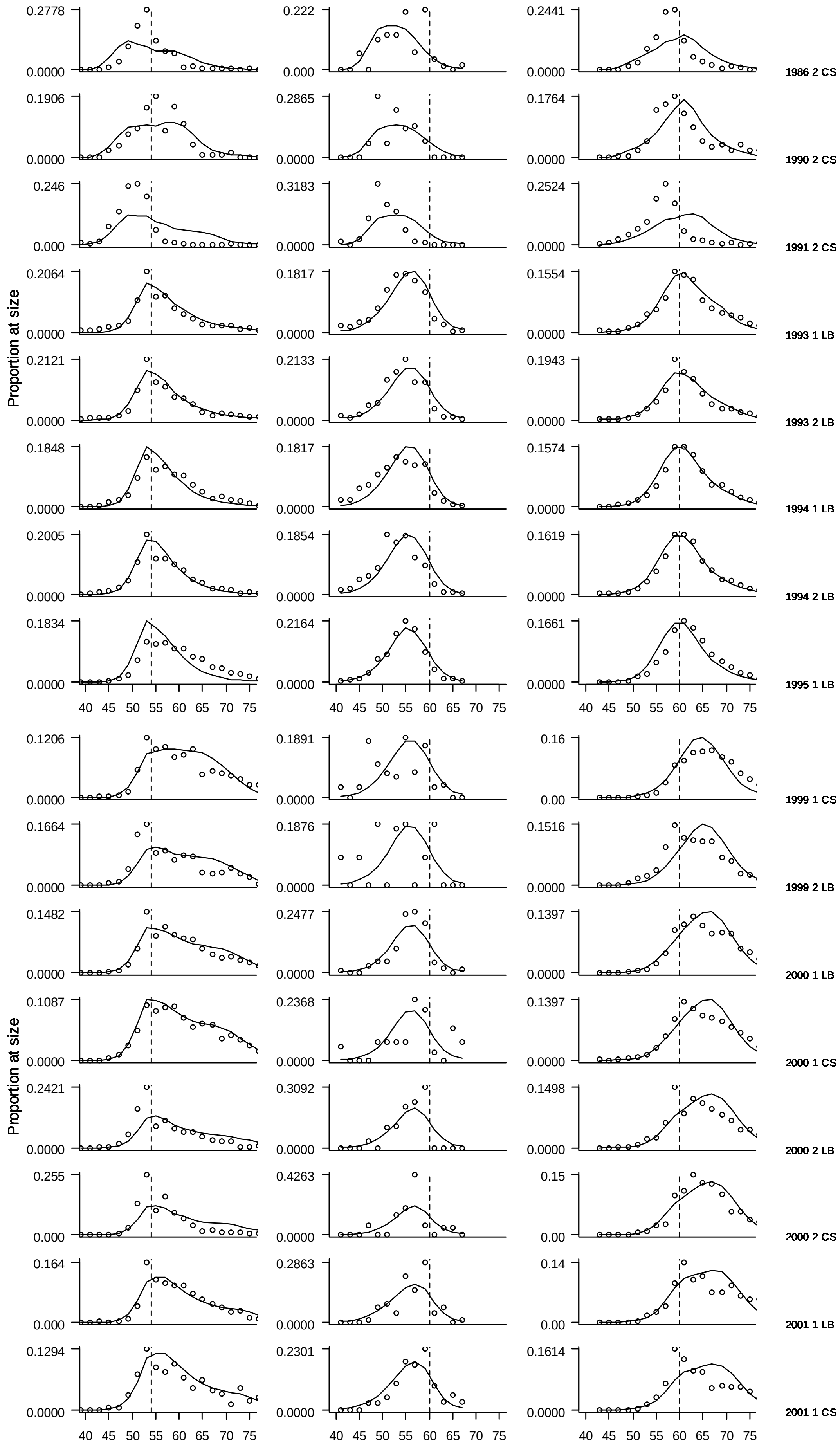

Figure 10: CRA 2 MPD base case fit: predicted (lines) and observed (circles) proportions-at-size; from left to right are males, immature females and mature females; numbers at right show the year, season (1=AW, 2=SS) and source (LB = logbooks, CS = observers).

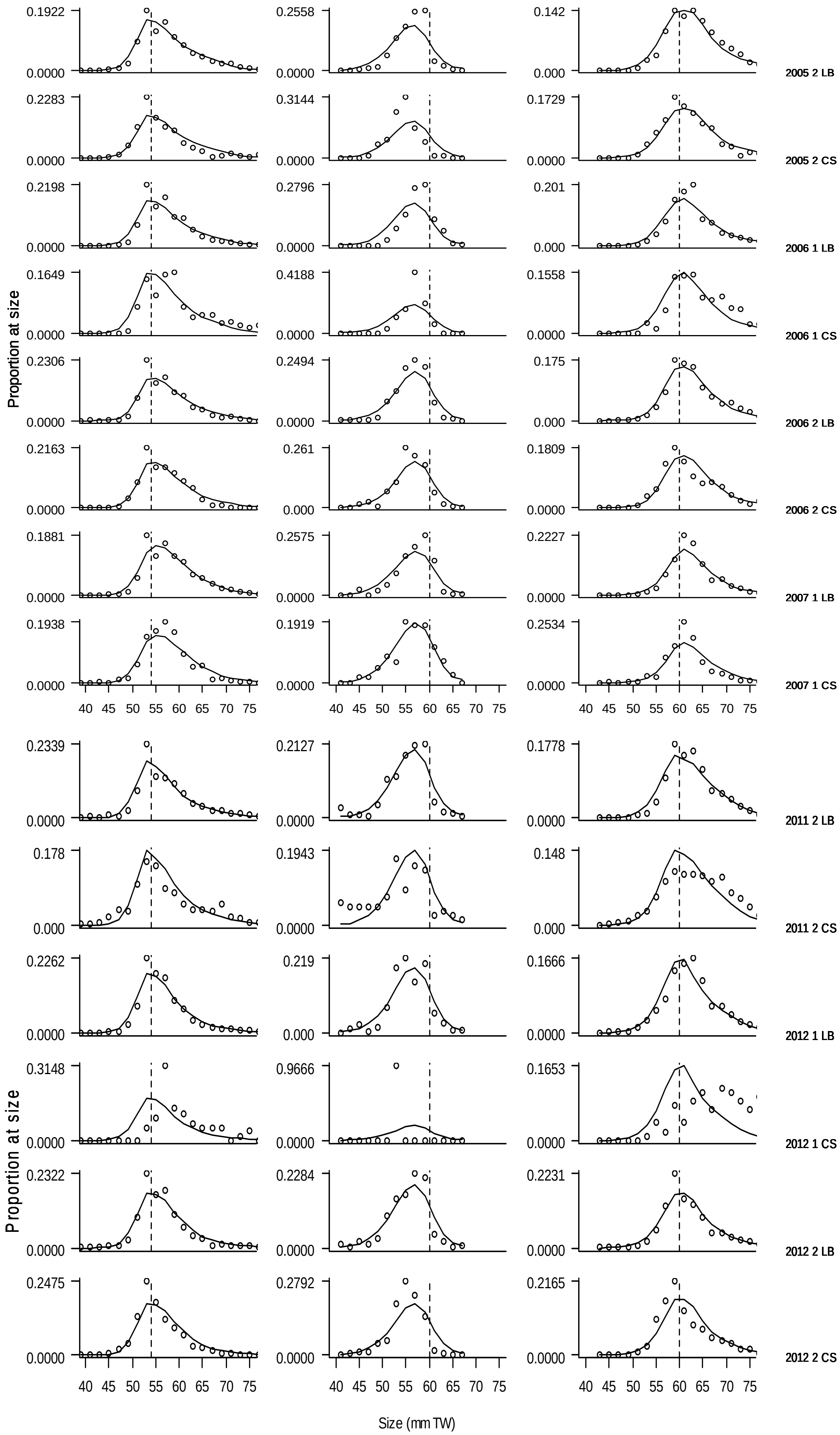

Figure 10 concluded.

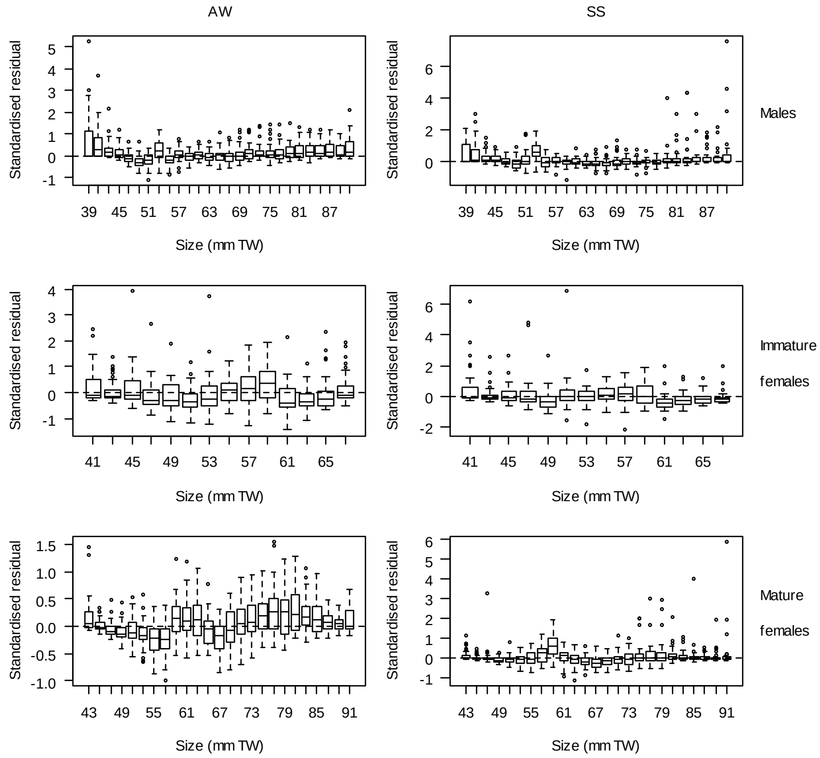

Figure 11: CRA 2 MPD base case fit: residuals from the fit to LFs by sex, size and season; AW on left and SS on right; from top to bottom are males, immature females and mature females.

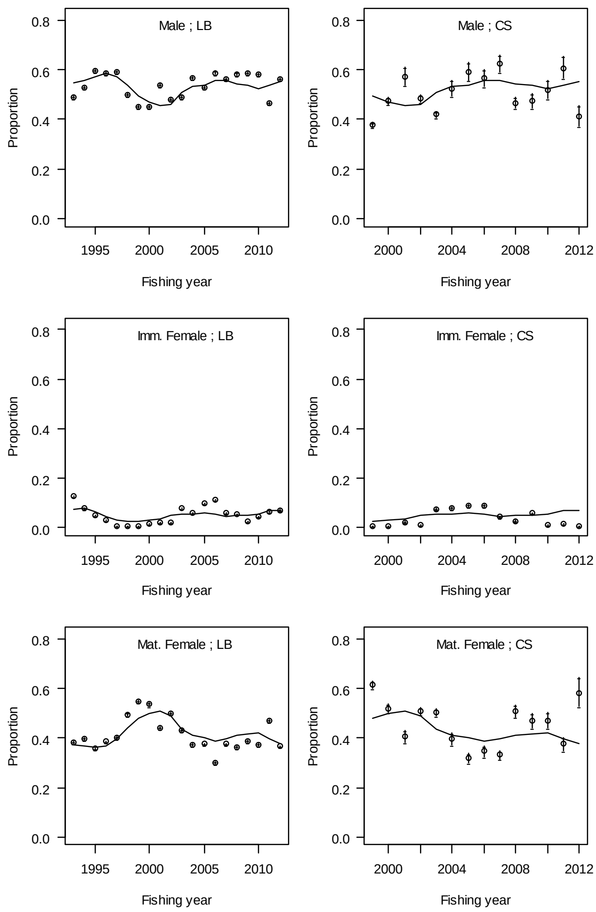

Figure 12: CRA 2 MPD base case fit: observed (circles) and predicted proportion-at-sex (lines) in AW by sex and data type; logbook data on left and observer data on right; from top to bottom are males, immature females and mature females.

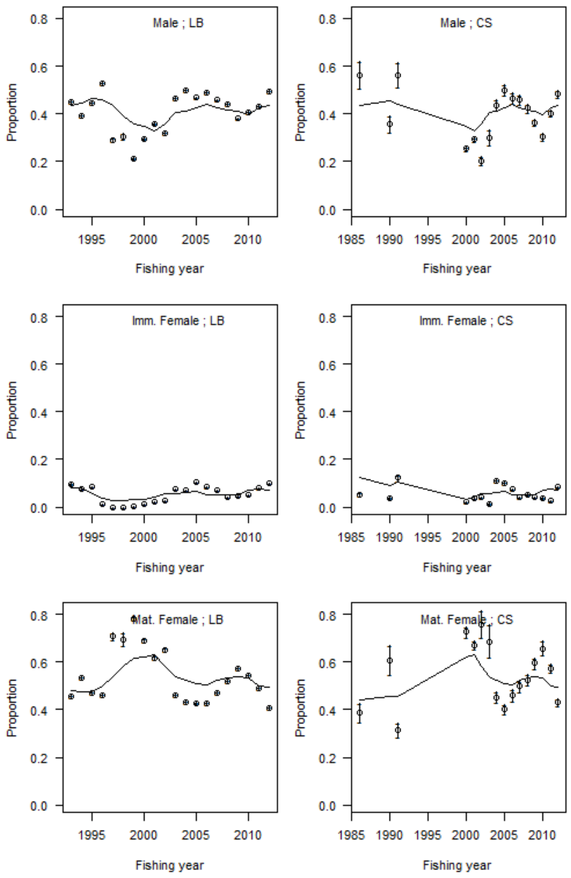

Figure 13: CRA 2 MPD base case fit CRA 2 MPD base case fit: observed (circles) and predicted proportion-at-sex (lines) in SS by sex and data type; logbook data on left and observer data on right; from top to bottom are males, immature females and mature females.

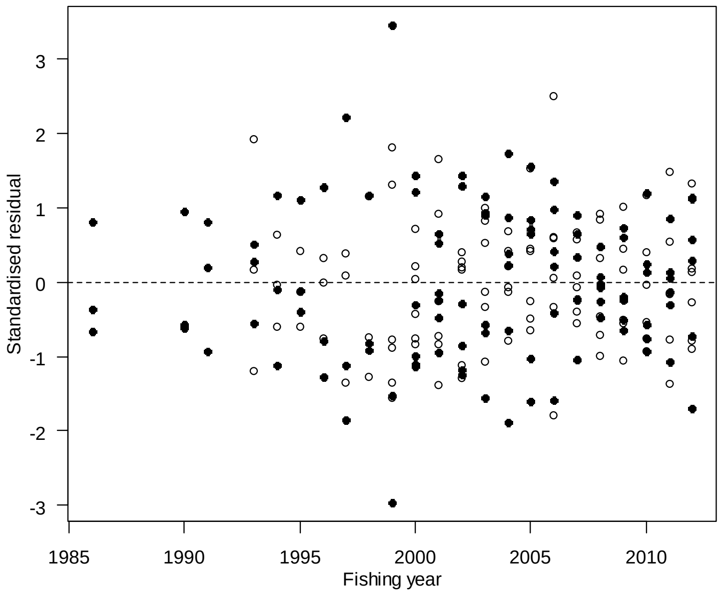

Figure 14: CRA 2 MPD base case fit: residuals from the fits to sex proportions: open circles are AW and closed are SS.

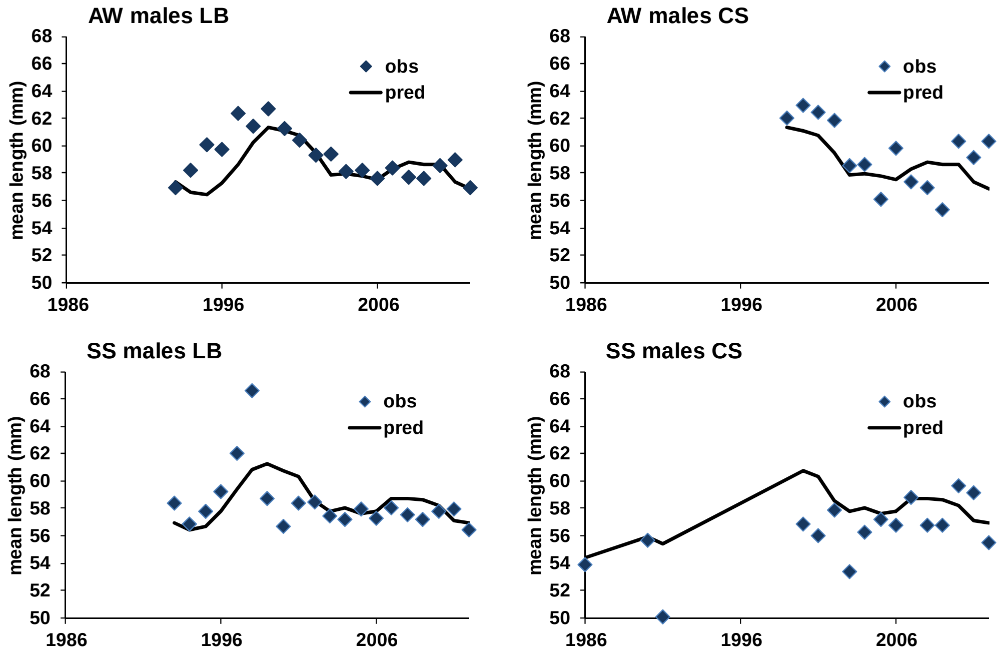

Figure 15: CRA 2 MPD base case fit: predicted (lines) and observed (diamonds) male mean length by season and data source; AW above and SS below; logbook data on left and observer data on right.

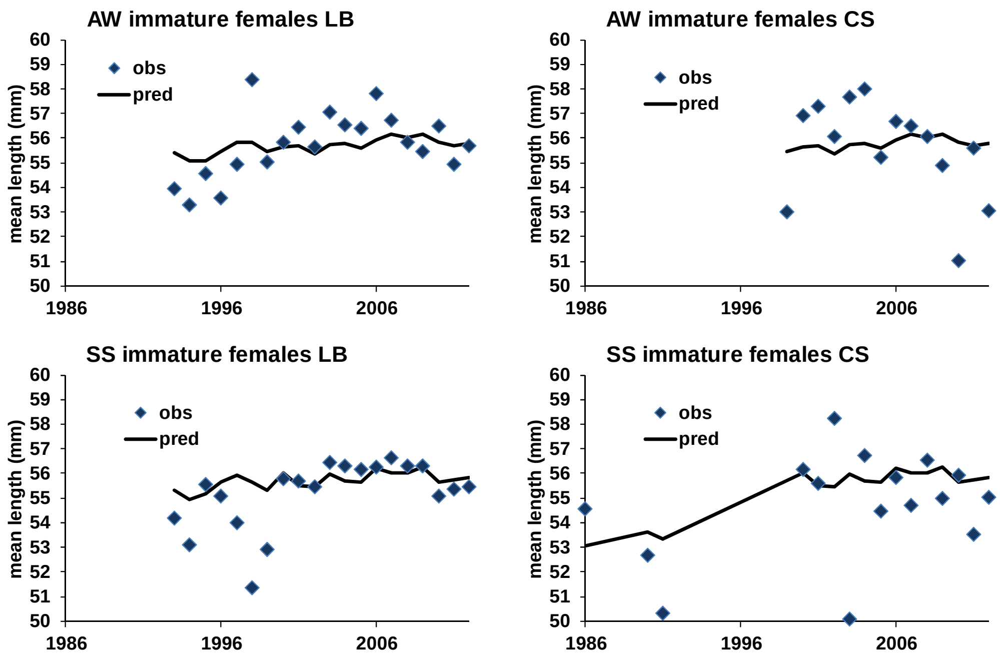

Figure 16: CRA 2 MPD base case fit: predicted (lines) and observed (diamonds) immature female mean length by season and data source; AW above and SS below; logbook data on left and observer data on right.

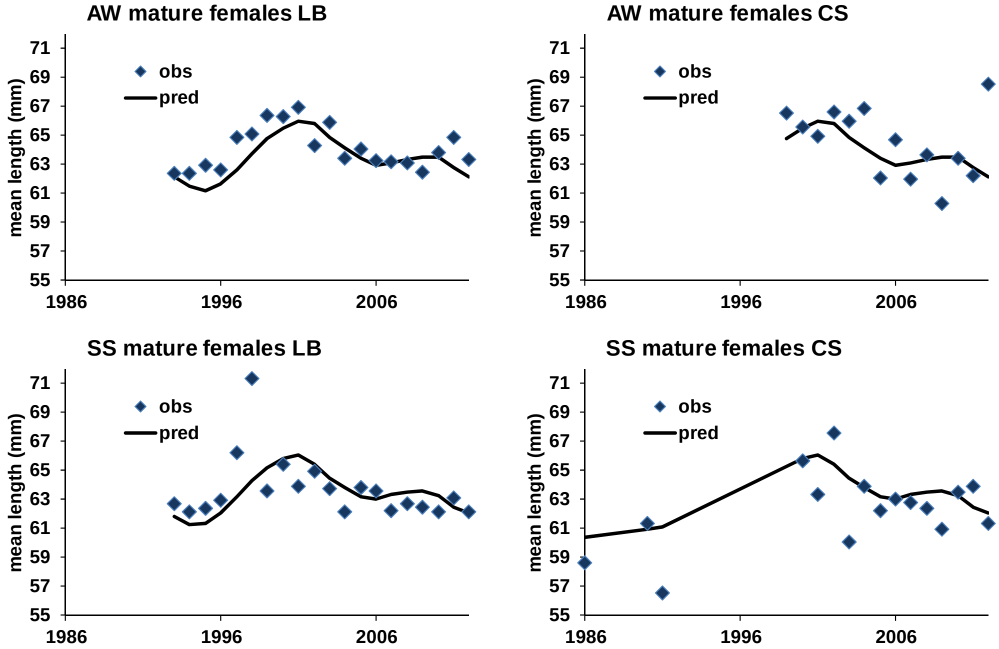

Figure 17: CRA 2 MPD base case fit: predicted (lines) and observed (diamonds) female mean length by season and data source; AW above and SS below; logbook data on left and observer data on right.

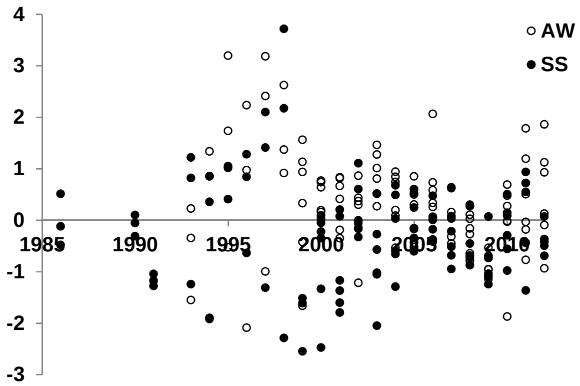

Figure 18: CRA 2 MPD base case fit: residuals from the fits to mean length: open circles are AW and closed circles SS; sexes are combined.

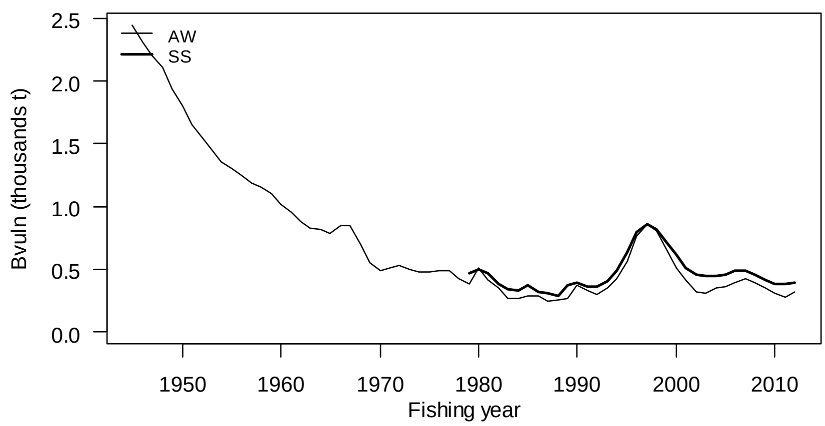

Figure 19: CRA 2 MPD base case fit: vulnerable biomass trajectory by season (light line AW, heavy line SS); the model used a yearly time step before 1979 that is shown as "AW".

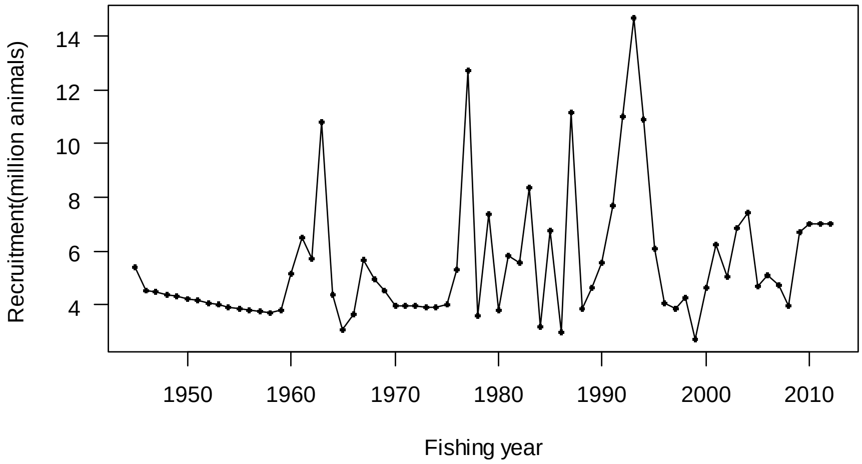

Figure 20: CRA 2 MPD base case fit: annual recruitment.

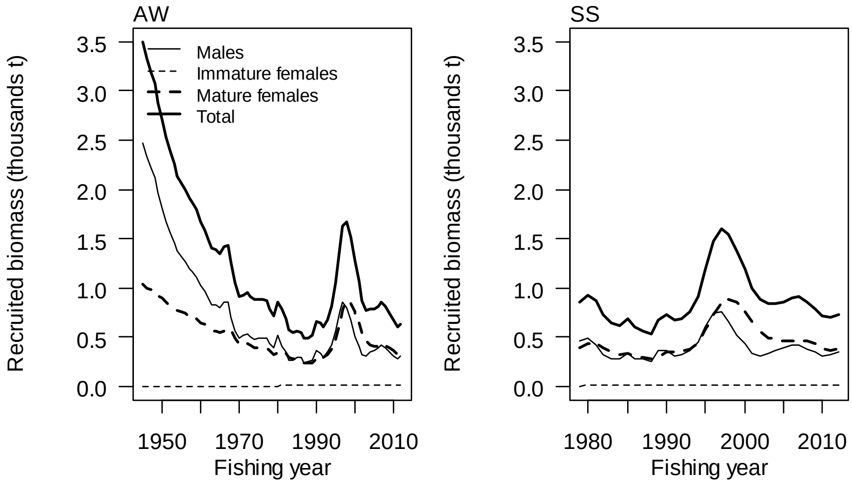

Figure 21: CRA 2 MPD base case fit: seasonal trajectories of recruited biomass; AW on left, SS on right.

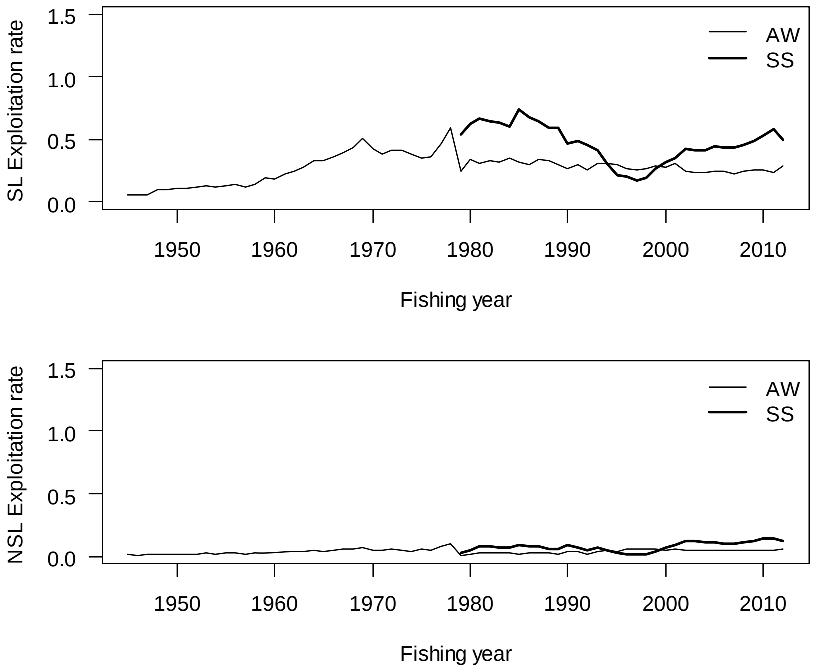

Figure 22: CRA 2 MPD base case fit: seasonal trajectories of exploitation rate for the SL (upper) and NSL fisheries; light line is AW and heavy line is SS.

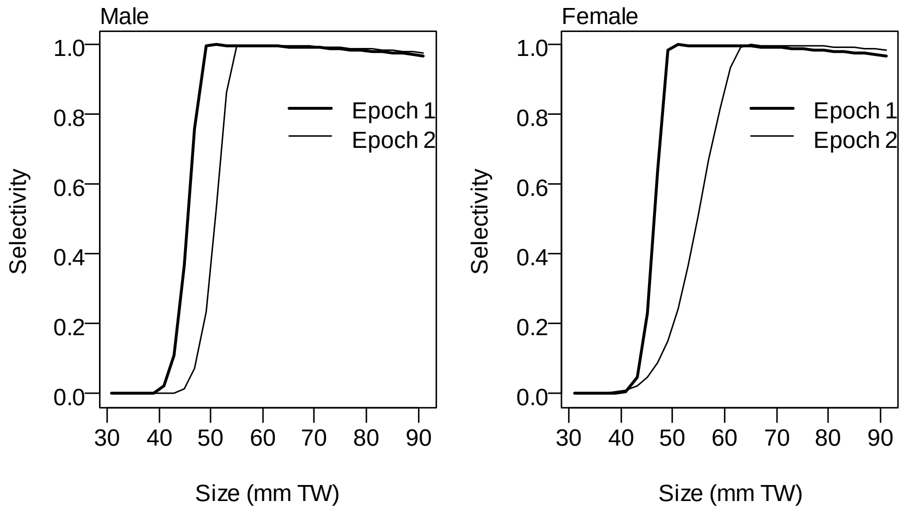

Figure 23: CRA 2 MPD base case fit: double normal selectivity-at-size for males and females in two epochs; the second epoch began in 1993; males on left, females on right; heavy line is epoch 1 and light line is epoch 2.

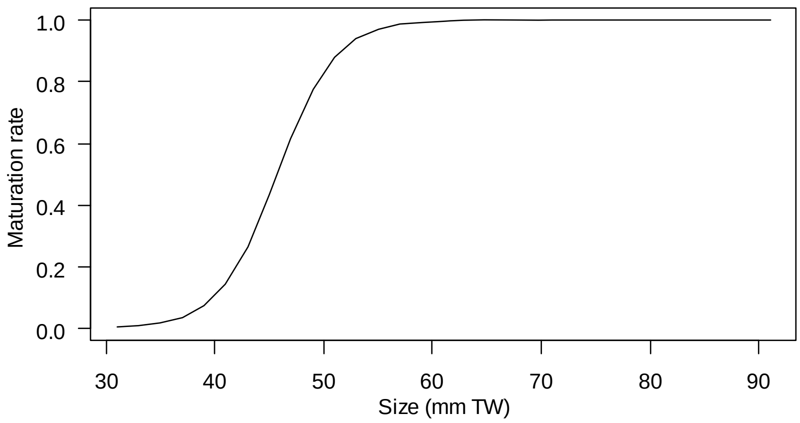

Figure 24: CRA 2 MPD base case fit: maturity-at-size.

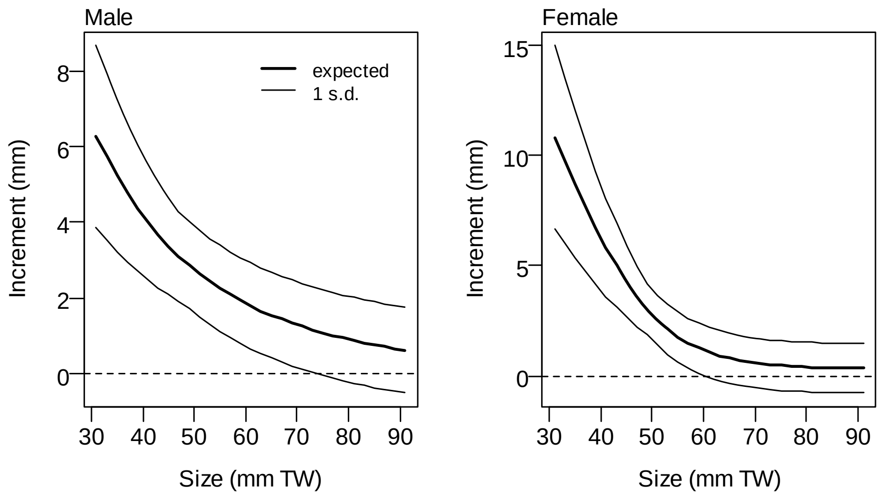

Figure 25: CRA 2 MPD base case fit: predicted increments against initial size at zero biomass (they are less at higher stock sizes because of density-dependence); lighter lines show one standard deviation; males on left and females on the right.

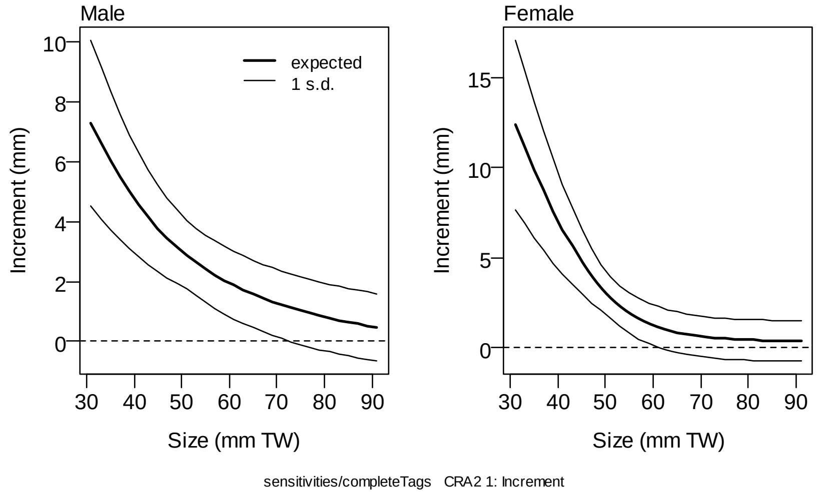

Figure 26: CRA 2 sens13 trial (using the complete tag data set): predicted increments against initial size at zero biomass; lighter lines are one standard deviation; males on left and females on the right.

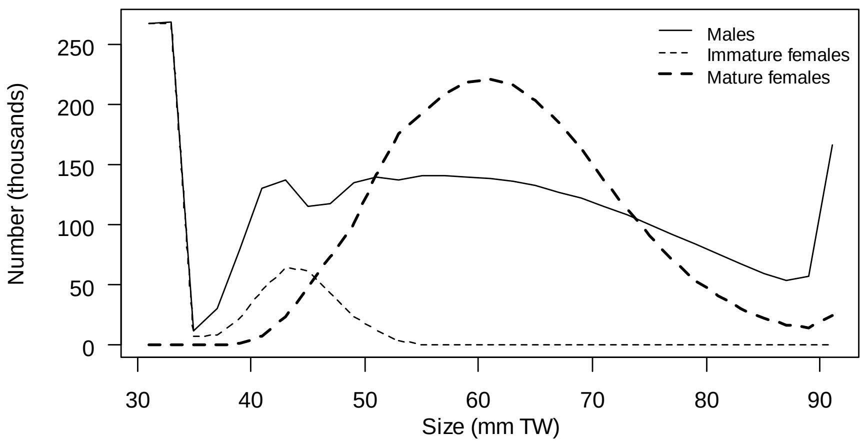

Figure 27: CRA 2 MPD base case fit: predicted size distributions by sex in the absence of fishing and with constant recruitment.

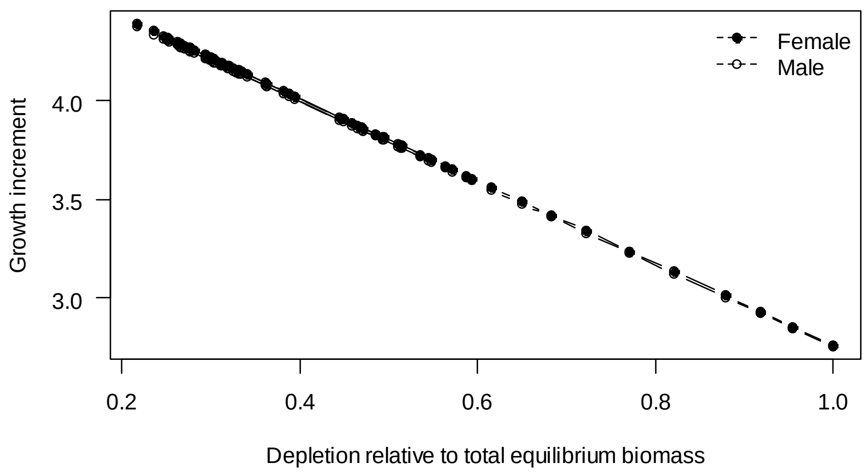

Figure 28: CRA 2 MPD base case fit: predicted increments at 50 mm TW as a function of total biomass in the base case MPD fit; note truncated y-axis.

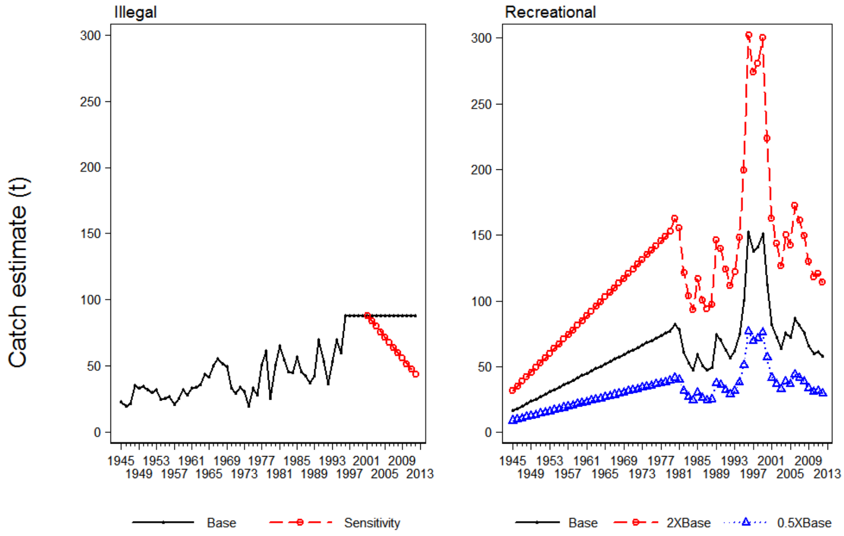

Figure 29: The base case illegal (left) and recreational catch trajectories, and the trajectories for the Lo Illegal sensitivity (left), and the Hi Rec and Lo Rec sensitivities (right).

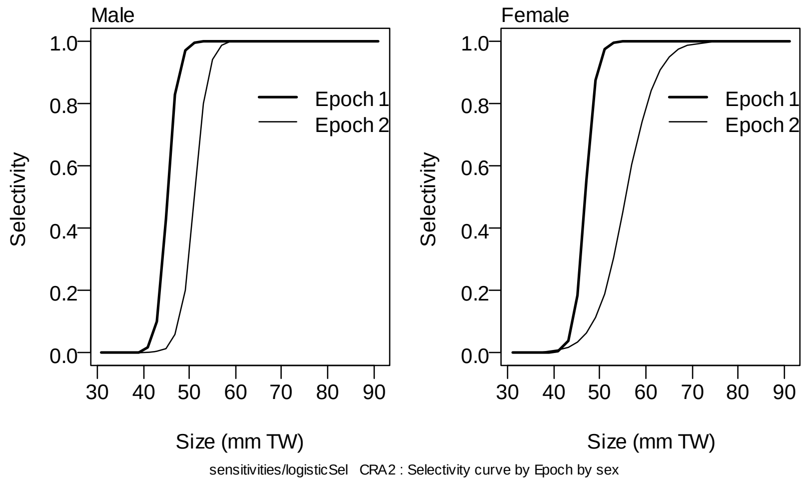

Figure 30: Logistic selectivity-at-size (sens8) for males (left) and females in two epochs; the second epoch (lighter line) began in 1993.

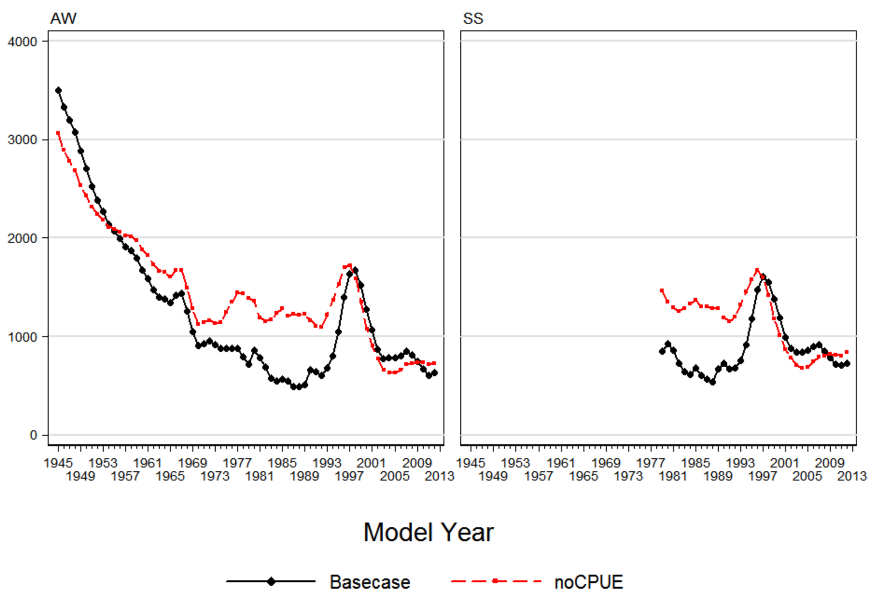

Figure 31: Comparison of the MPD base case recruited biomass trajectory (darker line), by season, with the trajectory from the noCPUE sensitivity trial; AW on left and SS on right.

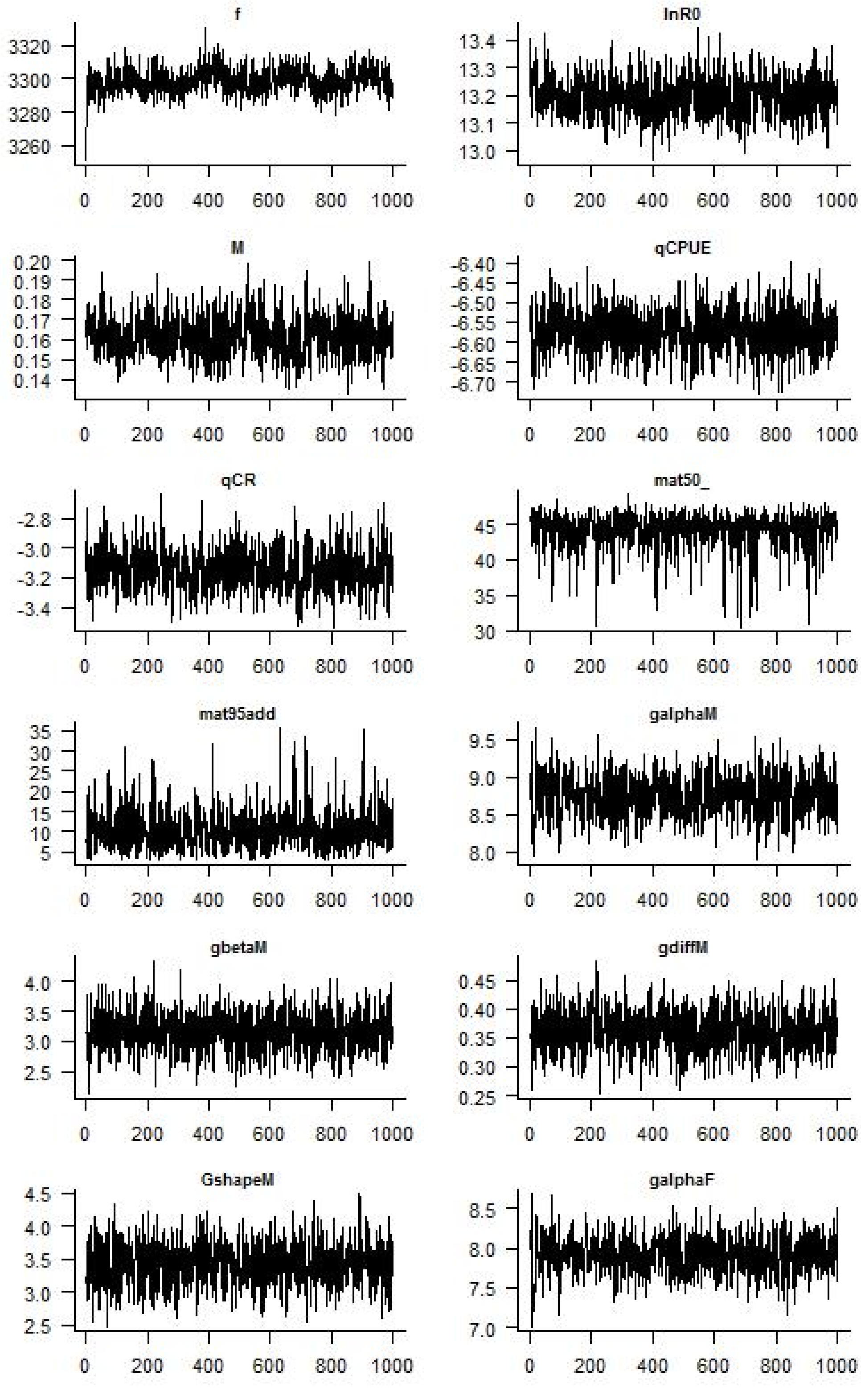

Figure 32: CRA 2 base case McMC: traces for estimated and derived parameters.

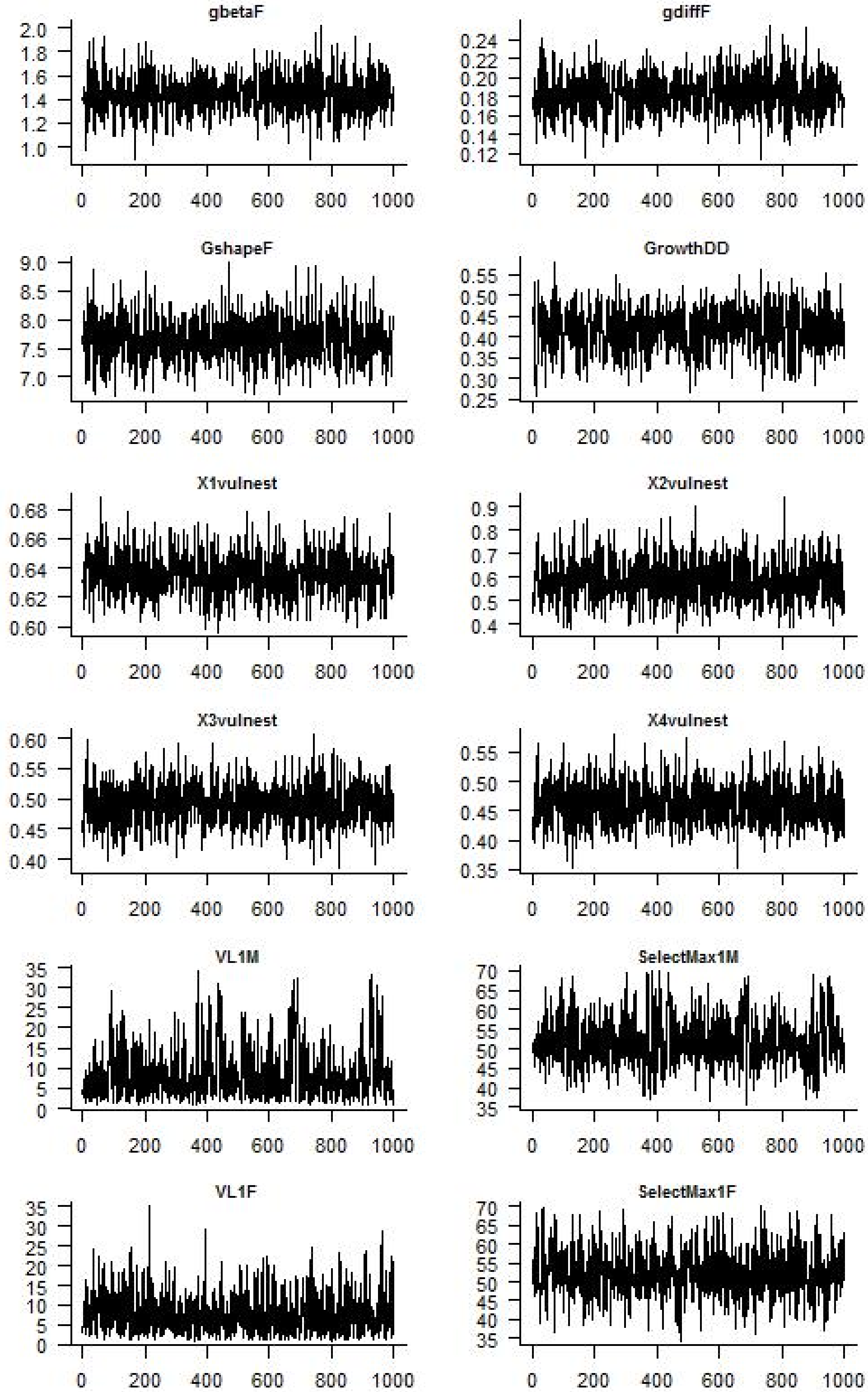

Figure 32 continued.

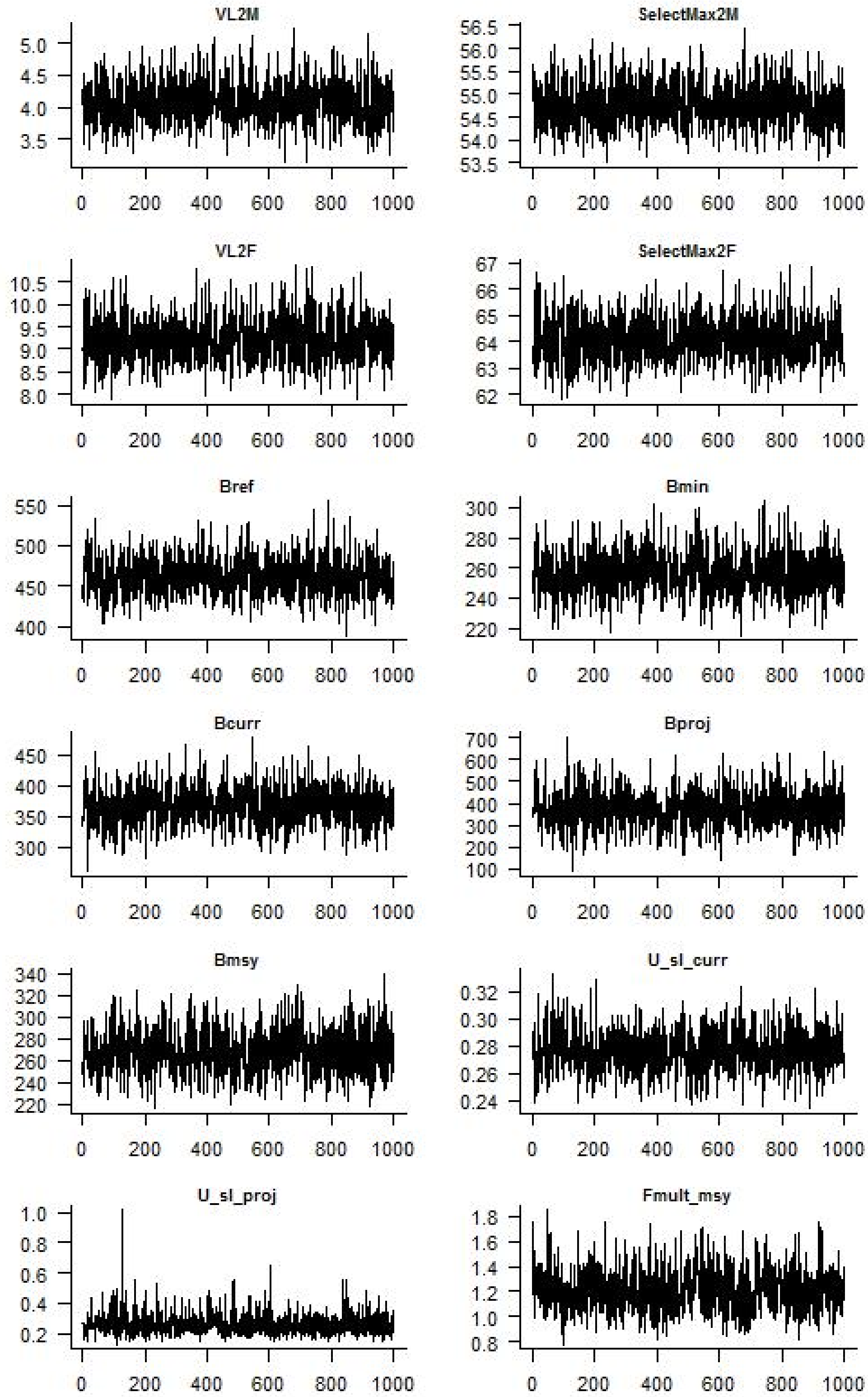

Figure 32 continued.

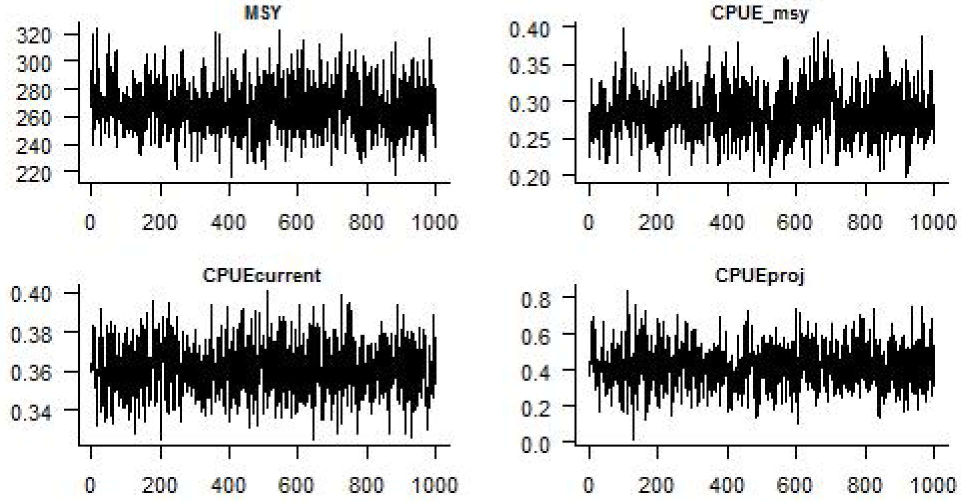

Figure 32 concluded.

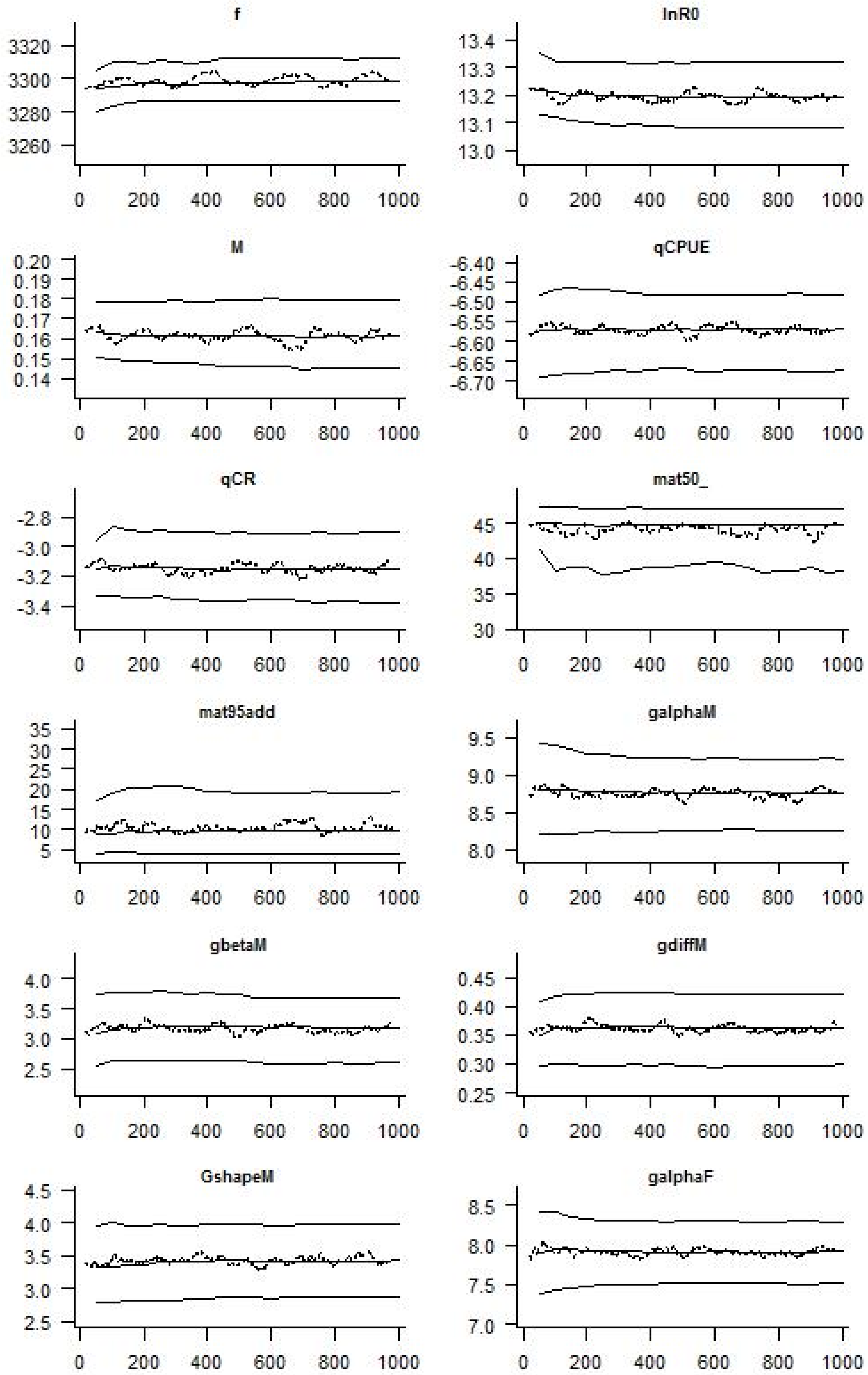

Figure 33: CRA 2 base case McMC: diagnostic plots for the traces seen in Figure 32. The solid lines are the running median and the 5th and 95th quantiles; the dashed line is a moving mean over 50 samples.

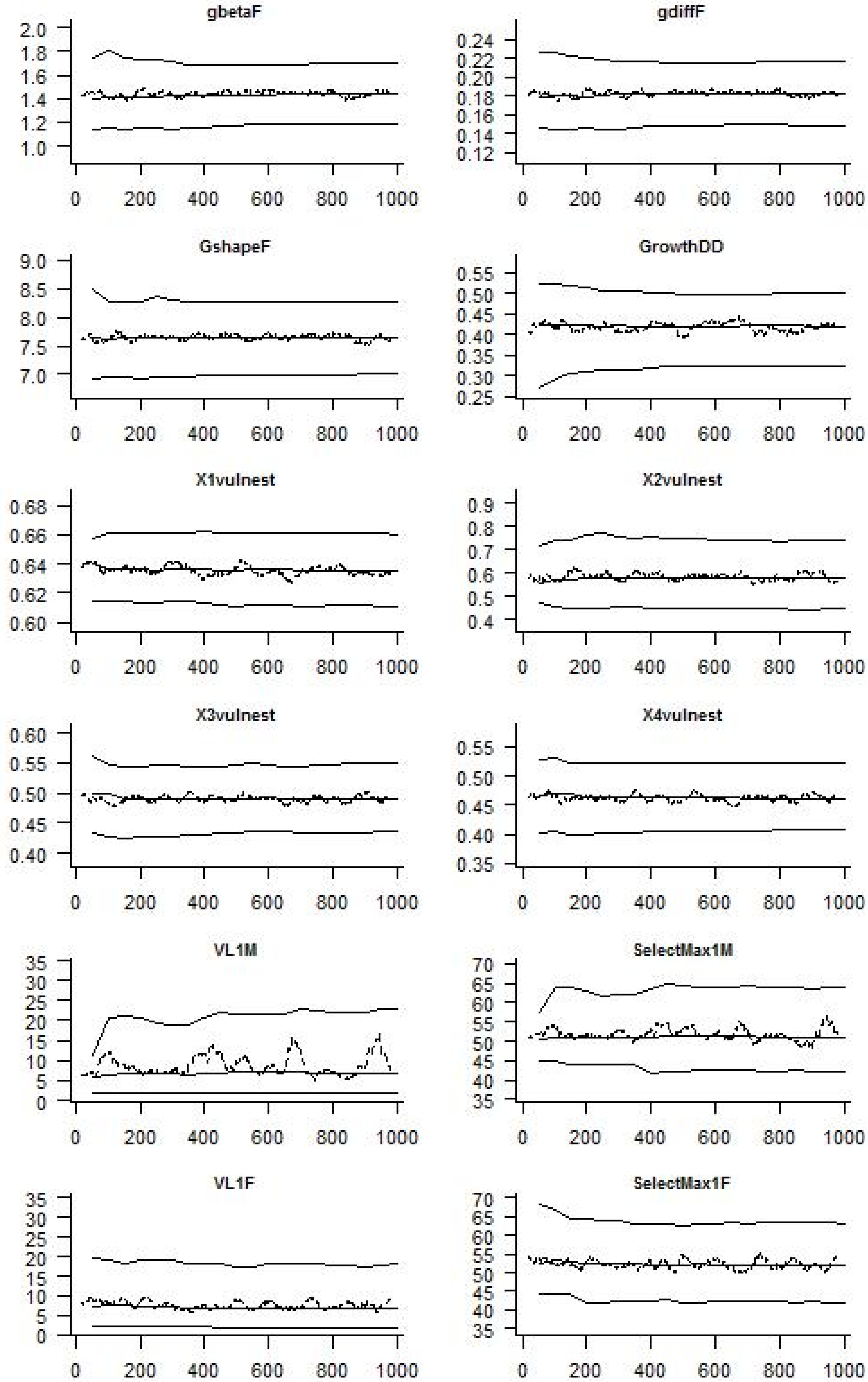

Figure 33 continued.

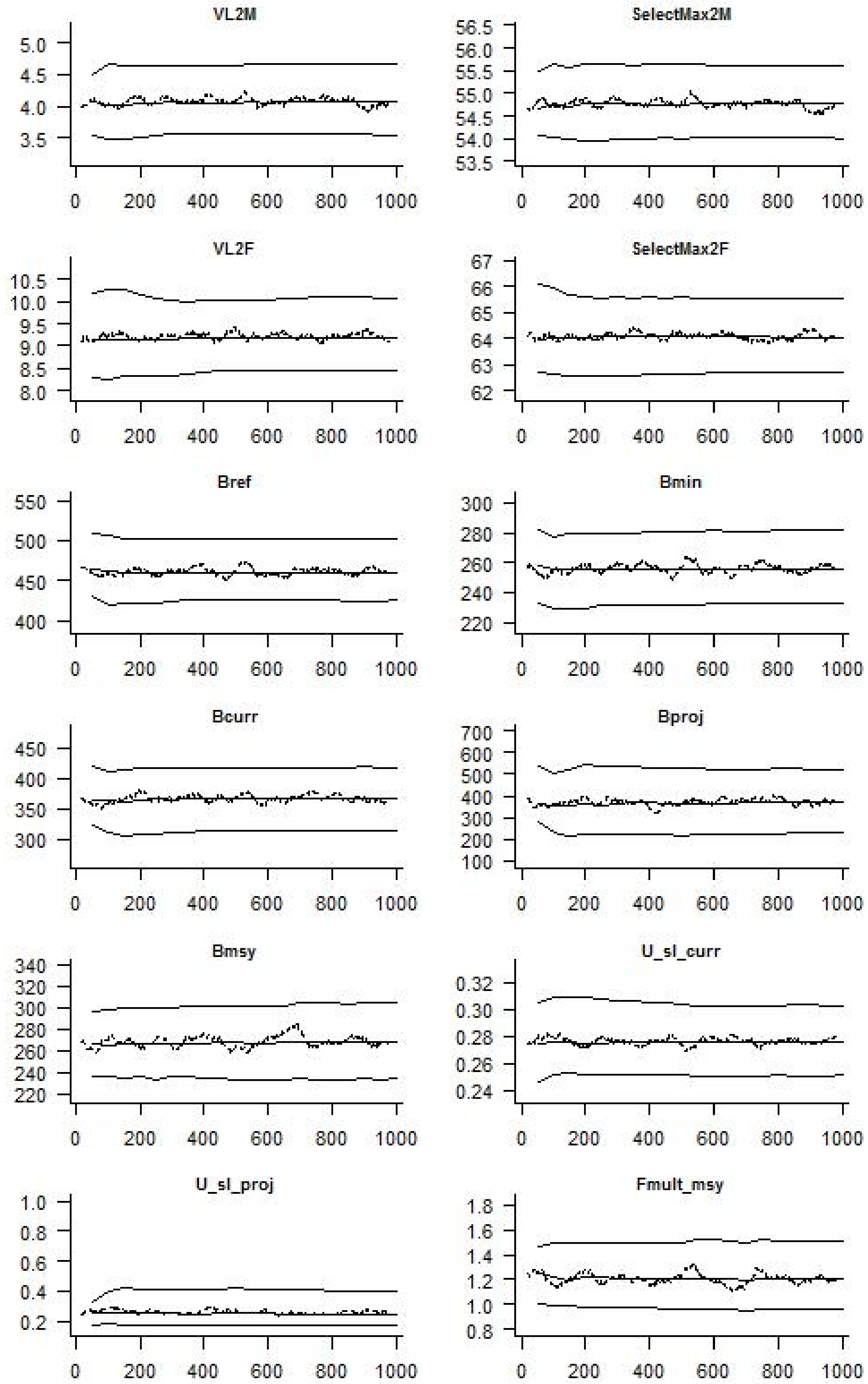

Figure 33 continued.

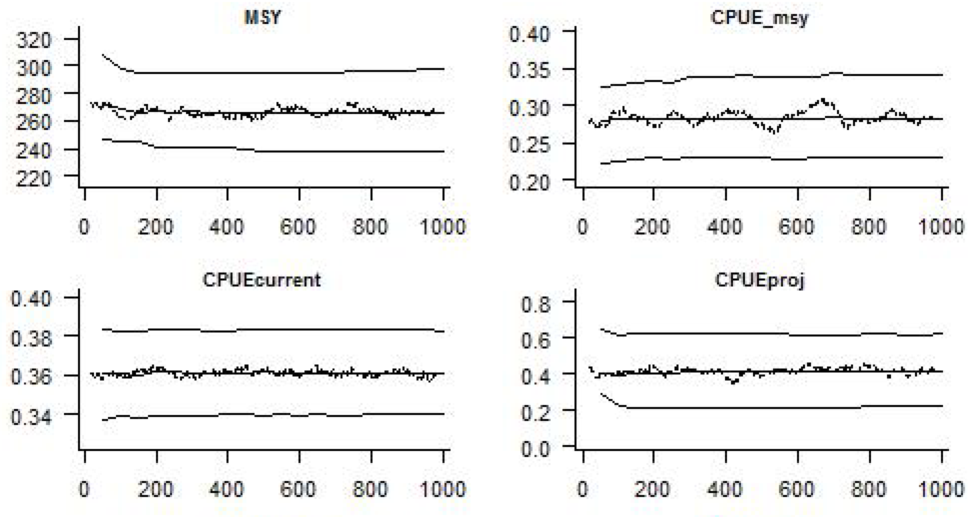

Figure 33 concluded.

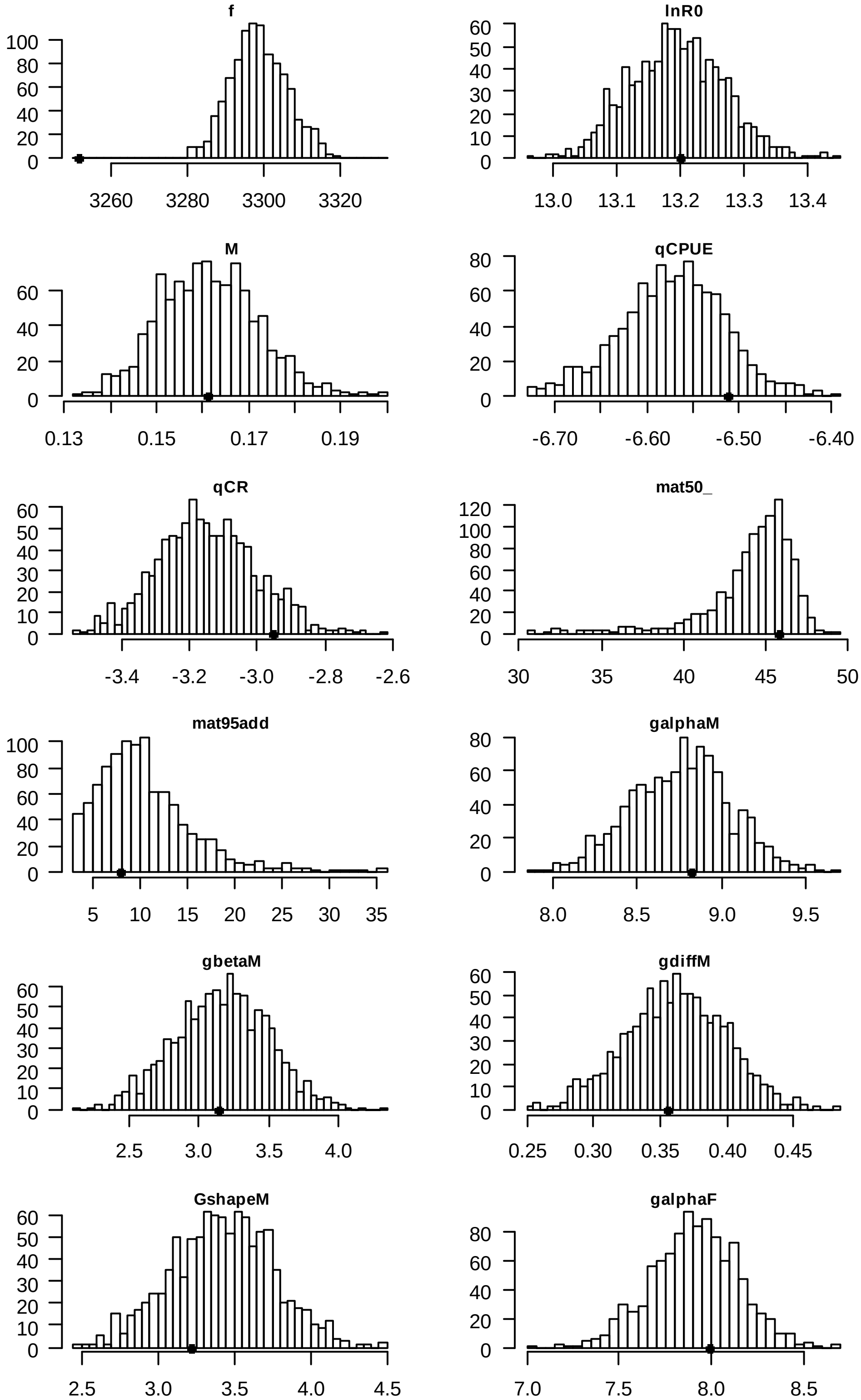

Figure 34: CRA 2 base case McMC: posterior distributions of estimated parameters from the base case McMC.

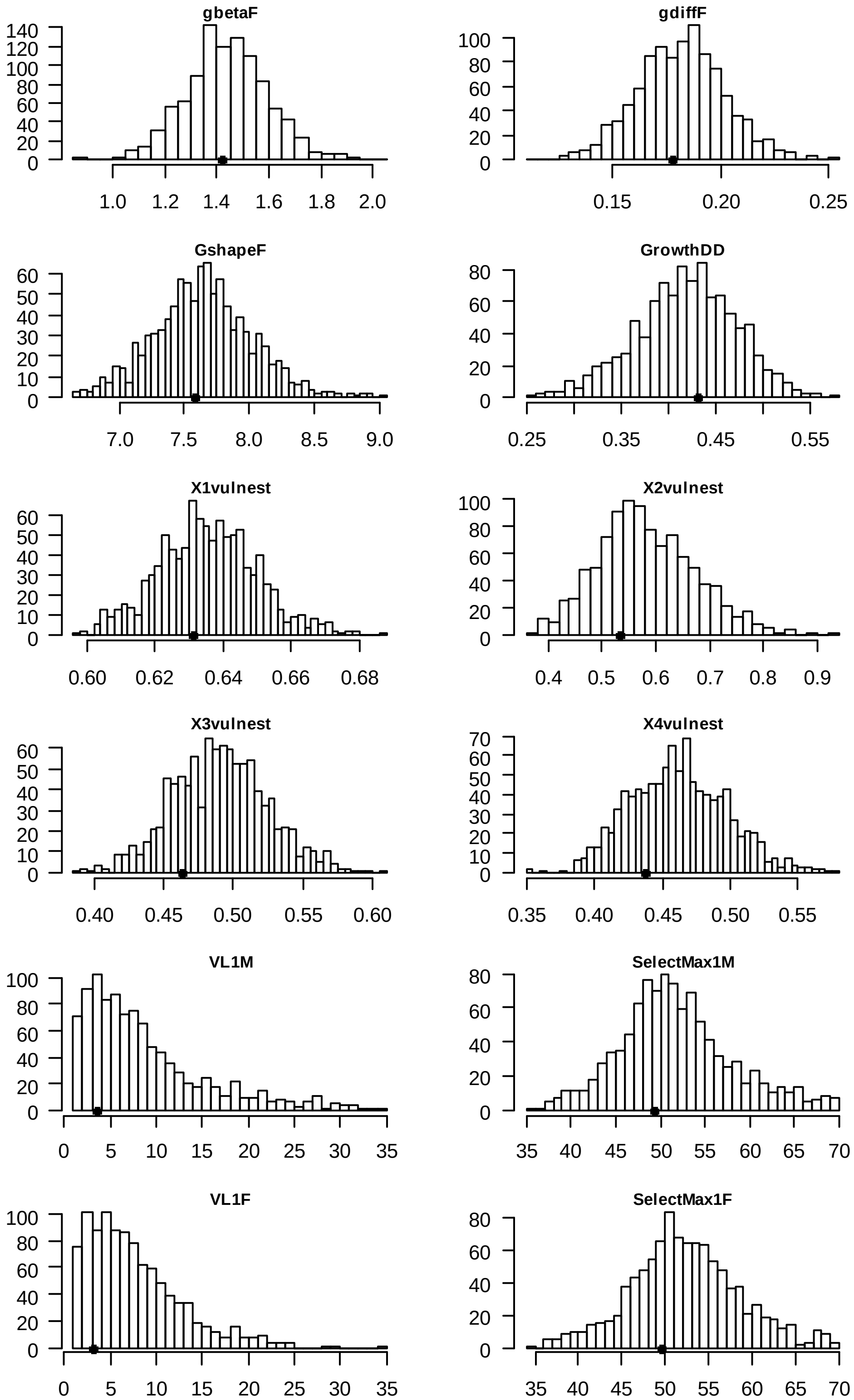

Figure 34 continued.

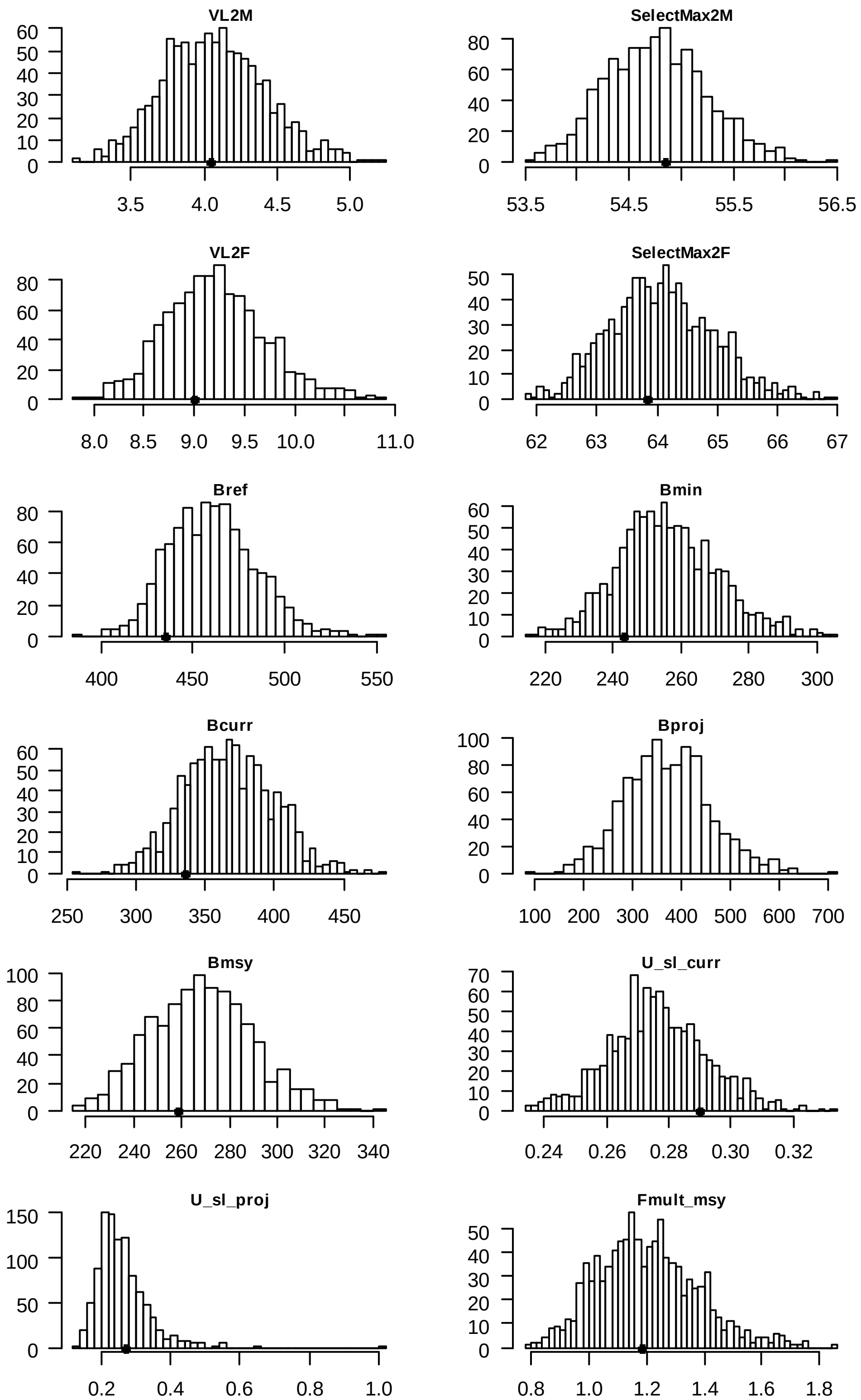

Figure 34 continued.

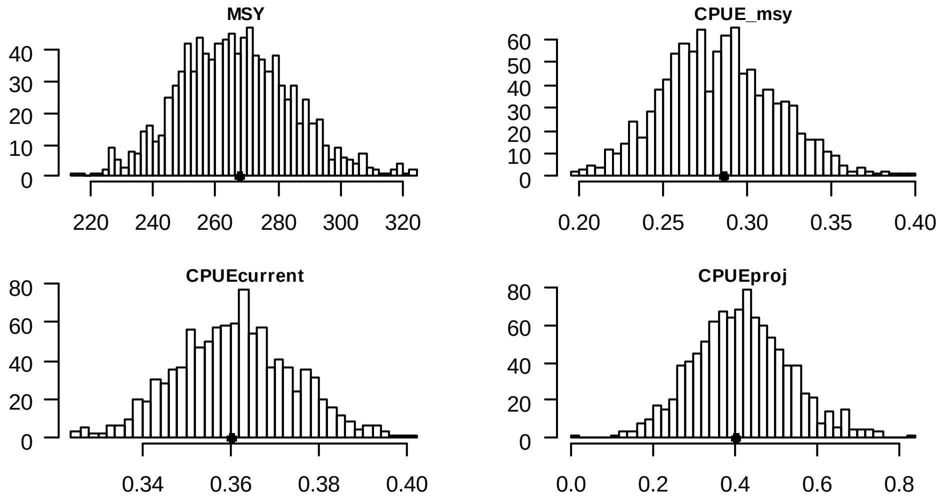

Figure 34 concluded.

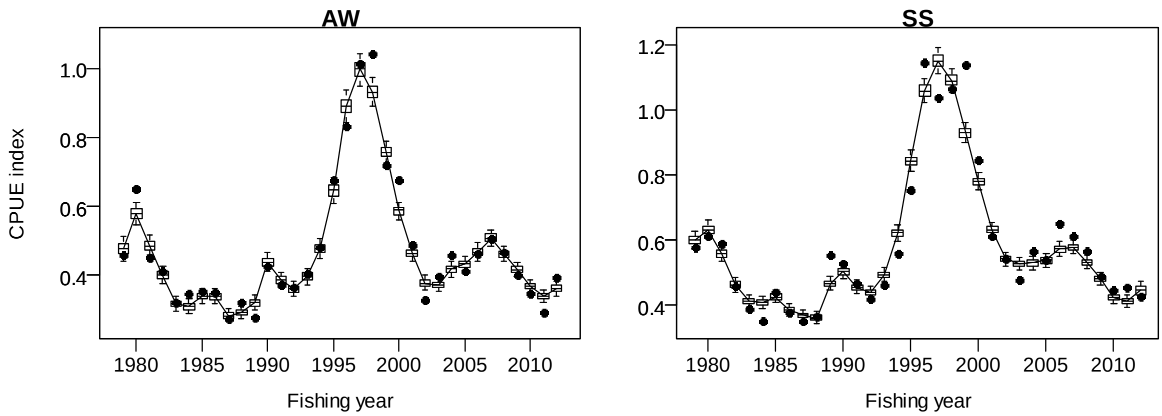

Figure 35: CRA 2 base case McMC: posterior of the fit to CPUE; AW on left and SS on right.

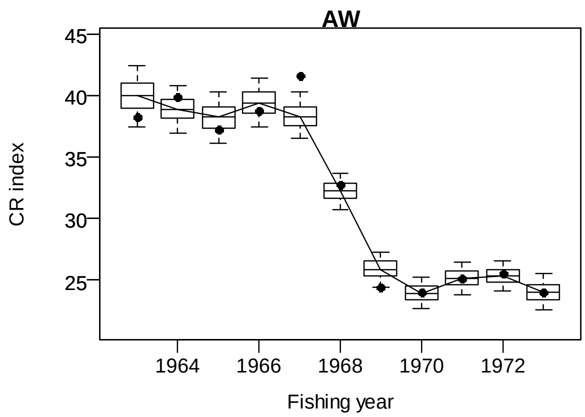

Figure 36: CRA 2 base case McMC: posterior of the fit to CR.

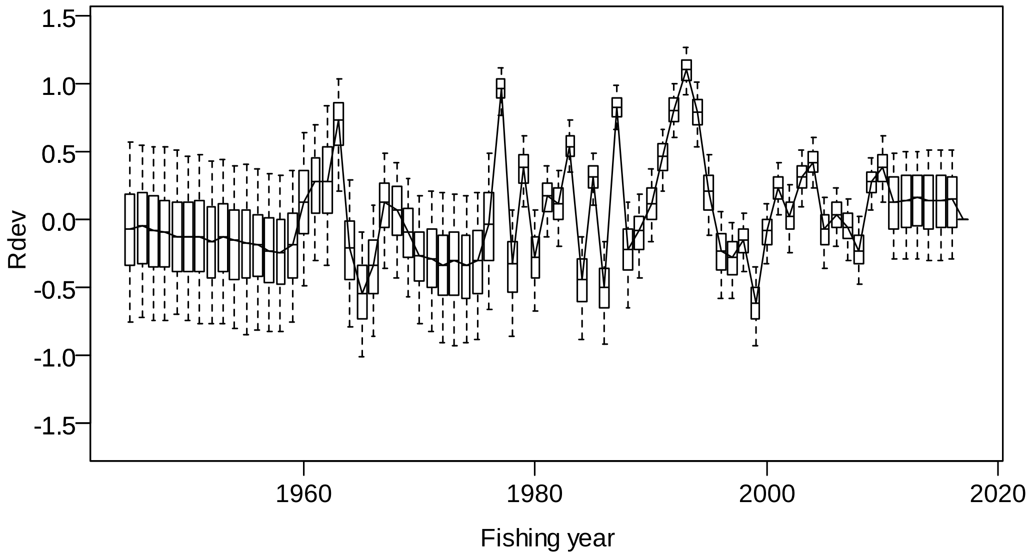

Figure 37: CRA 2 base case McMC: posterior of the recruitment deviations.

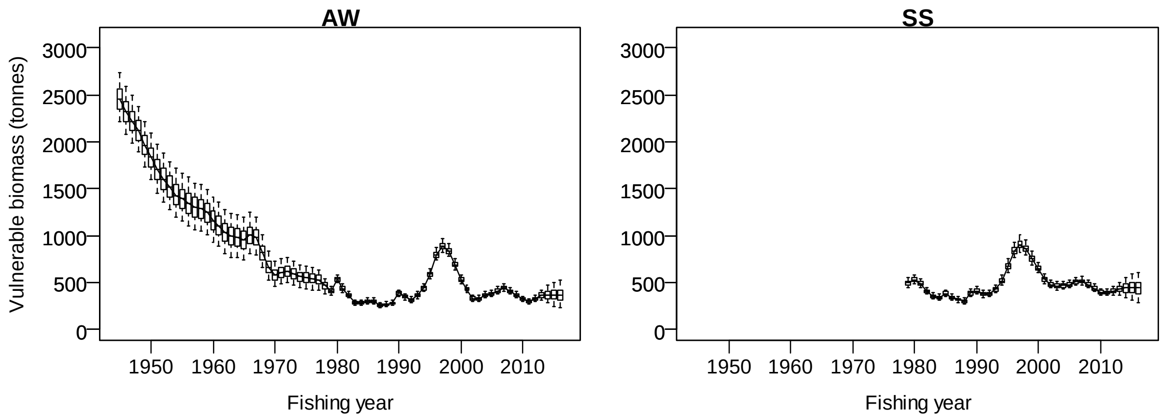

Figure 38: CRA 2 base case McMC: posterior of the trajectories of vulnerable biomass for the AW and SS seasons; AW on left and SS on right.

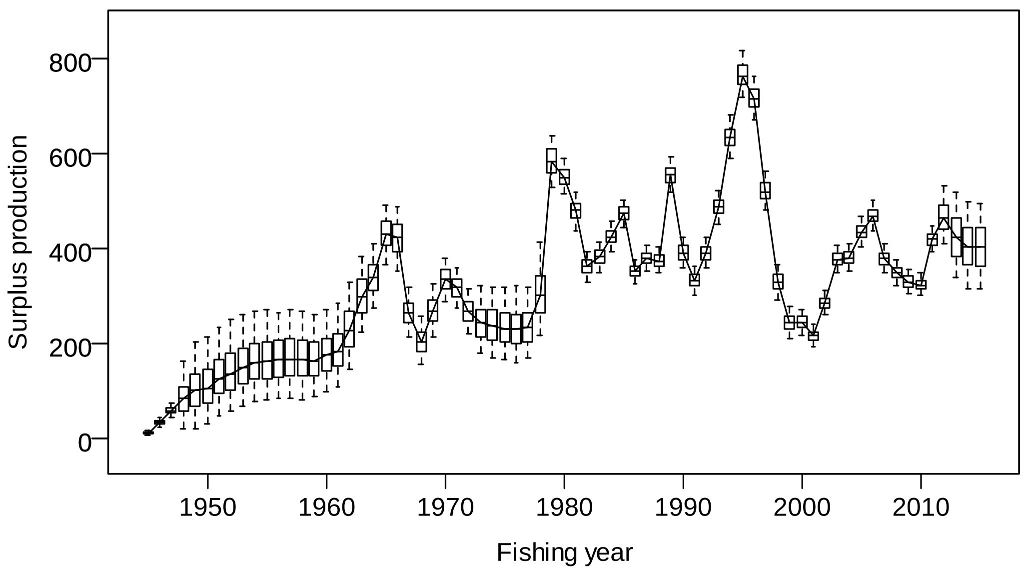

Figure 39: CRA 2 base case McMC: posterior of the surplus production trajectory.

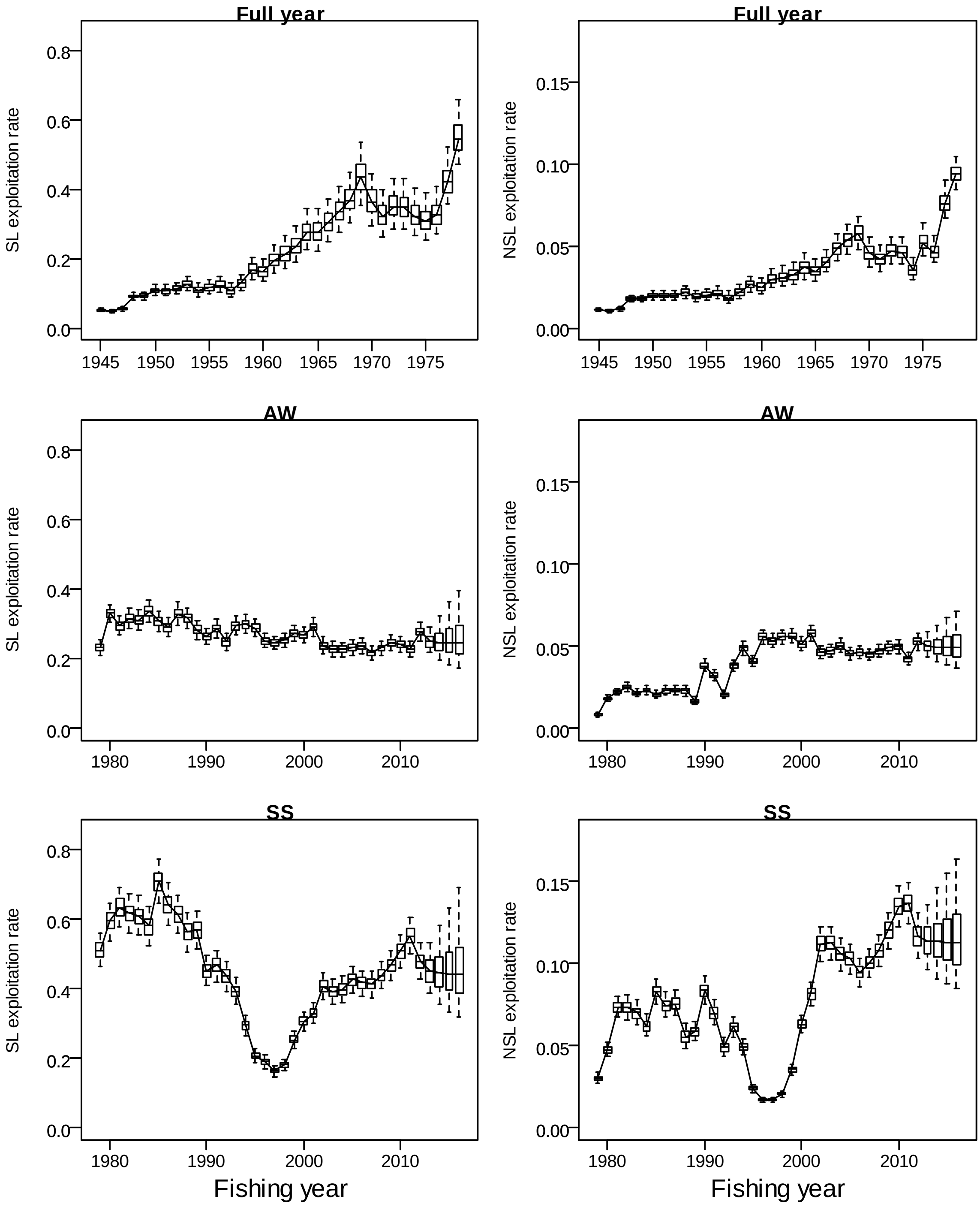

Figure 40: CRA 2 base case McMC: posterior of the trajectories of SL (left) and NSL exploitation rates for the whole year (top), and for the AW (middle) and SS seasons.

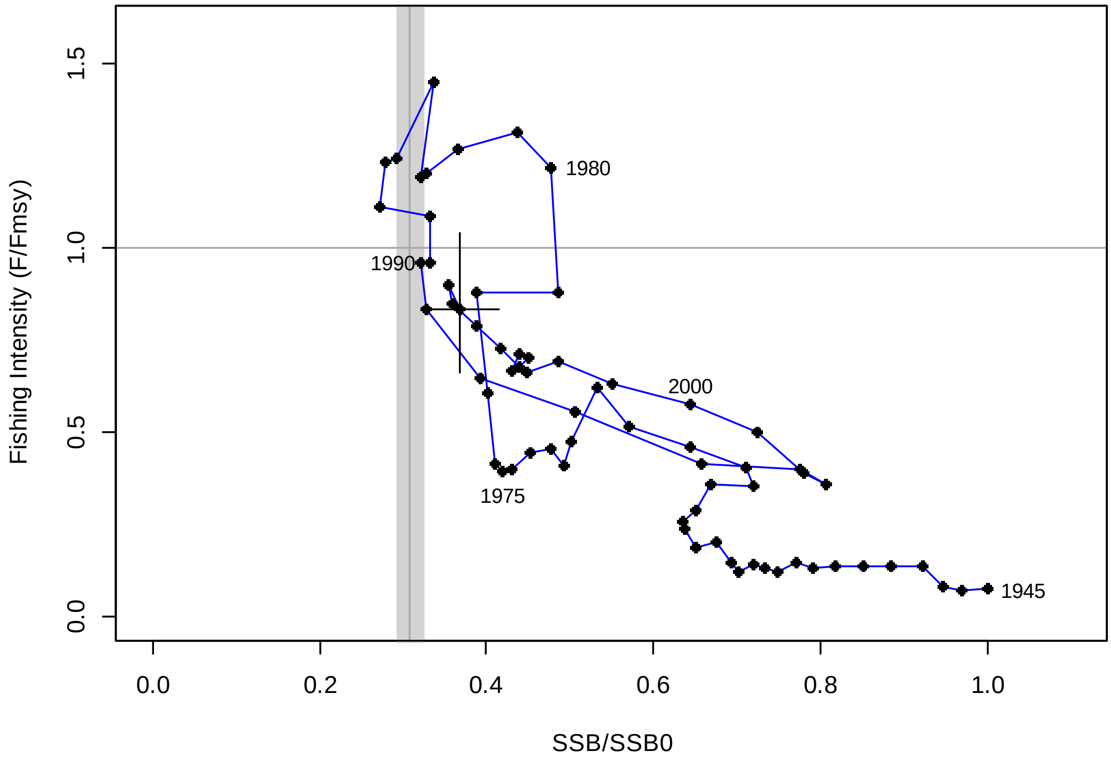

Figure 41: Phase plot that summarises the *SSB* history of the CRA 2 stock. The x-axis is spawning stock biomass *SSB* in each year as a proportion of the unfished spawning stock, *SSB0*. The y-axis is fishing intensity in each year as a proportion of the fishing intensity (*Fmsy*) that would have given *MSY* under the fishing patterns in that year. Each point on the figure shows the median of the posterior distributions of biomass ratio and fishing intensity ratio for one year. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy*; this ratio was calculated using the fishing pattern in 2012. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot (2012) show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

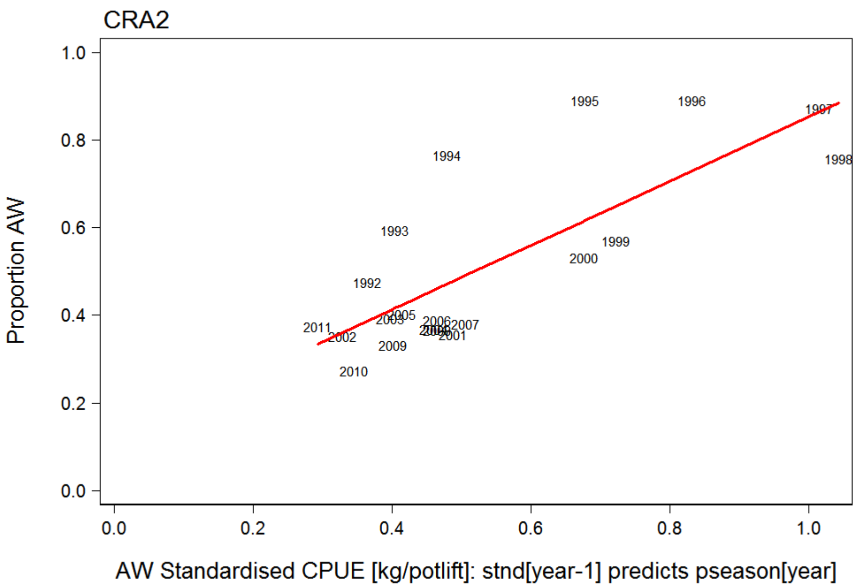

Figure 42: CRA 2: observed (years) and predicted (line) AW catch proportions; the line has intercept 0.1201 and slope 0.7334, with r^2 = 0.5997.

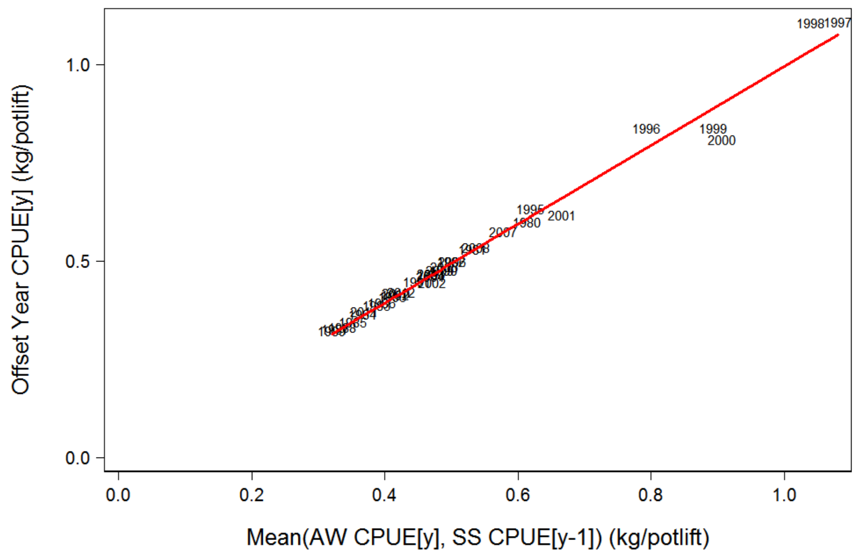

Figure 43: CRA 2: observed (years) and predicted (line) standardised offset-year CPUE versus the mean of the preceding AW and SS CPUE; the line has intercept -0.0083 and slope 1.0053, with r^2 = 0.9822

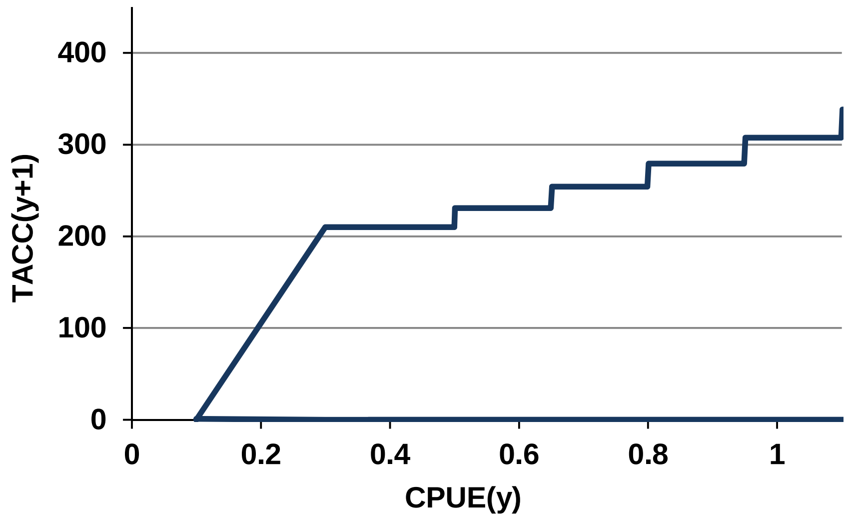

Figure 44: Generalised harvest control rule, showing TACC as a step function of offset-year CPUE in the previous year.

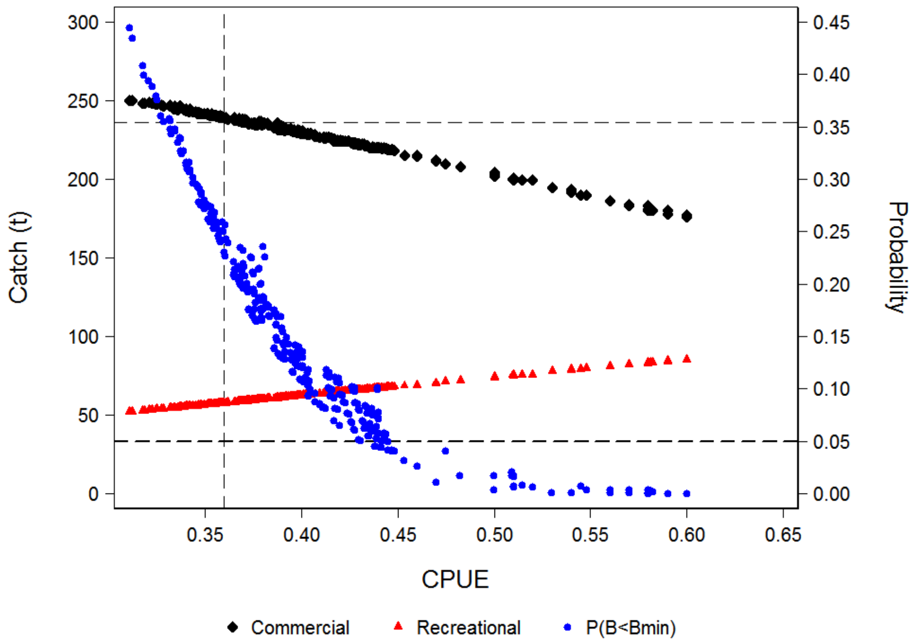

Figure 45: From the initial 488 rule evaluations, the relations among meanCPUE, meanComm and meanRec and the annual frequency of stock less than *Bmin*. The vertical line corresponds with CPUE=0.36 kg/potlift, the model-predicted CPUE for 2013. The lower horizontal dashed line indicates B<*Bmin* =0.05 and the upper horizontal dashed line indicates the 2013 commercial catch of 236 t. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs.

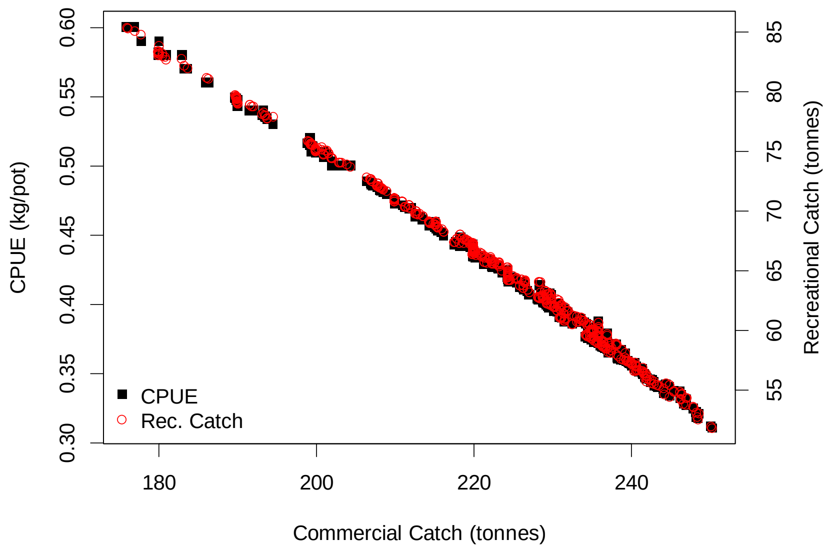

Figure 46: MeanCPUE and meanRec plotted against meanComm in the set of exploratory rules. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs.

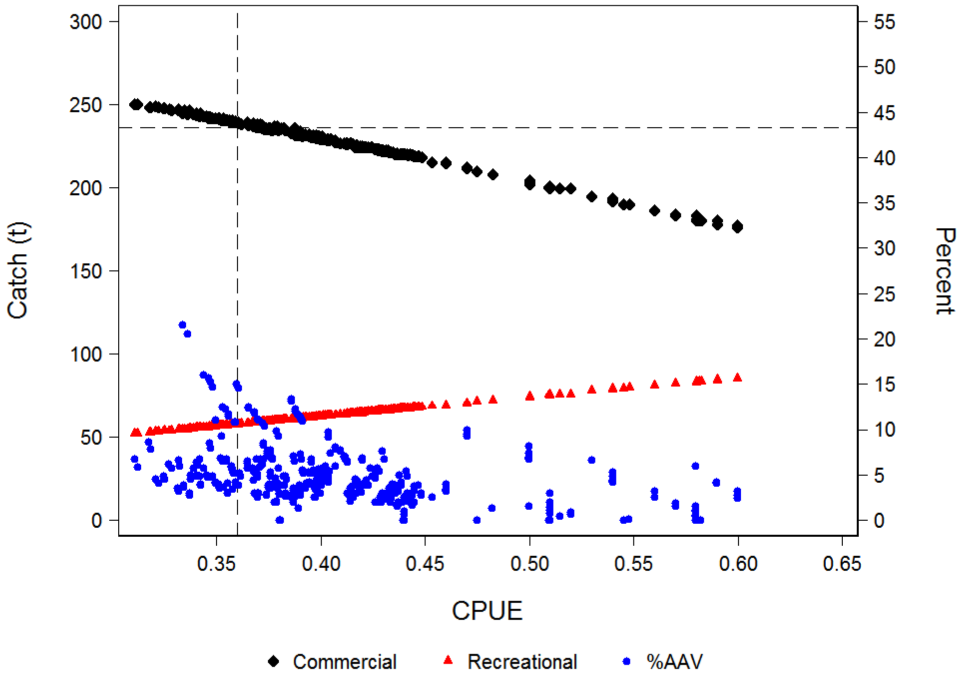

Figure 47: From the initial 488 rule evaluations, the relations among meanCPUE, meanComm and meanRec and the %AAVH indicator. The vertical line corresponds with CPUE=0.36 kg/potlift, the model predicted CPUE for 2013. The horizontal dashed line indicates the 2013 commercial catch of 236 t. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs.

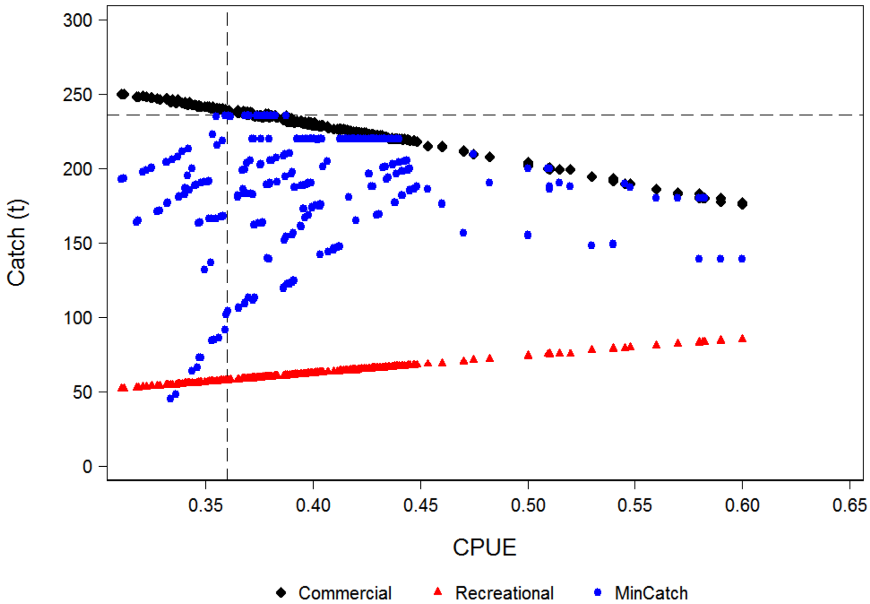

Figure 48: From the initial 488 rule evaluations, the relations among meanCPUE, meanComm, meanRec and minCatch. The vertical line corresponds with CPUE=0.36 kg/potlift, the model predicted CPUE for 2013. The horizontal dashed line indicates the 2013 commercial catch of 236 t. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs.

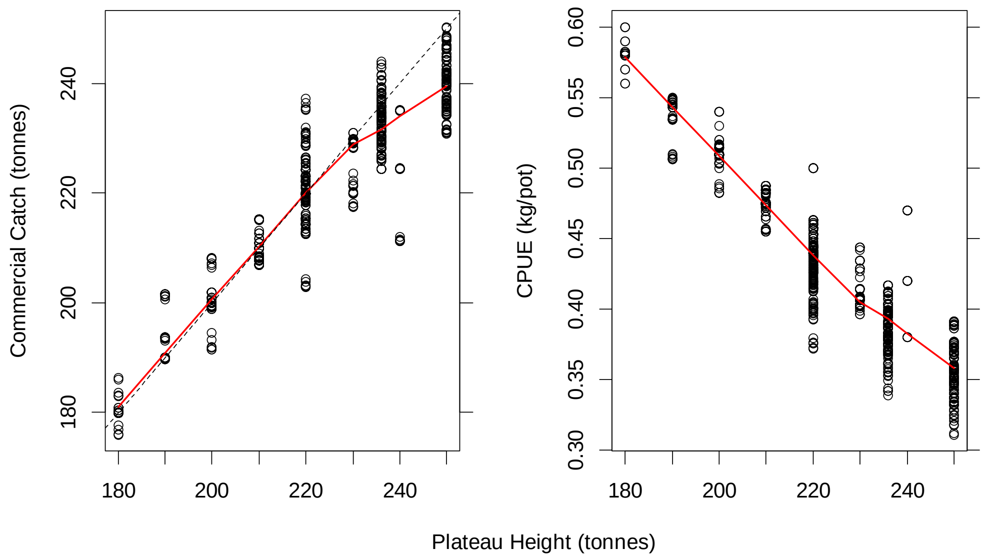

Figure 49: MeanComm (left) and meanCPUE by plateau height in the set of exploratory rules. Each point shows the result from one harvest control rule, summarised as the median over 1000 runs. A local regression smoother is also shown.

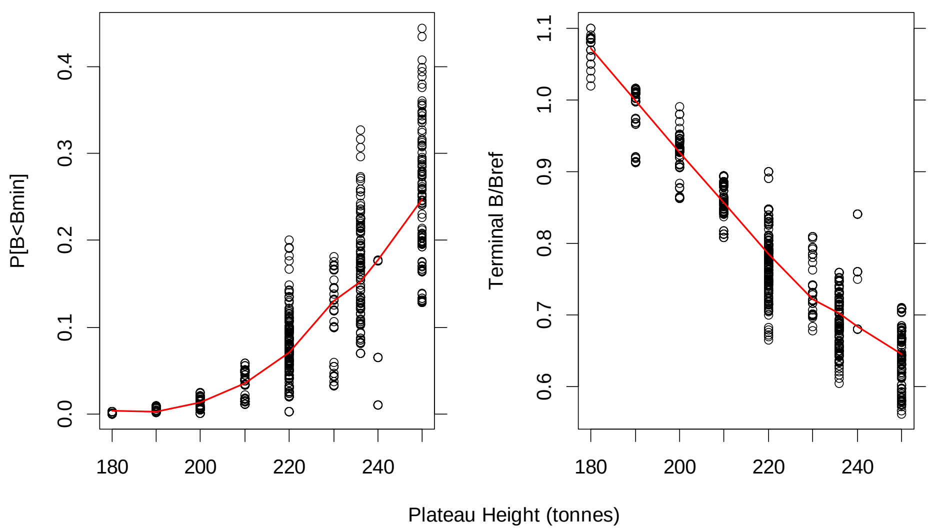

Figure 50: The B<*Bmin* safety indicator and the TB/Bref plotted against plateau height for the set of exploratory rules. Each point shows the result from one harvest control rule, summarised as the median over 1000 runs. A local regression smoother is also shown.

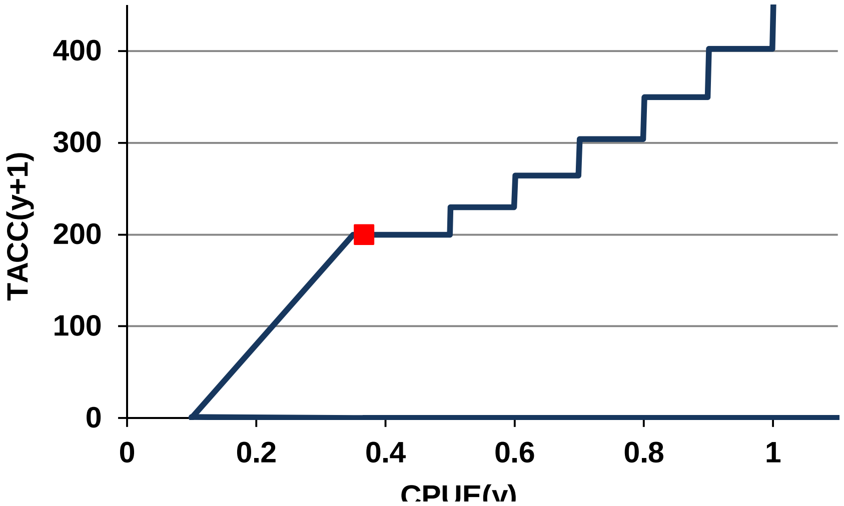

Figure 51: Rule 3 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

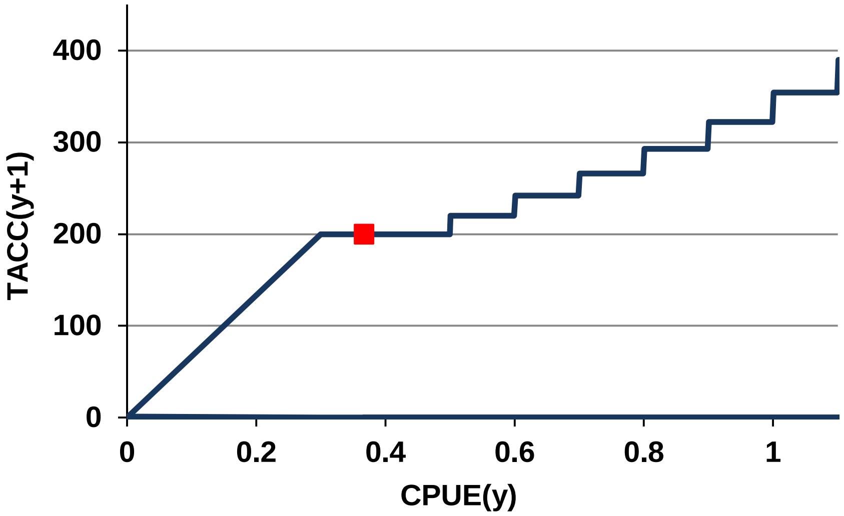

Figure 52: Rule 4 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

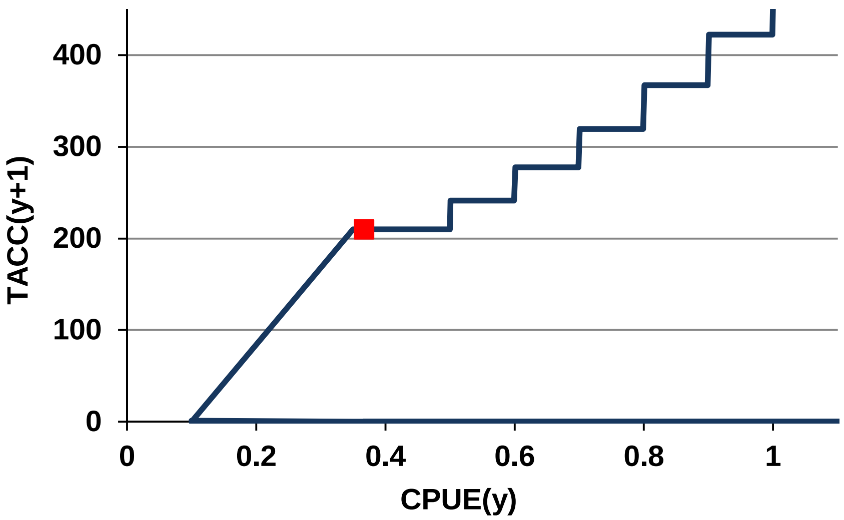

Figure 53: Rule 5 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

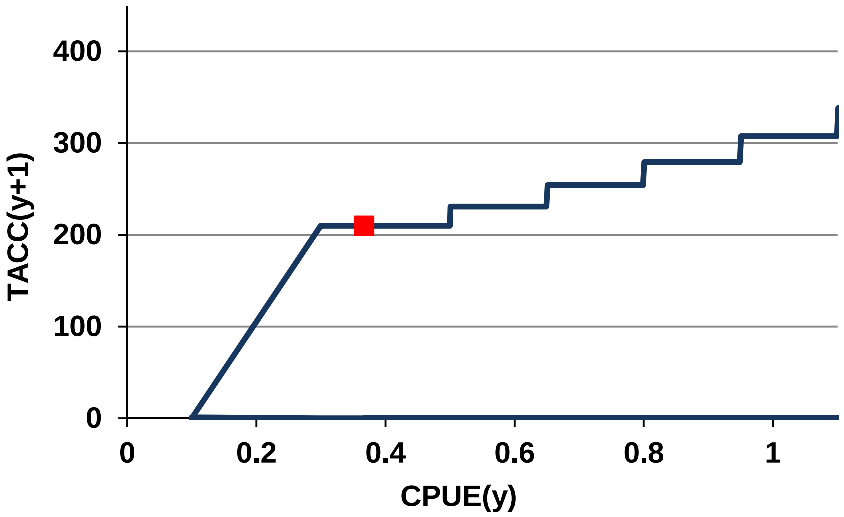

Figure 54: Rule 6 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

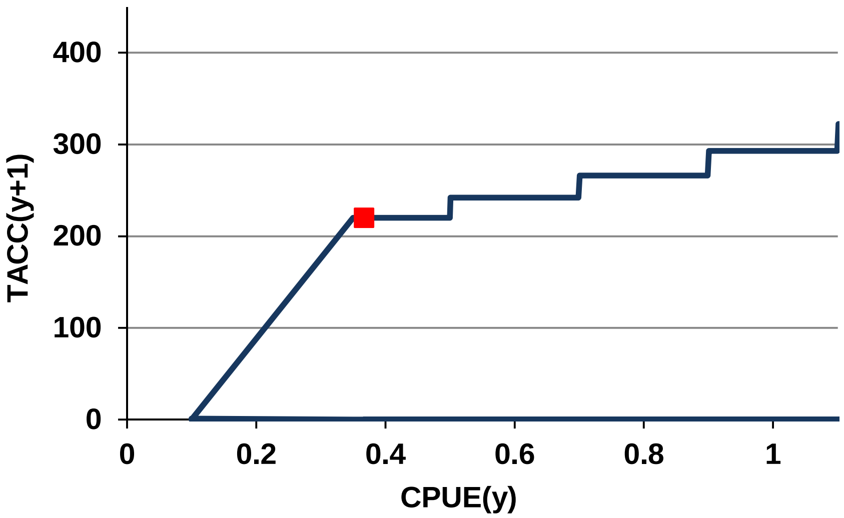

Figure 55: Rule 7 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

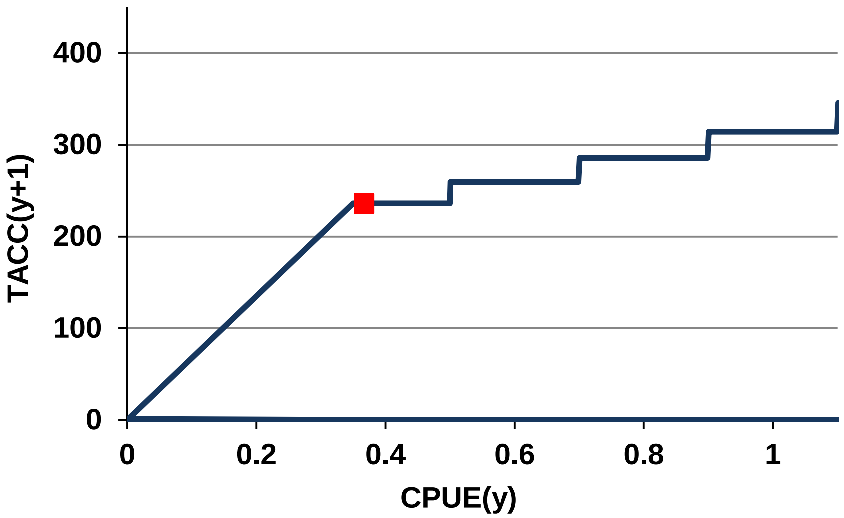

Figure 56: Rule 9 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

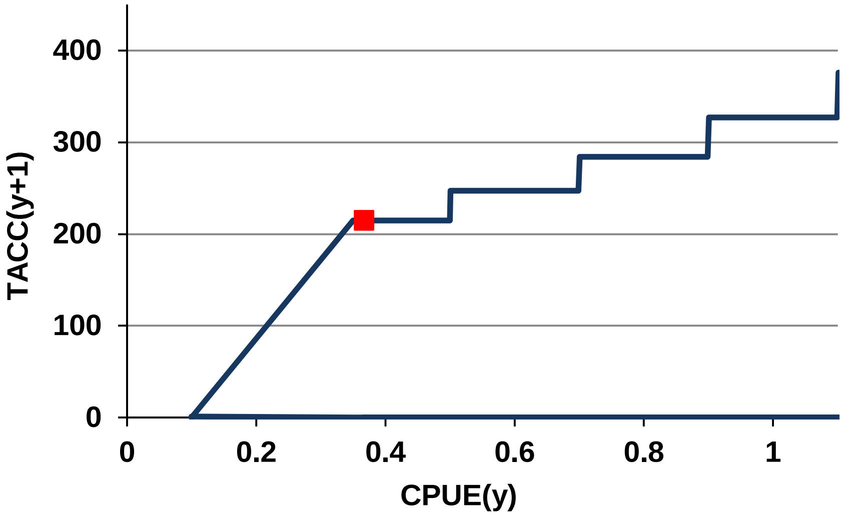

Figure 57: Rule 12 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

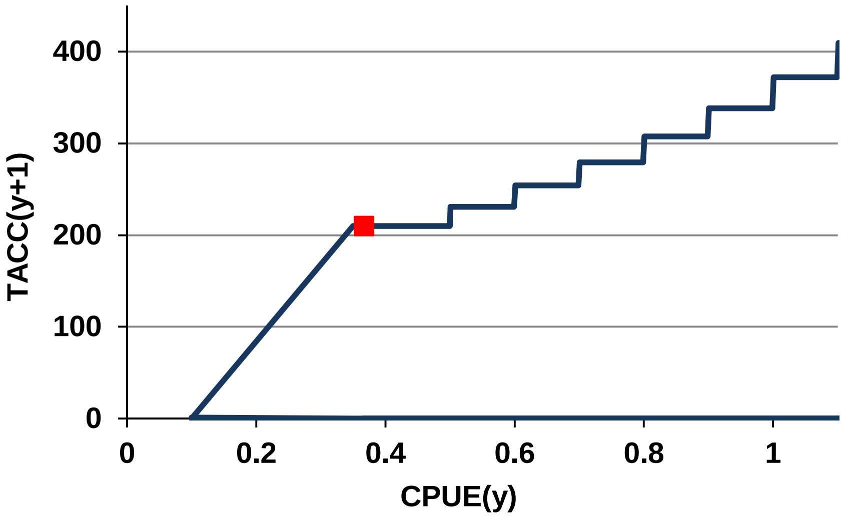

Figure 58: Rule 13 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

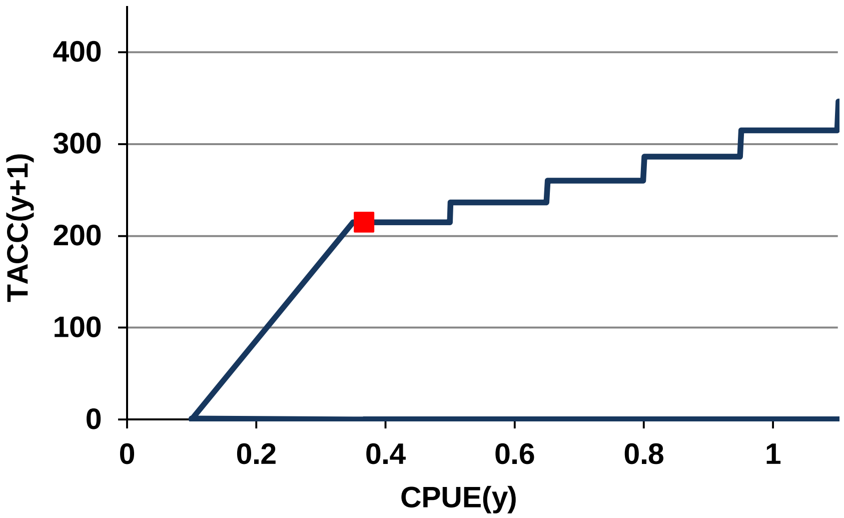

Figure 59: Rule 16 for CRA 2. The red square shows the 2013 offset-year CPUE of 0.3668 kg/potlift.

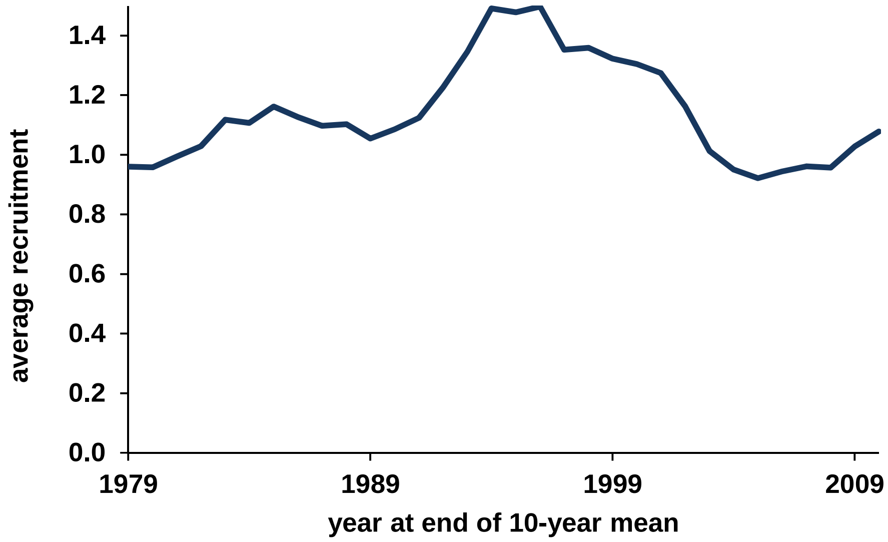

Figure 60: Average recruitment over time: the plot shows the running 10-year mean plotted against the last year used in the mean.

GLOSSARY

This glossary is intended to make the rock lobster stock assessment more accessible to non-technical readers. A knowledge of statistical terms is assumed and such terms are not explained here. Technical terms are defined with specific reference to rock lobster stock assessment and multi-stock length-based model (MSLM) and may not be applicable in other contexts.

Underlining indicates a cross-reference to a separate entry.

abundance index: usually a time-series of estimates of abundance in numbers or weight (biomass).

AD Model Builder: a modelling package widely used in fisheries work; it uses auto-differentiation to calculate the derivatives of the function value with respect to model parameters and passes these to an efficient minimiser; the user has to write only the model and calculate the function value.

allowance: the Minister must make Allowances for catch from various sectors within the TAC; Allowances plus the TACC sum to the TAC.

AW: autumn-winter season, 1 April through 30 September; see SS.

***B0*:** the biomass that would be attained if there were no fishing and recruitment were constant at its average level; in the MSLM the initial biomass is *B0.*

Bayesian stock assessment: a method that allows prior independent information to be used formally in addition to the data; the equivalent of the least-squares or maximum likelihood estimate is called the MPD (mode of the joint posterior distribution); often uncertainty is estimated using Markov chain Monte Carlo simulations (McMC) which give the posterior distributions of estimated and derived parameters.

***Bcurrent*:** the MSLM estimate of vulnerable biomass in the last year with data.

biomass: the weight of fish in part of the stock.

biological reference points: a target for the fishery or a limit to be avoided, or that invokes management action; expressed quantitatively, usually in units of fishing intensity or stock size.

***Bmin*:** the minimum of estimated vulnerable biomass in the years for which MSLM estimates biomass.

***Bmsy*:** in the *MSY* paradigm, the biomass that allows the stock to generate its maximum productivity; this biomass is usually less than half the unfished biomass.

bounds: model parameters can be restricted so that parameter estimates cannot be less than a lower bound or higher than an upper bound; these are sometimes necessary to prevent mathematical impossibility (e.g. a proportion must be between 0 and 1 inclusive) or to ensure biologically realistic model results.

***Bproj* :** vulnerable biomass in the last projection year, determined by running the model dynamics forward with specified catches and resampled recruitment.

***Bvuln*:** see vulnerable biomass.

catch: the numbers or weight (yield) of fish removed from the stock by fishing in a season or a year; considered in components such as commercial and illegal catches, or together as total catch; does not include fish returned alive to the sea.

catchability: a proportionality constant that relates an abundance index such as CPUE or CR to biomass, or that relates the puerulus settlement index to numbers; has the symbol *q*.

catch sampling: see logbooks and observer catch sampling.

cohort: a group of lobsters that settled in the same year.

converged chain: refers to McMC results; the "chain" is the sequence of parameter estimates; convergence means that the average and the variability of the parameter estimates are not changing as the chain gets longer.

CPUE: catch per unit of effort; has the units kg of catch per potlift; assumed to be an abundance index such that CPUE = catchability times vulnerable biomass; can be estimated in several ways (see standardisation).

CPUEpow: a parameter that determines the shape of the relation between CPUE and biomass; when equal to 1, the relation is linear; when less than 1, CPUE decreases less quickly than biomass (known as hyperstability); when greater than 1, CPUE decreases faster than biomass (known as hyperdepletion).

CR: an historical CPUE abundance index in kilograms per day from 1963–73.

customary fishing: fishing under permit by Maori for purposes associated with a marae; there is more than one legal basis for this.

density-dependence: populations are thought to self-regulate: as population biomass increases, growth might slow down, mortality increase, recruitment decrease or maturity occur later; growth is density-dependent if it slows down as the biomass increases.

derived parameter: any quantity that depends on the model's estimated parameters; e.g. average recruitment *R0* is an estimated parameter but initial biomass is a derived parameter that is determined by model parameters for growth, natural mortality and recruitment.

diagnostic plots: plots of running or moving statistics based on the McMC chains to check for convergence.

epoch: a period when selectivity was constant; different epochs have different estimated selectivity; epoch boundaries are associated with changes that affect selectivity, e.g. changes in escape gaps or MLS.

escape gaps: openings in the pot that allow small lobsters an opportunity to escape.

equilibrium: in models, a stable state that is reached when catch, fishing patterns, recruitment and other biological processes are constant; does not occur in nature.

exploitation rate: a measure of fishing intensity; catch in a year or period divided by initial biomass; symbol *U*.

explanatory variable: information associated with catch and effort data (e.g., month, vessel, statistical area or fishing year) that might affect CPUE; the standardisation procedure can identify patterns associated with explanatory variables and can relate changes in CPUE to the various causes.

***F*:** instantaneous rate of fishing mortality.

fishing intensity: informal term with no specific definition; higher fishing intensity involves higher fishing mortality or higher exploitation rate, or (as in the snail trial) a higher ratio of *F* to *Fmsy*.

fishing mortality: (symbol *F*) the instantaneous rate of mortality caused by fishing; if there were no natural mortality or handling mortality, survival from fishing would be e^{-F}; with fishing and natural mortality, survival is $e^{-(F+M)}$.

fishing pattern: the combination of selectivity and the seasonal distribution of catch.

fishing year: for rock lobsters, the year from 1 April through 30 March; often referred to by the April to December portion, *i.e.* 2009–10 is called “2009”.

fixed parameter: a parameter that could be estimated by the model but that is forced to remain at the specified initial value.

Fmsy: the instantaneous fishing mortality rate *F* that gives *MSY* under some simplistic constant conditions.

function value: given a set of parameters, how well the model fits the data and prior information; determined by the sum of negative log likelihood contributions from each data point and the sum of contributions from the priors; a smaller value reflects a better fit.

growth: lobsters grow when they moult; smaller lobsters do this more often than larger lobsters; the model assumes a continuous growth process described by a flexible growth sub-model that predicts mean growth increment for a time step based on sex and initial size, and predicts the variability of growth around this mean.

growthCV **:** determines the expected variability in growth around the mean increment for a given initial size.

harvest control rule: defines what the agreed management response will be at each observed level of the stock; often a mathematical relation between an observed index such as CPUE and the allowable catch.

Hessian matrix: a matrix of numbers calculated by the model using formulae based on calculus, then used to estimate variances and covariances of estimated parameters; if the matrix is well-formed it is “positive definite” and the model run is said to be “pdH”.

hyperdepletion: see *CPUEpow.*

hyperstability: see *CPUEpow.*

indicators: generic term for agreed formal outputs that act as the basis for the stock assessment or MPE comparisons.

initial value: when the model minimises, it has to start with a parameter set and the initial values comprise this set; the final estimates should be robust to the arbitrary selection of the initial values.

length frequency (LF) (also called size frequency)**:** The distribution of numbers-at-size (TW) from catch samples; based either on observer catch sampling or voluntary logbooks; the raw data are compiled with a complex weighting procedure.

length-based: a stock assessment using a model that keeps track of numbers-at-size over time.

likelihood contribution: for the model’s fit to a data set, there is a calculated negative log likelihood for each data point; the contribution to the function value for a dataset is the sum of all these; this approach to fitting data is based on maximum likelihood theory.

logbooks: in some areas, fishers tag four or five pots and when they lift one of these they measure all the lobsters and determine sex and female maturity; these data are a source of LFs for stock assessment; see also observer catch sampling.

***M*:** instantaneous rate of natural mortality.

management procedure: more properly "operational management procedure"; a set of rules that specify an input and how it will be determined, a harvest control rule and the conditions under which it will operate; a special form of decision rule because it has been extensively simulation tested.

MAR: median of the absolute values of residuals for a dataset. In a good estimation with multiple data sets, this should be close to 0.7; a common procedure is to weight datasets to try to obtain MAR close to 0.7.

maturity: the ability to reproduce; it is determined in catch sampling (for females only), by observing whether the abdominal pleopods have long setae.

maturation ogive: the relation between female size and the probability that an immature female will become mature in the next specified time step.

McMC: Markov chain – Monte Carlo simulations. In the minimisations, the model uses a mathematical procedure to find the set of parameters that give the best (smallest) function value. McMC simulations randomly explore the combinations of parameters in the region near the "best" set of parameters, using a sort of random walk, and from this the uncertainty in estimated and derived parameters can be measured. In one "simulation", the algorithm generates a new parameter set, calculates the function value and chooses whether to accept or reject the new point.

MFish: the New Zealand Ministry of Fisheries (now part of the Ministry for Primary Industries, MPI).

mid-season biomass: biomass after half the catch has been taken and half the natural mortality has acted in the time step.

minimising: the model fits to data are determined by estimated parameters, and the goodness of fit can be measured in terms of the model's function value, where a lower value reflects a better fit; when minimising, the model adjusts parameter values to try to reduce the function value, using a mathematical approach based on calculus.

MLS: minimum legal size; currently 54 mm TW for males and 60 mm TW for females for most of New Zealand, but some QMAs have different MLS regimes.

mortality: processes that kill lobsters; see natural mortality M and fishing mortality F; handling mortality of 10% is assumed for lobsters returned to the sea by fishing.

MPD: when the model is minimising, the result is the set of parameter estimates that give the lowest function value; these "point estimates" comprise the mode of the joint posterior distribution or MPD; also sometimes called maximum posterior density.

MPEs: management procedure evaluations; for each proposed harvest control rule, a run is made from each sample of the joint posterior distribution, indicators are calculated and collated, and a set of indicators for that rule with that operating model (which might be the base case or one of the robustness trials) is generated.

MPI: Ministry for Primary Industries (formerly Ministry of Fisheries or MFish).

MSY: under the MSY paradigm, the maximum average catch that can be taken sustainably from the stock under constant environmental conditions; usually calculated under simplistic assumptions.

MSY paradigm: a simplistic interpretation that predicts surplus production as a function of biomass: with zero surplus production at zero biomass, zero surplus production at carrying capacity (symbol K), and a maximum production at some intermediate biomass in between; this ignores the effects of age and size structure, lags in recruitment and variability in production that is unrelated to biomass.

MSLM: multi-stock length-based model; current version of the stock assessment model: length-based, Bayesian, with capacity for assessing multiple stocks simultaneously.

natural mortality: (symbol *M*) the instantaneous rate of mortality from natural causes. If there were no fishing mortality *F*, survival would be e^{-M}. With both fishing and natural mortality, survival is $e^{-(F+M)}$.

Newton-Raphson iteration: the model dynamics need a value for fishing mortality rate *F* in each time step; MSLM has information about catch, biomass and *M*, but there is no equation that can give *F* directly from these; Newton-Raphson iteration begins with an arbitrary value for *F* and calculates catch, then refines the value for *F* using a repeated mathematical approach based on calculus to obtain the *F* value that is correct.

normalised residual: the residual divided by the standard deviation of observation error that is assumed or estimated in the minimising procedure.

NRLMG: National Rock Lobster Management Group, a stakeholder group comprising representatives from MPI, commercial, customary and recreational sectors, that provides rock lobster management advice to the Minister for Primary Industries.

NSL catch: catch taken without regard to the MLS and prohibition on egg-bearing females; assumed by the model to be the illegal and customary catches; note that NSL catch includes fish above the MLS.

observer catch sampling: catch sampling in which an observer on a vessel measures all the fish in as many pots as possible on one trip.

offset year: the year from 1 October through 30 September, six months out of phase with the rock lobster fishing year.

operating model: a simulation model that represents the stock and that can be projected forward to test the results of using alternative harvest control rules.

parameters: in a simulation model, numbers that determine how the model works (they define mortality and growth rates, for instance) and that can be estimated during fitting to data or minimising.

pdH: see Hessian matrix.

period: sequential time steps (years or seasons or a mixture of both) in the stock assessment model.

population: in nature, a group of fish that shares common ecological and genetic features; in models, the numbers of fish contained in a stock unit within the model.

posterior distribution: the distribution of parameter estimates resulting from McMC simulation; is a Bayesian concept; the posterior distribution is a function of the prior probability distribution and the likelihood of the model given the data.

potlift: a unit of fishing effort; the commercial fishery uses traps or pots baited to attract lobsters and equipped with escape gaps; pots are sometimes lifted daily, often less frequently because of weather or markets; pots are often moved around during the fishing year.

pre-recruit: a fish that has not grown large enough (to or past the MLS) to become vulnerable to the fishery.

priors: short for prior probability distribution; these allow the modeller to estimate parameter values using Bayes's theorem and (if desired) to incorporate prior belief (based on data that are not being used by the model) about any likely parameter values.

productivity: stock productivity is a function of fish growth and recruitment, natural mortality and fishing mortality.

projections: given a set of parameters, assumed catches and recruitments, the stock assessment model or operating model dynamics can be run into the future and any indicators calculated that are wished; this is called projecting the model; projections are sometimes thought of as predictions but, more properly, projections determine the range of values in which parameters about the future stock may lie.

puerulus: settling lobster larvae; this stage is transitional between the planktonic phyllosoma larva and the benthic juvenile lobster; in reality the puerulus settlement index includes juveniles of the first instars. The puerulus settlement index for a stock is calculated from monthly observations of settlement on sets of collectors within the QMA, using a standardisation method.

QMA: A management unit in the Quota Management System, which in most cases is assumed to represent the extent of the biological stock; the unit of management in the quota management system; QMAs contain smaller statistical areas.

QQ plots: in an estimation where the data fit the model's assumptions about them, the normalised residuals would follow a normal distribution with mean zero and standard deviation of one; a QQ plot allows a comparison of the actual and theoretical distributions of normalised residuals by plotting the observed quantiles in a way that gives a straight line if they follow the theoretical expectations.

***R0* :** the base recruitment value in numbers of fish.

randomisation: in the puerulus randomisation trials, a new index is generated by randomly rearranging the yearly values data in a new order.

Rdevs: estimated model parameters that determine whether recruitment in a given year is above or below average; they modify the base recruitment parameter *R0.*

recreational: refers to catch taken legally under the recreational regulations; includes s. 111 catch taken by commercial fishers; includes Maori fishing that is not governed by a customary permit.

recruited biomass: the weight of all fish above the MLS, including egg-bearing females, whether or not they can be caught by the fishery.

recruitment: can mean recruitment to the population (as in puerulus settlement), recruitment to the model at a specified size, or recruitment to the stock (by growing above MLS); when used with no qualification in documentation here it means "recruitment to the model".

resampling: in projections, recruitment for a projection year is equal to estimated recruitment in a randomly chosen year that lies within the range of years being resampled.

residual: the observed data value minus the model's predicted value, for instance for CPUE in a given time step it would be the difference between the observed CPUE in that year and the model's predicted value.

RLFAWG (Rock Lobster Fishery Assessment Working Group): a group convened by MPI to discuss stock assessment alternatives and to act as peer-reviewers; comprises MPI, stakeholders and contracted peer-reviewers.

robustness trial: in making MPEs, the sensitivity of results to critical assumptions in the operating model is tested by making runs in robustness trials using a different operating model.

sdnr: the standard deviation of normalised residuals; in a good estimation with multiple data sets, this should be close to 1; a common procedure is to weight datasets to try to obtain sdnrs close to 1.

season: refers to the AW or SS seasons; for early years the MSLM model can be run with an annual time step.

selectivity: lobster pots do not catch very small lobsters; selectivity describes the relative chance of a lobster being caught, given its sex and size, hence "selectivity ogive".

sensitivity trials: a base case stock assessment model is the result of inevitable choices made by the modeller; sensitivity trials examine whether results are seriously dependent on ("sensitive to") these choices.

sex: in the model can be male, immature female or mature female; this set of three possibilities is referred to as "sex" (see maturity).

snail trail: a plot of historical fishing intensity against historical biomass.

SL catch: the catch that is taken respecting the MLS and prohibition on egg-bearing females; assumed by the model to be the commercial and recreational catches.

spawning stock biomass: *SSB***,** the weight of all mature females in the AW, without regard to MLS, selectivity or vulnerability; three specific forms are *SSBcurrent*, the estimated *SSB* in the last year with data; *SSBO*, the *SSB* in the first model year; *SSBmsy*, the *SSB* at equilibrium *Bmsy*.

SS: spring-summer season, 1 October through 30 March; see AW.

standardisation: a statistical procedure that extracts patterns in catch and effort data associated with explanatory variables; the pattern in the time variable (e.g. period or year) is interpreted as an abundance index.

statistical area: sub-area of a QMA that is identified in catch and effort data; the most detailed area information currently available from catch and effort data for rock lobster.

stock: by definition, a group of fish inhabiting a quota management area QMA; may often not coincide with biological population definitions.

stock assessment: an evaluation of the past, present and future status of the stock; a computer modelling exercise using a model such as MSLM that is minimised by fitting to observed fishery data; the results include estimated biomass and other trajectories; a comparison of the current stock size and fishing intensity with biological reference points ("stock status"), and often involves short-term projections with various catch levels.

stock-recruit relation: a relation between biomass and recruitment, with low recruitment at lower biomass; an optional component of MSLM.

surplus production: surplus production is growth plus recruitment minus mortality; if production would cause the stock biomass to increase it is "surplus" and can be taken as catch without decreasing the stock size; a concept central to the MSY paradigm.

sustainable yield: a catch that can be removed from a stock indefinitely without reducing the stock biomass; usually estimated with simplistic assumptions.

TAC/TACC: Total Allowable Catch and Total Allowable Commercial Catch limits set by the Minister for Primary Industries for a stock.

trace: refers to a plot of a parameter's values in the McMC simulation, plotted in the sequence they were obtained, taking every *n*th value of the simulation chain.

TW: tail width measured between the second abdominal spines.

vulnerability: outside the phrase vulnerable biomass (for which see below), means sex- and season-specific vulnerability; the relative chance of a lobster being caught, given its sex and the season; this allows males and females in the model to have different availabilities to fishing and for these to change with season.

vulnerable biomass: the biomass that is available to be caught legally: above the MLS, not egg-bearing if female, modified by selectivity and vulnerability; in the model this is called *Bvuln*; for comparing biomass with *Bref* and for reporting historical trajectories, the model calculates *Bvulref* using the last year's selectivity and MLS for consistency of comparison.

weights for datasets: weights are used to balance the importance of the different datasets to minimisation; higher weights decrease the sigma term in the likelihood and increase the contribution to the function value from that dataset; usually adjusted iteratively to achieve sdnr or MAR targets.

Z: total instantaneous mortality rate; $Z = F + M$.