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The 2012 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8, and review of management procedures

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This document describes stock assessments of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8 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, which estimated annual movement of lobsters from CRA 7 to CRA 8. The Rock Lobster Fishery Assessment Working Group (RLFAWG) 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. A set of randomisation trials found a significant signal in the puerulus settlement indices, but they appeared to lack predictive power and the base case was not fitted to puerulus. 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 near *Bref* in CRA 7 and well above all reference levels in CRA 8. At current catch levels, biomass was projected to increase in CRA 7 and to decrease in CRA 8, although it would remain well above reference levels.

The assessment model was used as the basis for an operating model to test management procedures for both stocks. At MPI request, the procedures tested determined the TACC as a function of CPUE, whereas the existing procedures for CRA 7 and CRA 8 determine the TAC. The evaluations involved analogues of the current procedures, which are the same as the existing rules if the non-commercial allowances remain fixed, and variants requested by industry and MPI. 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 document describes work conducted under Objectives 3 and 4 of contract CRA2009-01C, awarded by the Ministry for Primary Industries (MPI, formerly the Ministry of Fisheries) to the New Zealand Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contracted Objectives 3 and 4 to the authors of this report. The authors collaborated on all aspects of Objective 4 to produce a jointly authored stock assessment.

A companion document (Starr et al. 2013) describes the data used in the stock assessment. The model used was described by Haist et al. (2009). This document describes the stock assessments and evaluations of management procedures.

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

Specific objectives addressed by this report:

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

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

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

This document also presents a comprehensive glossary of terms used in the rock lobster stock assessment.

Descriptions of the CRA 7 and CRA 8 fisheries are given by Starr et al. (2013).

1.1 Background

Management procedures were first used in CRA 7 and CRA 8 in 1996 (Starr et al. 1997), with the catch limit for both stocks being driven by the combined CRA 7 and CRA 8 CPUE. The 1996 management procedure (then called the NSS Decision rule; see Breen et al. 2009b) was reviewed in 2002 (Bentley et al. 2003), and a new management procedure was developed, but which used the CRA 8 CPUE to drive the catch limits in both stocks. In 2007, after completing stock assessments for these two stocks in 2006 (Breen et al. 2006; Haist et al. 2009), new and independent management procedures were developed for each stock (Breen et al. 2008). The 2007 management procedure set TACs for CRA 8 for the years 2008–09 through 2012–13. In CRA 7, the new management procedure set TACs for 2008–09 through 2011–12 and then was replaced by a different rule that had been evaluated with the 2007 operating model (Breen 2010).

The management procedure work in this study comprises the fourth 5-year review of management procedures in CRA 7 and CRA 8. In 1996, when this work began, both stocks were seriously depleted, and the object was to rebuild the stocks. As will be seen, CRA 8 has rebuilt strongly since 1996, and now has a high abundance. CRA 7 has been more volatile, and is currently at low abundance.

1.1.1 CRA 7

The CRA 7 fishery extends from the Waitaki River south along the Otago coastline to Long Point. The most recent previous stock assessment was in 2006 (Breen et al. 2006; Haist et al. 2009), using the then new Bayesian multi-stock length-based model (MSLM). This was fitted to CRA 7 and CRA 8 simultaneously, and estimated movements between CRA 7 and CRA 8. The model was fitted to tag-recapture data, standardised CPUE from 1979–2006, historical catch rate data from 1963–73 and length frequency data from voluntary logbooks and observer catch sampling. Changes in MLS and selectivity caused by escape gap regulations were taken into account.

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

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

Historical aspects of the CRA 7 fishery are discussed by Street (1973) and Branson (1981). An important feature is the irregular movement of lobsters from CRA 7 to CRA 8 (Street 1969, 1971).

1.1.2 CRA 8

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

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

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

Historical aspects of the CRA 8 fishery are discussed by Branson (1981).

1.2 Overview of the process

The assessment team first conducted exploratory fits of the model to the data in a search for an acceptable base case. These results are MPDs.

From its choice of a base case, the team conducted a set of McMC sensitivity trials, comparing the base case McMC results with those from variant fits: this procedure explored the sensitivity of results to some key modelling decisions.

The Rock Lobster Fisheries Assessment Working Group (RLFAWG) rejected the team’s base case in favour of one of the variants, which then became the base case. The McMC sensitivity trials were not re-run.

A set of randomisation trials explored whether the puerulus settlement data contained a signal: they did, but there was a lack of predictive power, and the base case was not changed to include the fit to puerulus settlement.

From the base case and a set of variants, McMC simulations were made to produce the stock assessment and estimate its associated uncertainty.

From these McMCs, sets of short-term projections were made with current catches to explore the expected future states of the stocks.

The base case model was modified to act as a projection model, in which annual TACC was determined by the harvest control rule being evaluated, and alternative rules were evaluated.

1.3 Model

The purpose-built length-based lobster model was developed from an earlier version in 2006 (Haist et al. 2009). It is referred to as MSLM (multi-stock lobster model). The 2006 version was also length-based and integrated, meaning it could be fitted to multiple data sets and estimated all parameters at the same time. The MSLM and its predecessors were based on AD Model Builder (Fournier et al. 2012), which uses automatic differentiation of the function value with respect to each estimated parameter, and uses a fast and efficient non-linear function minimiser. Unlike the previous version, MSLM contains options for estimating parameters for multiple stocks either in common or stock-specific, stock-recruitment, density-dependent growth, non-linear abundance indices, alternative selectivity and growth models, alternative fisheries dynamics, starting at an exploited state, variable time step during a run, alternative likelihoods and marine protected area simulation.

The model is "driven by" catch estimates and is fitted to an abundance index, commercial CPUE. (Historical CPUE in catch per day and the puerulus settlement index were also explored.) It is also fitted to length frequency data and tag-recapture data. Other important inputs are historical size limits, length-weight relations and assumed prior probability distributions for estimated parameters.

As a purpose-built tool, MSLM is unique, but it has similarities to other stock assessment models used in New Zealand and Australia. In some ways MSLM is similar to the model developed for Tasmania by Punt & Kennedy (1997). The major differences are a coarser time step in the MSLM model, the multi-stock capabilities of the MSLM, and a range of other options for population and fishing dynamics in the MSLM model.

Length-based stock assessment models were reviewed by Punt et al. (2013), who reported length-based integrated models in use for lobsters in the United States (ASMFC 2009), Tasmania (Hartmann et al. 2011), Victoria (Walker et al. 2012), South Australia (Punt et al. 2012a), Western Australia (De Lestang et al. 2011) and South Africa, as well as for other shellfish such as abalone, crabs, shrimp and prawns, scampi, oysters and sea urchins. Many of the length-based lobster models have been used, as in this study, as operating models for evaluating management procedures (e.g. Punt et al. 2012b). One difference between the New Zealand rock lobster assessments and those in South Africa and Australia is that most other jurisdictions use fishery-independent survey data. Breen & Sykes (2012) explored the cost of fishery-independent surveys in New Zealand , and found that CPUE, although it has acknowledged problems, delivers a reasonably precise abundance index for minimal cost; they suggested that fishery-independent surveys of equivalent power would be prohibitively expensive.

Punt et al. (2013) review the advantages and disadvantages of length-based integrated models. Disadvantages include their highly complicated nature, making them inaccessible to stakeholders and managers, and their sensitivity to contradictory data and data weighting issues. Their ability to estimate year-class strength is less than that of age-based models, and the usual assumption of time-invariant growth may cause distortions. In CRA 3, where it was obvious that growth had changed, the MSLM was modified to estimate growth in two epochs (Breen et al. 2009a).

The generalised model CASAL (Bull et al. 2012) has many of the same features as MSLM, but because it is generalised, CASAL can be modified only more slowly and with less ease than MSLM. CASAL uses its own auto-differentiation and minimisation routines. Punt et al. (2013) suggest that generalised models have disadvantages: difficulty of adding new options, inefficiency of generalised code, difficulty of generalising management-specific outputs and of addressing stock-specific features. A major advantage of generalised models is the reduced potential for errors resulting from extensive testing of modules.

2. CHANGES TO THE MSLM MODEL FOR 2012

2.1 Retention

The major change to the MSLM model for 2012 involved the catch-at-length data for CRA 8. In this fishery, as abundance has increased, fishermen have become more selective about which fish they retain: differential size-grade prices can make two small lobsters worth much more than a large lobster of equal or greater weight. The companion data document (Starr et al. 2013) describes retention patterns seen in logbook records and how these change with changing abundance.

The model previously assumed that all lobsters appearing in the catch, after consideration of minimum legal size and the prohibition on berried females, were the lobsters removed from the stock by the fishery. Because in

CRA 8 this assumption is violated, the model dynamics were changed to include observed retention curves in the dynamics.

The retention calculations are applied to the "size-limited" fishery, which comprises the commercial and recreational fisheries. At this stage, because the recreational fishery was relatively small in CRA 7 and CRA 8, the recreational fishing dynamics implicitly use the same retention curve as the commercial fishery.

2.2 Likelihood

A change was made to the likelihood calculation for the tag-recapture data. In the previous version, the dataset weight was used in the calculation of the standard deviation of the error for each tag, σ_i^{tag} :

$$\sigma_i^{tag} = \sqrt{\left(\sigma_i^{inc}\right)^2 + \left(\sigma^{obs}\right)^2}\,\frac{\tilde{\sigma}}{\varpi^{tags}}$$

where σ_i^{inc} is the standard deviation of the predicted growth increment (it is dependent on the estimated growth CV and the predicted increment), σ^{obs} is the assumed standard deviation of observation error, $\tilde{\sigma}$ is a common variance component that can be estimated (in the base case it is fixed) and ϖ^{tags} is the weight assigned to the tag-recapture dataset.

When the robust normal likelihood was used, a change in the dataset weight affected its operation, with a lower weight reducing the number of records whose likelihood was truncated by the robustification. For the robust normal likelihood, ϖ^{tags} was removed from the equation above and the tag dataset likelihood was simply multiplied by the dataset weight.

2.3 Cumulative changes

Some model changes made in various years since the original description (Haist et al. 2009) are as follows.

General:

- in 2011, the Francis (2011) suggestion for weighting LF data was incorporated;
- in 2011, the number of fixed Newton-Raphson iterations for the instantaneous fishing mortality rates was made a control file option;
- in 2010, the model was revised to calculate the new "snail trail" agreed by the Stock Assessment Methods WG and deterministic *MSY*/*Bmsy* calculations were also coded (both based on instantaneous dynamics only);
- in 2008, the recreational exploitation rate was calculated by the model for use in projections and (later) in *MSY* calculations;
- in 2008, the inverse logistic growth model was coded (but has not been used so far);
- in 2008, fitting to puerulus data was incorporated, and an associated system of puerulus randomisation trials was developed;
- in 2008, the instantaneous fishing mortality rate option was extended to estimate the *F*s as a series of free parameters, as an alternative to the analytical solution using Newton-Raphson iterations.

For fitting to puerulus data and puerulus randomisation trials:

- the model can now use different years of puerulus data for different stocks (or fit to puerulus in one stock but not another);
- the model can assume different lags between settlement and recruitment to the model in each stock;
- likelihood components for puerulus are now calculated by stock so that statistics from puerulus randomisation trials can be assessed independently for each stock;
- the model can accommodate different start and end years for estimating *Rdev*s by stock, so that different puerulus lags can be accommodated in projections;
- the model can use different year ranges, by stock, for the *Rdev*s used in projections; these are used for re-sampling if standard projections are made and as the basis for statistical structure when MPEs are done.

For movements:

- for all years outside the range in which annual movement rates are estimated, the model assumes the average of the estimated movement rates;
- average movement rate is assumed in setting up initial conditions, for standard projections and in estimating MSY and “snail trail” calculations;
- for MPEs, movement is randomly re-sampled from the years where it was estimated.

For retention:

- commercial fishery retention patterns are estimated from the logbook data: the proportion retained by year, sex, and length bin;
- commercial fishery retention-at-size by sex, estimated outside the model, is used in the model to modify the sex- and length-specific NSL catch fishing mortality rates; because recreational catch is a component of the NSL catch, estimated retention rates affect the implied size structure of the recreational catch as well as the commercial catch;
- for projections, estimates of recreational catch exploitation rates do not include the partial retention assumption;
- MSY calculations assume full retention of all legal fish.

For multiple stocks:

- when the model is used for multiple stocks, MSY calculations in conjunction with the assumption of density-dependent growth require separate tag data sets for each region.

3. BASE CASE

3.1 Modelling choices

The assessment team discussed and resolved a variety of modelling choices on the path to finding a base case.

Start year: early trials explored the effect of choosing the model start year. When the start year was not 1945, an initial exploitation rate was estimated for each stock. The two main candidates for start year were 1963 and 1974, although some runs explored other values. The 2006 assessment for CRA 7 and CRA 8 (Haist et al. 2009) had a start year of 1976. The 1963-starting runs could be fit to the historical catch series, CR, but the modern CPUE data do not begin until 1979, and the LF data begin in the mid-1980s. Any choice must necessarily be arbitrary, and the team finally settled on 1974 as the start year, using a single annual season until 1979 and then using separate AW and SS seasons.

Stocks: the assessment could be done as two single-stock assessments or as a multi-stock assessment with a mixture of common and some stock-specific parameters, as was done in 2006 (Haist et al. 2009). Because movement from CRA 7 to CRA 8 was thought to be an important part of the biology of the stocks, the multi-stock option was used. Some early explorations also involved single-stock fits.

Tag data sets: the tag-recapture data contain 173 records for CRA 7 and over 8000 records for CRA 8 (Starr et al. 2013). One option, based on experimental fits to the two data sets, was to consider growth to be identical for the two stocks and to fit a single combined tag data set. However, to accommodate the separate data and their variability, the team chose to fit the tag data separately for each stock.

Density-dependent growth: early exploratory fits indicated a substantial improvement to the fit when density-dependence was estimated, so this option was adopted for the base case.

Data weighting: for LFs, we used the approach suggested by Francis (2011), which assigned much less weight to LF data than the iterative procedure used in previous assessments, which aimed at achieving a target value for sdnr or MAR. For CPUE, we used the iterative procedure that aimed to achieve an sdnr close to 1 and a MAR close to 0.67. For tagging data, we initially used this approach, but we down-weighted the tagging data out of a concern that the very large number of tag-recapture data in CRA 8 were effectively swamping the other data series. Because the number of tags was large only for CRA 8, we compensated by duplicating the CRA 7 records within the CRA 7 tag dataset.

Fit to recent CPUE: in many exploratory fits, the fit to the most recent CPUE was not strong, especially for SS (most fishing recently has been in AW). The model has a procedure for upweighting the CPUE data after a specified year by assigning a smaller process error: this option was explored but abandoned. CPUE weight was increased slightly to improve the fit relative to the sdnr weight.

Movements: movement was assumed to be relevant for fish from 45 to 60 mm TW (both sexes) and for years 1985 through 2010. When movement was unconstrained, the model estimated as much as 58% movement in each season for some years, and an average of 35% movement in each season; this was considered too high to be credible. After experimentation using paired runs with 5% or 25% caps on the movement parameters, 15% as a maximum movement cap in any season was chosen for the provisional base case.

Prior on *M*: recent assessments have used a lognormal prior with a mean of 0.12 and CV of 0.4. The previous multi-stock assessment (Haist et al. 2009) and the early exploratory fits were characterised by implausibly high *M* values in CRA 7 (at or near the upper bound of 0.35) and implausibly low values in CRA 8 (at or below 0.05). Behaviour of *M* was a major focus of the search for the base case, and involved experimenting with a variety of options; finally, the problem was addressed by reducing the CV on the *M*-prior to 0.15.

Growth model: explorations involved the parameters estimated by the growth model. Every run estimated the *Galpha* and *GBeta* parameters for each sex and stock; other parameters were explored as fixed or estimated. The provisional base case estimated the *Gshape* parameter. Estimating the growth CV was more likely to give a positive definite Hessian (pdH), but seemed to have little other effect; it was fixed in the provisional base case to 0.5, a value suggested by exploratory fitting to growth alone.

Shape of CPUE: some exploratory runs estimated *CPUEpow*, the shape of the relation between stock abundance and CPUE: when estimated, it was near 1.4, suggesting hyperdepletion. The base case involved fixed *CPUEpow* = 1.0, a linear relation.

Stock-recruitment: the model's stock-recruitment option was not used.

The "shorthand" parameter names used to display model results, so as to avoid symbols in the tables, are shown in Table 1.

3.2 Base case MPDs

Table 2 shows the control file specifications for the final base case. An earlier fit, presented by the stock assessment team as the "provisional base case", estimated *M* separately for the two stocks; this was rejected by the RLFAWG, who accepted as the "final base case" the same run fitted to a common *M*, because it was thought implausible that these two closely related stocks would have such disparate *M* estimates. Except for that change, the provisional and final base cases were as specified in Table 2 .

Before the RLFAWG had rejected their provisional base case, the assessment team fitted it to puerulus data and then proceeded to randomisation trials. Consequently the puerulus sensitivity runs are all based on the provisional base case.

The base case results from the simple minimisation (mode of the joint posterior distribution or MPD) are shown in Table 3. When separate *M*s were estimated, CRA 7 had a higher natural mortality rate than CRA 8; the common *M* of the final base case was intermediate.

In exploratory runs, there tended to be a correlation between growth and mortality for CRA 7: higher mortality estimates were accompanied by higher growth estimates. This was mediated by the movements: allowing higher seasonal movements allowed faster growth and lower *M*. The size data in CRA 7 contain few larger fish (Starr et al 2013), and the model's options for explaining this are high *M*, slow growth or high movements away from CRA 7.

Fitting to puerulus settlement caused very little change from the provisional base case results (compare the second and third columns of Table 3).

For both stocks, the model fit CPUE better in the late 2000s in AW than in SS, but the residual patterns were reasonably good (Figure 1 through Figure 4). In the periods of high CPUE, most fishing was in the spring-summer season.

Fits to the length frequencies for CRA 7 (Figure 5; only the first and last set of records are shown) were variable, and were not good for mature females because there were few of these in the data. Residual patterns are given in Figure 6. For CRA 8 (Figure 7; only the first and last set of records are shown), fits were better than seen in CRA 7 and the residuals (Figure 8) showed less pattern with size.

For CRA 7, the estimated growth model is shown in Figure 9 and the residuals in Figure 10; these are shown for CRA 8 in Figure 11 and Figure 12. Both models reflect considerable variation in growth. Figure 13 and Figure 14 show the vulnerable biomass trajectory for CRA 7 and CRA 8 respectively; both showed strong increases from 2000 after a long flat low period, and both have declined to some extent in recent years, although CRA 8 remains very high. Figure 15 and Figure 16 show the recruitment trajectories: both stocks had a strong pulse near 1980, and CRA 8 had another strong pulse in 2000 and 2001. **Error! Reference source not found.** and Figure 18 show the initial size structures by sex, Figure 19 and Figure 20 show estimated selectivity curves for the two stocks: note the shift to the right in epoch 2 for CRA 8.

3.3 Puerulus randomisation trials

Trials to determine whether there was a signal in the puerulus data were made by fitting the provisional base case model to the puerulus settlement data with a specified lag from 0 to 4 years between settlement and recruitment to the model, which occurs at mean 32 mm TW. At each specified lag, 500 additional fits were made with a randomised puerulus settlement vector obtained by resampling the data without replacement. Under the null hypothesis – that there is no signal in the data – the function value from the fit to real data should fall in the centre of the distribution of function values from the resampled data. A significant result is found when the function value is in the lower 5% of the distribution (this is a one-tailed test).

Results from the trials were significant (Table 4). For CRA 7, all lags from 0 through 3 years were significant, with 1 year's lag giving the best result. In absolute terms, a lag of zero is biologically unrealistic, but the model's growth between 32 mm and MLS may be under-estimated, so in practice, the lag and the model's growth estimates at small sizes may interact, such that a zero lag might be realistic. The model has no data from which to estimate growth near 32 mm TW, and few data until sizes near the MLS. For CRA 8, only the zero lag was significant.

The observed and predicted puerulus indices are compared in Figure 21. The figures illustrate the low precision of the settlement indices and the inability of the model to fit the extreme low values. The figures suggest that, despite the high significance of the randomisation trials, the predictive power of the settlement indices is low.

Despite the significance of the randomisation trials, confirming a signal in the data, the low predictive power suggested that little was to be gained from fitting to puerulus. The RLFAWG agreed to accept the non-puerulus fit as the final base case.

3.4 Base case McMC

The final base case was run as a set of one million Markov chain – Monte Carlo (McMC) simulations, starting at the base case MPD, saving every thousandth posterior parameter vector.

Posterior distributions of parameter estimates are summarised in Table 5. Results indicate that some parameters were well determined and others less well: in the latter group are *mat50* and *vuln4* for CRA 7 (probably because there were so few mature females in the data), *GBeta* for CRA 7 (because there were so few large fish in the CRA 7 data, Figure 5), CRA 7 growth density-dependence, the left-hand shape parameter for CRA 8 females in epoch 1, and movement parameters where the median estimate was low, e.g. 2002 ranged from 1% to 14%. Some estimated parameters were on an upper or lower bound, especially among the movement parameters.

Traces of estimated and derived parameters are shown in Figure 22; the posterior distributions in Figure 23 and simple diagnostic plots in Figure 24. Where the MPD estimate was on a bound, for instance for CRA 8 male *Gshape* and some of the movement estimates, the trace was not well mixed and usually did not move far from the MPD, because when the MPD estimate is on a bound, the estimated variance is incorrect and the McMC step size is small. For such parameters the posterior distributions were not very well-formed (Figure 23) and the diagnostics appeared poor (Figure 24), but these are usually not serious problems because of the small parameter space covered in the McMC; the effect is similar to having a fixed parameter.

Most estimated parameters showed well-mixed traces and are likely to be converged, and the derived parameters were all well mixed and generally appear to be converged. With more time available, it might have been advisable to run a longer McMC chain (a million simulations required about three days).

The posteriors of recruitment deviations are shown in Figure 25 and Figure 26 . Both stocks show increased recruitment near 1981 and again near 2001. Posterior trajectories of vulnerable biomass are shown in Figure 27 and Figure 28.

3.4.1 Stock assessment indicators

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

- ***Bmin***: the minimum value of AW vulnerable biomass observed during the period 1974–2011; for this and other biomass indicators, vulnerable biomass was calculated with the 2011 selectivity and MLS so that changes over time would not affect the vulnerable biomass estimate.
- ***Bcurr***: current biomass, taken as the AW 2011 vulnerable biomass.
- ***Bproj***: projected biomass, taken as AW 2015 biomass; these projections were made using the 2011 catches and using stochastic recruitment based on the mean and standard deviation of recruitment deviations estimated from 2000–09.
- ***Bref***: reference biomass, taken as the mean of AW vulnerable biomass in 1979–81.
- ***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 2011 size-limited instantaneous fishing mortality rate *F*; the multiplier that gave maximum SL catch (***MSY*)** was called ***Fmult.***
- ***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.

For CRA 8, the “soft limit” discussed by the Harvest Strategy Standard (MFish 2011) was agreed by the RLFAWG 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*. For CRA 7, *MSY* was achieved with very high fishing intensity, and associated spawning stock biomass was low, partly because of the high level of migration out of the area. The RLFAWG agreed that *MSY*-related indicators should not be used for CRA 7, and instead that *Bref*-related indicators should be used. The soft limit was defined as 50% *Bref* and the hard limit as 25% *Bref*.

3.5 Snail trail for CRA 8

The “snail trail” is a phase plot developed by the Stock Assessment Methods Working Group. It plots the estimated history of fishing intensity against biomass, based on the stock assessment’s McMC estimates. The snail trail for CRA 8 is shown in Figure 29.

The phase space in the plot is 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_y in year *y* 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 in year *y* as a proportion of the fishing intensity (*Fmsy*) that would have given *MSY* under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split, the balance between SL and NSL catches, average movement from CRA 7 to CRA 8 and full retention. *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* is *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 2011. 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 was greater than *Fmsy* from 1978 through 1999 and that *SSB* was below *SSBmsy* from 1982 through 2004. The current position of the stock is near the 1974 position, with low fishing intensity and with biomass well above *Bmsy*.

Because the RLFAWG agreed that *MSY*-based indicators were not useful for CRA 7, there is no equivalent snail trail plot for CRA 7.

3.6 Stock assessment

Indicator posteriors are summarised in Table 6. Note that that the distribution of *Bref* is shifted to the right compared with *Bmsy* for both stocks, in other words *Bref* is larger than *Bmsy* and is a more conservative quantity to use as a reference point.

For CRA 7, *Bmsy* was only slightly larger than *Bmin*, whereas *Bref* was several times *Bmin*. The current CRA 7 biomass was estimated as just below *Bref*, median 97% *Bref*, with only a 38% probability of being larger than *Bref*. Biomass was projected to increase over 3 years with 98% probability to a median of 22% above *Bref*. Except for the current biomass being slightly below *Bref*, none of the indicators would generate concern about the status of the stock.

For CRA 8, current biomass was estimated at a median 39% above *Bref*, with a 99% probability of being greater than *Bref*. Projected biomass decreased by a median of 16% to a median of 116% *Bref*, but remained above *Bref* with 77% probability. There was no chance that the stock would drop below the soft limit, no matter which definition was used for the soft limit.

4. MCMC SENSITIVITY TRIALS

The RLFAWG agreed on a set of sensitivity trials. Because of timing, these were based on the provisional base case formulation: the RLFAWG agreed to change the base case only after these trials were made, and they were not repeated against the final base case. The assessment team added the final trial on their own.

The complete set of trials was:

- **TwoM**: the provisional base case, with *M* estimated as stock-specific instead of in common.
- **OneM**: with *M* estimated in common between the two stocks, selected by the RLFAWG as the final base case.
- **Moves5% and Moves25%**: with 5% and 25% upper bounds respectively on seasonal movements from CRA 7 to CRA 8 (the base case used 15%).
- **FlatRec**: using an alternative catch vector that was based on a constant recreational catch, as opposed to the recreational catch being proportional to CPUE as in the base case (this is described by Starr et al. 2013).
- **FixShape**: with the shape of the growth curve (increment vs. initial size) fixed at 2 (concave upwards) instead of being estimated.
- **NoDD**: with no density-dependence in growth.
- **Poo (fit to puerulus)**: fitted to the puerulus settlement data: in this trial, the short-term projections were based on recruitment deviations from 2003–12 for CRA 7 and 2002–11 for CRA 8, because these late deviations can be estimated when puerulus data are fitted.

These trials were made with the provisional base case model, modified by the single change described above in each trial. However, to obtain pdH, it was necessary to estimate the *GrowthCV* parameter in the Moves25% and

NoDD trials. For each trial, the McMC chain was started at the base case MPD estimate and run for one million simulations, with 1000 samples saved.

The median parameter estimates are shown in Table 7. The Moves5% trial did not appear properly converged for CRA 7: *M* was on its upper bound, the biomass estimates were very high and the function value was substantially higher than the other trials. The effects of these trials on parameter estimates were generally small. The density-dependence parameter for CRA 7 varied substantially through the trials, but this is obviously poorly determined because of the paucity of tag-recapture data (see Table 6). The estimated movements (Figure 30) showed the same pattern through the trials except that for the higher or lower cap trials, which capped movement in the years when movement estimates were strong.

Indicators for CRA 7 are shown in Table 8. Because of the non-convergence, the biomass reference levels for Moves5% are not credible. Among the other trials, there was relatively little effect. Median *Bproj* was at least 15% (and usually more) above *Bref* in all trials.

Indicators for CRA 8 are shown in Table 9. *Bref* was greater than *Bmsy* in all trials. There wasn't much effect in the trials except for the NoDD trial, in which biomass indicators were substantially higher than in the base case: this was a substantially more optimistic assessment.

Indicators from the Poo trial are not strictly comparable with the other trials because of the different years of recruitment deviations involved. The projections were more optimistic than the provisional base case for CRA 7, and less optimistic for CRA 8.

5. MANAGEMENT PROCEDURE EVALUATIONS

Management procedure evaluations (MPEs) were made using the joint posterior distribution from the final base case stock assessment model as an operating model.

5.1 Base case operating model

Projections were made for 20 years, to 2032, with the model's 2012 fishery catching the 2012–13 TACC. Projected recruitments were based on the mean estimated recruitment for each stock for 2000–2009. The model used normal distributions of the recruitment deviations that had the same mean and variance as the estimates from each sample of the joint posterior, and recruitment was simulated with the autocorrelation within stocks and cross-correlations between stocks that were calculated from each sample of the joint posterior.

These projections re-sampled the estimated movements between CRA 7 and CRA 8. They simulated CPUE observation error based on the fits to observed offset-year CPUE, and the autocorrelations and cross-correlations in observed CPUE.

Projected commercial catches after 2012 were based on the TACC set by the harvest control rule that was being tested. Recreational catch was determined by stock abundance and the recreational exploitation rates observed in the sample from the joint posterior. Customary and illegal catches were fixed at their allowances. Because MPI requested that the harvest control rules generate a TACC, not a TAC, there was no need to simulate TAC.

The model was required to project the seasonal catch split; it did this based on CPUE from the previous year's AW season. For each stock, the proportion of catch taken in AW was regressed against standardised AW CPUE (Figure 31) and the regressions were used in the operating model (Table 10 and Table 11).

The model was also required to predict the offset-year CPUE, for use in the harvest control rule, from the most recent AW and SS CPUE based on model abundance, catchability and observation error. For each stock, the relation between observed standardised offset-year CPUE and the mean of standardised AW and SS CPUE was calculated (Table 12 and Table 13, Figure 32) for use by the model.

5.2 Robustness trial models

As well as the base case operating model, trials were made with final rule candidate in three robustness trials. In trial R1, the catchability coefficient was arbitrarily increased by 1% per year. This gave progressively higher

CPUE at any given stock abundance. Such an increase could happen as a result of technology changes (although it would likely not be gradual).

In trial R2, recruitment was arbitrarily decreased. 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. For CRA 7, recruitment was decreased by 38%, and for CRA 8 by 33%.

In trial R3, the CPUE observation error was arbitrarily doubled.

5.3 Harvest control rule family

For each stock we explored variants from one harvest control rule family. The generalised rule is illustrated in Figure 33. These rules have a plateau, on which the TACC is constant when CPUE remains within a specified range. Specific members of this rule family are determined by these parameters:

par1 rule family;
par2 TACC on the plateau;
par3 CPUE at the left-hand edge of the plateau;
par4 CPUE at the right-hand edge of the plateau;
par5 CPUE value at which TACC become zero;
par6 determines the slope of TACC above the plateau: it is the CPUE value at which the TACC is 1.5 times the plateau height;
par8 minimum change threshold;
par9 maximum change threshold;
par10 asymmetric latent year parameter.

The first six parameters define the relation between offset-year CPUE in a given year and the TACC in the following fishing year (Figure 33). The last three are potential buffering effects: 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.

MPEs were evaluated for the two stocks separately, because there is some potential for the two harvest control rules to interact. In practice, we found no effect of the CRA 8 rule on CRA 7, and (because of movements from CRA 7 to CRA 8), a slight effect of the CRA 7 rule on performance in CRA 8.

For each stock, the harvest control rule for the other stock was fixed at the analogue of the existing rule.

5.4 Indicators

Indicators for MPEs were agreed by the RLFAWG, along with the shorthand codes used in tables; '–' indicates not reported;

Code	Definition
mean (*Bio*/*Bref*)	mean biomass during the 20-year run, scaled as a proportion of *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	the 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 offset-year CPUE during the run;
meanCPUE	mean observed offset-year CPUE during the run;
%AAVH	average annual variation in TACC during the run (AAVH);
mean (*Bio*/*Bmsy*)[1]	projected biomass as a proportion of *Bmsy;*
–	CPUE in AW of the last projected year;
Biomass <*Bref*	the proportion of years in which biomass was less than *Bref;*
Biomass<*Bmin*	the proportion of years in which biomass was less than *Bmin;*
Biomass < *Bmsy*[1]	the proportion of years in which biomass was less than *Bmsy;*
TACC change	the proportion of years in which TACC changed;

Biomass<20%*SSB0*[1]	the proportion of years in which *SSB* was less than 20% *SSB0;*
Biomass<10%*SSB0*[1]	the proportion of years in which *SSB* was less than 10% *SSB0;*
Biomass<50%*Bref*	the proportion of years in which biomass was less than 50% *Bref;*
Biomass<25%*Bref*	the proportion of years in which biomass was less than 20% *Bref;*
TACC left of plateau	the proportion of years in which the TACC was to the left of the plateau
TACC right of plateau	the proportion of years in which the TACC was on the plateau
TACC on plateau	the proportion of years in which the TACC was to the right of the plateau

[1] CRA 8 only

The average annual variation in TACC was calculated as:

$$AAVH = \frac{\sum_{y=2013}^{y=2032} 100 \frac{\left| TACC_y - TACC_{y-1} \right|}{0.5\left(TACC_y + TACC_{y-1} \right)}}{20}$$

Indicators were calculated for each run. Except for indicators defined as "the 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.

A subset of these indicators was reported to the RLFAWG and NRLMG: only medians were reported, and for CRA 7 the *MSY*-based indicators and *SSB*-based indicators were not reported because of the RLFAWG agreement that these were not useful for CRA 7.

5.5 CRA 7

5.5.1 Productivity of the operating model

The relation between average commercial catch and average CPUE is shown in Figure 34, which suggests that an average catch near 125 t would be associated with CPUE between 1.0 and 1.5 kg/pot.

The relation between recreational and commercial catches (Figure 35) has the same form, because recreational catch is modelled as proportional to abundance. Stability of the TACC, measured by AAVH, increases as fishing intensity increases (Figure 36), and safety indicators have the same form (Figure 37).

5.5.2 MPEs

The TACC-generating analogue of the existing CRA 7 harvest control rule is shown in Figure 38. This rule replaced a harvest control that had been developed in 2007 (Breen et al. 2008), which was rejected by the CRA 7 industry after several years of operation (the first time that a management procedure had been changed before its scheduled review). The replacement rule was based on MPEs made in 2010 using the 2007 operating model (Breen 2010), and was implemented for the 2012–13 fishing year.

At a meeting held in Dunedin on 12 September 2012, CRA 7 stakeholders stated that they wanted to see a rebuild of the CRA 7 stock, a more stable fishery with good access, and increased management responsiveness [the last two items are contradictory to some extent].

Industry requested exploration of a narrow range of alternative rules. They wanted a rule without an asymmetric latent year and with a lower plateau height, and suggested exploration of a narrower plateau. Although the stock assessment team evaluated 65 harvest control rules, the final evaluations presented to the NRLMG comprised only 6 rules (see Table 14 and Table 15). The base case performance indicators (Table 16) suggested that rules were safe when run under the base case model. The maximum proportion of years with biomass below *Bref* was 3% for the current rule and less than 2% for the other rules. Virtually no years were less than *Bmin*, or 50% *Bref*, the MPI soft limit, or 25% *Bref*, the MPI hard limit.

In the abundance indicators, the current rule (55) showed the lowest biomass and CPUE; the others were reasonably similar to each other. Yield indicators were highest for the current rule and similar at lower values for the others, except that rule 64 was higher than the other 80 t plateau rules, and rule 38 had a lower minimum catch than the others. The 5-year mean catch was about 5 t less than the 20-year mean.

In stability indicators, the AAVH ranged from 4.9% (rule 39) to 9.6% (rule 64), all reasonably low. The TACC changed in 27% of years for rule 55, 32–33% for rules 39 and 65, and about 40% for the rest.

The biggest change was caused by the decreased plateau height, reflected in abundance and yield indicators for rule 55 compared with the other rules. Within the remaining five rules, a wider plateau gave more stability (rule 65 compared with the rest). The increased *par5* affected only the minimum commercial catch (rule 38 compared with the rest), and the change from 5% to 10% minimum change threshold decreased the proportion of years with change from 44% to 31% (rule 12 compared with rule 39). The increased slope on the right gave a higher yield for rule 64 (compared with rule 39).

Indicators from the three robustness trials are shown in Table 17, Table 18 and Table 19. The main effects in robustness trial R1 (increased catchability) compared with the base case were about a 10% increase in mean CPUE, 20% increase in AAVH and the proportion of years with changes, and more time spent to the right of the plateau. Yield indicators increased, but only slightly. Safety indicators remained good.

When recruitment was reduced in trial R2, the safety indicators remained acceptable except for rule 55, where the proportion <*Bref* exceeded 0.70 for most rules and the proportion less than 50% *Bref* was 8–12% for most rules. Abundance decreased by 40–45%; minimum catch decreased by about the same; average yields decreased by about 5% in the 5-year term and 20% in the longer term; stability indicators both increased substantially and the time spent left of the plateau increased to well over 50%.

In the R3 trial, with increased noise in CPUE, mean abundance and yield were about the same, but minimum values decreased by 20–25%. The main effect was in decreased stability and reduced time spent on the plateau. Safety indicators were all good.

Thus, even in the most pessimistic of the robustness trials, all five alternatives to the existing rule were safe (rule 55 was not safe in the R2 trial). Differences among the alternative rules were not great.

5.5.3 CRA 7 single-stock run

During the MPE stage, the RLFAWG requested to see a run in which the stock assessment model was fitted to CRA 7 alone, i.e. a single-stock run. This was made with the same specifications as the final base case, but with no movements, with *M* estimated (compared with a single *M* estimated for both stocks in the final base case), and no density-dependence (because of the paucity of CRA 7 tag-recapture data). An inadvertent difference was that growth CV was fixed to 0.3 instead of 0.5 in the final base case.

Medians of estimated parameters are compared with the final base case in Table 20. The estimated *M* was larger in the CRA 7-only run (and somewhat higher than in the TwoM sensitivity trial, Table 7). Growth parameters were similar. Other parameters were generally similar.

The stock assessment indicators (Table 21) were also generally similar. The largest difference was that, in the CRA 7-only run, median *Bcurr* was greater than *Bref*, and there was a much higher probability that current biomass was greater than *Bref*.

The CRA 7-only run was used to do MPEs on rule 55, analogue of the existing CRA 7 rule (Table 22). The CRA 7-only run and final base case results were very similar: the CRA 7-only run was slightly more optimistic than the base case, with higher catches and more time spent on the plateau.

5.6 CRA 8

5.6.1 Productivity of the operating model

The relation between average commercial catch and average CPUE is shown in Figure 39, which suggests that an average catch near 1000 t would be associated with CPUE between 3 and 4 kg/pot.

The relation between recreational and commercial catches (Figure 40) has the same form as the CPUE plot, because recreational catch is modelled as being proportional to abundance. Instability of the TACC, indicated by higher %AAVH, increases as fishing intensity increases (Figure 41), and safety indicators have the same form (Figure 42).

5.6.2 MPEs

The existing rule (its analogue as a TACC rule is shown in Figure 33) was first used to set the catch limit for the 2008–09 fishery, and was due to be reviewed in this study. At a meeting held in Dunedin on 12 September 2012, CRA 8 stakeholders perceived the CRA 8 fishery as stable (apart from variable recruitment) with good access and high abundance; they expressed wishes to see the current situation continue. Industry expressed no wish to see any other rule explored, and MPI requested exploration two additional rules that differed from the existing rule only in the plateau height.

The assessment team explored more harvest control rules as part of the review, then, after examining results, focussed on the three requested rules, which the RLFAWG agreed were sufficient to show the NRLMG. Parameters for these three rules are given in Table 23. Rule 1 is the analogue of the current rule under the assumption that allowances would be the same as in 2012; the two others have increased plateau heights of 1100 and 1200 t for rules 2 and 3 respectively with all other parameters being the same. The rule parameters are shown in Table 23, and the TACCs they give as a function of CPUE are shown in Table 24.

Results are shown in Table 25 for the base case, Table 26 for the R1 robustness trial, Table 27 for the R2 trial and Table 28 for the R3 trial.

Under the base case operating model (Table 25), all the rules would maintain the stock above *Bref* with high probability and would produce no safety indicators of concern. There was a tradeoff between average catch and average abundance.

Safety indicators for all three rules are very low (i.e., the rules are safe) except in the R2 robustness trial, with reduced recruitment. In that trial, the proportion of years with biomass less than B*ref* reached 22% for rule 1, 39% for rule 2 and nearly 51% for rule 3. The proportion of years with biomass less than 20% of spawning stock biomass *SSBO* was over 4% for rule 3; this was acceptable but starting to approach the soft limit.

In the base case, abundance indicators decrease with increasing plateau height, and yield increases with increasing plateau height. The median AAVH was low for all rules and the proportion of years with TACC change is 13–16% for all rules. All rules spent little time on the left of the plateau, and time spent on the plateau increases as the plateau height increases.

In the R1 trial (increasing catchability, Table 26), the abundance indicators increased because CPUE increased for the same level of abundance, but yield indicators stayed nearly the same. Stability decreased, reflected in an increased proportion of years with changes. The time spent on the plateau decreased for all rules, at the expense of time both to the left and to the right of the plateau.

In the R2 trial (decreased recruitment, Table 27), abundance indicators decreased by about 30%. Recreational catch indicators follow the abundance indicators. The mean commercial catch declined by only 3% for rule 1, but by 8% and 12% for rules 2 and 3. Similarly, the proportion of years with changes was 22% in rule 1, but 33% and 43% for rules 2 and 3. Time spent to the left of the plateau increased to 21% in rule 1, but to 38% and 51% in rules 2 and 3.

In the R3 trial (increased CPUE noise, Table 28), there were few effects on yield or abundance, but stability decreased, with the proportion of years with TACC changes increasing to about 25%. In rule 1, changes to where the rule spent its time were minor, while in rule 3 time spent on the plateau decreased.

All three rules appeared to be safe, although rule 3 approached thresholds in the reduced recruitment trial. The higher plateau heights were associated with decreased abundance, increased yield and decreased stability.

5.7 The effect of fitting to puerulus

Projections were made from the Poo sensitivity trial with the existing rule analogues for both stocks, and compared with the same projections made from the TwoM sensitivity trial (because the Poo trial estimated two *M*s). Results are shown in Table 29.

For CRA 7, results from the Poo trial had lower average biomass and CPUE by about 5%, and slightly lower commercial catches. Stability was less, with AAVH being about 9% greater, and biomass was below *Bref* more often than in the TwoM trial.

For CRA 8, average biomass and CPUE were also less by about 5%. Commercial catch was the same, and AAVH was very low. These changes were not great.

The major change between the two sets of MPEs, apart from some minor parameter differences, was that they used a different set of years for *Rdev* projections: the TwoM used 2000–2009 for both stocks while the Poo trial used 2003–12 for CRA 7 and 2002–11 for CRA 8, based on the lags seen in puerulus randomisation trials.

6. DISCUSSION AND CONCLUSIONS

Although the final base case showed acceptable fits to data, it was not a comfortable fit. The stock assessment model fitted the data reasonably well, but with difficulties. The estimated *M* for CRA 7 was higher than seemed credible until a) the weight on tag data was reduced and b) the prior on *M* was made stronger. The model tended to estimate quite high seasonal movements in some years – over 50% – and this was probably driven by the lack of large fish in the CRA 7 size data. High *M* was also obtained in the 2011 stock assessment of CRA 4 (Breen et al. 2012): in that assessment, the high *M* was not a result of conflicting data sets: it occurred when each of the data sets was removed singly.

The *M* estimated for CRA 8 was on the lower end of credibility until the weight and prior changes were made. The RLFAWG rejected the two-*M* model, apparently because of the difference in the estimates of *M* for each stock. Whether *M* can be estimated by size-based models is controversial (e.g. Lee et al. 2011; Francis 2012).

Whatever the merits of the RLFAWG choice of a base case, the McMC sensitivity trials showed little effect of the modelling choices on state-of-the-stock conclusions.

The RLFAWG expressed concern that the recreational catch assumption was not credible, particularly in recent years. It was assumed that recreational catch was proportional to abundance, which gave high catches in recent years in CRA 8 because of recent high abundance (see Starr et al. 2013). Again, the sensitivity trial that explored this found little effect of the variable recreational catch assumption compared with an assumed constant catch.

The puerulus randomisation trials suggested that there is a signal in the settlement data, but these data appeared to have little predictive power. The short lags that give the best relation with settlement were too short to be biologically realistic, suggesting that the model over-estimated the time lobsters take to grow from 32 mm TW to MLS. The parameter estimates and stock assessment indicators changed little when the model was fitted to puerulus, and projections from the two models with one harvest control rule showed similar performances.

As we found in previous stock assessments, for these stocks *Bref* appeared to be a more conservative reference point than *Bmsy*. For CRA 7, because of the small fish in the size data and the consequent high movements and high M, *Bmsy* appeared to be an aggressive reference point: the model suggested that MSY must be taken with high fishing intensity, resulting in a very low biomass. With stakeholders wanting high abundance, *Bmsy* is an unrealistic reference point.

The stock assessment suggests that CRA 7 is near *Bref* but projected to increase under current catches and recruitment levels. The CRA 8 biomass is well above reference levels; it is projected to decrease in the short term but projected to remain well above reference levels.

The harvest control rules we tested gave good medium-term performance under the assumptions of the operating model.

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Table 1: Parameter names and their meanings.

Parameter	Explanation
ln(*R0*)	natural log of the base recruitment *R0*
M	instantaneous natural mortality rate
initial *U*	initial exploitation rate in 1974
mat50	size at 50% female maturation
mat95add	difference between *mat50* and *mat95*
Galpha	growth at 50 mm TW
GBeta	growth at 80 mm TW
Gshape	shape of growth curve: positive implies concave up
GrowthDD	density-dependence
vuln1	seasonal vulnerability: males SS
vuln2	seasonal vulnerability: immature females AW
vuln3	seasonal vulnerability: all females SS
vuln4	seasonal vulnerability: mature females AW
SelectLeft	shape of left-hand part of selectivity
SelectMax	size at maximum selectivity
movement	proportion of seasonal movement
Fmult	multiplier on current *F* that gives *MSY*
years to MLS	years from recruitment to model to MLS

Table 2: Specifications for the final base case.

First year and last year	1974	2011				
Two seasons from	1979					
First and last estimated *Rdev*s	1974	2009				
First and last *Rdev*s resampled	2000	2009				
Bref years	1979	1985				
Movement sizes (mm TW)	45–60					
Movement years	1985–2010					
Bins and recruitment to model	Midpoint of first	Midpoint of last	Width	Mean recruit size	Std. dev. recruit size	
	31	91	2	32	2	
	likelihood	weight				
LFs	multinomial	1.2				
Tags	robust normal	0.5				
CPUE	lognormal	1.4				
CPUE process error	0.25					
Fishing dynamics	instantaneous					
Newton-Raphson iterations	4					
Growth model	Schnute-Francis					
Which *vuln*	AW	SS				
Males	0	1				
Immature females	2	3				
Mature females	4	3				
Priors	Phase	Lower	Upper	Prior type	Prior mean	Prior CV
ln(*R0*)	1	1	25	0		
Initial *U*	4	0	0.99	0		
M	5	0.01	0.35	2	0.12	0.15
*Rdev*s	2	-2.3	2.3	1	0	0.4
ln(*qCPUE*)	1	-25	0	0		
CPUEpow:	-1	0.001	2	0		
mat_50:	3	30	80	0		

mat_95-50:	3	5	60	0		
Galpha:	2	1	20	0		
Gdiff:	2	0.001	1	0		
Gshape:	3	0.1	15	0		
growthCV	-3	0.01	2	0		
Density-dependence	5	0	1	0		
Growth *minstd*	-2	0.01	5	0		
Growth *obserr*	-1	0.00001	10	0		
Select *Lvar* male	4	1	50	0		
Select *Lvar* female	4	1	50	0		
Select *Rvar* male	-3	1	250	0		
Select *Rvar* female	-3	1	250	0		
SelMax male	5	30	70	0	56	2
SelMax female	5	30	70	0	56	2
vuln	3	0.01	1	0		
Movement	4	0	0.15	0		
Upper and lower bins for LF fitting	CRA 7	CRA 7	CRA 8	CRA 8		
Males	2	31	5	31		
Immature females	3	19	6	20		
Mature females	10	31	10	31		
	Males	Females				
Length-weight intercept	3.39E-06	1.04E-05				
Length-weight exponent	2.9665	2.6323				
Handling mortality rate	0.1					

Table 3: Base case MPD results: all biomass in tonnes; sdnr: standard deviation of normalised residuals; MAR: median of absolute residuals; LL: likelihood contribution; where no stock or sex is given the result is common to both stocks or both sexes.

Stock	Sex	Quantity	Final base case one *M*	Provisional base case two *M*	Provisional base case plus puerulus
		LFs sdnr	0.368	0.364	0.363
		LFs MAR	0.117	0.116	0.115
		LFs LL	168.6	167.0	165.6
		Tags sdnr	1.425	1.425	1.425
		Tags MAR	0.698	0.697	0.697
		Tags LL	5125.0	5122.6	5123.2
		CPUE sdnr	1.095	1.083	1.084
		CPUE MAR	0.722	0.709	0.724
		CPUE LL	-141.8	-143.6	-143.4
		Poo sdnr	n.a.	n.a.	1.3049
		Poo MAR	n.a.	n.a.	0.654
		Poo LL	n.a.	n.a.	92.8
		Prior contributions	-40.2	-38.6	-42.0
		Objective function value	5111.6	5107.4	5196.3
CRA 7		ln(*R0*)	13.01	13.21	13.18
CRA 8		ln(*R0*)	14.57	14.43	14.44
CRA 7		*M*	0.098	0.132	0.130
CRA 8		*M*	0.098	0.080	0.080
CRA 7		initial *U*	0.033	0.000	0.000
CRA 8		initial *U*	0.175	0.216	0.220
CRA 7		ln(*qCPUE*)	-6.169	-6.230	-6.239
CRA 8		ln(*qCPUE*)	-6.782	-6.755	-6.751

Stock	Sex	Quantity	Final base case one *M*	Provisional base case two *M*	Provisional base case plus puerulus
CRA 7		ln(*qPuerulus*)	-6*	-6*	-17.02
CRA 8		ln(*qPuerulus*)	-6*	-6*	-14.65
CRA 7		*mat50*	67.0	66.5	66.3
CRA 7		*mat95add*	8.1	8.0	7.9
CRA 8		*mat50*	59.1	59.2	59.2
CRA 8		*mat95add*	7.8	7.9	7.9
CRA 7	male	*Galpha*	4.02	4.03	4.01
CRA 7	male	*GBeta*	2.96	2.93	3.07
CRA 7	male	*Gshape*	5.325	4.768	5.389
CRA 7	female	*Galpha*	3.84	3.78	3.83
CRA 7	female	*GBeta*	1.79	1.84	1.91
CRA 7	female	*Gshape*	5.735	5.639	5.764
CRA 8	male	*Galpha*	5.50	5.51	5.51
CRA 8	male	*GBeta*	3.28	3.28	3.27
CRA 8	male	*Gshape*	0.100	0.100	0.100
CRA 8	female	*Galpha*	4.53	4.53	4.53
CRA 8	female	*GBeta*	1.82	1.81	1.81
CRA 8	female	*Gshape*	2.291	2.260	2.269
CRA 7		*GrowthDD*	0.381	0.275	0.292
CRA 8		*GrowthDD*	0.584	0.660	0.662
CRA 7		*vuln1*	0.827	0.830	0.826
CRA 7		*vuln2*	0.922	0.861	0.902
CRA 7		*vuln3*	1.000	0.916	0.965
CRA 7		*vuln4*	0.581	0.454	0.466
CRA 8		*vuln1*	0.762	0.739	0.740
CRA 8		*vuln2*	0.674	0.680	0.679
CRA 8		*vuln3*	0.447	0.441	0.441
CRA 8		*vuln4*	0.402	0.393	0.394
CRA 7	male	*SelectLeft*	4.45	5.32	4.56
CRA 7	male	*SelectMax*	44.48	46.45	44.78
CRA 7	female	*SelectLeft*	4.25	4.41	4.32
CRA 7	female	*SelectMax*	44.54	44.96	44.73
CRA 7	male	*SelectLeft* - epoch 1	6.23	6.31	6.29
CRA 8	male	*SelectMax* - epoch 1	54.86	54.94	54.88
CRA 8	female	*SelectLeft* - epoch 1	6.82	6.88	6.86
CRA 8	female	*SelectMax* - epoch 1	56.00	55.96	55.92
CRA 8	male	*SelectLeft* - epoch 2	3.69	3.68	3.68
CRA 8	male	*SelectMax* - epoch 2	54.86	54.76	54.77
CRA 8	female	*SelectLeft* - epoch 2	4.12	4.13	4.13
CRA 8	female	*SelectMax* - epoch 2	56.84	56.79	56.79
		1985 movement	0.000	0.000	0.000
		1986 movement	0.000	0.000	0.000
		1987 movement	0.087	0.111	0.105
		1988 movement	0.080	0.095	0.095
		1989 movement	0.000	0.000	0.000
		1990 movement	0.000	0.000	0.000
		1991 movement	0.150	0.150	0.150
		1992 movement	0.090	0.099	0.101
		1993 movement	0.150	0.150	0.150
		1994 movement	0.150	0.150	0.150
		1995 movement	0.150	0.150	0.150

Stock	Sex	Quantity	Final base case one *M*	Provisional base case two *M*	Provisional base case plus puerulus
		1996 movement	0.150	0.150	0.150
		1997 movement	0.150	0.150	0.150
		1998 movement	0.150	0.150	0.150
		1999 movement	0.148	0.146	0.150
		2000 movement	0.006	0.014	0.017
		2001 movement	0.111	0.114	0.116
		2002 movement	0.150	0.150	0.150
		2003 movement	0.000	0.000	0.000
		2004 movement	0.000	0.000	0.000
		2005 movement	0.005	0.000	0.000
		2006 movement	0.150	0.150	0.150
		2007 movement	0.150	0.150	0.150
		2008 movement	0.150	0.150	0.150
		2009 movement	0.150	0.150	0.150
		2010 movement	0.150	0.150	0.150
CRA 7	male	years to MLS	3.5	3	3
CRA 7	female	years to MLS	3.5	3	3
CRA 8	male	years to MLS	5	5	5
CRA 8	female	years to MLS	6	6	6

Table 4: Probability of obtaining the observed fit between puerulus settlement indices and recruitment given no relationship between the two. Results are from 500 randomization trials at lags from 0 to 4 years between puerulus settlement and recruitment to the model. Asterisks indicate significance at the 0.05 level.

Lag	CRA 7	CRA 8
0	*0.006	*0.028
1	*0.000	0.230
2	*0.002	0.604
3	*0.046	0.600
4	0.118	0.606

Table 5: Summary of the posterior distribution of parameter estimates from the final base case McMC: the minimum, maximum, median, 5th and 95th quantiles of the posterior distributions of estimated parameters; where no stock or sex is given the result is common to both stocks or both sexes.

Stock	Sex	Quantity	Min	0.05	Median	0.95	Max
		Objective function value	4000.5	4047.6	4058.7	4071.2	4082.5
CRA 7		ln(*R0*)	12.72	12.89	13.06	13.24	13.44
CRA 8		ln(*R0*)	14.30	14.41	14.54	14.67	14.78
		M	0.078	0.089	0.100	0.112	0.122
CRA 7		initial *U*	0.000	0.010	0.048	0.091	0.131
CRA 8		initial *U*	0.050	0.097	0.150	0.211	0.286
CRA 7		ln(*qCPUE*)	-6.777	-6.511	-6.301	-6.066	-5.875
CRA 8		ln(*qCPUE*)	-7.126	-7.022	-6.843	-6.674	-6.487
CRA 7		*mat50*	63.1	65.3	71.3	78.9	80.0
CRA 7		*mat95add*	5.0	6.2	11.3	17.9	22.6
CRA 8		*mat50*	57.2	58.2	59.4	61.1	63.6
CRA 8		*mat95add*	5.0	6.1	8.4	11.6	16.6
CRA 7	male	*Galpha*	3.05	3.36	3.73	4.24	4.56
CRA 7	male	*GBeta*	0.07	1.27	2.59	3.65	4.14
CRA 7	male	*Gshape*	0.859	2.718	4.702	6.729	8.131

Stock	Sex	Quantity	Min	0.05	Median	0.95	Max
CRA 7	female	*Galpha*	2.74	3.07	3.45	3.96	4.45
CRA 7	female	*GBeta*	0.29	0.77	1.63	2.69	3.56
CRA 7	female	*Gshape*	2.848	4.166	5.784	7.559	10.033
CRA 8	male	*Galpha*	5.13	5.26	5.49	5.71	5.89
CRA 8	male	*GBeta*	2.52	2.86	3.25	3.65	3.88
CRA 8	male	*Gshape*	0.100	0.100	0.104	0.107	0.107
CRA 8	female	*Galpha*	4.17	4.32	4.52	4.71	4.99
CRA 8	female	*GBeta*	1.57	1.67	1.83	1.97	2.05
CRA 8	female	*Gshape*	1.203	1.637	2.275	2.870	3.541
CRA 7		*GrowthDD*	0.029	0.114	0.241	0.389	0.500
CRA 8		*GrowthDD*	0.434	0.490	0.565	0.632	0.693
CRA 7		*vuln1*	0.572	0.680	0.821	0.963	1.000
CRA 7		*vuln2*	0.585	0.711	0.866	0.982	1.000
CRA 7		*vuln3*	0.920	0.928	0.955	0.993	1.000
CRA 7		*vuln4*	0.034	0.185	0.588	0.940	1.000
CRA 8		*vuln1*	0.622	0.685	0.768	0.864	0.973
CRA 8		*vuln2*	0.426	0.548	0.724	0.928	0.989
CRA 8		*vuln3*	0.308	0.384	0.487	0.606	0.711
CRA 8		*vuln4*	0.265	0.331	0.441	0.579	0.753
CRA 7	male	*SelectLeft*	1.4	3.3	5.6	8.7	12.1
CRA 7	male	*SelectMax*	39.0	42.5	46.7	51.6	55.2
CRA 7	female	*SelectLeft*	1.3	2.5	4.7	7.6	11.0
CRA 7	female	*SelectMax*	39.0	41.3	45.0	49.7	55.6
CRA 7	male	*SelectLeft* - epoch 1	3.3	4.8	7.3	11.2	15.6
CRA 8	male	*SelectMax* - epoch 1	49.1	51.9	56.4	62.8	69.6
CRA 8	female	*SelectLeft* - epoch 1	2.8	5.1	9.4	14.9	19.4
CRA 8	female	*SelectMax* - epoch 1	45.8	53.2	59.4	68.1	70.0
CRA 8	male	*SelectLeft* - epoch 2	2.7	3.1	3.7	4.4	5.1
CRA 8	male	*SelectMax* - epoch 2	52.7	53.7	54.7	55.8	56.6
CRA 8	female	*SelectLeft* - epoch 2	2.8	3.5	4.2	5.1	6.2
CRA 8	female	*SelectMax* - epoch 2	54.2	55.8	57.0	58.4	60.0
		1985 movement	0.000	0.001	0.004	0.007	0.008
		1986 movement	0.000	0.001	0.006	0.009	0.011
		1987 movement	0.000	0.018	0.099	0.145	0.150
		1988 movement	0.000	0.007	0.084	0.144	0.150
		1989 movement	0.000	0.000	0.009	0.013	0.015
		1990 movement	0.000	0.000	0.001	0.002	0.002
		1991 movement	0.141	0.142	0.146	0.150	0.150
		1992 movement	0.000	0.017	0.097	0.145	0.150
		1993 movement	0.064	0.081	0.124	0.146	0.150
		1994 movement	0.142	0.143	0.146	0.149	0.150
		1995 movement	0.136	0.137	0.140	0.150	0.150
		1996 movement	0.143	0.144	0.149	0.150	0.150
		1997 movement	0.130	0.133	0.145	0.149	0.150
		1998 movement	0.145	0.146	0.147	0.150	0.150
		1999 movement	0.000	0.011	0.081	0.143	0.150
		2000 movement	0.000	0.007	0.069	0.140	0.150
		2001 movement	0.000	0.011	0.082	0.143	0.150
		2002 movement	0.099	0.106	0.130	0.148	0.150
		2003 movement	0.000	0.002	0.031	0.073	0.083
		2004 movement	0.000	0.005	0.023	0.051	0.057
		2005 movement	0.000	0.005	0.054	0.132	0.150
		2006 movement	0.139	0.141	0.147	0.150	0.150
		2007 movement	0.130	0.133	0.142	0.149	0.150

Stock	Sex	Quantity	Min	0.05	Median	0.95	Max
		2008 movement	0.144	0.145	0.147	0.150	0.150
		2009 movement	0.142	0.142	0.145	0.150	0.150
		2010 movement	0.140	0.141	0.145	0.150	0.150

Table 6: Summary of the posterior distributions (median, 5th and 95th quantiles) of the stock assessment indicators from the final base case McMC.

	CRA 7			CRA 8		
Indicator	Median	0.05	0.95	Median	0.05	0.95
Bmin	147.8	113.4	187.8	734.2	626.7	847.7
Bcurr	599.5	454.9	770.1	2758.2	2130.9	3377.5
Bref	616.3	516.2	735.2	1970.1	1648.1	2408.1
Bproj	754.8	536.8	1061.3	2303.7	1547.3	3093.6
Bmsy	217.4	185.2	255.4	1221.2	1003.9	1465.0
MSY	154.1	136.6	174.1	1136.1	1042.5	1236.0
Fmult	10.11	7.1	13.65	2.04	1.65	2.51
SSBcurr	99.5	51.2	176.3	4532.0	4052.1	5036.7
SSBproj	138.1	77.0	226.1	4526.0	3844.2	5228.3
SSBmsy	5.7	1.8	13.4	2130.4	1809.9	2522.6
CPUEcurrent	0.956	0.830	1.090	2.678	2.327	3.093
CPUEproj	1.294	0.952	1.742	2.004	1.303	2.705
CPUEmsy	0.275	0.211	0.371	0.896	0.745	1.066
Bcurr/Bmin	4.057	3.343	4.944	3.712	3.079	4.452
Bcurr/Bref	0.972	0.812	1.157	1.385	1.108	1.675
Bcurr/Bmsy	2.754	2.107	3.551	2.247	1.881	2.663
Bproj/Bcurr	1.251	1.027	1.588	0.843	0.662	1.014
Bproj/Bref	1.225	0.913	1.629	1.165	0.814	1.534
Bproj/Bmsy	3.465	2.474	4.852	1.885	1.393	2.411
SSBcurr/SSB0	0.120	0.072	0.187	0.713	0.639	0.789
SSBproj/SSB0	0.164	0.110	0.239	0.712	0.627	0.799
SSBcurr/SSBmsy	17.641	8.204	43.704	2.132	1.862	2.434
SSBproj/SSBmsy	24.282	11.057	60.361	2.121	1.833	2.458
SSBproj/SSBcurr	1.377	1.205	1.622	1.000	0.903	1.090
USLcurrent	0.067	0.052	0.089	0.218	0.182	0.271
USLproj	0.077	0.055	0.109	0.280	0.209	0.417
USLproj/USLcurrent	1.155	0.892	1.464	1.282	1.038	1.698
P(*Bcurr*>*Bmin*)	1.00			1.00		
P(*Bcurr*>*Bref*)	0.38			0.99		
P(*Bcurr*>*Bmsy*)	1.00			1.00		
P(*Bproj*>*Bmin*)	1.00			1.00		
P(*Bproj*>*Bref*)	0.87			0.77		
P(*Bproj*>*Bmsy*)	1.00			1.00		
P(*Bproj*>*Bcurr*)	0.98			0.06		
P(*SSBcurr*>*SSBmsy*)	1.00			1.00		
P(*SSBproj*>*SSBmsy*)	1.00			1.00		
P(*USLproj*>*USLcurr*)	0.81			0.98		
P(*Bcurr*<0.5*Bref*)	0.00			0.00		
P(*Bproj*<0.5*Bref*)	0.00			0.00		
P(*Bcurr*<0.25*Bref*)	0.00			0.00		
P(*Bproj*<0.25*Bref*)	0.00			0.00		

Table 7: Median parameter estimates from the McMC sensitivity trials; cells shaded indicate that the parameter was fixed at the value shown.

Stock	Sex	Quantity	TwoM	OneM	Moves 5%	Moves 25%	Flat Rec	Fix Shape	NoDD	Poo
		function	4054.0	4058.7	4101.3	4029.7	4054.7	4062.8	4083.1	4147.7
CRA 7		ln(*R0*)	13.30	13.06	16.04	13.46	13.59	13.65	13.56	13.32
CRA 8		ln(*R0*)	14.42	14.54	13.94	14.33	14.37	14.31	14.64	14.42
CRA 7		*M*	0.142	0.100	0.350	0.132	0.156	0.157	0.166	0.144
CRA 8		*M*	0.082	0.100	0.092	0.083	0.084	0.081	0.104	0.081
CRA 7		initial *U*	0.001	0.048	0.001	0.001	0.030	0.030	0.043	0.001
CRA 8		initial *U*	0.197	0.150	0.077	0.192	0.188	0.179	0.203	0.198
CRA 7		ln(*qCPUE*)	-6.346	-6.301	-9.128	-6.221	-6.434	-6.379	-6.322	-6.302
CRA 8		ln(*qCPUE*)	-6.827	-6.843	-6.898	-6.825	-6.831	-6.813	-7.182	-6.817
CRA 7		*mat50*	70.27	71.25	65.23	69.83	69.32	68.19	68.02	69.29
CRA 7		*mat95add*	10.66	11.25	8.83	10.79	10.59	9.64	9.69	10.43
CRA 8		*mat50*	59.36	59.41	59.21	59.28	59.39	59.33	59.17	59.41
CRA 8		*mat95add*	8.35	8.35	8.29	8.24	8.29	8.12	7.60	8.40
CRA 7	male	*Galpha*	3.731	3.735	3.257	4.535	3.465	3.504	3.771	3.757
CRA 7	male	*GBeta*	2.690	2.586	1.868	3.213	2.246	2.051	2.572	2.676
CRA 7	male	*Gshape*	4.162	4.702	3.522	4.061	2.951	2	2.368	3.988
CRA 8	male	*GrowthCV*	0.5	0.5	0.5	0.338	0.5	0.5	0.346	0.500
CRA 7	female	*Galpha*	3.466	3.450	3.233	4.272	3.269	3.537	3.555	3.452
CRA 7	female	*GBeta*	1.712	1.629	2.140	1.766	1.683	1.207	1.802	1.759
CRA 7	female	*Gshape*	5.340	5.784	5.603	5.757	4.442	2	4.353	5.319
CRA 7	female	*GrowthCV*	0.5	0.5	0.5	0.266	0.5	0.5	0.349	0.500
CRA 8	male	*Galpha*	5.380	5.486	5.546	5.420	5.407	5.541	4.300	5.487
CRA 8	male	*GBeta*	3.174	3.247	3.481	3.233	3.172	4.051	2.262	3.234
CRA 8	male	*Gshape*	0.107	0.104	0.104	0.101	0.102	2	0.101	0.101
CRA 8	male	*GrowthCV*	0.5	0.5	0.5	0.516	0.5	0.5	0.522	0.500
CRA 8	female	*Galpha*	4.423	4.518	4.574	4.502	4.461	4.514	3.599	4.506
CRA 8	female	*GBeta*	1.780	1.826	1.819	1.803	1.794	1.788	1.428	1.806
CRA 8	female	*Gshape*	2.209	2.275	2.141	2.211	2.172	2	1.875	2.216
CRA 8	female	*GrowthCV*	0.5	0.5	0.5	0.489	0.5	0.5	0.495	0.500
CRA 7		*GrowthDD*	0.154	0.241	0.000	0.288	0.022	0.004	0	0.140
CRA 8		*GrowthDD*	0.609	0.565	0.589	0.636	0.616	0.667	0	0.640
CRA 7		*vuln1*	0.850	0.821	0.849	0.859	0.831	0.842	0.839	0.850
CRA 7		*vuln2*	0.789	0.866	0.843	0.769	0.767	0.825	0.758	0.778
CRA 7		*vuln3*	0.827	0.955	0.841	0.798	0.810	0.834	0.771	0.818
CRA 7		*vuln4*	0.439	0.588	0.210	0.402	0.371	0.340	0.320	0.462
CRA 8		*vuln1*	0.740	0.768	0.736	0.737	0.741	0.769	0.778	0.748
CRA 8		*vuln2*	0.742	0.724	0.731	0.722	0.757	0.722	0.815	0.723
CRA 8		*vuln3*	0.479	0.487	0.477	0.468	0.492	0.485	0.567	0.471
CRA 8		*vuln4*	0.414	0.441	0.416	0.421	0.429	0.423	0.520	0.417
CRA 7	male	*SelectLeft*	6.61	5.59	5.04	7.66	7.34	7.24	7.09	6.63
CRA 7	male	*SelectMax*	49.19	46.70	46.66	51.78	51.58	52.26	51.41	49.51
CRA 7	female	*SelectLeft*	5.14	4.71	4.87	5.62	6.55	6.35	6.49	5.19
CRA 7	female	*SelectMax*	46.23	45.02	46.07	47.29	50.08	50.77	49.96	46.53
CRA 7	male	*SelLeft_1*	7.19	7.33	7.72	7.32	7.69	7.83	6.67	7.47
CRA 8	male	*SelMax_1*	56.02	56.44	55.76	56.17	56.92	56.73	55.04	56.42
CRA 8	female	*SelLeft_1*	9.34	9.42	9.26	9.04	10.99	8.29	7.81	8.09
CRA 8	female	*SelMax_1*	59.55	59.44	57.84	58.88	62.19	57.90	57.37	57.70
CRA 8	male	*SelLeft_2*	3.70	3.66	3.72	3.75	3.69	3.81	3.56	3.67
CRA 8	male	*SelMax_2*	54.67	54.70	54.24	54.70	54.59	54.80	54.26	54.60
CRA 8	female	*SelLeft_2*	4.26	4.21	4.40	4.23	4.30	4.22	4.14	4.21
CRA 8	female	*SelMax_2*	56.99	56.97	56.85	56.95	57.04	56.88	56.83	56.88

Stock	Sex	Quantity	TwoM	OneM	Moves 5%	Moves 25%	Flat Rec	Fix Shape	NoDD	Poo
		max move	0.149	0.149	0.049	0.249	0.149	0.149	0.149	0.149
		meanmove	0.091	0.096	0.036	0.155	0.102	0.103	0.093	0.091
		1985 move	0.001	0.004	0.049	0.003	0.001	0.009	0.002	0.003
		1986 move	0.002	0.006	0.049	0.019	0.004	0.062	0.011	0.002
		1987 move	0.098	0.099	0.049	0.174	0.147	0.133	0.099	0.096
		1988 move	0.086	0.084	0.049	0.164	0.090	0.093	0.094	0.088
		1989 move	0.004	0.009	0.026	0.017	0.001	0.005	0.002	0.007
		1990 move	0.002	0.001	0.011	0.001	0.001	0.003	0.001	0.001
		1991 move	0.148	0.146	0.046	0.248	0.149	0.148	0.149	0.149
		1992 move	0.090	0.097	0.047	0.145	0.103	0.098	0.096	0.106
		1993 move	0.140	0.124	0.037	0.179	0.137	0.134	0.145	0.026
		1994 move	0.146	0.146	0.046	0.244	0.148	0.146	0.143	0.141
		1995 move	0.142	0.140	0.033	0.235	0.149	0.149	0.149	0.138
		1996 move	0.149	0.149	0.043	0.246	0.149	0.147	0.142	0.147
		1997 move	0.140	0.145	0.036	0.170	0.140	0.142	0.132	0.133
		1998 move	0.144	0.147	0.024	0.249	0.148	0.148	0.143	0.148
		1999 move	0.077	0.081	0.012	0.158	0.082	0.075	0.086	0.084
		2000 move	0.067	0.069	0.025	0.133	0.070	0.072	0.064	0.068
		2001 move	0.088	0.082	0.048	0.167	0.100	0.084	0.084	0.084
		2002 move	0.090	0.130	0.048	0.173	0.134	0.147	0.093	0.109
		2003 move	0.016	0.031	0.043	0.099	0.062	0.054	0.010	0.037
		2004 move	0.010	0.023	0.025	0.060	0.036	0.046	0.011	0.026
		2005 move	0.024	0.054	0.026	0.063	0.056	0.069	0.045	0.056
		2006 move	0.131	0.147	0.046	0.240	0.143	0.143	0.140	0.146
		2007 move	0.120	0.142	0.025	0.114	0.148	0.134	0.138	0.129
		2008 move	0.149	0.147	0.022	0.244	0.149	0.149	0.148	0.140
		2009 move	0.148	0.145	0.020	0.242	0.148	0.147	0.149	0.149
		2010 move	0.145	0.145	0.041	0.246	0.148	0.144	0.149	0.145

Table 8: CRA 7: Medians of stock assessment indicators for the McMC sensitivity trials.

Indicator	TwoM	OneM	Moves 5%	Moves 25%	Flat Rec	Fix Shape	NoDD	Poo
Bmin	155.5	147.8	2815.9	127.0	170.7	159.2	151.8	149.4
Bcurr	599.6	599.5	8147.0	505.8	659.9	605.8	573.4	583.9
Bref	633.1	616.3	7047.3	447.4	669.6	637.7	613.1	619.2
Bproj	727.2	754.8	8456.1	659.8	796.8	741.5	717.9	820.3
CPUEcurrent	0.9	1.0	0.9	0.8	0.9	0.9	0.9	0.9
CPUEproj	1.183	1.294	0.839	1.220	1.178	1.168	1.174	1.402
Bcurr/Bmin	3.863	4.057	2.880	3.977	3.874	3.813	3.788	3.920
Bcurr/Bref	0.944	0.972	1.159	1.123	0.982	0.954	0.929	0.944
Bproj/Bcurr	1.200	1.251	1.028	1.300	1.198	1.201	1.233	1.401
Bproj/Bref	1.145	1.225	1.209	1.475	1.193	1.155	1.160	1.330
USLcurrent	0.066	0.067	0.004	0.081	0.059	0.064	0.069	0.068
USLproj	0.080	0.077	0.007	0.089	0.076	0.079	0.081	0.071
USLproj/USLcurrent	1.227	1.155	1.654	1.084	1.301	1.242	1.198	1.039
P(*Bcurr*>*Bmin*)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
P(*Bcurr*>*Bref*)	0.299	0.382	0.912	0.124	0.438	0.321	0.276	0.308
P(*Bproj*>*Bmin*)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
P(*Bproj*>*Bref*)	0.782	0.866	0.799	0.776	0.830	0.744	0.783	0.883
P(*Bproj*>*Bcurr*)	0.926	0.975	0.549	0.966	0.894	0.890	0.947	0.952
P(*USLproj*>*USLcurr*)	0.891	0.811	0.951	0.686	0.944	0.885	0.830	0.565

Table 9: CRA 8: Medians of stock assessment indicators for the McMC sensitivity trials.

Indicator	TwoM	OneM	Moves 5%	Moves 25%	Flat Rec	Fix Shape	NoDD	Poo
Bmin	721.7	734.2	775.0	722.5	731.0	709.4	964.8	715.5
Bcurr	2767.3	2758.2	3013.0	2837.9	2875.1	2769.3	4378.0	2784.4
Bref	1922.8	1970.1	2033.7	1566.6	1905.9	1943.3	2432.2	1890.8
Bproj	2360.5	2303.7	2580.1	2482.2	2452.6	2376.0	4176.3	1962.0
Bmsy	1361.4	1221.2	1203.4	1297.8	1320.8	1336.4	2180.6	1333.2
MSY	1151.2	1136.1	1146.2	1127.2	1128.7	1126.2	1224.1	1159.3
Fmult	1.7	2.0	2.3	1.8	2.0	1.7	1.6	1.8
SSBcurr	4828.0	4532.0	5458.7	4945.1	4799.6	4466.9	5498.4	4817.9
SSBproj	4994.2	4526.0	5467.0	5166.1	5024.2	4627.4	5725.7	4988.1
SSBmsy	2723.0	2130.4	2373.8	2651.3	2604.9	2560.4	3459.1	2671.1
CPUEcurrent	2.8	2.7	2.9	2.8	2.8	2.7	3.1	2.8
CPUEproj	2.115	2.004	2.188	2.230	2.142	2.133	2.817	1.694
CPUEmsy	1.082	0.896	0.845	1.024	1.000	1.067	1.353	1.053
Bcurr/Bmin	3.838	3.712	3.900	3.934	3.912	3.898	4.519	3.887
Bcurr/Bref	1.445	1.385	1.488	1.806	1.498	1.424	1.797	1.475
Bcurr/Bmsy	2.027	2.247	2.505	2.175	2.192	2.048	2.000	2.095
Bproj/Bcurr	0.850	0.843	0.854	0.865	0.851	0.859	0.942	0.701
Bproj/Bref	1.233	1.165	1.270	1.570	1.266	1.220	1.698	1.035
Bproj/Bmsy	1.728	1.885	2.144	1.896	1.865	1.752	1.914	1.464
SSBcurr/SSB0	0.660	0.713	0.900	0.688	0.688	0.723	0.452	0.689
SSBproj/SSB0	0.685	0.712	0.900	0.717	0.721	0.747	0.476	0.712
SSBcurr/SSBmsy	1.77	2.13	2.31	1.87	1.84	1.75	1.56	1.81
SSBproj/SSBmsy	1.84	2.12	2.32	1.95	1.92	1.81	1.64	1.87
SSBproj/SSBcurr	1.039	1.000	1.001	1.046	1.046	1.035	1.045	1.032
USLcurrent	0.218	0.218	0.198	0.214	0.211	0.219	0.143	0.217
USLproj	0.274	0.280	0.250	0.260	0.276	0.272	0.155	0.329
USLproj/USLcurrent	1.255	1.282	1.266	1.228	1.315	1.240	1.095	1.520
P(*Bcurr*>*Bmin*)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
P(*Bcurr*>*Bref*)	0.998	0.991	1.000	1.000	1.000	1.000	1.000	0.999
P(*Bcurr*>*Bmsy*)	1.000	1.000	1.000	1.000	1.000	1.000	0.998	1.000
P(*Bproj*>*Bmin*)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.985
P(*Bproj*>*Bref*)	0.857	0.765	0.931	0.910	0.910	0.826	0.999	0.543
P(*Bproj*>*Bmsy*)	0.994	0.999	1.000	1.000	0.999	0.998	0.989	0.839
P(*Bproj*>*Bcurr*)	0.100	0.063	0.061	0.096	0.082	0.075	0.293	0.085
P(*SSBcurr*>*SSBmsy*)	1.000	1.000	1.000	1.000	1.000	1.000	0.970	1.000
P(*SSBproj*>*SSBmsy*)	1.000	1.000	1.000	1.000	1.000	1.000	0.985	0.980
P(*USLproj*>*USLcurr*)	0.946	0.981	0.982	0.955	0.973	0.954	0.750	0.953
P(*SSBcurr*<0.2*SSB0*)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P(*SSBproj*<0.2*SSB0*)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
P(*SSBcurr*<0.1*SSB0*)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P(*SSBproj*<0.1*SSB0*)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 10: Parameters for the predictive relationship between AW CPUE and the proportion of catch taken in AW.

	Slope	Intercept	R^2
CRA 7	0.0111	0.7877	0.0023
CRA 8	0.1226	0.4342	0.4166

Table 11: Observed and predicted CRA 7 and CRA 8 AW catch proportion split, based on the observed standardised AW CPUE from the previous fishing year.

Fishing			CRA 7			CRA 8
Year	AW CPUE	Obs propn	Pred propn	AW CPUE	Obs propn	Pred propn
1992	0.3692	–	–	0.6298	–	–
1993	0.7068	0.9189	0.7918	0.8926	0.5269	0.5114
1994	0.5461	0.9143	0.7955	0.7537	0.4613	0.5436
1995	0.3155	0.9054	0.7937	0.8217	0.4084	0.5266
1996	0.2197	0.7537	0.7912	0.6720	0.3763	0.5349
1997	0.1519	0.6631	0.7901	0.5786	0.3740	0.5166
1998	0.2288	0.6755	0.7894	0.5512	0.3021	0.5051
1999	0.2181	0.6611	0.7902	0.7420	0.4599	0.5018
2000	0.3221	0.7205	0.7901	0.8985	0.5575	0.5251
2001	0.5281	0.8036	0.7912	0.8182	0.5451	0.5443
2002	0.5729	0.8302	0.7935	0.9395	0.5567	0.5345
2003	0.5850	0.7643	0.7940	1.5182	0.7954	0.5494
2004	0.8663	0.8929	0.7942	1.5073	0.7692	0.6203
2005	1.2090	0.9861	0.7973	1.8519	0.8526	0.6190
2006	1.7562	0.9529	0.8011	2.3212	0.8710	0.6612
2007	1.5450	0.8866	0.8072	2.5814	0.8057	0.7188
2008	1.9501	0.8192	0.8048	3.5730	0.8902	0.7507
2009	0.9419	0.5582	0.8093	3.4093	0.6976	0.8722
2010	0.8024	0.6022	0.7981	2.7384	0.7448	0.8522
2011	0.7336	0.8106	0.7966	2.6294	0.6628	0.7699

Table 12: Parameters for the predictive relationship between seasonal CPUE and offset-year CPUE.

	Slope	Intercept	R^2
CRA 7	0.8987	0.0354	0.9589
CRA 8	0.8784	0.0957	0.9934

Table 13: Observed and predicted CRA 7 and CRA 8 AW offset year CPUE, based on the observed standardised AW CPUE in year *y* and SS CPUE in year *y*-1.

					CRA 7					CRA 8
Fishing Year	AW CPUE	SS CPUE	Mean CPUE	Offset CPUE	Pred Offset	AW CPUE	SS CPUE	Mean CPUE	Offset CPUE	Pred Offset
1979	–	0.9247	–	–	–	–	2.1723	–	–	–
1980	1.0082	0.6965	0.9664	0.9806	0.9040	1.8251	1.7940	1.9987	1.9425	1.8513
1981	0.8191	0.6100	0.7578	0.7755	0.7165	1.7779	1.7049	1.7859	1.6951	1.6644
1982	0.4302	0.5766	0.5201	0.4979	0.5029	1.3671	1.5580	1.5360	1.5002	1.4449
1983	0.3730	0.4863	0.4748	0.4416	0.4621	0.8906	1.2789	1.2243	1.2042	1.1711
1984	0.5696	0.5216	0.5279	0.5419	0.5099	1.0786	1.0874	1.1788	1.1453	1.1311
1985	0.8355	0.6052	0.6785	0.7130	0.6453	1.3878	1.1852	1.2376	1.1520	1.1828
1986	0.8427	0.8365	0.7239	0.7369	0.6861	0.9422	1.2799	1.0637	1.0400	1.0300
1987	0.8250	0.5946	0.8307	0.8394	0.7820	1.0420	1.3049	1.1610	1.1315	1.1155
1988	0.3794	0.4844	0.4870	0.4785	0.4731	0.7428	1.0053	1.0238	1.0382	0.9950
1989	0.2465	0.4675	0.3655	0.3334	0.3639	0.8058	0.9439	0.9056	0.8837	0.8911
1990	0.4461	0.4162	0.4568	0.4593	0.4459	0.7918	0.9078	0.8679	0.8408	0.8580
1991	0.9617	1.3291	0.6889	0.6504	0.6546	0.6789	0.9472	0.7934	0.7760	0.7926
1992	0.3692	0.4535	0.8491	0.4424	0.7986	0.6298	0.7659	0.7885	0.7760	0.7883
1993	0.7068	0.3432	0.5802	0.5879	0.5568	0.8926	0.9876	0.8292	0.7758	0.8241
1994	0.5461	0.3117	0.4446	0.5067	0.4350	0.7537	0.9062	0.8706	0.8507	0.8605
1995	0.3155	0.2468	0.3136	0.3153	0.3173	0.8217	0.9729	0.8640	0.8371	0.8546
1996	0.2197	0.3420	0.2333	0.2291	0.2451	0.6720	0.9957	0.8224	0.8012	0.8181
1997	0.1519	0.3181	0.2470	0.1905	0.2574	0.5786	0.8370	0.7871	0.7545	0.7871
1998	0.2288	0.3804	0.2734	0.2502	0.2812	0.5512	0.9075	0.6941	0.6897	0.7054
1999	0.2181	0.2861	0.2993	0.2610	0.3044	0.7420	0.8266	0.8247	0.8050	0.8201
2000	0.3221	0.4225	0.3041	0.3131	0.3087	0.8985	0.9929	0.8625	0.8268	0.8533
2001	0.5281	0.4880	0.4753	0.4905	0.4626	0.8182	1.2504	0.9056	0.8836	0.8911

2002	0.5729	0.8249	0.5304	0.5481	0.5121	0.9395	1.6982	1.0949	1.0606	1.0575
2003	0.5850	0.6597	0.7050	0.6431	0.6690	1.5182	2.3388	1.6082	1.5943	1.5083
2004	0.8663	1.0996	0.7630	0.7868	0.7212	1.5073	2.7366	1.9230	1.7664	1.7849
2005	1.2090	2.4470	1.1543	1.1797	1.0728	1.8519	3.9218	2.2942	2.1455	2.1109
2006	1.7562	2.0992	2.1016	1.8047	1.9242	2.3212	4.5994	3.1215	2.7465	2.8375
2007	1.5450	1.8003	1.8221	1.6361	1.6730	2.5814	4.2559	3.5904	3.0960	3.2494
2008	1.9501	1.5243	1.8752	1.8944	1.7207	3.5730	5.8198	3.9144	3.8870	3.5340
2009	0.9419	1.4880	1.2331	1.0301	1.1436	3.4093	5.2287	4.6146	4.0742	4.1490
2010	0.8024	0.9658	1.1452	1.0550	1.0647	2.7384	4.6693	3.9835	3.5249	3.5947
2011	0.7336	–	0.8497	0.8010	0.7991	2.6294	–	3.6494	3.2129	3.3012

Table 14: CRA 7: parameters for the six final rule candidates: 55 is the analogue of the rule used in 2012–13.

	Plateau height	Plateau left	Plateau right	Shut-down CPUE	Slope parameter	Minimum change threshold	Maximum change threshold	Latent year
Serial	*par2*	*par3*	*par4*	*par5*	*par6*	*par8*	*par9*	*par10*
12	80	1	1.75	0.17	3.00	0.05	0.50	0
38	80	1	1.75	0.50	2.50	0.10	0.50	0
39	80	1	1.75	0.17	3.00	0.10	0.50	0
55	100	1	2.00	0.17	2.42	0.10	0.50	1
64	80	1	1.75	0.17	2.17	0.10	0.50	0
65	80	1	2.00	0.17	2.42	0.10	0.50	0

Table 15: CRA 7: TACC as a function of offset-year CPUE in the six final rule candidates.

CPUE	Rule					
	12	38	39	55	64	65
0.00	0.0	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0	0.0
0.20	3.2	0.0	3.2	4.0	3.2	3.2
0.30	12.8	0.0	12.8	16.0	12.8	12.8
0.40	22.4	0.0	22.4	28.0	22.4	22.4
0.50	32.0	0.0	32.0	40.0	32.0	32.0
0.60	41.6	16.0	41.6	52.0	41.6	41.6
0.70	51.2	32.0	51.2	64.0	51.2	51.2
0.80	60.8	48.0	60.8	76.0	60.8	60.8
0.90	70.4	64.0	70.4	88.0	70.4	70.4
1.00	80.0	80.0	80.0	100.0	80.0	80.0
1.25	80.0	80.0	80.0	100.0	80.0	80.0
1.50	80.0	80.0	80.0	100.0	80.0	80.0
1.75	80.0	80.0	80.0	100.0	80.0	80.0
2.00	88.0	93.3	88.0	100.0	104.0	80.0
2.25	96.0	106.7	96.0	130.0	128.0	104.0
2.50	104.0	120.0	104.0	160.0	151.9	128.0
2.75	112.0	133.3	112.0	190.0	175.9	151.9
3.00	120.0	146.7	120.0	220.0	199.9	175.9

Table 16: CRA 7 performance indicators for six rules run under the base case operating model: for indicator definitions see text; values shown are the median of the posterior distributions and the proportions of years in which the proposition was true.

Indicator						Rule
	12	38	39	55	64	65
mean (*Bio/Bref*)	1.495	1.493	1.495	1.363	1.471	1.492
minComm	66.2	57.4	66.5	79.0	66.5	66.5
meanComm	81.3	82.3	81.4	98.3	85.1	81.3
mean5-yrComm	77.3	75.2	76.7	92.9	77.0	76.7
minRec	16.3	16.4	16.3	15.4	16.3	16.3
meanRec	23.4	23.4	23.5	21.3	23.1	23.4
minCPUE	0.919	0.923	0.919	0.856	0.916	0.919
meanCPUE	1.570	1.570	1.571	1.427	1.547	1.567
%AAVH	5.8	8.9	4.9	5.3	9.6	6.8
proportion of years with						
Biomass <*Bref*	0.112	0.101	0.112	0.174	0.114	0.112
Biomass<*Bmin*	0.000	0.000	0.000	0.000	0.000	0.000
TACC change	0.439	0.408	0.312	0.270	0.416	0.330
Biomass<50%*Bref*	0.000	0.000	0.000	0.001	0.000	0.000
Biomass<25%*Bref*	0.000	0.000	0.000	0.000	0.000	0.000
TACC left of plateau	0.117	0.106	0.117	0.176	0.118	0.116
TACC right of plateau	0.329	0.327	0.329	0.133	0.301	0.197
TACC on plateau	0.554	0.567	0.554	0.691	0.580	0.686

Table 17: CRA 7 performance indicators for six rules run under the R1 robustness trial (increasing catchability).

Indicator						Rule
	12	38	39	55	64	65
mean (*Bio/Bref*)	1.477	1.470	1.478	1.350	1.439	1.472
minComm	68.5	60.9	68.8	82.8	68.8	68.8
meanComm	84.3	86.6	84.4	100.8	91.3	85.8
mean5-yrComm	77.7	76.0	77.3	93.6	77.6	77.2
minRec	16.3	16.4	16.3	15.3	16.2	16.3
meanRec	23.1	23.1	23.2	20.9	22.6	23.0
minCPUE	0.960	0.964	0.961	0.904	0.959	0.961
meanCPUE	1.743	1.734	1.745	1.581	1.693	1.733
%AAVH	6.8	10.1	5.7	6.2	11.7	9.1
proportion of years with						
Biomass <*Bref*	0.118	0.109	0.118	0.186	0.121	0.118
Biomass<*Bmin*	0.000	0.000	0.000	0.000	0.000	0.000
TACC change	0.484	0.445	0.347	0.289	0.468	0.381
Biomass<50%*Bref*	0.000	0.000	0.000	0.002	0.000	0.000
Biomass<25%*Bref*	0.000	0.000	0.000	0.000	0.000	0.000
TACC left of plateau	0.081	0.073	0.081	0.126	0.082	0.081
TACC right of plateau	0.446	0.440	0.447	0.211	0.411	0.292
TACC on plateau	0.473	0.487	0.472	0.663	0.507	0.627

Table 18: CRA 7 performance indicators for six rules run under the R2 robustness trial (reduced recruitment).

Indicator	Rule					
	12	38	39	55	64	65
mean (*Bio/Bref*)	0.847	0.892	0.846	0.781	0.846	0.846
minComm	40.7	25.7	40.7	42.8	40.7	40.7
meanComm	67.1	61.6	66.9	73.6	67.0	66.9
mean5-yrComm	73.5	68.8	73.2	87.0	73.2	73.2
minRec	10.5	11.4	10.5	9.3	10.5	10.5
meanRec	13.4	14.2	13.4	12.3	13.4	13.4
minCPUE	0.583	0.629	0.583	0.517	0.583	0.583
meanCPUE	0.915	0.966	0.915	0.843	0.915	0.915
%AAVH	14.0	22.0	12.9	12.6	13.1	12.9
proportion of years with						
Biomass <*Bref*	0.716	0.674	0.714	0.798	0.715	0.714
Biomass<*Bmin*	0.024	0.005	0.023	0.036	0.023	0.023
TACC change	0.638	0.623	0.518	0.464	0.527	0.517
Biomass<50%*Bref*	0.080	0.034	0.080	0.119	0.080	0.080
Biomass<25%*Bref*	0.005	0.000	0.004	0.007	0.004	0.004
TACC left of plateau	0.630	0.571	0.629	0.726	0.630	0.628
TACC right of plateau	0.016	0.019	0.017	0.002	0.016	0.005
TACC on plateau	0.355	0.410	0.355	0.271	0.354	0.367

Table 19: CRA 7 performance indicators for six rules run under the R3 robustness trial (increased noise in projected CPUE).

Indicator	Rule					
	12	38	39	55	64	65
mean (*Bio/Bref*)	1.491	1.512	1.488	1.393	1.455	1.481
minComm	50.4	40.0	50.6	58.6	49.9	50.4
meanComm	82.5	82.3	82.3	95.9	87.8	83.9
mean5-yrComm	74.4	69.0	74.4	86.9	75.0	74.1
minRec	16.4	16.6	16.4	15.7	16.3	16.4
meanRec	23.5	23.9	23.5	21.9	22.8	23.3
minCPUE	0.734	0.741	0.732	0.680	0.719	0.728
meanCPUE	1.632	1.655	1.634	1.519	1.595	1.624
%AAVH	14.8	20.7	14.0	12.5	19.9	16.8
proportion of years with						
Biomass <*Bref*	0.102	0.082	0.103	0.148	0.109	0.104
Biomass<*Bmin*	0.000	0.000	0.000	0.000	0.000	0.000
TACC change	0.657	0.631	0.550	0.424	0.631	0.551
Biomass<50%*Bref*	0.000	0.000	0.000	0.001	0.000	0.000
Biomass<25%*Bref*	0.000	0.000	0.000	0.000	0.000	0.000
TACC left of plateau	0.184	0.167	0.184	0.224	0.195	0.187
TACC right of plateau	0.366	0.382	0.367	0.215	0.342	0.254
TACC on plateau	0.450	0.451	0.449	0.562	0.463	0.558

Table 20: CRA 7: Comparison of the median estimated parameter values between the final base case McMC and the CRA 7-only McMC sensitivity trial.

Sex	Quantity	Final base	CRA 7 only
	function value	4058.7	-405.8
	ln(*R0*)	13.06	13.04
	M	0.100	0.171
	initial *U*	0.048	0.001
	ln(*q*)	-6.301	-6.180
	mat50	71.3	67.3
	mat95add	11.3	9.6
Male	*Galpha*	3.73	3.77
Male	*GBeta*	2.59	2.71
Male	*Gshape*	4.702	3.421
Female	*Galpha*	3.45	3.52
Female	*GBeta*	1.63	2.07
Female	*Gshape*	5.784	4.679
	GrowthDD	0.241	0.000
	vuln1	0.821	0.849
	vuln2	0.866	0.833
	vuln3	0.955	0.815
	vuln4	0.588	0.384
Male	*SelectLeft*	5.6	5.4
Male	*SelectMax*	46.7	47.0
Female	*SelectLeft*	4.7	5.2
Female	*SelectMax*	45.0	46.8

Table 21: Comparison of the median stock assessment indicators between the final base case McMC and the CRA 7-only McMC sensitivity trial.

Indicator	Final base	CRA 7 only
Bmin	147.8	135.4
Bcurr	599.5	598.0
Bref	616.3	562.4
Bproj	754.8	750.2
CPUEcurrent	0.956	1.058
CPUEproj	1.294	1.424
Bcurr/Bmin	4.057	4.392
Bcurr/Bref	0.972	1.070
Bproj/Bcurr	1.251	1.247
Bproj/Bref	1.225	1.340
USLcurrent	0.067	0.067
USLproj	0.077	0.078
USLproj/USLcurrent	1.155	1.164
P(Bcurr>Bmin)	1.000	1.000
P(Bcurr>Bref)	0.382	0.718
P(Bproj>Bmin)	1.000	1.000
P(Bproj>Bref)	0.866	0.960
P(Bproj>Bcurr)	0.975	0.974
P(USLproj>USLcurr)	0.811	0.798

Table 22: Comparison of the median MPE indicators (above the line) and the proportions of years in which the indicator was true (below the line) between the final base case McMC and the CRA 7-only McMC sensitivity trial.

Indicator	Final base	CRA 7 only
mean (*Bio/Bref*)	1.363	1.349
minComm	79.0	81.0
meanComm	98.3	98.6
mean5-yrComm	92.9	95.1
minRec	15.4	17.3
meanRec	21.3	21.1
minCPUE	0.856	0.883
meanCPUE	1.427	1.411
%AAVH	5.34	4.63
proportion of years with		
Biomass <*Bref*	0.174	0.108
Biomass<*Bmin*	0.000	0.000
TACC change	0.270	0.236
Biomass<50%*Bref*	0.001	0.000
Biomass<25%*Bref*	0.000	0.000
TACC left of plateau	0.176	0.142
TACC right of plateau	0.133	0.097
TACC on plateau	0.691	0.762

Table 23: CRA 8: Parameters for the three final rule candidates: rule 1 is the current rule.

	Plateau height	Plateau left	Plateau right	Shut-down CPUE	Slope parameter	Minimum change threshold	Maximum change threshold	Latent year
Serial	*par2*	*par3*	*par4*	*par5*	*par6*	*par8*	*par9*	*par10*
1	962	1.9	3.2	0.4535	8.6244	5%	0.50	none
2	1100	1.9	3.2	0.4535	8.6244	5%	0.50	none
3	1200	1.9	3.2	0.4535	8.6244	5%	0.50	none

Table 24: CRA 8: TACC as a function of offset-year CPUE in three rules.

			Rule
CPUE	1	2	3
0.00	0.0	0.0	0.0
0.25	0.0	0.0	0.0
0.50	30.9	35.4	38.6
0.75	197.2	225.5	246.0
1.00	363.5	415.6	453.4
1.25	529.7	605.7	660.8
1.50	696.0	795.8	868.2
1.75	862.2	985.9	1075.6
2.00	962.0	1100.0	1200.0
2.25	962.0	1100.0	1200.0
2.50	962.0	1100.0	1200.0
2.75	962.0	1100.0	1200.0
3.00	962.0	1100.0	1200.0
3.25	966.4	1105.1	1205.5
3.50	988.6	1130.4	1233.2

3.75	1010.8	1155.8	1260.8
4.00	1032.9	1181.1	1288.5
4.25	1055.1	1206.5	1316.1
4.50	1077.3	1231.8	1343.8
4.75	1099.4	1257.2	1371.4
5.00	1121.6	1282.5	1399.1
5.50	1165.9	1333.2	1454.4
6.00	1210.3	1383.9	1509.7

Table 25: CRA 8 performance indicators for three rules run under the base case operating model.

			Rule
Indicator	1	2	3
mean (*Bio/Bref*)	1.795	1.602	1.458
minComm	962.0	1100.0	1200.0
meanComm	989.1	1110.5	1200.0
mean5-yrComm	962.0	1100.0	1200.0
minRec	86.2	77.7	69.6
meanRec	99.6	89.5	81.9
minCPUE	2.610	2.400	2.164
meanCPUE	3.450	3.054	2.771
%AAVH	0.7	0.4	0.3
mean (*Bio/Bmsy*)	2.936	2.615	2.382
Biomass <*Bref*	0.014	0.033	0.066
Biomass<*Bmin*	0.000	0.000	0.000
Biomass < *Bmsy*	0.000	0.000	0.001
TACC change	0.159	0.130	0.135
Biomass<20%*SSB0*	0.000	0.000	0.000
Biomass<10%*SSB1*	0.000	0.000	0.000
Biomass<50%*Bref*	0.000	0.000	0.000
Biomass<25%*Bref*	0.000	0.000	0.000
TACC left of plateau	0.008	0.030	0.071
TACC right of plateau	0.601	0.379	0.230
TACC on plateau	0.390	0.591	0.699

Table 26: CRA 8 performance indicators for three rules run under the R1 robustness trial (increasing catchability).

			Rule
Indicator	1	2	3
mean (*Bio/Bref*)	1.769	1.580	1.445
minComm	962.0	1100.0	1200.0
meanComm	1011.5	1128.1	1213.5
mean5-yrComm	962.0	1100.0	1200.0
minRec	85.4	77.1	69.1
meanRec	98.0	88.6	81.1
minCPUE	2.742	2.558	2.374

	Rule		
Indicator	1	2	3
meanCPUE	3.798	3.375	3.065
%AAVH	1.0	0.7	0.6
mean (Bio/Bmsy)	2.885	2.587	2.363
Biomass <*Bref*	0.015	0.037	0.076
Biomass<*Bmin*	0.000	0.000	0.000
Biomass < *Bmsy*	0.000	0.001	0.003
TACC change	0.197	0.160	0.144
Biomass<20%*SSB0*	0.000	0.000	0.001
Biomass<10%*SSB1*	0.000	0.000	0.000
Biomass<50%*Bref*	0.000	0.000	0.001
Biomass<25%*Bref*	0.000	0.000	0.000
TACC left of plateau	0.004	0.018	0.041
TACC right of plateau	0.729	0.547	0.385
TACC on plateau	0.267	0.435	0.574

Table 27: CRA 8 performance indicators for three rules run under the R2 robustness trial (decreased recruitment).

	Rule		
Indicator	1	2	3
mean (*Bio/Bref*)	1.251	1.090	1.002
minComm	849.3	720.3	678.1
meanComm	956.6	1025.3	1058.0
mean5-yrComm	962.0	1100.0	1200.0
minRec	51.2	42.8	38.9
meanRec	72.5	63.0	58.0
minCPUE	1.674	1.375	1.254
meanCPUE	2.485	2.148	1.971
%AAVH	1.3	4.6	6.9
mean (Bio/Bmsy)	2.047	1.777	1.634
Biomass <*Bref*	0.218	0.386	0.506
Biomass<*Bmin*	0.003	0.005	0.007
Biomass < *Bmsy*	0.024	0.049	0.076
TACC change	0.219	0.335	0.429
Biomass<20%*SSB0*	0.015	0.027	0.041
Biomass<10%*SSB1*	0.000	0.000	0.000
Biomass<50%*Bref*	0.011	0.019	0.028
Biomass<25%*Bref*	0.000	0.000	0.000
TACC left of plateau	0.210	0.382	0.507
TACC right of plateau	0.166	0.077	0.046
TACC on plateau	0.624	0.541	0.447

Table 28: CRA 8 performance indicators for three rules run under the R3 robustness trial (increased noise in projected CPUE).

	Rule		
Indicator	1	2	3
mean (*Bio/Bref*)	1.779	1.587	1.456
minComm	962.0	1100.0	1200.0
meanComm	1000.1	1119.7	1206.0
mean5-yrComm	968.7	1100.0	1200.0
minRec	85.7	77.3	69.2
meanRec	98.8	88.6	81.4
minCPUE	2.298	2.073	1.867
meanCPUE	3.445	3.062	2.775
%AAVH	2.1	1.7	1.8
mean (Bio/Bmsy)	2.911	2.606	2.385
Biomass <*Bref*	0.013	0.030	0.060
Biomass<*Bmin*	0.000	0.000	0.000
Biomass < *Bmsy*	0.000	0.000	0.001
TACC change	0.296	0.246	0.245
Biomass<20%*SSB0*	0.000	0.000	0.001
Biomass<10%*SSB1*	0.000	0.000	0.000
Biomass<50%*Bref*	0.000	0.000	0.001
Biomass<25%*Bref*	0.000	0.000	0.000
TACC left of plateau	0.021	0.054	0.100
TACC right of plateau	0.569	0.400	0.280
TACC on plateau	0.409	0.546	0.620

Table 29: For the analogues of the existing CRA 7 and CRA harvest control rules, performance indicators from the TwoM and Poo trials compared.

	CRA 7		CRA 8	
	TwoM	Poo	TwoM	Poo
mean (*Bio/Bref*)	1.226	1.161	1.919	1.828
minComm	70.9	67.8	962.0	962.0
meanComm	94.4	92.9	998.7	981.5
mean5-yrComm	89.9	90.3	962.0	962.0
minRec	13.7	13.4	92.1	92.5
meanRec	18.0	17.1	106.7	101.7
minCPUE	0.772	0.744	2.763	2.764
meanCPUE	1.243	1.173	3.689	3.510
%AAVH	5.77	6.27	0.54	0.00
Biomass <*Bref*	0.246	0.312	0.007	0.002
Biomass<*Bmin*	0.000	0.000	0.000	0.000
TACC change	0.284	0.301	0.093	0.078
TACC left of plateau	0.279	0.327	0.005	0.003
TACC right of plateau	0.056	0.046	0.694	0.661
TACC on plateau	0.664	0.627	0.301	0.337

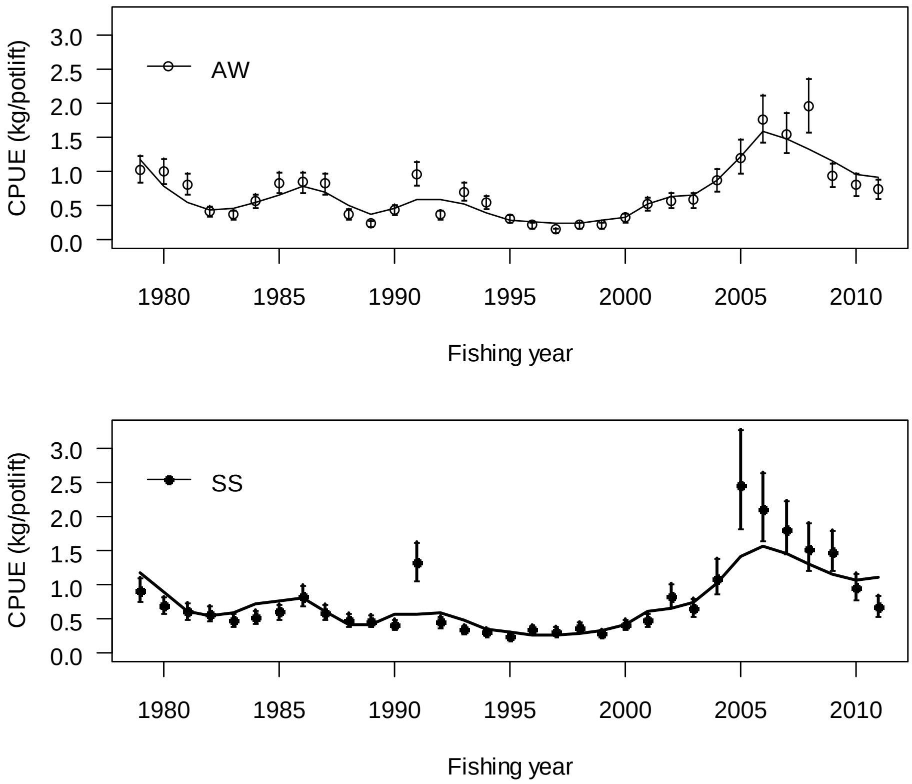


Figure 1: CRA 7: MPD fit to CPUE from the final base case MPD: dots are observed CPUE with one standard error; lines are predicted.

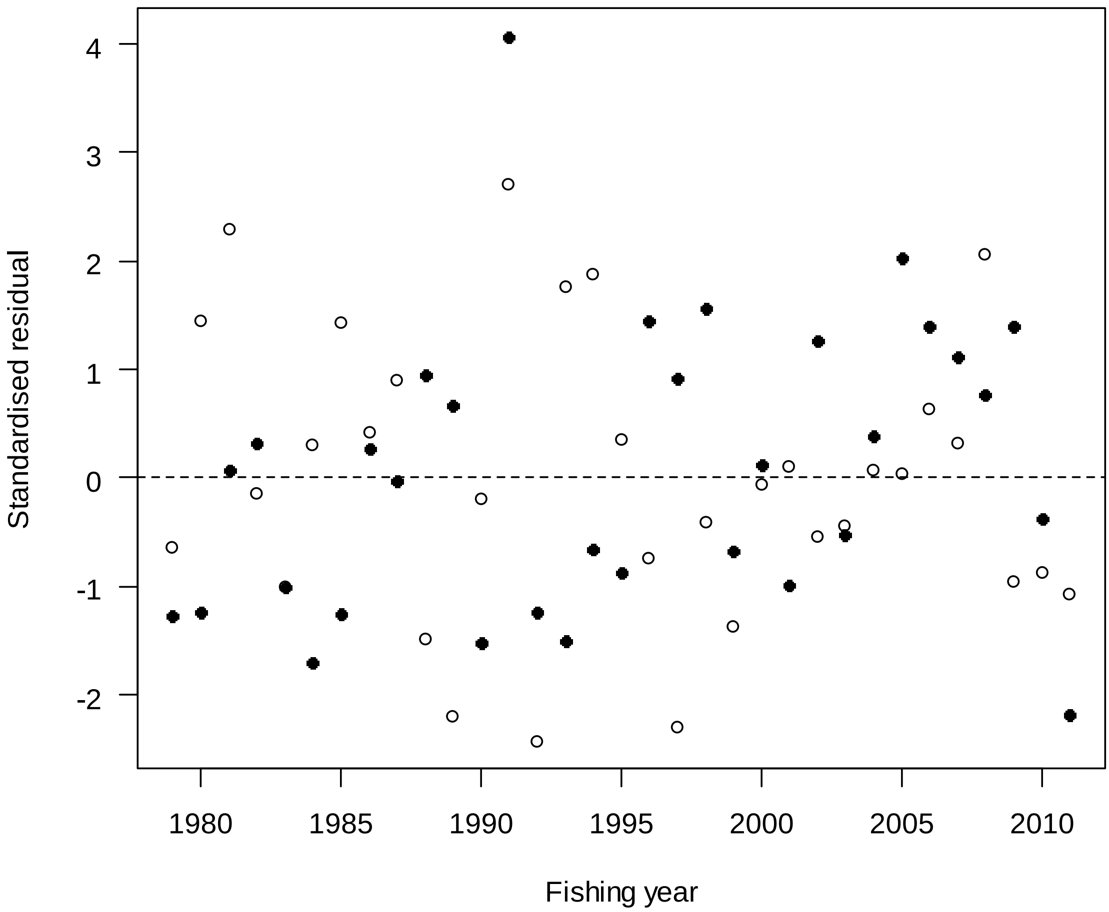


Figure 2: CRA 7: Residuals from the fit to CPUE from the final base case MPD: open circles are AW and solid circles are SS.

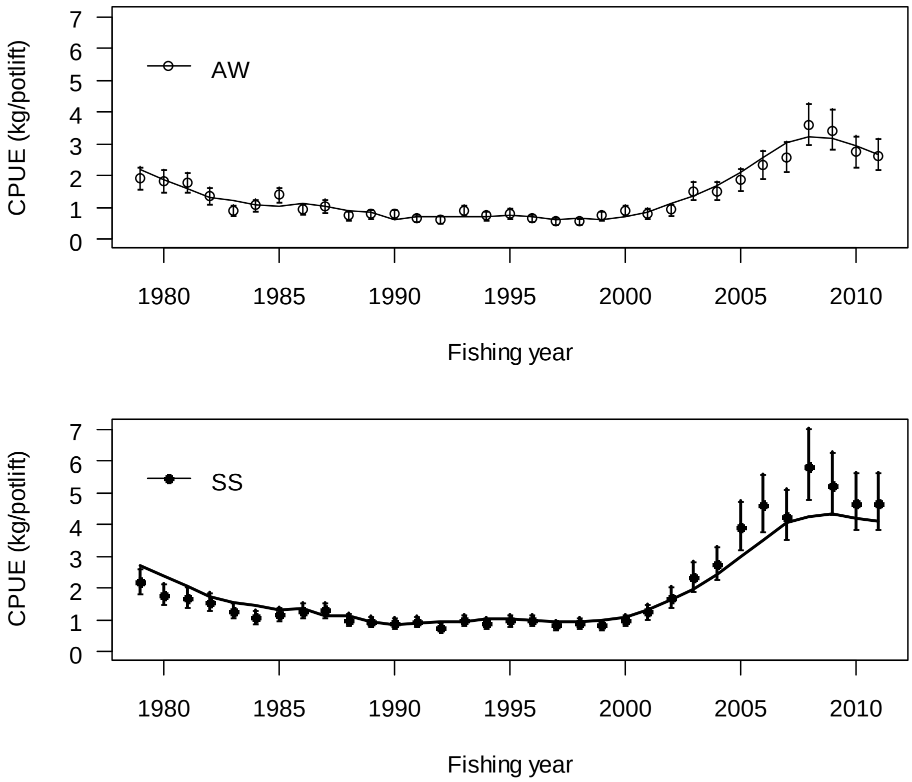


Figure 3: CRA 8: MPD fit to CPUE from the final base case MPD: dots are observed CPUE with one standard error; lines are predicted.

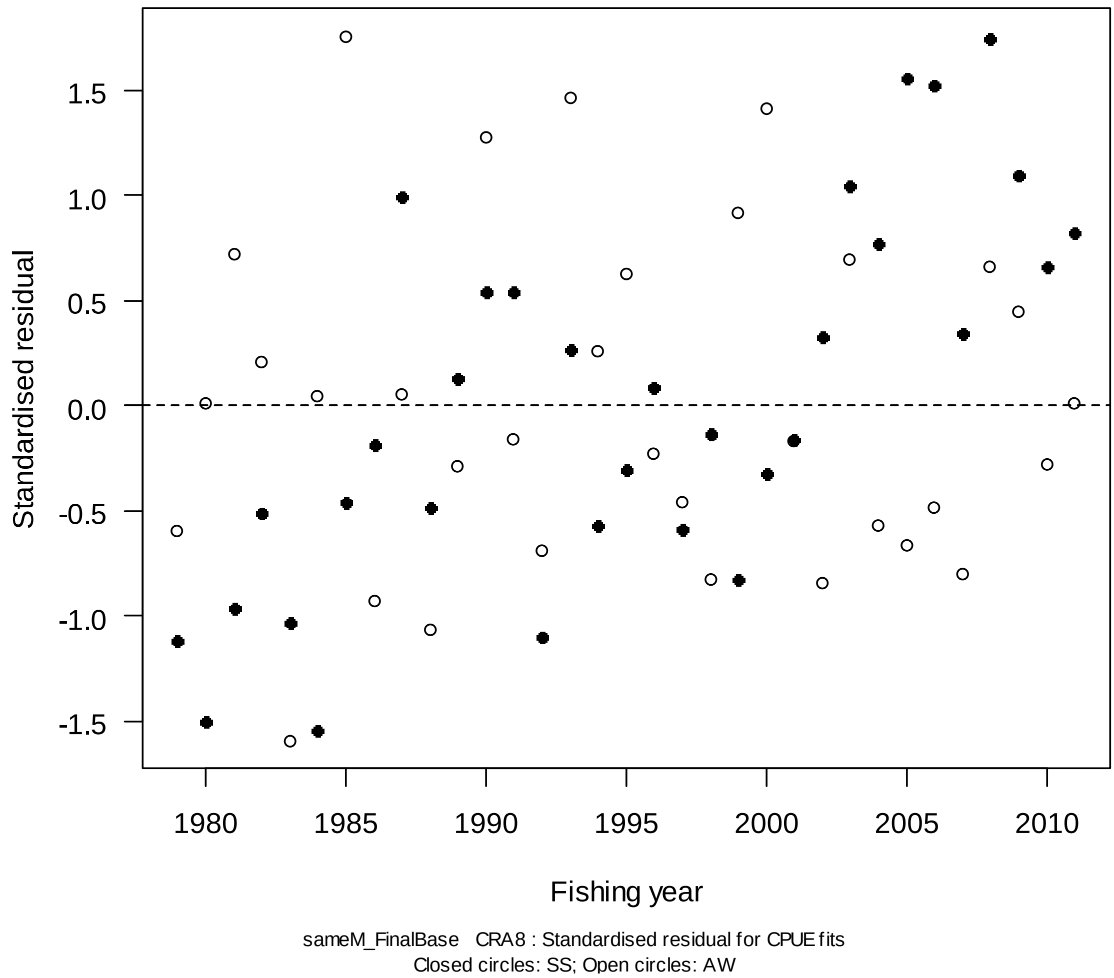


Figure 4: CRA 8: Residuals from the fit to CPUE from the final base case MPD: open circles are AW and solid circles are SS.

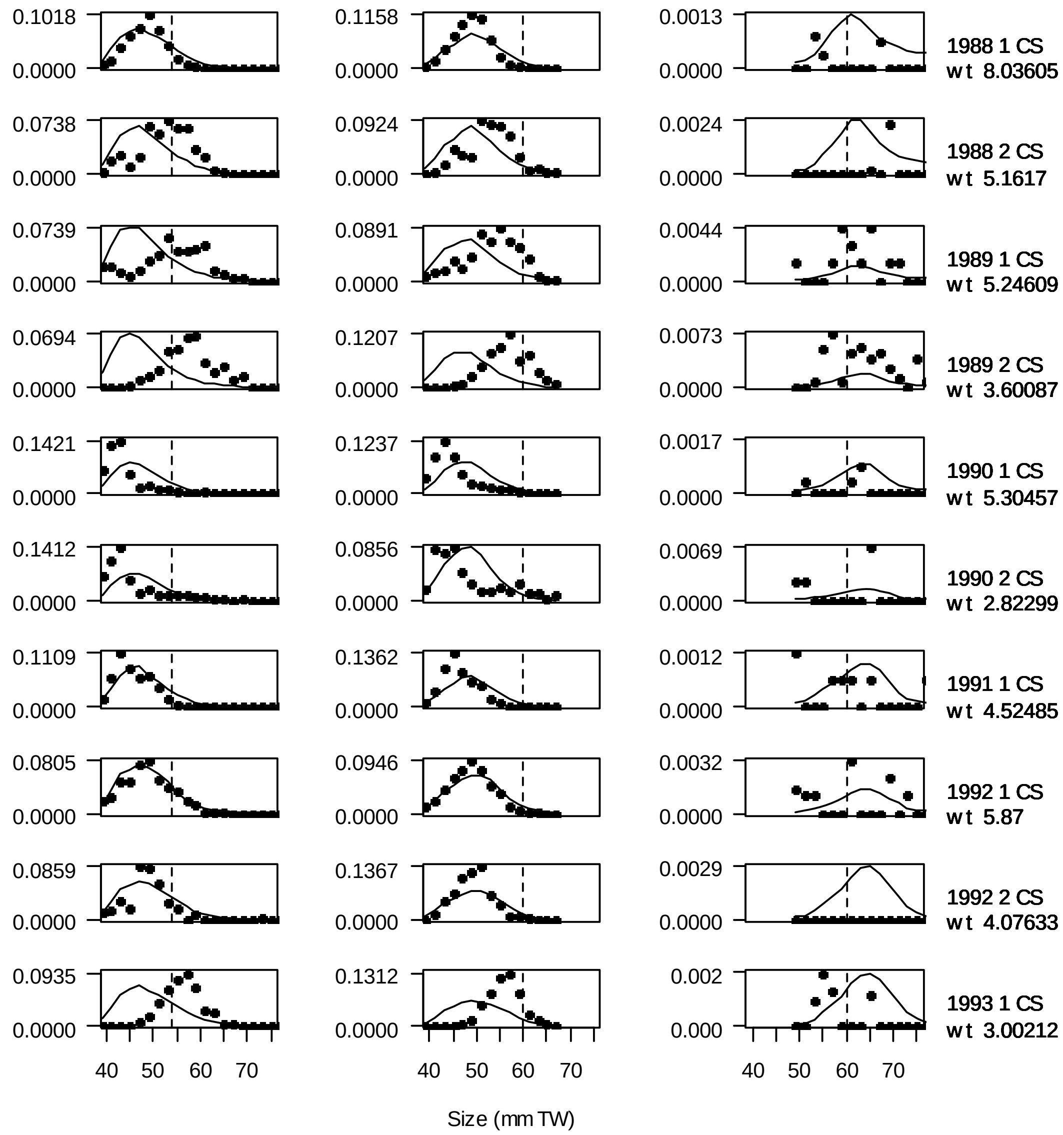


Figure 5: CRA 7: Fits to length frequencies in the final base case MPD: males on the left, immature females in the centre and mature females on the right; solid circles are the observed proportions-at-size (normalised across all sex categories) and the lines are predicted; information on the right for each record shows the year, season (1 = AW, 2 = SS), source (CS = observer catch sampling, LB = logbooks) and relative weight; note that scales vary among sexes and among records.

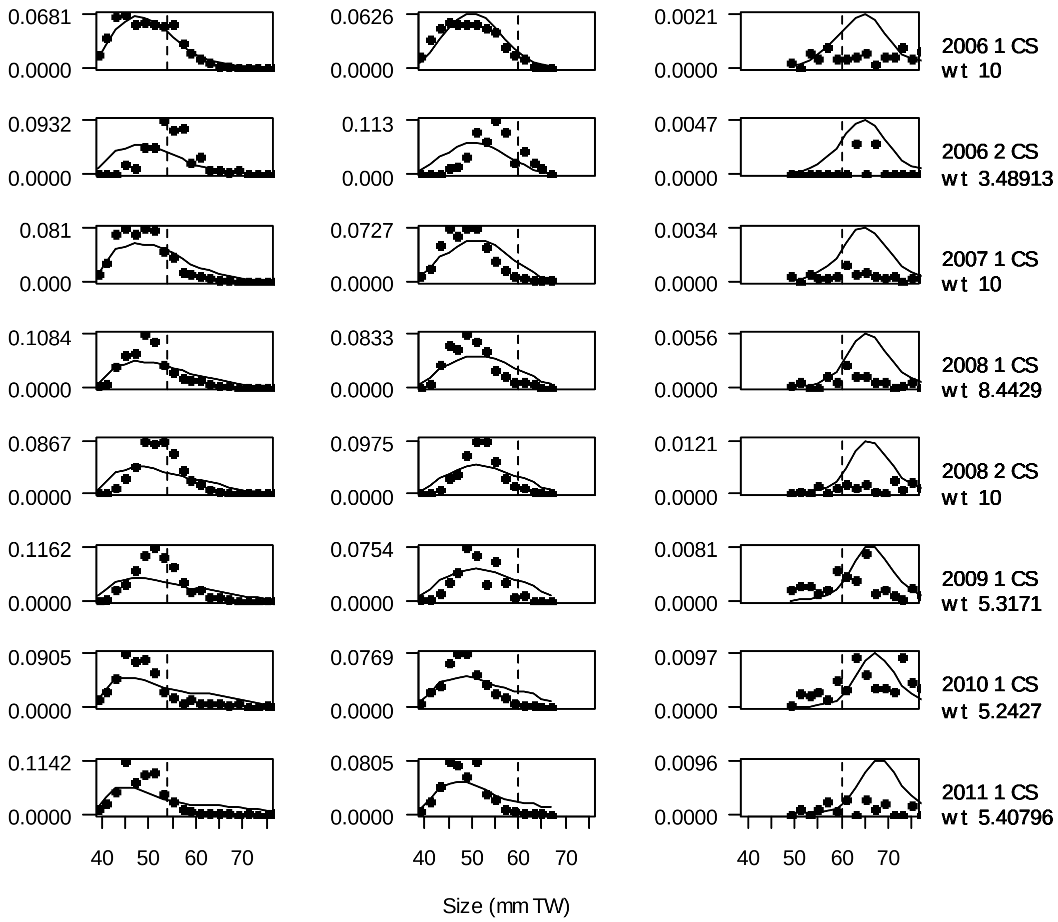


Figure 5 part 2.

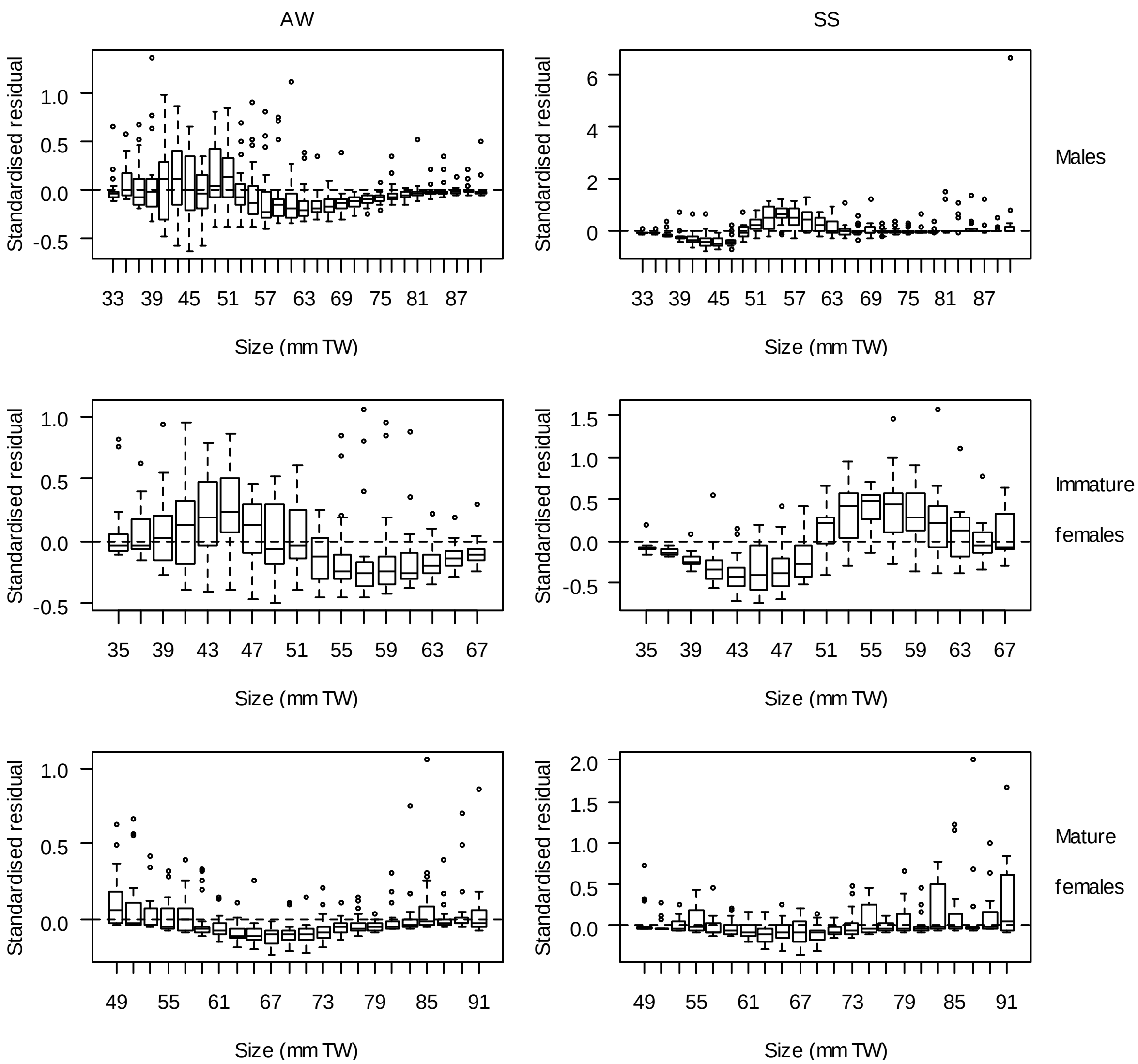


Figure 6: CRA 7: Normalised residuals from fits to length frequencies in the final base case MPD by sex and season.

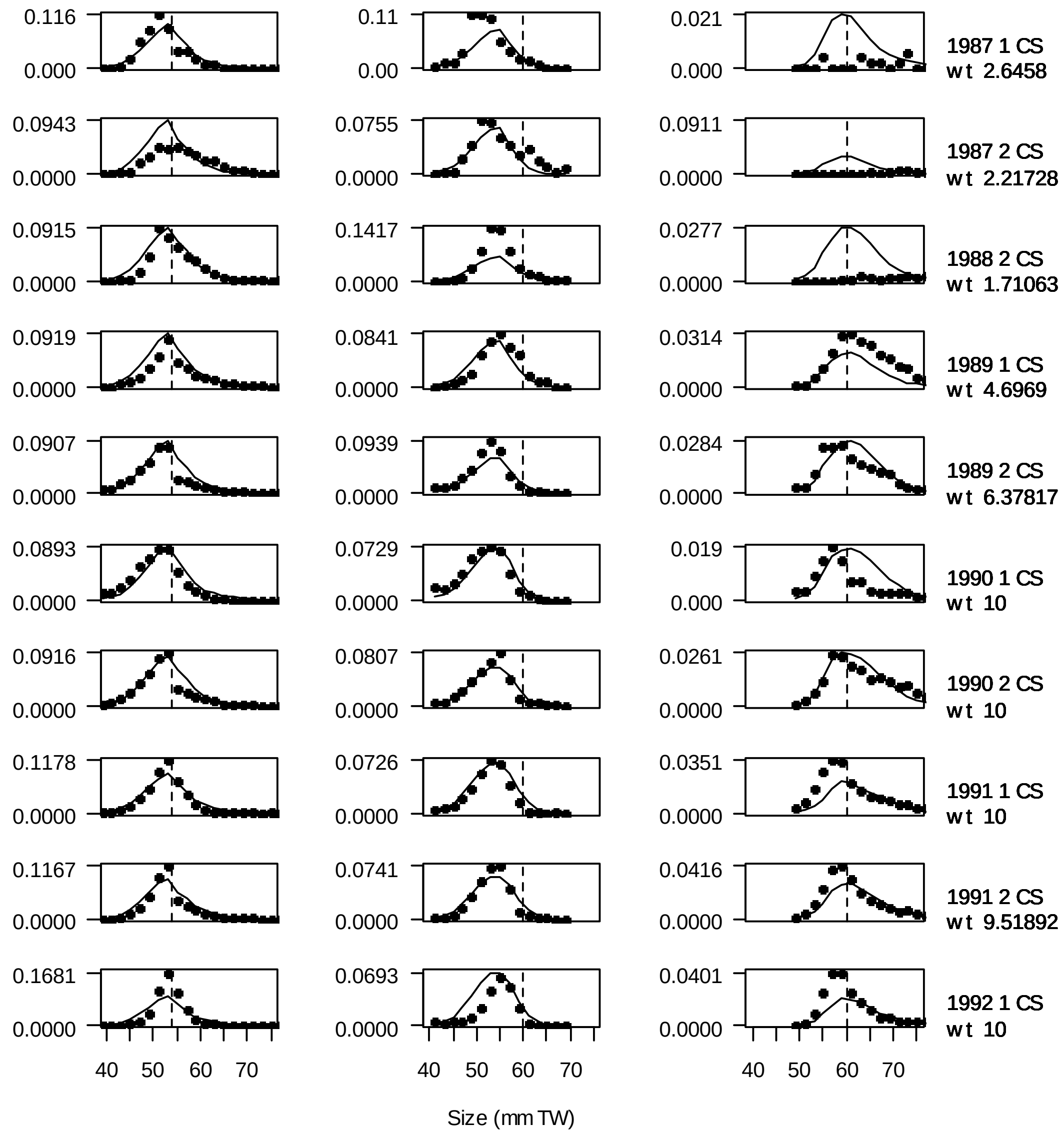


Figure 7: CRA 8: Fits to length frequencies in the final base case MPD: males on the left, immature females in the centre and mature females on the right; solid circles are the observed proportions-at-size (normalised across all sex categories) and the lines are predicted; information on the right for each record shows the year, season (1 = AW, 2 = SS), source (CS = observer catch sampling, LB = logbooks) and relative weight; note that scales vary among sexes and among records.

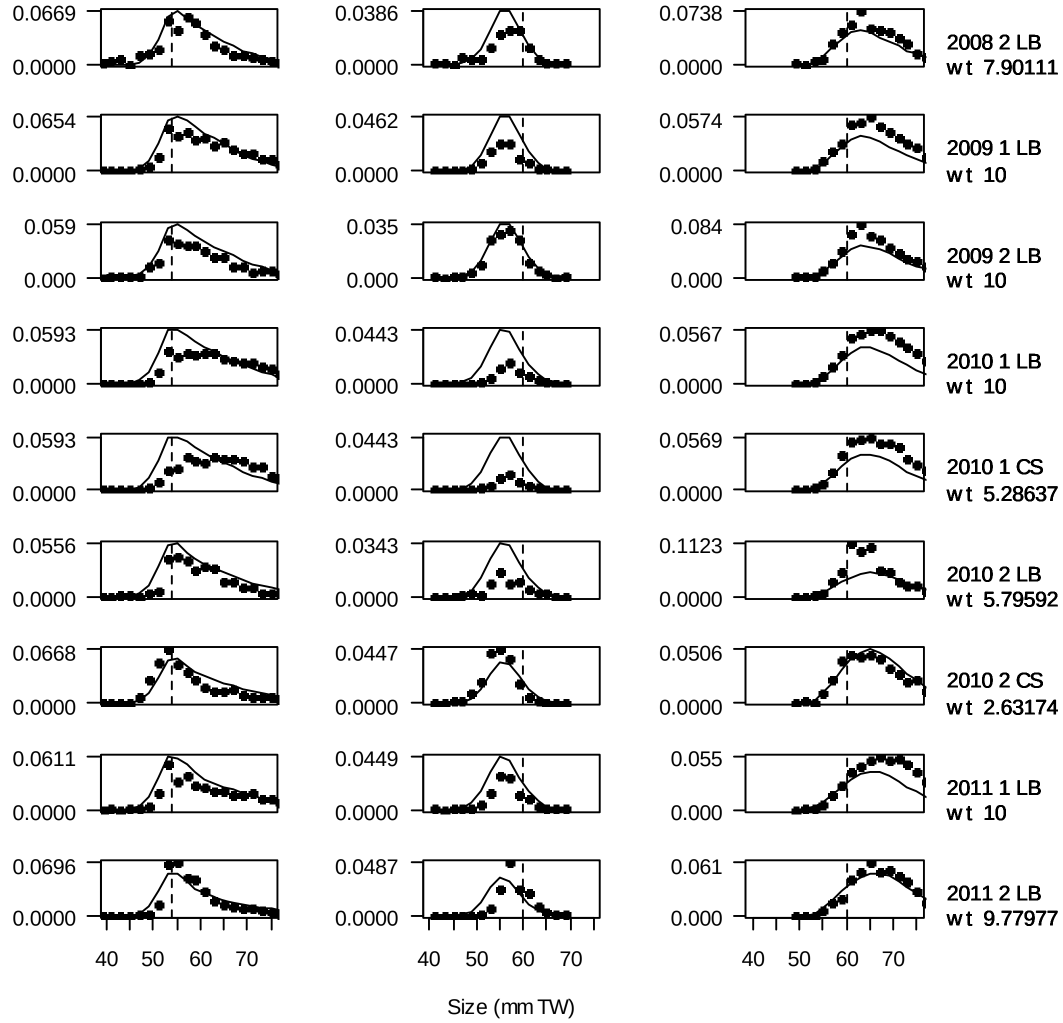


Figure 7 part 2.

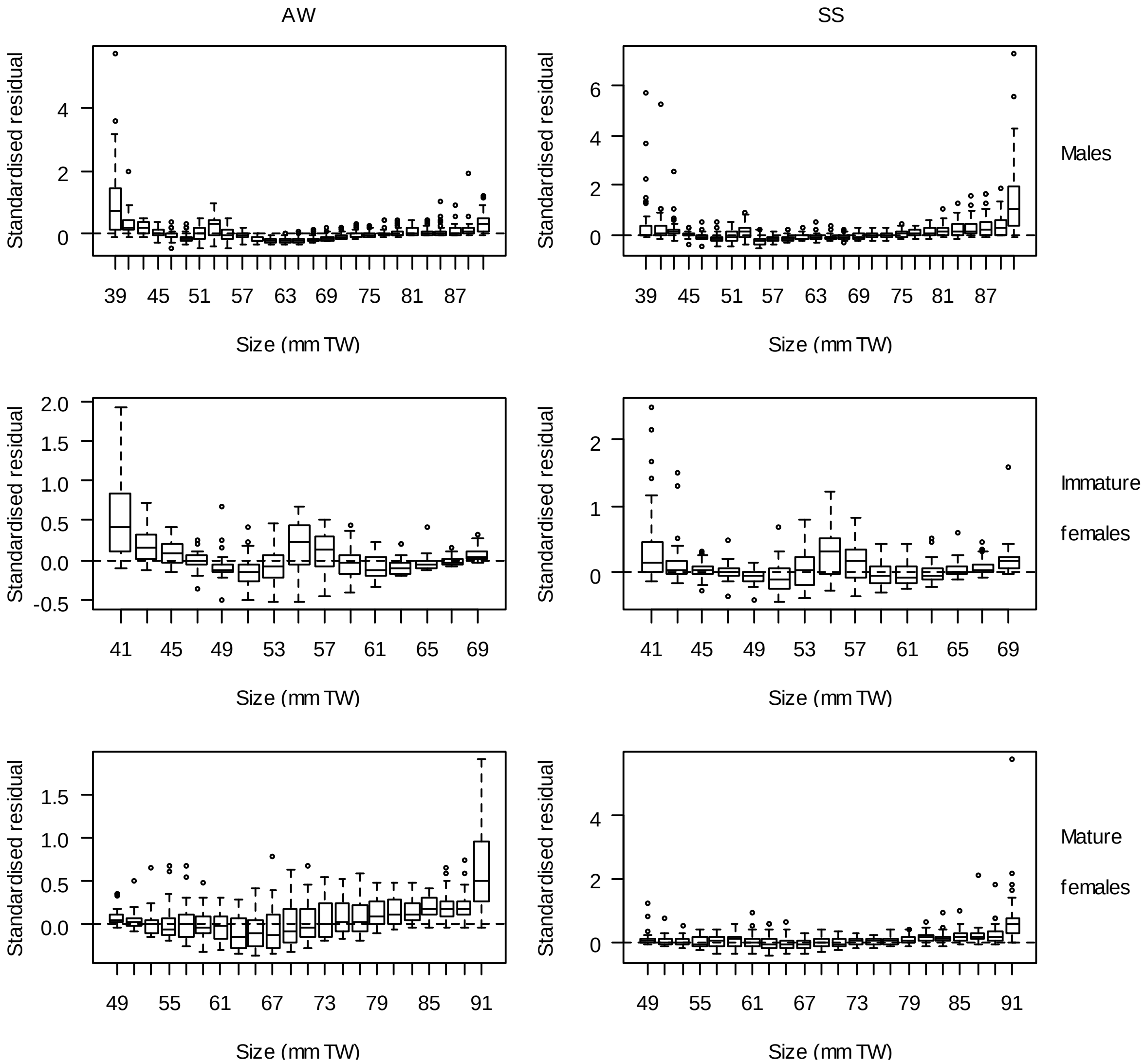


Figure 8: CRA 8: Normalised residuals from fits to length frequencies in the final base case MPD by sex and season.

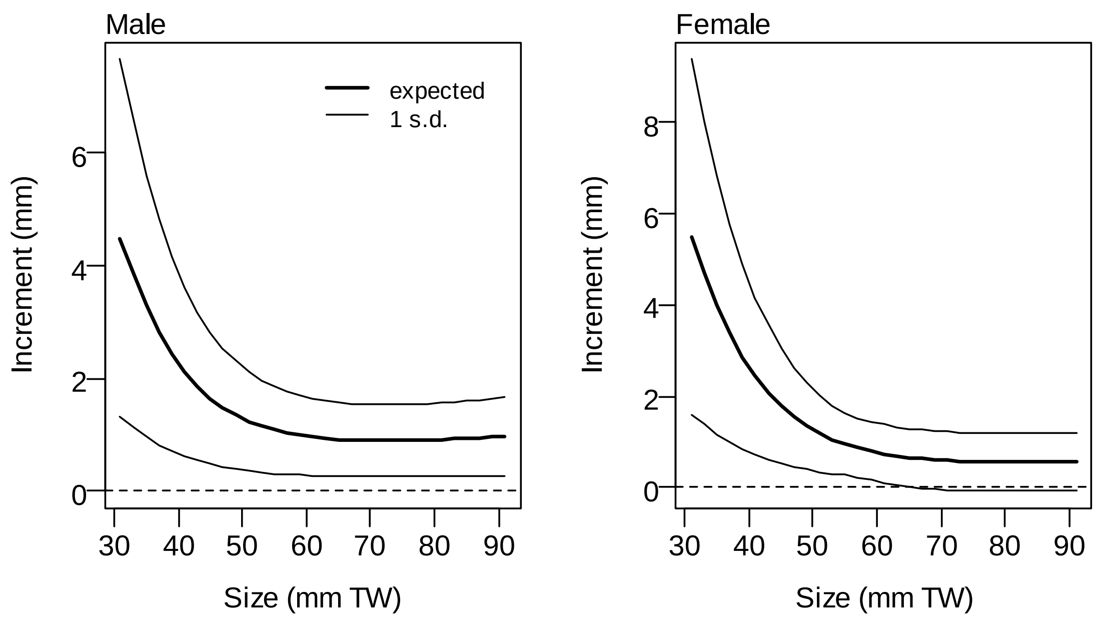


Figure 9: CRA 7: Predicted growth increment as a function of initial size from the final base case MPD.

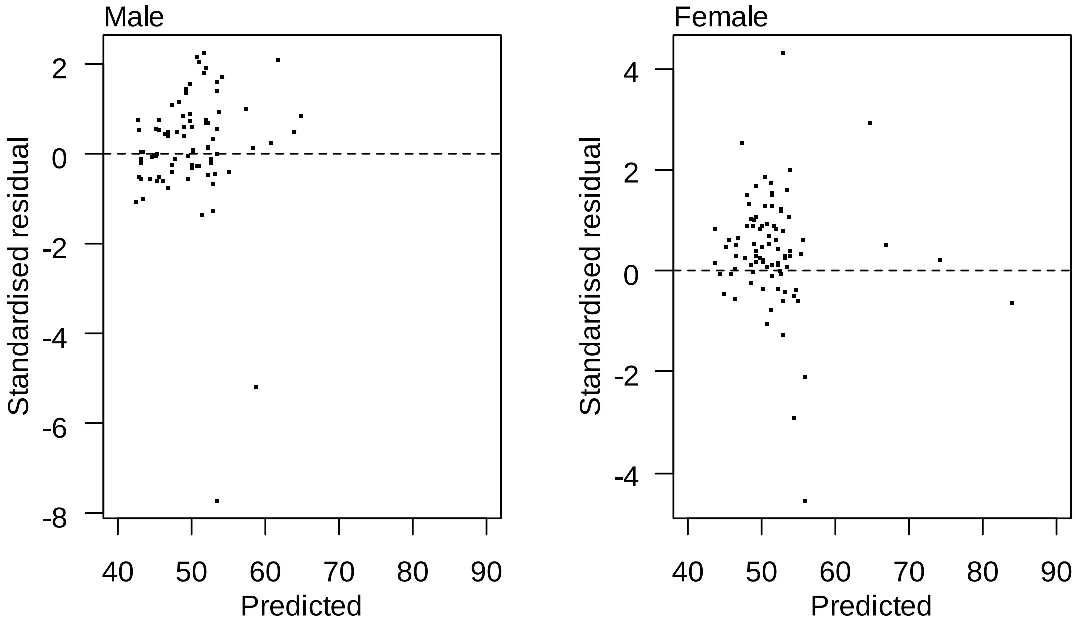


Figure 10: CRA 7 Standardised residuals from the fit to tag-recapture data in final base case MPD.

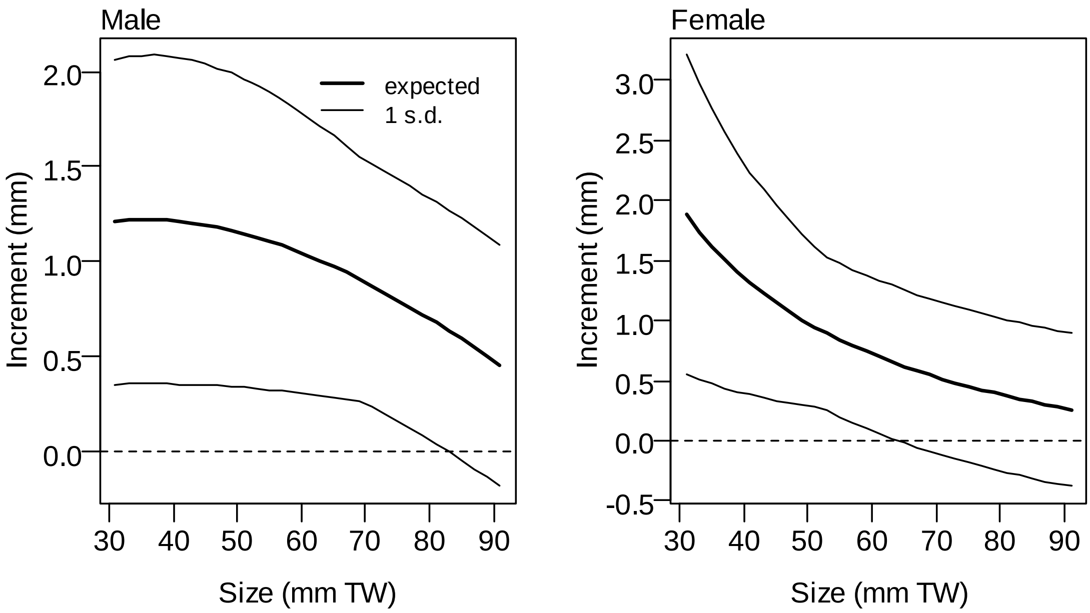


Figure 11: CRA 8: Predicted growth increment as a function of initial size from the final base case MPD.

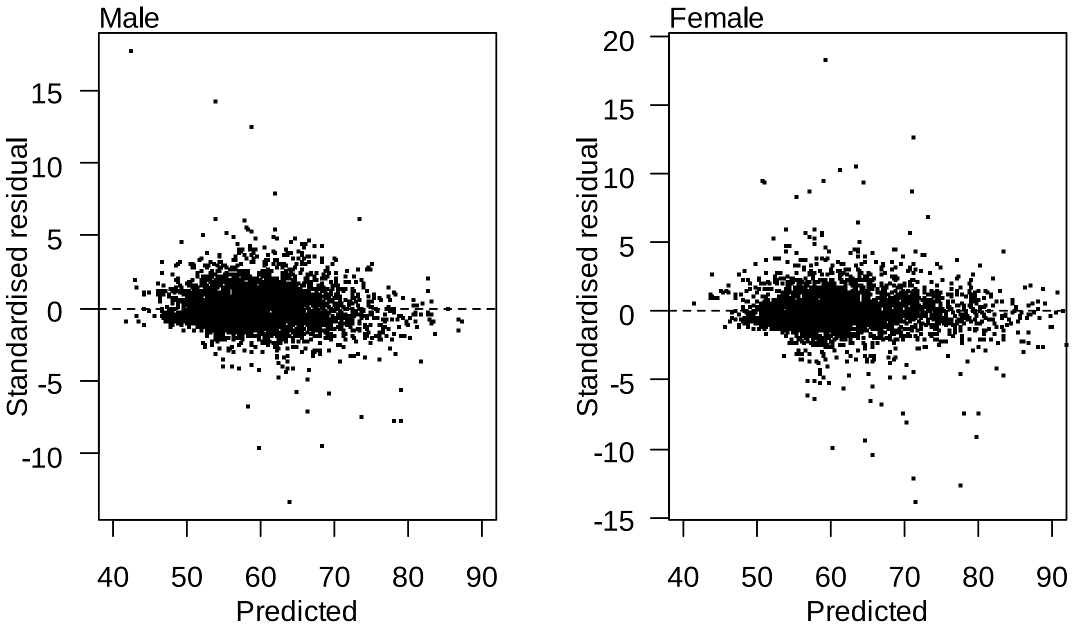


Figure 12: CRA 8: Standardised residuals from the fit to tag-recapture data in final base case MPD.

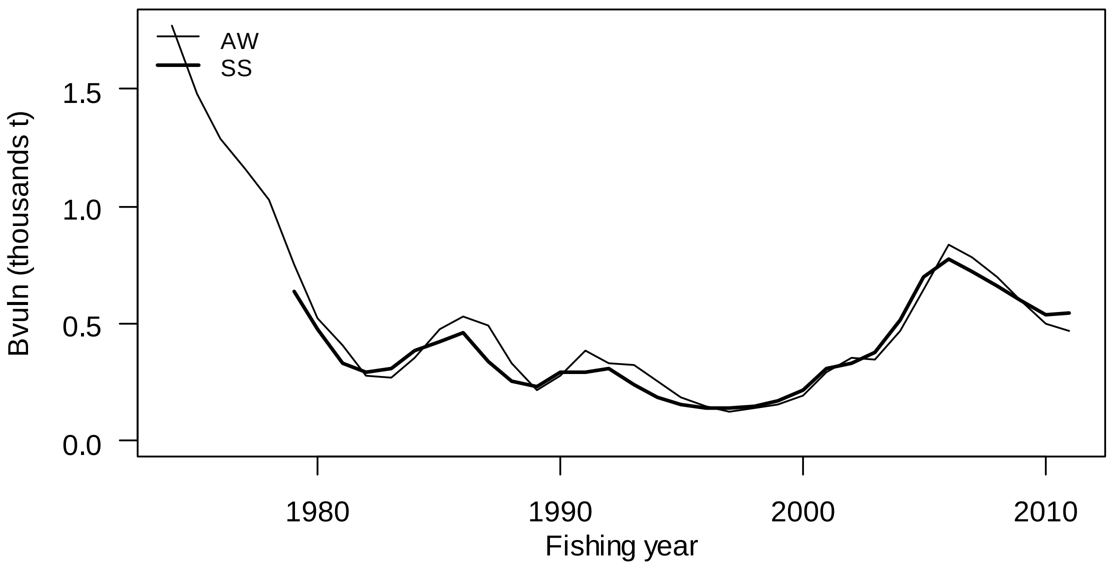


Figure 13: CRA 7: Trajectory of vulnerable biomass from the final base case MPD.

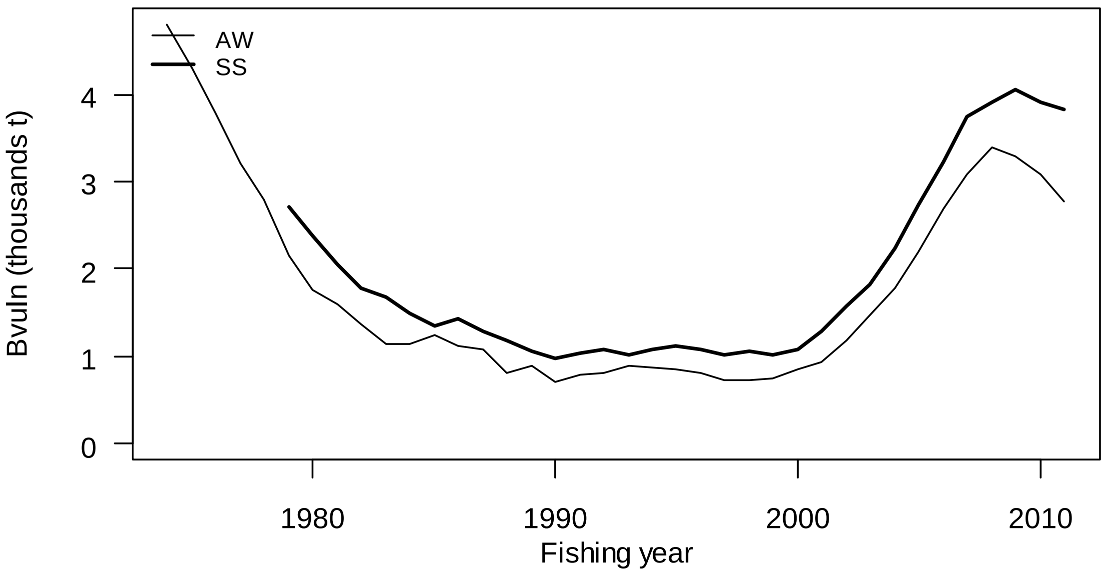


Figure 14: CRA 8: Trajectory of vulnerable biomass from the final base case MPD.

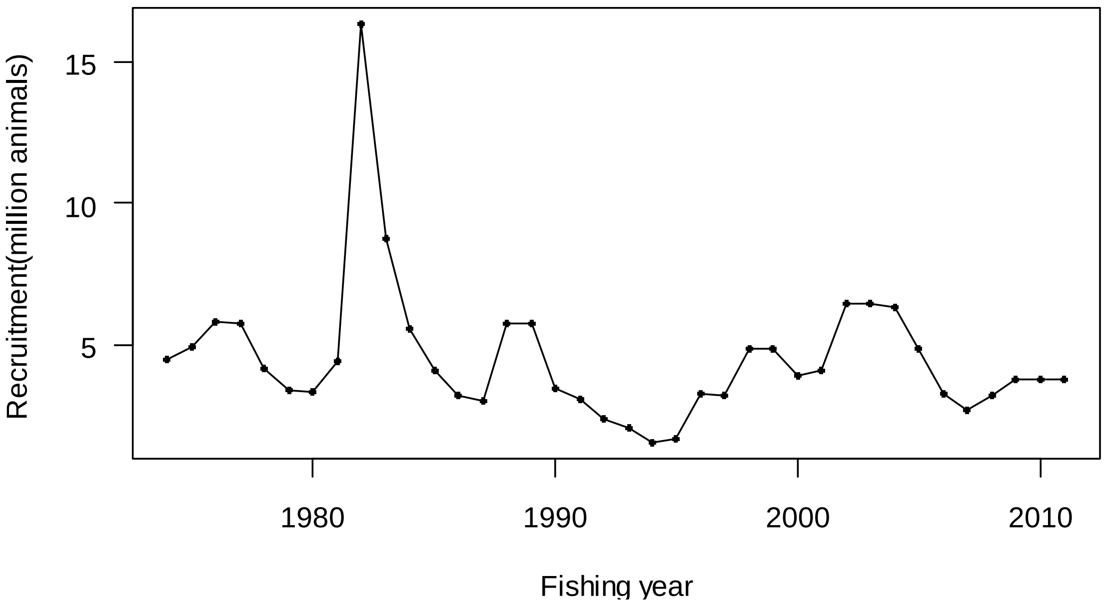


Figure 15: CRA 7: recruitment trajectory from the final base case MPD.

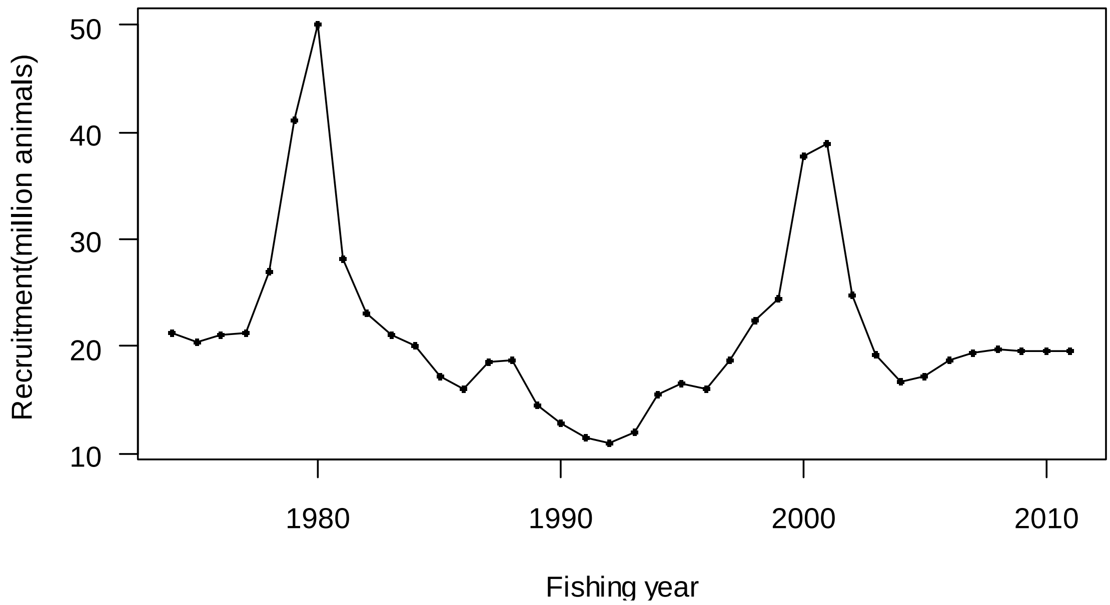


Figure 16: CRA 8: Recruitment trajectory from the final base case MPD.

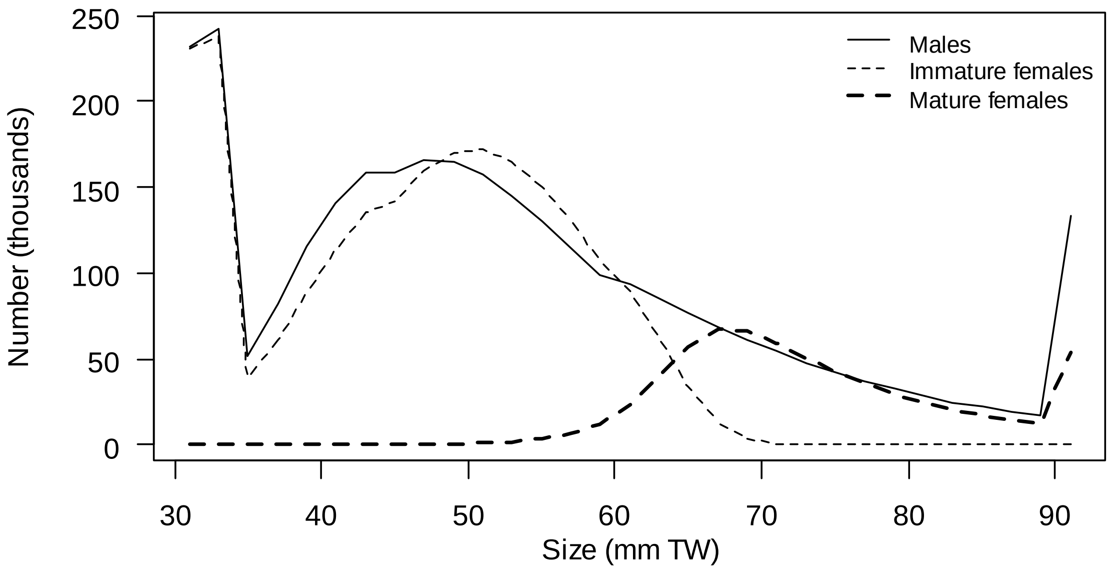


Figure 17: CRA 7: Initial length structure from the final base case MPD.

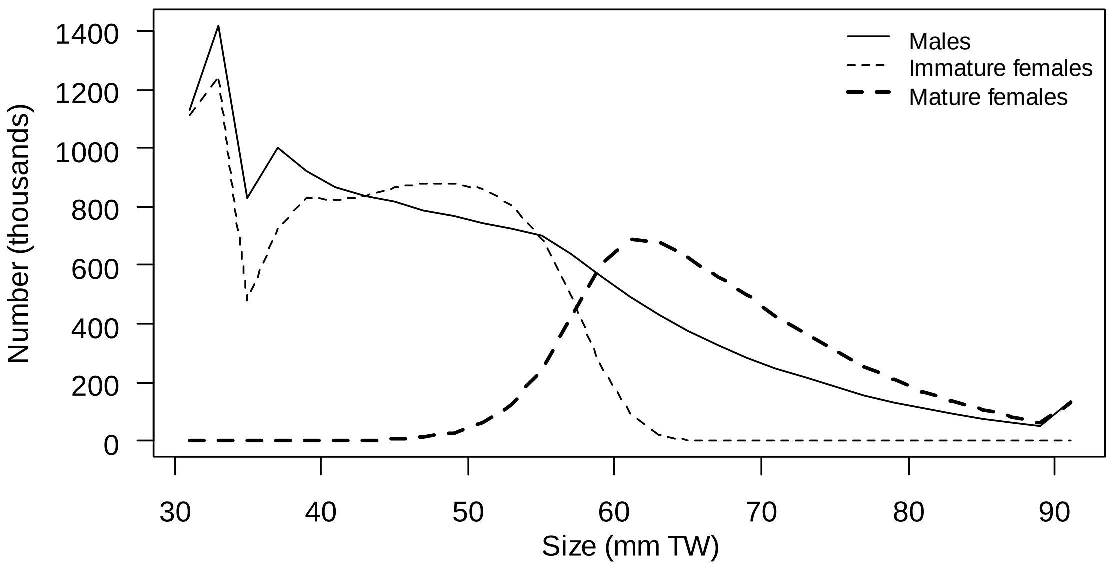


Figure 18: CRA 8: Initial length structure from the final base case MPD.

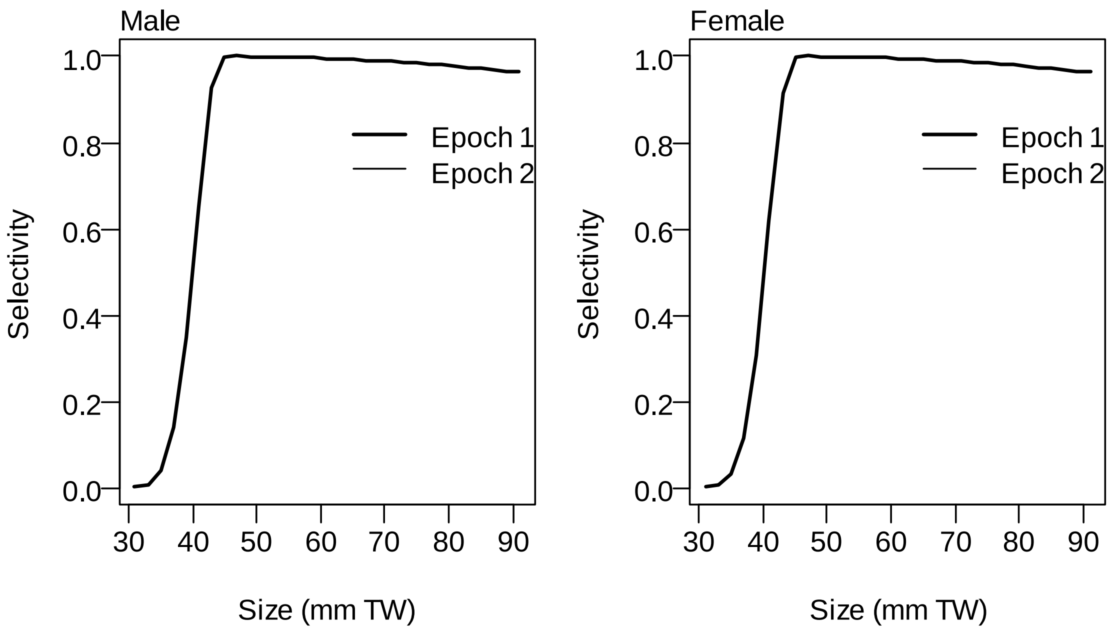


Figure 19: CRA 7: Estimated selectivity from the final base case MPD.

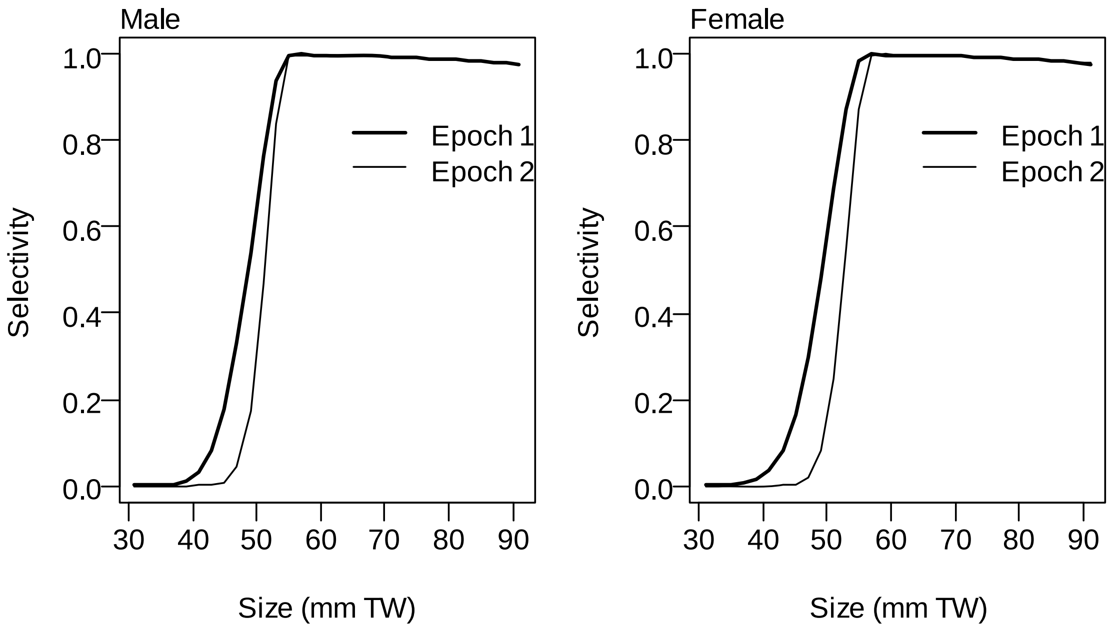


Figure 20: CRA 8: Estimated selectivity from the final base case MPD; epoch 2 began in 1993.

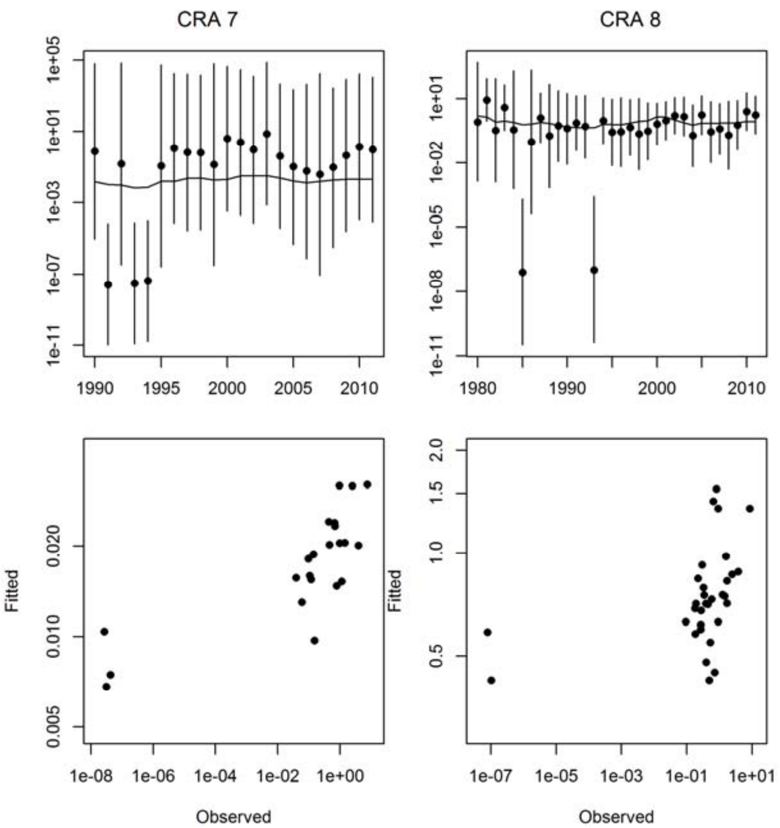


Figure 21: Fitted (solid line) and observed (points) puerulus settlement indices by year (upper panels) and fitted versus observed indices (lower panels) for CRA 7 and CRA 8. Results are from model fits with a lag of 1 for CRA 7 and lag of 0 for CRA 8.

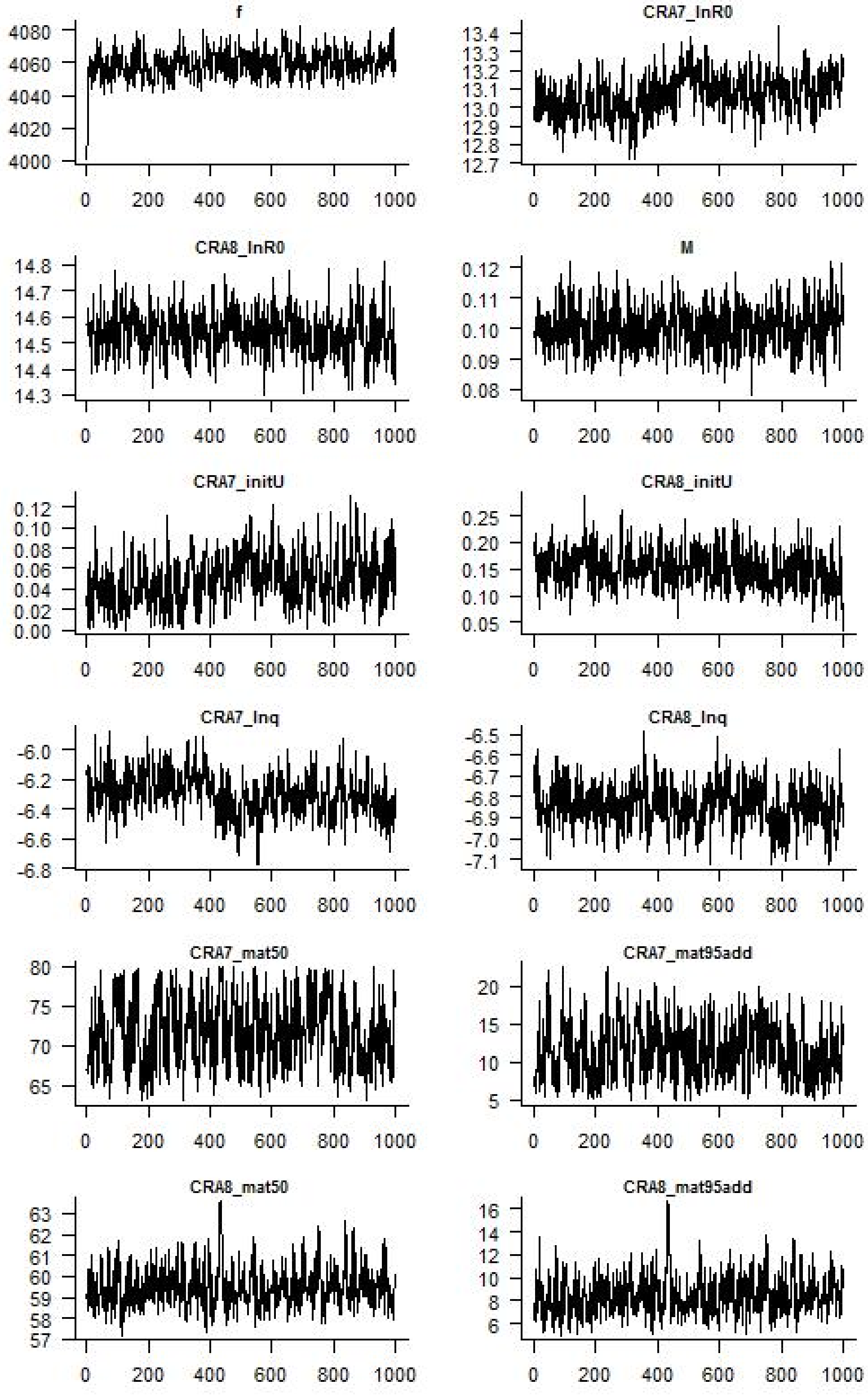
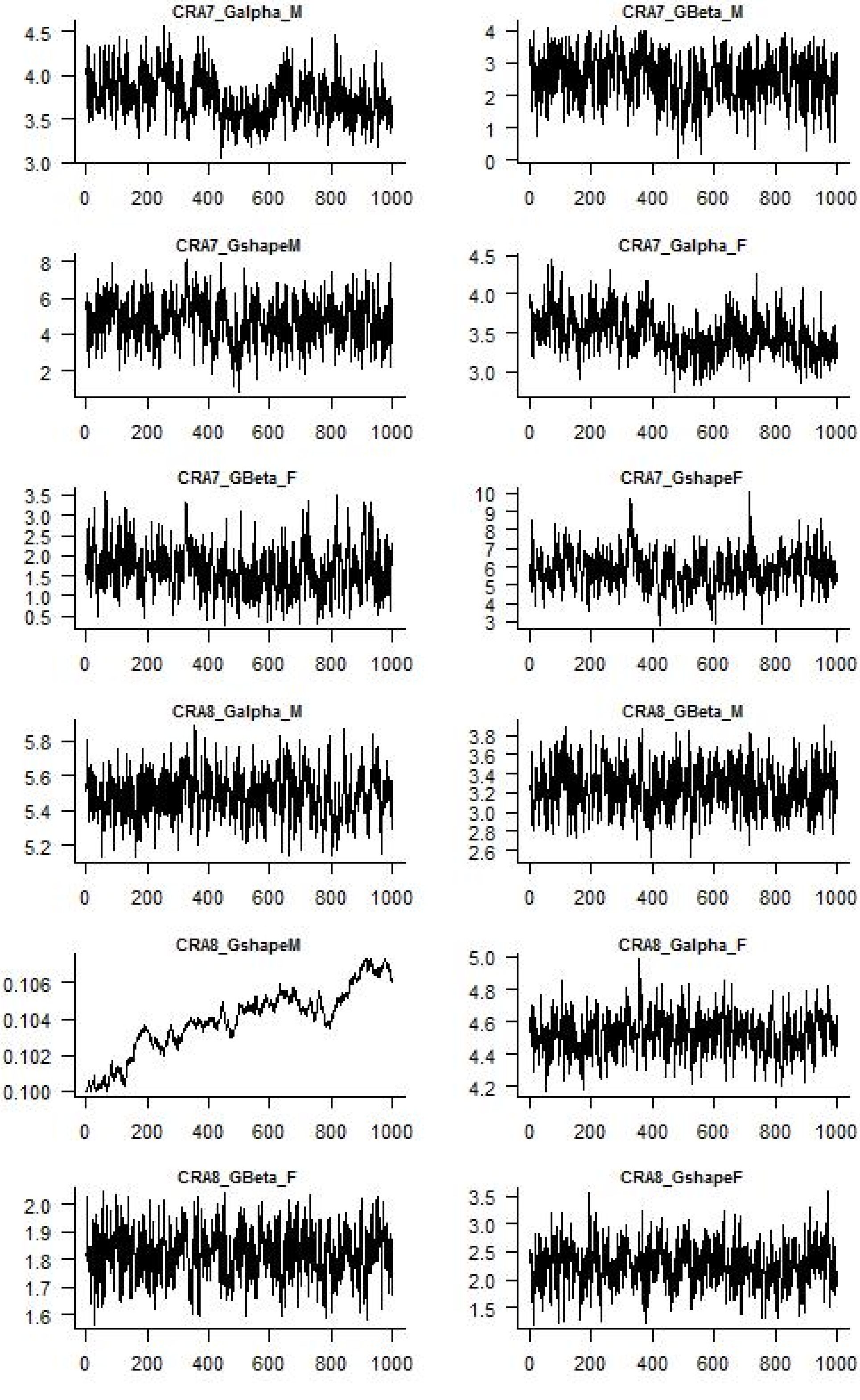
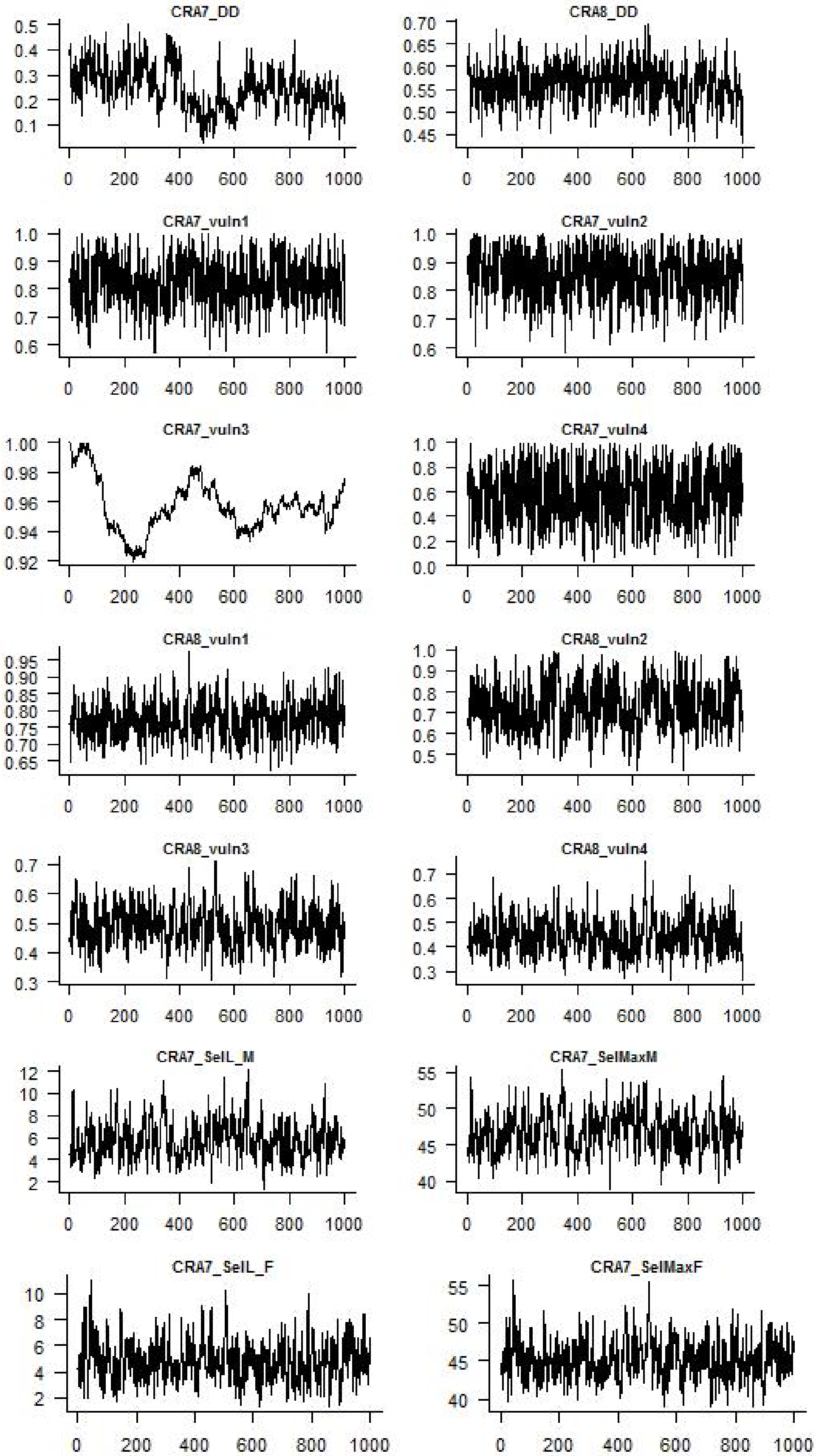


Figure 22: Traces of estimated and derived parameters from the final base case McMC.


CRA7_Galpha_M
CRA7_GBeta_M
CRA7_GshapeM
CRA7_Galpha_F
CRA7_GBeta_F
CRA7_GshapeF
CRA8_Galpha_M
CRA8_GBeta_M
CRA8_GshapeM
CRA8_Galpha_F
CRA8_GBeta_F
CRA8_GshapeF



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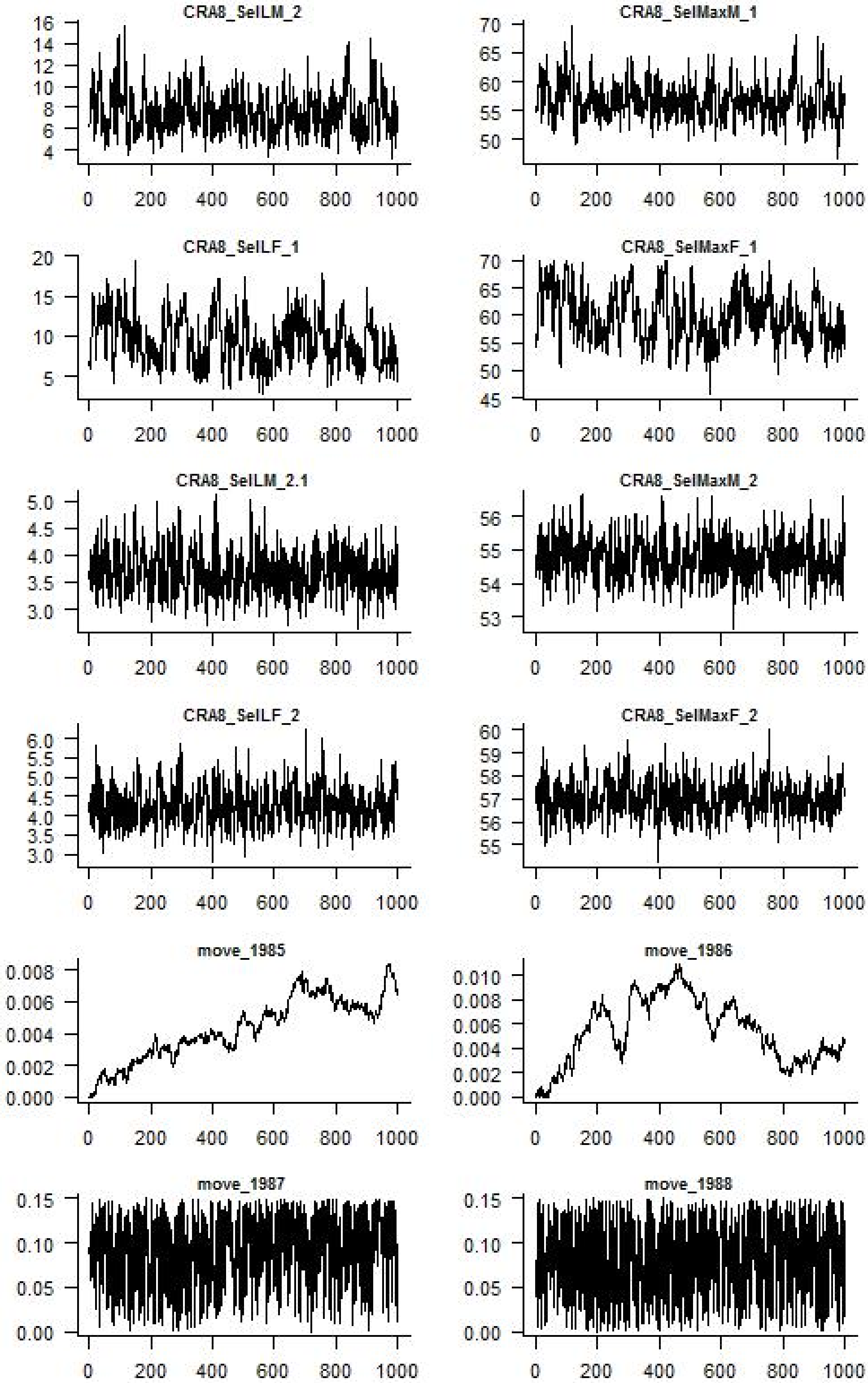

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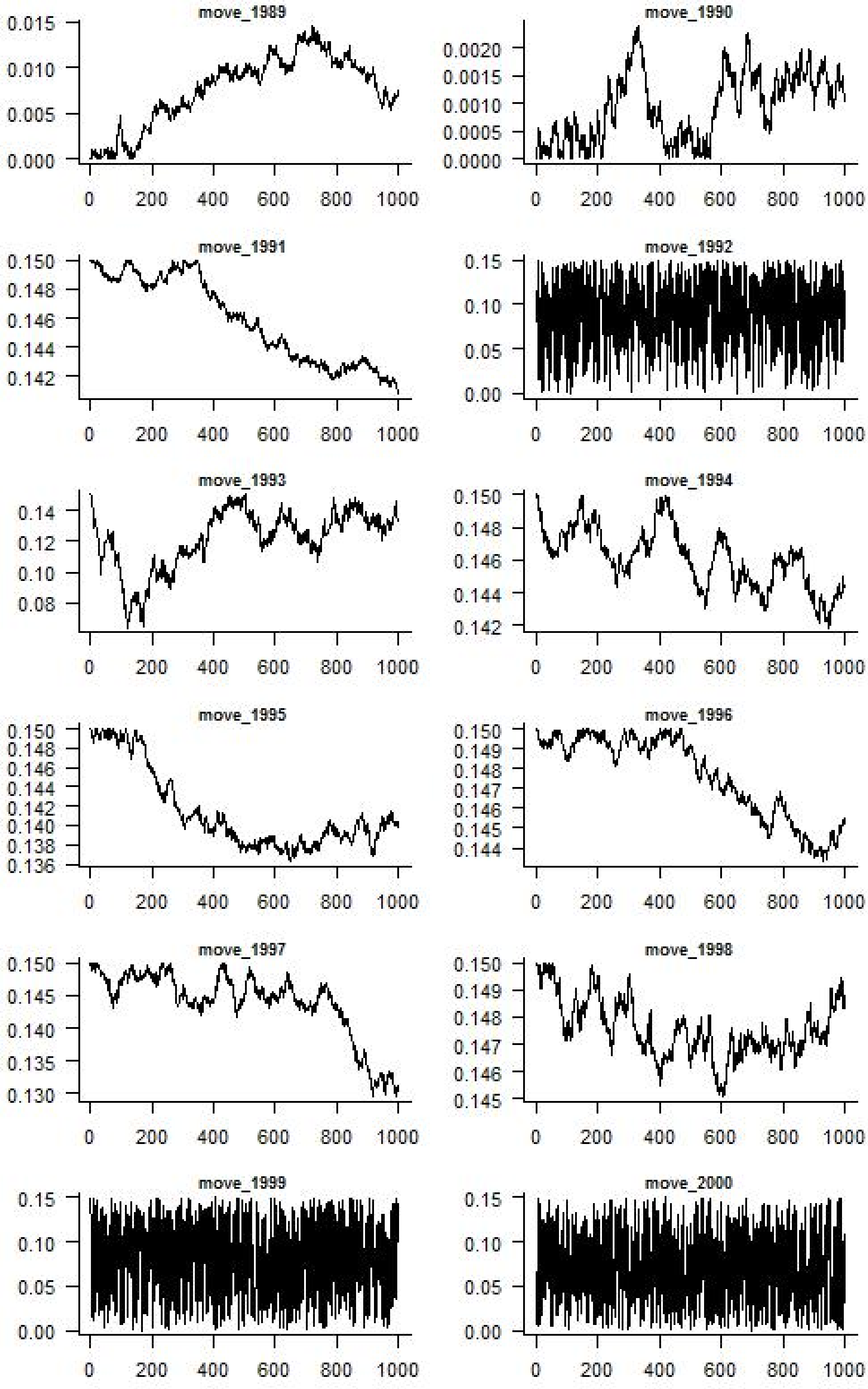

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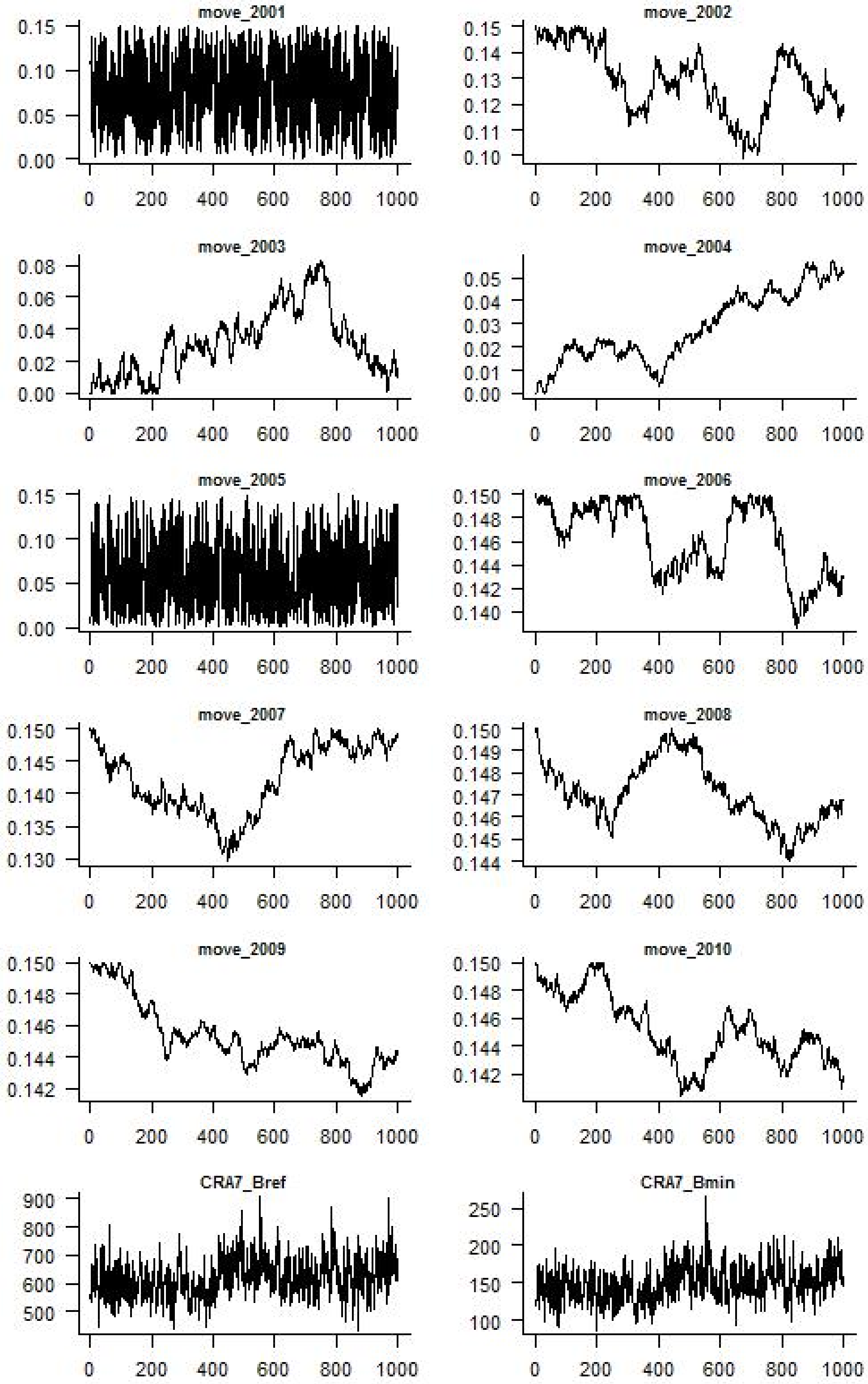

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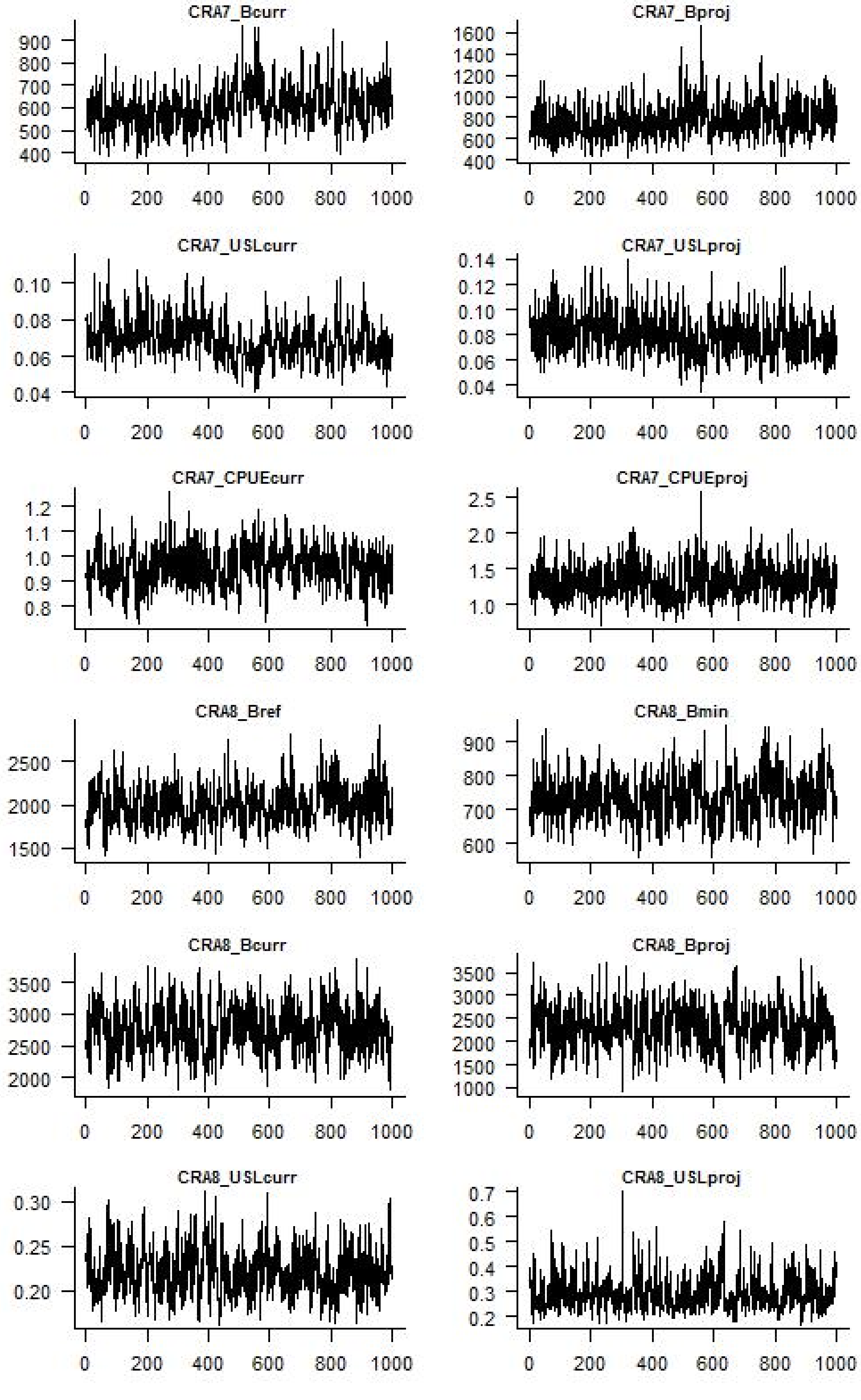

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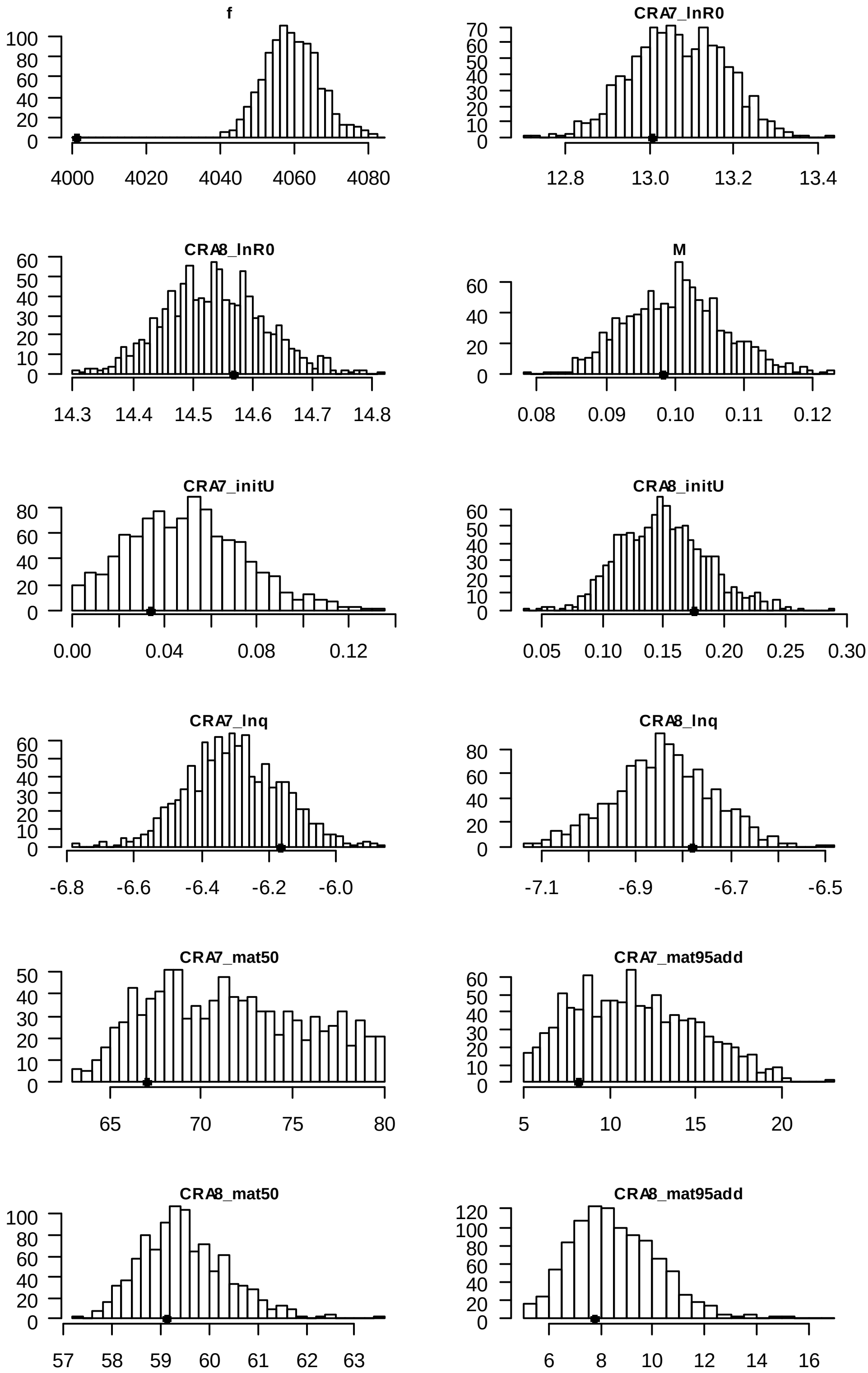
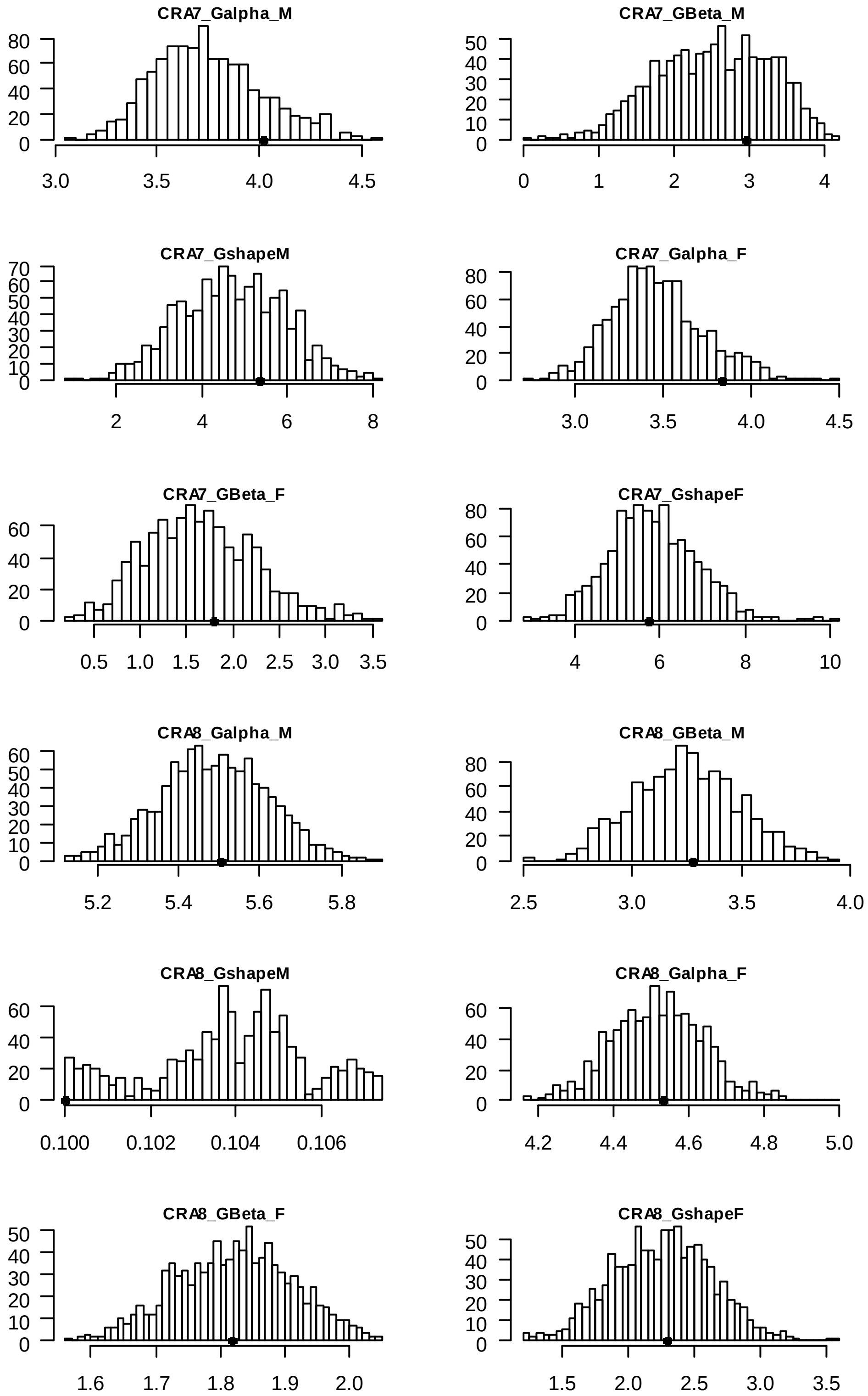


Figure 23: Posterior distributions of estimated and derived parameters from the final base case McMC; the solid circle indicates the MPD estimate.



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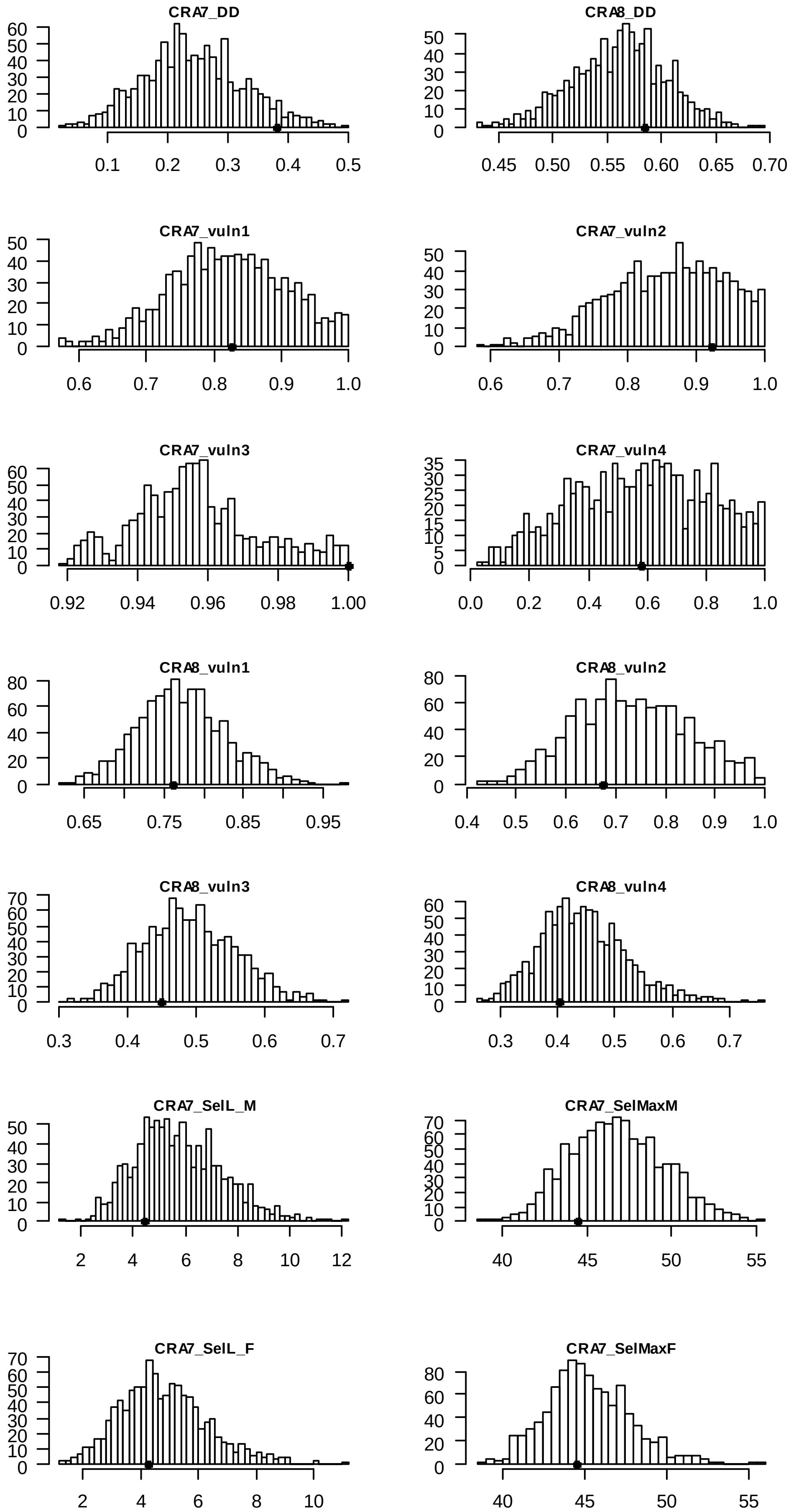

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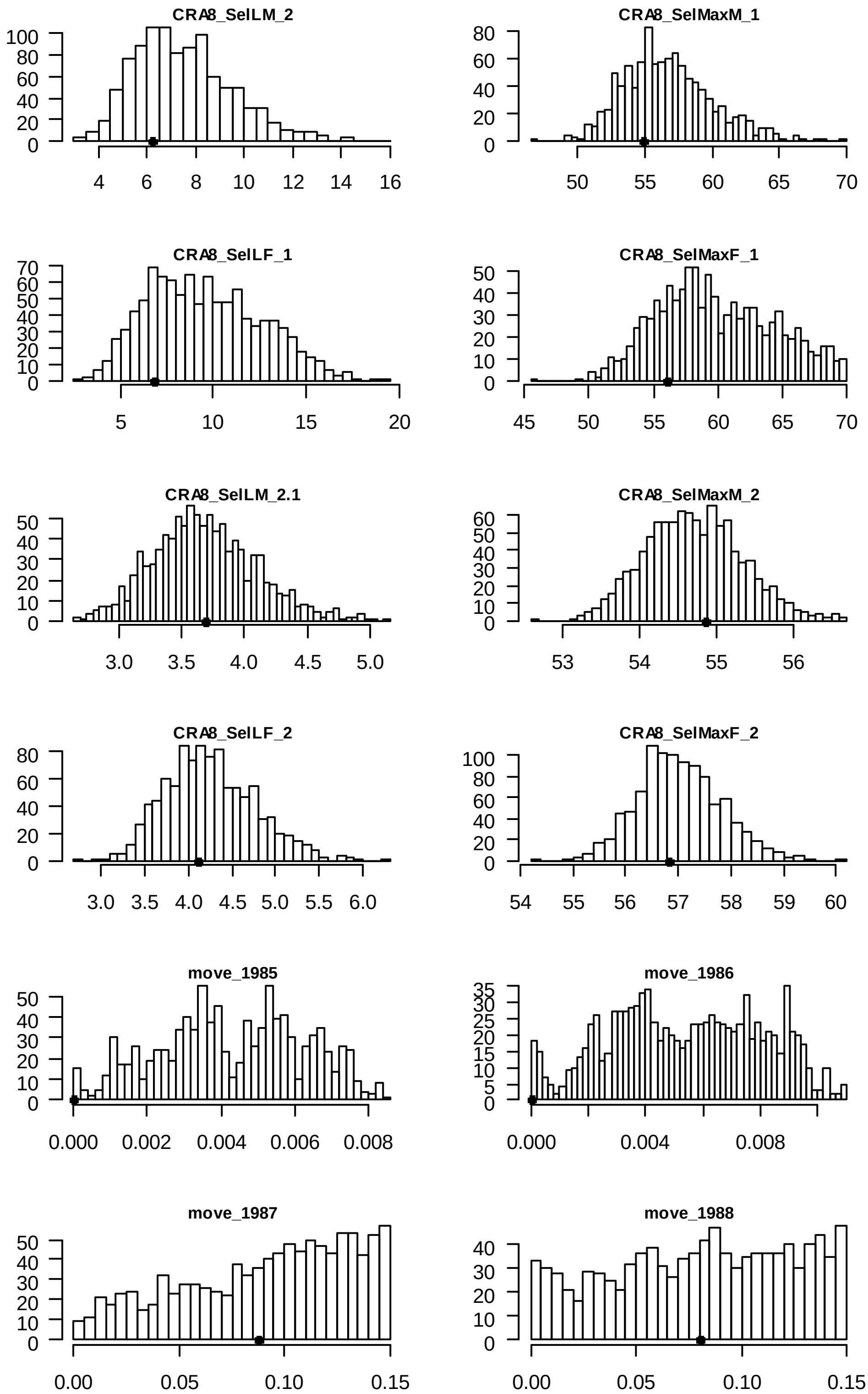

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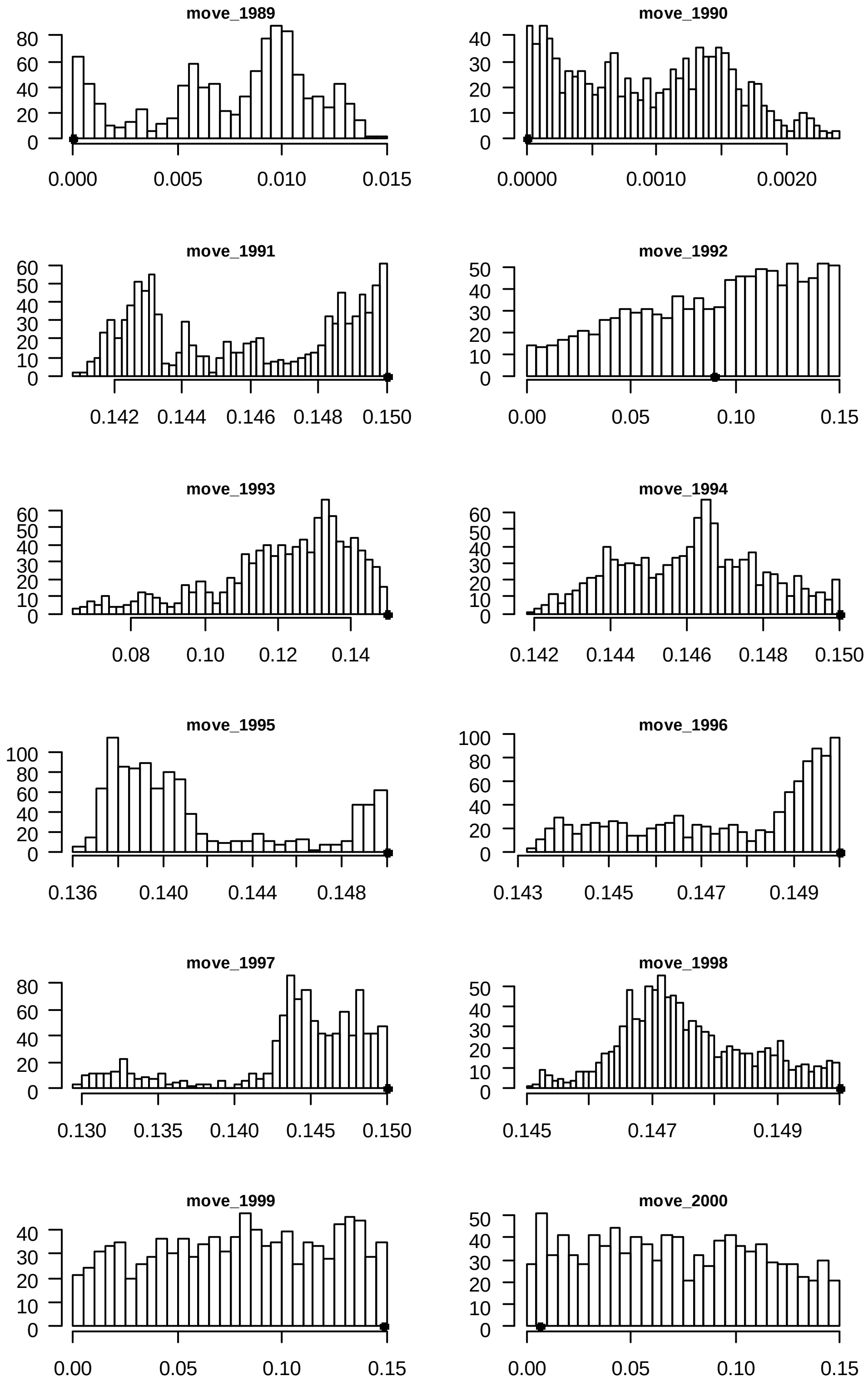

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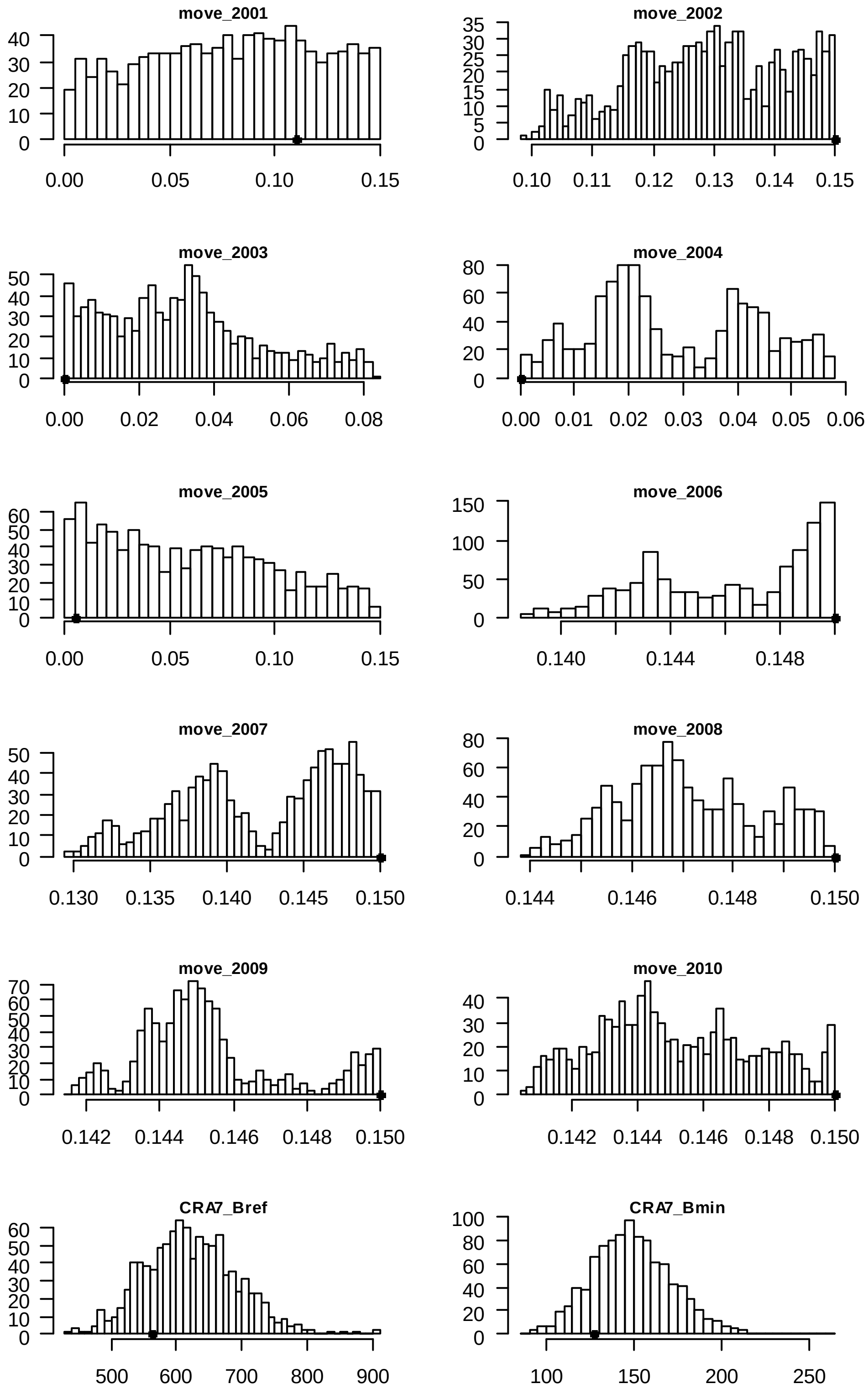

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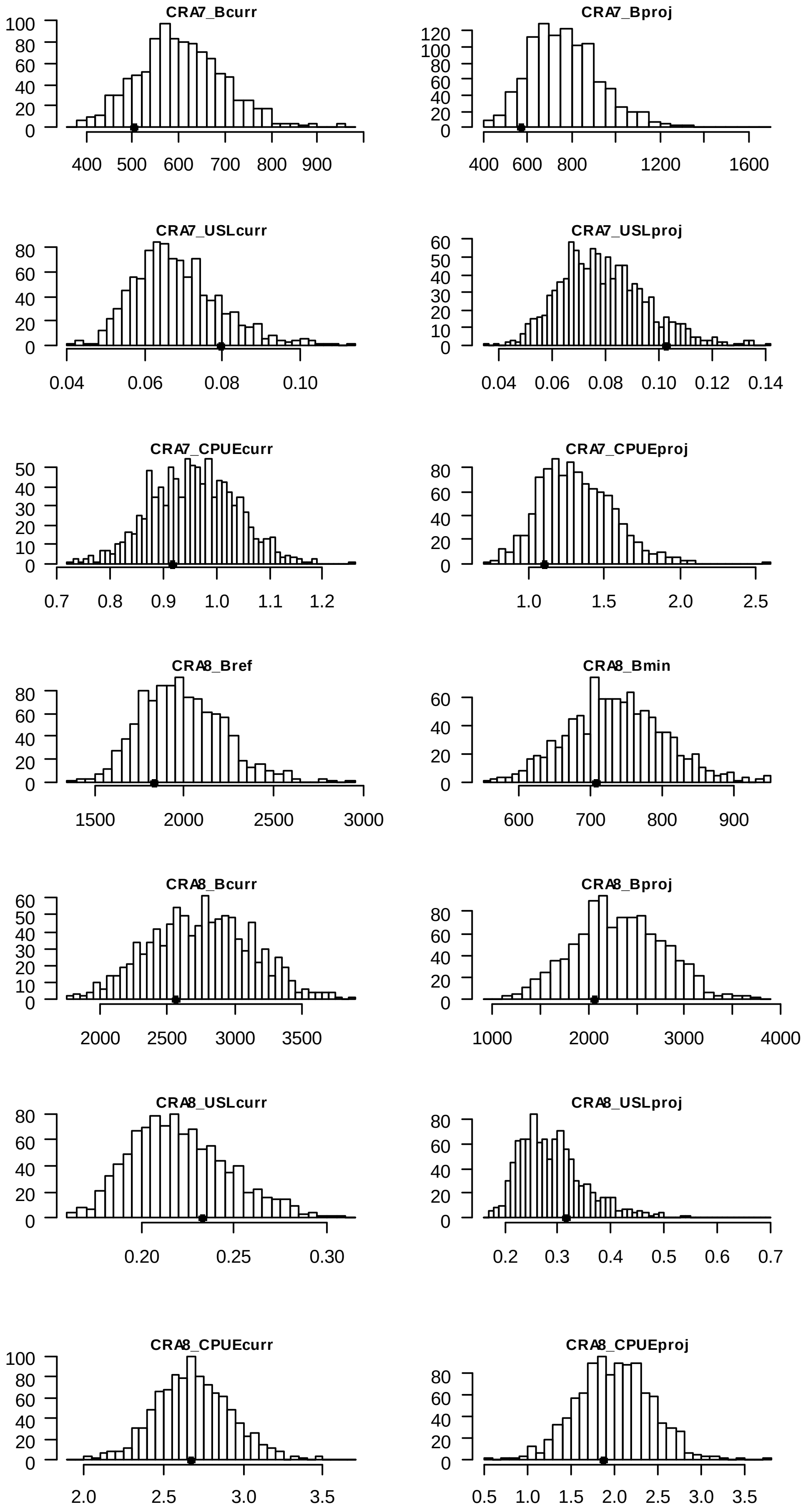

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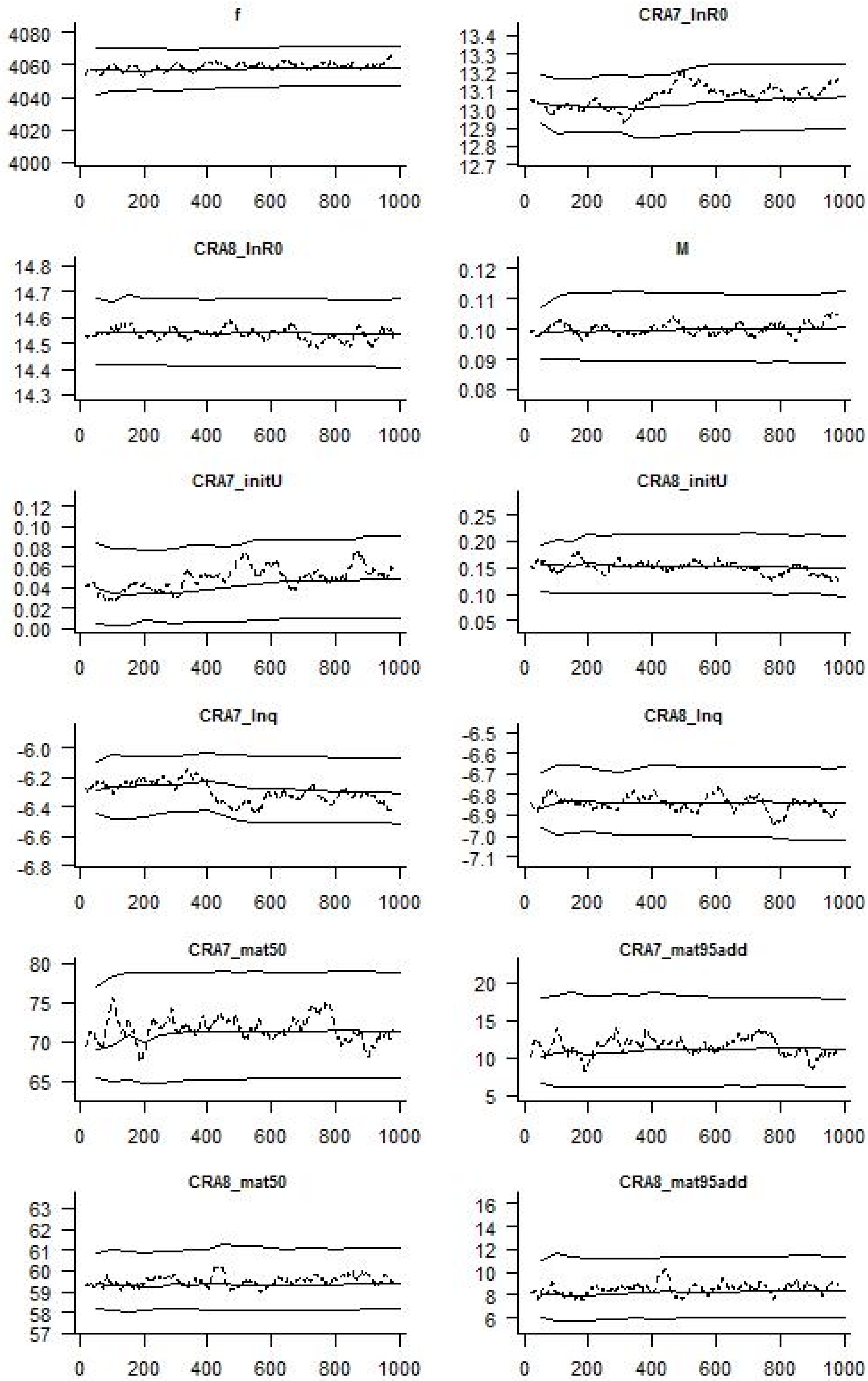
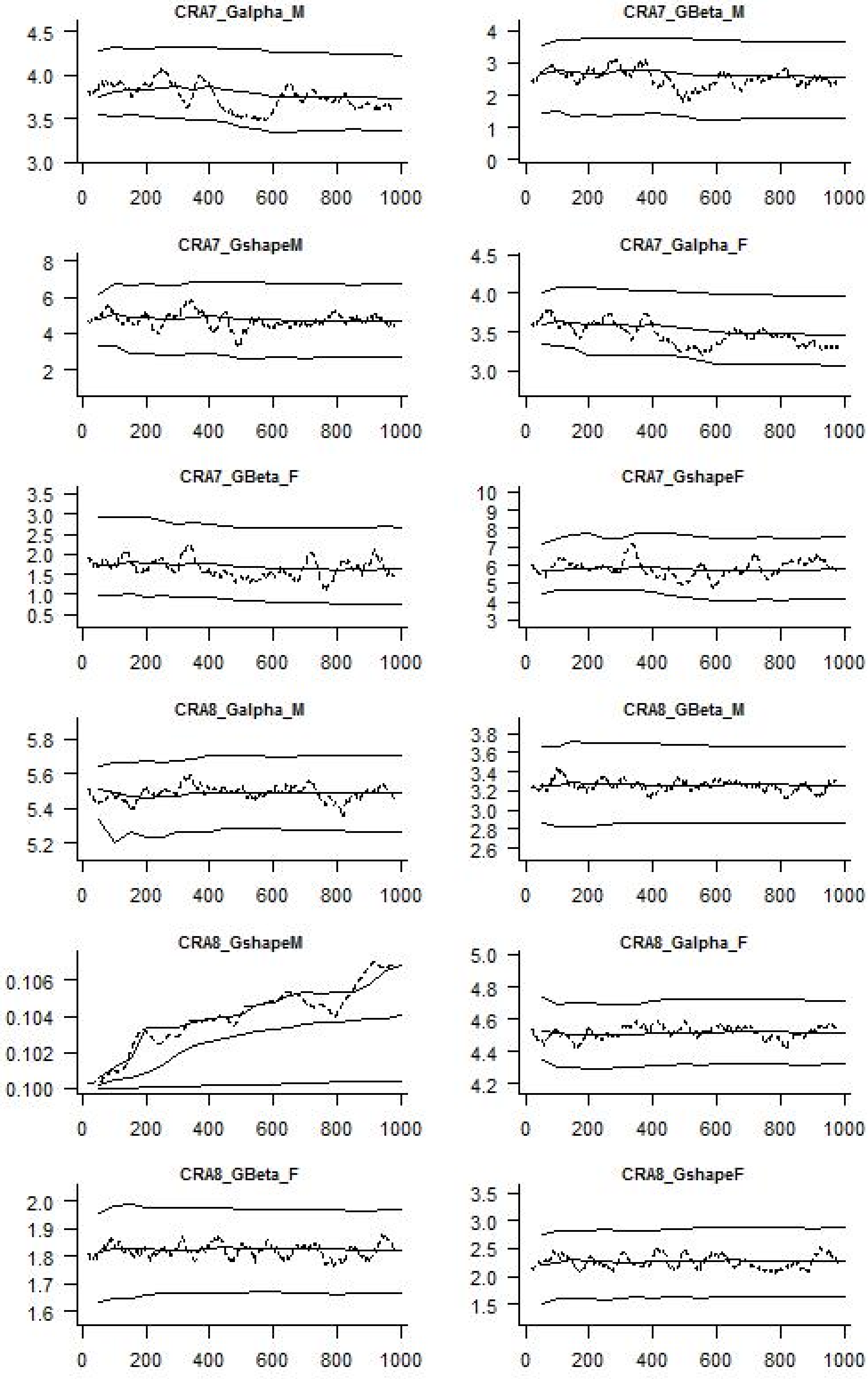


Figure 24: Diagnostics plots for the parameters from the final base case McMC. The central solid line is the running median, other solid lines are the running 5th and 95th quantiles, and the dotted line is a moving mean over 40 samples.



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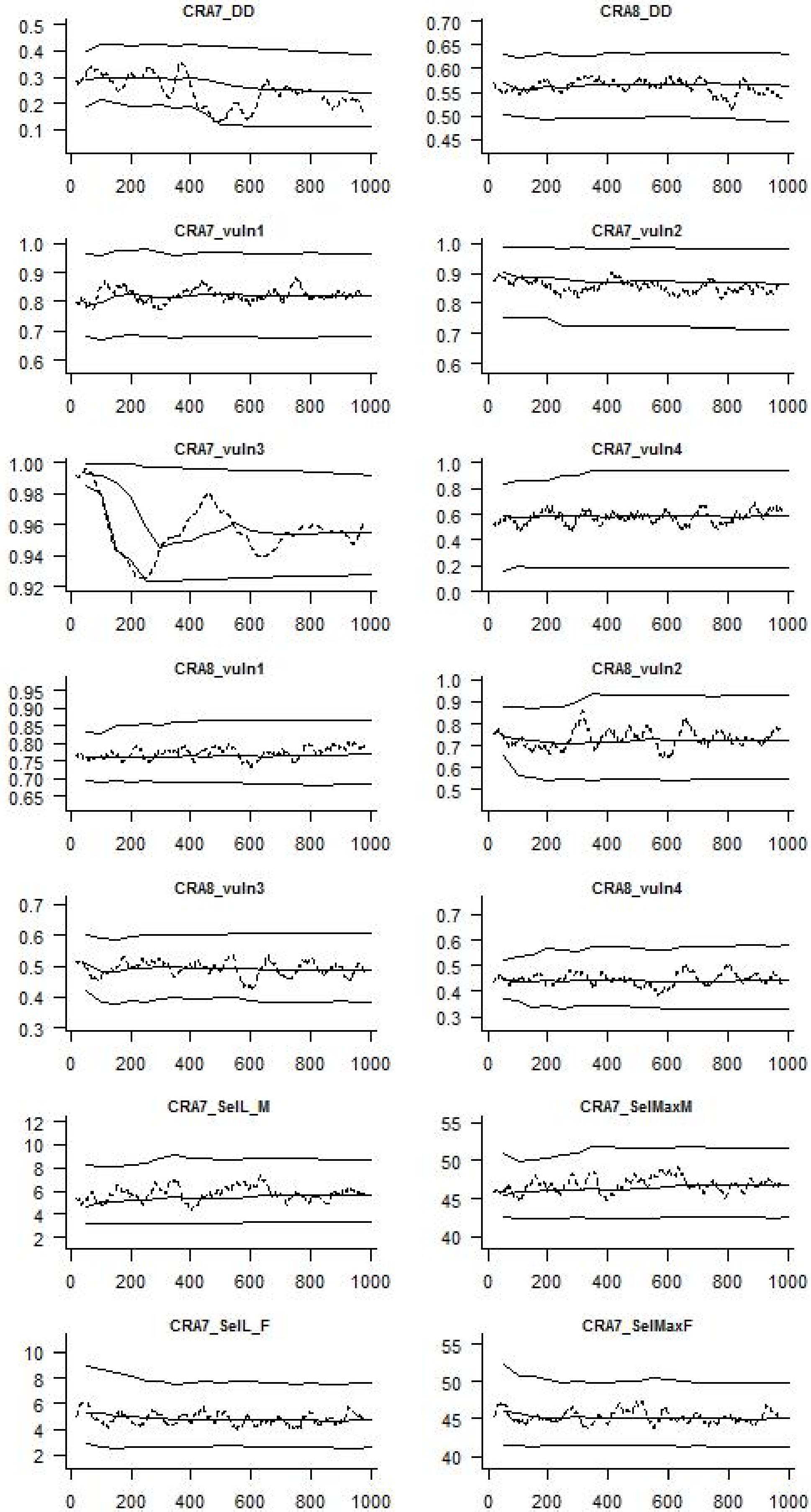

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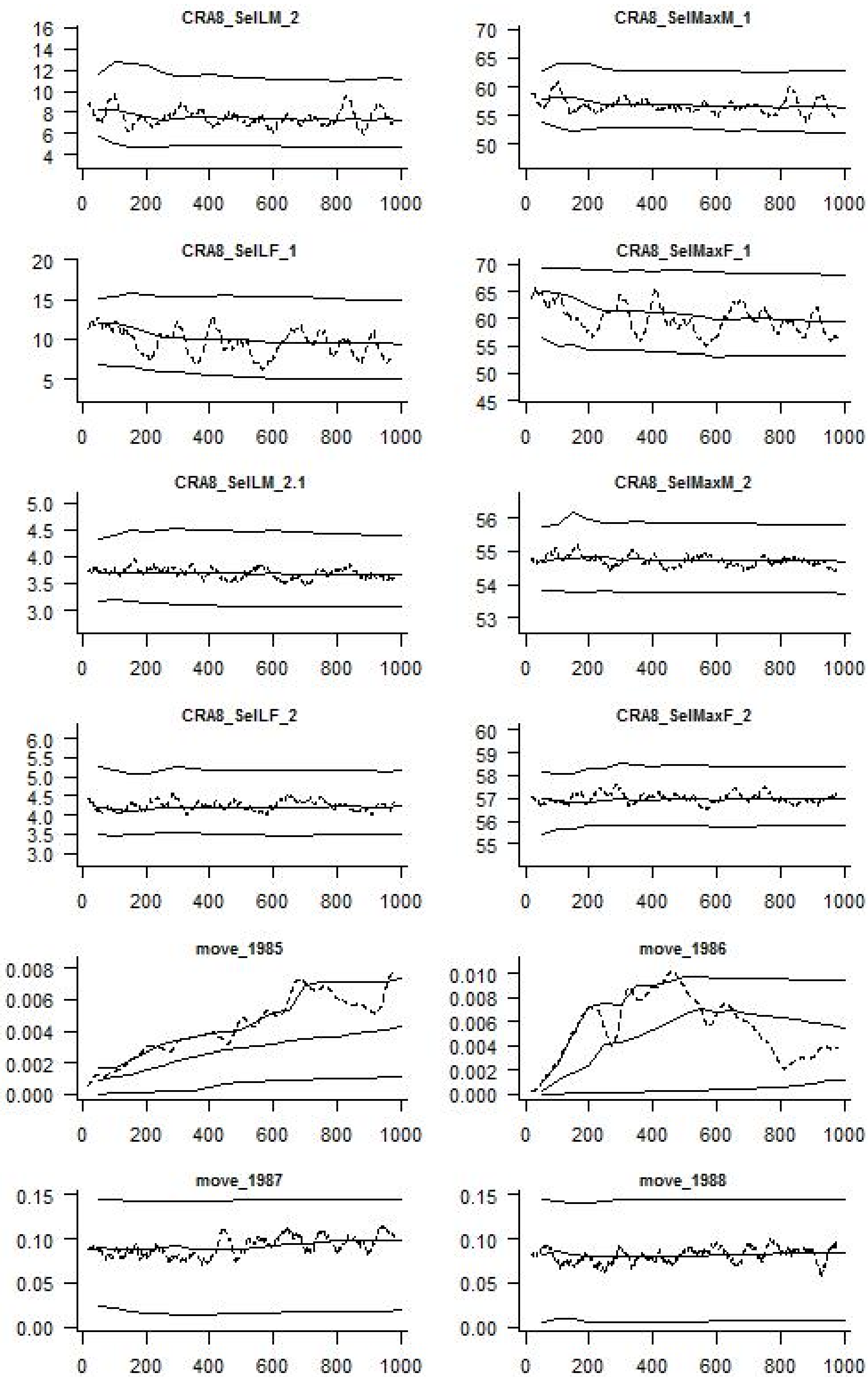

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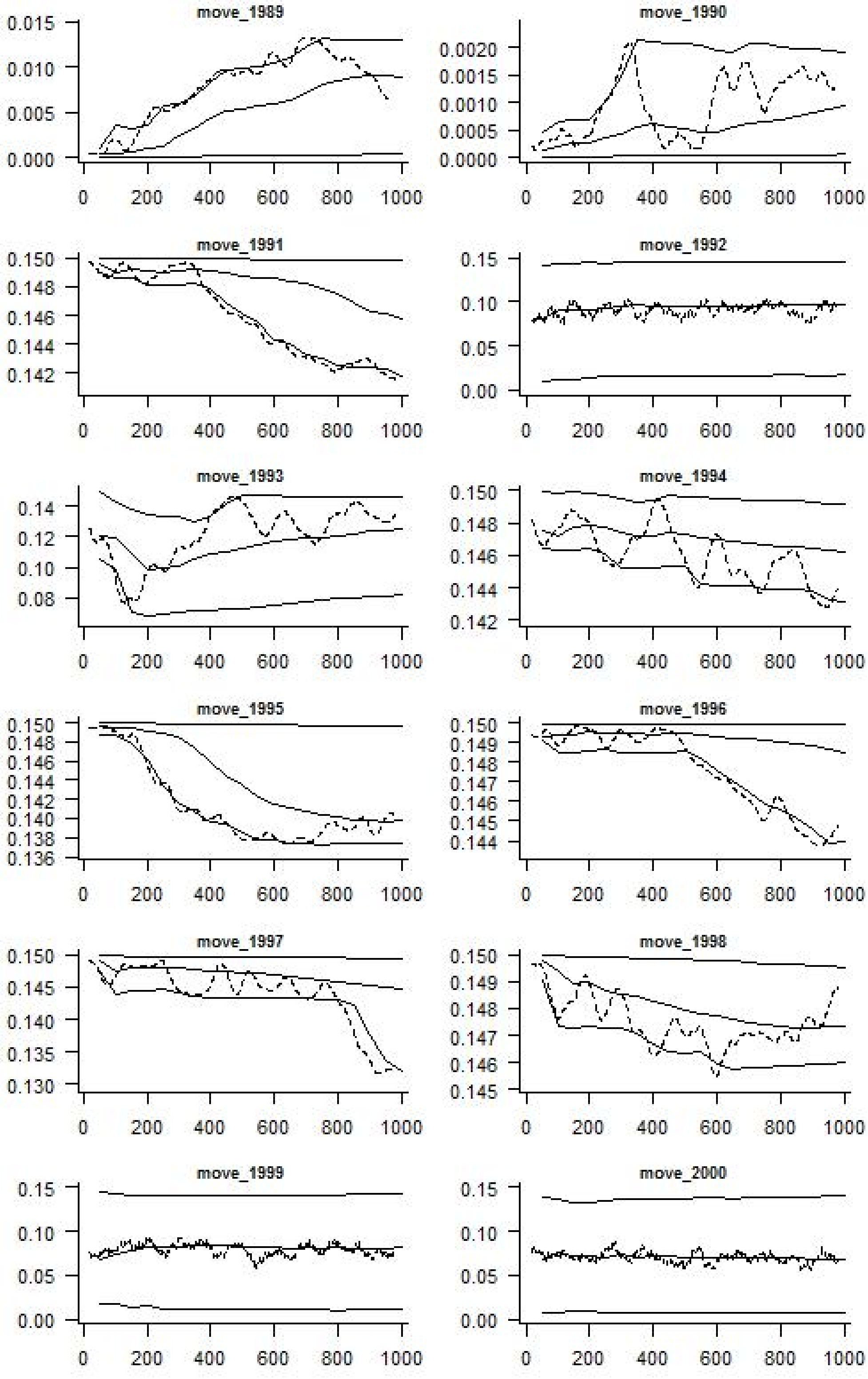

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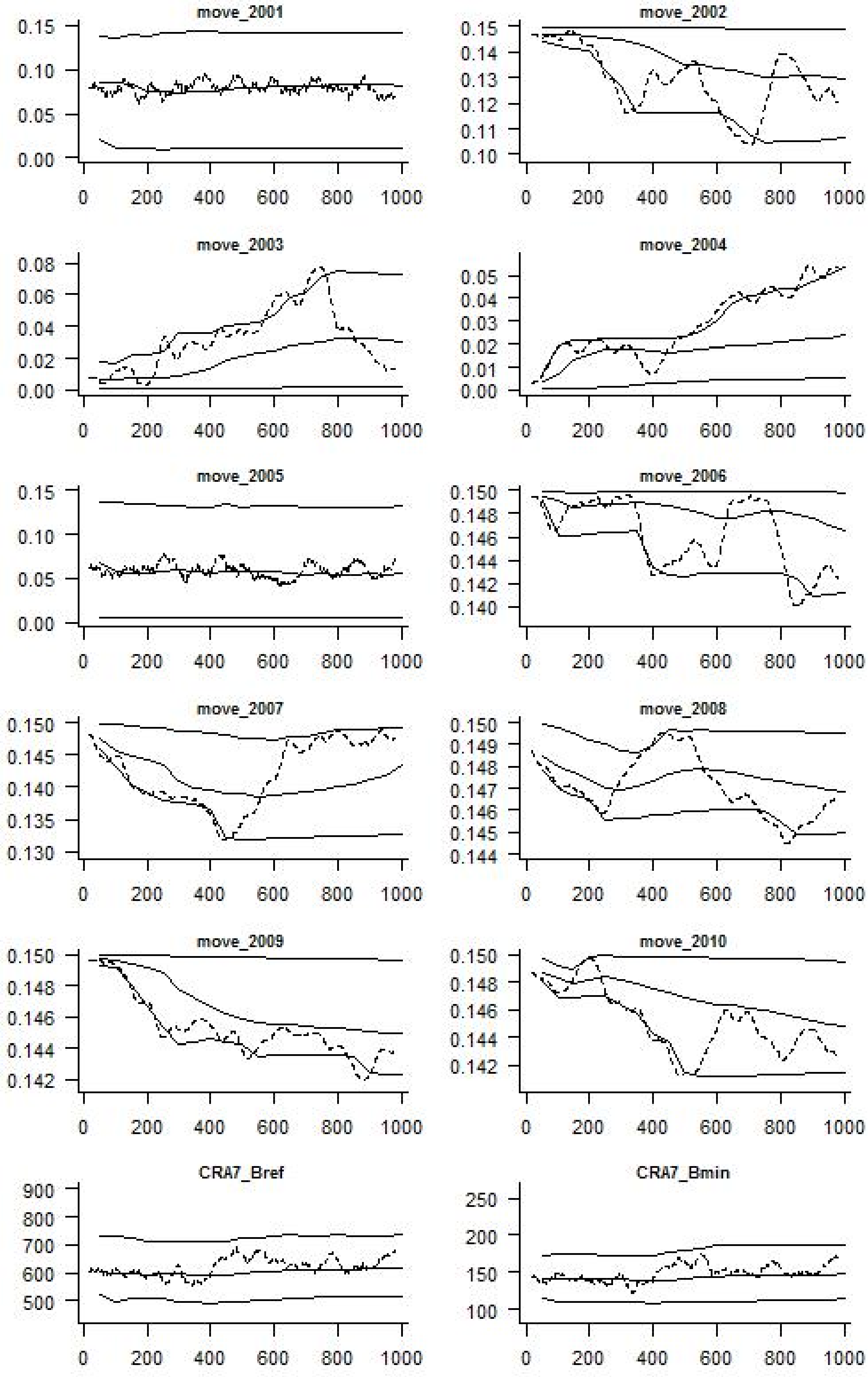

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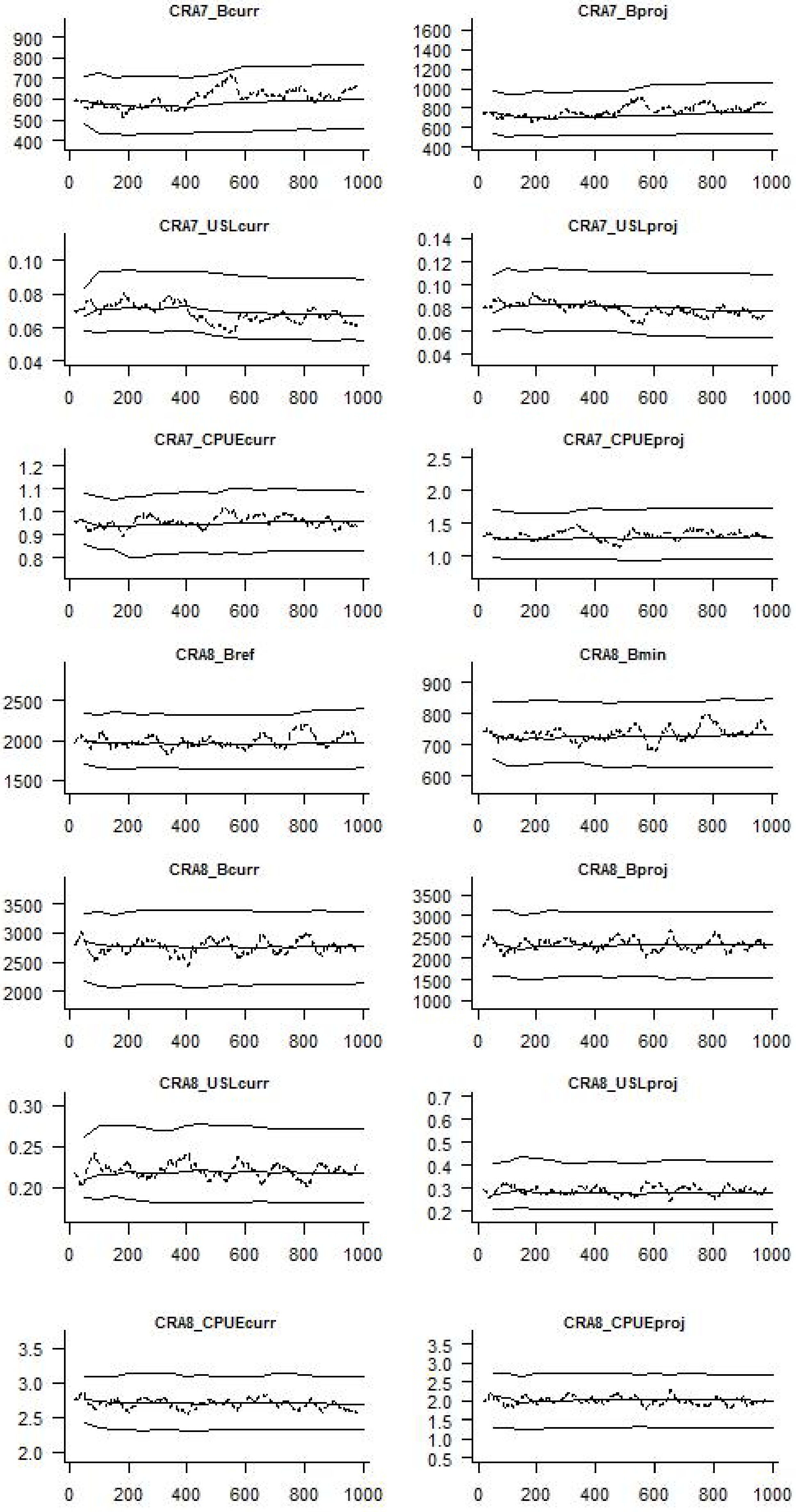

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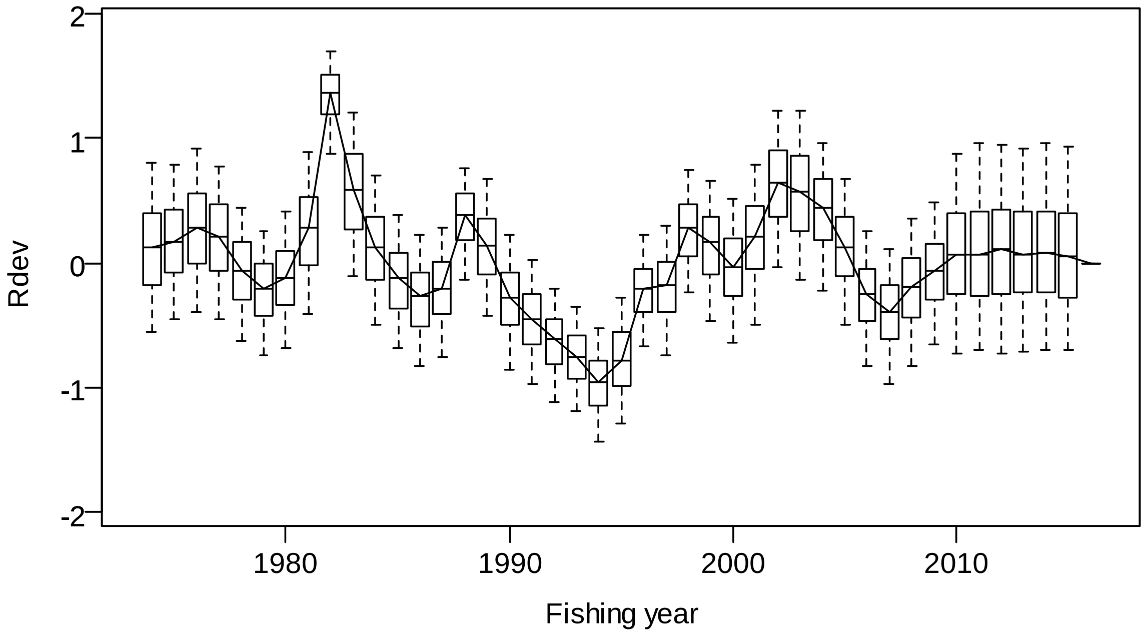

Figure 25: CRA 7: Posterior trajectory of the recruitment deviations from the final base case McMC.

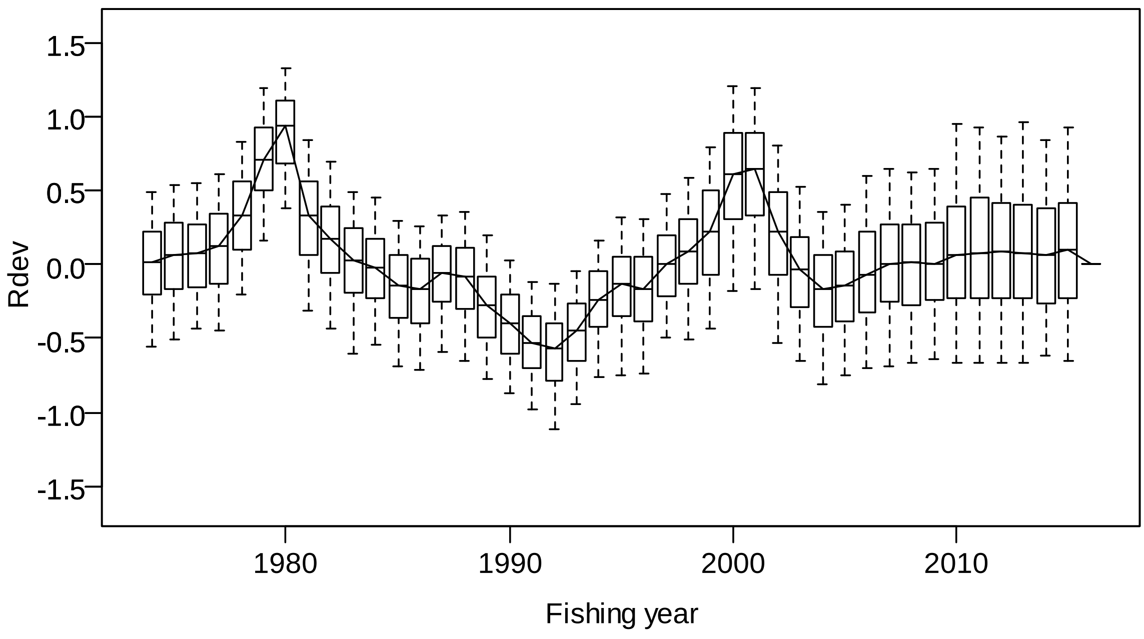

Figure 26: CRA 8: Posterior trajectory of the recruitment deviations from the final base case McMC.

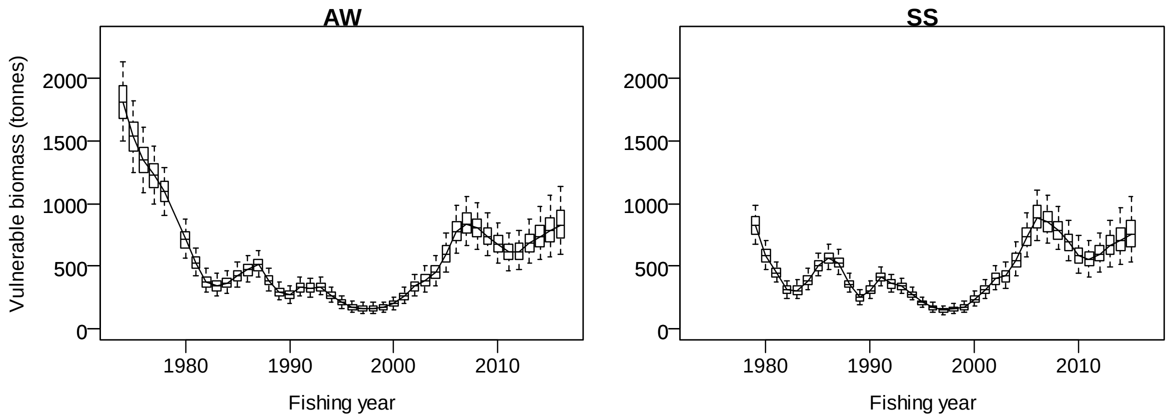

Figure 27: CRA 7: Posterior trajectory of vulnerable biomass from the final base case McMC.

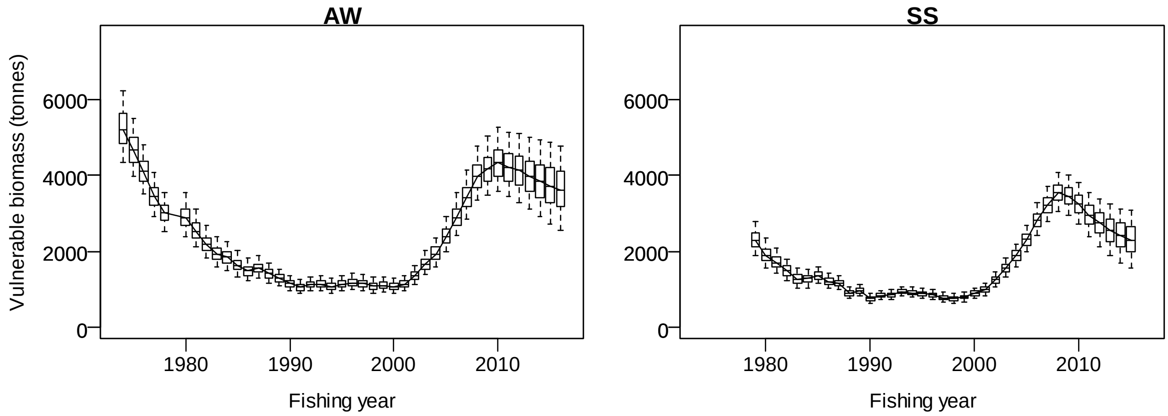

Figure 28: CRA 8: Posterior trajectory of vulnerable biomass from the final base case McMC.

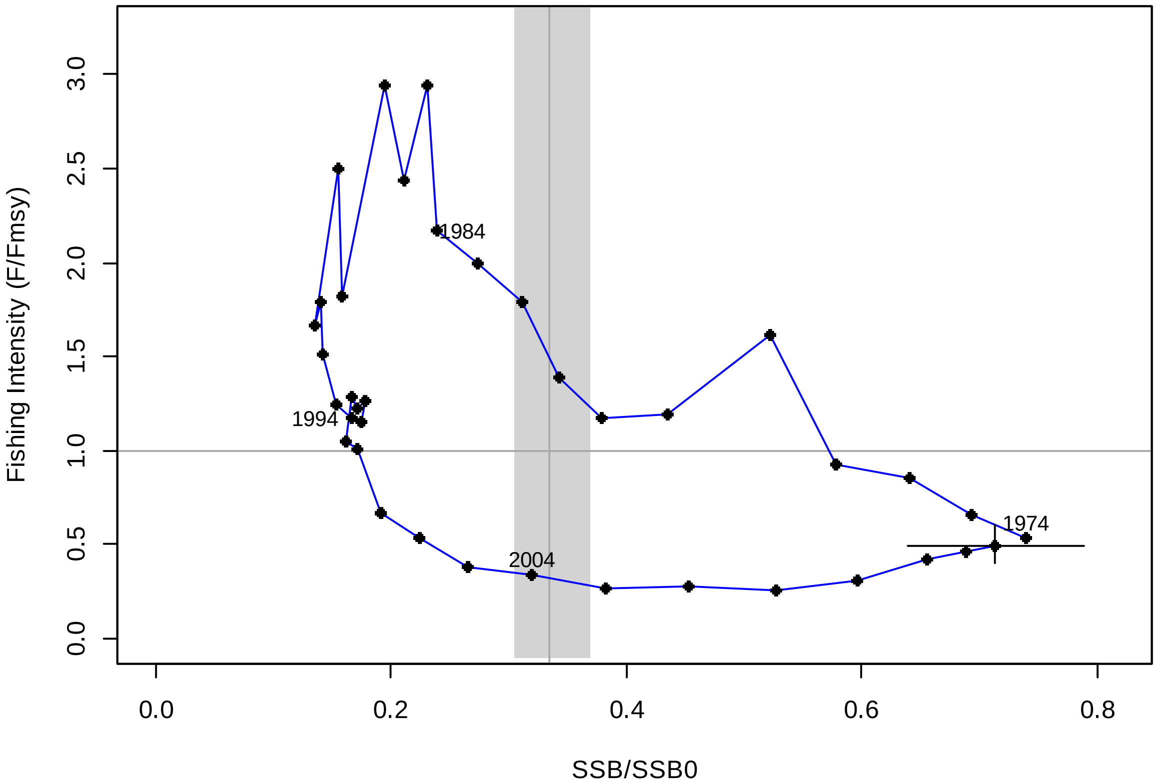

Figure 29: Phase plot of fishing intensity vs. biomass in CRA 8, based on the final base case McMC. The phase space in the plot is biomass on the x-axis and fishing intensity on the y-axis. Specifically, the x-axis is spawning stock biomass *SSB* in year y as a proportion of the unfished spawning stock, *SSB0*. *SSB0* is constant for all years of a run, but varies through the 1000 runs. The y-axis is fishing intensity in year y as a proportion of the fishing intensity (*Fmsy*) that would have given *MSY* under the fishing patterns in year y; fishing patterns include MLS, selectivity, the seasonal catch split, the balance between SL and NSL catches, average movement from CRA 7 to CRA 8 and full retention. *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* is *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* (the spawning stock biomass associated with *MSY*) as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2011. 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.

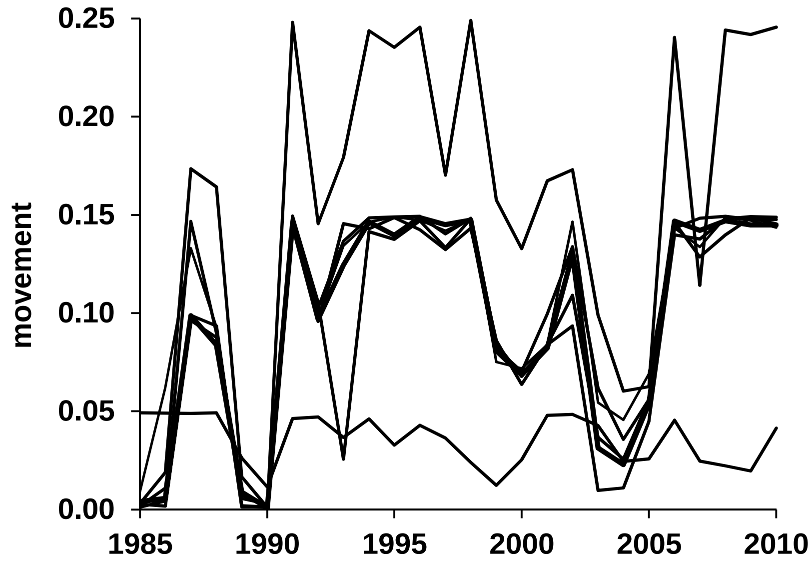

Figure 30: Medians of the annual movement parameters from the McMC sensitivity trials: the bold line is the final base case.

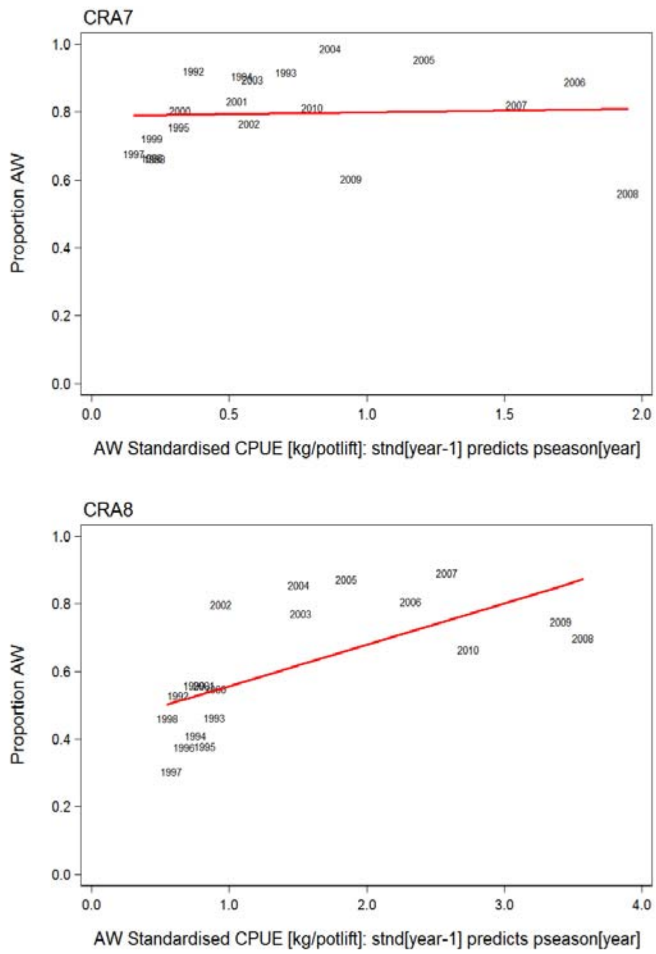

Figure 31: Plots of AW predictive season split: CRA 7 above and CRA 8 below.

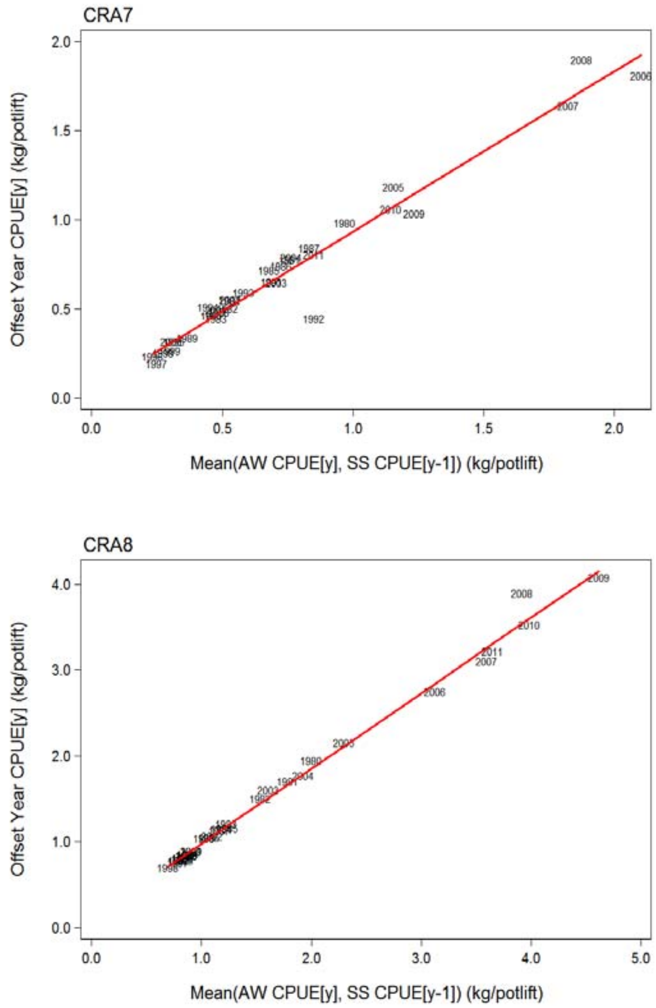

Figure 32: Plots of predictive offset year CPUE: CRA 7 above and CRA 8 below.

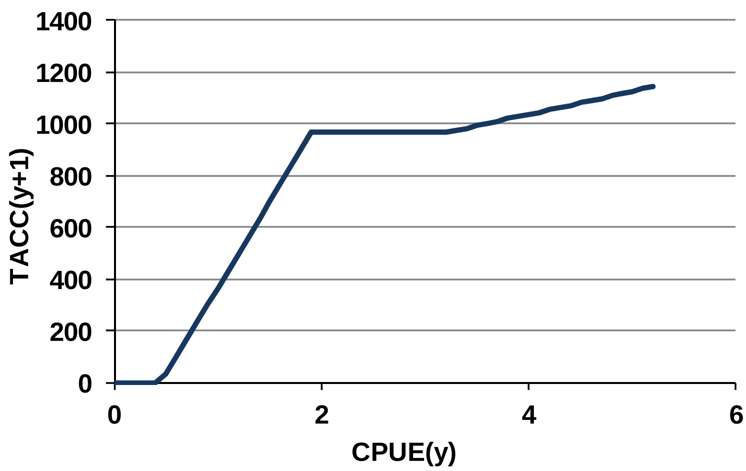

Figure 33: An example of the generalised harvest control rule family used in this study: this is the analogue of the existing CRA 8 harvest control rule, translated from a TAC-generating rule to a TACC-generating rule under the assumption that non-commercial allowances would be the same. The important components of this rule family are: a CPUE value at which TACC becomes zero, the CPUE values at the left- and right-hand edges of the plateau, the TACC on the plateau and a slope for the region above the plateau.

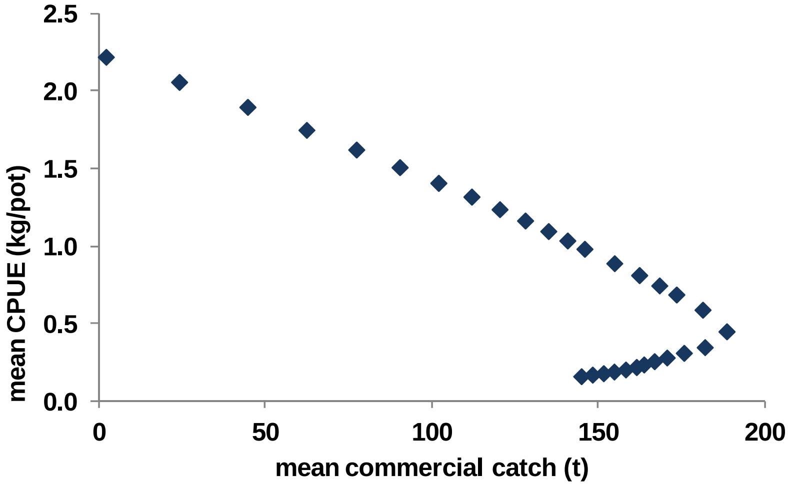

Figure 34: CRA 7: relation between mean catch and mean CPUE. Each point is the median from one fixed-rate harvest control rule.

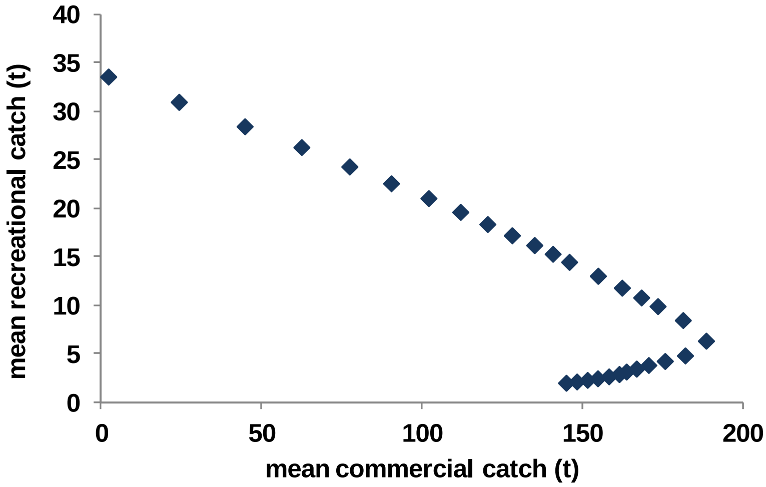

Figure 35: CRA 7: relation between average commercial and recreational catches.

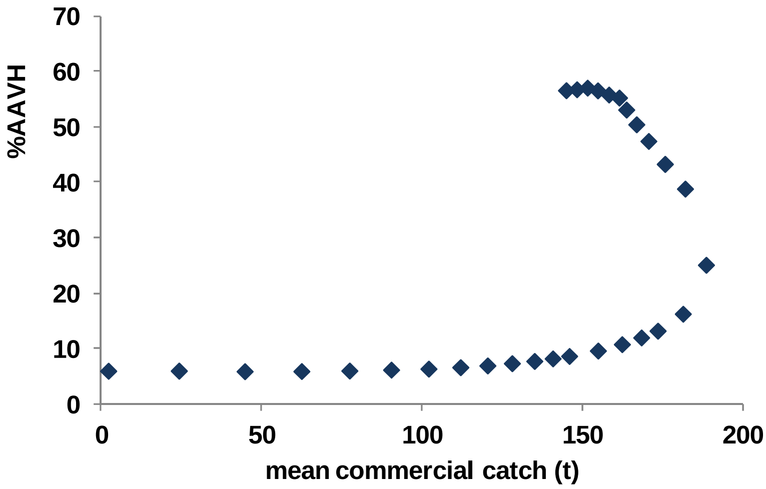

Figure 36: CRA 7: relation between commercial catch and AAVH (average annual variation in TACC).

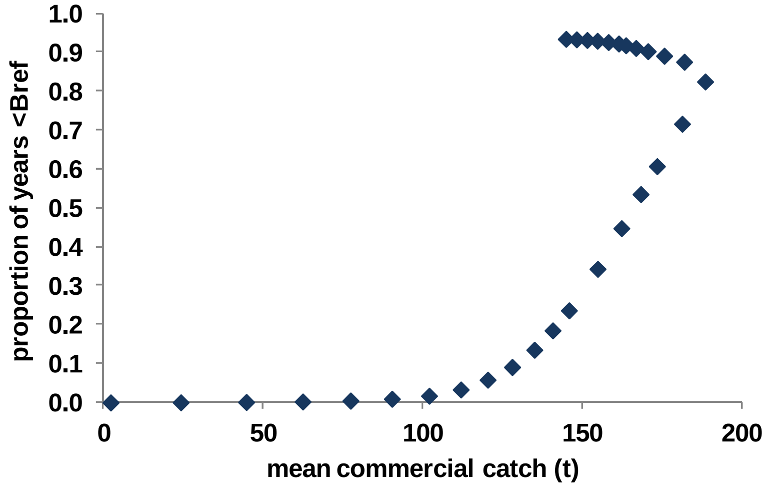

Figure 37: CRA 7: relation between commercial catch and the proportion of years with biomass less than *Bref*.

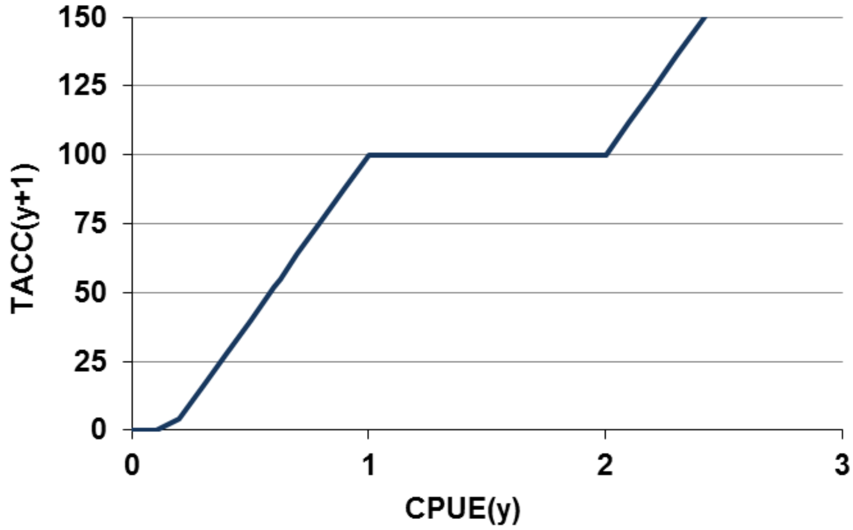

Figure 38: The analogue of the existing CRA 7 harvest control rule, translated from a TAC-generating rule to a TACC-generating rule under the assumption that non-commercial allowances would be the same.

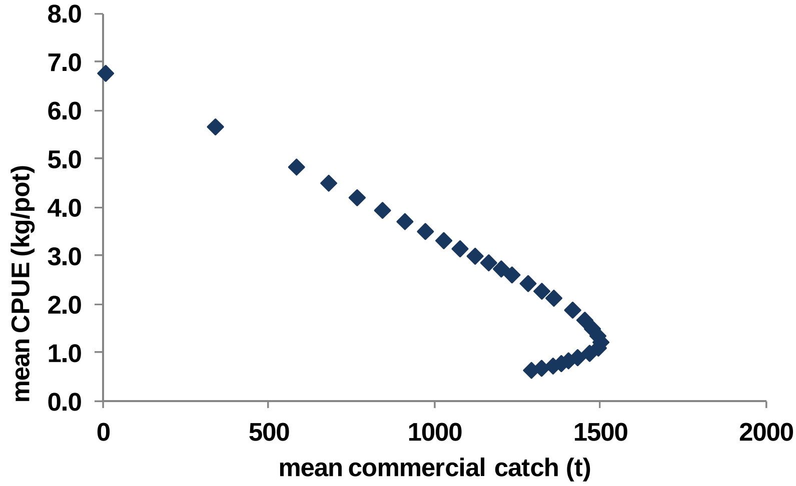

Figure 39: CRA 8: relation between mean catch and mean CPUE.

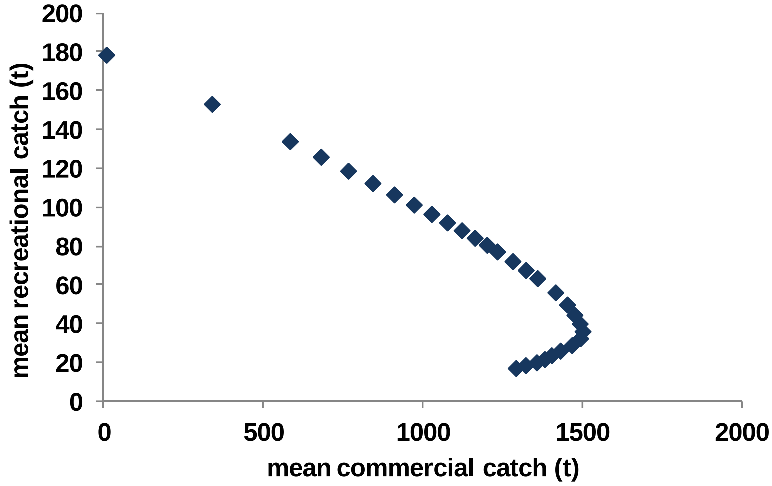

Figure 40: CRA 8: relation between average commercial and recreational catches.

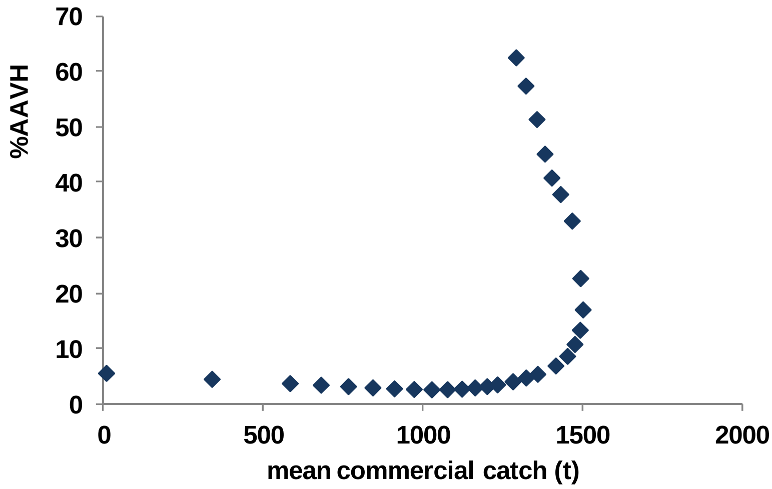

Figure 41: CRA 8: relation between commercial catch and AAVH (average annual variation in TACC).

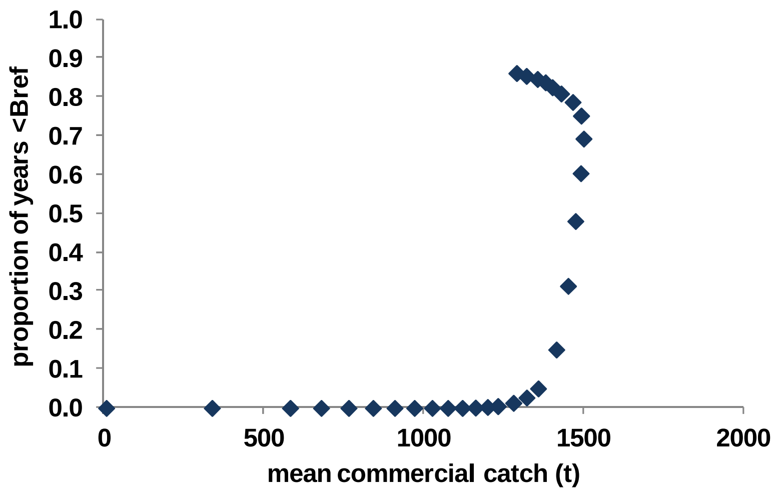

Figure 42: CRA 8: relation between commercial catch and the proportion of years with biomass less than *Bref*.

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/TACC; Allowances must 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 is 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.

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): 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;

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).

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: 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) 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; $Z = F + M$.