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The 2014 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 1 and development of management procedures

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This document describes a new stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 1 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 done using the multi-stock length-based model (MSLM). The Rock Lobster Fishery Assessment Working Group oversaw this work, and all technical decisions were agreed beforehand or subsequently approved by the group. The model was fitted to catch per unit effort (CPUE), size frequency and tag-recapture data. This document describes the procedures used to find an acceptable base case and shows the model fits. The assessment was based on Markov chain Monte Carlo (MCMC) simulations, and the document describes the diagnostics for these and shows the results of MCMC sensitivity trials. Short-term projections were made at the current assumed levels of catch.

This stock assessment suggests that $B_{current}$ has zero probability of being below the default hard and soft limits of 10% and 20% spawning stock biomass and a probability of 1.0 of being above B_{msy} and B_{ref}. Similar probabilities are associated with $B_{project}$. At current catch levels, biomass is projected to stay near current levels, given recent recruitments.

The assessment model was used as the basis for an operating model to test management procedures for CRA 1, which has not previously been managed in this way. The rules tested determined annual total allowable commercial catch as a function of offset-year CPUE, in keeping with recent similar evaluations for other rock lobster QMAs. These rules were "plateau" rules, which give high catch stability, with a series of increasing steps above the right-hand edge of the plateau. Each rule was tested with 1000 21-year simulations, based on the MCMC posteriors, to address parameter uncertainty, and with stochastic variation in CPUE observation error and in recruitment. Rule behaviour under alternative operating model assumptions was tested using two robustness trials. 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.

1. INTRODUCTION

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

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

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

During 2014, the National Rock Lobster Management Group (NRLMG) agreed that Objective 4 should be addressed with a stock assessment for CRA 1 and CRA 3, and that Objective 5 should be addressed by development of management procedures for CRA 1 and CRA 3. The CRA 3 work is described by Haist el al. (2015). This document describes the CRA 1 work, using the data described by Starr et al. (2015). The previous assessment of CRA 1 was in 2002 (Starr et al. 2003).

The CRA 1 stock assessment used the multi-stock length-based model (MSLM; Haist et al. 2009) and followed the pattern of recent lobster stock assessments (e.g. Starr et al. 2014; Haist et al. 2013).

Decisions on modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).

CRA 1 extends from Kaipara Harbour on the west coast to the Waipu River, south of Bream Bay and Whangarei (Figure 1). A total allowable catch (TAC) has never been set for CRA 1 because the total allowable commercial catch (TACC) has remained unchanged since the early 1990s, before the introduction of the 1996 Fisheries Act. The current TACC has been 131 tonnes since 1993–94, and the TACC is caught in most years (see table 1 in Starr et al. 2015).

This project also developed management procedures for CRA 1. Management procedures are simulation-tested decision rules (see Johnston & Butterworth (2005) for discussion of a management procedure used to manage rock lobsters in South Africa). Management procedures are now a major part of New Zealand rock lobster management (Bentley et al. 2003b; Breen et al. 2009b). They were used to rebuild the depleted CRA 8 stock in New Zealand and to manage the volatile CRA 7 stock (Starr et al. 1997; Bentley et al. 2003a; Breen et al. 2008; Haist et al. 2013); a voluntary management procedure was used to govern annual catch entitlement (ACE) shelving in CRA 4 to rebuild a badly depleted stock (Breen et al. 2009c) and was revised by Breen et al. (2012); a management procedure was adopted for CRA 5 for the 2012–13 season, after using a voluntary management procedure designed to maintain high abundance (Breen 2009a). A revised management procedure was adopted for CRA 3 in 2010 (Breen et al. 2009a) and in CRA 2 in 2013 (Starr et al. 2014). A management procedure was also implemented for CRA 9 in 2014, based on a surplus-production model (Breen 2014).

This document describes the base case stock assessment, using mode of the posterior distribution (MPD) and Markov chain Monte Carlo (MCMC) inference methods, the projection model, the management procedure evaluations and the final harvest control rules that were submitted to the NRLMG.

Technical terms and abbreviations used throughout this document are defined in the Glossary.

2. BASE CASE MPD AND SENSITIVITY TRIALS

2.1 Model parameters

The descriptions and tables in this section refer to some of the model parameters, and the list below provides a description of the estimated parameters:

- ln(*R0*): the natural logarithm of average recruitment
- ln(*qCPUE*): the natural logarithm of catchability coefficient for the catch per unit effort (CPUE) abundance index
- ln(*qCR*): the natural logarithm of catchability coefficient for the historical catch rate (CR) abundance index (not used in the CRA 1 base case run)
- *M*: the instantaneous rate of fishing mortality
- *Rdev*s: annual recruitment deviations (in natural logarithm space) that allow annual recruitment to be less than or greater than average
- *sigmaR*: the standard deviation of *Rdev*s
- *CPUEpow*: a parameter that determines the shape of the relation between CPUE and abundance (1 implies linear)
- *Mat50*: size at which 50% of immature females become mature at a moult
- *Mat95add*: the difference between *mat50* and *mat95*
- *Galpha*: annual growth increment at 50 mm tail width (TW)
- *Gdiff*: the estimated difference between *Galpha* and *GBeta*
- *GBeta*: : annual growth increment at 80 mm TW
- *GrowthCV*: the relation between expected increment and its standard deviation
- *Gshape*: a shape parameter: 1 gives a linear relation between increment and initial size while greater than 1 gives a curve concave upwards
- *GrowthDD*: a density-dependent growth parameter (described below)
- *StdObs*: standard deviation of observation error
- *StdMin*: the minimum standard deviation of growth

- *Vulnest*: a set of four parameters that estimate the vulnerability of a sex class in a season relative to that of specified sex and season
- *Sel_L*: the shape of the left-hand side of the selectivity-at-length curve
- *Sel_Max*: the size at which selectivity-at-length is maximum
- *Sel_R*: the shape of the right-hand side of the selectivity-at-length curve
- *Gmax*: maximum growth increment for the inverse logistic growth model
- *L50*: the size at which growth is 50% of maximum for the inverse logistic growth model
- *L95*: the size at which growth is 95% of maximum for the inverse logistic growth model.

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

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

where B_t is the total biomass (tonnes) in period t and $B0$ is the initial total biomass (tonnes).

2.2 Stock assessment indicators

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

- *Bmin*: the minimum value of autumn-winter (AW) vulnerable biomass; for this and other biomass indicators, vulnerable biomass was calculated with the 2013 selectivity and minimum legal size (MLS) so that changes over time would not affect the vulnerable biomass estimate
- *Bcurr:* current biomass, taken as the beginning AW 2014 vulnerable biomass
- *Bproj:* projected biomass, taken as AW 2017 biomass; these projections were made using the 2013 catches and using stochastic recruitment based on the mean and standard deviation of recruitment deviations estimated from 2002–2011
- *Bref:* reference biomass, taken as the mean of AW vulnerable biomass in 1979–1988, with the vulnerable biomass defined as for *Bmin*
- *Bmsy:* the equilibrium AW vulnerable biomass associated with *MSY*, determined with a 50-year projection using the mean recruitment from 2002–2011, using 2013 non-commercial catches and fishing patterns (AW/SS catch split, MLS, selectivity), using full retention, and running a set of projections with multiples of the 2013 size-limited instantaneous fishing mortality rate *F*; the multiplier that gave maximum SL catch (*MSY*) was called *Fmult*, with the vulnerable biomass as for *Bmin*
- *SSBcurr, SSBproj, SSBmsy:* indicators using spawning stock biomass (SSB), 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 2013 and 2017, taken as SL catch divided by AW vulnerable biomass
- various ratios of these quantities
- the “soft limit” discussed by the Harvest Strategy Standard (MFish 2011) was agreed by 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.*

Bref is the biomass in a time when the stock was stable, catch and CPUE were considered good, and the stock subsequently declined and recovered, indicating that the *Bref* was a safe place to be. The previous assessment also used 1979–88, based on the biomass trajectory that was available at the time. *Bref* is calculated with the current (2013–14) regulations instead of the regulations that applied during 1979–88.

2.3 Model options

The MSLM has many options for alternative choices for fitting to data. This section describes the options and the choices made for the CRA 1 assessment.

Starting year: In some earlier rock lobster stock assessments, the model was started in the 1970s, even though data are available from 1945, in order to solve problems associated with the assessment. In preliminary fits, no such problems were encountered, so a 1945 start was used for CRA 1.

Last year: was the last year of available data, 2013–14[1].

Seasons: the model has a user-specified time step, and allows a change of time step size in the period being modelled. We used an annual step for 1945–78 and a 6-monthly time step for 1979–2013. An unavoidable simplification resulting from these assumptions is that berried females are allowed to be caught in the model until 1979.

Size structure: as in previous assessments, we used 31 2 mm bins for each sex, ranging from 30 to 90 mm.

Model recruitment size: recruitment to the model occurs with a mean of 32 mm and a standard deviation of 2 mm.

Data: length frequencies (LFs), catch per unit effort (CPUE), and tag data were included in the model. No puerulus or pre-recruit data are available for CRA 1. The historical catch rate (CR) data were initially included in the model, but were found to have substantial leverage in the estimates of *M* and the recruitment deviates, resulting in high estimates for *M* and some of the recruitment deviates sitting on the parameter bounds. These problems disappeared when this series was dropped so the base case model did not include these data. The fit which includes the CR data is provided as a MPD sensitivity run.

Likelihoods: data sets can be fitted with a variety of likelihood options. For LFs we have assumed a multinomial distribution as for all recent assessments (but see below for a discussion of two alternative fitting approaches). For abundance indices, we have used the lognormal distribution in all recent assessments. For tag-recapture increments we have used a robust normal in all recent assessments.

Dataset weights: were determined iteratively as discussed below.

Fishing mortality dynamics: the three model choices are a) instantaneous, using Newton-Raphson iteration to determine *F* from biomass, catch and *M*, b) instantaneous with *F*s estimated as model parameters, or c) finite. We used the first option as in the past two stock assessments. The number of Newton-Raphson iterations is a sub-option for choice (a). We determined that the MPD results were insensitive to either three or five Newton-Raphson iterations and used 3 Newton-Raphson iterations in the MCMC simulations.

Growth model: the model can use a) a version of the Schnute-Francis model or b) the inverse logistic model. We used the Schnute-Francis model as done in all previous stock assessments because this model has consistently shown better diagnostics and fits to the data.

Density-dependent growth: this option was not used in the base case because, unlike for CRA 2 (see Starr et al. 2014), this parameter had no impact on the fit to the data. We conducted an MPD sensitivity trial which included density-dependence.

Stock-recruitment function: this option was not used, which is consistent with all previous rock lobster stock assessments.

Movements: the model can estimate movements between stocks when there are multiple stocks. This option was not used because CRA 1 was assessed as a single stock (see Appendix C in Starr et al. [2015] for a discussion of spatial heterogeneity in CRA 1).

Recruitment deviations: can be estimated for all years or a subset of years. We estimated them from 1945 to 2011.

[1] each fishing year is designated by the first year of the pair: e.g. 2013–14 is referenced by 2013.

Initial exploitation rate: we assume that the stock is in equilibrium with average recruitment when starting in 1945.

Selectivity epochs: we estimate separate selectivity functions before and after 1993, in recognition that selectivity would have changed when the escape gap and female MLS regulations were changed beginning with the 1993–94 fishing year.

Selectivity type: the available model options are logistic or double normal. We chose double normal with a fixed right-hand limb with minimal descent. We made an MPD sensitivity trial using logistic selectivity and another which estimated the right-hand limb for both epochs.

Category with sex/seasonal vulnerability=1: the model estimates sex/seasonal vulnerabilities relative to a specified sex and season. We specified that males in AW should be 1 and others should be estimated relative to that. This gave estimated values for the remaining sex/season categories that were all less than 1. We used *vulnest1* for males in spring-summer (SS), *vulnest2* for immature females in AW, *vulnest3* for both types of female in SS and *vulnest4* for mature females in AW.

"Punt's phenomenon": The 2013 CRA 2 stock assessment used a reduced tag-recapture data set by dropping recovery observations resulting from lobsters that had been re-released. This was done because, in some instances, re-released lobsters tend to have smaller than predicted increments, presumably caused by slower-growing fish being less likely to be above the MLS and thus more likely to be returned to the sea. Therefore the inclusion of re-released tags may bias the growth estimates. However, no evidence of this effect could be found in the CRA 1 tag data set, and, because data were limited, the base case included all of the available tag data. An MPD sensitivity run was made which was based on tag data from only the first release-recovery observation.

2.4 Fitting to length frequencies

Two options are available for fitting to the LFs. The option used in assessments before 2013 compared observations and predictions that were normalised across all three sex groups. Thus the model was estimating both the relative proportions of males by size and the relative proportion of males against females at the same time.

The second option (new in 2013) fits to the LFs in each sex class separately, so within a record the males are normalised independently of the females, and mature females independently of males and immature females. The model also fits to the sex proportions using a multinomial likelihood, and uses three independent weights for the proportions-at-size in the three sex classes and a fourth for the overall sex proportions.

We used the second approach in the base case, and ran two MPD sensitivity trials with the option used in previous stock assessments.

2.5 Initial explorations

Exploring for a base case involved:

- experimenting with dataset weights
- experimenting with the LF estimation method
- adding informed priors to constrain some model parameters.

A constraint when finding a base case was the need for the estimated Hessian matrix to be positive definite (pdH) so that a MCMC simulation could be performed.

Informed priors were used to constrain the four selectivity ogives (one for males and females in each of the two epochs) because early model fits indicated that the available data had very little information for finding sensible values for these parameters in the first epoch (the available LF data started in 1994, after the change in the escape gap regulations). Because the model code did not allow fixing the parameters for only part of the reconstruction, the available solutions were to reduce the two epochs to a single epoch or to use informed priors. The latter approach was adopted, using the median values from the CRA 2 base case posterior distributions (Starr et al. 2014) from the CRA 2 second epoch to set the mean for the priors presented Table 1. A normal distribution with CV=0.2 was assumed for these parameters because the CRA 2 posterior distributions had very tight CVs.

Unlike other recent CRA stock assessments, the growth parameters, including *GrowthCV*, were well behaved, with good model fits and acceptable residual patterns. Informative priors were initially used for the *GrowthCV* parameters, but these proved to be unnecessary, with the same parameter estimates obtained using an uninformative prior. However, one LF record (1993 SS LB) consistently had large standardised residuals (greater than 600 for mature females). We were concerned that these large residuals would affect the minimisation procedure and the MCMC search. Consequently, we discarded the entire sample even though it represented over 1400 measured lobsters. We also discarded all samples where fewer than 100 lobsters had been measured (there were three of these), reasoning that these samples would not be representative of the fishery. This left 38 LF samples for use in this model.

2.6 Base case: MPD results

The specifications for parameter estimation in the chosen base case are shown in Table 1. Most priors were uniform with appropriate bounds. Informative priors were used for *M* (the same prior used in previous rock lobster stock assessments, based on a literature search) and the recruitment deviations (normal in natural log space with a mean of zero and standard deviation of 0.4). Informed priors were also used on the four estimated selectivity parameters for the reasons described in the preceding section. The dataset weights and other fixed values are shown in Table 2.

The fit to CPUE (Figure 2) is good, except that the model was unable to match the SS peak CPUE in the late 2000s. The CPUE residuals (Figure 3) show no obvious trends and the observed and predicted CR (Figure 4) are remarkably similar, even though the model is not fitting to these data.

The fit to tag-recaptures is harder to explore because of the differing times at liberty. Figure 5 compares the predictions and observations. Figure 6 shows that residuals tend to fit the theoretical distribution. Unlike in CRA 2, the residuals for both sexes do not show a trend from positive to negative with increasing size (Figure 7). There is a suggestion in males that there is a “Punt phenomenon” effect, with subsequent recoveries showing negative residuals, but this effect is absent in the female recoveries (Figure 8).

Fits to LF data (Figure 9) are acceptable with no apparent trend in the residuals by size and sex (Figure 10). Fits to the sex proportions in the AW season are good (Figure 11) while there is a systematic bias in the fit of the sex SS proportions, with the model over-estimating the male proportion and under-estimating the mature female proportion (Figure 12). This bias can be seen in the residuals as well (Figure 13). A great deal of effort was expended in trying to find model fits which did not show this bias. These included overfitting the LF data using the previous weighting procedure for length data, making the SS females the most vulnerable category, and fixing shape to widen the growth gap between males and females. Some of these trials are reported below as sensitivity runs. However, it was not possible to find a combination of model options which did not show the pattern observed in Figure 12.

A plot of the observed and predicted mean length by year, sex and season shows a gradually increasing trend over time for both males and mature females (Figure 14). Most of the estimates lie within one standard deviation of the predicted mean length.

The vulnerable biomass trajectory (Figure 15) shows a long biomass decline from the start of the fishery until the mid-1970s, followed by a gradually increasing biomass trend. Recruitment (Figure 16) shows much variability after 1979, when the modern data first become available.

Recruited biomass, shown seasonally in Figure 17, has similar biomass trends as seen for the vulnerable biomass. Exploitation rates have been low for the NSL fishery (Figure 18) while the SL fishery has shown different patterns over the two seasons, with peaks in AW before 1980 while the SS peaked from 1980 to the mid-1990s. Both seasons have similar exploitation rates (unlike other CRA

QMAs, where the SS exploitation rate tends to be greater than the AW exploitation rate), ranging just above 0.1. Maximum exploitation rates have been relatively low in CRA 1, never rising much above 0.4.

The epoch 1 selectivity curves do not move far from the prior while the epoch 2 selectivity functions have flattened relative to the prior (Figure 19). The female epoch 2 selectivity function is shifted well to the right, with peak selectivity occurring above 70 mm tail width, probably caused by the high recent female mean length values that can be seen in Figure 14. The estimated maturity function shows that most females are mature by the time they reach the MLS of 60 mm (Figure 20). Predicted increments-at-size are shown in Figure 21. The equilibrium size structure at the beginning of the model reconstruction is shown in Figure 22. The large size of the 90+ length bin for males in this figure is caused by the parameters of the growth model which predict a large proportion of males greater than 90 mm TW at equilibrium. This prediction is uncertain and cannot be tested. However, the frequency of large males in CRA 9, located immediately below CRA 1 on the west coasts of the North and South Islands, shows very high proportions of males in the 90+ size bin in recent fishing years (see figure A3 in Breen 2014).

Base case results are shown in the first data column of Table 3. The *sdnr* values for the tags, CPUE and sex proportions are all near one. Similarly, the median absolute residual (MAR) values are near the target value of 0.67, indicating a reasonable correspondence with the model distributional assumptions.

The estimate for *M* is similar to the prior, while the growth parameter estimates are reasonable and not hard against the bounds. The estimates for the *GrowthCV* parameters are relatively low, reflecting the good fits to the observed recoveries that can be seen in Figure 5. The *vulnest*s are all less than one, suggesting that the vulnerability has been parameterised appropriately.

B_{ref} is estimated at 359 tonnes (vulnerable biomass in AW, using the period 1978–88) which is lower than the estimate of B_{msy}. The base case suggests that the current biomass is well above B_{ref} and 40% above B_{msy}.

2.7 MPD sensitivity trials

We ran a range of trials that explored the sensitivity of model estimates and results to modelling choices. These were:

base2: "N-R 3": with three Newton-Raphson iterations instead of five. This run became the MCMC "base case" because the estimated parameters and likelihoods were nearly identical to the "N-R 5" MPD base case. This version was taken to MCMC because of the reduced search time required.

sens1: "Add CR": add the CR (1963–1973 catch/day) series to the likelihood.

sens2: "Alt recreational catch": uses an alternative procedure to estimate recreational catch, resulting in an increasing catch series (see Figure 23).

sens3: "Half illegal catch": uses half of the base case illegal catch trajectory (see Figure 24). This sensitivity needed to have *GrowthCVM* and *GrowthCVF* fixed to the base case values to allow this run to be taken to the MCMC level.

sens4: "Double illegal catch": uses twice the base case illegal catch trajectory (see Figure 24).

sens5: "Only Rel=0": only uses tags where the release-recovery pairs resulted from the first recapture. This reduced the 1675 tag recoveries to 1444 recoveries.

sens6: "DD on": estimate the density dependence parameter.

sens7: "CPUEpow": estimate the relation between biomass and CPUE with a power function instead of a simple linear function.

sens8: "Old LF=10": uses the original fitting procedure (see Section 2.4) based on normalisation across all sex categories, weighting the LF data at 10 (results in approximately the same weight as the base case Francis procedure).

sens9: "Old LF=30": uses the original fitting procedure (see Section 2.4) based on normalisation across all sex categories, weighting the LF data at 30 (greatly overweighting the LF data relative to the base case).

sens10: "No trunc": with the weight on each of the 38 LF records set at its raw value, rather than being truncated to lie between 1 and 10 (there were no records with values over 10). This sensitivity run needed to have *GrowthCVM* and *GrowthCVF* fixed to the base case values to give sensible parameter estimates.

sens11: "Est righthand limb": estimate the right hand limb selectivity parameter rather fixing it. This adds four parameters to the model, one each for males and females in the two epochs.

sens12: "Fixed shape": fix the *GShape*M and *GShapeF* parameters to MPD values from a growth model estimated across all nine Quota Management Areas (QMAs). This sensitivity run also fixed *GrowthCVM* and *GrowthCVF* to the base case values and was done to force a wider distance between the time required by males and females to reach the MLS.

sens13: "Fixed shape+switch vulnest": fix the *GShape*M and *GShapeF* parameters to values estimated across all nine QMAs (as in sens12) as well as setting the SS females to have highest relative vulnerability. *GrowthCVM* and *GrowthCVF* were fixed to the base case values to force a wider distance between the time required by males and females to reach the MLS

sens14: "Logistic selectivity": estimate selectivity as a logistic function rather than the double normal used in the base case and the other sensitivity runs

Results from these sensitivity runs are compared with the base case in Table 3. Reducing the Newton/Raphson iterations from five to three resulted in the same total likelihood and parameter estimates which only differed in the fourth or fifth decimal place. These results were so close that this run was considered to be equivalent to the base case and was used for the MCMC search procedure because of the reduced computational time. The remaining 13 sensitivity runs were also made with only three Newton/Raphson iterations.

Adding in the CR series (sens1) caused considerable change to the base case results and demonstrated why this series was not used in the CRA 1 base case. The estimate for *M* doubled from 0.11 to 0.22 while the likelihood contribution from the priors increased from –50.6 to –8.1 (Table 3). The fits to the LF, tag and CPUE data are all poorer than for the base case, indicating that the higher *M* estimate came primarily from getting a better fit to the CR data and was not consistent with the other data sets. This was not considered acceptable behaviour and resulted in moving this run from candidate base case to a sensitivity run.

The alternative recreational catch trials (sens2) and the two alternative illegal catch trials (sens3 and sens4) had only small effects on the model results. All three estimated similar ratios for B_{2014} with the 1979–1988 reference period. There was an expected variation in MSY, with the lower illegal catch having a lower MSY and the opposite effect with the higher illegal catch. MSY was not affected by the alternative recreational catch trajectory because the total catches in these two models is similar. The fits to the data vary between these three sensitivity runs, but the differences are not large.

Model results differed little when the tag recovery data set was reduced to recoveries from the first release (sens5; Table 3). The fits to the LF and CPUE data hardly changed as did the sex proportions. There were some differences in the growth parameter estimates and a drop in *GrowthCVM* (but *GrowthCVF* did not change). Surprisingly B_{ref} dropped while B_{msy} increased, but the ratio of *Bcurr/Bref* did not change.

There was no impact at all when density dependence was estimated (sens6), with the estimate for the associated parameter scarcely moving away from its initial value of zero (Table 3).

CPUEpow, when estimated, was quite large (greater than two; sens7; Table 3). This results in a better fit to the CPUE data (by about 8 likelihood units) but changes little else from the base case fit. This improvement in the fit is obtained by the model getting a somewhat better fit to the SS peak in the late 2000s (Figure 25). However, the model prediction is still below the peak and the high value for *CPUEpow* precludes the use of this model in the management procedure. This sensitivity trial resulted in an increase in B_{ref} and no change in B_{msy} relative to the base case. The ratio B_{curr}/B_{ref} also dropped while there was little change in B_{curr}/B_{msy} relative to the base case.

Two different sensitivity analyses were run when fitting the LFs using the older procedure (sens8 and sens9). The lower weight run (weight of 10; sens8; Table 3) was done to emulate the weight using the base case Francis procedure (as can be seen by comparing the LF, *sdnr* and MAR). The higher weight run (weight of 30; sens9; Table 3) deliberately overweighted the LFs in an attempt to reduce or eliminate the bias shown in the SS sex ratios plotted in Figure 12. Both runs had worse fits to the CPUE data, with sens9 (LF=30) having a much poorer fit (by nearly 20 likelihood units; Table 3). Unfortunately, neither sens8 nor sens9 solved the problem of the biased sex ratios (Figure 26).

Using the raw LF weights (sens10; Table 3) resulted in no change from the base case. This was because, unlike in other CRA QMAs, there were no LF samples with weights greater than 10. The low weights (much less than one) from some of the samples resulted in very poor model fitting behaviour, with the estimates of *M* rising to greater than 0.30 and the estimate for ln(*R0*) going to its upper bound. This behaviour disappeared when the *GrowthCV* parameters were fixed to the base case estimates.

Estimating the right hand limb of the selectivity function (sens11; Table 3) resulted in strong estimated descending limbs for males in both epochs and for females in the first epoch (Figure 27). It is unclear why the model estimated such strong descending limbs in the first epoch because there are no LF data in the model which are associated with the first epoch, with the first samples available in 1994. The signal did not seem to come from the CPUE data, because the fit to the CPUE in this sensitivity trial is the same as for the base case (Table 3). The lack of a descending limb for females in the second epoch can be explained by the high mean lengths in this sex category during this epoch (see Figure 14). This sensitivity trial resulted in an increase in B_{ref} and a drop in B_{msy} relative to the base case. The ratio B_{curr}/B_{ref} also dropped while B_{curr}/B_{msy} increased.

Two sensitivity trials were run to try to force a widening of the time to reach MLS between the sexes. Females have much faster initial growth when fitting the model to the CRA 1 tag data (Figure 21). This resulted in a narrowing of the time taken to reach MLS, with both sexes nearly equal in the base case and the sensitivity trials which use the tagging data (Table 3). In an attempt to see how widening this gap would affect the sex ratio bias identified in Figure 12, the *GShape* parameters were fixed to values that resulted in faster initial male growth (Figure 28). The values for these parameters were taken from a global analysis of all the available rock lobster tagging data (P.A. Breen, pers. comm.). Two versions of this “fixed shape” trial were run. The first (sens12) used the same pattern for the *VulnEst* parameters as in the base case. The other (sens13) estimated the *VulnEst* parameters relative to the females in the SS season. It should be noted that the male AW vulnerability was estimated at one in this trail, indicating that this parameterisation is not appropriate (Table 3). While these two trials were successful in widening the gap between the recruitment of each sex to 1.5 years (sens12) and to two years (sens13) from the 0.5 years in the base case, neither of these sensitivity trials had much effect on the sex ratio bias (Figure 29).

A sensitivity trial was run which estimated selectivity with a logistic function rather than the double normal used in the base case (sens14; Table 3). This trial required setting informative priors on the selectivity parameters for the same reason as was done with the double normal parameters in the base case. Mean values were taken from a similar sensitivity trial made for the CRA 2 stock assessment (Starr et al. 2014), again assuming a normal distribution with CV=0.2. The fits to the LF, tagging and CPUE data for this sensitivity trial were very similar to the base case, as were the estimates for B_{ref}, B_{msy}, B_{curr}/B_{ref} and B_{curr}/B_{msy} (Table 3).

3. BASE CASE MCMC

3.1 Finding MCMC stationarity in the “base case”

Because of poor MCMC performance which indicated non-stationarity in the base case, the CRA 1 base case MCMC was extended in several ways:

1. The initial MCMC chain of two million iterations was restarted and run for a further eight million iterations, saving every 2000th iteration, giving a final chain of 4000 samples. This chain was then thinned by retaining every 4th sample for a final sample of 1000.
2. Four different base case MCMCs were started, two of which used three Newton-Raphson (N-R) iterations to estimate the catch and the other two used five (this was done because the CRA 3 assessment found some indication of significant differences between the chains generated using

the two different N-R assumptions). Three of these chains were started with different random number seeds while the fourth used the same seed as the long chain described in the previous paragraph. Three of these chains were run for six million iterations, saving every 2000th iteration and the fourth was run for four million, again saving every 2000th iteration. The resulting 11 000 draws were then stacked and thinned to a final sample of 1000 by retaining every 11th iteration.

3. A variant on the "base case" was run, based on the observation that an MPD run using an uninformative prior on *M* reached nearly the same minimum as the base case which estimated *M* using an informative prior (lognormal with mean=0.12 and CV=0.4). Four runs were started, each with different random number seeds, two of which used three N-R iterations and the other two used five N-R iterations. These were each run for two million iterations, saving every 2000th iteration. The resulting sample of 4000 was stacked and thinned to a final sample of 1000 by retaining every 4th iteration.

Projections were made to 2017 assuming the 2013 catch distribution. Recruitments were resampled from the most recent 10 years (2002 to 2011).

3.2 Comparison of chains with different number Newton-Raphson (N-R) iterations

We compared the samples and density plots from "base case" posteriors that used either three or five N-R iterations (see Figure 30 and Figure 31 for examples) and concluded that there were no serious differences between the two methods, allowing us to combine the samples.

3.3 Comparison of different "base case" assumptions

We compared the samples and density plots from "base case" posteriors that were based on the "long" chain described in Paragraph 3.1.1 [above] and the "stacked" chain described in Paragraph 3.1.2 [above] (see Figure 32 and Figure 33 for examples) and concluded that there was no difference between the two approaches.

We compared the chains and density plots that were based on runs which assumed an informative prior on *M* (lognormal with mean=0.12 and CV=0.4, described in Paragraphs 1 and 2 [above]) with equivalent runs which placed an uninformative prior on *M*. The empirical cumulative distribution function (ECDF) plots showed some differences between these two approaches, which were possibly greater than those seen with the previous two comparisons (Figure 34). These differences carried through to the posterior density distributions (Figure 35). However, it was decided that the trace plots from the models based on a uniform distribution for *M* showed more evidence of non-stationarity than did the traces from the models using an informed prior on *M* (Figure 36). Consequently it was decided to use the "stacked uniform" model as a sensitivity run and retain the "stacked informed" model as the "base case".

3.4 Base Case results

Posterior distributions of parameter estimates are summarised in Table 4 and compared with the MPD. Trace plots are shown in Figure 37, with diagnostics in Figure 38 and the posterior distributions in Figure 39. The trace plots show good behaviour with no downward drift in the leading parameters (e.g. *M* and *lnR0*) but there is a possible gradual drop in some derived parameters (e.g. B_{min} and B_{ref}). However, the current stock status derived parameter (B_{2013}/B_{ref}) shows good mixing (Figure 40). The posterior distribution plots (Figure 39) indicate that the parameters stayed away from the bounds except in a few isolated instances (e.g. mat95Add, Figure 39A; 3vulnest, Figure 39B).

Posterior distributions of derived parameters are summarised in Table 5. Trace plots are also shown in Figure 37, diagnostic plots in Figure 38 and posterior distributions in Figure 39.

The indicators (Table 5) suggest that 2013 biomass was 73% above *Bmin* (5th to 95th quantiles 53% to 95%), and above B_{min} with 100% probability. B_{ref} is based on the years 1979–1988 which was the definition used in the previous CRA 1 stock assessment (Starr et al. 2003). The projections indicate that the stock is likely to stay near its current level given the current catch distribution.

Paired cross-correlation plots are provided in Figure 41A to Figure 41C, grouped by parameters of interest. The full set of parameters are compared in Figure 42 using colour codes to indicate the degree of correlation.

The posterior of the fit to CPUE (Figure 43) is similar to the MPD fit, with predicted values unable to reach the SS peak in the late 2000s. The fit to the AW series and the remainder of the SS series is acceptable.

Recruitment deviations are variable with an apparent mean just below 400 000 recruits over the last 30 years (Figure 44). The estimated female maturity function is well formed but substantially shifted from the MPD equivalent (Figure 45). The selectivity functions by sex in Epoch 1 are determined by the prior and the tight distribution reflects the lack of data in this model relevant to that epoch (Figure 46). The Epoch 2 functions show a broad distribution which is likely to reflect the variability inherent in the LF data.

Both the total (Figure 47) and vulnerable biomass (Figure 48) trajectories show a strong decline from 1945 to the early 1970s, followed by a gradual increase to current levels. The strong decline is a construct of the model which has no information about the stock apart from catch until 1979 when the CPUE data are introduced. The estimate of *M* (median near 0.12) requires a large initial stock size under the assumption of constant average recruitment to account for all the catches. The sensitivity "FixedM" which is based on a higher *M* paints a considerably different picture of the initial conditions (see below).

The "snail trail" plot for the "base case" (Figure 49) shows most of the weight in the lower right hand quadrant and with the current (2013) biomass well in the "safe" zone. According to this plot, there was only one excursion below B_{msy}, in the late 1980s and early 1990s which appeared to have been reversed by the mid-1990s.

3.5 Stock assessment

The base case indicators (Table 5) suggest i) that the stock is well above the B_{min}, B_{msy} and B_{ref} reference levels; ii) that the stock is likely to grow slightly larger than its present level under current levels of catch; and iii) that the stock is well above the MPI default hard and soft thresholds of 10% and 20% *SSB0*. The snail trial (Figure 49) shows that the spawning stock is well above the *SSBmsy* level, with fishing intensity about half of F_{msy}.

3.6 MCMC sensitivity trials

We conducted five sensitivity trials:

sens1: "uniform M": same as the "base case", except that *M* was estimated with an uninformative prior rather than the informative prior used in the "base case"

sens2: "Alt recreational catch": uses an alternative procedure to estimate recreational catch, resulting in an increasing catch series

sens3: "Half illegal catch": uses half of the base case illegal catch trajectory. This sensitivity needed to have *GrowthCVM* and *GrowthCVF* fixed to the base case values to allow this run to be taken to the MCMC level

sens4: "Double illegal catch": uses twice the base case illegal catch trajectory

sens5: "Fixed *M*=0.2": same as the "base case", except *M* fixed at 0.2

The three sensitivity trials involving alternative catch trajectories were started from the MPD values and run for two million MCMC simulations, saving every 2000th iteration to obtain 1000 samples of the joint posterior distribution. Two independent chains of two million were run for the "FixedM" sensitivity run, saving 1000 samples from each chain. These were then stacked and thinned as described above. The "uniformM" sensitivity run was described in Paragraph 3 on page 11. As for the base case, projections were made to 2017 assuming the 2013 catch distribution after adjusting the non-commercial projection catches to reflect the alternate catch trajectory, where appropriate. Recruitment was resampled from the most recent ten years (2002 to 2011).

Median parameter estimates for these four sensitivity runs and the base case are presented in Table 6 (model parameter estimates) and Table 7 (derived parameter estimates and probabilities).

These trials were consistent with the MPD results (compare Table 6 with Table 3), although there seemed to be more uncertainty in the MCMC posterior distributions than were inferred from the MPD results. For instance, even though the MPD estimates for *VulnEst* were all well away from the upper bound in each sensitivity run, all four sensitivity trials had some weight on the upper bound of one for SS females (see Figure 50 for an example of this).

The "FixedM" sensitivity run provides an interesting alternative run to the base case run. The diagnostic plots (Figure 51) show that leading parameters *lnR0* and the various growth parameters are well behaved. However, unlike for the "base case", the vulnerability parameter for SS females (3vulnest) is hard against the bounds and shows poor MCMC behaviour (Figure 52). Figure 53 shows that the higher *M* in this sensitivity run requires a much smaller initial biomass, with consequent effects on the estimated stock status relative to *SSB0* and B_{msy} (compare the median estimates for these derived parameter values in Table 7: they are much higher for M=0.20).

A "snail trail" plot for the "uniform *M*" sensitivity run (Figure 54) resembles the equivalent figure for the "base case" (see Figure 49), with most of the weight in the lower right-hand quadrant and with the current (2013) biomass well in the "safe" zone.

4. MANAGEMENT PROCEDURE DEVELOPMENT

4.1 Projection model

Projections were made by drawing from the mean and standard deviation of recruitments from 2002 to 2011. Projections were made for 21 years.

For catches:

- TACC was determined from projected offset-year CPUE and the harvest control rule being evaluated
- recreational catch was estimated based on the exploitation rates calculated from the 1979–2013 average recreational exploitation rate as estimated in each MCMC simulation
- other non-commercial catches were fixed at their 2013 estimates(10 tonnes for customary and 72 tonnes for illegal).

Projections simulated CPUE observation error deviations using observed distributions of CPUE deviations and their autocorrelations.

The projected AW/SS catch split was determined from a regression of the observations of the proportion of catch taken in AW against standardised AW CPUE (Figure 55). Projected offset-year CPUE, used by the harvest control rule, was based on the most recent AW and SS CPUE values, using the relation between observed standardised offset-year CPUE and the mean of standardised AW and SS CPUE (Figure 56).

4.2 Harvest control rules

The form of the harvest control rules tested was similar to those used for CRA 2 in 2013 (except that the order of the parameters has been rearranged; Starr et al. 2014; Figure 57). These rules have a plateau, on which the TACC is constant when CPUE remains within the plateau range, and a series of steps on the right side of the plateau. On the left side of the plateau, parameters specify the CPUE when the TACC becomes zero. Other parameters specify the minimum and maximum change thresholds and a latent year switch.

Rule parameters:

- *par1*: rule type (type 4)

- *par2*: CPUE at TACC=0
- *par3*: CPUE at the left side of the plateau (kg/potlift)
- *par4*: CPUE at the right side of the plateau (kg/potlift)
- *par5*: plateau height (t TACC)
- *par6*: step width
- *par7*: step height
- *par8*: the minimum change threshold
- *par9*: the maximum change threshold
- *par10*: a switch for an asymmetric latent year

If a minimum change threshold is specified, the TACC cannot be changed by less than this. Similarly with the maximum change threshold. If an asymmetric latent year is specified, then TACC cannot increase if there has been a TACC change in the preceding year. The rules presented here had a minimum change threshold of 5%, no maximum threshold and no latent year.

4.3 Indicators

Indicators for management procedure evaluations (MPEs) were the same as those agreed by the RLFAWG for CRA 2, with the addition of four new indicators and some changes to the probability indicators used for CPUE (Table 8). As in previous MPEs, biomass is the beginning AW biomass; CPUE is offset-year CPUE calculated from seasonal mid-season CPUEs using the relation described in Figure 56.

Average annual variation (AAVH) in TACC was calculated as:

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

where $TACC_y$ is the TACC (tonnes) during year y.

Indicators were calculated for each run (a run is a 21-year projection from a single sample of the joint posterior distribution of parameters). Except for indicators defined as proportions, indicators were summarised for the whole set of 1000 runs by the 5th and 95th quantiles and medians of the posterior distributions.

4.4 Finding rules to present

The exploration of rules for CRA 1 was conducted in several steps (Table 9). The first phase was determined from an examination of a plot of the CPUE time series for CRA 1 (Figure 58) which indicated that CPUE hovered for over a decade near 1.0 kg/potlift before rising to its current level of near to or greater than 1.5 kg/potlift. This led to an initial decision to fix the left (*par3*) and right (*par4*) hand plateau parameters to 1.0 and 1.5 kg/potlift and to investigate the effect of plateau height (*par5*), step width (*par6*), step height (*par7*) and CPUE resulting in a zero TACC (*par2*) in the first exploration phase (Table 9).

Table 10 shows the ranges of indicators seen in each phase of the exploratory rule evaluations. The second and third exploration phases attempted to improve on the previous phase by reducing the %AAV indicator while maintaining the remaining indicators in zones that were considered acceptable. Average commercial catch varied from near 100 tonnes to over 200 tonnes and average recreational catch varied about the same relative amount (but were negatively correlated), from 40 to 80 tonnes in the first phase. The P(<*Bmin*) safety indicator never went above 0.013 of the years with stock abundance less than *Bmin*, while the P(<*Bref*) and P(<*Bmsy*) indicators were also rarely breached, with the highest probabilities seen at 0.13 and 0.11 respectively. These explorations indicated that the overall CRA 1 system was reasonably stable and could maintain or even improve on existing productivity levels.

A major trade-off in these evaluations is between commercial catch and stock abundance (Figure 59). Because the recreational catch is determined by an exploitation rate, recreational catch increases as commercial catch decreases (Figure 60). The trade-off between these two fisheries is not one to one: a decrease in commercial catch that comes about when a rule operates is divided between the recreational catch and rebuilding of the stock. Another trade-off is between the safety indicators [P(B<*Bmin*) and P(B<*Bref*)] because the frequency of years with stock lower than *Bmin* or *Bref* increases as commercial catch increases (see Figure 59 and Figure 60).

Stability, as measured by the %AAV indicator, tends to be higher at higher abundance (Figure 59 and Figure 60), but shows contrast among rules that give the same average commercial catch. An interesting aspect of the CRA 1 MPE is the high level of stability that can be obtained across all levels of catch (Figure 61).

The greatest contrast among the rule parameters was in plateau height, with higher values giving higher commercial catch, lower recreational catch, lower stock biomass and CPUE and poorer safety indicators (Appendix Table 1). The CPUE value where TACC=0 was relatively unimportant in rule results and was subsequently fixed at parameter value=0.1. Appendix Table 1 shows a sorting approach looking for parameter estimates that tended to reduce the %AAV indicator while still allowing good performance in other important indicators. The parameter values determined from Appendix Table 1 were used in the subsequent evaluation phases so that %AAV was minimised. This was especially true for the step height parameter (*par7*), which tended to have rules with high %AAV when this parameter was given a high (greater than 0.1) value.

4.5 Example rules

Based on the evaluations in the first three phases, the CRA 1 assessment team determined that the rule parameters which showed the greatest contrast were *par4* (right side of plateau), *par5* (plateau height) and *par7* (step height). The other three rule parameters that were investigated showed very little contrast (*par2*, *par3* and *par6*). The assessment team selected the following parameter values for the final rules: *par4* = {1.4, 1.5, 1.7}; *par5* = {120, 130, 150}; *par7* = {0.05, 0.1}. These values were selected to provide contrast in the final set of rules and to include existing observations from the CRA 1 fishery (such as the current CPUE which is close to 1.5 kg/potlift and current commercial catch at 130 t) in the range of parameter values considered. The above 8 parameter values defined 18 blocks of 12 rules each using the parameter ranges defined for “Phase 3” in Table 9. The assessment team noted that, within each block of 12 rules, the contrast in most of the indicators was low (see Appendix Table 2 for examples of this). Consequently, the rule with the lowest %AAV was arbitrarily selected from each block of 12 to represent that block. This almost always was the rule where *par3* (left side plateau) = 0.8 because the rule with this parameter value tended to have the lowest %AAV without compromising the safety or catch indicators. Table 11 gives the parameters used for each of the 18 selected rules and plots of the 18 rules are presented in Appendix Figure 1 to Appendix Figure 9.

4.6 MPE base case and robustness trials

The chosen candidate rules were evaluated with the base case operating model and also a set of robustness trials. The trials agreed by the RLFAWG were:

- a trial in which the CPUE observation error was arbitrarily doubled “Hi_Obs”
- a trial in which recruitment was arbitrarily decreased by using the lowest value in the 10-year moving average of estimated recruitment deviations for projections (see Figure 62); for this trial the mean recruitment deviation was decreased to 0.0 from 0.209 “Lo_rect”[2]

Table 12 compares the rule indicators across the 18 examples rules for the base case trial. These indicators are plotted for the same rules in Figure 63, Figure 64 and Figure 65. The %AAV is higher for the rules where *par7* = 0.1, but all are less than 4% because rules were selected to minimise this

[2] Figure 62 indicates that the lowest decadal value (average 1964–1973= –0.190) occurred well outside the availability of length frequency data that could inform recruitment. The next lowest level in Figure 62 is the period 1981–1990, with a mean recruitment of 0.0, which would have been more likely to have been informed by the model data.

parameter. Safety indicators are all low, (P(<*Bmin*) is always less than 0.01) and P(<*Bref*) is near 0.09 for the rules where *par5* = 150. Rules with lower values for *par5* tend to spend more time to the right of the plateau and no rules spend much time on the left side of the plateau (Figure 65).

Results are shown for each of the 18 example rules for robustness trial one (higher CPUE observation error) in Table 13. This trial had very little effect, with the results similar to or lower than for the base case. Robustness trial two (low mean recruitment) showed sensitivity to lower recruitment, with the P(<*Bmin*) indicator near to or below 0.02 for the rules with *par5* = 120 tonnes, below 0.05 for the rules with *par5* = 130 tonnes, and from 0.12–0.13 for the rules with *par5* = 150 tonnes (Table 14), indicating that CRA 1 will be sensitive to long periods of low recruitment. This issue is of concern and indicates the need for relatively frequent (every 5–6 years) review of this MPE.

It seemed likely that the poor rule performance for the *par5* = 150 tonne rules stemmed from the low value used for *par3* (left side of the plateau), which was set to 0.8 or 0.9 kg/potlift in the 18 rules defined in Table 11. Robustness Trial 2 was repeated, again using the set of rules defined in Table 11, except with *par3* = 1.1 kg/potlift. This trial showed much improved behaviour with respect to the "safety" indicators, with the P(<*Bmin*) indicator well below 0.01 for the rules with *par5* = 120 tonnes or 130 tonnes, and near 0.02 for the rules with *par5* = 150 tonnes (Table 15).

5. DISCUSSION

While the base case MPD model showed acceptable fits to most of the data, we were unable to model the spring-summer sex ratios, which showed a systematic bias in the estimates of the proportion female for 12 of the 13 samples collected after 2000 (see Figure 12 and Figure 13). It is possible that the inability of the model to fit the peak SS CPUE in the late 2000s (see Figure 2) is related to this bias. A great deal of effort was expended in trying to find model fits which did not show this bias. These included overfitting the LF data, using the previous weighting procedure for length data (MPD sens8 and sens9), making the SS females the most vulnerable category (MPD sens13), and fixing shape (MPD sens12) to widen the growth gap between males and females. However, it was not possible to find a combination of model options which did not show the pattern observed in Figure 12. Although it was not possible to eliminate this bias, it was felt that the overall model results were acceptable for providing management advice.

The model exhibited poor behaviour when fitting to the early CR data, resulting in unacceptably high estimates for M (rising from 0.11 to 0.22 – MPD sens1 in Table 3). Other rock lobster QMA stock assessments have shown little sensitivity to this data set (e.g., Starr et al. 2014); consequently this data set was omitted from the model. The remaining MPD sensitivity runs showed relatively little shift from the base case. These included estimating density dependence (MPD sens6), altering the recreational (sens2) and illegal (sens3 and sens4) catches. The only sensitivity runs which affected the estimated stock status were *CPUEpow* (sens7) and *estimate right-hand limb* (sens11). These models were not pursued because the estimate for the CPUE power function exceeded two (2.28) which would make the operating model unsuitably insensitive to CPUE changes while the extreme descending right-hand limbs in epoch 1 seemed unrealistic and not informed by data.

Non-stationarity in the base case MCMC chain was addressed in several ways: A) by running a very long (11 million draws) chain; B) stacking shorter chains that were started using different random number seeds; C) repeating the base case using an uninformative prior for M rather than the informative prior used in the base case, again opting to "stack" chains started with different random number seeds. Each of these options was thinned to 1000 samples selected uniformly across all draws. The first two options gave nearly the same results and the second "stacked" option (B) was used as the base case. Model (C), based on a uniform prior for M, showed poorer convergence diagnostics and was retained as a sensitivity run.

Both MPD and MCMC sensitivity trials suggested that the results were relatively robust to most modelling choices. In particular, the ratio $B_{current}/B_{ref}$ was nearly constant across all MPD and MCMC sensitivity runs, with the exception of *CPUEpow* (MPD sens7) and *estimate right-hand limb* (MPD sens11) .

The lack of information on non-commercial catches and their trends are a major source of uncertainty in rock lobster stock assessments, particularly when estimating yields. However, the recent large-scale multi-species recreational survey has increased the confidence in the current level of recreational catch estimates, although the charter fleet was not included in this survey. The ramp survey conducted in 2013–14 resulted in a higher recreational catch estimate for CRA 1 compared to the 2011 survey, but both were of a similar order of magnitude. This latter survey only covered a portion of CRA 1 and did not extend over the late-autumn/winter months. The assumption that recreational catch is proportional to abundance may not be correct because the recreational fishery is supposed to be limited by a daily bag limit. However, our opinion is that bag limits, unless they are very low, have limited effect on constraining recreational catches (largely because of transferability of catches and failure of many participants to catch the bag limit) and that it is reasonable to assume that recreational catch varies with abundance. Illegal catch is even more poorly known than the recreational catch, but the sensitivity runs have shown that relaxing these catch assumptions has little effect on the key B_{curr}/B_{ref} management reference level (see sens2, sens3 and sens4 in Table 3 and in Table 7).

This stock assessment suggests that B_{curr} has a probability of zero of being below the default hard and soft limits of 10% and 20% spawning stock biomass (Table 5) and a probability of 1.0 of being above B_{msy} and B_{ref}. Similar probabilities are associated with B_{proj}, obtained after four years of applying constant catches at levels equivalent to the 2013/14 catches. B_{proj} has a probability of 0.58 of being larger than B_{curr}.

The model was converted to an operating model for evaluating management procedures (MPs). We explored a range of plateau rules of the form used in past rock lobster stock assessments. Rule parameters were selected with the intent to maintain the current situation, while allowing for reasonably quick response if stock indicators fell. Some rules were explored which allowed for modest increases to the current TACC.

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

Parameter	Estimation phase	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV	Initial value
ln(*R0*)	1	1	25	0	–	–	18
M	4	0.01	0.35	2	0.12	0.4	0.12
Rdevs	2	-2.3	2.3	1	0	0.4	0
ln(*qCPUE*)	1	-25	0	0	–	–	-6
ln(*qCR*)	1	-25	2	0	–	–	-3
CPUEpow	-1	0.001	2	0	–	–	1
Mat_50	3	30	80	0	–	–	60
Mat_95add	3	3	60	0	–	–	10
GalphaM	2	1	20	0	–	–	7.5
GalphaF	2	1	20	0	–	–	7.5
GdiffM	2	0.001	1	0	–	–	0.12
GdiffF	2	0.001	1	0	–	–	0.12
GshapeM	3	0.1	15	0	–	–	4
GshapeF	3	0.1	15	0	–	–	4
GrowthCVM	5	0.01	2	1/0	0.49	.098	0.49
GrowthCVF	5	0.01	2	1/0	0.63	.126	0.63
Growth_DD	5	0	1	0	–	–	0
Sel_L_male	4	1	50	1	4.1	0.82	4.1
Sel_L_female	4	1	50	1	9.2	1.84	9.2
Sel_Max_male	5	30	90	1	55	11	55
Sel_Max_female	5	30	90	1	64	12.8	64
vulnest1	3	0.01	1	0	–	–	0.8
vulnest2	3	0.01	1	0	–	–	0.8
vulnest3	3	0.01	1	0	–	–	0.8
vulnest4	3	0.01	1	0	–	–	0.8

Table 2: Fixed quantities in the base case.

Quantity	Value	
LF: sex proportion dataset weight	14.0	
LF: male dataset weight	2.5	
LF: immature female dataset weight	1.0	
LF: mature female dataset weight	2.0	
CPUE dataset weight	2.8	
Tag dataset weight	0.7	
Length-weight parameters	a	b
Male	4.16E-06	2.935
Female	1.30E-05	2.545
Newton-Raphson iterations	3 or 5	
Handling mortality	0.1	
Minimum survival	0.02	

Table 3: CRA 1 base case MPD results, and results from sensitivity trials described in the text. Grey shading indicates quantities not estimated.

Quantity	base1 N-R 5	base2 N-R 3	sens1 Add CR	sens2 Alt recrea-tional catch	sens3 Half illegal catch	sens4 Double illegal catch	sens5 Only Rel=0	sens6 DD on	sens7 CPUE pow	sens8 Old LF=10	sens9 Old LF=30	sens10 No Trunc	sens11 Est right-hand limb	sens12 Fixed shape	sens13 Fixed shape +switch vulnest	sens14 Logistic select-ivity
LFs-*sdnr*	0.438	0.438	0.516	0.435	0.436	0.439	0.443	0.437	0.415	0.539	0.846	0.436	0.404	0.610	0.635	0.432
LFs-MAR	0.136	0.137	0.142	0.136	0.137	0.136	0.136	0.136	0.134	0.166	0.280	0.132	0.137	0.141	0.143	0.135
LFs-LL	3138.9	3138.9	3152.3	3139.4	3137.0	3142.3	3139.6	3138.9	3140.4	4184.8	12512.1	3104.9	3127.0	3149.9	3150.1	3139.2
Tags-*sdnr*	1.09	1.09	1.09	1.09	1.09	1.09	1.08	1.09	1.09	1.09	1.09	1.09	1.09	1.10	1.11	1.09
Tags-MAR	0.708	0.708	0.718	0.708	0.703	0.708	0.709	0.708	0.705	0.710	0.708	0.709	0.703	0.722	0.719	0.709
Tags-LL	2412.8	2412.8	2419.1	2412.8	2412.5	2413.2	2072.3	2412.8	2410.7	2413.6	2419.7	2412.7	2410.0	2431.7	2436.8	2412.8
CPUE-*sdnr*	0.995	0.995	1.000	0.999	0.995	0.998	0.984	0.995	0.895	1.039	1.224	0.994	0.993	1.008	1.036	0.997
CPUE-MAR	0.656	0.656	0.687	0.660	0.646	0.672	0.614	0.656	0.600	0.612	0.711	0.661	0.604	0.646	0.661	0.652
CPUE-LL	-131.2	-131.2	-130.8	-130.9	-131.2	-131.0	-131.9	-131.2	-137.8	-128.1	-113.4	-131.2	-131.3	-130.2	-128.2	-131.0
CR-*sdnr*	–	–	0.90	–	–	–	–	–	–	–	–	–	–	–	–	–
CR-MAR	–	–	0.64	–	–	–	–	–	–	–	–	–	–	–	–	–
CR-LL	–	–	-30.2	–	–	–	–	–	–	–	–	–	–	–	–	–
Sex propns -*sdnr*	1.08	1.08	1.10	1.10	1.07	1.11	1.09	1.08	1.16	–	–	1.07	1.04	1.10	1.05	1.08
Sex propns -MAR	0.603	0.603	0.614	0.604	0.624	0.618	0.602	0.603	0.583	–	–	0.584	0.572	0.640	0.594	0.594
Prior LL	-50.6	-50.6	-8.1	-49.4	-51.4	-49.0	-50.2	-50.6	-52.0	-50.5	-46.5	-50.7	-52.6	-47.4	-50.7	-49.7
Function value	5369.8	5369.8	5402.4	5371.9	5366.9	5375.6	5029.8	5369.8	5361.3	6419.8	14771.9	5335.7	5353.1	5404.0	5408.1	5371.3
ln(*R0*)	12.6	12.6	13.0	12.5	12.5	12.7	12.5	12.6	12.6	12.5	12.4	12.6	12.8	12.4	12.6	12.6
M	0.113	0.113	0.222	0.113	0.112	0.116	0.112	0.113	0.108	0.111	0.097	0.114	0.088	0.101	0.115	0.113
ln(*qCPUE*)	-6.06	-6.06	-6.20	-6.09	-5.91	-6.31	-5.99	-6.06	-13.81	-5.96	-5.89	-6.05	-6.31	-6.05	-6.37	-6.00
ln(*qCR*)	-3.01	-3.01	-1.65	-2.73	0.76	-3.01	-23.12	-3.42	-9.32	-24.72	-10.42	-11.60	-24.63	-10.87	-4.49	-4.17
CPUEpow	1*	1*	1*	1*	1*	1*	1*	1*	2.28	1*	1*	1*	1*	1*	1*	1*
*mat50_*	48.9	48.9	48.6	48.9	49.0	48.8	48.9	48.9	48.3	48.7	48.8	48.8	48.9	50.9	51.0	49.0
mat95add	14.8	14.8	12.7	14.7	15.2	14.2	14.8	14.8	17.0	15.5	15.0	14.7	17.2	13.6	12.9	14.6
galphaM	7.94	7.94	7.82	7.93	7.95	7.92	8.14	7.94	7.91	7.91	7.89	7.94	8.01	7.93	7.97	7.92
gbetaM	3.15	3.15	3.17	3.11	3.21	3.04	3.38	3.15	3.04	3.36	3.49	3.09	2.97	4.13	3.61	3.23
gdiffM	0.397	0.397	0.406	0.393	0.404	0.384	0.415	0.397	0.384	0.425	0.443	0.389	0.371	0.521	0.453	0.407
GshapeM	2.29	2.29	1.35	2.24	2.37	2.16	2.29	2.29	2.00	2.36	2.79	2.24	1.93	4.38*	4.38*	2.30
GCVM	0.267	0.267	0.270	0.267	0.267*	0.268	0.235	0.267	0.267	0.270	0.273	0.267*	0.265	0.267*	0.267*	0.267
galphaF	7.58	7.58	7.69	7.59	7.58	7.61	7.57	7.59	7.65	7.70	7.57	7.59	7.54	6.83	6.73	7.58
gbetaF	1.29	1.29	1.54	1.29	1.27	1.32	1.29	1.29	1.14	1.41	1.57	1.29	1.02	0.84	0.98	1.28
gdiffF	0.170	0.170	0.200	0.170	0.167	0.174	0.171	0.170	0.149	0.182	0.207	0.169	0.135	0.123	0.146	0.169
GshapeF	5.71	5.71	6.01	5.72	5.67	5.80	5.78	5.71	5.63	6.26	6.04	5.71	5.33	2.602*	2.602*	5.67

Quantity	base1 N-R 5	base2 N-R 3	sens1 Add CR	sens2 Alt recrea-tional catch	sens3 Half illegal catch	sens4 Double illegal catch	sens5 Only Rel=0	sens6 DD on	sens7 CPUE pow	sens8 Old LF=10	sens9 Old LF=30	sens10 No Trunc	sens11 Est right-hand limb	sens12 Fixed shape	sens13 Fixed shape +switch vulnest	sens14 Logistic select-ivity
GCVM	0.175	0.175	0.168	0.175	0.175*	0.177	0.177	0.175	0.177	0.176	0.200	0.175*	0.174	0.175*	0.175*	0.175
GrowthDD	0*	0*	0*	0*	0*	0*	0*	0.001	0*	0*	0*	0*	0*	0*	0*	0*
vulnest1	0.648	0.648	0.672	0.653	0.644	0.656	0.653	0.648	0.591	0.661	0.625	0.645	0.584	0.689	1.000	0.652
vulnest2	0.505	0.505	0.770	0.515	0.470	0.556	0.486	0.504	0.365	0.399	0.435	0.506	0.363	0.491	0.688	0.491
vulnest3	0.582	0.582	0.921	0.592	0.545	0.643	0.560	0.582	0.386	0.449	0.488	0.585	0.430	0.589	0.811	0.576
vulnest4	0.404	0.404	0.643	0.412	0.380	0.438	0.389	0.404	0.320	0.329	0.342	0.403	0.293	0.412	0.646	0.400
VL1M	4.11	4.11	4.04	4.11	4.11	4.12	4.11	4.11	4.14	4.10	4.10	4.11	4.23	4.10	4.13	49.7[1]
VR1M	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	15.3	200*	200*	9.9[2]
SelectMax1M	52.3	52.3	57.6	52.0	52.9	51.3	53.0	52.3	46.0	55.0	54.0	52.1	56.2	53.2	49.7	63.4[3]
VL1F	9.25	9.25	8.91	9.26	9.22	9.29	9.27	9.25	9.06	9.29	9.35	9.25	9.17	9.29	9.19	10.3[4]
VR1F	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	17.8	200*	200*	52.9[5]
SelectMax1F	72.4	72.4	71.7	72.4	72.2	72.6	72.5	72.4	66.4	73.7	74.1	72.4	66.7	71.5	73.8	9.8[6]
VL2M	9.59	9.59	9.71	9.55	9.64	9.49	9.64	9.59	9.72	10.25	10.78	9.57	9.41	11.03	10.37	57.4[7]
VR2M	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	13.1	200*	200*	17.3[8]
SelectMax2M	62.3	62.3	64.0	62.3	62.4	62.1	62.5	62.3	62.9	64.0	64.8	62.3	61.8	64.0	61.5	–
VL2F	16.3	16.3	18.6	16.4	15.9	16.8	16.5	16.3	14.1	17.7	17.4	16.2	13.5	11.5	12.7	–
VR2F	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	200*	250	200*	200*	–
SelectMax2F	73.6	73.6	83.0	73.9	72.4	75.1	73.9	73.6	67.7	74.0	74.4	73.5	66.7	67.6	71.2	–
Bcurr/Bref	1.76	1.76	1.74	1.74	1.77	1.75	1.76	1.76	1.30	1.87	1.95	1.76	1.40	1.76	1.72	1.74
Bref	359	359	403	373	314	460	338	359	407	317	297	356	528	352	503	342
Bmsy	450	450	144	448	403	538	465	450	430	423	508	447	304	562	569	442
Bcurr/Bmsy	1.40	1.40	4.86	1.45	1.37	1.50	1.28	1.40	1.23	1.41	1.14	1.40	2.42	1.10	1.52	1.35
MSY	159	159	155	158	173	133	158	160	160	158	149	160	227	151	163	158
Fmult	1.31	1.31	5.06	1.24	1.38	1.18	1.18	1.31	1.16	1.29	0.97	1.31	3.69	0.98	1.45	1.25
Male yrs to MLS	2	2	2.5	2	2	2	2	2	2	2	2	2	2	2	1.5	2
Female yrs to MLS	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3.5	3.5	2.5

[1] Select50_1M; [2] SelectAdd95_1M; [3] Select50_1F; [4] SelectAdd95_1F; [5] Select50_2M; [6] SelectAdd95_2M; [7] Select50_2F; [8] SelectAdd95_2F;

Table 4: Summaries of estimated parameter posteriors from the base case (stacked informed *M*) MCMC.

Epoch	Sex	Parameter	Min	0.05	Median	0.95	Max	MPD
		function value	4586.2	4592.6	4603.2	4616.9	4628.2	4556.1
		ln(*R0*)	12.2	12.4	12.6	12.9	13.1	12.56
		M	0.086	0.102	0.125	0.155	0.187	0.113
		ln(*qCPUE*)	-6.86	-6.60	-6.35	-6.12	-5.80	-6.055
		mat50	30.0	33.3	45.0	50.7	54.8	48.9
		mat95add	3.3	9.2	25.8	53.1	59.8	14.8
	male	*Galpha*	7.42	7.71	7.93	8.16	8.38	7.94
	male	*Gbeta*	1.58	2.29	2.90	3.75	4.61	3.15
	male	*Gdiff*	0.198	0.287	0.365	0.474	0.586	0.397
	male	*Gshape*	0.55	1.50	2.51	3.81	4.76	2.291
	female	*Galpha*	6.90	7.28	7.61	7.94	8.25	7.58
	female	*Gbeta*	0.92	1.11	1.31	1.54	1.77	1.29
	female	*Gdiff*	0.119	0.144	0.173	0.203	0.235	0.170
	female	*Gshape*	4.41	5.09	5.88	6.67	7.59	5.71
		vulnest1	0.564	0.621	0.665	0.711	0.758	0.648
		vulnest2	0.160	0.425	0.690	0.953	1.000	0.505
		vulnest3	0.424	0.561	0.768	0.968	1.000	0.582
		vulnest4	0.288	0.382	0.517	0.663	0.811	0.404
epoch 1	male	*Sel_VL*	1.59	2.93	4.20	5.56	7.22	4.11
epoch 1	male	*Sel_max*	30.2	36.0	48.5	59.3	64.0	52.3
epoch 1	female	*Sel_VL*	2.85	6.41	9.29	12.22	15.80	9.25
epoch 1	female	*Sel_max*	35.0	53.9	73.2	78.7	82.6	72.4
epoch 2	male	*Sel_VL*	6.28	7.60	9.47	11.90	14.07	9.59
epoch 2	male	*Sel_max*	55.4	58.1	61.1	64.6	67.3	62.3
epoch 2	female	*Sel_VL*	9.3	13.5	17.3	21.9	25.4	16.3
epoch 2	female	*Sel_max*	57.5	67.8	75.4	84.3	89.6	73.6

Table 5: Summaries of indicator posteriors from the base case MCMC.

CRA 1	5%	Median	95%
Bmin	220.2	315.1	424.9
Bcurr	654.5	850.5	1114.4
Bref	385.6	493.1	634.7
Bproj	608.1	884.4	1224.7
Bmsy	331.5	421.0	522.6
MSY	136.6	161.1	192.7
Fmult	1.21	1.92	3.28
SSBcurr	699.1	811.2	952.3
SSBproj	644.8	820.3	1028.5
SSBmsy	405.7	485.1	584.3
CPUEcurrent	1.25	1.36	1.47
CPUEproj	1.06	1.39	1.79
CPUEmsy	0.418	0.635	0.907
Bcurr/Bmin	2.31	2.66	3.66
Bcurr/Bref	1.53	1.73	1.95
Bcurr/Bmsy	1.43	2.00	2.99
Bproj/Bcurr	0.840	1.022	1.247
Bproj/Bref	1.39	1.78	2.30
Bproj/Bmsy	1.34	2.08	3.24
SSBcurr/SSB0	0.423	0.500	0.599
SSBproj/SSB0	0.392	0.506	0.653
SSBcurr/SSBmsy	1.35	1.66	2.10
SSBproj/SSBmsy	1.27	1.68	2.24
SSBproj/SSBcurr	0.868	1.01	1.18
USLcurrent	0.066	0.084	0.108
USLproj	0.060	0.084	0.122
USLproj/USLcurrent	0.803	1.001	1.261
Btotcurrent	1649	1949	2353
Btotcurrent/Btot0	0.317	0.395	0.509
Ntotcurrent	2,578,080	3,205,570	4,065,240
Ntotcurrent/Ntot0	0.507	0.622	0.771
P(*Bcurr*>*Bmin*)		1	
P(*Bcurr*>*Bref*)		1	
P(*Bcurr*>*Bmsy*)		1	
P(*Bproj*>*Bmin*)		1	
P(*Bproj*>*Bref*)		0.999	
P(*Bproj*>*Bmsy*)		0.997	
P(*Bproj*>*Bcurr*)		0.576	
P(*SSBcurr*>*SSBmsy*)		1	
P(*SSBproj*>*SSBmsy*)		0.998	
P(*USLproj*>*USLcurr*)		0.507	
P(*SSBcurr*<*0.2SSB0*)		0	
P(*SSBproj*<*0.2SSB0*)		0	
P(*SSBcurr*<*0.1SSB0*)		0	
P(*SSBproj*<*0.1SSB0*)		0	

Table 6: Median parameter estimates from the base case (stacked informed *M*) and five MCMC sensitivity trials.

Epoch	Sex	Parameter	Basecase	sens1 Uniform *M*	sens2 Alt recrea-tional catch	sens3 Half illegal catch	sens4 Double illegal catch	sens5 Fixed *M*=0.2
		function value	4603.2	4605.0	4,604.3	4,665.6	4,599.7	4610.3
		ln(*R0*)	12.6	12.7	12.6	12.8	12.5	13.2
		M	0.125	0.129	0.123	0.128	0.124	0.2*
		ln(*qCPUE*)	-6.35	-6.38	-6.41	-6.59	-6.24	-6.69
		mat50	45.0	45.0	45.2	45.2	44.9	45.6
		mat95add	25.8	25.7	24.4	23.8	26.5	22.9
	male	*Galpha*	7.93	7.93	7.95	7.93	7.96	7.88
	male	*Gbeta*	2.90	2.84	2.81	2.84	2.92	2.83
	male	*Gdiff*	0.365	0.359	0.354	0.357	0.368	0.359
	male	*Gshape*	2.51	2.50	2.50	2.41	2.56	2.14
	female	*Galpha*	7.61	7.59	7.60	7.61	7.57	7.67
	female	*Gbeta*	1.31	1.31	1.31	1.32	1.29	1.43
	female	*Gdiff*	0.173	0.173	0.171	0.174	0.170	0.187
	female	*Gshape*	5.88	5.85	5.85	5.81	5.81	6.09
		vulnest1	0.665	0.667	0.672	0.673	0.661	0.686
		vulnest2	0.690	0.713	0.703	0.716	0.680	0.812
		vulnest3	0.768	0.799	0.788	0.809	0.760	0.991
		vulnest4	0.517	0.542	0.531	0.539	0.514	0.683
epoch 1	male	*Sel_VL*	4.20	4.16	4.20	4.17	4.11	4.16
epoch 1	male	*Sel_max*	48.5	48.8	49.2	47.1	50.3	48.1
epoch 1	female	*Sel_VL*	9.29	9.29	9.26	9.35	9.21	9.31
epoch 1	female	*Sel_max*	73.2	73.4	72.8	73.4	73.4	75.6
epoch 2	male	*Sel_VL*	9.47	9.49	9.56	9.48	9.61	9.31
epoch 2	male	*Sel_max*	61.1	61.1	61.2	61.2	61.2	61.4
epoch 2	female	*Sel_VL*	17.3	17.5	17.2	17.1	17.2	18.5
epoch 2	female	*Sel_max*	75.4	75.6	75.3	75.6	74.8	79.6

Table 7: Median indicator values and probability indicators from the base case and five CRA 1 MCMC sensitivity trials.

Indicator	Basecase	sens1 Uniform *M*	sens2 Alt recrea-tional catch	sens3 Half illegal catch	sens4 Double illegal catch	sens5 Fixed *M*=0.2
Bmin	315.1	332.9	340.3	286.4	402.8	433.6
Bcurr	850.5	882.3	889.0	779.5	1076.0	1187.4
Bref	493.1	509.5	516.1	451.9	618.5	690.4
Bproj	884.4	926.4	931.4	808.2	1105.3	1213.0
Bmsy	421.0	415.3	427.2	370.3	493.8	268.2
MSY	161.1	166.2	160.5	176.9	137.1	228.4
Fmult	1.92	2.07	1.80	2.16	1.74	6.43
SSBcurr	811.2	823.7	831.9	734.6	975.3	974.0
SSBproj	820.3	846.2	851.9	745.4	983.2	1002.2
SSBmsy	485.1	476.6	472.0	442.1	535.8	397.9
CPUEcurrent	1.36	1.36	1.35	1.36	1.35	1.35
CPUEproj	1.39	1.41	1.39	1.41	1.37	1.37
CPUEmsy	0.635	0.589	0.607	0.609	0.585	0.249
Bcurr/Bmin	2.66	2.64	2.60	2.66	2.63	2.68
Bcurr/Bref	1.73	1.73	1.72	1.73	1.73	1.71
Bcurr/Bmsy	2.00	2.15	2.09	2.09	2.16	4.45
Bproj/Bcurr	1.02	1.03	1.03	1.03	1.02	1.02
Bproj/Bref	1.78	1.80	1.78	1.77	1.77	1.75
Bproj/Bmsy	2.08	2.23	2.19	2.18	2.21	4.54
SSBcurr/SSB0	0.500	0.513	0.514	0.507	0.514	0.684
SSBproj/SSB0	0.506	0.522	0.523	0.514	0.518	0.700
SSBcurr/SSBmsy	1.66	1.74	1.75	1.66	1.81	2.45
SSBproj/SSBmsy	1.68	1.77	1.80	1.68	1.83	2.51
SSBproj/SSBcurr	1.01	1.02	1.01	1.01	1.01	1.02
USLcurrent	0.0845	0.0817	0.083	0.093	0.067	0.0601
USLproj	0.0837	0.0798	0.079	0.092	0.067	0.0610
USLproj/USLcurrent	1.00	0.99	0.98	1.00	1.02	1.02
Btotcurrent	1949	2006	2,014	1,768	2,421	2636
Btotcurrent/Btot0	0.395	0.412	0.412	0.398	0.425	0.627
Ntotcurrent	3,205,570	3,327,850	3,345,750	2,926,430	4,039,080	4,638,490
Ntotcurrent/Ntot0	0.622	0.635	0.648	0.616	0.656	0.800
P(Bcurr>Bmin)	1	1	1	1	1	1
P(Bcurr>Bref)	1	1	1	1	1	1
P(Bcurr>Bmsy)	1	0.999	1	0.999	1	1
P(Bproj>Bmin)	1	1	1	1	1	1
P(Bproj>Bref)	0.999	1	1	0.998	1	0.999
P(Bproj>Bmsy)	0.997	0.998	0.998	0.996	0.999	1
P(Bproj>Bcurr)	0.576	0.611	0.612	0.592	0.552	0.562
P(SSBcurr>SSBmsy)	1	1	1	1	1	1
P(SSBproj>SSBmsy)	0.998	1	0.999	0.997	0.999	1
P(USLproj>USLcurr)	0.507	0.478	0.443	0.486	0.533	0.577
P(SSBcurr<0.2SSB0)	0	0	0	0	0	0
P(SSBproj<0.2SSB0	0	0	0	0	0	0
P(SSBcurr<0.1SSB0)	0	0	0	0	0	0
P(SSBproj<0.1SSB0)	0	0	0	0	0	0

Table 8: List of MPE indicators.

	Indicator	Definition
1.	mean(B_y/*Bref*)	mean biomass during the 21-year run, scaled as a proportion of *Bref*;
2.	Term(B_y/*Bref*)	terminal biomass, scaled as a proportion of *Bref*;
3.	min(CommCat)	minimum commercial catch during the run;
4.	mean(CommCat)	mean commercial catch during the run;
5.	mean5-yrComm	the mean commercial catch during the first five years of the run;
6.	min(RecCat)	minimum recreational catch during the run;
7.	mean(RecCat)	mean recreational catch during the run;
8.	min(CPUE)	minimum observed fishing year CPUE during the run;
9.	mean(CPUE)	mean observed fishing year CPUE during the run;
10.	%AAVH	average annual variation in TACC during the run (AAVH);
11.	mean(B_y/*Bmsy*)	projected vulnerable biomass as a proportion of *Bmsy*;
12.	mean(predCPUE)	average predicted CPUE
13.	min(predCPUE)	minimum predicted CPUE
14.	AW terminal total biomass	Total terminal B_y at beginning of AW season
15.	AW terminal total biomass/total B0	Total terminal B_y at beginning of AW season as a ratio of the unfished total terminal biomass
16.	AW terminal total numbers	Total numbers N_y at beginning of AW season
17.	AW terminal total numbers/total N0	Total numbers N_y at beginning of AW season as a ratio of the unfished total terminal biomass
18.	B_y <*Bref*	the proportion of years in which biomass was less than *Bref*;
19.	B_y <*Bmin*	the proportion of years in which biomass was less than *Bmin*;
20.	B_y < *Bmsy*	the proportion of years in which biomass was less than *Bmsy*;
21.	P(TACC change)	the proportion of years in which TACC changed;
22.	B_y <20%*SSB0*	the proportion of years in which SSB was less than 20% *SSB0*;
23.	B_y <10%*SSB0*	the proportion of years in which SSB was less than 10% *SSB0*;
24.	B_y <50%*Bref*	the proportion of years in which biomass was less than 50% *Bref*;
25.	B_y <25%*Bref*	the proportion of years in which biomass was less than 20% *Bref*;
26.	P(B_y <left of plateau)	the proportion of years in which the TACC was to the left of the plateau
27.	P(B_y >right of plateau)	the proportion of years in which the TACC was to the right of the plateau
28.	P(CPUE>1.14 kg/pot)	Probability of CPUE > 1.14 kg/potlift
29.	P(CPUE>1.5 kg/pot)	Probability of CPUE > 1.5 kg/potlift
30.	P(CPUE>1.8 kg/pot)	Probability of CPUE > 1.8 kg/potlift

Table 9: Ranges of values used for each rule parameter in exploratory runs.

Function	Par	Min	Max
Phase 1 exploration			
CPUE@TACC=0	*par2*	0.1	0.5
plateau height	*par5*	110	150
step width	*par6*	0.05	0.25
step height	*par7*	0.05	0.25
Phase 2 exploration			
plateau left	*par3*	0.8	1.1
plateau height	*par5*	110	150
plateau right	*par4*	1.4	1.7
Phase 3 exploration			
plateau left	*par3*	0.8	1.1
plateau height	*par5*	110	150
plateau right	*par4*	1.4	1.7
step width	*par6*	0.15	0.25
step height	*par7*	0.05	0.10

Table 10: The range of indicator values in the evaluated rules.

Indicator	Phase 1 (500 rules) Min	Phase 1 (500 rules) Max	Phase 2 (80 rules) Min	Phase 2 (80 rules) Max	Phase 3 (480 rules) Min	Phase 3 (480 rules) Max
Avg(B/Bref)	1.05	2.37	1.03	2.31	1.02	2.42
Term(B/Bref)	0.83	2.67	0.77	2.55	0.77	2.73
Min(CommCat)	10	157	91	150	90	157
Avg(CommCat)	110	201	109	175	109	178
Min(RecCat)	24	67	25	67	25	68
Avg(RecCat)	38	80	38	78	37	81
Min(CPUE)	0.52	1.63	0.56	1.60	0.55	1.64
Avg(CPUE)	0.94	2.04	0.93	1.99	0.92	2.08
%AAV	0.000	47.641	0.000	9.003	0.000	11.008
P(B[y]<Bref)	0.0017	0.1347	0.0013	0.1027	0.0013	0.1112
P(B[y]<Bmin)	0.0000	0.0122	0.0000	0.0081	0.0000	0.0095
P(B[y]<Bmsy)	0.0035	0.1090	0.0027	0.0831	0.0027	0.0871
P(TACCchange)	0.134	0.584	0.197	0.540	0.095	0.596
P(B[y]<leftP)	0.012	0.239	0.001	0.238	0.001	0.245
P(B[y]>rightP)	0.101	0.662	0.114	0.728	0.111	0.775

Table 11: Parameters for the 18 rules chosen by the CRA 1 stock assessment team.

Function	Par	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
CPUE @TACC=0	*par2*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
plateau left	*par3*	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
plateau right	*par4*	1.4	1.5	1.7	1.4	1.5	1.7	1.4	1.5	1.7	1.4	1.5	1.7	1.4	1.5	1.7	1.4	1.5	1.7
plateau height	*par5*	120	120	120	120	120	120	130	130	130	130	130	130	150	150	150	150	150	150
step width	*par6*	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
step height	*par7*	0.05	0.05	0.05	0.1	0.1	0.1	0.05	0.05	0.05	0.1	0.1	0.1	0.05	0.05	0.05	0.1	0.1	0.1
minimum change	*par8*	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 12: Median values for 15 selected indicators from the base case for all 18 example rules.

	Rule Number																	
Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Avg(B/Bref)	1.76	1.78	1.82	1.71	1.75	1.80	1.66	1.68	1.72	1.62	1.66	1.71	1.45	1.48	1.51	1.44	1.48	1.51
Term(B/Bref)	1.76	1.80	1.85	1.69	1.74	1.82	1.62	1.64	1.70	1.57	1.61	1.67	1.30	1.33	1.38	1.31	1.33	1.38
Min(CommCat)	126	120	120	120	120	120	136	130	130	130	130	130	150	150	150	150	150	150
Avg(CommCat)	126	126	121	131	128	123	136	136	130	139	136	132	157	154	150	155	153	150
Min(RecCat)	52	53	53	51	52	53	49	50	51	48	49	51	42	43	44	42	43	44
Avg(RecCat)	61	62	63	59	61	62	58	59	60	57	58	59	52	53	54	52	53	54
Min(CPUE)	1.24	1.25	1.27	1.20	1.23	1.26	1.16	1.18	1.20	1.13	1.16	1.20	0.97	0.99	1.02	0.98	1.00	1.03
Avg(CPUE)	1.54	1.56	1.59	1.50	1.53	1.58	1.46	1.48	1.51	1.43	1.46	1.50	1.29	1.31	1.34	1.29	1.31	1.34
%AAV	0.513	0.513	0.000	4.009	4.006	2.505	0.513	0.513	0.000	4.004	3.297	2.004	0.513	0.000	0.000	3.007	2.505	1.002
P(B[y]<Bref)	0.0136	0.0119	0.0093	0.0117	0.0098	0.0084	0.0322	0.0292	0.0231	0.0289	0.0253	0.0234	0.1112	0.1026	0.0874	0.1015	0.0937	0.0868
P(B[y]<Bmin)	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0013	0.0013	0.0012	0.0013	0.0012	0.0012	0.0095	0.0087	0.0071	0.0081	0.0076	0.0071
P(B[y]<Bmsy)	0.0138	0.0119	0.0094	0.0135	0.0113	0.0092	0.0296	0.0278	0.0227	0.0291	0.0264	0.0232	0.0871	0.0825	0.0707	0.0825	0.0766	0.0707
P(TACCchange)	0.120	0.116	0.103	0.434	0.397	0.293	0.117	0.109	0.096	0.401	0.355	0.247	0.132	0.122	0.104	0.342	0.301	0.192
P(B[y]<leftP)	0.007	0.006	0.005	0.005	0.005	0.012	0.016	0.015	0.012	0.014	0.013	0.012	0.065	0.061	0.051	0.059	0.055	0.051
P(B[y]>rightP)	0.680	0.563	0.338	0.645	0.531	0.317	0.580	0.467	0.258	0.542	0.433	0.232	0.386	0.285	0.128	0.352	0.259	0.117

Table 13: Median values for 15 selected indicators from Robustness Trial 1 (increased CPUE observation error) for all 18 example rules.

	Rule Number																	
Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Avg(B/Bref)	1.76	1.77	1.80	1.70	1.74	1.79	1.66	1.67	1.70	1.61	1.64	1.69	1.46	1.48	1.50	1.43	1.46	1.49
Term(B/Bref)	1.77	1.79	1.83	1.68	1.72	1.79	1.62	1.65	1.68	1.55	1.59	1.65	1.32	1.34	1.37	1.30	1.32	1.36
Min(CommCat)	120	120	120	120	120	120	130	130	130	130	130	130	150	150	150	150	150	150
Avg(CommCat)	127	126	123	133	129	125	137	136	132	141	138	133	155	153	150	157	155	151
Min(RecCat)	52	52	53	50	51	52	49	50	50	48	49	50	42	43	43	41	42	43
Avg(RecCat)	61	61	62	59	60	62	58	59	59	57	58	59	52	53	53	51	52	53
Min(CPUE)	1.11	1.12	1.14	1.07	1.10	1.13	1.04	1.06	1.07	1.02	1.03	1.07	0.89	0.90	0.92	0.87	0.89	0.92
Avg(CPUE)	1.55	1.57	1.60	1.51	1.53	1.57	1.48	1.49	1.51	1.43	1.46	1.50	1.30	1.32	1.35	1.28	1.31	1.34
%AAV	2.052	1.795	1.026	7.013	6.507	5.004	2.051	1.539	1.026	6.507	5.512	3.991	1.795	1.282	1.026	5.510	4.510	2.998
P(B[y]<Bref)	0.0118	0.0108	0.0097	0.0122	0.0106	0.0082	0.0287	0.0269	0.0236	0.0303	0.0270	0.0234	0.1028	0.0986	0.0882	0.1047	0.0957	0.0869
P(B[y]<Bmin)	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0010	0.0009	0.0009	0.0011	0.0009	0.0008	0.0079	0.0072	0.0067	0.0078	0.0071	0.0066
P(B[y]<Bmsy)	0.0122	0.0115	0.0102	0.0151	0.0119	0.0093	0.0284	0.0262	0.0232	0.0304	0.0278	0.0241	0.0818	0.0795	0.0725	0.0842	0.0782	0.0713
P(TACCchange)	0.239	0.216	0.178	0.580	0.538	0.423	0.224	0.202	0.163	0.546	0.490	0.361	0.220	0.197	0.157	0.475	0.416	0.291
P(B[y]<leftP)	0.009	0.008	0.007	0.009	0.008	0.017	0.020	0.019	0.017	0.021	0.019	0.016	0.070	0.067	0.061	0.072	0.066	0.061
P(B[y]>rightP)	0.647	0.545	0.358	0.602	0.509	0.332	0.560	0.461	0.282	0.515	0.425	0.260	0.389	0.303	0.162	0.348	0.271	0.149

Table 14: Median values for 15 selected indicators from the Robustness Trial 2 (average recruitment: 1981–1990= 0.0) for all 18 example rules.

	Rule Number																	
Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Avg(B/Bref)	1.28	1.30	1.32	1.29	1.31	1.33	1.19	1.20	1.22	1.20	1.21	1.23	1.03	1.04	1.06	1.04	1.05	1.06
Term(B/Bref)	1.05	1.06	1.10	1.08	1.09	1.12	0.93	0.94	0.96	0.95	0.95	0.96	0.78	0.78	0.78	0.78	0.78	0.78
Min(CommCat)	120	120	120	120	120	120	115	117	121	118	120	121	102	103	105	103	104	105
Avg(CommCat)	123	120	120	122	121	120	131	130	130	131	130	130	143	143	142	143	142	142
Min(RecCat)	34	35	36	35	36	36	30	31	32	31	31	32	25	25	26	25	25	26
Avg(RecCat)	45	46	46	45	46	46	42	43	43	43	43	43	37	38	38	38	38	38
Min(CPUE)	0.80	0.82	0.85	0.82	0.84	0.85	0.70	0.71	0.73	0.72	0.73	0.73	0.56	0.57	0.58	0.57	0.57	0.58
Avg(CPUE)	1.14	1.16	1.18	1.15	1.17	1.18	1.06	1.08	1.10	1.07	1.09	1.10	0.93	0.94	0.95	0.94	0.94	0.95
%AAV	0.513	0.510	0.000	2.505	2.004	1.503	1.539	1.196	0.850	3.006	2.505	1.479	4.351	4.016	3.636	4.724	4.510	3.668
P(B[y]<Bref)	0.213	0.201	0.182	0.198	0.188	0.168	0.311	0.296	0.274	0.294	0.281	0.271	0.495	0.482	0.460	0.484	0.471	0.458
P(B[y]<Bmin)	0.022	0.021	0.018	0.019	0.019	0.010	0.045	0.043	0.039	0.041	0.040	0.039	0.132	0.128	0.120	0.125	0.122	0.119
P(B[y]<Bmsy)	0.149	0.143	0.130	0.141	0.135	0.119	0.217	0.208	0.194	0.208	0.199	0.191	0.366	0.356	0.339	0.355	0.346	0.337
P(TACCchange)	0.162	0.149	0.130	0.308	0.259	0.214	0.211	0.198	0.176	0.327	0.283	0.208	0.335	0.318	0.295	0.409	0.373	0.312
P(B[y]<leftP)	0.133	0.127	0.113	0.122	0.116	0.173	0.208	0.199	0.182	0.193	0.186	0.180	0.383	0.372	0.352	0.370	0.360	0.350
P(B[y]>rightP)	0.233	0.154	0.049	0.218	0.143	0.045	0.181	0.114	0.033	0.168	0.107	0.031	0.117	0.072	0.016	0.108	0.066	0.015

Table 15: Median values for 15 selected indicators from the alternative Robustness Trial 2 (average recruitment: 1981–1990= 0.0) and using *par3*=1.1 kg/potlift for all 18 example rules.

	Rule Number																	
Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Avg(B/Bref)	1.33	1.33	1.35	1.32	1.33	1.35	1.26	1.26	1.27	1.25	1.26	1.27	1.14	1.14	1.15	1.13	1.14	1.15
Term(B/Bref)	1.18	1.19	1.20	1.18	1.19	1.20	1.10	1.10	1.10	1.10	1.10	1.10	0.98	0.98	0.98	0.98	0.98	0.98
Min(CommCat)	94	95	96	94	95	96	94	94	95	94	95	95	93	94	94	93	94	94
Avg(CommCat)	117	117	116	118	117	116	123	123	122	123	123	122	132	132	131	132	132	131
Min(RecCat)	37	37	38	37	37	38	35	35	35	35	35	35	31	31	31	31	31	31
Avg(RecCat)	47	47	47	46	47	47	44	45	45	44	45	45	41	41	41	41	41	41
Min(CPUE)	0.87	0.88	0.88	0.87	0.88	0.88	0.81	0.82	0.82	0.81	0.82	0.82	0.71	0.71	0.72	0.71	0.71	0.72
Avg(CPUE)	1.18	1.19	1.20	1.17	1.19	1.20	1.12	1.13	1.14	1.12	1.13	1.14	1.02	1.03	1.03	1.02	1.03	1.03
%AAV	3.219	3.011	2.629	5.008	4.229	3.344	4.447	4.190	3.868	5.592	5.064	4.105	6.228	6.098	5.831	6.998	6.687	5.948
P(B[y]<Bref)	0.128	0.124	0.116	0.127	0.121	0.116	0.197	0.192	0.184	0.197	0.189	0.183	0.364	0.359	0.348	0.365	0.356	0.347
P(B[y]<Bmin)	0.003	0.003	0.003	0.003	0.003	0.003	0.006	0.006	0.005	0.006	0.006	0.005	0.021	0.021	0.020	0.021	0.021	0.020
P(B[y]<Bmsy)	0.093	0.090	0.085	0.093	0.089	0.085	0.132	0.130	0.124	0.133	0.128	0.124	0.229	0.225	0.220	0.229	0.224	0.219
P(TACCchange)	0.329	0.310	0.285	0.480	0.422	0.329	0.388	0.371	0.347	0.511	0.460	0.379	0.489	0.473	0.455	0.578	0.538	0.473
P(B[y]<leftP)	0.382	0.371	0.355	0.386	0.370	0.353	0.477	0.466	0.450	0.481	0.464	0.449	0.627	0.618	0.605	0.633	0.620	0.605
P(B[y]>rightP)	0.240	0.157	0.050	0.222	0.145	0.046	0.187	0.117	0.034	0.171	0.109	0.031	0.122	0.073	0.017	0.111	0.068	0.016

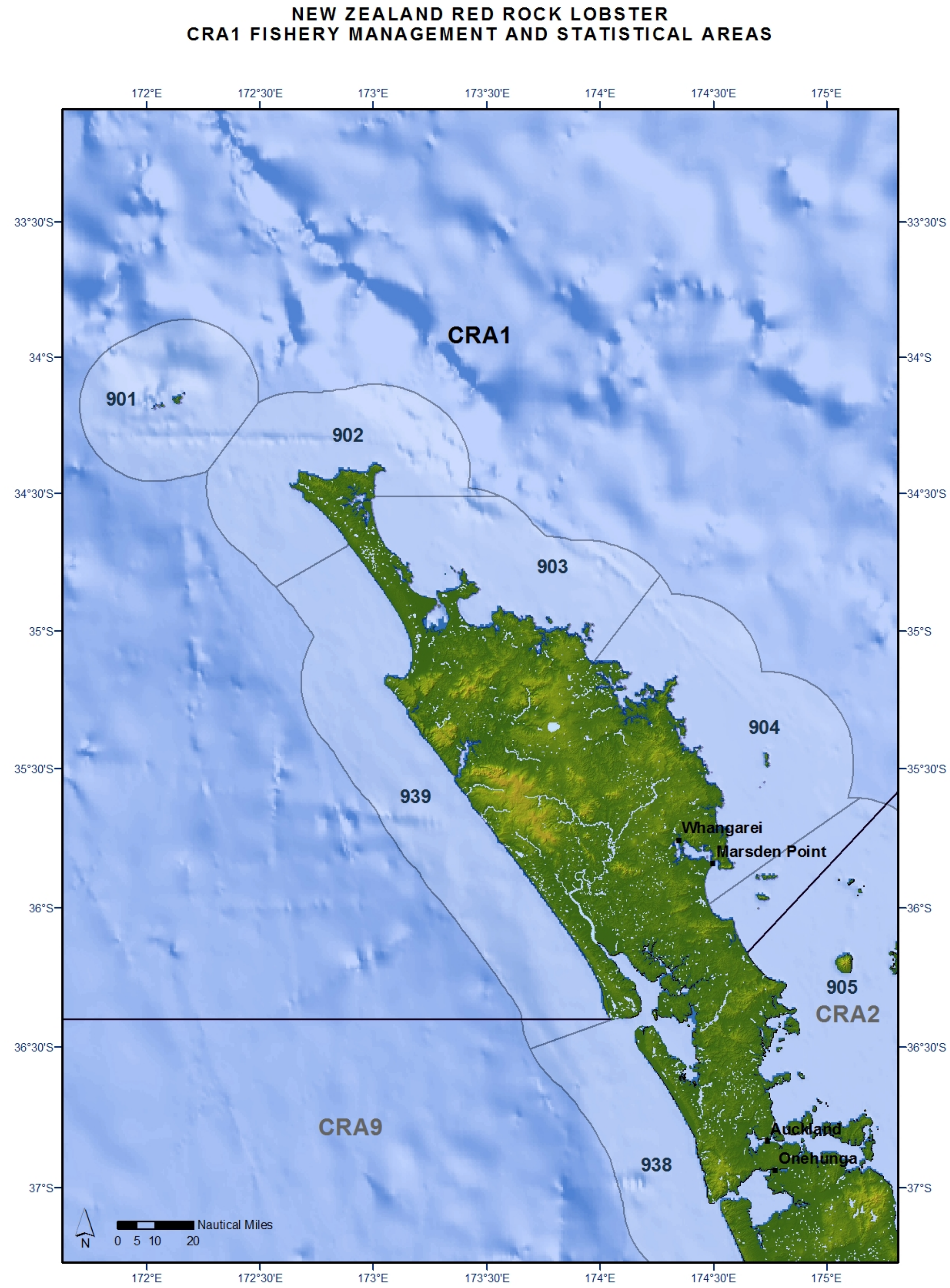


Figure 1: CRA 1 rock lobster statistical areas (light blue).

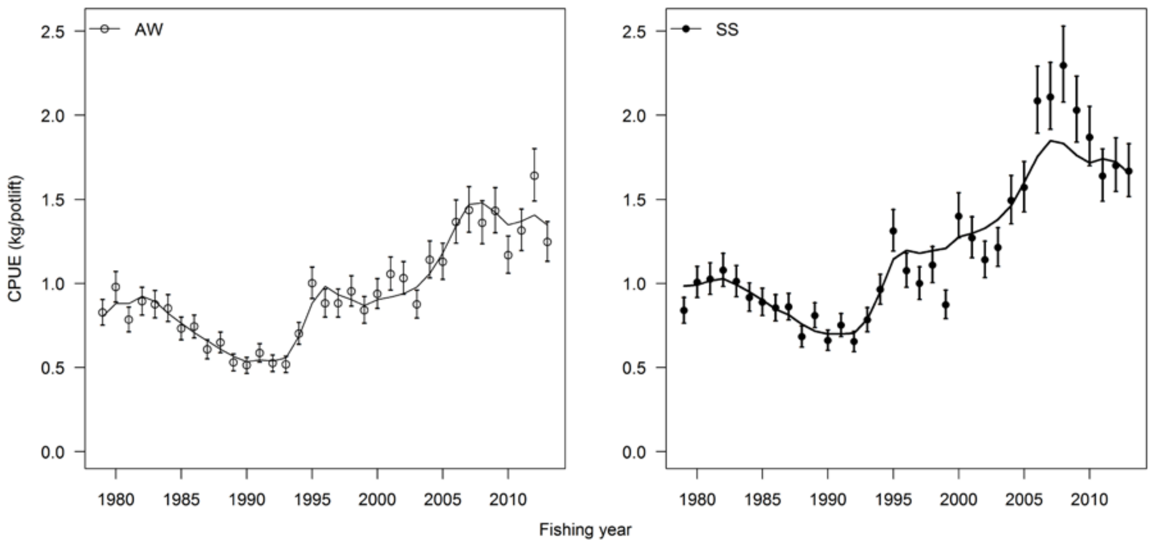


Figure 2: Fit to catch per unit effort (CPUE) by year during autumn-winter (AW) and spring-summer (SS) in the CRA 1 base case model. Points show observed values, bars show one standard deviation, and lines show predicted values.

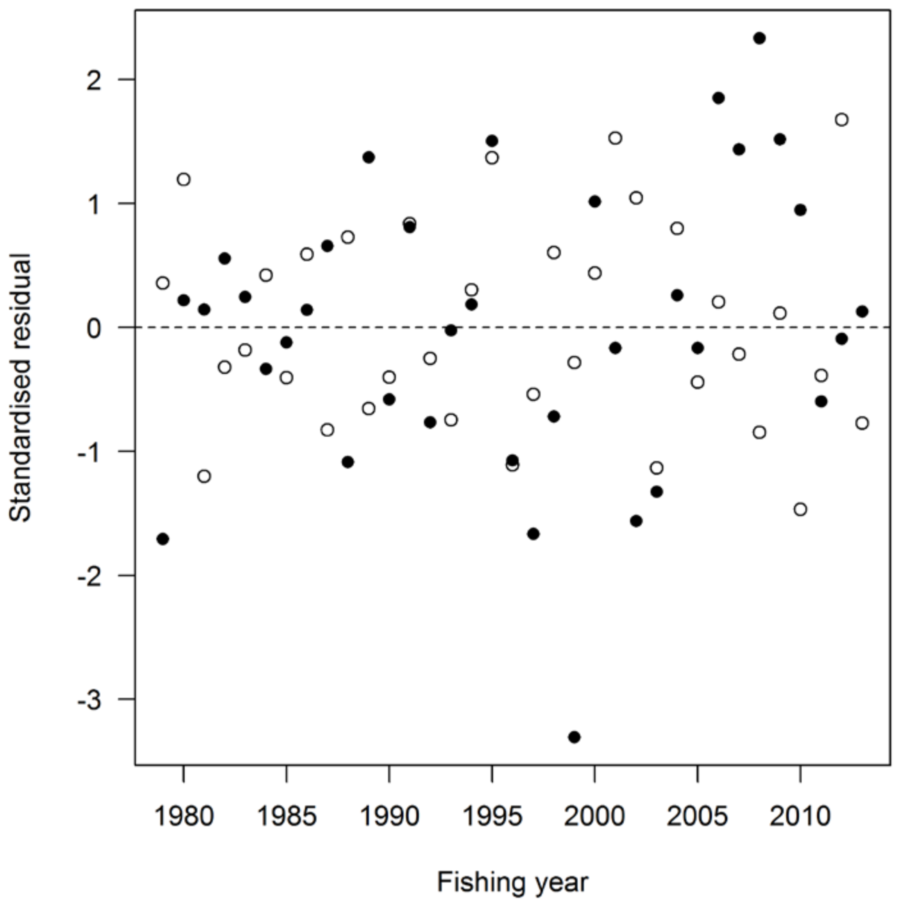


Figure 3: Standardised residuals from the fit to catch per unit effort. Open circles are autumn-winter (AW), closed are spring-summer (SS).

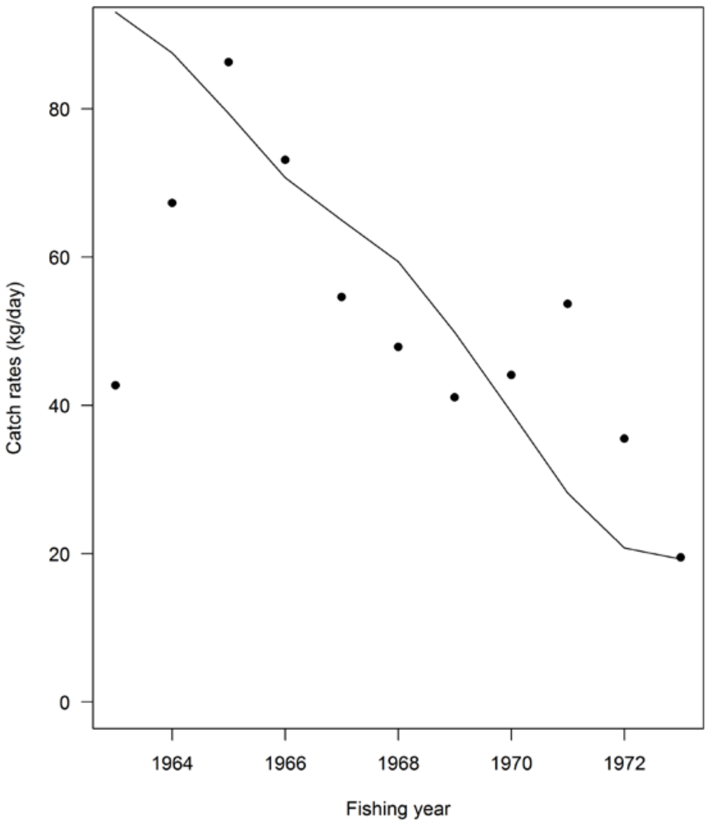


Figure 4: Predicted (line) and observed (points) catch rates (kg/day) by year in the CRA 1 base case model. Note that we do not fit to catch rate in the base case.

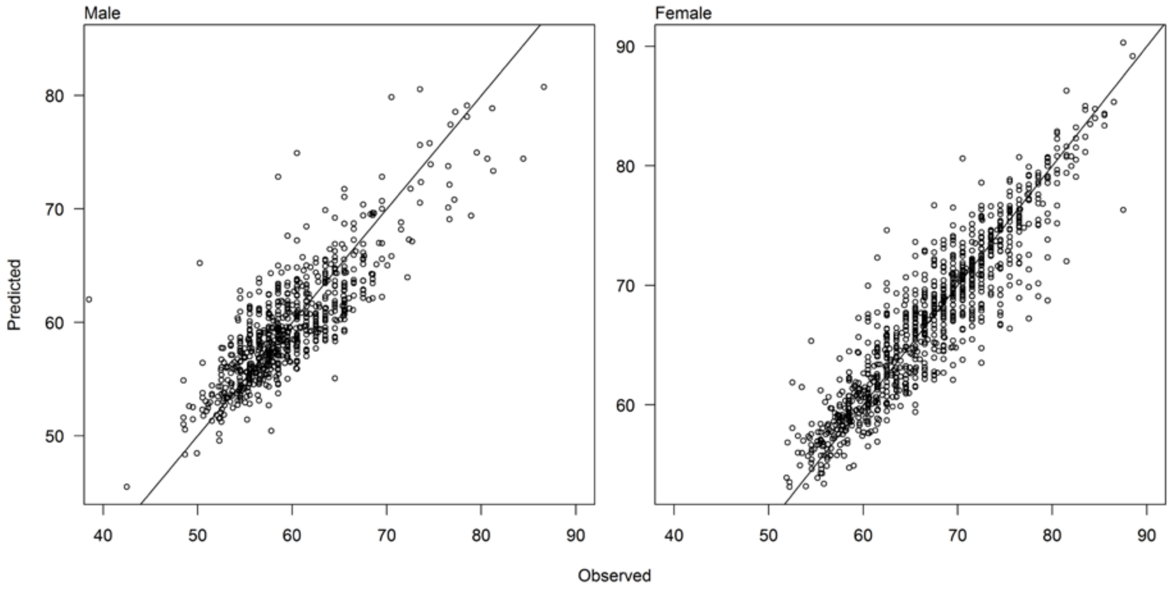


Figure 5: Predicted versus observed increments (mm) in the tag-recapture data by sex.

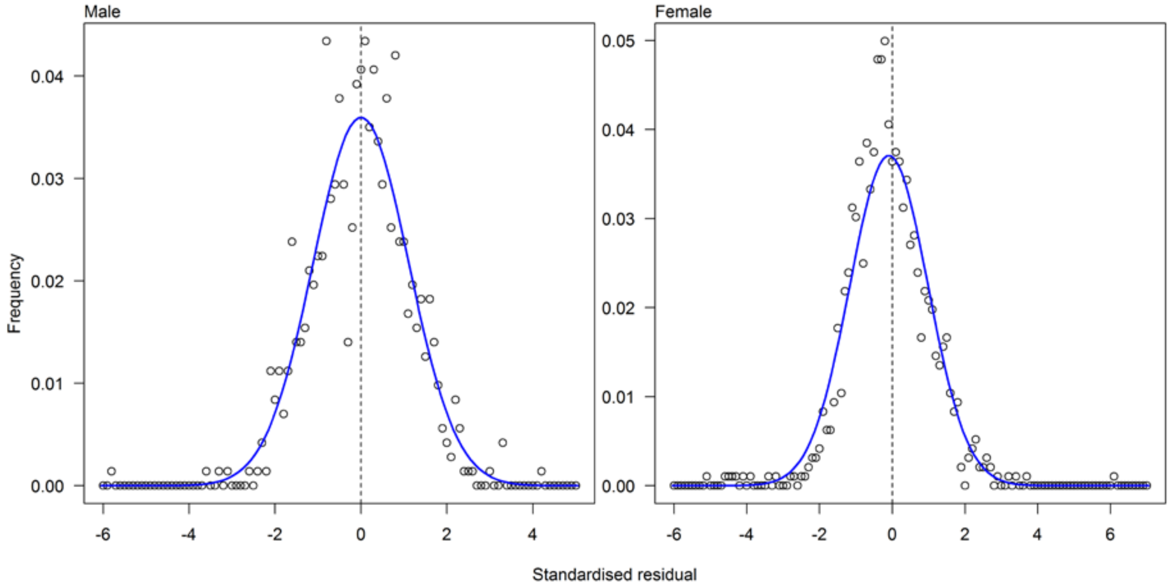


Figure 6: Distribution of standardised residuals from the fit to tag-recapture data by sex. Note that the likelihood uses robustified calculations.

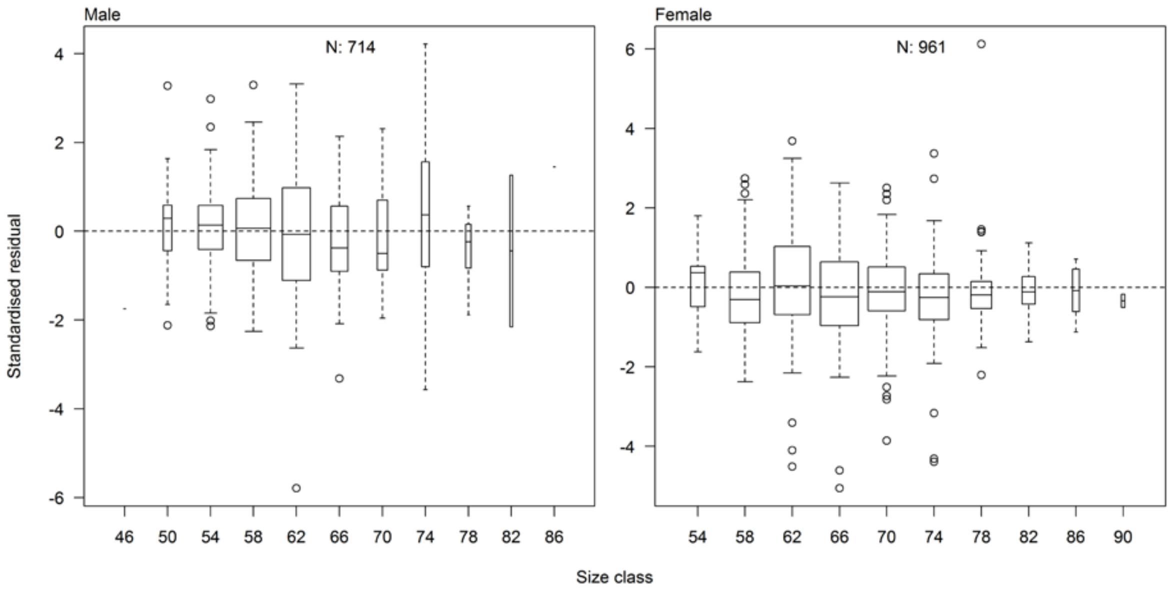


Figure 7: Distributions of standardised residuals from tag-recapture data by sex and size. The width of each box is proportional to the number of observations in the category. The total sample size (N) for each sex is given at the top of each plot.

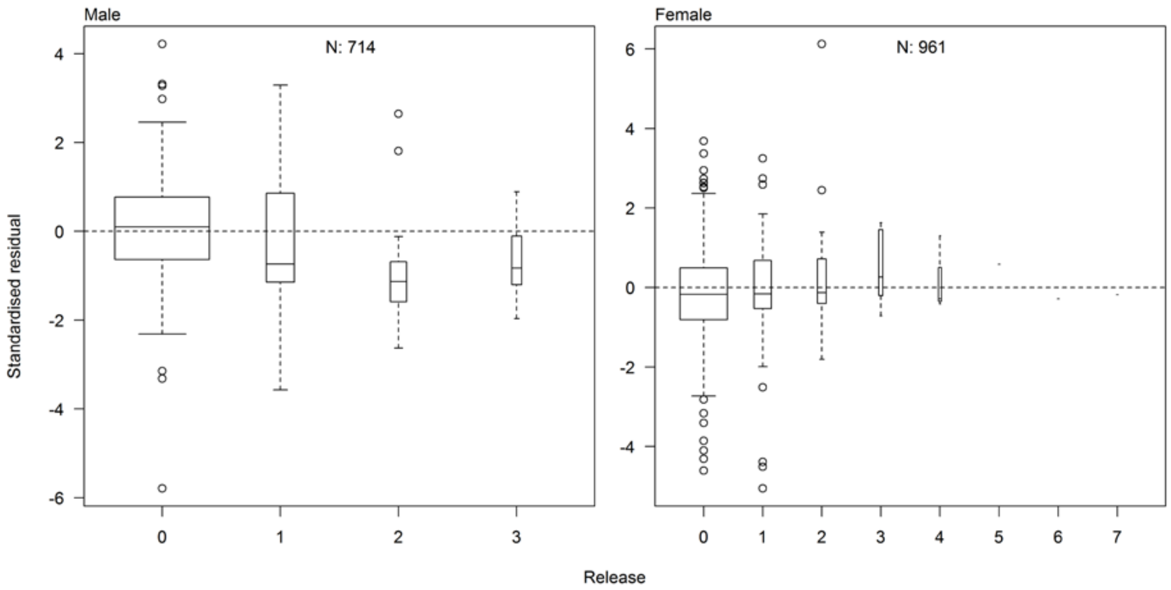


Figure 8: Distributions of standardised residuals from tag-recapture data by sex and release event. The width of each box is proportional to the number of observations in the category. The total sample size (N) for each sex is given at the top of each plot.

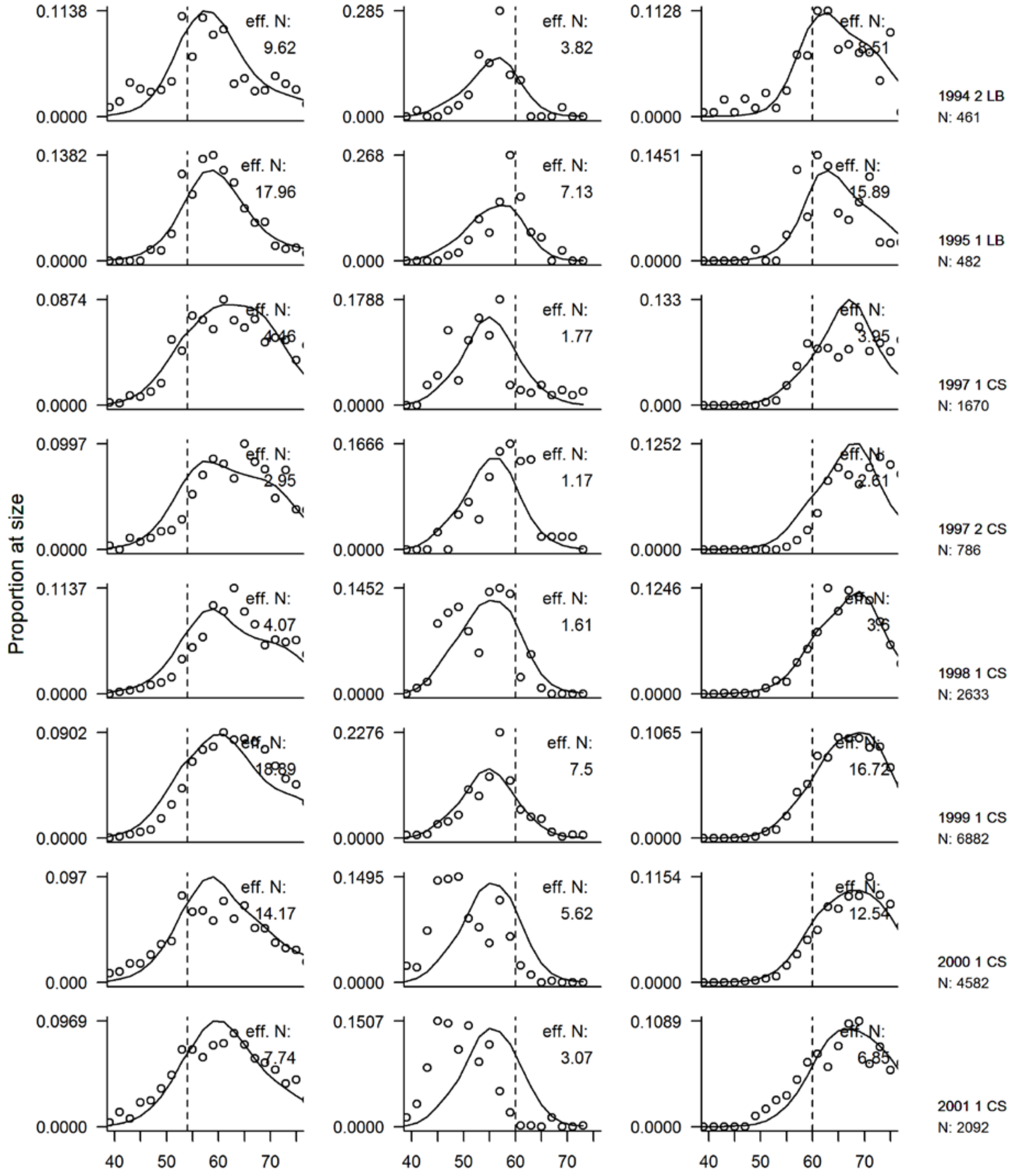


Figure 9A: Fit to the base case length-frequencies (1994 SS LB to 2001 AW CS).

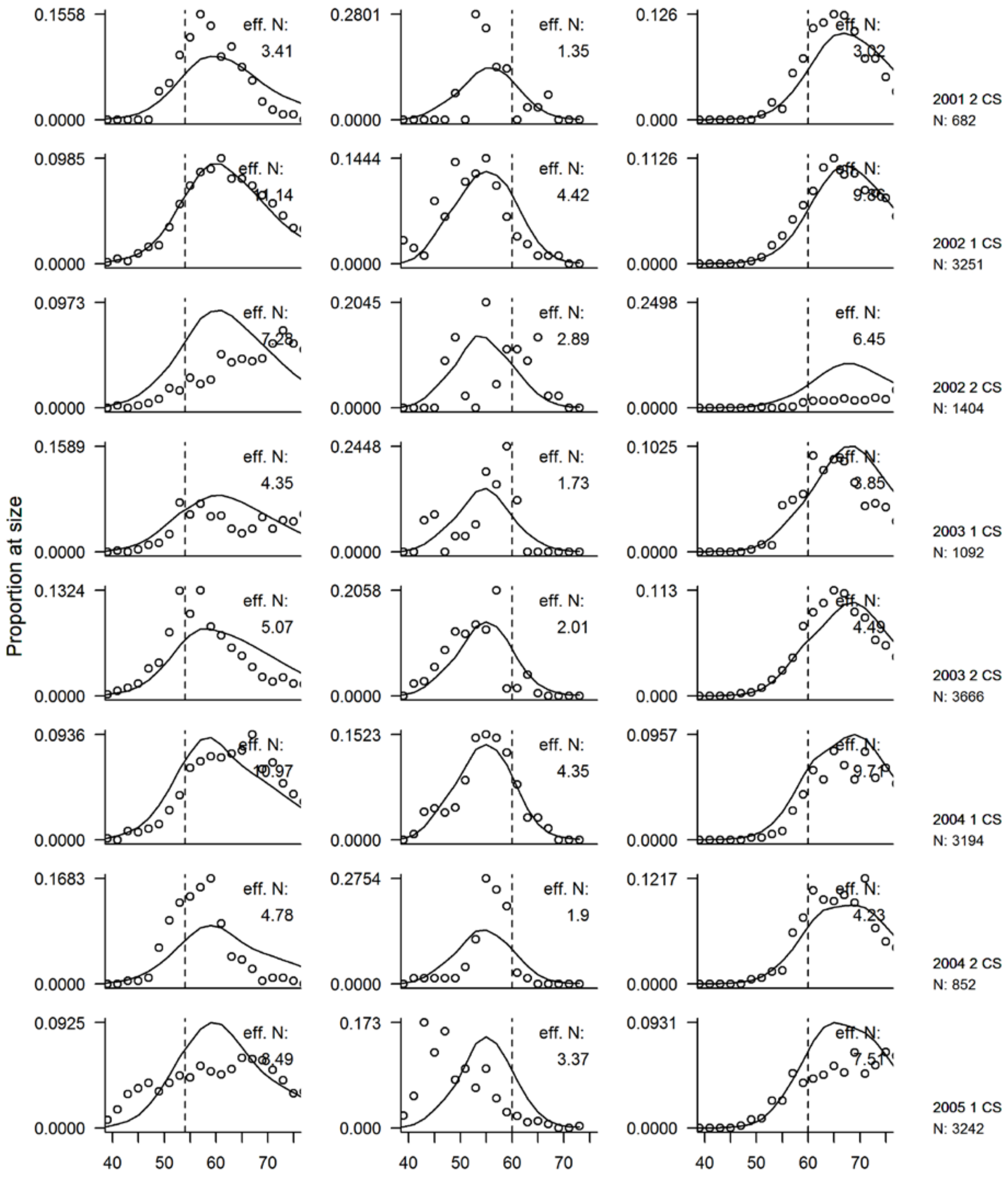


Figure 9B: Fit to the base case length-frequencies (2001 SS CS to 2005 AW CS).

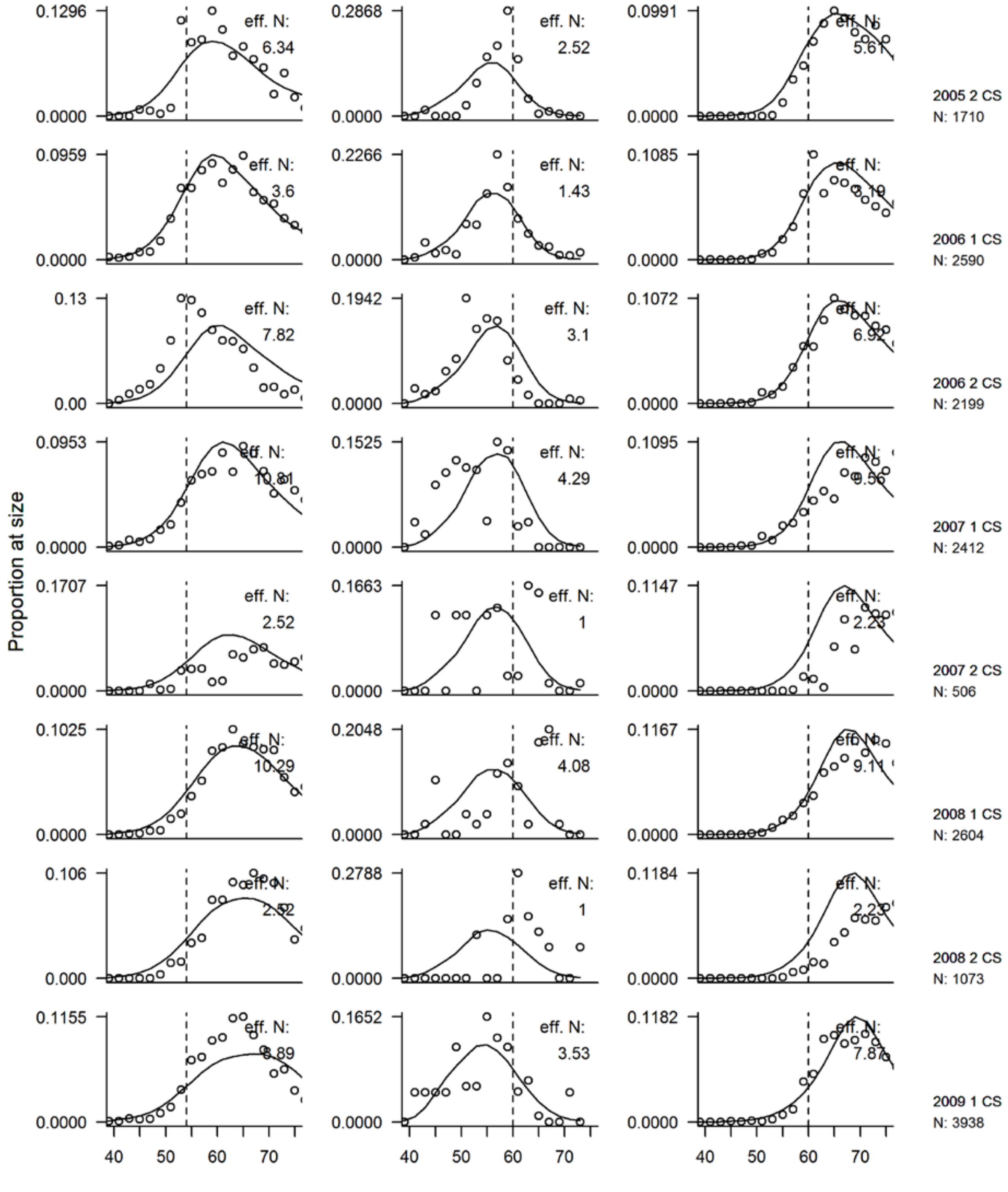


Figure 9C: Fit to the base case length-frequencies (2005 SS CS to 2009 AW CS).

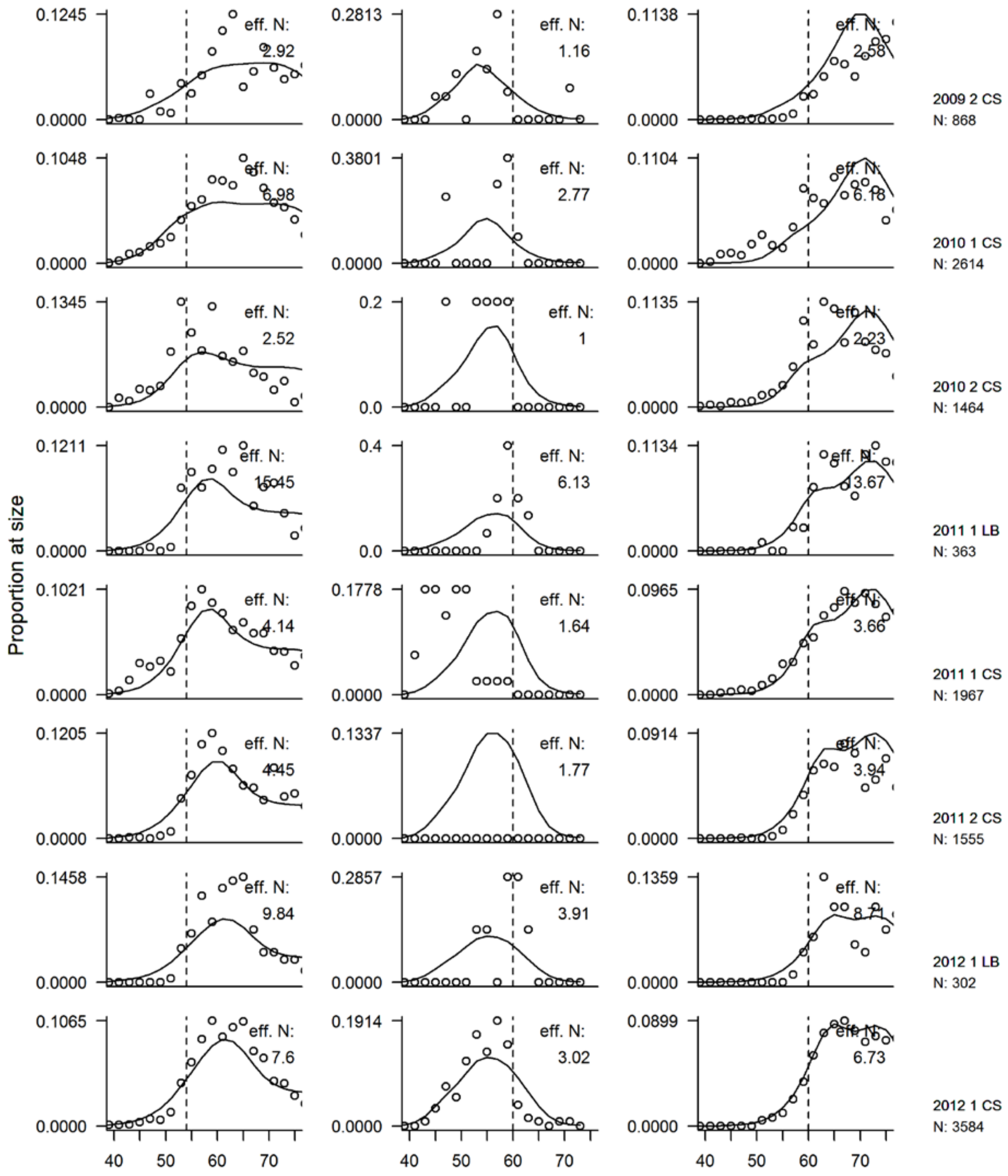


Figure 9D: Fit to the base case length-frequencies (2009 SS CS to 2012 AW CS).

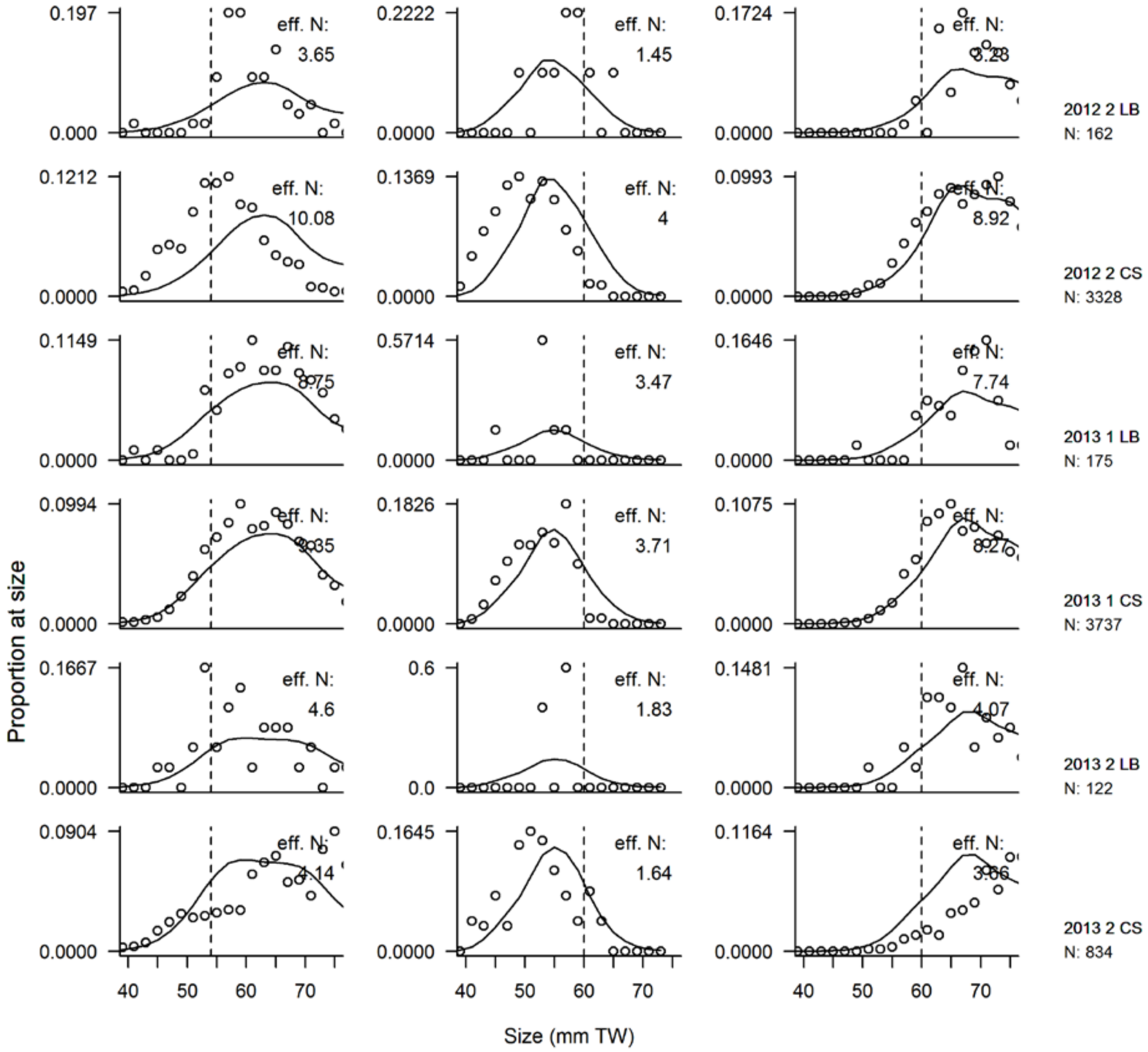


Figure 9E: Fit to the base case length-frequencies (2012 SS CS to 2013 SS CS).

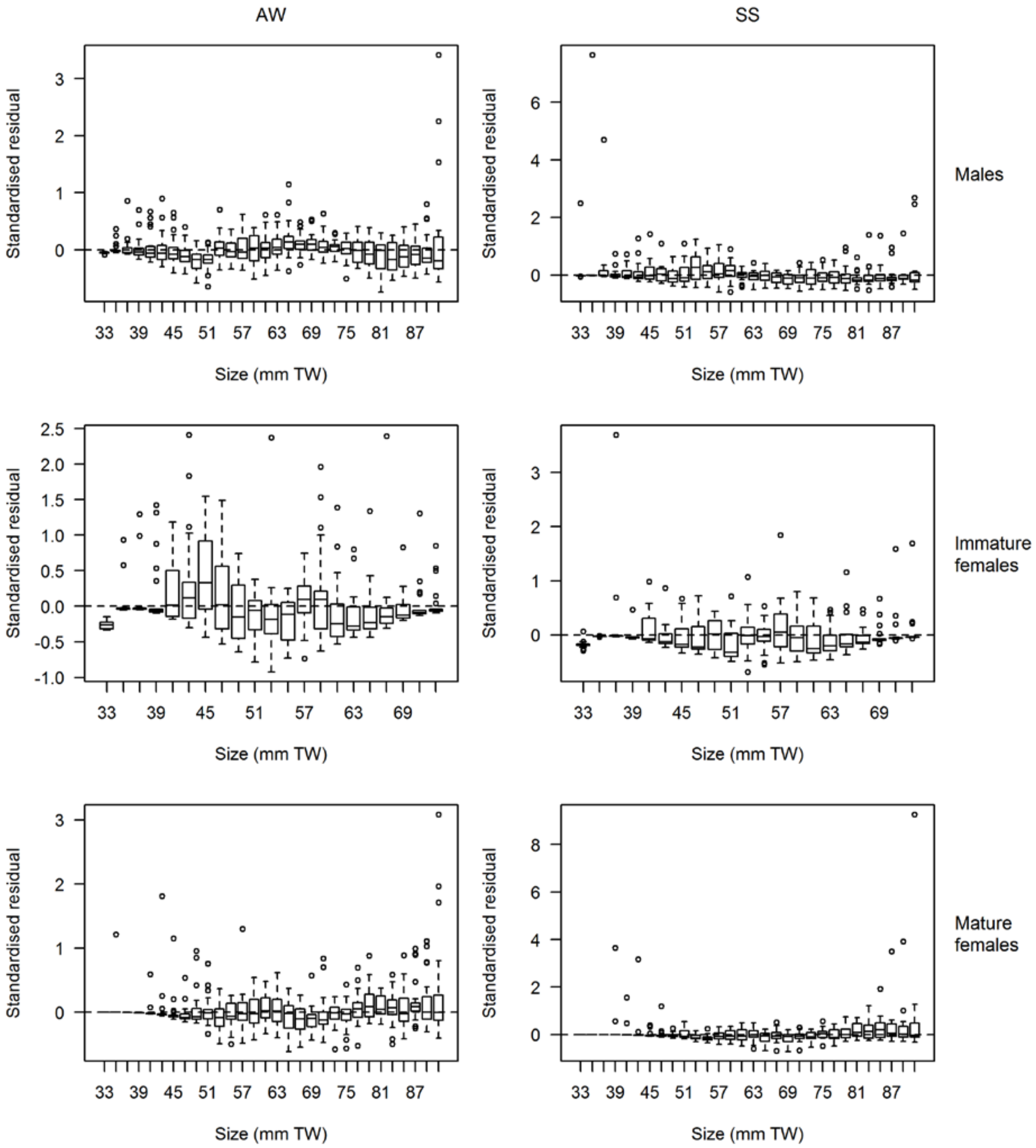


Figure 10: Standardised residuals from the fits to length-frequencies by sex and size during autumn-winter (AW) and spring-summer (SS).

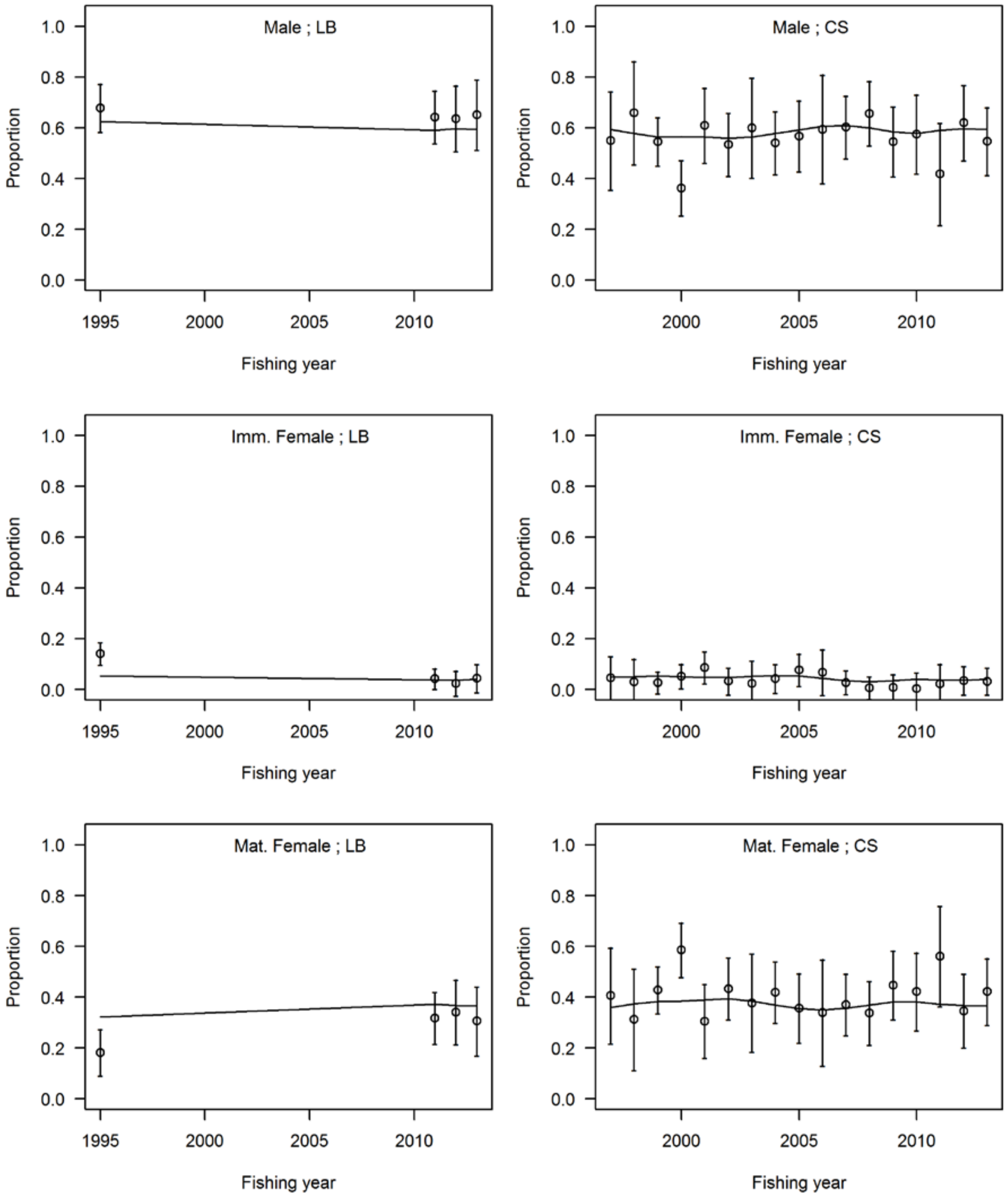


Figure 11: Observed (circles) and predicted (lines) sex proportion fits in autumn-winter by sex and data type.

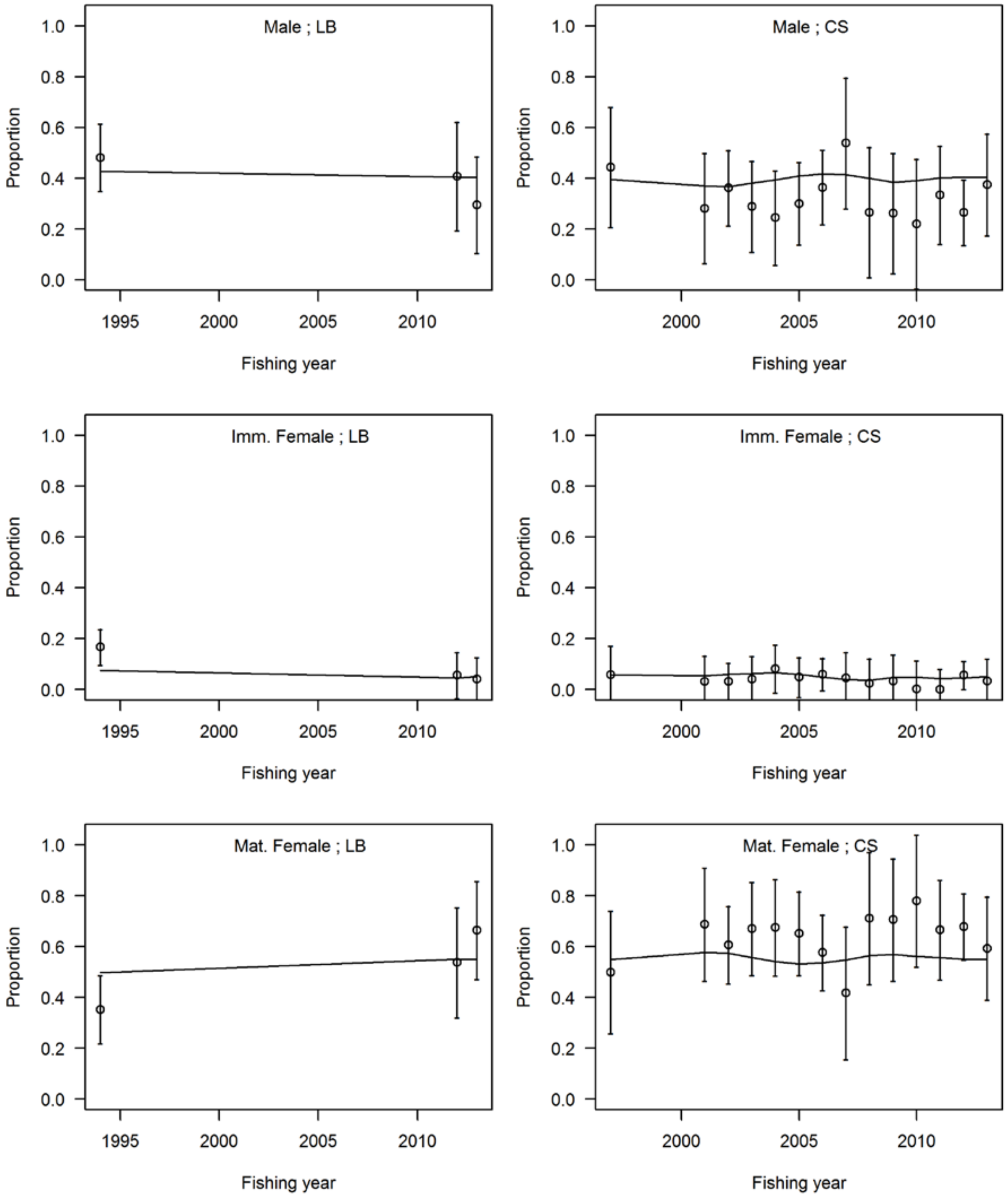


Figure 12: Observed (circles) and predicted (lines) sex proportion fits in spring-summer by sex and data source for the MPD base case.

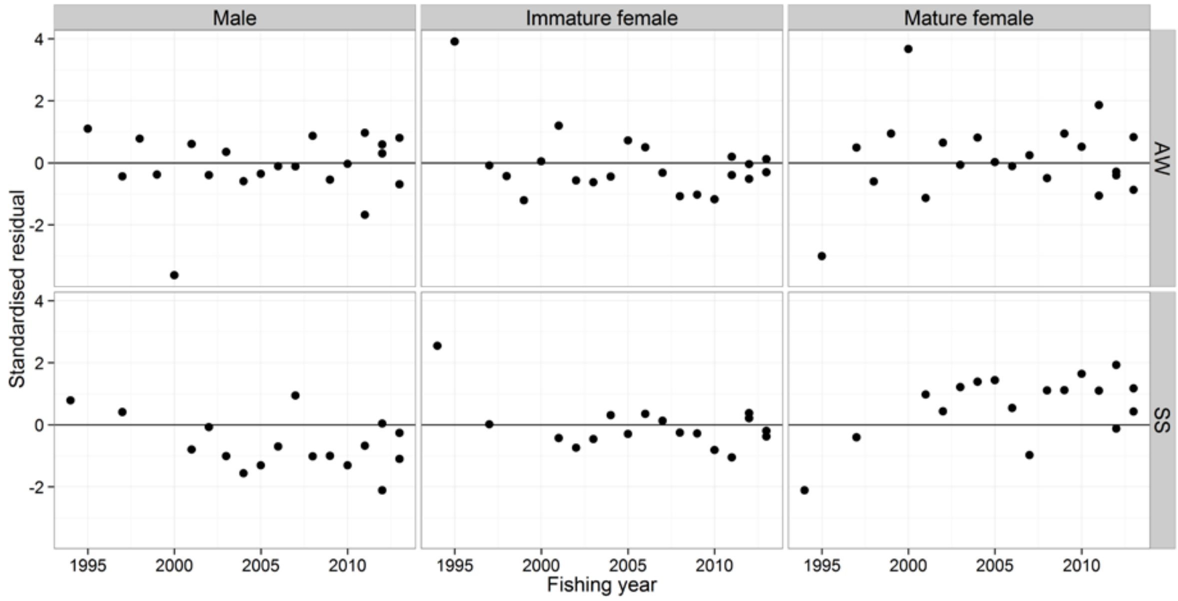


Figure 13: Standardised residuals from the fits to sex proportions by season and sex category.

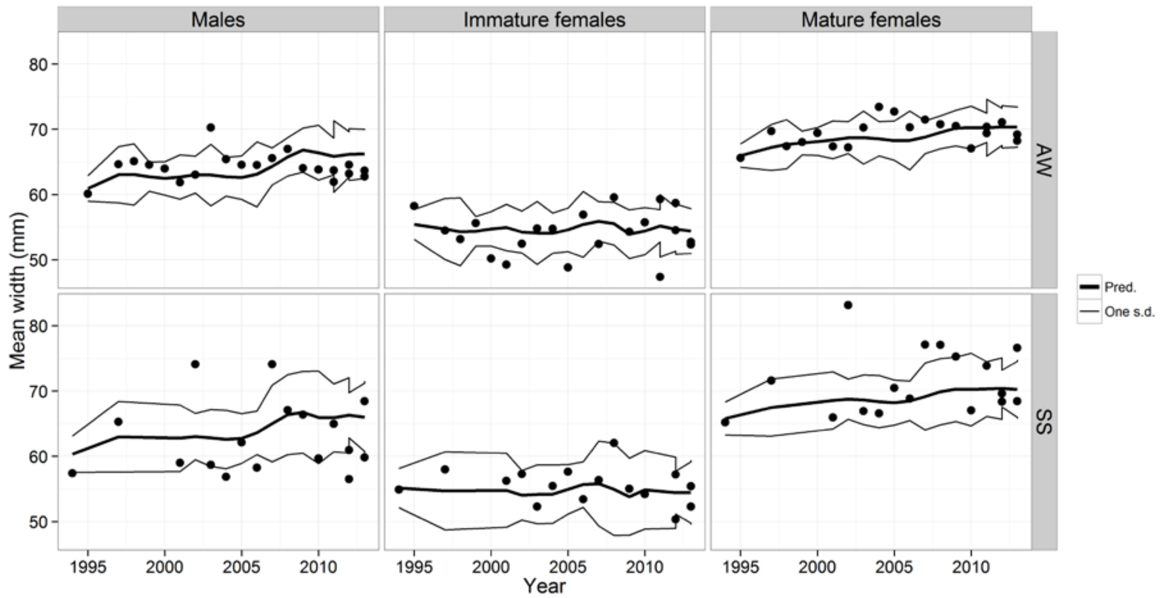


Figure 14: Predicted (solid line) and observed (filled circles) mean tail width by sex category and season. Thinner lines show one standard deviation from the predicted mean.

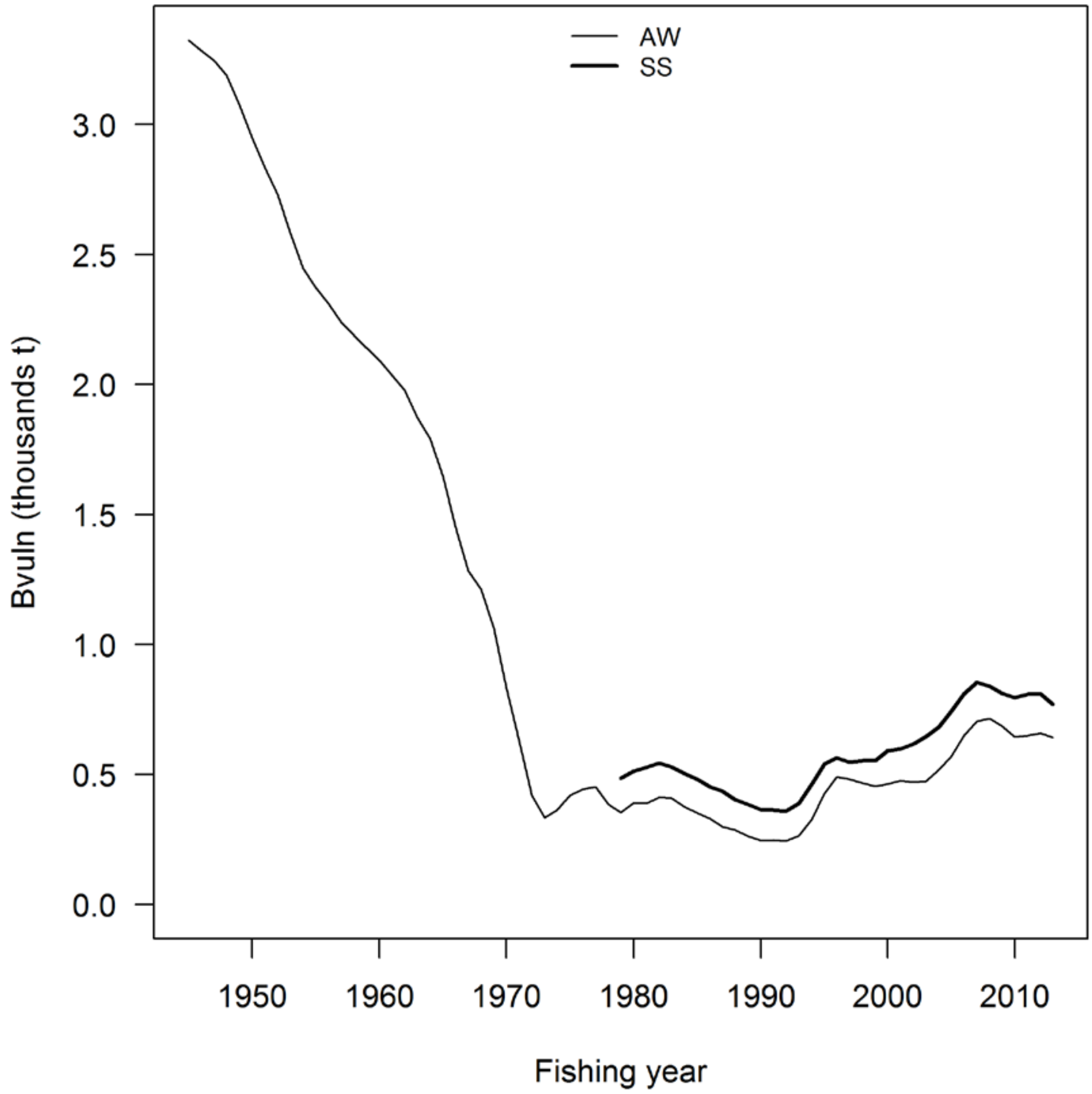


Figure 15: CRA 1 vulnerable biomass (thousands of tonnes) by fishing year and season for the base case MPD. The model used a yearly time step before 1979 that is shown as "AW".

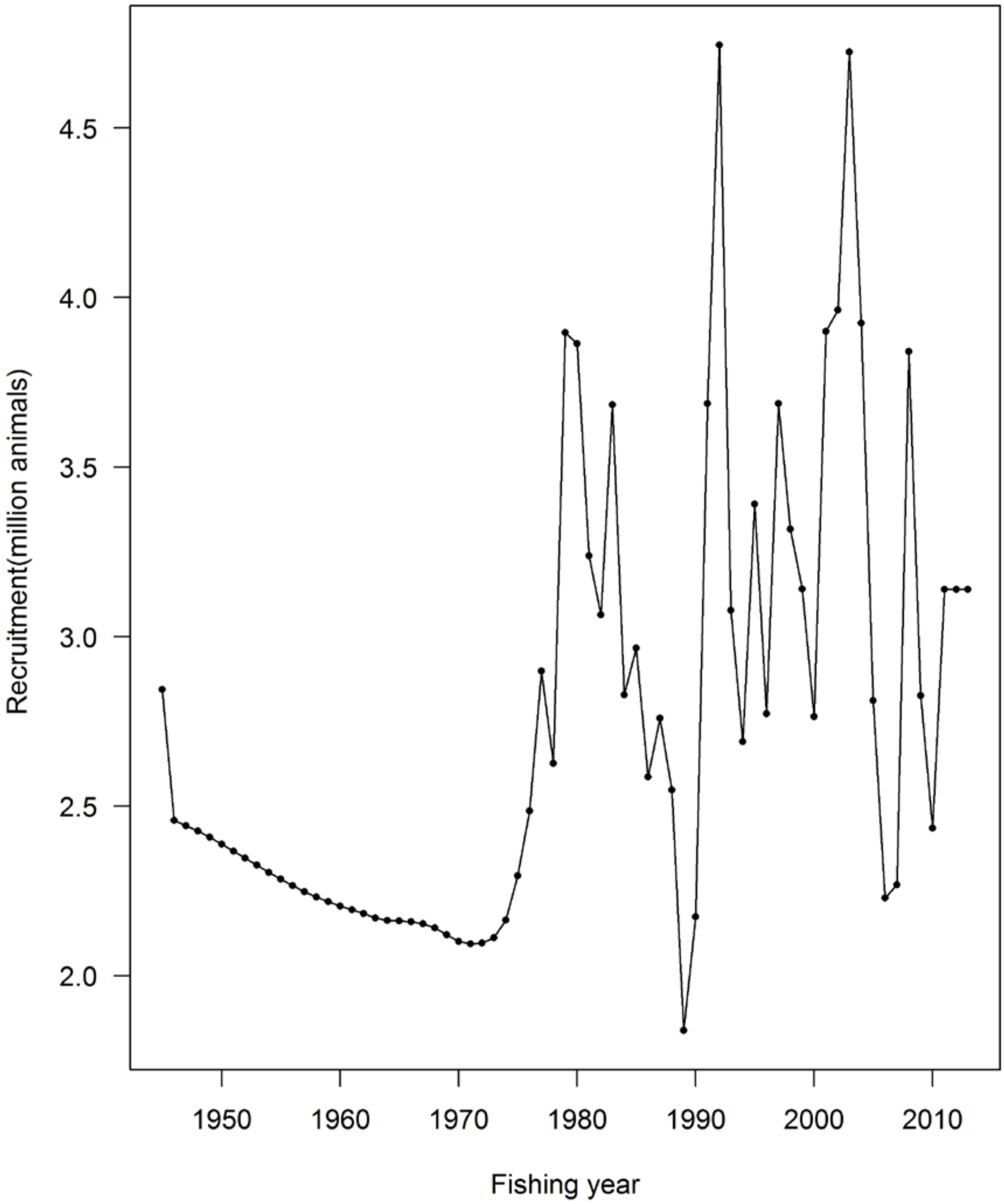


Figure 16: Annual recruitment from the base case MPD fit.

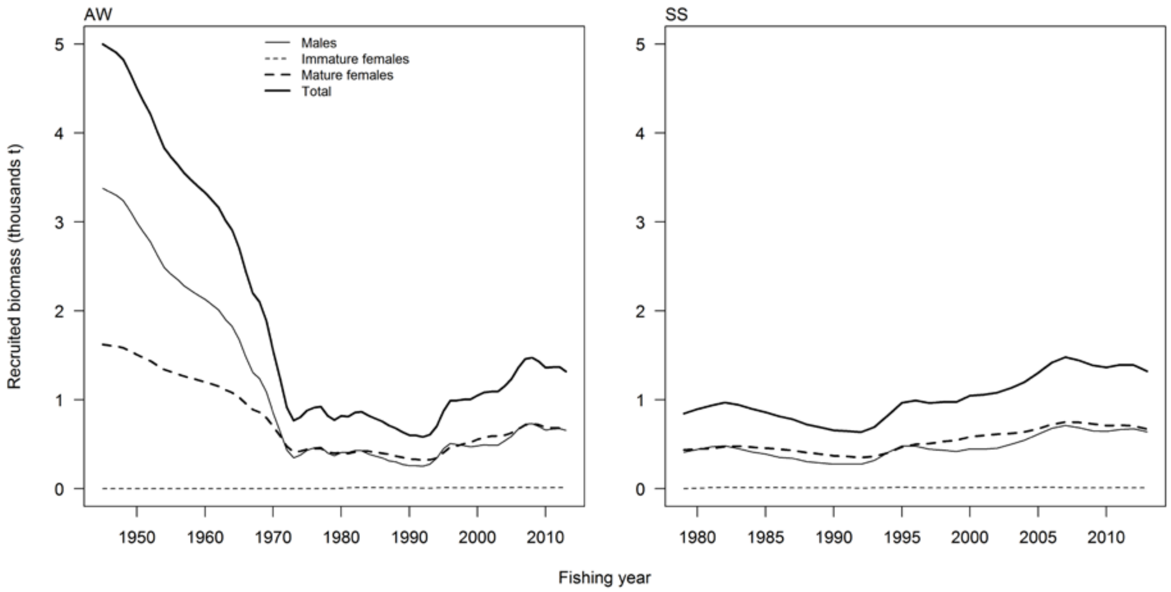


Figure 17: Seasonal trajectories of recruited biomass (thousands of tonnes) by sex category and total recruited biomass from the base case MPD fit. The model used a yearly time step before 1979 that is shown in the AW panel.

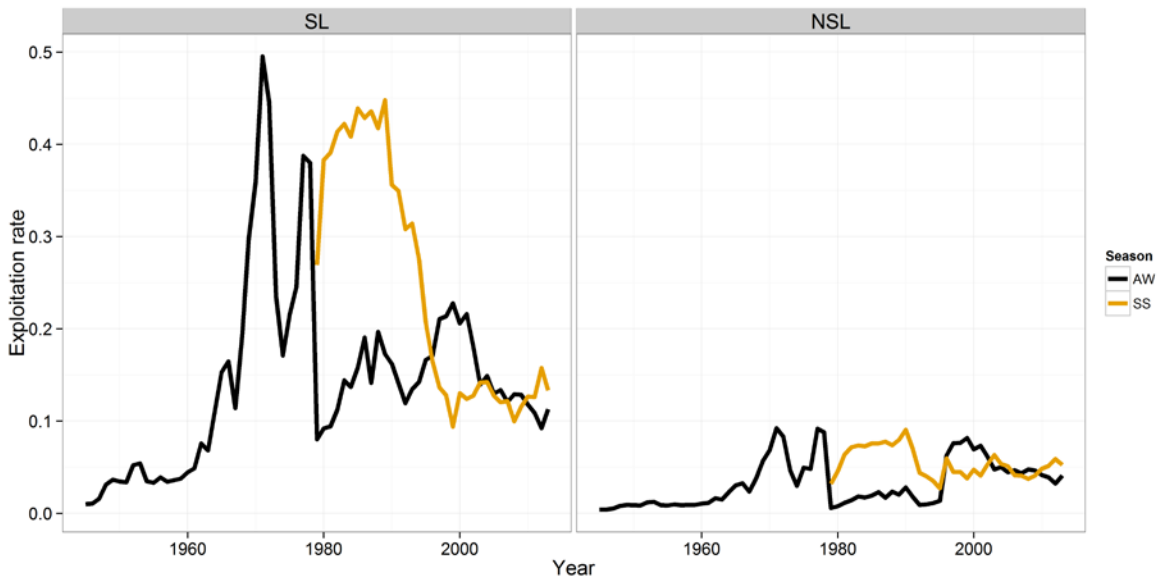


Figure 18: Trajectories of exploitation rate for the size limited (SL) and non-size limited (NSL) fisheries during autumn-winter (AW) and spring-summer (SS) from the base case MPD fit.

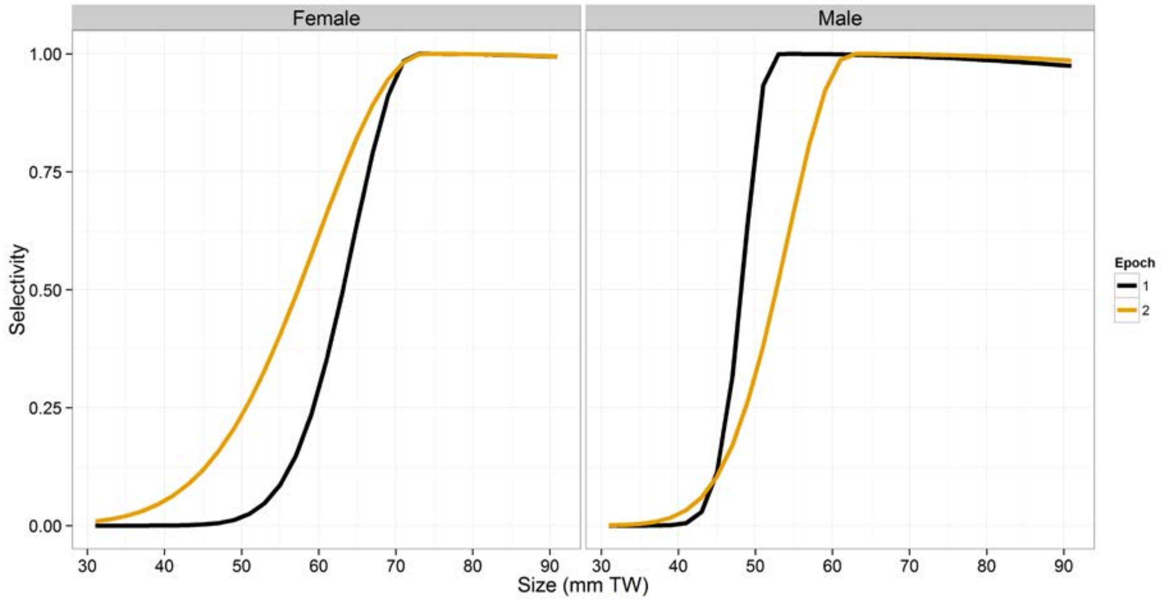


Figure 19: Selectivity-at-size (mm tail width) for males and females in two epochs. The second epoch began in 1993.

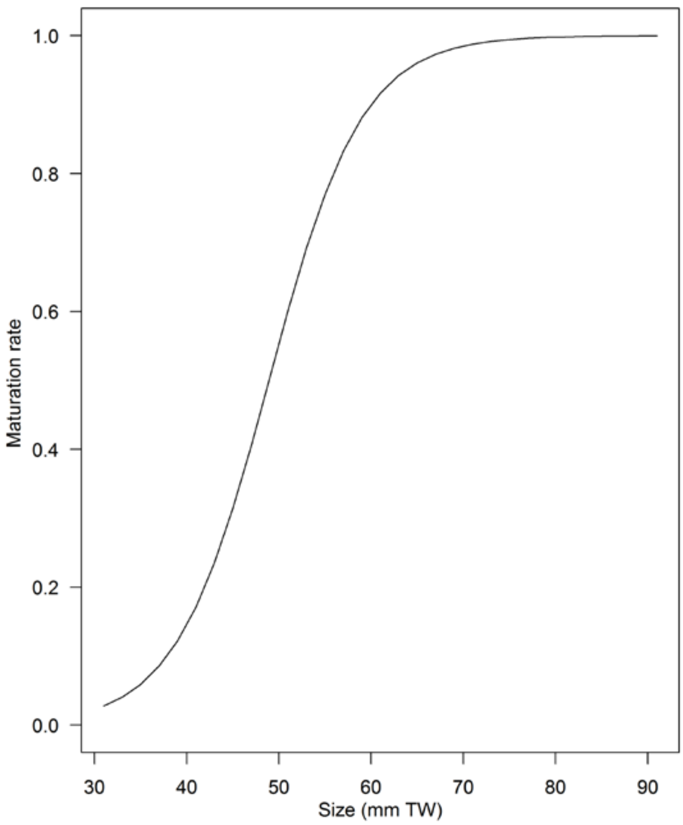


Figure 20: Maturity-at-size (mm tail width) from the base case MPD fit.

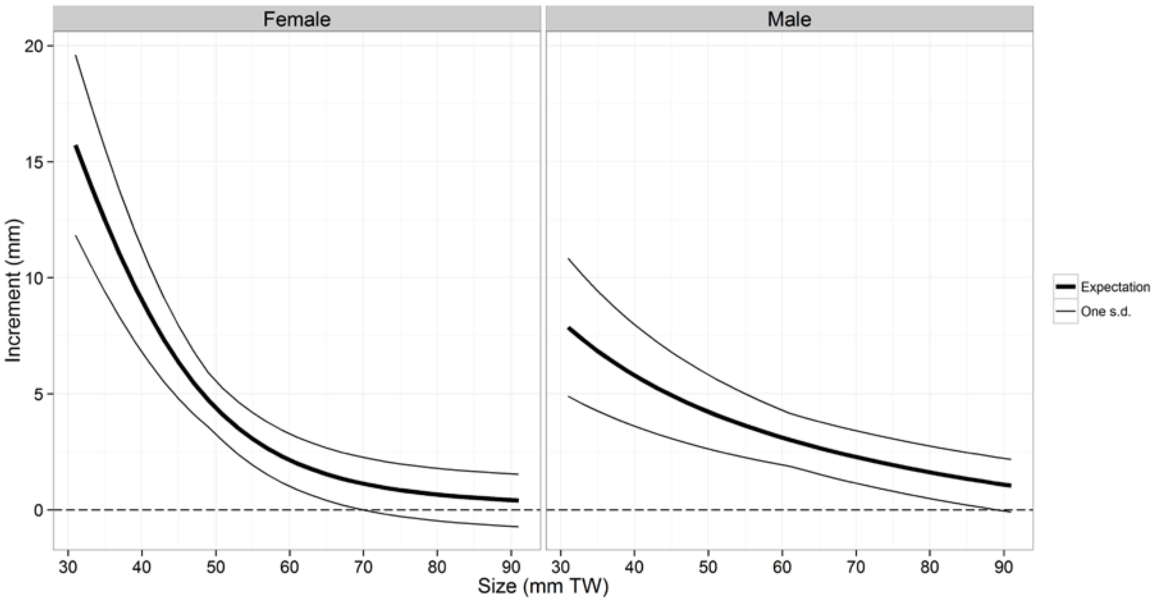


Figure 21: Predicted increments (mm tail width) by initial size (mm tail width) and sex from the base case MPD fit. Thinner lines show one standard deviation from the predicted mean.

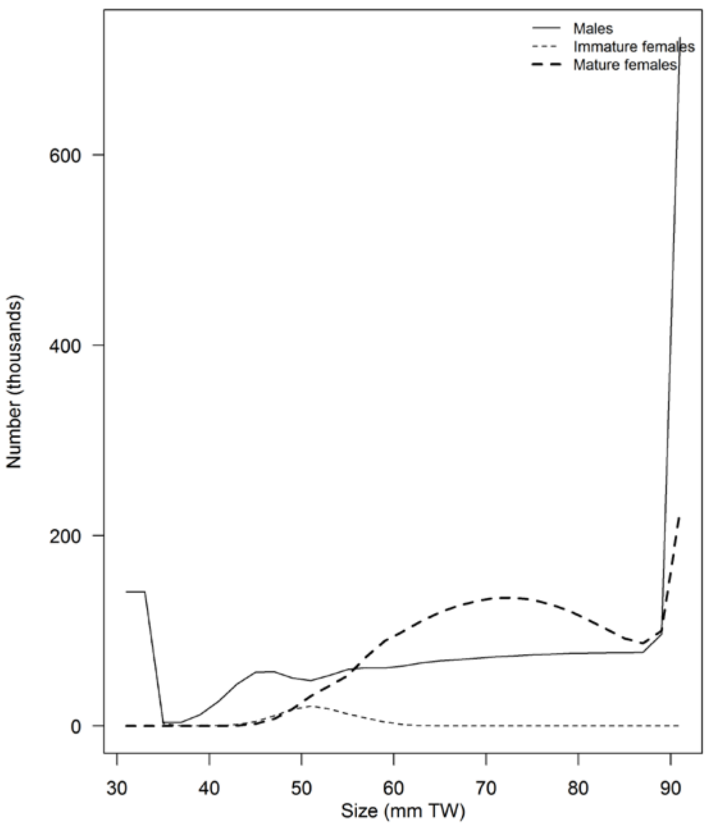


Figure 22: The predicted size distributions by sex in the absence of fishing and with constant recruitment, from the base case MPD fit.

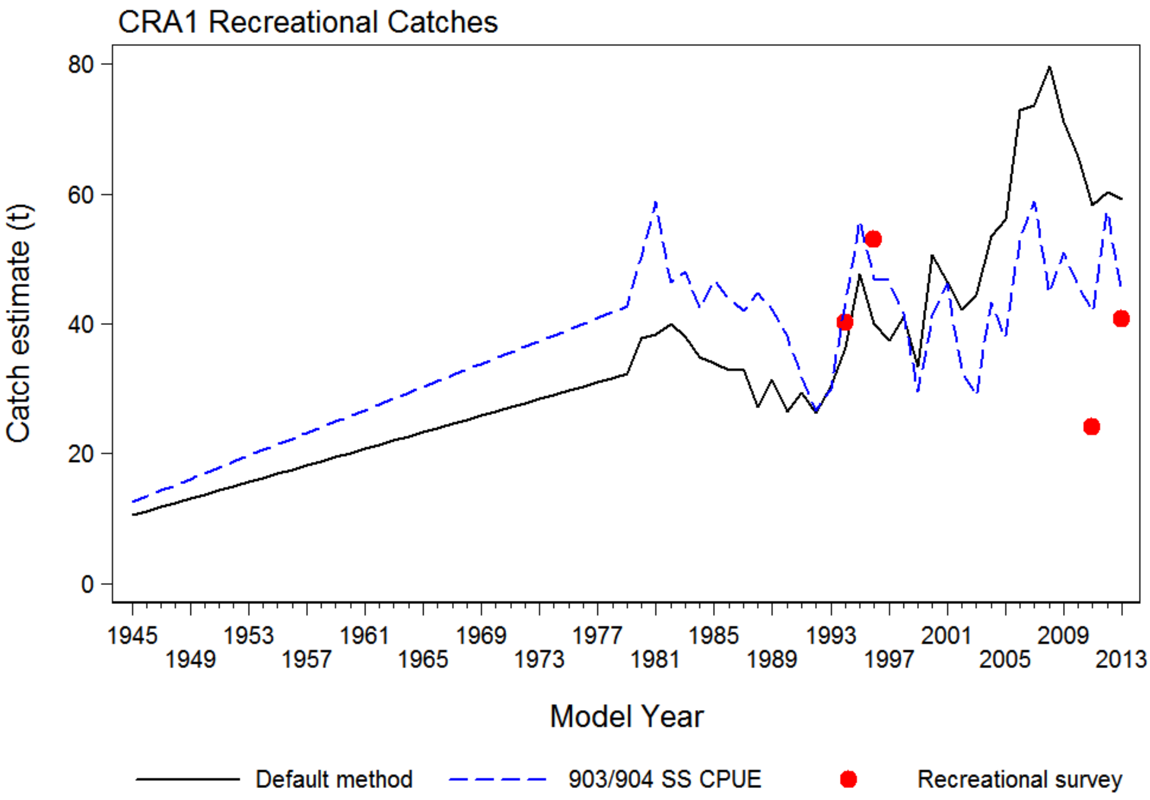


Figure 23: Two alternative recreational catch trajectories: the base case used the "903/904 SS CPUE" trajectory while the "Alt recreational catch" sensitivity run used the "Default method" recreational catch trajectory.

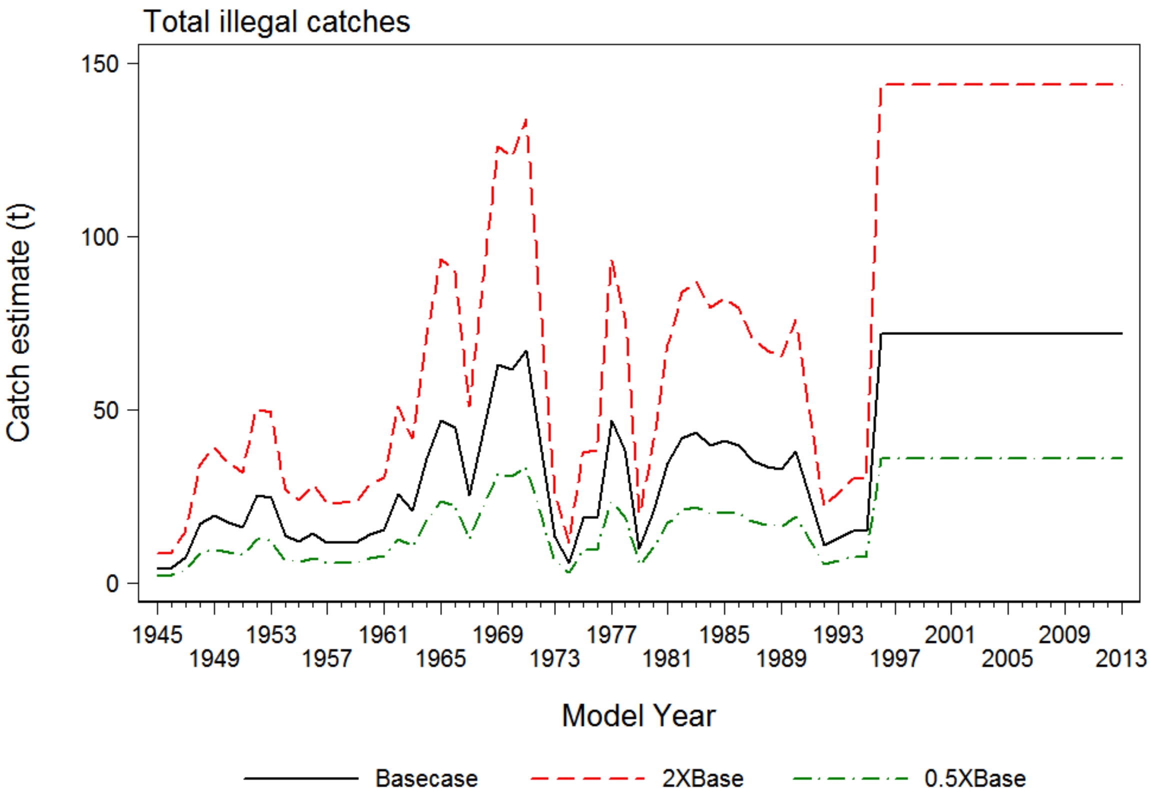


Figure 24: Three alternative illegal catch trajectories: the base case trajectory based on export discrepancy information up to 1990 and fishery officer estimates afterward. The other two trajectories are double and half of the base case trajectory.

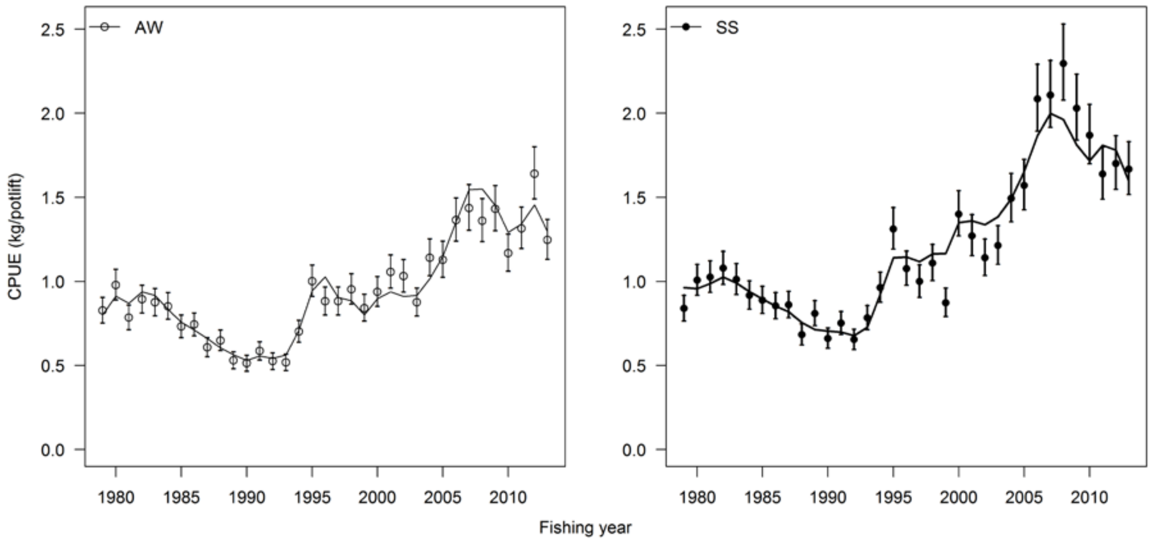


Figure 25: The fit to CPUE in the "CPUEpow" sensitivity trial (sens7).

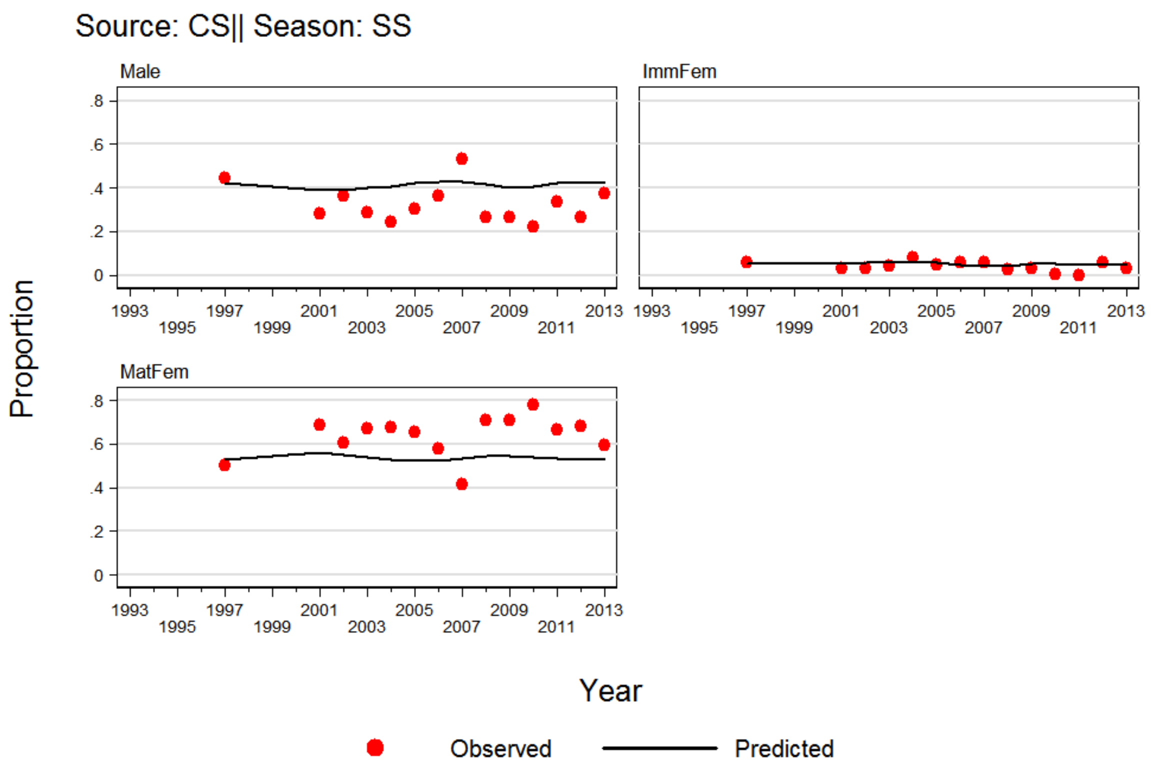


Figure 26: Proportion by sex for catch sampling in the spring-summer season (sens9, OldLF=30).

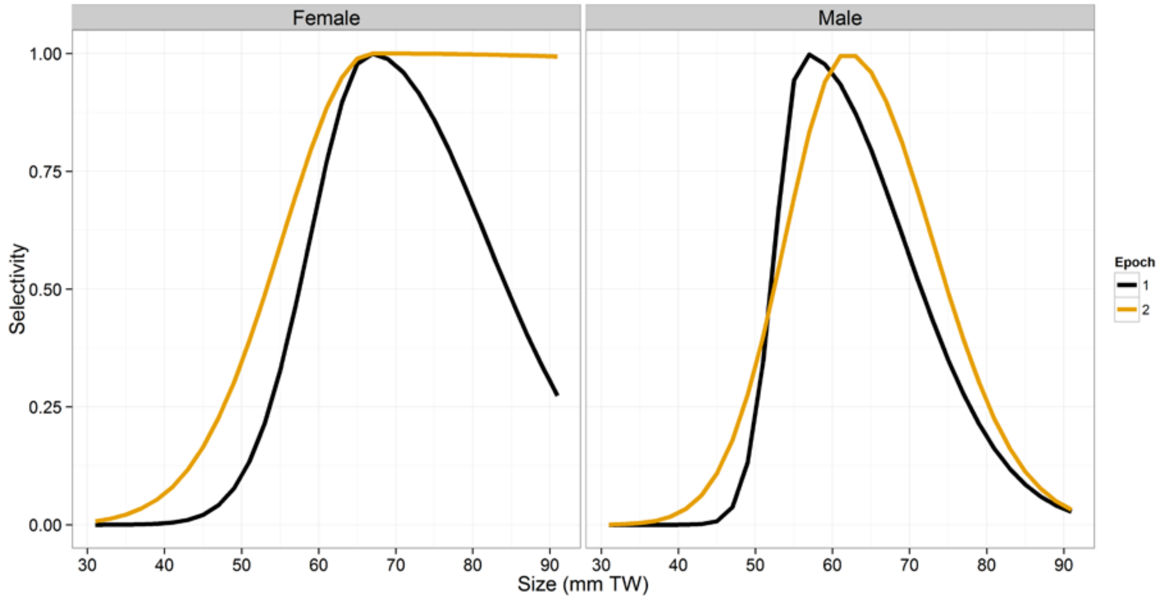


Figure 27: Selectivity functions by sex and epoch (sens11, est righthand limb).

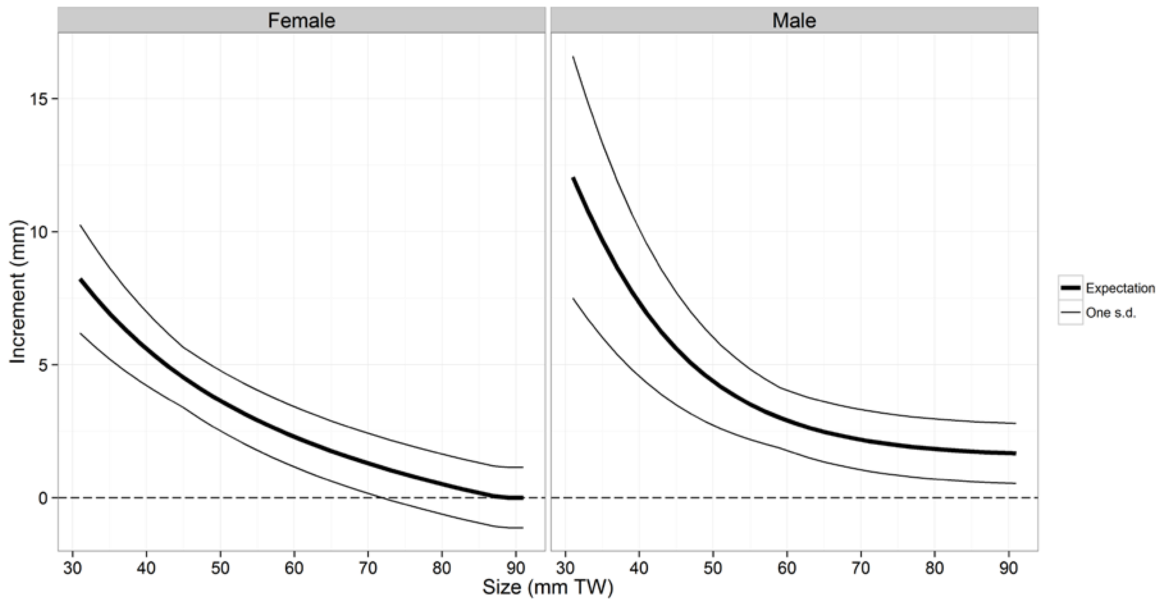


Figure 28: Predicted increments (mm tail width) against initial size (mm tail width) by sex (sens12, fixed shape).

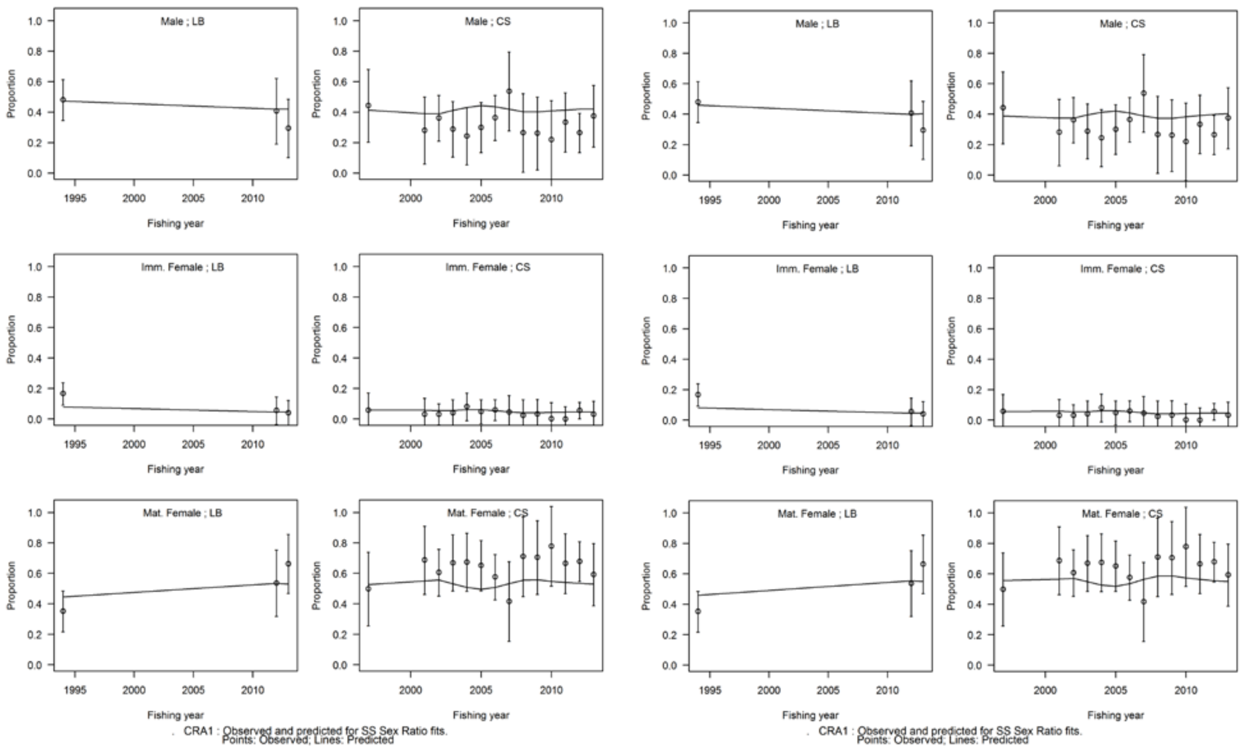


Figure 29: Observed (circles) and predicted (lines) sex proportion fits in spring-summer by sex and data source for the two sensitivity runs with fixed *GShape* parameters; [left panel]: sens12: fixed shape; [right panel]: sens13: fixed shape+switch vulnest.

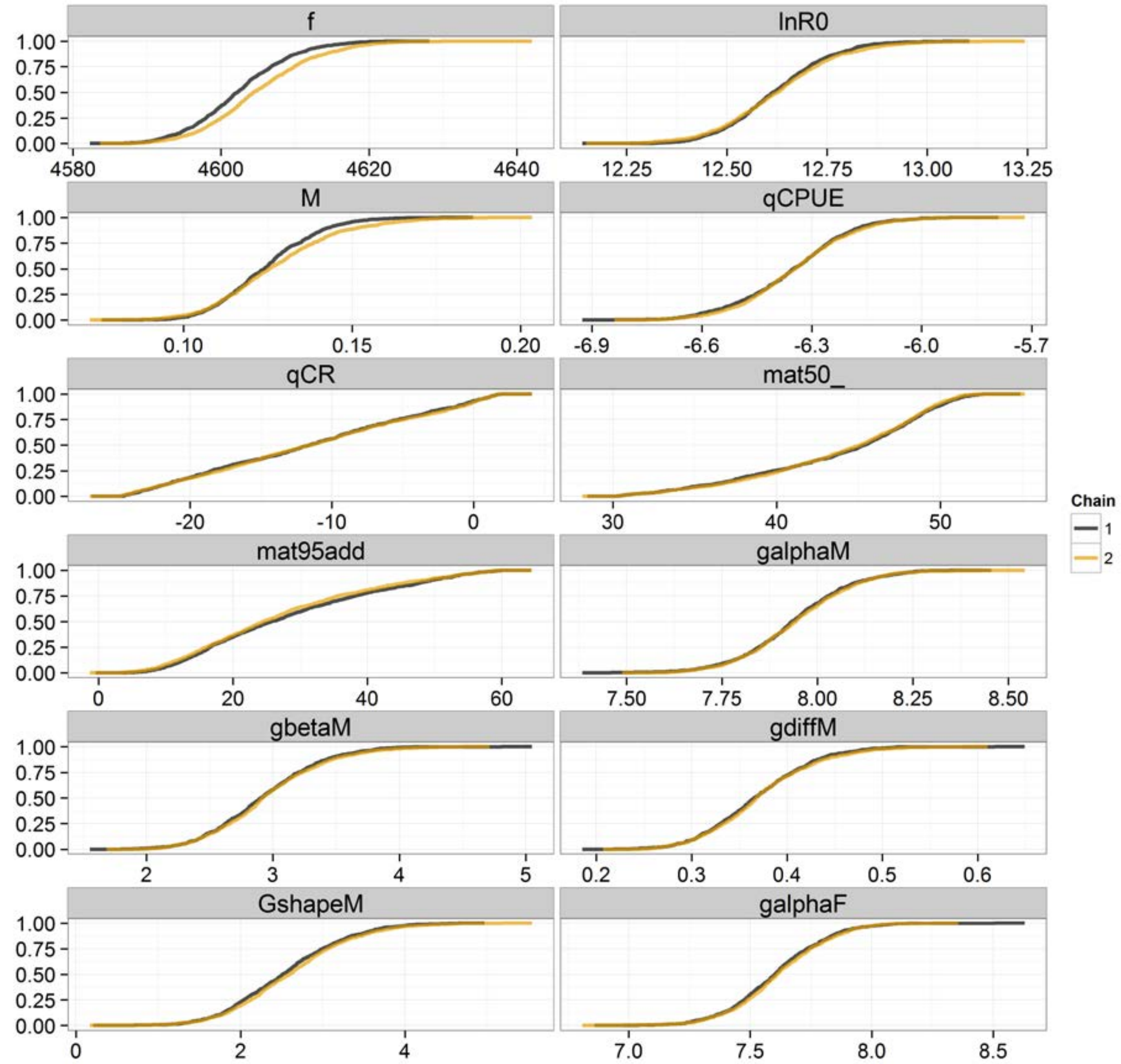


Figure 30: Comparison of empirical cumulative distributions (ECD) of the posteriors for key parameters generated for the "base case" using two different Newton-Raphson (N-R) assumptions: chain 1 (black)=3 N-R; chain 2 (yellow)=5 N-R.

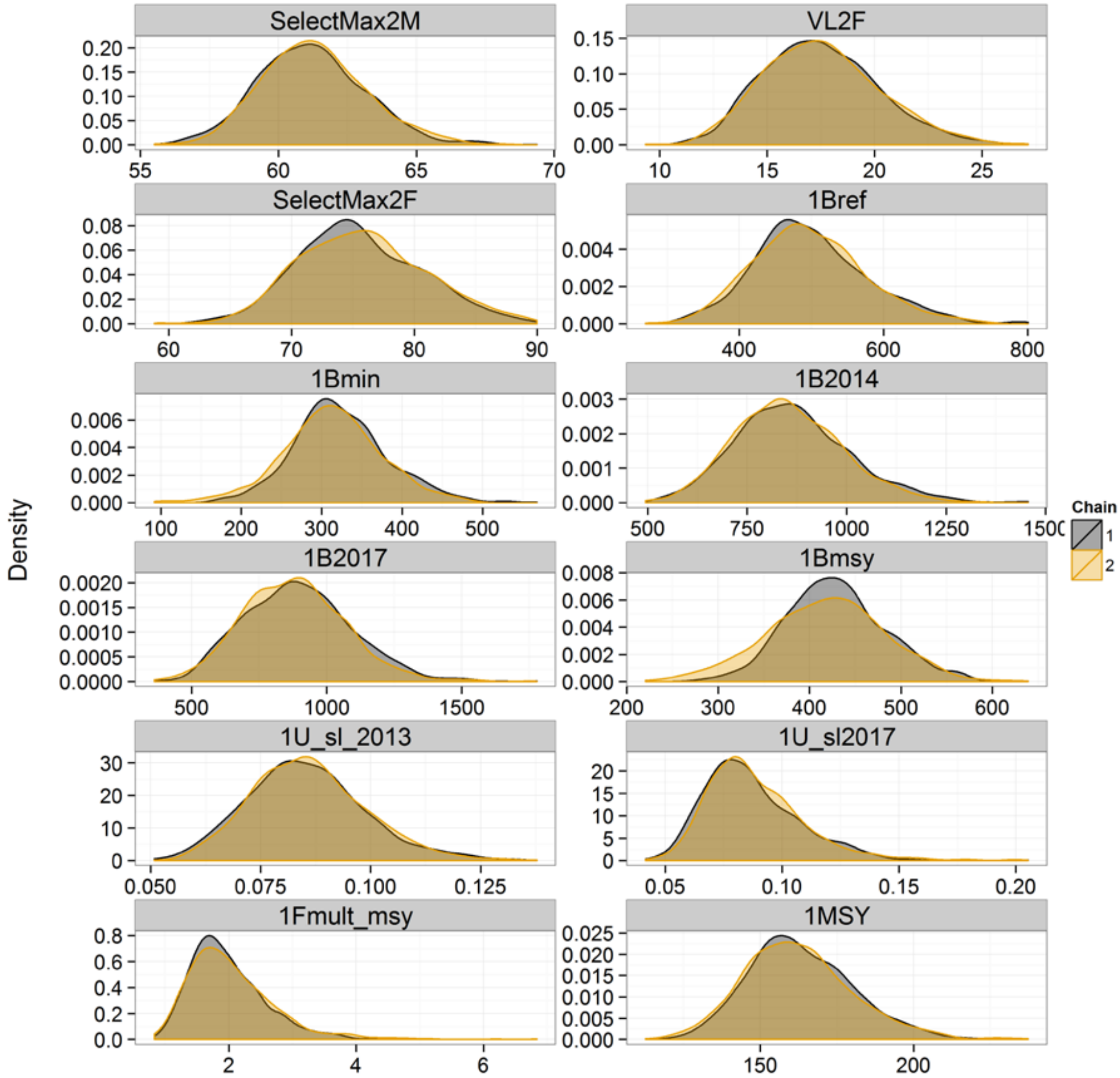


Figure 31: Comparison of posterior density plots for important derived parameters generated for the "base case" using two different Newton-Raphson (N-R) assumptions: chain 1 (black)=5 N-R; chain 2 (yellow)=3 N-R.

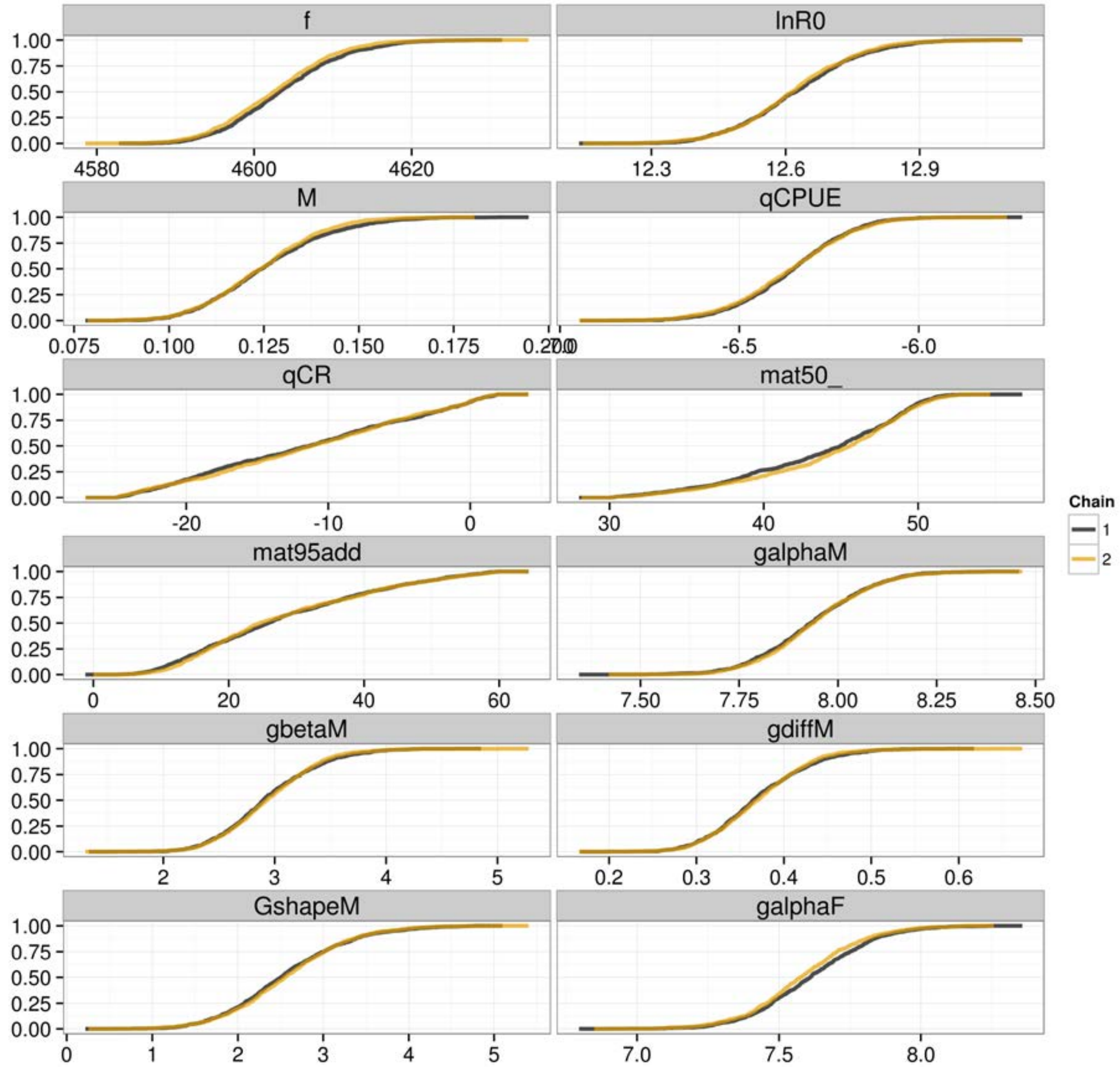


Figure 32: Comparison of empirical cumulative distributions (ECD) of the posteriors for key parameters, with Chain 1 (black) representing the stacked chain and Chain 2 (yellow) representing the long chain for base case runs using an informed prior on natural mortality (*M*).

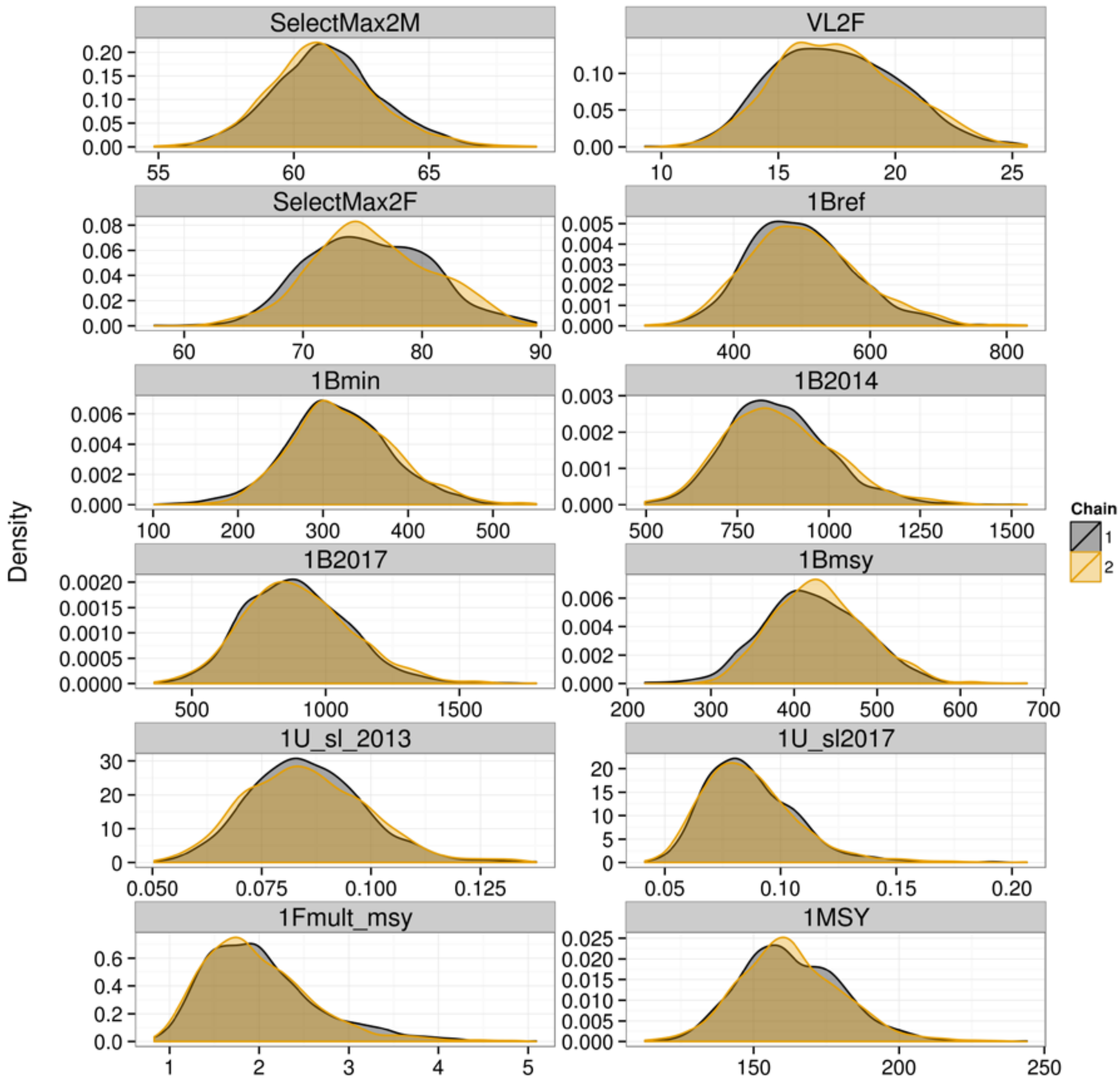


Figure 33: Comparison of posterior density distributions for important derived parameters, with Chain 1 (black) representing the stacked chain and Chain 2 (yellow) representing the long chain for base case runs using an informed prior on natural mortality (*M*).

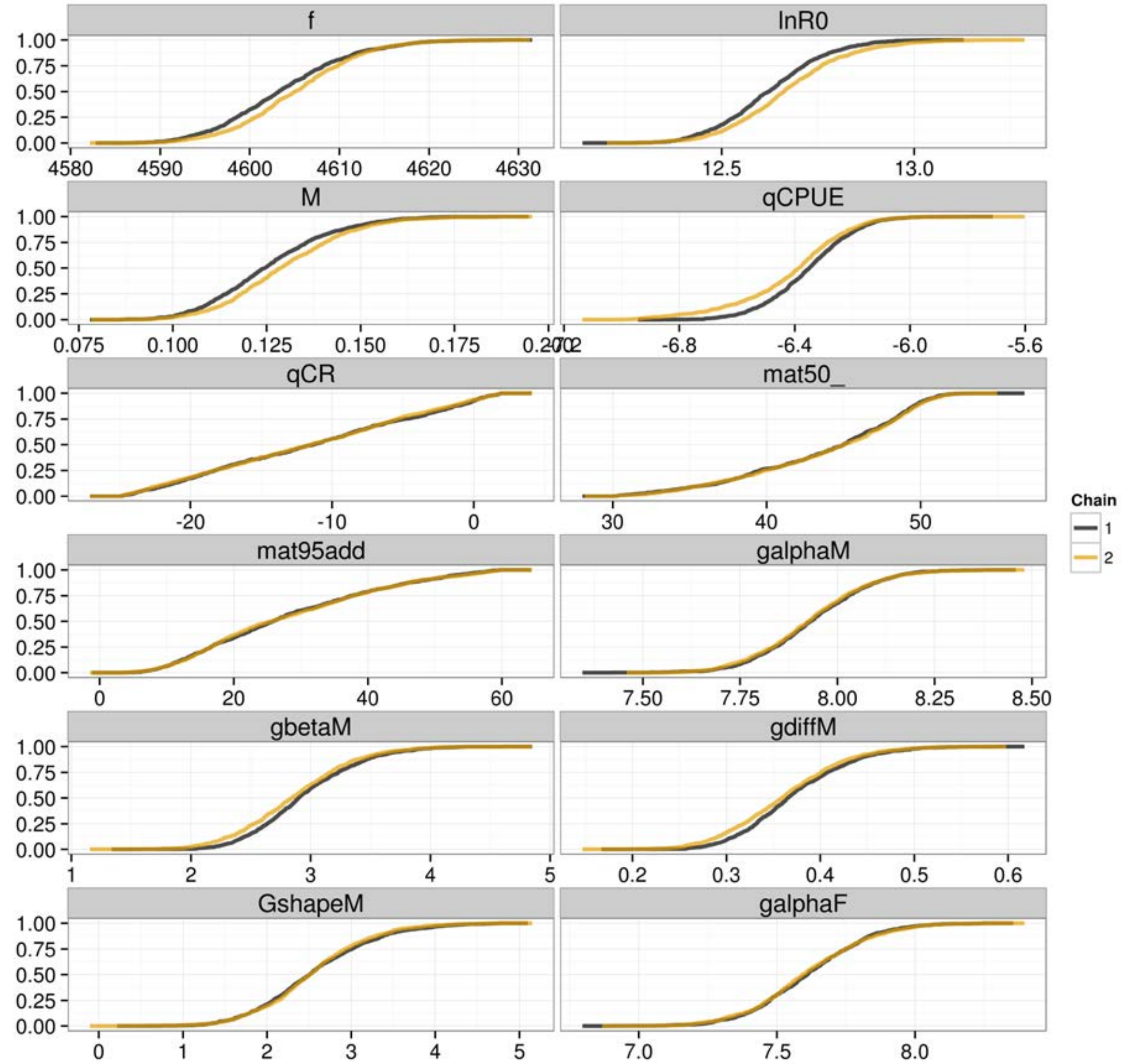


Figure 34: Comparison of empirical cumulative distributions (ECD) of the posteriors for key parameters, with Chain 1 (black) representing the base case using an informed prior on natural mortality (*M*) and Chain 2 (yellow) representing the runs using an uninformed prior on natural mortality (*M*).

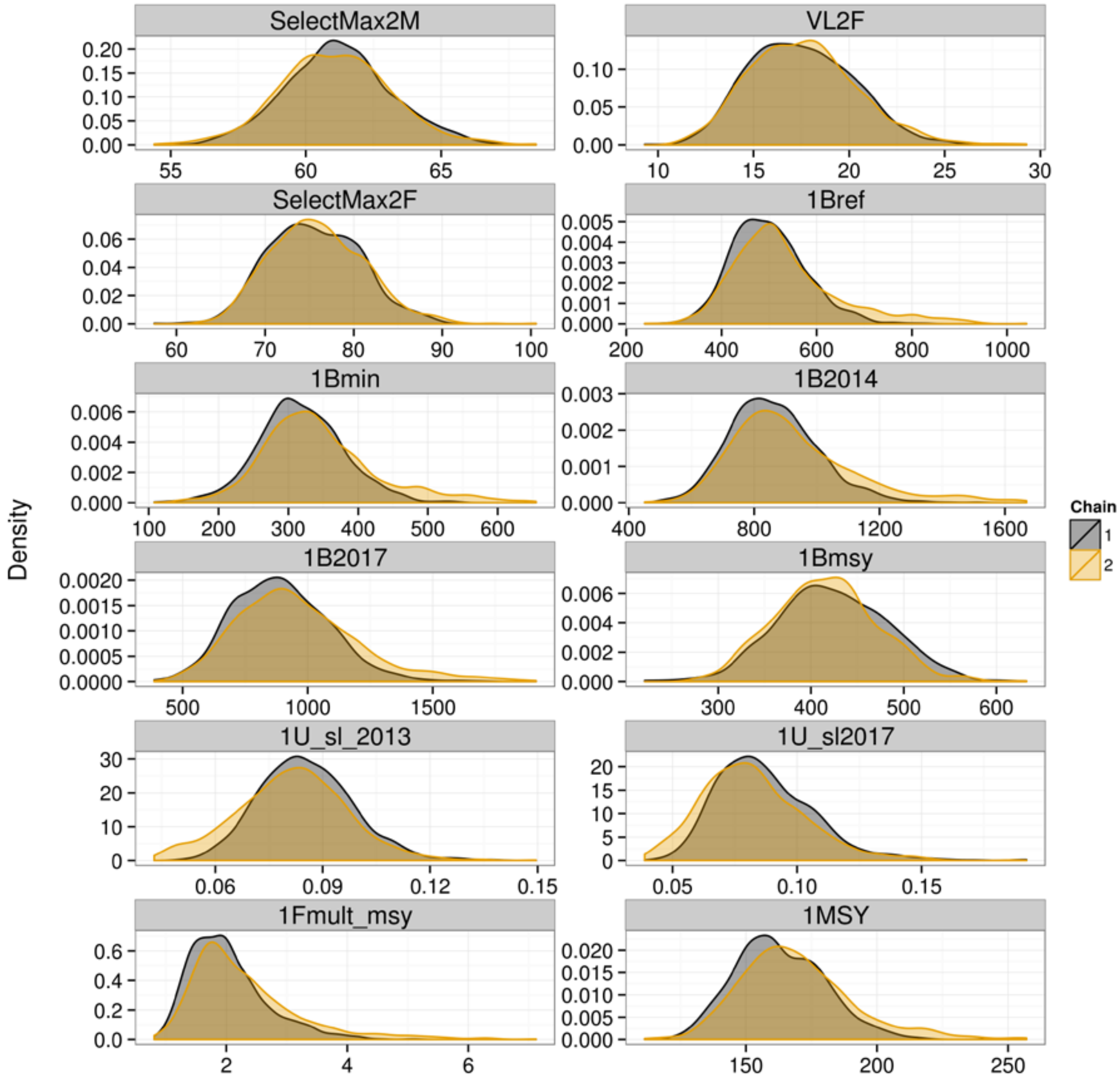


Figure 35: Comparison of posterior density distributions for important derived parameters, with Chain 1 (black) representing the base case using an informed prior on natural mortality (*M*) and Chain 2 (yellow) representing the runs using an uninformed prior on natural mortality (*M*).

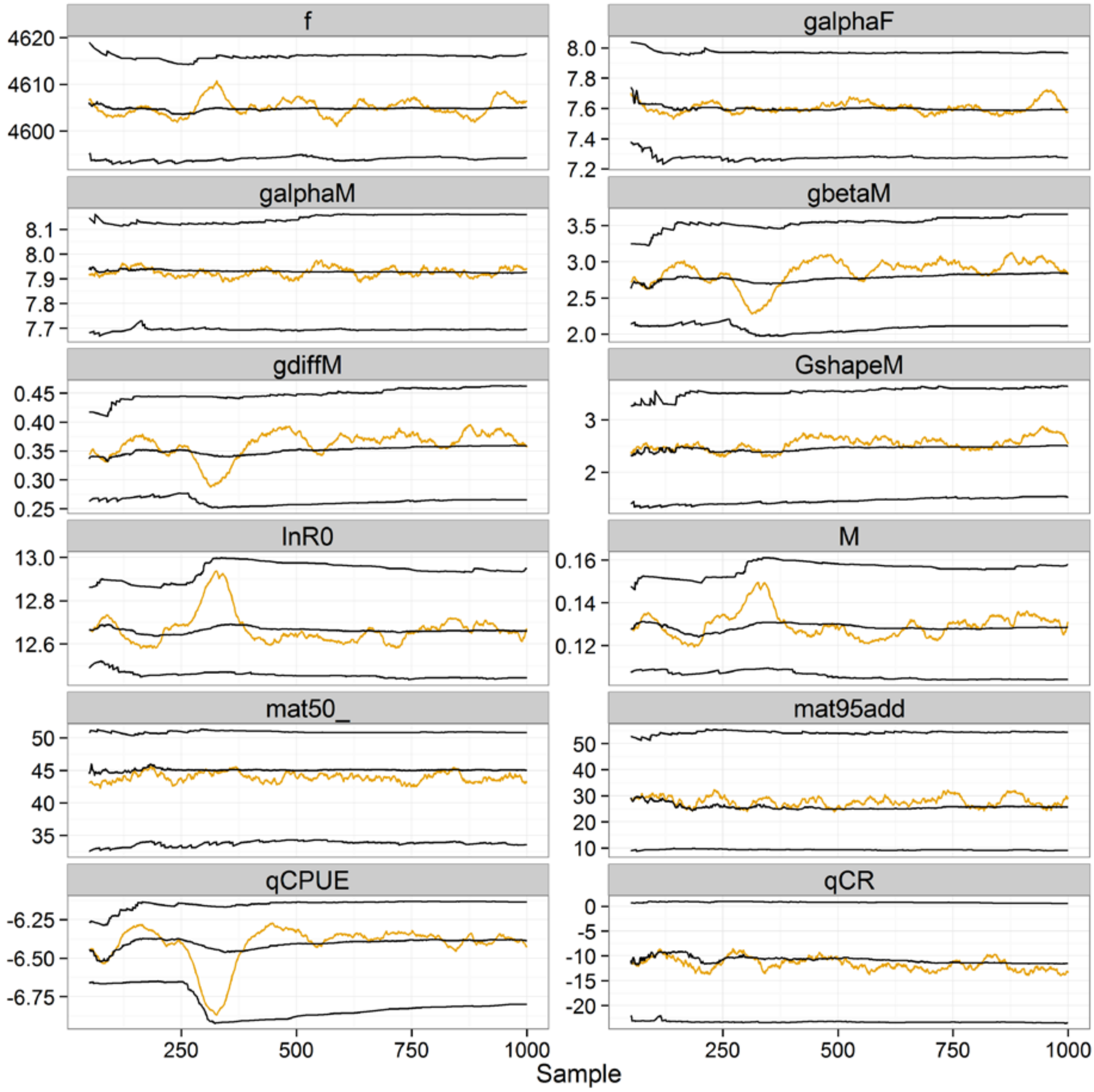


Figure 36: Diagnostic plots for the traces from the variant "base case" MCMC which used an uninformed prior on *M*. The solid black lines are the running median and the 5th and 95th quantiles. The gold line is a moving mean over 50 samples.

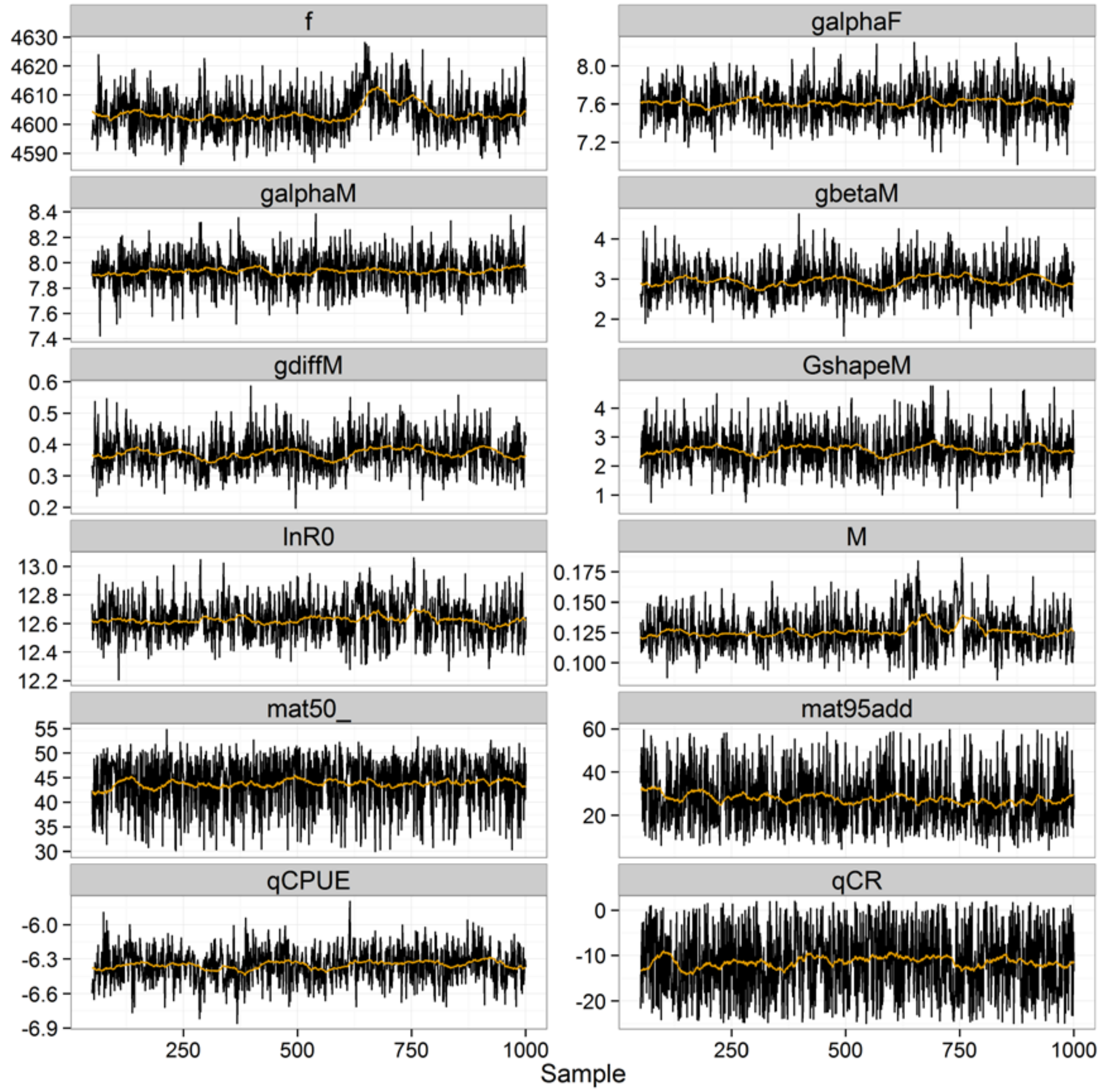


Figure 37A: Traces for estimated and derived parameters from the base case MCMC. The gold line is a moving mean over 50 samples.

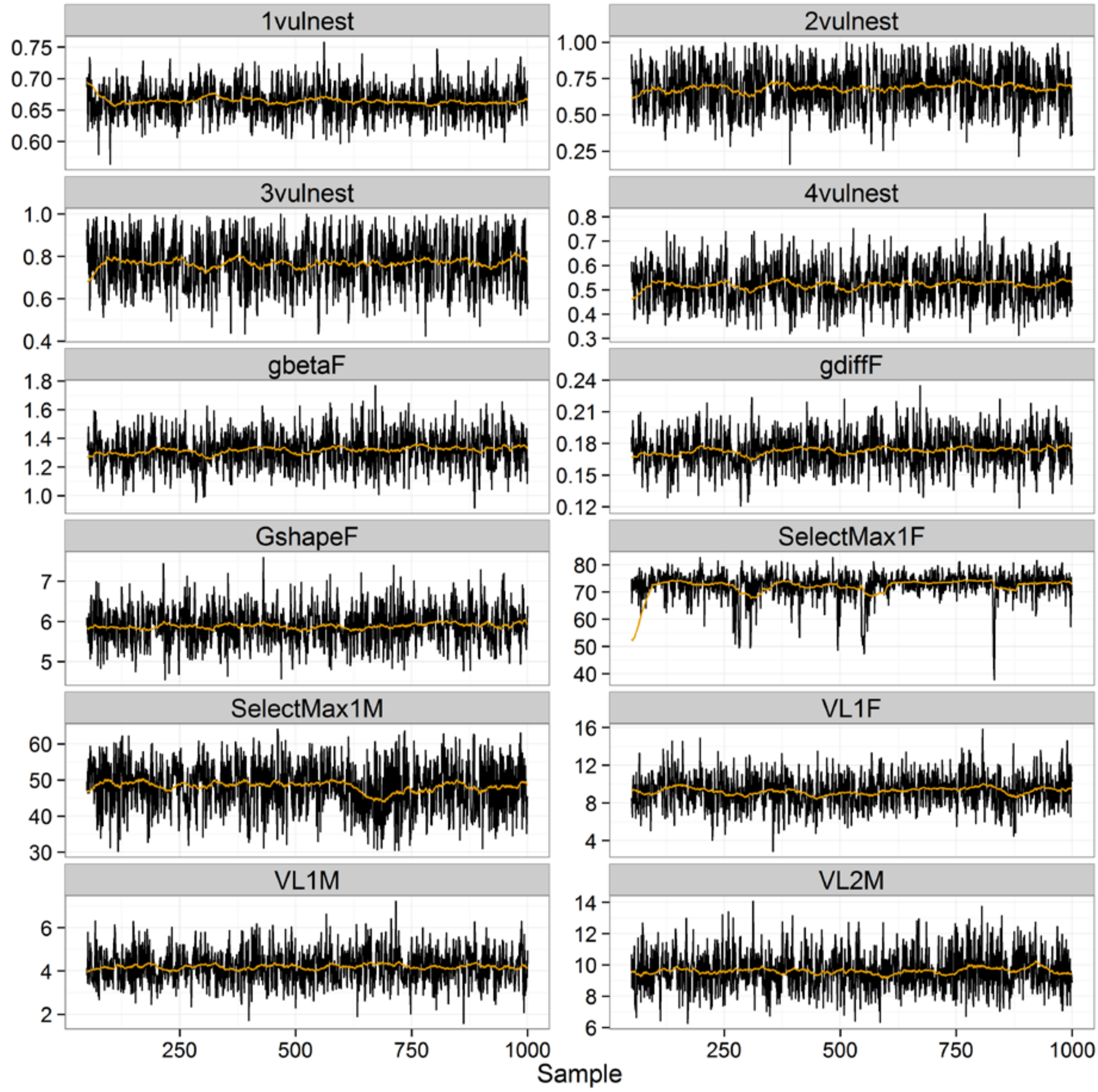


Figure 37B: Traces for estimated and derived parameters from the base case MCMC (continued).

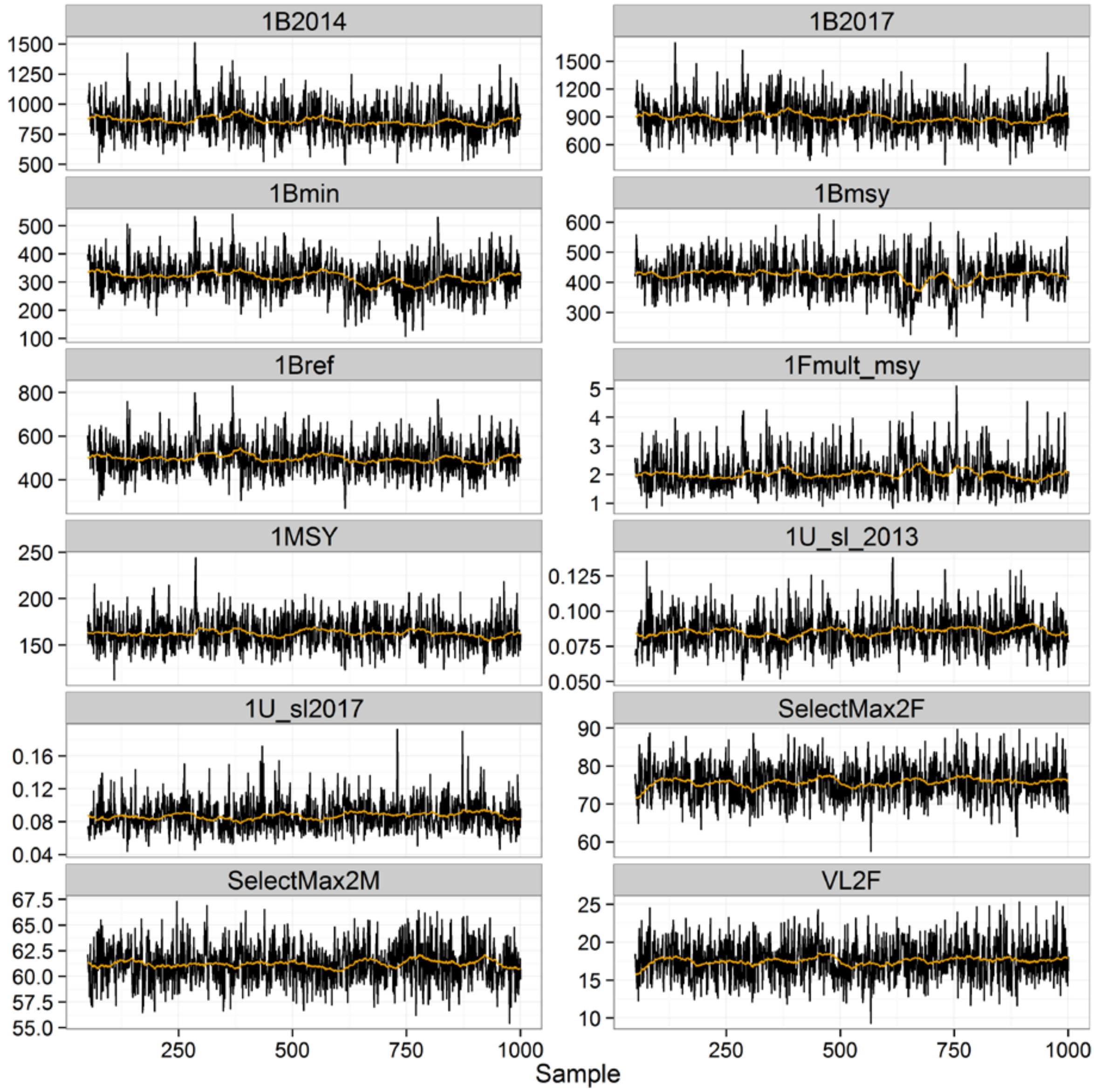


Figure 37C: Traces for estimated and derived parameters from the base case MCMC (continued).

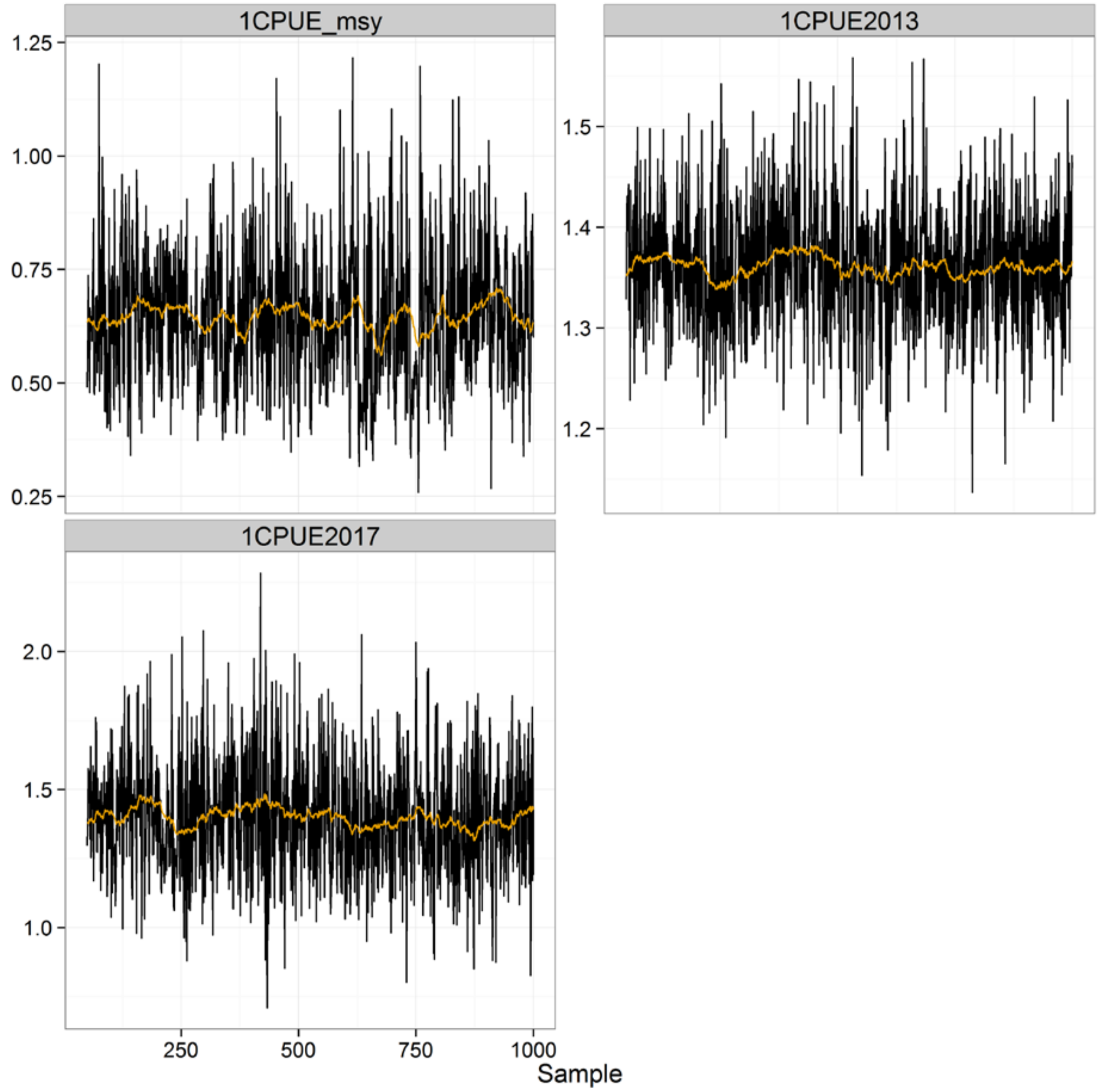


Figure 37D: Traces for estimated and derived parameters from the base case MCMC (continued).

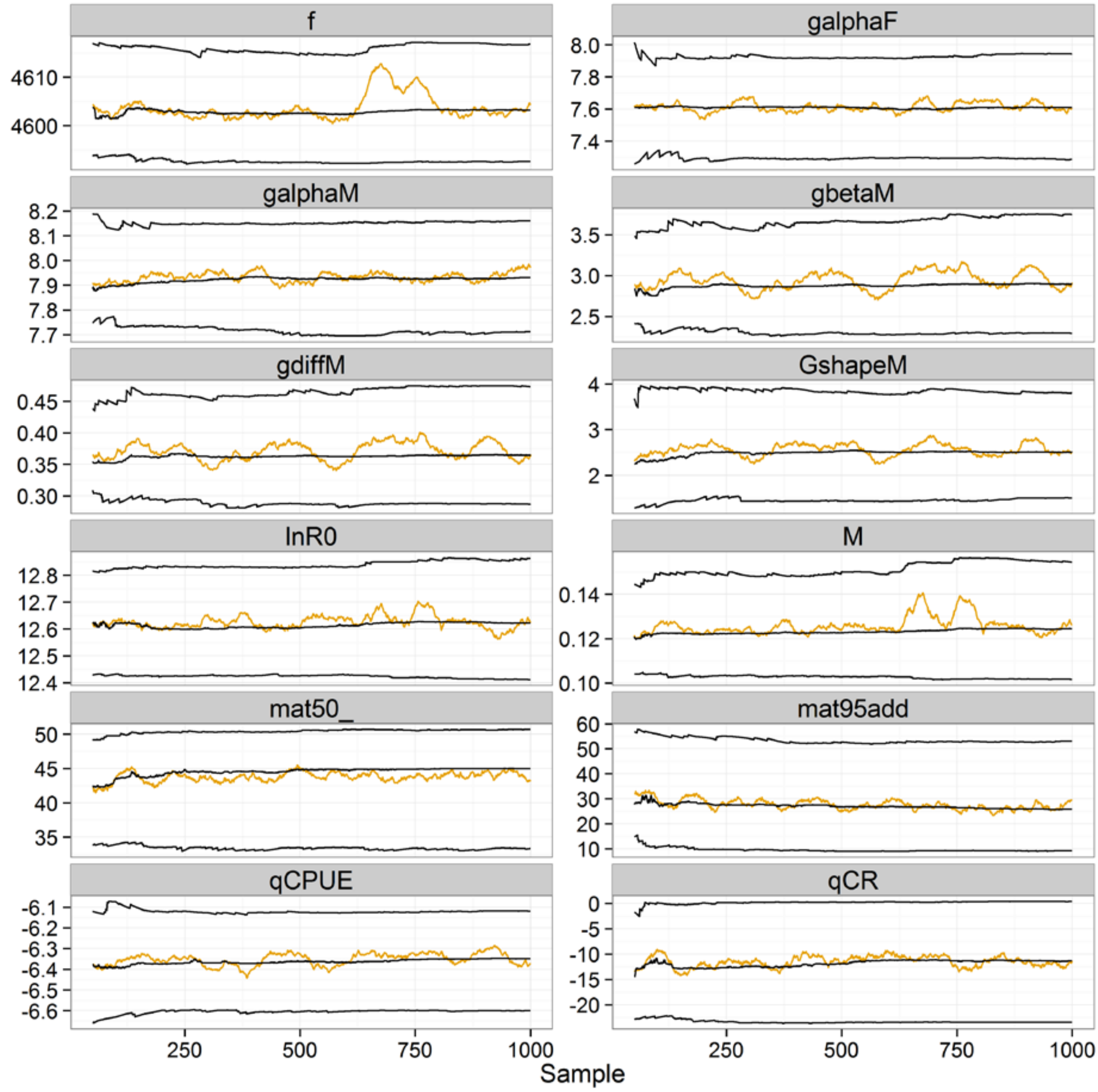


Figure 38A: Diagnostic plots for the traces seen in Figure 37. The solid black lines are the running median and the 5th and 95th quantiles. The gold line is a moving mean over 50 samples.

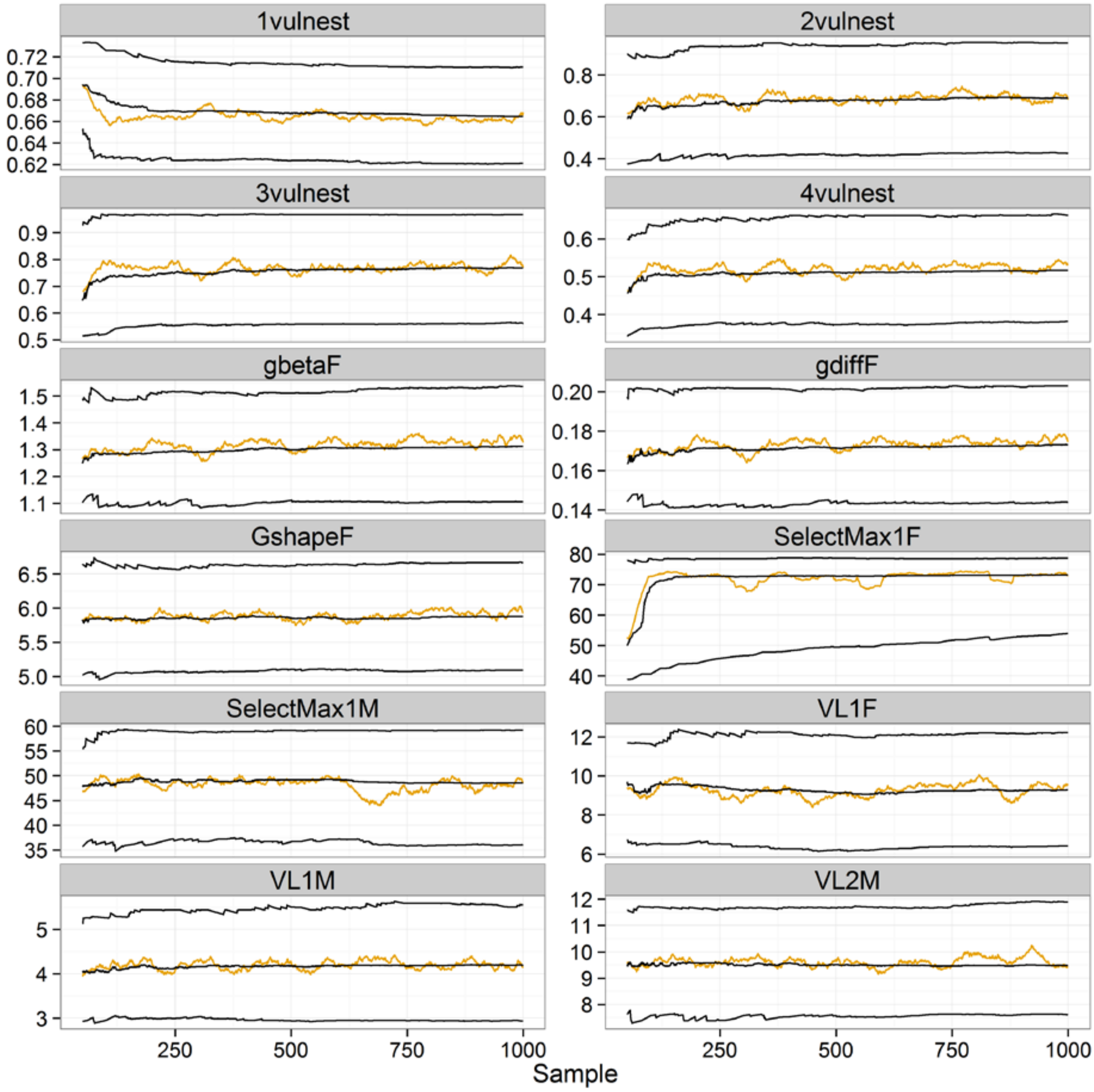


Figure 38B: Diagnostic plots for the traces seen in Figure 37 (continued).

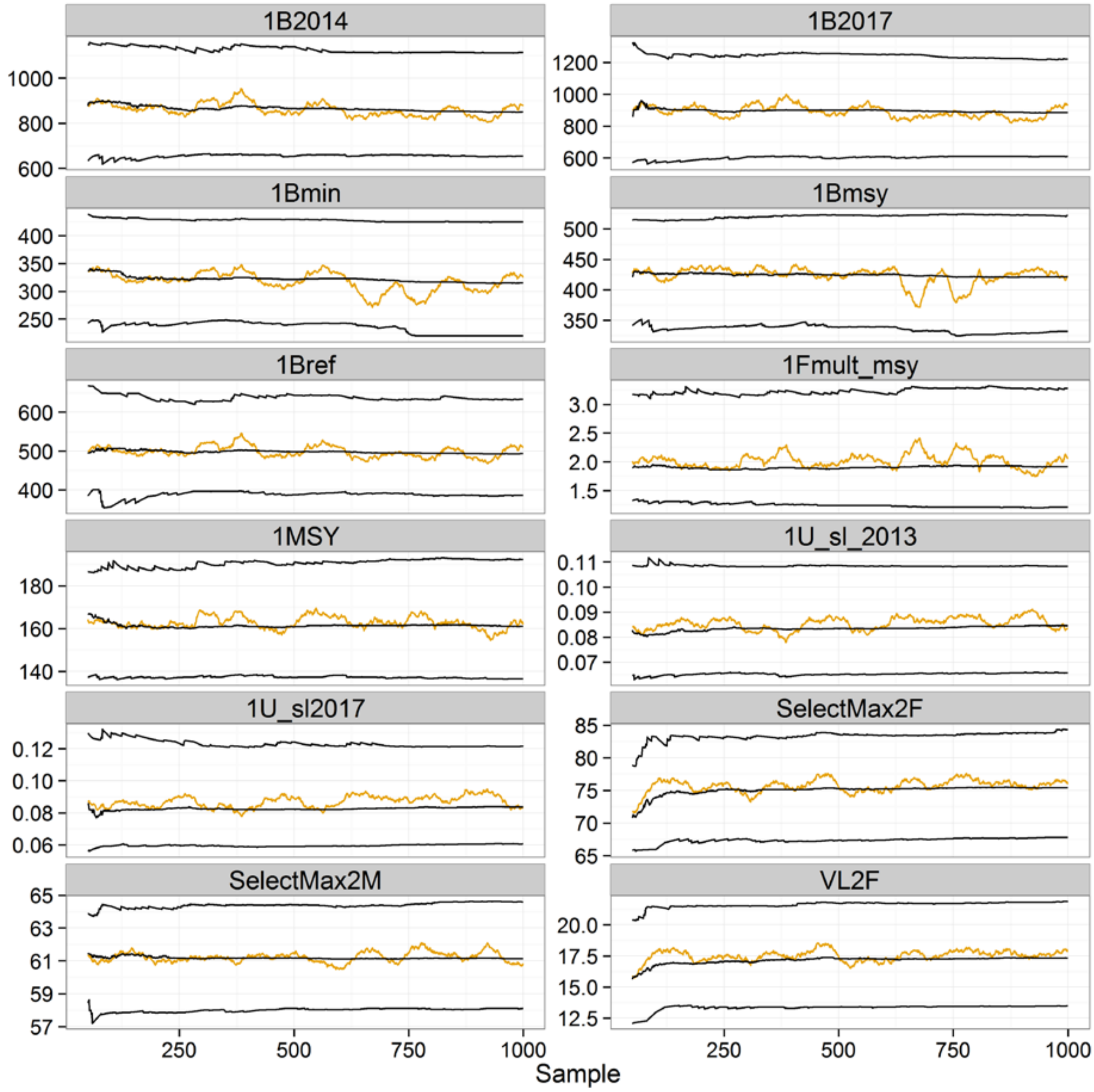


Figure 38C: Diagnostic plots for the traces seen in Figure 37 (continued).

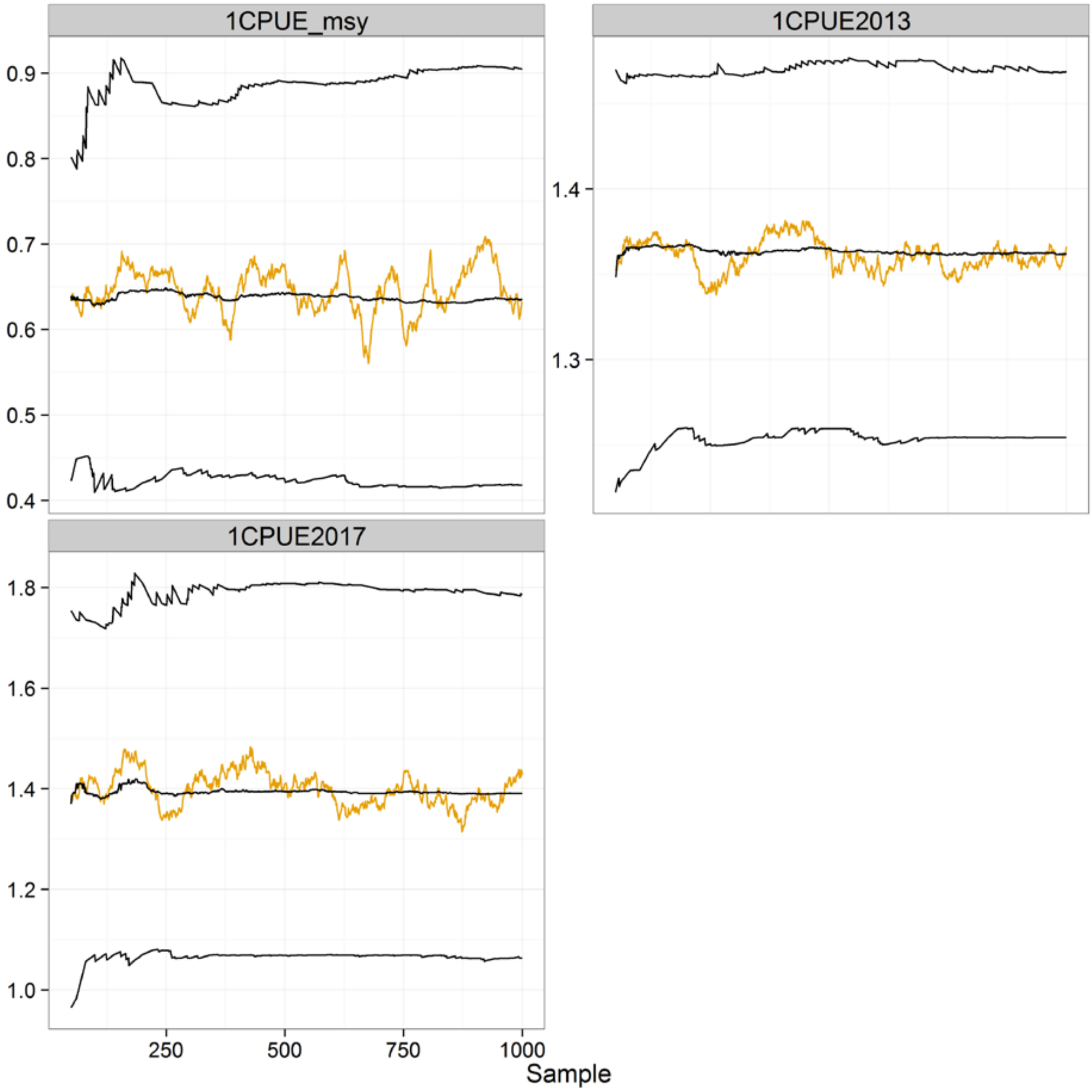


Figure 38D: Diagnostic plots for the traces seen in Figure 37 (continued).

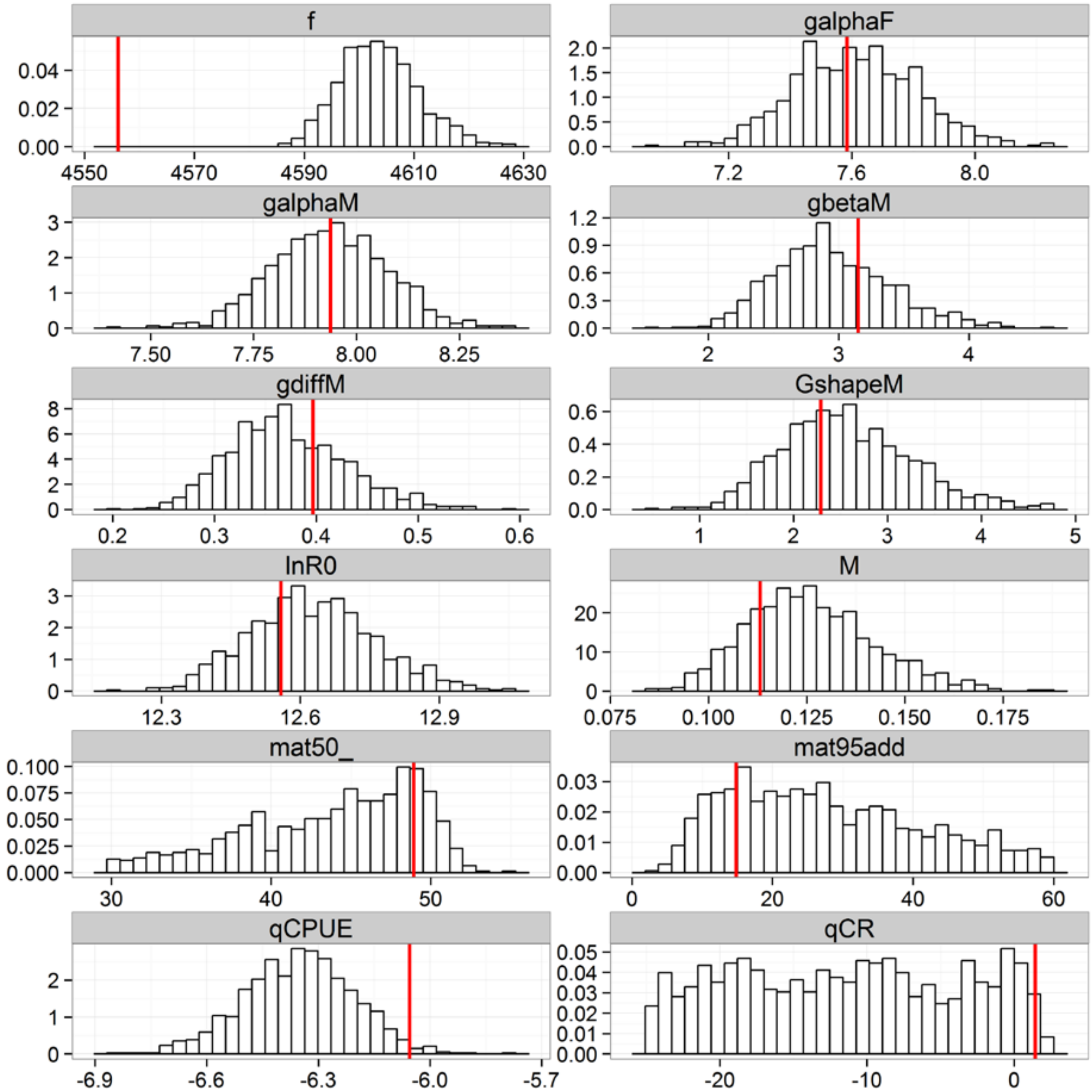


Figure 39A: Posterior distributions of estimated parameters from the base case MCMC. Vertical bar indicates the MPD estimate.

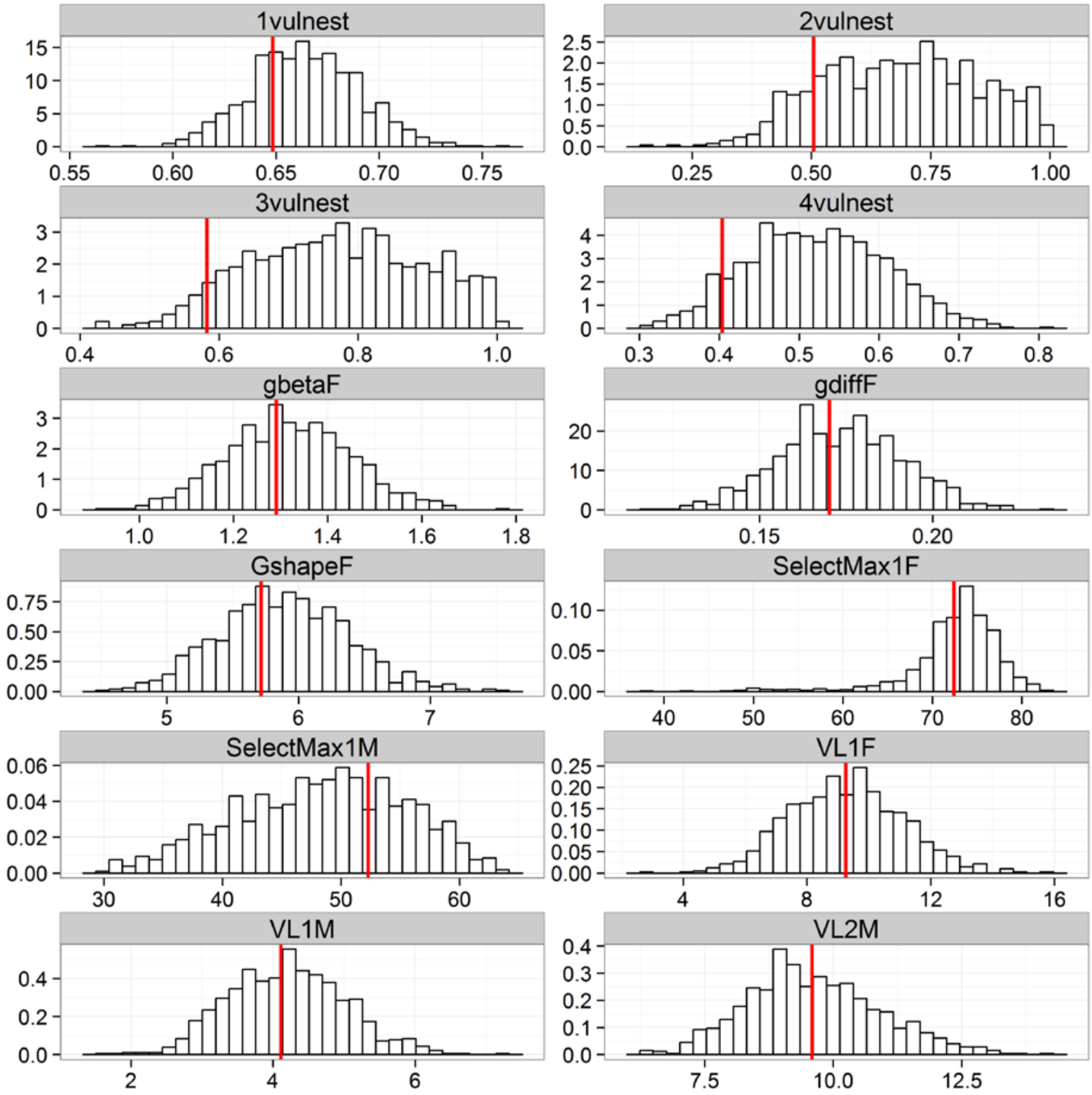


Figure 39B: Posterior distributions of estimated parameters from the base case MCMC (continued).

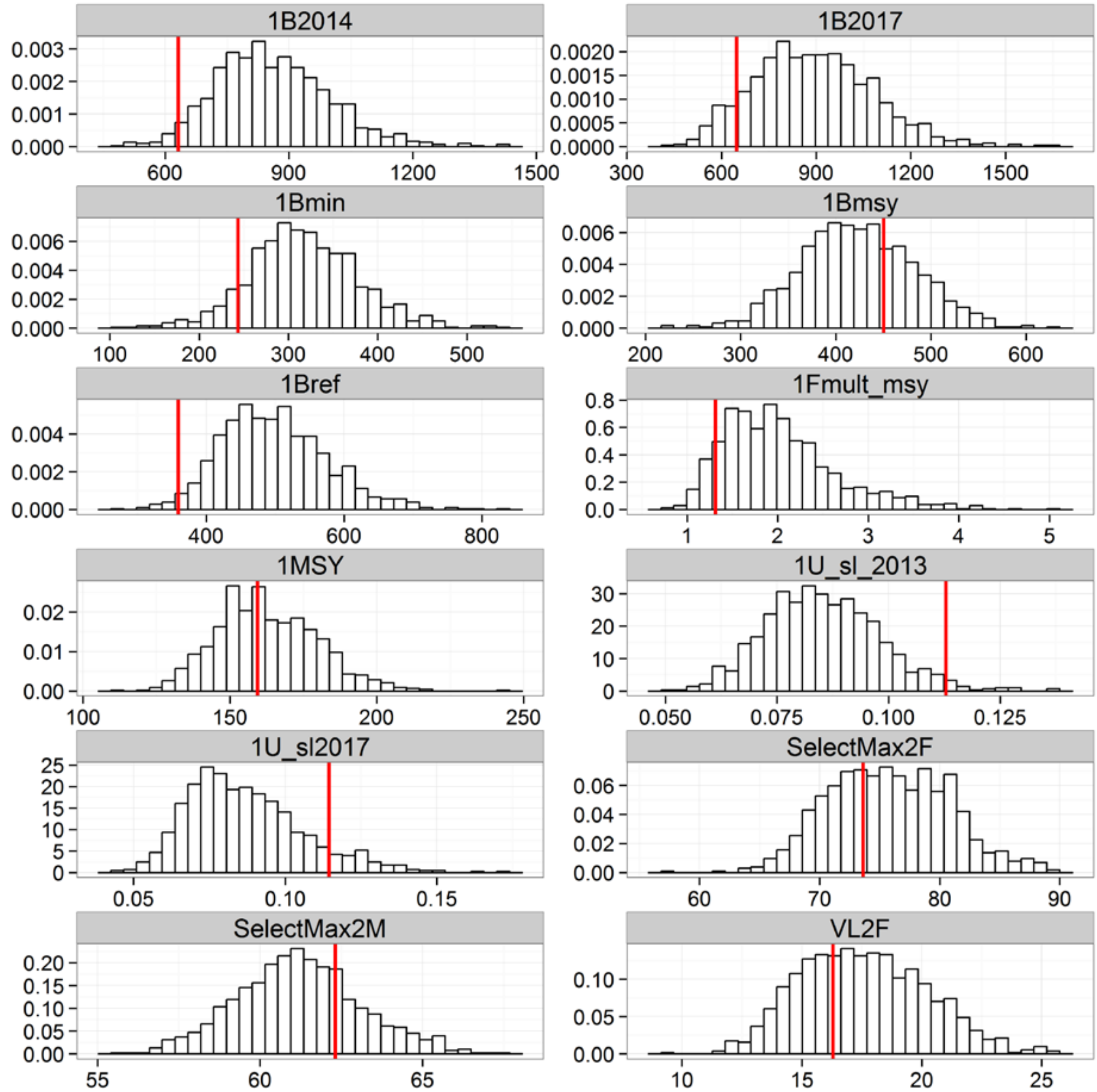


Figure 39C: Posterior distributions of estimated parameters from the base case MCMC (continued).

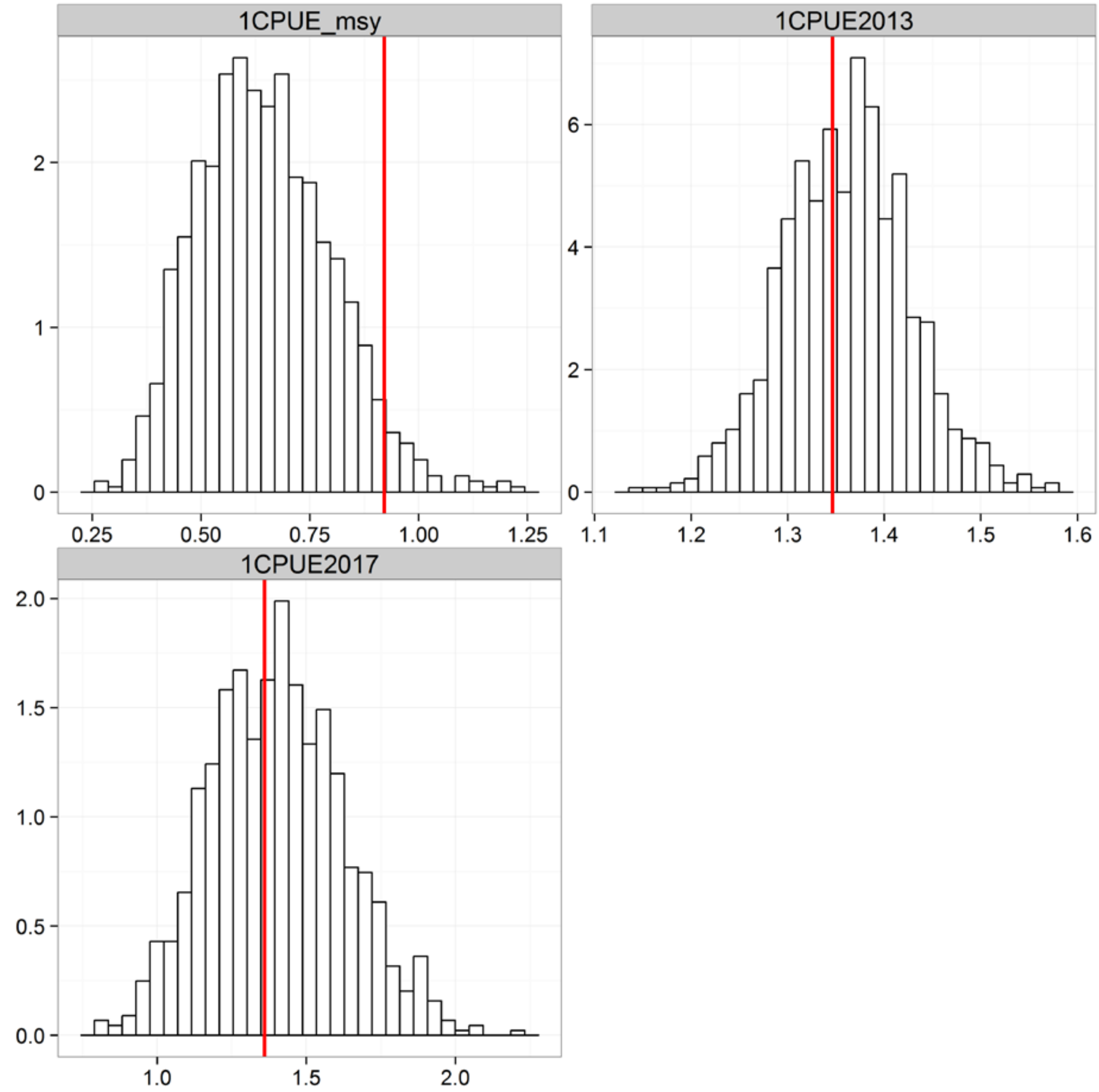


Figure 39D: Posterior distributions of estimated parameters from the base case MCMC (continued).

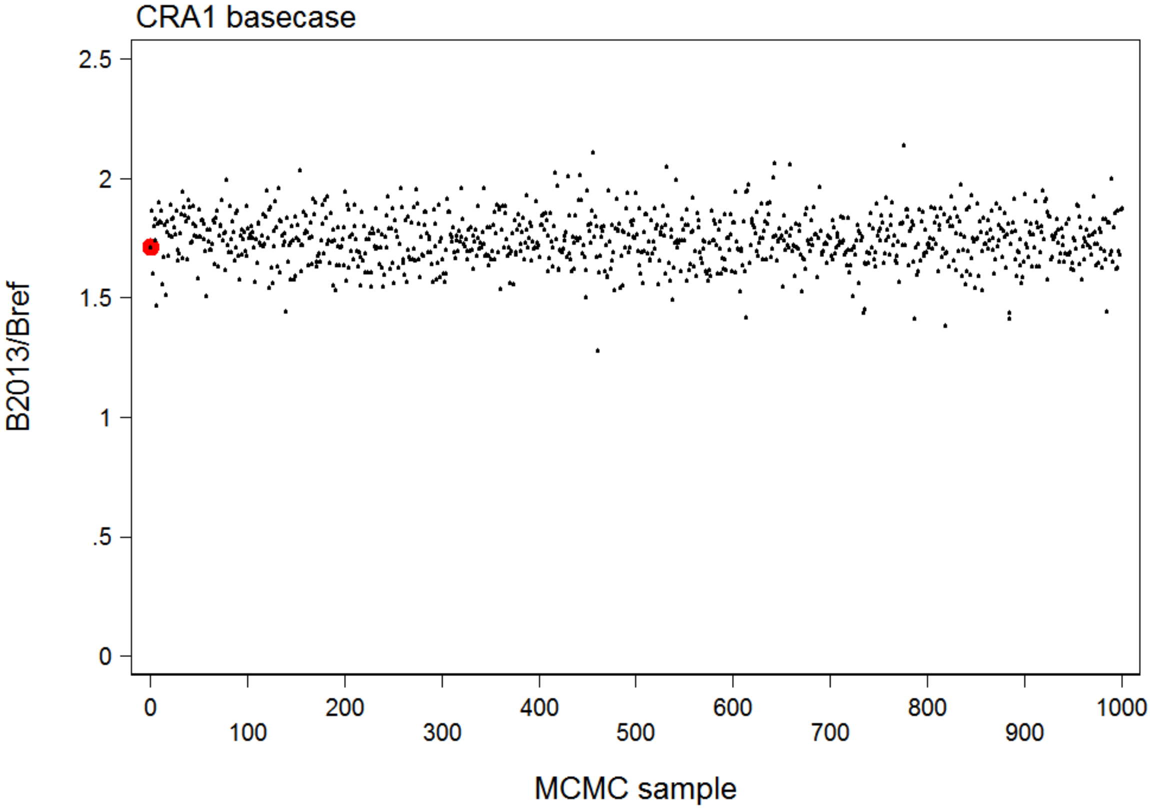


Figure 40: Trace plot of B_{2013}/B_{ref} for the CRA 1 base case MCMC. B_{ref} is defined as the mean AW beginning year vulnerable biomass from 1979–1988. B_{2013} is the AW beginning year vulnerable biomass in 2013. The MPD estimate is indicated by a large red circle.

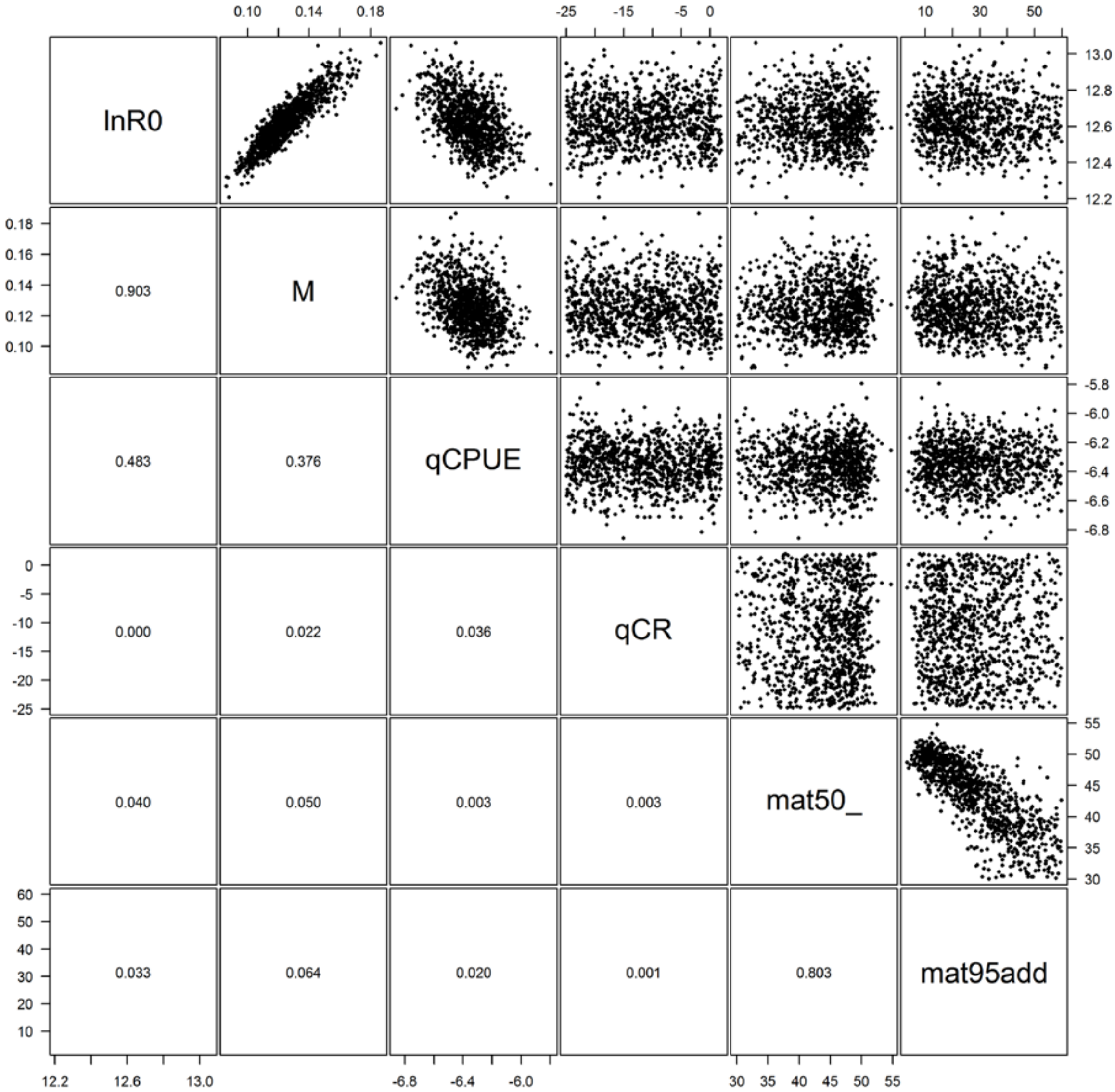


Figure 41A: Paired correlation plots for the indicated base case model parameters, with correlation coefficients provided in the mirrored cells.

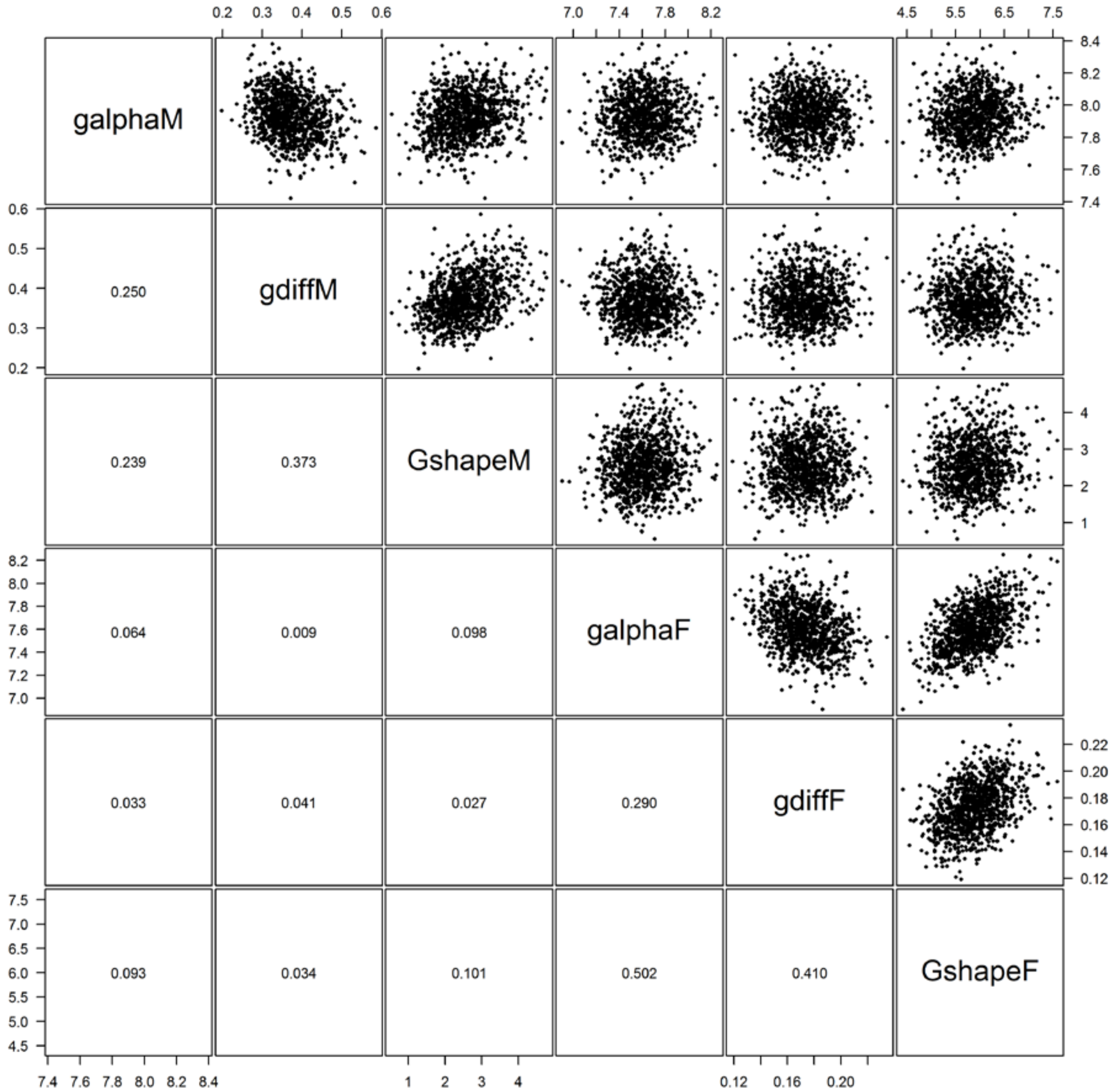


Figure 41B: Paired correlation plots for the indicated base case model parameters (continued).

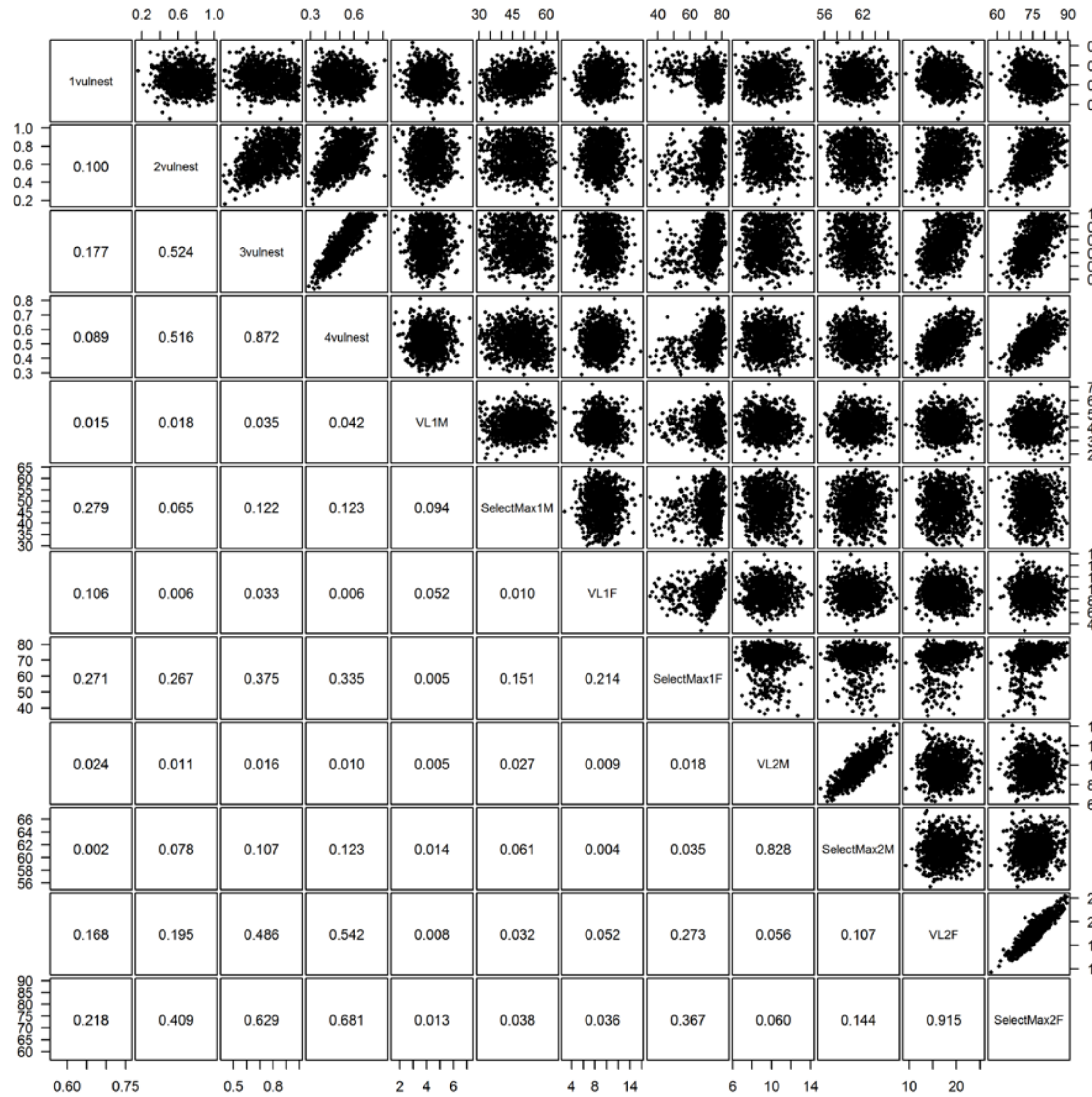


Figure 41C: Paired correlation plots for the indicated base case model parameters (continued).

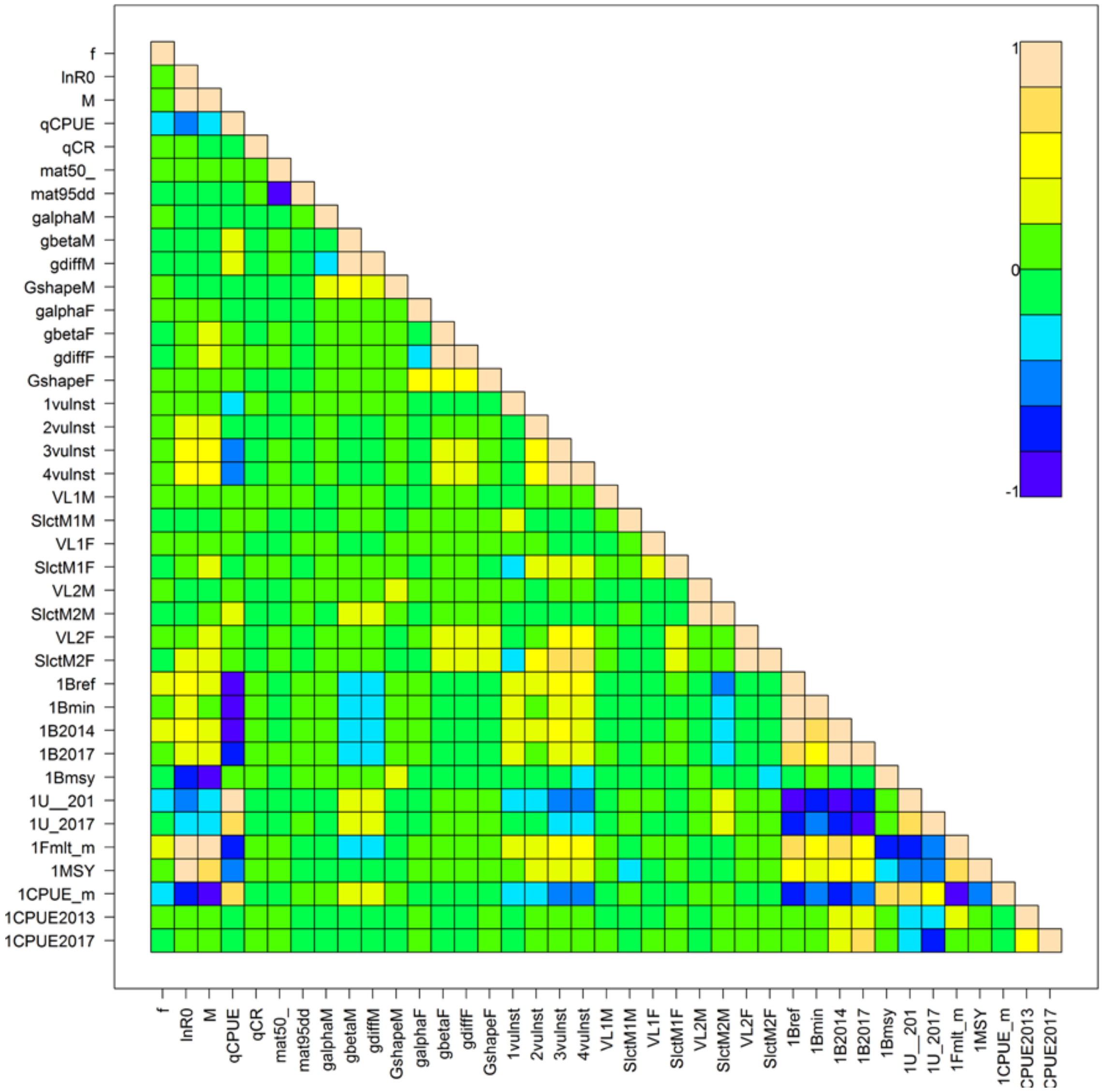


Figure 42: Paired correlation plots for all base case model parameters with level of correlation indicated by colour code.

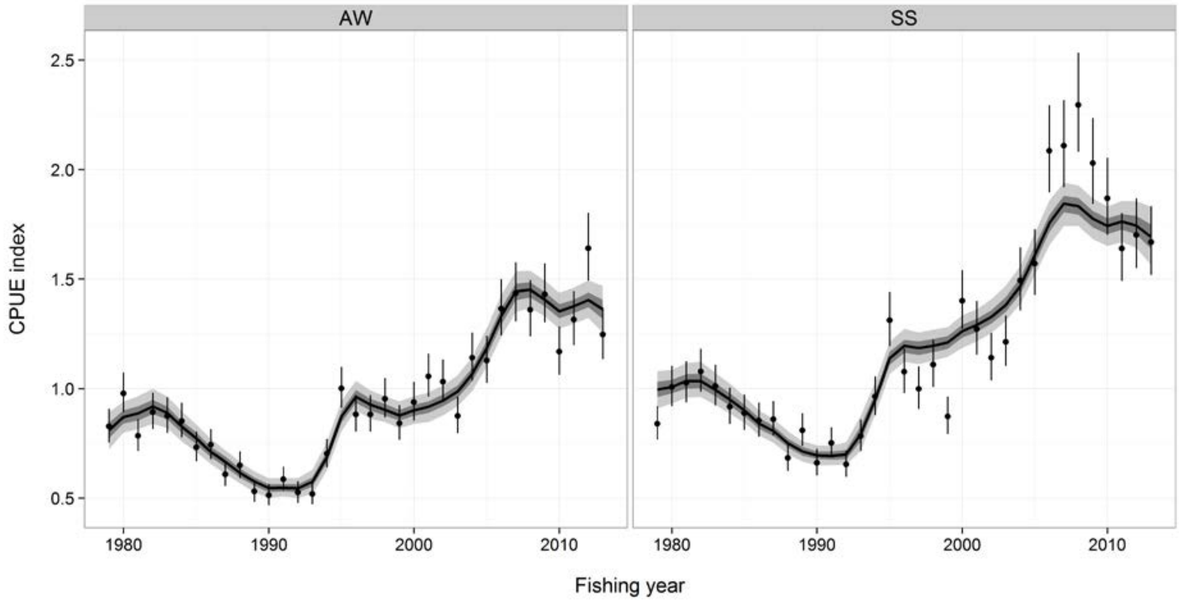


Figure 43: Posterior of the fit to CPUE for CRA 1 for the base case MCMC by season. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. Error bars on the CPUE index values are two standard deviations.

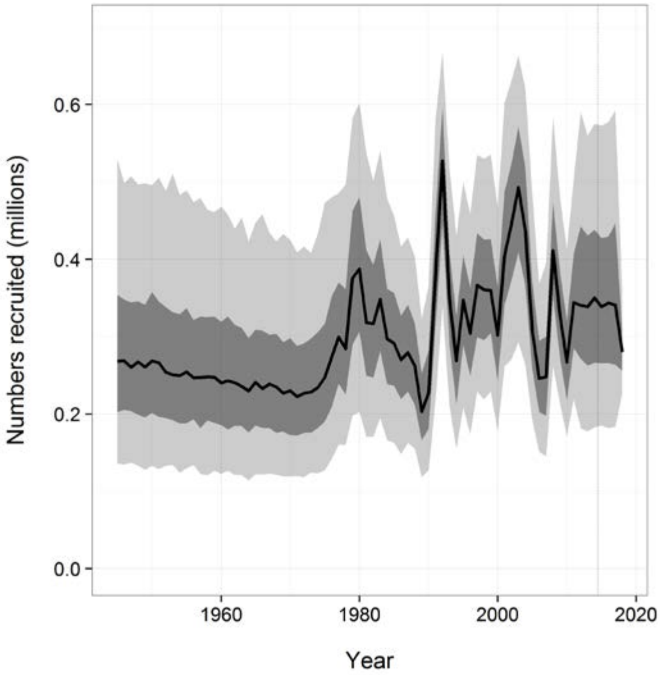


Figure 44: Number of recruits from 1945 to 2013 and projected recruits from 2014 to 2017 for the CRA 1 base case MCMC. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The vertical line shows 2013, the final fishing year of the model reconstruction.

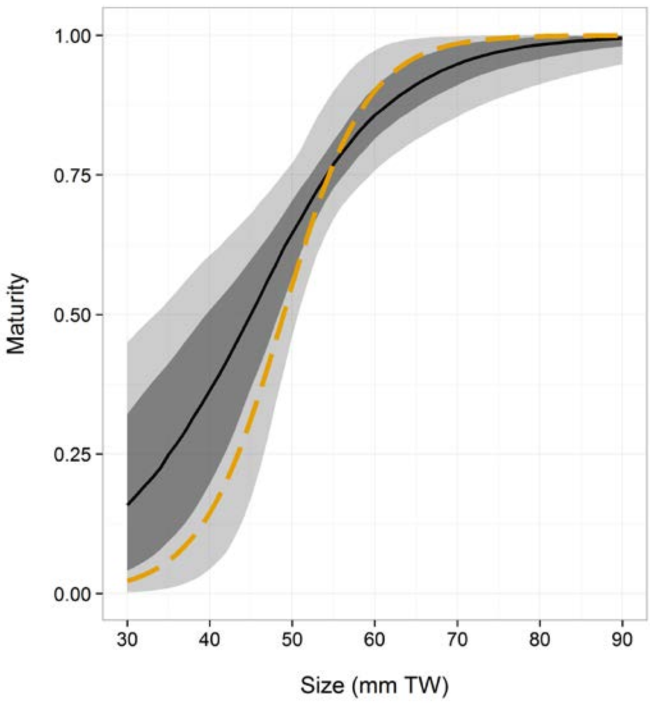


Figure 45: Posterior distribution of the estimated female maturity function the CRA 1 base case MCMC. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The dashed yellow line is the MPD estimate.

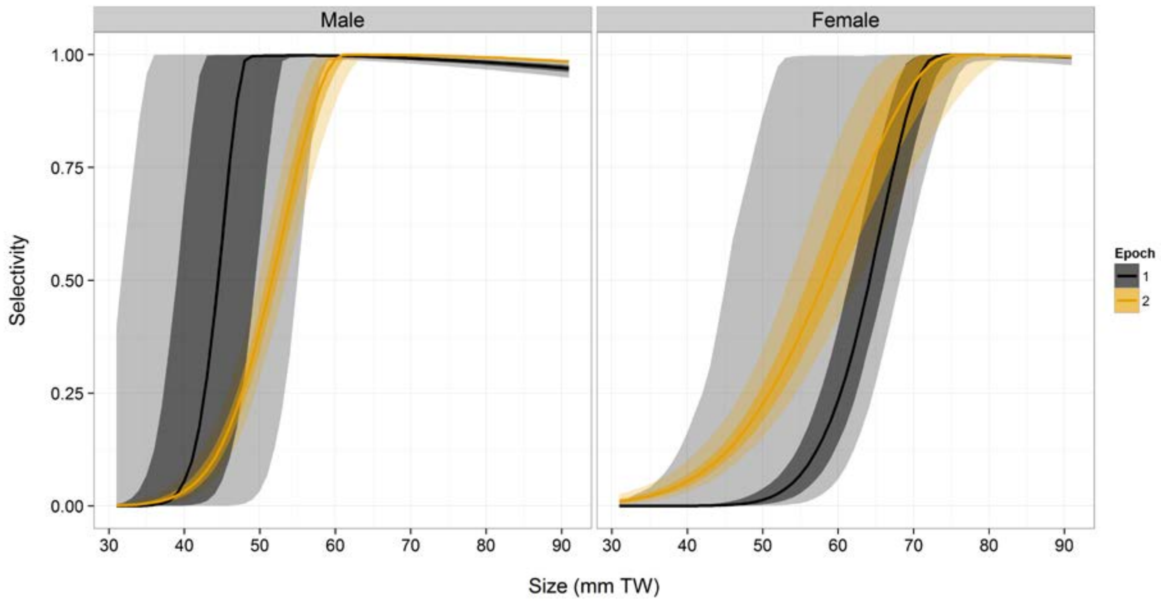


Figure 46: Posterior distribution of the estimated selectivity functions by sex and by epoch from the CRA 1 base case MCMC. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution.

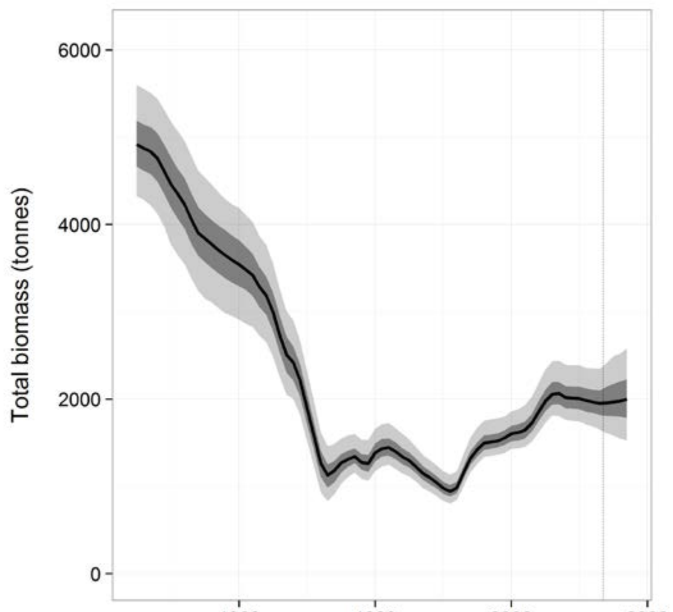


Figure 47: Total biomass from 1945 to 2013 and projected biomass from 2014 to 2017, based on the 2013 catch distribution for the CRA 1 base case MCMC. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The vertical line shows 2013, the final fishing year of the model reconstruction.

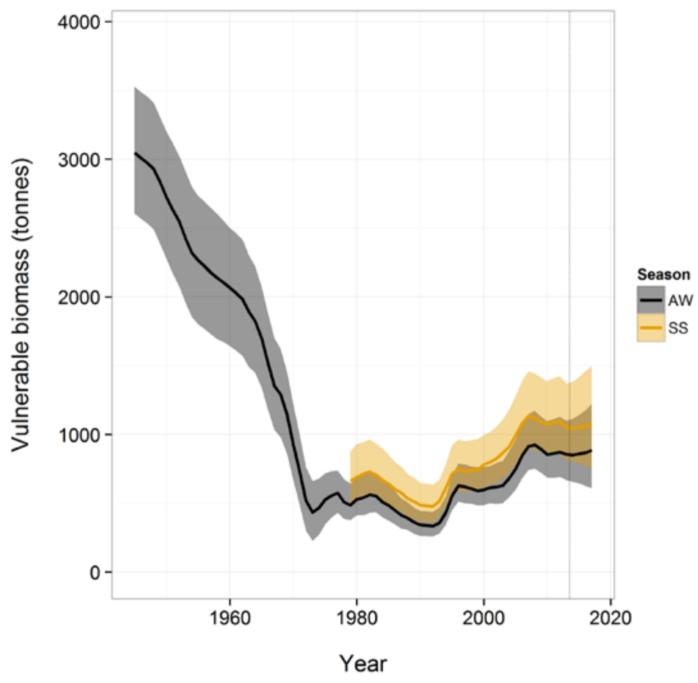


Figure 48: Vulnerable [reference] biomass from 1945 to 2013 by season and projected vulnerable biomass by season from 2014 to 2017 for the CRA 1 base case MCMC, assuming the 2013 catch distribution. Shaded areas show the 90% credibility intervals and the heavy solid line is the median of the posterior distributions. The vertical line shows 2013, the final fishing year of the model reconstruction. Biomass before 1979 is annual, but is plotted using the AW coding.

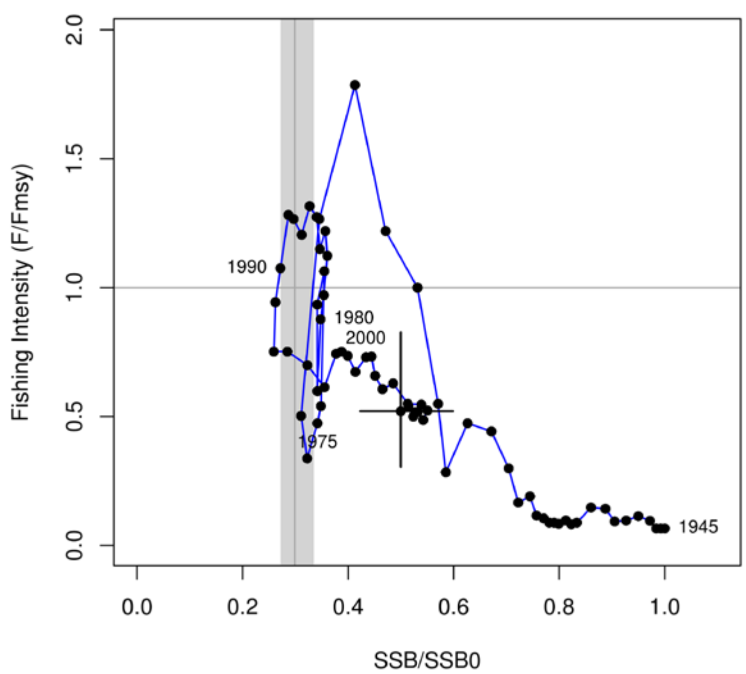


Figure 49: Snail trail for the CRA 1 "base case" (stacked informed prior for *M*). The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval in both directions for the final model year (2013).

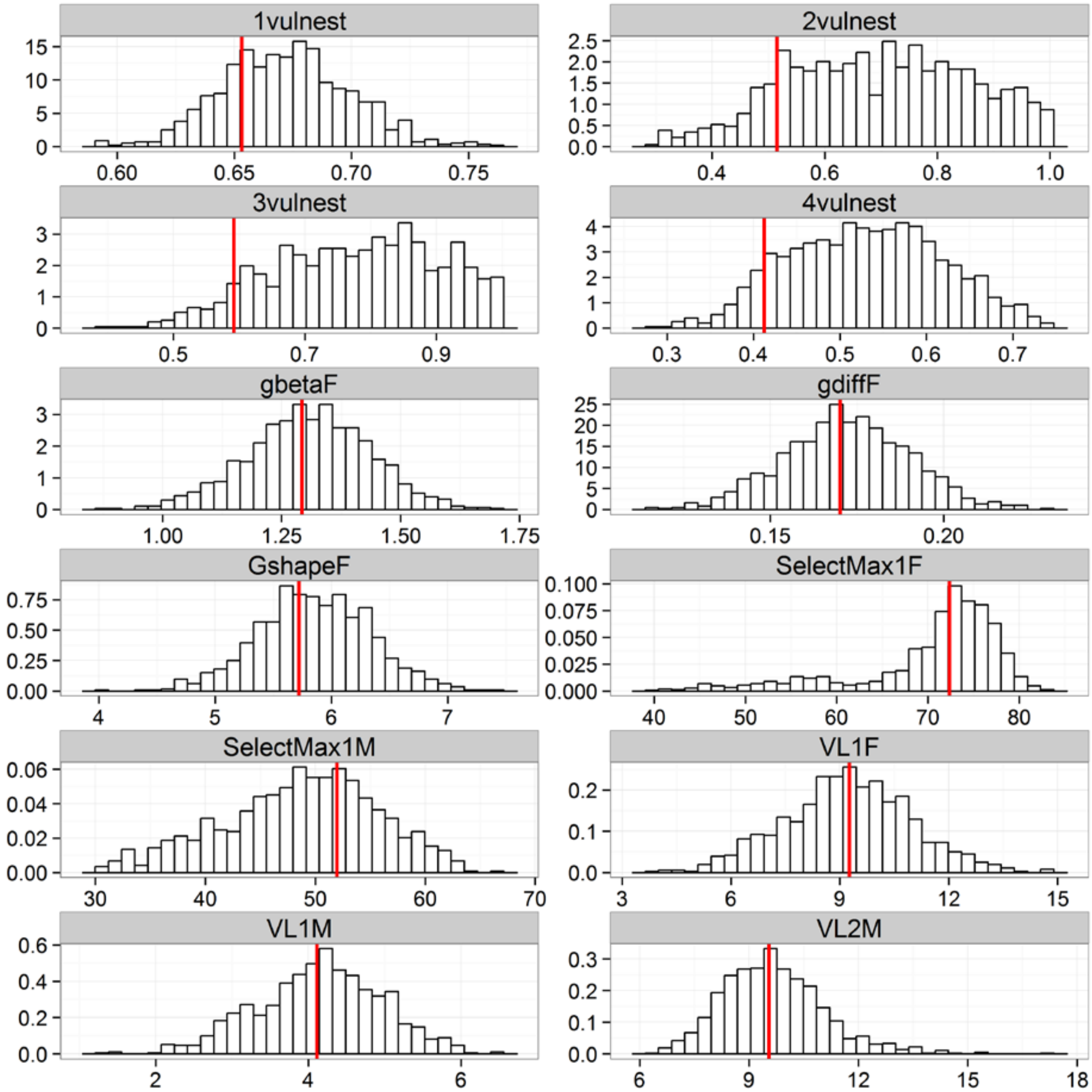


Figure 50: Posterior distributions of some estimated parameters from the "alt recreational catch" MCMC sensitivity run. Vertical bar indicates the MPD estimate.

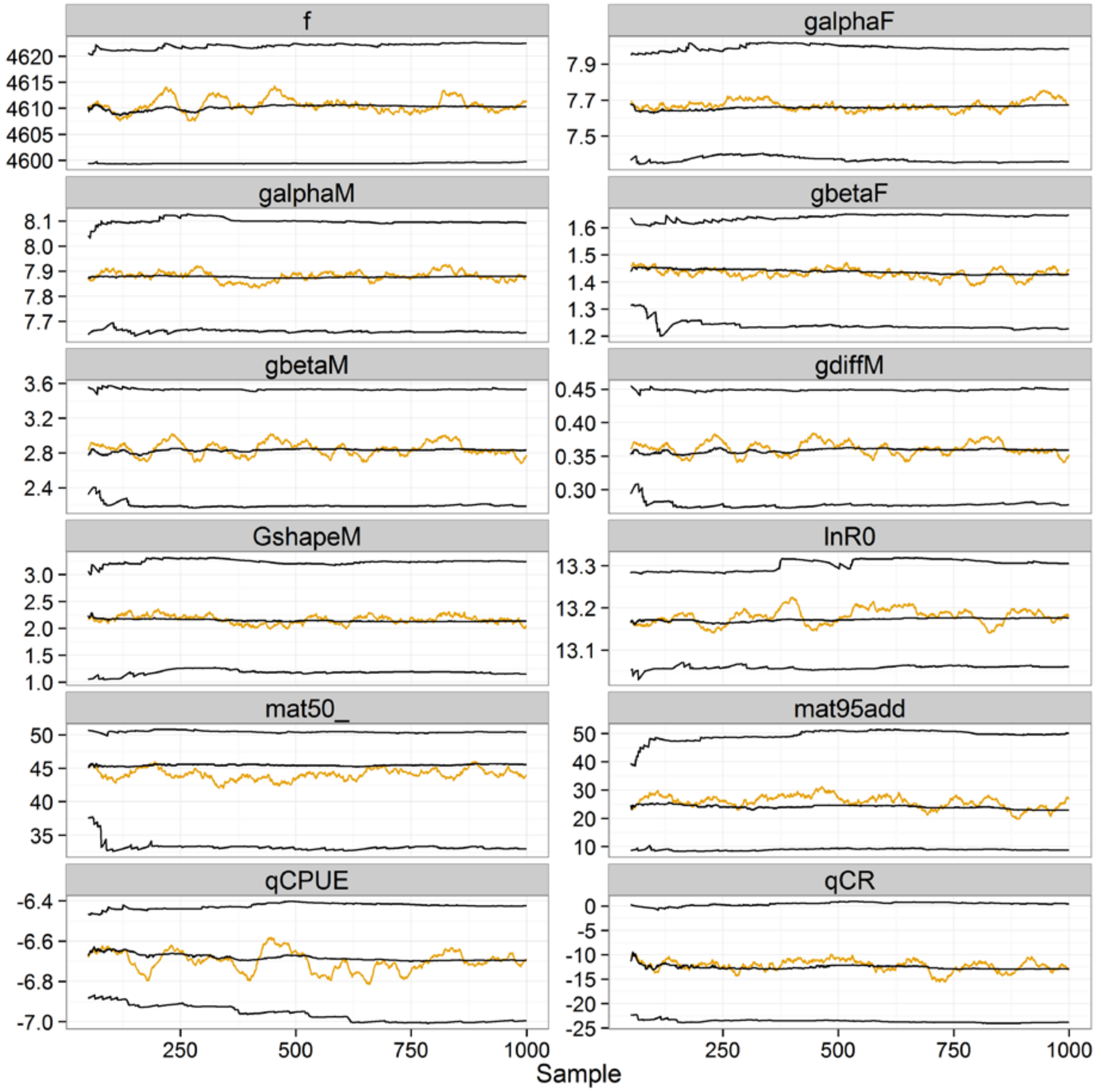


Figure 51: Diagnostic plots for the traces from the "FixedM" sensitivity run. The solid black lines are the running median and the 5th and 95th quantiles. The gold line is a moving mean over 50 samples.

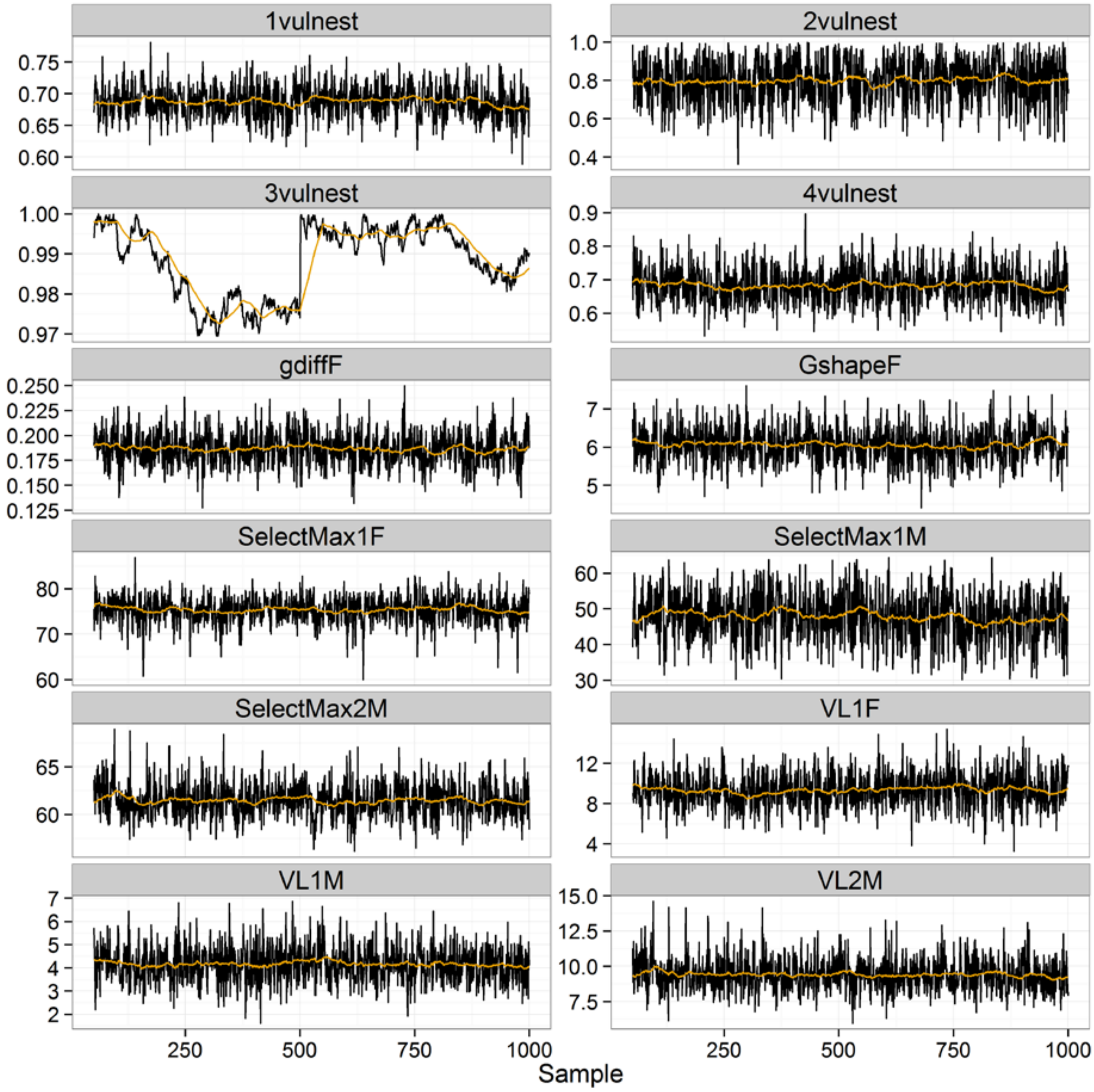


Figure 52: Traces for some estimated parameters from the "FixedM" sensitivity run. The gold line is a moving mean over 50 samples.

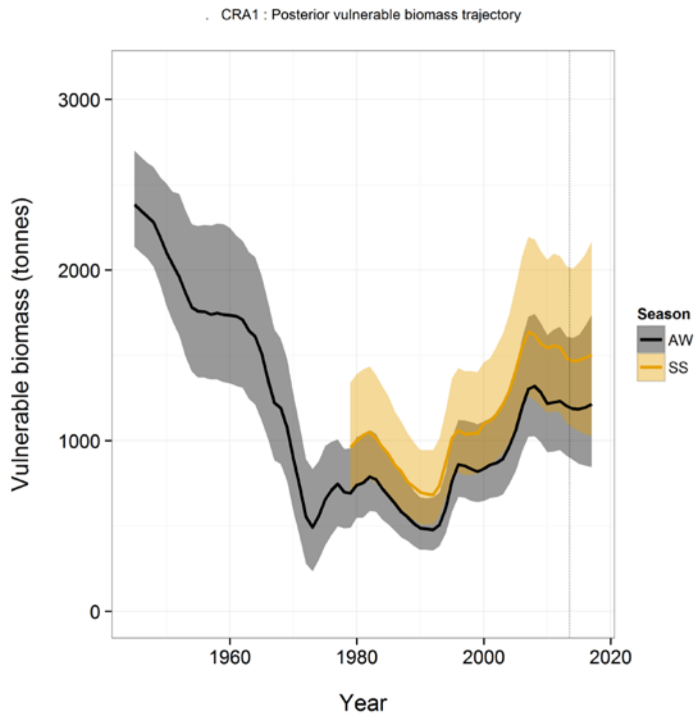


Figure 53: Vulnerable [reference] biomass from 1945 to 2013 by season and projected vulnerable biomass by season from 2014 to 2017 for the "FixedM" MCMC, assuming the 2013 catch distribution. Shaded areas show the 90% credibility intervals and the heavy solid line is the median of the posterior distributions. The vertical line shows 2013, the final fishing year of the model reconstruction. Biomass before 1979 is annual, but is plotted using the AW coding.

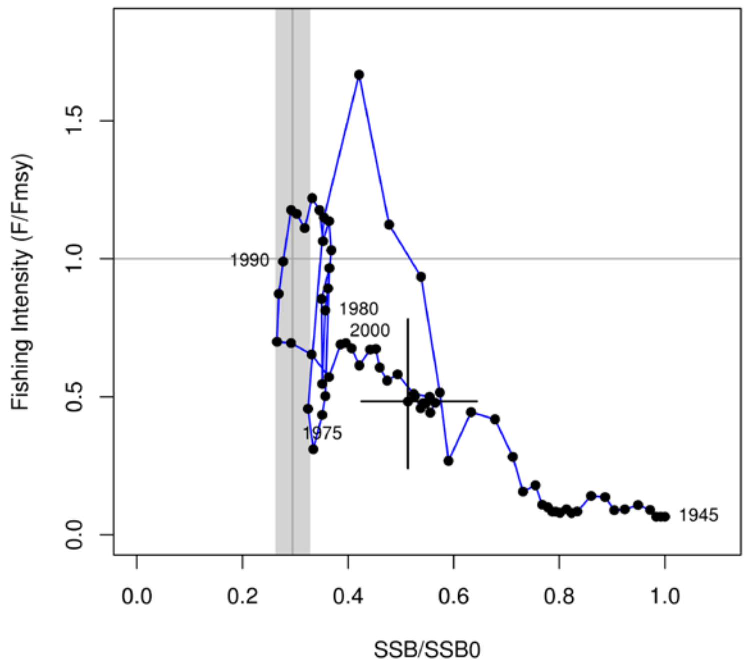


Figure 54: Snail trail for the CRA 1 "uniformM" (stacked informed prior for *M*) sensitivity run. The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval in both directions for the final model year (2013).

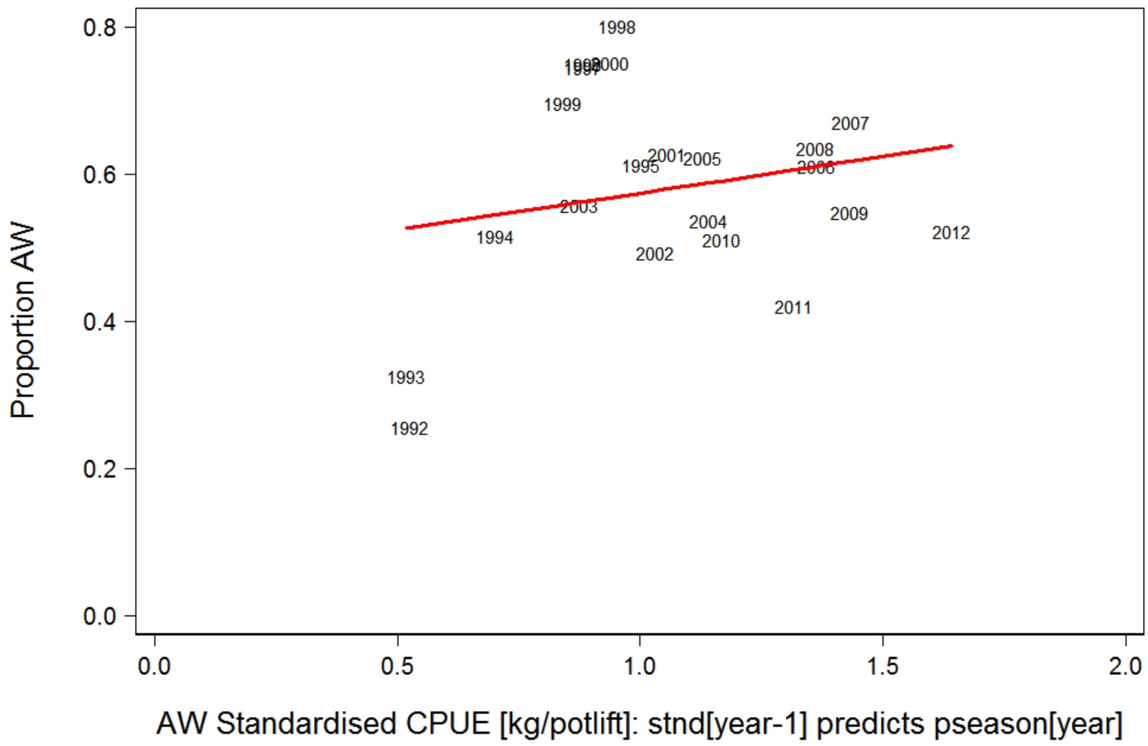


Figure 55: CRA 1 observed and predicted (line) autumn-winter catch proportions; intercept=0.475 and slope 0.099, with R^2 = 0.0454.

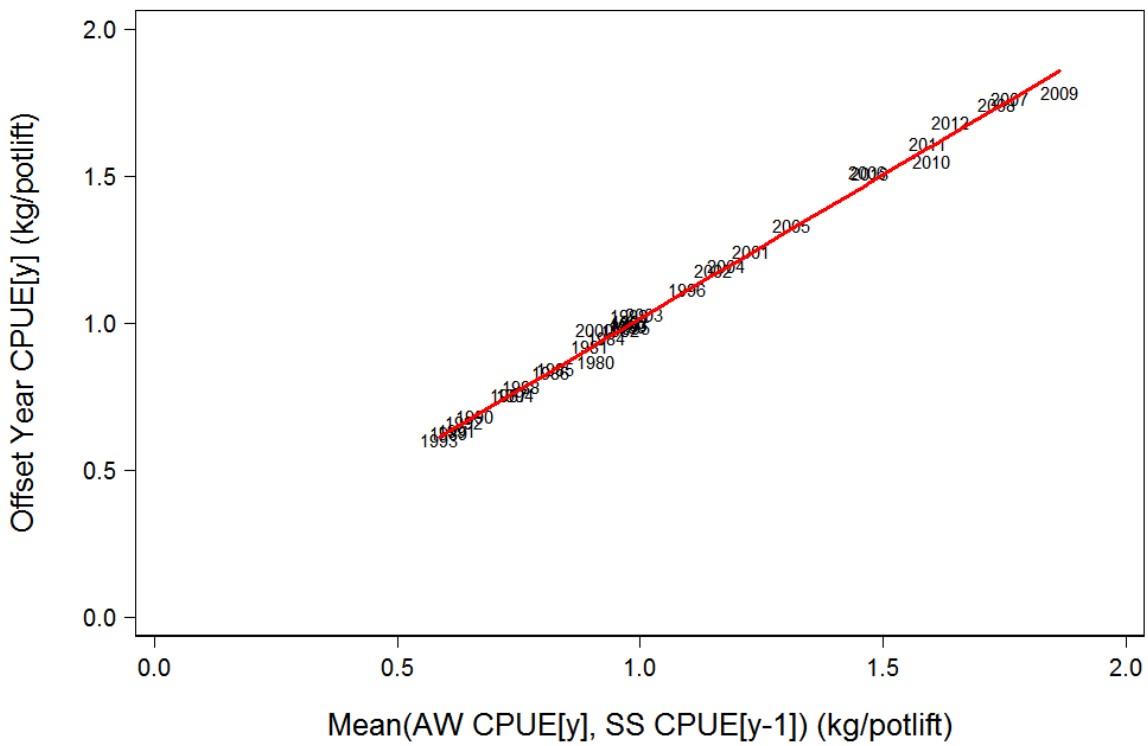


Figure 56: CRA 1: Observed and predicted (line) Standardised offset-year CPUE versus the mean of the preceding AW and SS CPUE; intercept=0.0384 and slope=0.978, with R^2 = 0.995.

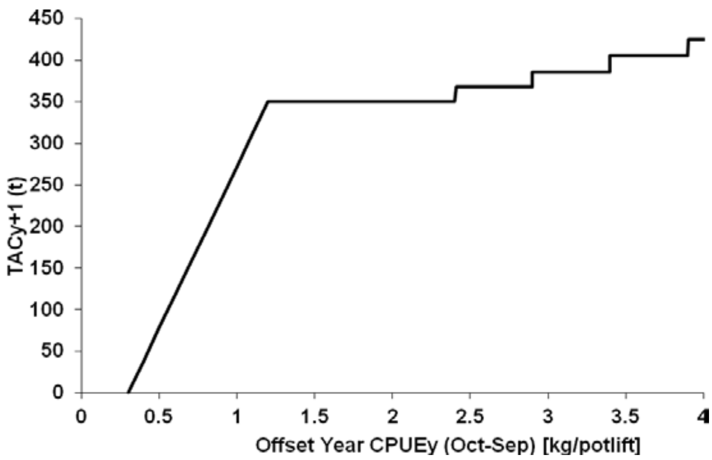


Figure 57: Generalised harvest control rule.

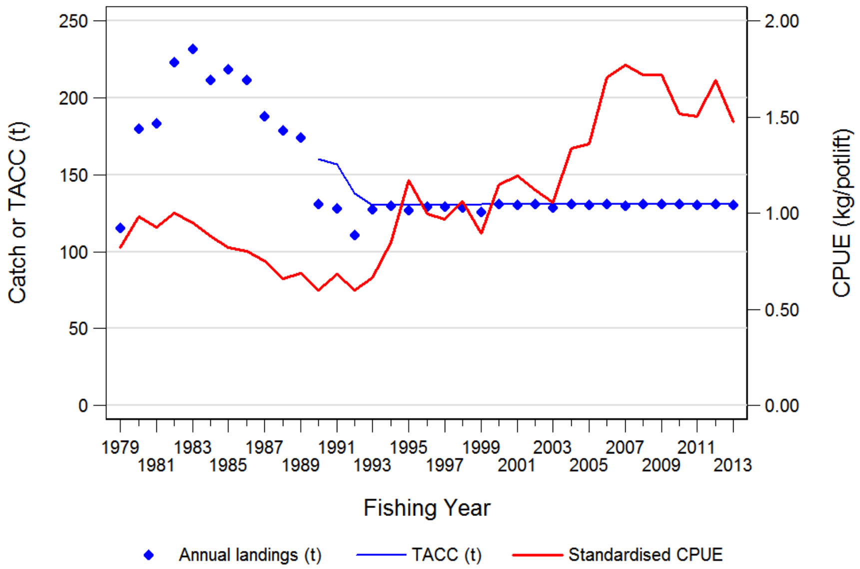


Figure 58: Plot showing relationship of annual CPUE, catch and TACC in CRA 1.

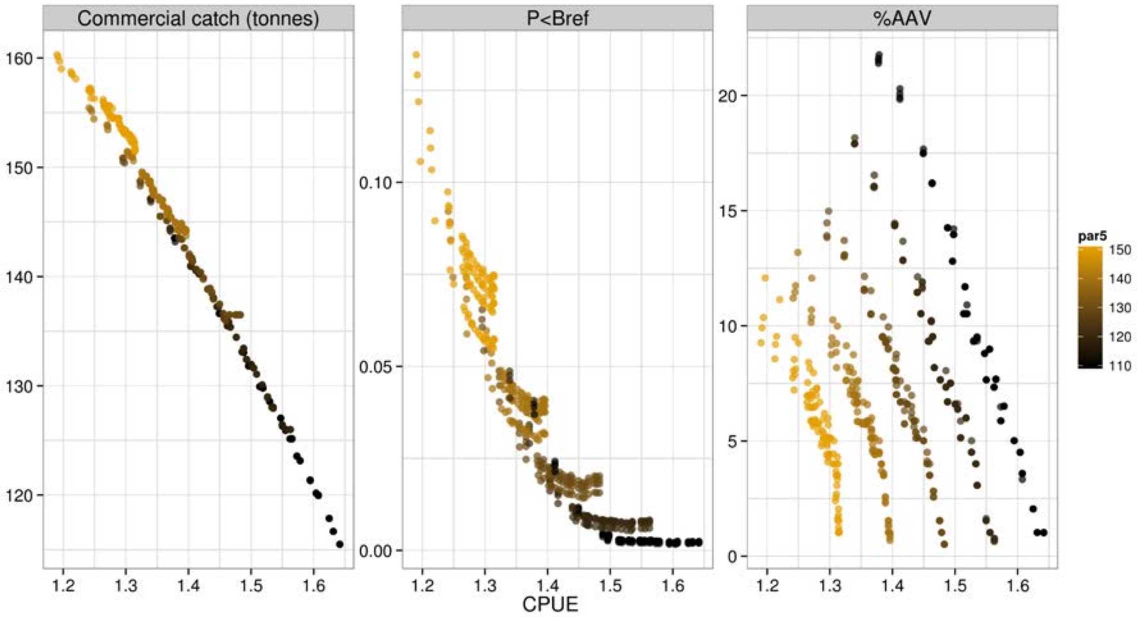


Figure 59: From the initial (phase 1) 500 rule evaluations, the relations among average offset-year CPUE, average commercial catch, the annual frequency of stock less than *Bref* and the %AAV. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates which value of the *par5* parameter was used in the harvest control rule.

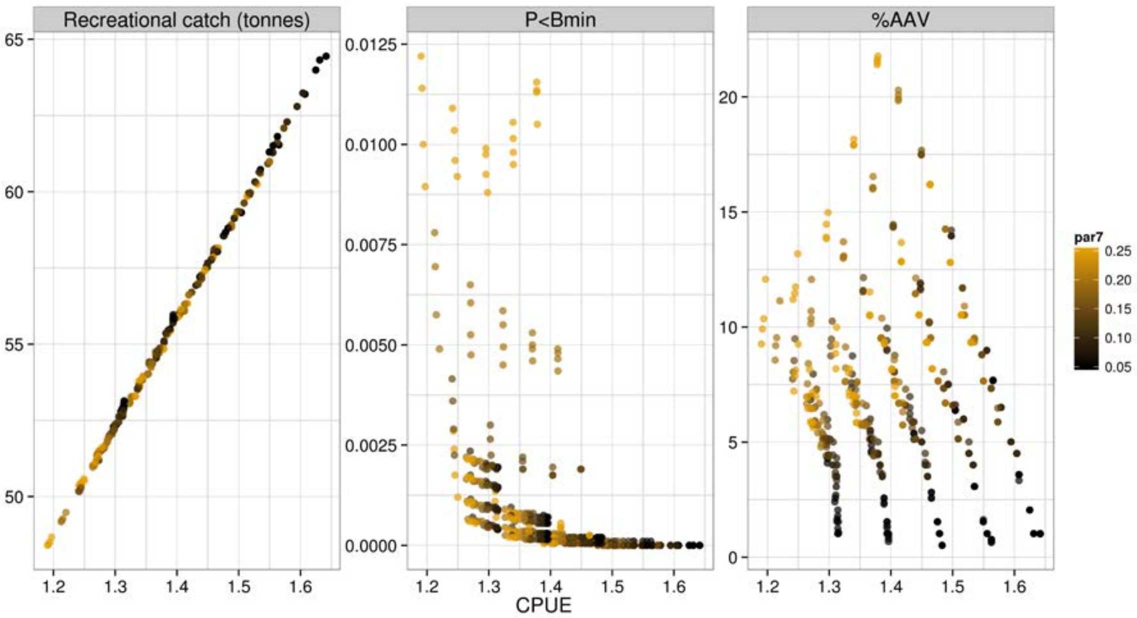


Figure 60: From the initial (phase 1) 500 rule evaluations, the relations among average offset-year CPUE, average recreational catch, the annual frequency of stock less than *Bmin* and the %AAV. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates which value of the *par7* parameter was used in the harvest control rule.

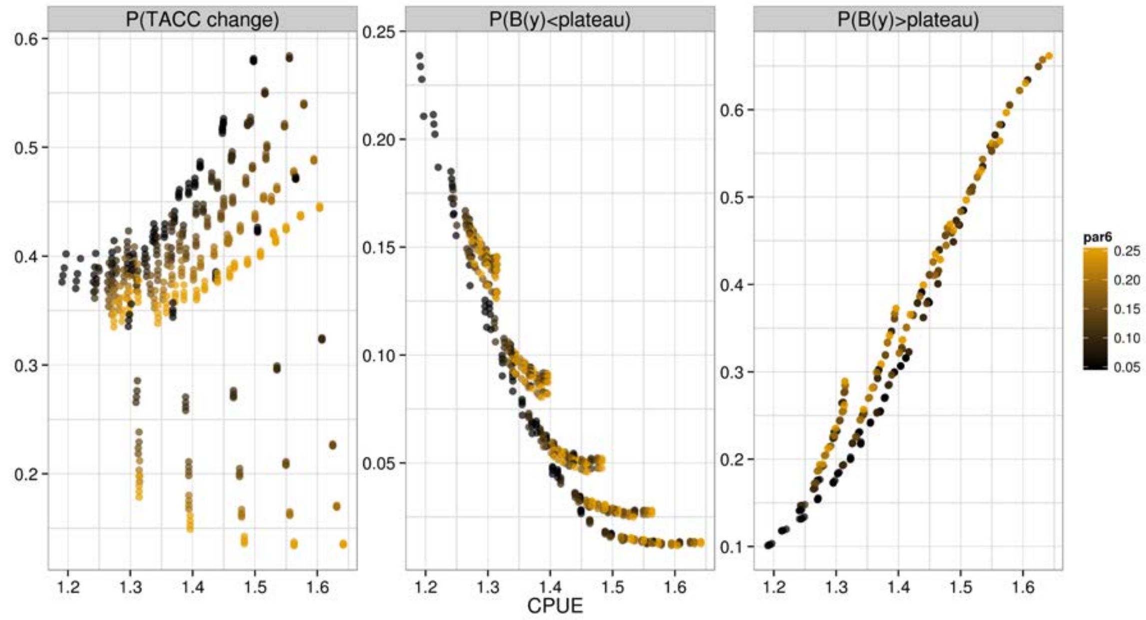


Figure 61: From the initial (phase 1) 500 rule evaluations, the relations among average offset-year CPUE, the proportion of TACC changes, and the proportion of time spent on the left and right side of the plateau. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates which value of the *par6* parameter was used in the harvest control rule.

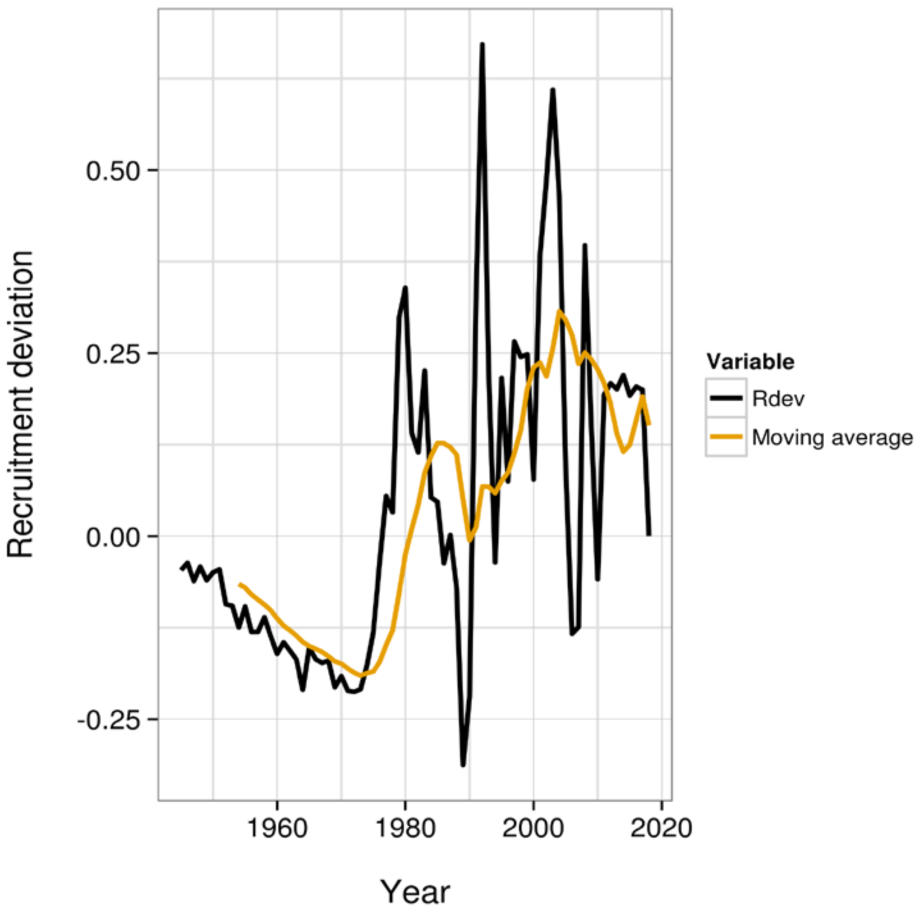


Figure 62: Running 10-year medians of the posterior of absolute recruitment deviations for the CRA 1 base case plotted against the final year used in the mean. The mean 2002–2011 recruitment deviation is 0.209. The lowest 10-year mean recruitment is –0.190 (1964–1973). An alternative period for the lowest 10-year mean recruitment is 1981–1990 with a value of 0.00.

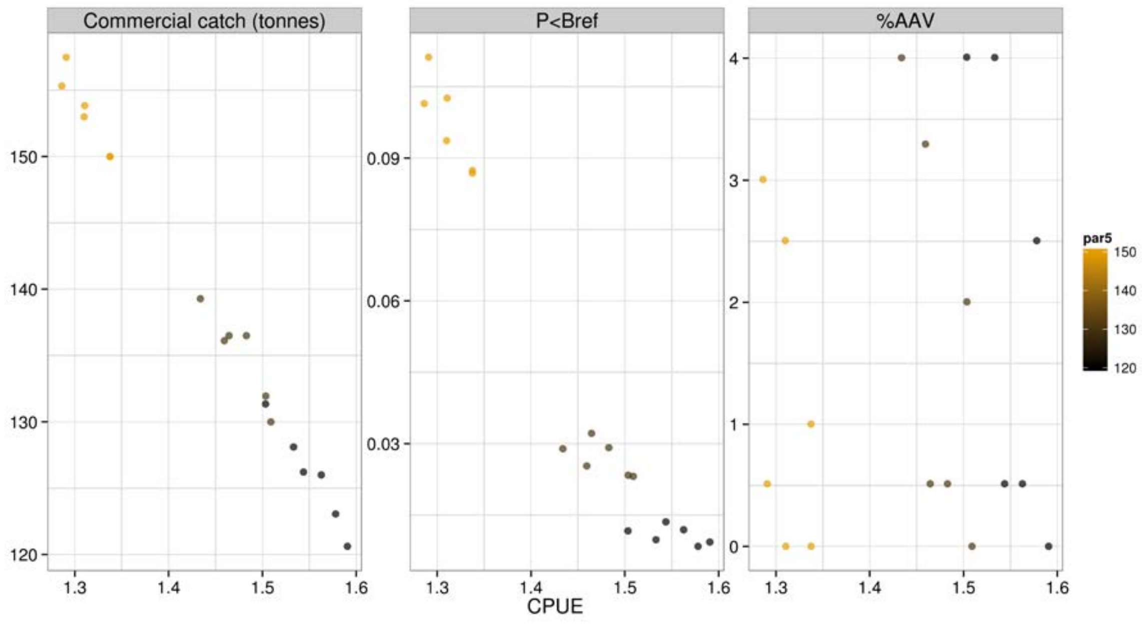


Figure 63: For the final 18 example rules, the relations among average offset-year CPUE, average commercial catch, the annual frequency of stock less than *Bref* and the %AAV. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates which value of the *par5* parameter was used in the harvest control rule.

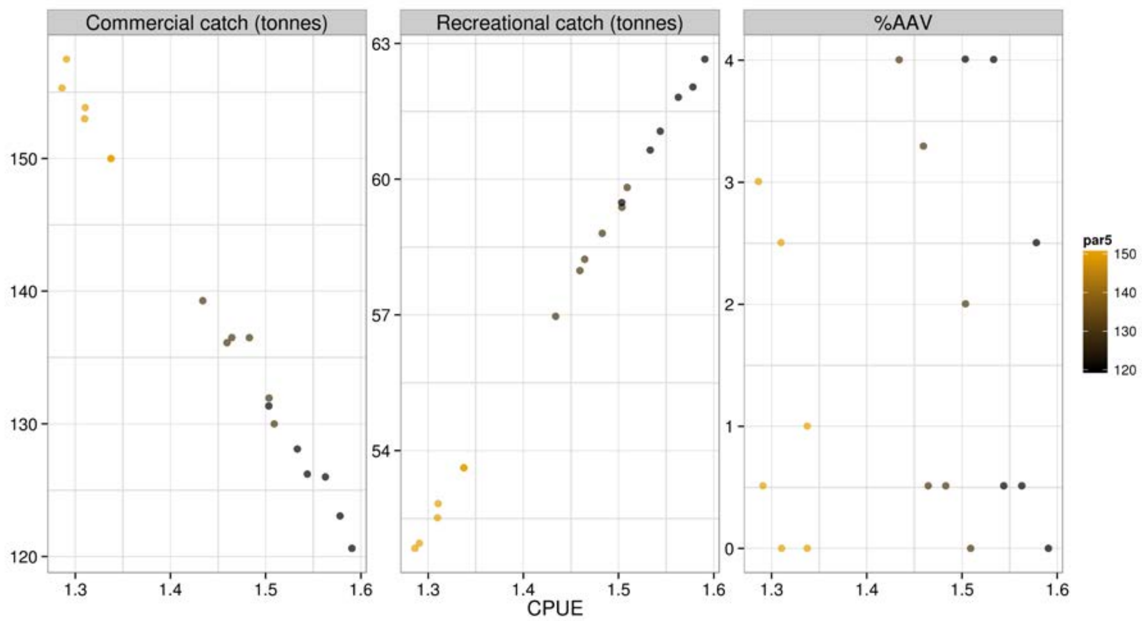


Figure 64: For the final 18 example rules, the relations among average offset-year CPUE, average commercial catch, average recreational catch, and the %AAV. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates which value of the *par7* parameter was used in the harvest control rule.

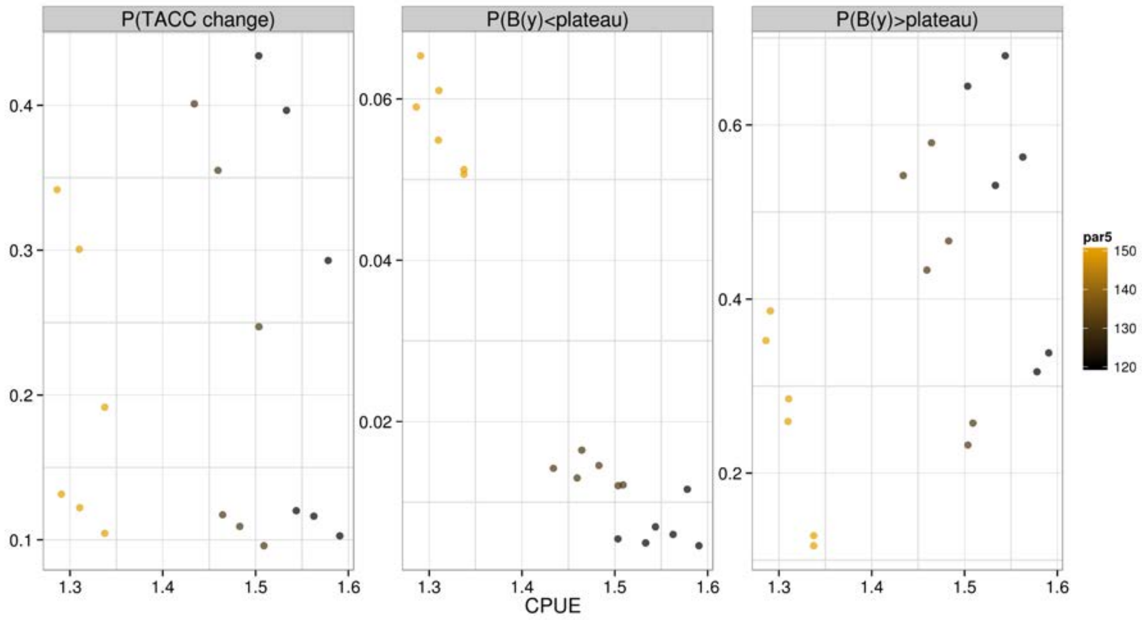


Figure 65: For the final 18 example rules, the relations among average offset-year CPUE, the proportion of TACC changes, and the proportion of time spent on the left and right side of the plateau. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates which value of the *par6* parameter was used in the harvest control rule.

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).

ADMB: a modelling package widely used in fisheries work (http://admb-project.org/). It uses auto-differentiation to calculate the derivatives of the function value with respect to model parameters and passes these to an efficient minimiser.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

catch sampling: see logbooks and observer catch sampling.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

hyperdepletion: see *CPUEpow.*

hyperstability: see *CPUEpow.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

offset year: the year from 1 October through to 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 data values in a new order.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TW: tail width (mm) 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; $Z = F + M$.

APPENDIX: ADDITIONAL TABLES AND FIGURES IN SUPPORT OF THE CRA 1 MPE

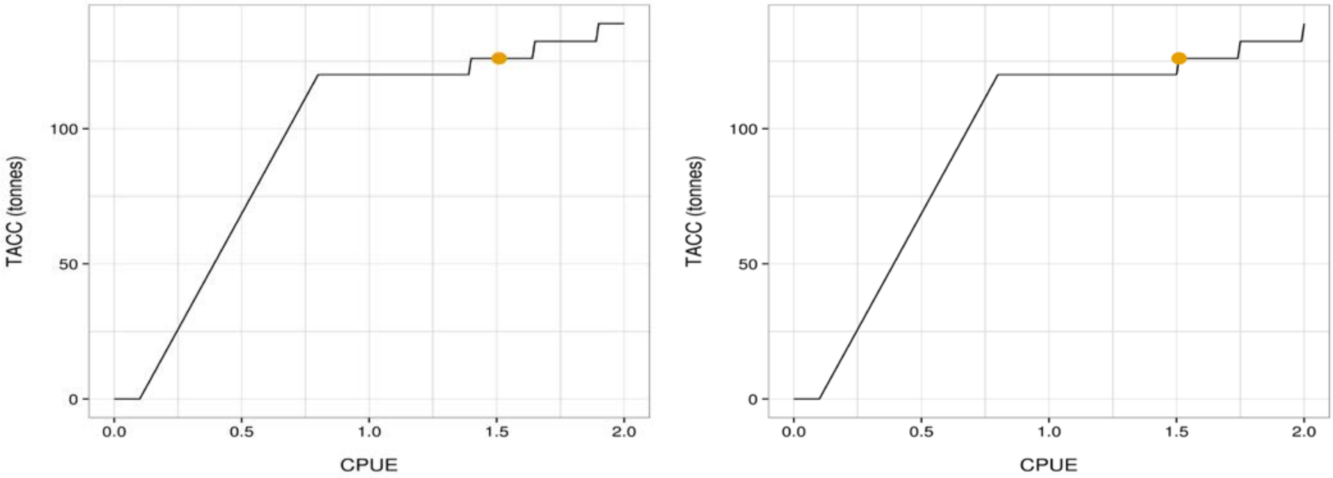
Appendix Table 1: Average median indicator value for a range of parameter values for four rule parameters evaluated during the Phase 1 (see Table 8), showing the effect of different cutoffs to the %AAV indicator on the number of rules remaining below the cut-off and the mean values for the medians of the indicators. Also shown is the number of rules in each rule parameter category. Only rules where the P(<*Bref*) is less than 0.01 were included in this table.

	%AAV cutoff				%AAV cutoff				%AAV cutoff				%AAV cutoff				%AAV cutoff				%AAV cutoff				%AAV cutoff			
	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
	N				Avg commercial catch (t)				Avg recreational catch (t)				Avg Offset Year CPUE				Avg %AAV				P(B<Bref)				P(CPUE>1.0 kg/pot)			
par2																												
0.1	14	18	25	38	136.3	136.7	137.5	139.7	58.3	58.1	57.8	56.9	1.465	1.461	1.451	1.429	1.06	1.35	1.93	2.77	0.031	0.032	0.033	0.038	0.834	0.831	0.825	0.806
0.2	14	18	25	37	136.3	136.7	137.5	139.3	58.3	58.1	57.8	57.1	1.465	1.461	1.451	1.433	1.10	1.38	1.99	2.78	0.030	0.030	0.032	0.035	0.835	0.832	0.826	0.810
0.3	14	18	23	35	136.3	136.6	136.5	138.5	58.3	58.1	58.1	57.4	1.465	1.461	1.461	1.441	1.15	1.45	1.88	2.74	0.028	0.029	0.028	0.031	0.836	0.833	0.835	0.820
0.5	13	17	21	29	135.0	135.6	135.7	137.0	58.7	58.5	58.4	57.9	1.476	1.470	1.468	1.455	1.13	1.42	1.79	2.48	0.021	0.023	0.023	0.025	0.850	0.844	0.844	0.834
par5																												
110	8	12	16	20	116.1	116.7	117.5	118.0	64.4	64.3	64.0	63.8	1.636	1.633	1.626	1.622	1.02	1.37	1.91	2.43	0.002	0.002	0.002	0.002	0.959	0.959	0.959	0.959
120	12	12	16	23	126.1	126.1	126.6	127.2	61.5	61.5	61.3	61.1	1.556	1.556	1.551	1.545	1.10	1.10	1.59	2.39	0.007	0.007	0.007	0.007	0.925	0.925	0.925	0.925
130	12	16	19	24	136.5	136.5	136.4	136.4	58.7	58.5	58.4	58.3	1.479	1.476	1.473	1.470	1.03	1.44	1.77	2.26	0.018	0.018	0.018	0.018	0.866	0.866	0.866	0.867
140	12	16	22	33	144.2	144.3	144.3	144.6	55.9	55.8	55.7	55.4	1.395	1.393	1.391	1.385	1.11	1.44	2.04	2.84	0.037	0.037	0.037	0.037	0.784	0.784	0.784	0.782
150	11	15	21	39	151.8	151.9	152.1	152.6	53.0	53.0	52.9	52.6	1.314	1.313	1.313	1.307	1.27	1.58	2.11	3.18	0.068	0.068	0.068	0.069	0.685	0.684	0.684	0.677
par6																												
0.05	0	0	0	6	–	–	–	149.6	–	–	–	53.5	–	–	–	1.333	–	–	–	4.47	–	–	–	0.057	–	–	–	0.718
0.1	0	11	20	21	–	143.8	136.3	137.1	–	55.7	58.1	57.8	–	1.395	1.461	1.454	–	2.57	2.88	2.98	–	0.039	0.026	0.029	–	0.784	0.842	0.834
0.15	15	20	20	27	139.1	135.5	135.5	139.1	57.4	58.5	58.5	57.2	1.441	1.471	1.471	1.437	1.54	1.67	1.67	2.38	0.031	0.027	0.027	0.034	0.823	0.843	0.843	0.812
0.2	20	20	24	37	135.0	135.0	137.2	138.6	58.7	58.7	57.9	57.4	1.475	1.475	1.453	1.439	1.07	1.07	1.51	2.48	0.026	0.026	0.031	0.032	0.844	0.844	0.825	0.820
0.25	20	20	30	48	134.7	134.7	137.9	138.0	58.8	58.8	57.6	57.5	1.479	1.479	1.448	1.445	0.83	0.83	1.72	2.71	0.027	0.027	0.031	0.032	0.844	0.844	0.823	0.821
par7																												
0.05	55	71	80	86	136.0	136.4	135.4	136.4	58.4	58.2	58.5	58.2	1.467	1.463	1.472	1.462	1.11	1.40	1.61	1.81	0.028	0.029	0.026	0.029	0.838	0.835	0.844	0.835
0.1	0	0	14	43	–	–	145.4	140.5	–	–	55.0	56.6	–	–	1.375	1.419	–	–	3.56	4.05	–	–	0.044	0.034	–	–	0.767	0.808
0.15	0	0	0	8	–	–	–	150.4	–	–	–	53.2	–	–	–	1.325	–	–	–	4.47	–	–	–	0.060	–	–	–	0.706
0.2	0	0	0	2	–	–	–	154.5	–	–	–	51.8	–	–	–	1.287	–	–	–	4.85	–	–	–	0.076	–	–	–	0.653
0.25	0	0	0	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	55	71	94	139																								

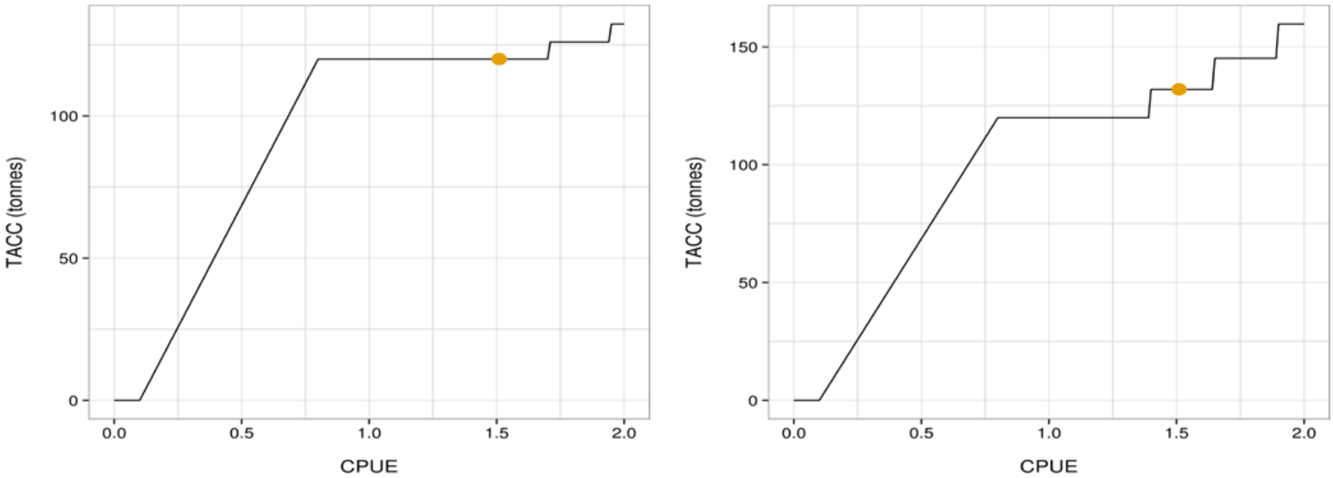
Appendix Table 2: Two example tables of 12 rule blocks showing the similarity in 11 indicator values across all 12 rules in the block. The rule which has been highlighted with orange was selected from the block for inclusion in the example rules. Rule numbers are from the final group of 480 rules (Phase 3: Table 8).

	97	101	105	109	113	117	121	125	129	133	137	141
par3	0.8	0.9	1	1.1	0.8	0.9	1	1.1	0.8	0.9	1	1.1
par4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
par5	120	120	120	120	120	120	120	120	120	120	120	120
par6	0.15	0.15	0.15	0.15	0.2	0.2	0.2	0.2	0.25	0.25	0.25	0.25
par7	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Avg(B/Bref)	1.74	1.74	1.74	1.74	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
Term(B/Bref)	1.72	1.72	1.72	1.73	1.75	1.75	1.75	1.76	1.76	1.76	1.77	1.77
Avg(CommCat)	129	129	129	129	128	127	127	127	126	126	126	126
Avg(RecCat)	60	60	60	60	61	61	61	61	61	61	61	61
Min(CPUE)	1.22	1.22	1.22	1.22	1.23	1.23	1.23	1.23	1.24	1.24	1.24	1.24
Avg(CPUE)	1.53	1.53	1.53	1.53	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
%AAV	1.79	1.79	2.05	2.05	1.03	1.03	1.03	1.45	0.51	0.51	1.03	1.03
P(B[y]<Bref)	0.0132	0.0113	0.0086	0.0053	0.0134	0.0116	0.0085	0.0052	0.0136	0.0118	0.0086	0.0052
P(B[y]<Bmsy)	0.0140	0.0131	0.0114	0.0089	0.0139	0.0130	0.0111	0.0088	0.0138	0.0129	0.0108	0.0085
P(B[y]<left_plat)	0.006	0.014	0.030	0.057	0.007	0.015	0.030	0.056	0.007	0.015	0.030	0.056
P(B[y]>right_plat)	0.665	0.666	0.667	0.670	0.674	0.674	0.675	0.679	0.680	0.680	0.682	0.685

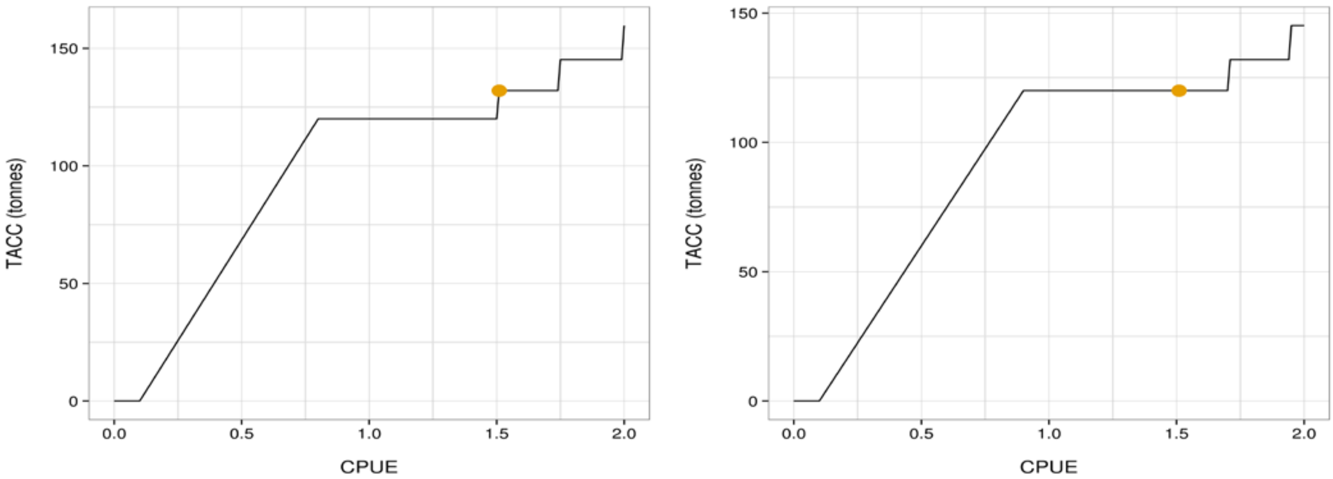
	385	389	393	397	401	405	409	413	417	421	425	429
par3	0.8	0.9	1	1.1	0.8	0.9	1	1.1	0.8	0.9	1	1.1
par4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
par5	150	150	150	150	150	150	150	150	150	150	150	150
par6	0.15	0.15	0.15	0.15	0.2	0.2	0.2	0.2	0.25	0.25	0.25	0.25
par7	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Avg(B/Bref)	1.45	1.45	1.46	1.47	1.45	1.46	1.46	1.47	1.45	1.45	1.46	1.48
Term(B/Bref)	1.31	1.32	1.34	1.37	1.30	1.32	1.34	1.38	1.30	1.32	1.34	1.39
Avg(CommCat)	157	156	154	153	157	156	154	152	157	157	154	152
Avg(RecCat)	52	52	52	52	52	52	52	53	52	52	52	53
Min(CPUE)	0.97	0.97	0.97	0.99	0.97	0.97	0.98	0.99	0.97	0.97	0.98	0.99
Avg(CPUE)	1.29	1.29	1.29	1.30	1.29	1.29	1.29	1.31	1.29	1.29	1.29	1.31
%AAV	1.14	1.54	2.05	2.66	0.90	1.03	1.54	2.05	0.51	0.82	1.03	1.79
P(B[y]<Bref)	0.1085	0.0983	0.0789	0.0570	0.1096	0.0989	0.0791	0.0565	0.1112	0.1001	0.0796	0.0564
P(B[y]<Bmsy)	0.0852	0.0769	0.0658	0.0523	0.0857	0.0772	0.0658	0.0521	0.0871	0.0782	0.0662	0.0519
P(B[y]<left_plat)	0.064	0.100	0.154	0.230	0.064	0.101	0.153	0.227	0.065	0.102	0.154	0.227
P(B[y]>right_plat)	0.372	0.374	0.377	0.382	0.381	0.382	0.386	0.392	0.386	0.388	0.392	0.398



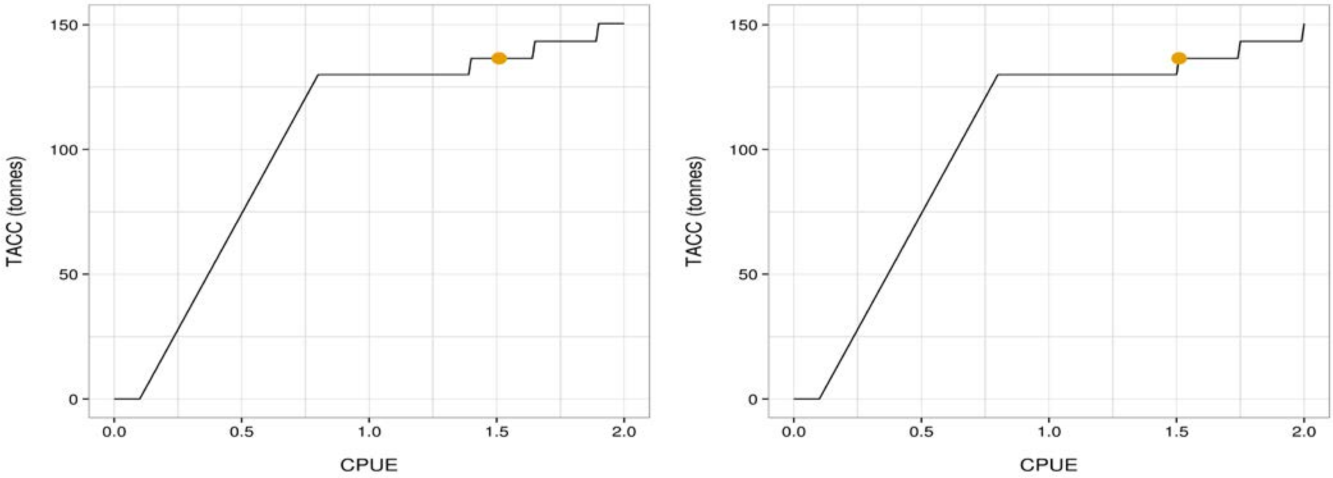
Appendix Figure 1: Plots of Rule 1 [left panel] and Rule 2 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



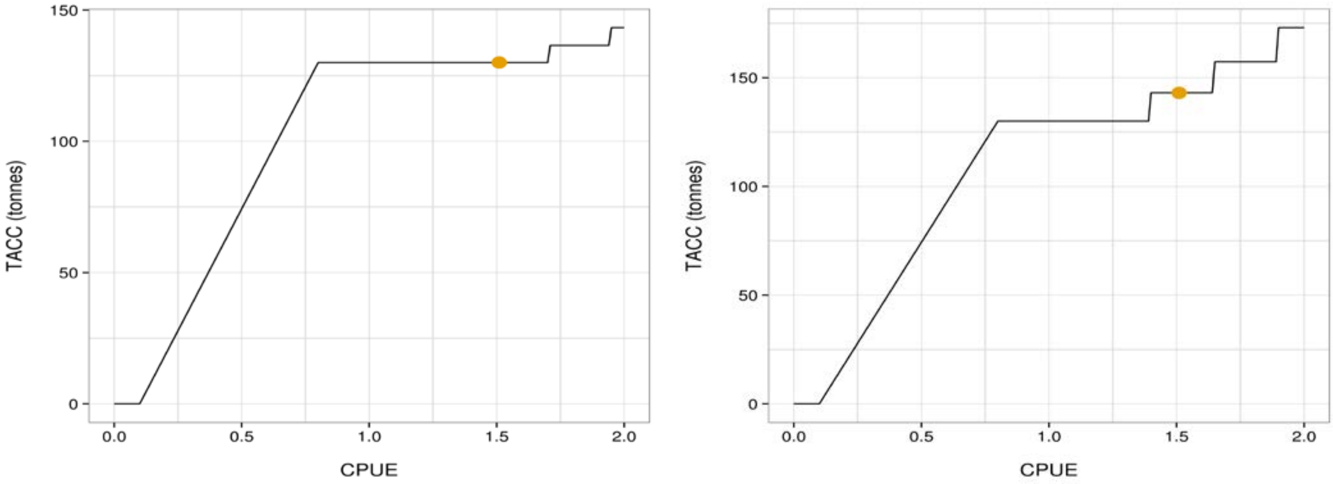
Appendix Figure 2: Plots of Rule 3 [left panel] and Rule 4 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



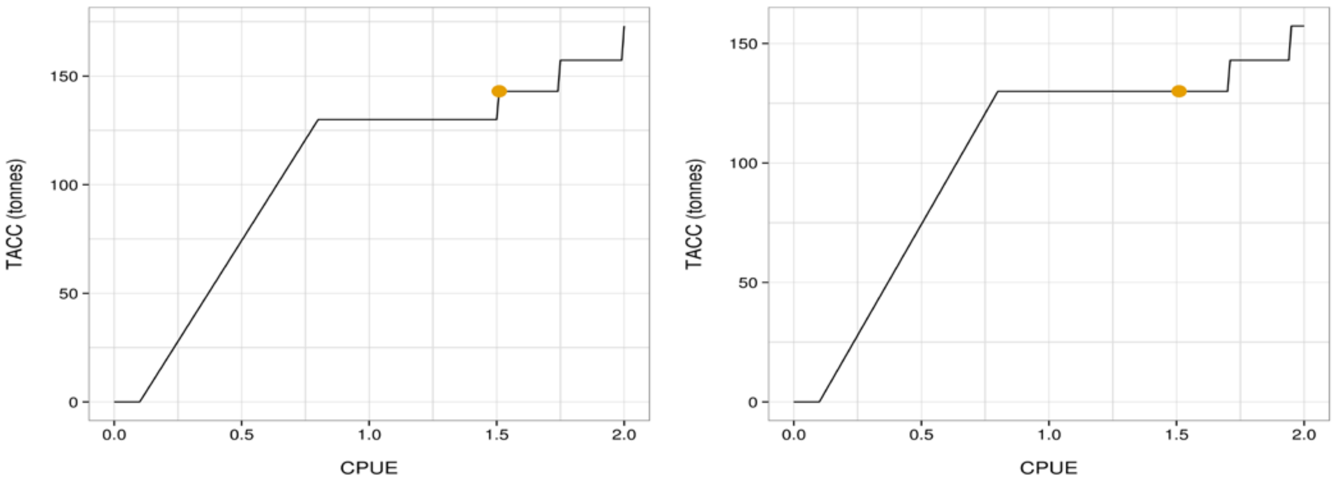
Appendix Figure 3: Plots of Rule 5 [left panel] and Rule 6 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



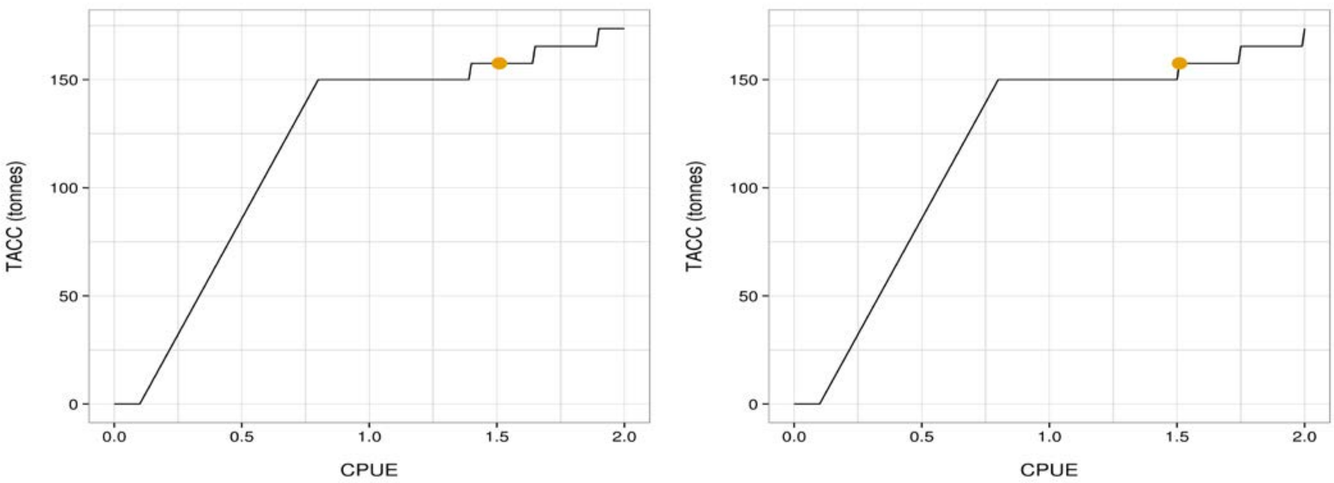
Appendix Figure 4: Plots of Rule 7 [left panel] and Rule 8 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



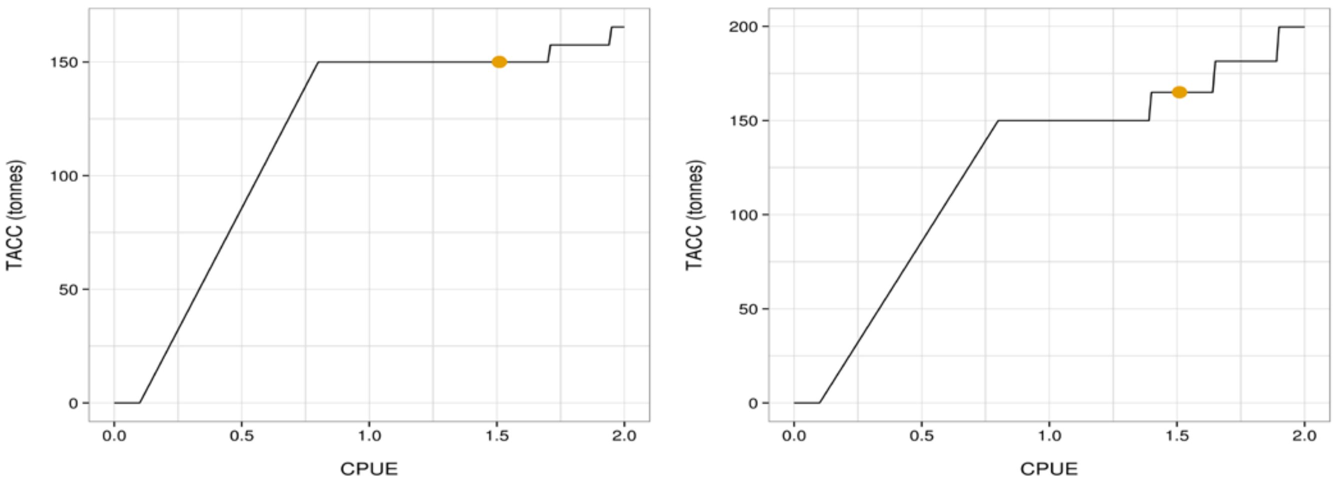
Appendix Figure 5: Plots of Rule 9 [left panel] and Rule 10 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



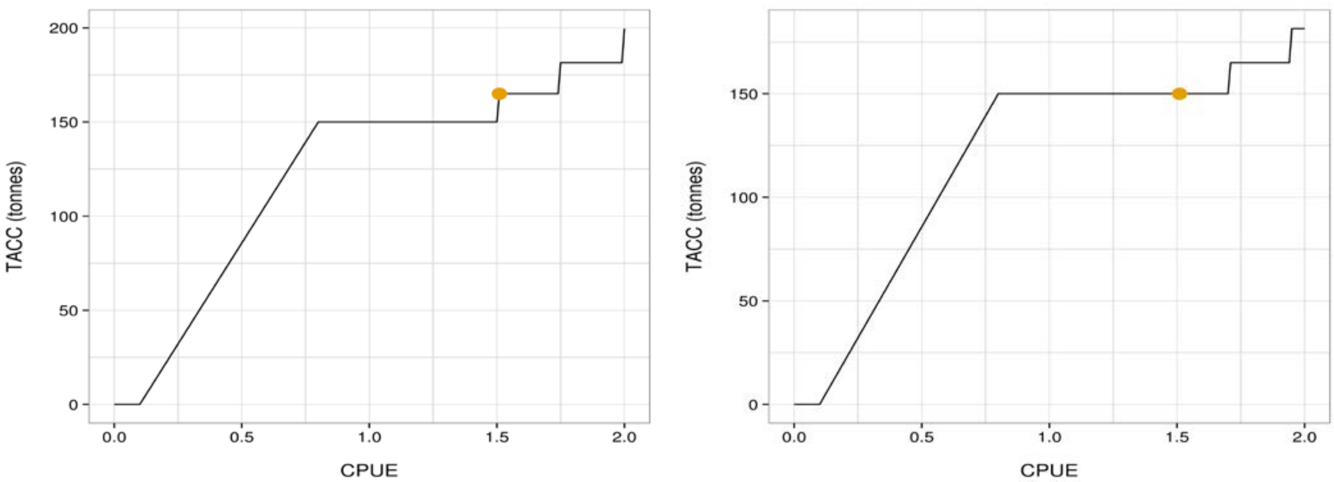
Appendix Figure 6: Plots of Rule 11 [left panel] and Rule 12 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



Appendix Figure 7: Plots of Rule 13 [left panel] and Rule 14 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



Appendix Figure 8: Plots of Rule 15 [left panel] and Rule 16 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).



Appendix Figure 9: Plots of Rule 17 [left panel] and Rule 18 [right panel]. The circle marks the most recent value for the 2012–2013 offset year CPUE (1.51 kg/potlift).