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# The 2015 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 5 and development of management procedures

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P.J. Starr
D.N. Webber

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This document describes a stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 5 and evaluations of operational management procedures. The work was done 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 (RLFAWG) oversaw this work, and all technical decisions were agreed beforehand or subsequently approved by the group. The model was fitted to catch, 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 selected two equally credible base case runs, differing only by the assumption that growth did or did not have a density dependent response, where growth is faster when the stock is low and slower when the stock abundance is high. Both base case runs estimate that $B_{current}$ has close to 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 decline, probably due to lower than average recent recruitment.

The assessment model was used as the basis for an operating model to test updated management procedures (MPs) for CRA 5. The rules tested determined annual total allowable commercial catch (TACC) as a function of offset-year CPUE, in keeping with recent evaluations for other rock lobster QMAs. The emphasis of the testing was to look at the properties of the rule when operating at low biomass: at what level should action be taken and how strong should the response be? Each rule was tested with 1000 21-year simulations, based on the MCMC posteriors from both base case runs, to address parameter uncertainty, along with added stochastic variation in CPUE observation error and in recruitment. Rule behaviour under alternative operating model assumptions was tested using five robustness trials. Management procedure candidates that met the sustainability criteria as well as providing acceptable levels of catch and low year-to-year variation 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 document describes work done to address Objectives 4 and 5 of the Ministry for Primary Industries (MPI) contract CRA2012-01C. This three-year contract, which began in April 2013, was awarded to New Zealand Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contracted 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 2015, the National Rock Lobster Management Group (NRLMG) agreed that Objective 4 should be addressed with stock assessments for CRA 5, CRA 7 and CRA 8, and that Objective 5 should be addressed by development of management procedures for CRA 5, CRA 7 and CRA 8. The CRA 7&8 work is described by Breen el al. (2016). This document describes the CRA 5 work, using the data described by Starr et al. (2016). The previous stock assessment of CRA 5 was in 2010 (Haist et al. 2011).

The stock assessment is being conducted with the model of Haist et al. (2009), using a six-month time step from 1979. The model used two abundance indices: an historical catch per day series (1963–73), and a standardised catch per pot-lift series (1979–2014); estimated size-limited and non-size-limited catches; length frequencies (LFs) from observers and voluntary logbooks. A growth sub-model is fitted to observed growth increments derived from tag recovery data collected from 1975 to the present. This stock assessment used the posterior distributions from estimated growth model parameters derived from a meta-analysis of all the available New Zealand lobster tagging data (Webber 2015a, Webber 2015b) as informed priors. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).

CRA 5 (Figure 1) includes all of Tasman and Golden Bays as well as the Marlborough Sounds. It extends down the northern part of the east coast of the South Island, past Kaikoura and the Banks Peninsula as far down as the Waitaki River. The CRA 5 TAC and TACC were last changed in April 1999 and are subject to review each year based on the results of the management procedure evaluation. The current CRA 5 TACC for commercial catch is 350 t. Allowances set by the Minister of Fisheries in 1999 were 40 t for customary catch, 40 t for recreational catch, 37 t for illegal unreported removals for a total TAC of 467 t. The fishery is open to recreational fishing all year with MLS 54 mm TW for males and 60 mm TW for females.

This project also evaluated updated management procedures for CRA 5, in accordance with the existing rock lobster research plan which specifies a review of existing management procedures every five years. 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, being the current basis for the management of eight of the nine CRA QMAs (Breen et al. 2009, Breen 2015).

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. MODEL SPECIFICATIONS

### 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 series
- ln(*qCR*): the natural logarithm of catchability coefficient for the historical catch rate (CR) abundance index series
- ln(*qPoo*): the natural logarithm of catchability coefficient for the puerulus settlement index series
- *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 (not estimated, use *Gdiff* instead)
- *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)
- *GrowthStdObs*: standard deviation of observation error
- *GrowthStdMin*: 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

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 2014 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 2015 vulnerable biomass

- *Bproj:* projected biomass, taken as AW 2018 biomass; these projections were made using the 2014 catches and using stochastic recruitment based on the mean and standard deviation of recruitment deviations estimated from 2003–2012
- *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 2003–2012, using 2014 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 2014 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 2014 and 2018, 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 period when the stock was stable, catch and CPUE were considered good, and the stock subsequently declined and recovered, indicating that the *Bref* was a safe place to be. The previous assessment used the period 1979–88, based on the biomass trajectory that was available at the time. However *Bref* is calculated with the current (2014) 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 5 assessment.

**Starting year:** In some rock lobster stock assessments, even though data are available from 1945, the model was started in a later year in order to solve problems associated with the assessment. No such problems were encountered for CRA 5, so a 1945 start was used.

**Last year:** was the last year of available data, 2014–15[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 1979–2014. 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.

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

**Data:** seasonal catches, historical catch rate (CR), length frequency data (LFs), catch per unit effort (CPUE), tag data and puerulus settlement data were included in the model. See below for a discussion on the analysis which formed the basis for including the settlement data.

**Likelihoods:** data sets can be fitted with a variety of likelihood options. For seasonal catches, we have used the lognormal distribution as in all recent assessments. 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 as in all recent assessments. For tag-recapture increments we have used a normal distribution this year (in previous assessments the robust normal distribution was used but was found to produce unsatisfactory behaviour in MCMC simulations).

**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 recent 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 three Newton-Raphson iterations in the MCMC simulations.

**Growth model:** the model uses the Schnute-Francis model as in all previous stock assessments.

**Density-dependent growth:** this option was tested as an MPD sensitivity trial and was subsequently treated as one of two equally credible base case runs.

**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 5 was assessed as a single stock.

**Recruitment deviations:** can be estimated for all years or a subset of years. We estimated them from 1945 to 2012.

**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 did not make an MPD sensitivity trial using logistic selectivity because in the past such assessments have differed very little from the fixed right-hand double normal but we did do an MPD sensitivity run which estimated the right-hand limb for both epochs.

**Year 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 this fixed parameter. 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 (Starr et al. 2014). 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. No evidence of this effect could be found in the CRA 5 tag data set from an MPD sensitivity run which was based on tag data from only the first release-recovery observation.

## 2.4 Fitting to length frequency distributions

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 only used the second approach in this stock assessment.

## 2.5 Puerulus Randomisation Trials

We ran a randomisation trial to test the validity of including the puerulus index series (Figure 2) in the model. This was done by predicting puerulus observations based on the model estimated recruitment:

$$\hat{I}_t^{puerulus} = q^{puerulus} R_{t-k}$$

where

$\hat{I}_t^{puerulus}$ is the predicted puerulus index,

$R_t$ is recruitment to the model in year $t$,

$k$ is the lag between settlement and recruitment to the model, and

$q^{puerulus}$ is an estimated catchability between the puerulus index and model recruitment

A lognormal likelihood was used to compare the predicted and observed recruitments. The trial consisted of fitting the model to 1000 randomly sorted puerulus index series to get a distribution of total likelihoods. The total likelihood obtained when fitting the model with the observed puerulus series was then compared with the distribution of 1000 total likelihoods obtained from the randomised trial, with the expectation that, if the actual likelihood was located in the lowest 5% of the distribution of randomised likelihoods, it would be valid to use the observed puerulus index series in the model. We made this trial over 0 to 5 lag years $k$. Table 1 shows that the model fitted to the puerulus indices lies below the 5% threshold of simulations (ranking 21 in 1000 simulations) for lag=1, which is significant for this test. This is comparable to the 2010 CRA 5 stock assessment (Haist et al. 2011) which found, using an equivalent trial, that a lag of 0 gave a similar result. As a result of this trial, both selected base cases included the puerulus index series with a lag year=1. Sensitivity runs which did not include the puerulus data were also taken to the MCMC level.

## 2.6 Informative priors for growth model parameters

The parameterisation used for the Schnute-Francis model in the MLSM model has four sex-specific parameters (*GAlpha*, *Gdiff* [=*GBeta* – *GAlpha*], *GShape* and *GrowthCV*) and two joint-sex parameters (*GrowthStdObs* and *GrowthStdMin*). These parameters are defined above in Section 2.1. This growth model has too many parameters for reliable estimation in this model, so common practice in previous assessments has been to fix some of the CV parameters (such as *GrowthStdMin*) and to put informed priors on *GShape* and *GrowthCV* because the available QMA-specific data lack sufficient information to estimate these parameters. Unfortunately, these *ad-hoc* informed priors were created without a formal supporting analysis.

A meta-analysis was performed before undertaking the 2015 CRA 5 stock assessment which estimated the parameters of rock lobster growth model, using the same parameterisation as in the MSLM, and which was based on the full tagging data set across all rock lobster QMAs (Webber 2015a, Webber 2015b). This analysis was performed using a Bayesian hierarchical approach implemented with conditionally autoregressive (CAR) priors, allowing the model to search the full likelihood space implied by the available data. The primary outputs from this analysis were Bayesian posterior estimates for all male, female and combined sex growth model parameters, with the exception of *GrowthStdMin*, which was deemed unnecessary within a Bayesian context when priors are being used. This analysis was reviewed and accepted by the RLFAWG in August and September 2015, with the intention of using the mean and standard deviation from the estimated posterior distributions for the *GShape*, *GrowthCV* and *GrowthStdObs* parameters as informed priors in all subsequent stock assessments. The remaining parameters (*GAlpha* and *Gdiff*, by sex) are well enough determined by the QMA-specific tagging data that they can be adequately estimated using an uninformative prior. However the RLFAWG agreed to use the meta-analysis (median) point estimates as initial values for these latter parameters. The growth model priors used in the CRA 5 stock assessment are provided in Table 2.

### 2.7 Initial explorations

Exploring for a base case involved:

- experimenting with dataset weights
- adding informed priors to constrain some model parameters
- fixing maturity 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.

## 3. MPD RESULTS

### 3.1 Base case (base1)

The specifications for parameter estimation in the "base1" base case are shown in Table 2. Most variables were estimated with uniform (uninformative) priors using wide bounds. Informative priors were used on *M* (using a prior used in previous assessments which was based on a literature search) and the recruitment deviations (normal in log space with a mean of zero and standard deviation of 0.4). Informed priors were used on five growth parameters based on a meta-analysis of the available New Zealand tagging data (described in Section 2.6). The dataset weights and other fixed values are shown in Table 3. Because the puerulus data were found to be significant with lag=1 year (see above), the base case MPD run included these data, The period over which recruitment deviations was estimated was 1945 to 2012.

The fit to CPUE (Figure 3) is acceptable, with the model matching the overall pattern of the indices in both seasons. However, there are patterns in the residuals which point to a poor fit within the series. For instance, the recent (post 2000) AW residuals are generally positive while the corresponding SS residuals are negative (Figure 4). It is likely that these patterns are the result of processes that are not included in the stock assessment model, such as movement between statistical areas.

The fits to the CR indices are good (Figure 5).

The fit to tag-recaptures is harder to explore because of the differing times at liberty. Figure 6 compares the predictions and observations. Figure 7 shows that residuals tend to fit the theoretical distribution. The residuals for both sexes do not show a trend from positive to negative with increasing size (Figure 8). There is no evidence from the residual pattern by release category that there is a “Punt phenomenon” effect in the tagging data (Figure 9).

Fits to LF data (Figure 10) are acceptable, although there are positive residuals peaking at the MLS and a pattern of negative residuals at sizes below the MLS (Figure 11). This pattern seems to apply to both males and females in both seasons. There are also a few very large residuals for small males (see Figure 11). These were dropped in a sensitivity run where they had no effect on model conclusions (see below). The model is unable to fit to the observed pattern of sex proportions in both the SS and AW seasons, with the model driving through the middle of the observations in both seasons (Figure 12 and Figure 13). The lack of fit can be seen in the residuals as well (Figure 14). It is likely that the residual pattern observed in the CPUE fit is related to this poor fit to the sex ratio data. Given the lack of success in 2014 when trying to reduce bias in the fit to the CRA 1 sex ratios (Webber & Starr 2015), the stock assessment team concluded that there was little that could be done to improve the fit to these data, with the lack of fit probably the result of processes which are currently not part of the stock assessment model.

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 15). Most of the estimates lie within one standard deviation of the predicted mean length.

The vulnerable biomass trajectory (Figure 16) shows a long biomass decline from the start of the fishery until the early 1990s, followed by an increasing trend that has levelled out at about two-thirds of the level at the beginning of the reconstruction. Recruitment (Figure 17) shows strong patterns after 1979, when modern data first become available.

Recruited biomass, shown seasonally in Figure 18, has similar trends to vulnerable biomass. Exploitation rates have been low for the NSL fishery, apart from a peak in the early 1990s 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 (Figure 19). Both seasons now have similar exploitation rates, with the AW slightly greater than 0.1 while the SS exploitation rate is just below 0.1. Maximum exploitation rates have been relatively low in CRA 5 except for SS in the 1980s and early 1990s, when exploitation rates hovered around 0.6 for one or two years.

The Epoch 1 and Epoch 2 selectivity curves seem credible for males, with the maximum occurring just below the appropriate MLS in Epoch 1 and very near to the MLS in Epoch 2 (Figure 20). The female Epoch 1 selectivity function goes to the upper bound of 90 mm which is not credible while the Epoch 2 female selectivity estimates a maximum selectivity about 10 mm greater than the MLS. This latter behaviour may be due to the large mean size of females in this fishery (see Figure 15). The estimated maturity function shows that females are all mature by the time they reach the MLS of 60 mm (Figure 21). Predicted increments-at-size are shown in Figure 22. The equilibrium size structure at beginning of the model reconstruction is shown in Figure 23.

Base case results are shown in the first data column of Table 4. The *sdnr* values for the LFs, tags, CPUE, CR and sex proportions are all near one. The MAR (median average residual) values are near the target value of 0.67 for CPUE and sex proportions, indicating a reasonable correspondence with the model distributional assumptions. The MAR values for the LF data are very low and the MAR values for the tag and CR data sets are below the target value.

The estimate for $M$ is near 0.17, which is acceptable, and the growth parameter estimates are all consistent with the meta-analysis results (Webber 2015a, Webber 2015b). All the *vulnest* estimates were less than one and do not approach either bound, suggesting that the vulnerability has been parameterised appropriately.

*Bref* is estimated at 834 t (vulnerable biomass in AW), using the period 1978–88 which is well above the estimate of *Bmsy* (524 t). The base case suggests that the current biomass is well above both *Bref* and *Bmsy*.

## 3.2 MPD Sensitivity Trials

We selected a second base case (base2) which was the same as base1 except that the density-dependence parameter was estimated. We also ran 16 additional trials that explored the sensitivity of model estimates and results to a range of modelling choices and data sources.

These were (including the two base case runs):

**base1:** as described in Section 3.1 (include puerulus data [lag=1] but no density dependence)
**base2:** same as "base1", but estimate the density dependence parameter
**sens1:** same as "base1" but without puerulus data
**sens2:** same as "base2" but without puerulus data
– sensitivity runs "sens3" to "sens6" are based on "base1" (include puerulus data [lag=1] but no density dependence
**sens3:** "Alt recreational catch": uses the "power140" procedure to estimate recreational catch, resulting in an increasing catch series (see Figure 24)
**sens4:** "Est right-hand limb": estimate the right-hand limb selectivity parameter rather than fixing it. This adds four parameters to the model, one each for males and females in the two epochs
**sens5:** "Growth prior CVs=30%": arbitrarily widen the CV for the priors used for the growth model parameters *Gshape*, *GCV* and *GStdObs*
**sens6:** doubling data weight on the CPUE index series
– sensitivity runs "sens7" to "sens18" are based on "sens1" (no puerulus data and no density dependence
**sens7:** "N-R 5": with five Newton-Raphson iterations instead of three (this serves as an alternate "base case" because the estimated parameters and likelihoods are nearly identical to the "N-R 3" base case)
**sens8:** "Half illegal catch": uses half of the base case illegal catch trajectory (see Figure 25)
**sens9:** "Double illegal catch": uses twice the base case illegal catch trajectory (see Figure 25)
**sens10:** "Only Rel=0": only uses tags where the release-recovery pairs resulted from the first recapture. This reduced the 7035 tag recoveries to 5174 recoveries
**sens11:** "Only Rel≠0": only uses tags where the release-recovery pairs from the first recapture event were not used. This reduced the 7035 tag recoveries to 1861 recoveries. This sensitivity was done to investigate a possible tagging effect on the growth rate immediately after tagging and as an alternative way to investigate the "Punt phenomenon"
**sens12:** "CPUEpow": estimate the relation between biomass and CPUE with a power function instead of a simple linear function. This sensitivity run needed to have Mat95add parameter fixed to the estimated value for the N-R 3 base 1 run because under a uniform prior, the parameter estimate went to the upper bound of 60 mm
**sens13:** "No trunc": with the weight on each of the 60 LF records set at its raw value, rather than being truncated to lie between 1 and 10s
**sens14:** "Remove 4 SS/AW 'observations'": remove the four LF sample records with large standardised residuals
**sens15:** "drop CR data": drop the CR data in the model
**sens16:** "drop CPUE data": drop the CPUE data in the model
**sens17:** "drop LF data": drop the length frequency data in the model
**sens18:** "drop tag data": drop the tagging data in the model

Results for these sensitivity runs are compared in Table 4 for the two base case runs and the six sensitivity runs which were taken to the MCMC level and in Table 5 for an additional 12 sensitivity runs which were only taken to the MPD level.

There was a strong impact on the analysis when density dependence was estimated, with considerable improvement in the likelihood (over 50 likelihood units) coming from the addition of the single parameter (Table 4). This was true whether the puerulus data series was included (base2) or dropped (sens2). For this reason, the “base2” run was elevated to be an alternate base case.

Increasing the Newton/Raphson iterations from 3 (sens1, Table 4) to 5 (sens7, Table 5) resulted in the same total likelihood and parameter estimates only differed by small amounts. These results were so close that NR3 and NR5 were considered to be equivalent. The two base case runs and all other sensitivity runs were made with only three Newton/Raphson iterations to speed up model analysis time. Note that this comparison was done on runs which did not include the puerulus data.

The alternative recreational catch trials (sens3, Table 4) and the two alternative illegal catch trials (sens8 and sens9, Table 5) had only small effects on the model results. All three had similar ratios with the 1979–1988 reference period and there was some variation in the size of 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 close.

Model results differed little when the tag recovery data set was reduced to recoveries from the first release (sens10, Table 5). The fits to the LF and CPUE data hardly changed as were the sex proportion fits. There were almost no differences in the growth parameter estimates, and the reference point estimates and stock status estimates were similar. This was probably due to the highly informative priors being used and because the bulk of the tagging data were from the first release. There were more differences with the tag data set that excluded all first release-recovery events (testing for growth interference effects: sens11, Table 5). This run was slightly more optimistic with respect to the *Bref* and *Bmsy* reference points and growth appeared to be marginally faster, but the results did not differ substantially from the base case. The second parameter for the logistic maturity function (*Mat95Add*) needed to be fixed at the base case value for this sensitivity run to give a credible result.

*CPUEpow*, when estimated, was quite large (=2.25) (sens12, Table 5). This results in a much better fit to the CPUE data (by 33 likelihood units). This improvement in the fit was obtained by the model getting a better fit to the sequential patterns visible in the late 2000s CPUE (Figure 26). This run was less optimistic with respect to the *Bref* and *Bmsy* reference points, but the results did not differ substantially from the base case with this model predicting that current stock status was greater than the reference points.

Using the raw LF weights (sens13, Table 5) resulted in little change from the base case with respect to the *Bref* and *Bmsy* reference points, with this model being slightly lower relative to *Bref* compared to the base case and slightly greater than *Bmsy* compared to the base case. This run was reweighted twice in an attempt to improve the LF *sdnr*s.

The four length frequency records responsible for the large residuals to the fit to the LF data in the base case runs that are apparent in Figure 11 were dropped in sens14 (Table 5; see Figure 27 for the equivalent LF residuals for this run), with no effect on the model predictions relative to the base case. These were records with large numbers of measured lobsters, so these samples were retained in the model.

A comparison of the “base1” base case with sens1 and equivalent comparison of “base2” with sens2 shows that there is little effect from adding the puerulus data (assuming a lag of 1 year between settlement and recruitment) to the model (Table 4) with respect to fit to data, parameter estimates and estimates of stock status. The stock status ratios, *Bcurr/Bref* and *Bcurr/Bmsy*, are very similar, as are the likelihood and parameter estimates. The main difference in these models will be in the projections, with the two base case models predicting lower future recruitment compared to the model which omits the puerulus data (Figure 28). Future recruitment in both models is predicted to be above the long-term (1945–2012) average recruitment, with the recent (2003–2012) average recruitment predicted to be 16% and 18% above average for the base and sens1 runs, respectively.

Estimating the right-hand limb (sens4, Table 4) of the selectivity function resulted in strong estimated descending limbs for males in both epochs and for females in the first epoch (Figure 29). The lack of a descending limb for females in the second epoch can be explained by the high predicted mean lengths in this sex category during this epoch (see Figure 15). This sensitivity trial estimated a lower M (0.13 compared to 0.17 in the base case), indicating that the higher M in the base case is likely to be the result of the assumption to keep the right-hand limb of the selectivity function flat. Both stock status ratios, *Bcurr/Bref* and *Bcurr/Bmsy*, dropped relative to the base case, but are still well above these reference levels.

Sens5 (Table 4) explores the effect of widening the priors on the *GShape*, *GCV* and the *GSD* parameters. Table 2 shows that the CVs for these priors are low, ranging from 2% (*GCV*) to 8% (*GShape*). The CVs for these priors were increased arbitrarily to 30% and the model was refitted. Not surprisingly, the growth parameters estimates changed, particularly *GShape* which increased from about 5.5 for both males and females in the base case to over 7 in this sensitivity run. However, the stock status ratios, *Bcurr/Bref* and *Bcurr/Bmsy*, are similar to the base case estimates and well above the reference values.

Sens15 to sens18 (Table 5) explore the effect of systematically dropping each of the data sets one at a time. A comparison of the estimates for sens15 (drop the historical CR data series, Table 5) with the "base1" base case or sens1 (Table 4) shows that this data series has very little impact on the model estimates except for M, which is estimated at 0.16 instead of the 0.17 estimate in the base case. The effect of dropping the other data sets is much greater, although none of these runs estimate that current stock status is below either reference level.

An additional sensitivity (sens6, Table 4) explored the effect of arbitrarily doubling the relative weight on the CPUE data series. This was done to see if the fit to this series could be improved from the one presented in Figure 3 and Figure 4. While this run improved the apparent fit to the CPUE series (Figure 30), the fits to the length data deteriorated as did the likelihoods to the CR, puerulus and the prior penalties (Table 4). There was a 2.2 unit improvement in the fit to the tag data. However, this run (and others not reported here) show the stock status to be well above the reference points. Stock status as estimated by sens6 drops 21% to 2.25 (for *Bref*) and 23% to 3.07 (for *Bmsy*) relative to the level estimated by the base case.

## 4. MCMC RESULTS

### 4.1 Base case

Given the MPD results, two equally credible base case runs were selected, with one fixing density dependence at zero and the other estimating density dependence (base1 in Table 4; base2 in Table 4). Both of these runs included the puerulus data. The latter model was run for 3 150 000 Markov chain Monte Carlo (MCMC) simulations, starting at the base case MPD and sampling every 3000 to give 1050 posterior samples, leaving 1000 samples after the first 50 were discarded as a burn-in. The former model (without density dependence) required a longer burn-in period. Consequently this model was run for 4 150 000 simulations, again sampling every 3000 to give 1350 posterior samples and leaving 1000 samples after the first 350 were discarded as a burn-in. Projections were made to 2018 assuming the 2014 catch distribution. Recruitments were resampled from the most recent 10 years (2006 to 2015), including the one year lag relative to the 2014 puerulus index. The default model *sigmaR* (0.4) was used given that the standard deviation of the recruitment residuals between 2006 and 2015 was near 0.3.

Both base case runs included the puerulus data series because the randomisation test indicated that this series was significant, using the criteria presented in Section 2.5 (Table 1). The two runs differed in the estimation status of the density-dependence parameter, with *base1* forcing *GDD*=0 while *base2* estimated the *GDD* parameter. Both model runs required fixing the *Mat95Add* parameter (the second parameter of the logistic maturation rate ogive) to 3.26, the estimate made by sens1 MPD run (Table 4: sens1 is the same as base1, including relative weights, except that the puerulus settlement indices are not used).

Posterior distributions of parameter estimates for both models are summarised in Table 6 and also compared with the MPD. Traces for both models are shown for all major parameters in Figure 31A to D, with diagnostics in Figure 32A to D. Similarly, histograms of the posterior distributions for both models are shown in Figure 33. The traces for the leading parameters (e.g. *M* and *lnR0*) and derived parameters (e.g. $B_{min}$ and $B_{ref}$) all show reasonable stability in both models, with the possible exception of a downward drift in ln(R0) and M at the beginning of the search for base1, a feature which is missing in base2. Current stock status derived parameters ($B_{2014}/B_{ref}$ and $B_{2014}/B_{msy}$) show good stability in both models (Figure 31D). The posterior distribution plots (Figure 33A to D) indicate that most of the parameters stayed away from their bounds in both models, with the exception of the maximum selectivity parameter for females in Epoch 1 (*SelectMax1F*), which is poorly determined from lack of data for immature females in the sampling years before 1993.

Posterior distributions of derived parameters for both models are summarised in Table 7 and the associated indicator probabilities are given in Table 8. Traces for these parameters are shown in Figure 31A to D, diagnostic plots in Figure 32A to D and histograms of the posterior distributions in Figure 33A to D.

The indicators (Table 7) suggest that the 2014 biomass was nearly 5 times greater than *Bmin* (5th to 95th quantiles 4.1 to 5.5) for base1 and slightly lower (4.4 and 5–95 quantiles: 3.9–4.9) for base2. In both models 2014 biomass is predicted to be above all three reference points (*Bmin*, *Bref* and *Bmsy*) with 0.95 probability (Table 8). *Bref* is based on the years 1979–1988 which was the definition used in the 2010 CRA 5 stock assessment (Haist et al. 2011). The projections indicate that the stock is likely to decline (P=0.81 for base1 and P=0.97 for base2) given the current catch distribution. However, the projected stock is expected to remain well above *Bmin*, *Bmsy* and *Bref* (Table 7 and Table 8) in both models.

Paired cross-correlation plots for both models are provided in Figure 34A to Figure 34C, grouped by parameters of interest. The full set of parameters are compared in Figure 35 using colour codes to indicate the degree of correlation.

The posterior of the fit to CPUE (Figure 36) seems slightly better than the MPD fit for both models, with the base2 model possibly slightly better than base1. Unfortunately neither model is able to fit the systematic runs of 3 to 5 years that are apparent in the data, given the current configuration. The fit to the historic CR data series is very similar to the MPD fit for both models (Figure 37).

The posterior trajectories for the predicted fit to the puerulus data differ between the two models (Figure 38), with the minor peaks seen in the early 1990s and 2000s that are visible in base1 appearing in different years in base2. The sex ratio plots are also similar to the MPD fit for both models (Figure 39).

Recruitments are variable with an apparent mean just below 400 000 recruits over the last 30 years (Figure 40), with somewhat differing patterns estimated by these two models. Both the total (Figure 41) and vulnerable biomass (Figure 42) trajectories show a long declining period from 1945 to the late 1970s, followed by a short reversal in the early 1980s. The CRA 5 stock biomass then dropped to its lowest levels in the early 1990s, followed by a rebuilding to a peak in the late 2000s. Currently the stock appears to be in a slow decline, although it still remains well above all three reference points even at the end of the reference period. The biomass trajectory for base2 (with DD) is much tighter than the equivalent for base1 (without DD).

"Snail trail" plots for both base1 and base2 (Figure 43) show that the majority of the trajectory is in the lower right hand quadrant (the so-called "safe" zone) with the current (2014) 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.

## 4.2 MCMC Sensitivity runs

Six sensitivity runs, based on the above two base runs, were selected to go to the MCMC level (Table 9). Table 9 describes the nature of each sensitivity run, the length of each MCMC chain and the amount of the chain that was discarded as "burn-in". Most of these runs (including the two base runs) needed to have the second parameter (*Mat95Add*) of the maturation rate ogive fixed at the MPD estimate so that it would give sensible MCMC posteriors. In spite of this step, only four of the eight runs showed "acceptable" or "good" MCMC diagnostics while the remaining four had evidence of non-convergence. Trace plots (Figure 44 to Figure 46), cumulative posterior frequencies (Figure 47 to Figure 50), running means (Figure 51 to Figure 53) and posterior histograms (Figure 54 to Figure 56) are provided for all eight MCMC runs described in Table 9 (most of the MCMC diagnostics for the two base cases are in Figure 31 to Figure 33).

As for the two base case runs, projections were made to 2018 assuming the 2014 catch distribution. Recruitments for the model runs which included the puerulus data were resampled from the most recent 10 years (2006 to 2015), observing the one year lag relative to the 2014 puerulus index. Otherwise the default model *sigmaR* (0.4) was used for the projection recruitments given that the standard deviation of the recruitment residuals between 2006 and 2015 was near 0.3.

The sensitivity runs that are labelled "poor" with respect to the convergence characteristics of the MCMC posteriors generally show chains with drifting means. For instance, the sens4 model run where density dependence is estimated and the puerulus series is not included shows divergence in the third (blue) sub-chain for both *M* and ln(*R0*) (see Figure 48, column B), indicating that the mean from this part of the chain will differ from the first two thirds of the chain. Similar poor MCMC behaviour can be seen in every one of the other model runs labelled "poor" in Table 9. The posterior parameter distributions for the "estimate R-H limb" sensitivity run are particularly poor (Figure 55, column B), indicating that the MCMC parameter estimates for this run should be considered unreliable.

Notwithstanding the poor MCMC convergence properties for four of the sensitivity runs listed in Table 9, median parameter estimates for each run are provided in Table 10, as well as the equivalent estimates for the two base case runs. Table 11 provides the median indicator values for each sensitivity run while Table 12 gives the probability values for breaching selected reference points. *Bref* is based on the years 1979–1988 which was the definition used in the 2010 CRA 5 stock assessment (Haist et al. 2011). The projections indicate that the stock is likely to decline over the next four years (P ranges from 0.7 to nearly 1 for P(*Bproj*>*Bcurr*), except for the sens1 run [no DD and no puerulus]), given the current catch distribution. However, stock size at the end of the projection period is expected to remain well above *Bmin*, *Bmsy* and *Bref* (Table 11) for all model runs.

The posterior of the fit to the CPUE data for the sensitivity run which placed additional weight on the CPUE series shows little improvement relative to the fit by the related base run (including puerulus data but no DD; Figure 57). This run also had poor MCMC convergence characteristics, indicating that it is unlikely that this run will be satisfactory as an operating model for an MPE robustness trial.

Recruitment trajectories for each of the eight model runs defined in Table 9 are provided in Figure 58 and Figure 59. These plots demonstrate that the presence/absence of puerulus data and the estimation status of the density dependence parameter have the greatest effect on the model recruitment estimates rather than any of the underlying sensitivity assumptions. The vulnerable biomass trajectories for the eight model runs defined in Table 9 are shown in Figure 60 and Figure 61, showing that the general form of these plots is similar across this range of sensitivity runs. A possible exception to this generalisation could be made for sens1 (no puerulus and no density dependence) which does not show the same declining trend after 2010 as do the other seven sensitivity runs (Figure 60, lower left panel).

## 5. MANAGEMENT PROCEDURE EVALUATION

### 5.1 Projection model

For the models which include the puerulus data, recruitment observations for the projections were made by drawing from the mean recruitment between 2006 and 2015 (given that the last puerulus observation was in 2014 and puerulus was fit with a lag of one year). All models used the assumed recruitment standard deviation (*sigmaR*) of 0.4. Mean recruitment for the model without puerulus data was taken over the period 2003–2012. 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 calculated from the 1979–2014 average recreational exploitation rate observed in the minimisation model
- other non-commercial catches were fixed at their 2014 estimates (10 t for customary and 30 t for illegal).

Projections simulated CPUE observation error deviations using observed distributions of CPUE deviations and their autocorrelations. The projected AW/SS catch split used the relation determined from a regression of the proportion of catch taken in AW against standardised AW CPUE (Figure 62).

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 63).

### 5.2 Harvest control rules

A range of step function harvest control rules were investigated that were based on the existing CRA 5 harvest control rule (Figure 64 depicts a generalised harvest step rule). These rules have a plateau, on which the TACC is constant when CPUE remains within a specified 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 (showing the corresponding *p#* in Figure 64):

- *par1*: rule type (type 4)
- *par2*(*p*2): CPUE at TACC=0
- *par3*(*p*3): CPUE at the left side of the plateau (kg/potlift)
- *par4*(*p*4): CPUE at the right side of the plateau (kg/potlift)
- *par5*(*p*5): plateau height (t TACC)
- *par6*(*p*6): step width
- *par7*(*p*7): 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 minimum change threshold of 5% and 10%, no maximum threshold and no latent year.

## 5.3 Indicators

The indicators below are consistent with those used to evaluate the CRA 1 MP (Webber & Starr 2015). As in previous MPEs, biomass is beginning AW biomass; CPUE is offset-year CPUE calculated from seasonal mid-season CPUEs using the relation shown in Figure 63.

| | 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) | median of the minimum observed fishing year CPUE during the run; |
| 9. | mean(CPUE) | median of the 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 25% *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 |

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

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

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 their posterior distributions.

## 5.4 Finding rules to present

The exploration of rules for CRA 5 was based on the existing CRA 5 management procedure and the aspirations of stakeholders (Table 14). Stakeholders indicated that the rule should remain as long as possible on the "plateau" (*par 5*) but that the rule should correct very quickly if CPUE fell below the left-hand edge of the plateau. This led to exploration of a range of parameter options that controlled the steepness of the rule at the left side, which are *par 2* (CPUE value when TACC=0) and *par 3* (left side inflection point). Stakeholders indicated that there was little interest in maximising catch through changing the parameter values which affect the stepping properties of a rule: right-hand inflection point (*par 4*), step width (*par 6*), step height (*par 7)* (Table 14). Stakeholders also indicated that, unlike the existing rule, they wanted a minimum change parameter (*par 8*) to avoid inconsequential changes. The range of parameter values explored is shown in Table 14, for a total of 216 rules.

## 5.5 Base case evaluations

The two base case runs (base1: with puerulus and no density dependence and base2: with puerulus and density dependence) show relatively little contrast in most of the indicators. Base2 (with density dependence) is more pessimistic than base1 (without density dependence) but still does not breach any of the safety indicators, even at the upper bounds of the results (Table 15). Neither run ever goes below *Bmin* and there is only a very small probability of base2 going below *Bmsy*. There is a measurable probability of going below *Bref* for base2, especially for the upper 95$^{th}$ quantile (over 12%). However, *Bref* is not usually considered to be a limit threshold which needs to be avoided with high probability.

There is also little difference between the two base cases in terms of the amount of catch generated, both commercial and recreational, and in average CPUE levels (Table 15). Base2 shows lower AAV% than in base1 and both runs indicate that there is a reasonable probability of dropping below the left side of the plateau (11% for base1 and 6% for base2).

## 5.6 MPE robustness trials

Given the lack of contrast in the results shown in Table 15, a close look at the performance of the five robustness trials outlined in Table 13 is required. Two of the robustness trials involve setting the average recruitment used in the projections to the lowest observed decadal mean recruitment (see Figure 65). This was done for the two base case models (with and without density dependence). Other trials included doubling the standard deviation associated with the CPUE observations (*hiStdObs*), using an alternative (higher) recreational catch trajectory and dropping the puerulus index series (no density dependence) (Table 13).

There is almost no contrast in the three safety indicators across five of the seven Table 13 models (Figure 66). However, there are rules which go below *Bref* for the two models where recruitment has been set to the lowest decadal value, with the probability of breaching this reference level nearing 50% for the model with density dependence and low recruitment (Figure 66). Even these models show very little propensity of going below the other two safety indicators.

Average commercial and recreational catches vary within fairly narrow ranges while AAV% stays below 8% for all rules (Figure 67). All this comes at a cost, with most rules with puerulus data having reasonably large probabilities (some greater than 60%) of dropping below the left-hand inflection point and having a high probability of having at least one TACC change (Figure 68). Note that the robustness trial without puerulus data seems considerably more productive than the other six trials, with the "model 3" (black) markers generally sitting well outside of the other six trials. This is likely to be a function of the recent relatively poor recruitment indicated by the puerulus settlement index but not reflected in the years up to 2012, leading to lower recruitment averages for the trials which include the puerulus series compared to the model run which excludes these data.

Table 16 compares the median values for all the indicators across all seven Table 13 trials, while Table 17 compares the 95$^{th}$ quantile across all seven model trials. These tables show that there is not much difference between these trials either in terms of response to safety indicators or in terms of average catch. The exception to this generalisation are the two models where recruitment has been forced to the lowest decadal average, whether or not density dependence is estimated. These models show slightly lower average commercial catch, much lower minimum commercial catches and lower average CPUE. They also show higher probabilities of breaching *Bref* while still having low probabilities of going below *Bmin* or *Bmsy*. These tables also show that the robustness trial with the higher recreational catch leads to about 10–12 t additional recreational catch with very little difference in any of the safety or other performance indicators (compare ‘base1’ with ‘altrec’ in Table 16 and Table 17).

## 5.7 Advice on specific parameter values

Table 18 shows how the three safety probability indicators vary across the four investigated values of *par3* while holding *par2* constant. These two parameters determine the steepness of the left side of the rule and this table shows that there is little contrast in the *par3* performance indicators across the values of *par2*. This leads to the advice that the choice of *par2* is not likely to have sustainability implications. On the other hand, Table 18 shows that there are sustainability implications associated with *par3*, the left-hand inflection point of the plateau, with relatively high probabilities (7–37%) associated with going below *Bref* when the left-hand inflection point goes to 1.0 kg/potlift or lower for the two low-recruitment robustness trials. Similarly, the two low-recruitment robustness trials perform poorly across the three values used for *par5* (plateau height), with the probability of going below *Bref* approaching 50% for *par5*=375 t for the low recruitment model with density dependence when *par3*=0.8 kg/potlift (Table 19). Even base2 (density dependence with 2006–2015 recruitment) has a 13% probability of going below *Bref* when *par3*=0.8 kg/potlift. There is also a 7% probability of going below *Bmsy* for *par5*=375 t for the low recruitment model with density dependence when *par3*=0.8 kg/potlift (Table 19).

Results across the robustness trials are less definitive for the catch and AAV indicator values (see Table 20 and Table 21). For instance, average commercial catch is nearly constant for each *par3* value, regardless of the *par2* value used (Table 20). Note that higher commercial catches and lower AAV% are associated with lower values of *par3* while the higher values of *par3* show the reverse. Recreational average catch is unaffected by the *par3* parameter. When *par3* is investigated as a function of *par5* (plateau height), average commercial catch reflects the *par5* value very closely (Table 21), as would be expected, with similar average recreational catch for each *par3* value. Again AAV% increases with higher *par3* values for every model/trial.

*Par8* (minimum change threshold) shows almost no difference in the median values of the three safety indicators for the two investigated values for this parameter across all the robustness trials (Table 22), indicating that there should be no sustainability concerns regarding either value. Table 23 shows that the average commercial and recreational catches are insensitive to the *par8* values investigated while there is a small decrease in the mean %AAV for the higher (0.1) value for *par8*.

# 6. DISCUSSION

We feel that the use of the newly created informative priors (see Section 2.6) for the more poorly estimated growth parameters has greatly improved the performance of the estimation phase of the stock assessment. With the use of these priors, the estimates for these parameters remain credible and do not run up against their bounds. This behaviour also feeds into the MCMC search procedure, ensuring that the parameter estimates do not stray into a non-credible space.

We needed to explore the implications of including/excluding density dependence in this stock assessment and MPE, given that this process could have important implications for rock lobster management. Because there is little in the way of objective criteria to include or exclude density-dependence, we chose to present both options as equally credible base case runs. Fortunately, the effect of density-dependence on the sustainability indicators, given the way it has been parameterised in this model, seems to be small at the stock size levels which were modelled in this MPE. Similarly, there appear to be no implications with respect to average or long-term levels of catch or productivity associated with density dependence.

While the base case MPD model showed acceptable fits to most of the data, we were unable to model the time series of SS and AW sex ratios, which showed a systematic pattern which the model could not match (see Figure 13 and Figure 14). There was also a pattern in the residuals to the CPUE fit (Figure 4). These patterns in some of the model fits indicate that there are likely to be unmodelled processes in these data that should be investigated in future stock assessments.

The 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.

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).

This stock assessment suggests that $B_{curr}$ has a probability close to zero of being below the default hard and soft limits of 10% and 20% spawning stock biomass (Table 8) 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 2014–15 catches. $B_{proj}$ has probabilities of 0.19 and 0.03 of being larger than $B_{curr}$ for two base case runs.

We investigated management procedure rules that span a range of values that were informed by the current CRA 5 rule. We have shown that there will be few sustainability concerns for any of the parameter values across the seven base case and robustness trials, apart from a tendency to drop below *Bref* for the trials where recruitment was reduced to the lowest decadal average and the left-hand inflection point was set to 1.0 kg/potlift (or below). How much weight should be placed on these results is not clear, but they should possibly lead away from selecting rules where *par3* is 1.0 kg/potlift (or lower).

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**Table 1: Relative position of total model likelihood when fitting to the observed puerulus indices in a distribution of total likelihoods obtained from 1000 randomly sorted puerulus fits. Grey shading indicates the lag year which shows a significant improvement in likelihood with the addition of the puerulus index series.**

| lag | Position | Total LL |
|---|---|---|
| 0 | 213 | 11774.2 |
| 1 | 21 | 11770.3 |
| 2 | 58 | 11771.5 |
| 3 | 219 | 11774.0 |
| 4 | 252 | 11774.2 |
| 5 | 73 | 11772.1 |

**Table 2: Specifications for the MPD base1 case (no density dependence). 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. Grey indicates values used for variables fixed in this base case run but estimated in a sensitivity or alternate base run. Yellow indicates values implemented as a result of a hierarchical Bayesian meta-analysis of the NZ rock lobster tagging data set (Webber 2015a, Webber 2015b).**

| 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 |
| ln(*qPoo*) | 1 | -25 | 0 | 0 | – | – | -6 |
| *CPUEpow* | -1 | 0.001 | 6 | 0 | – | – | 1 |
| *Mat50* | 3 | 30 | 80 | 0 | – | – | 60 |
| *Mat95add* | 3 | 1 | 60 | 0 | – | – | 10[1] |
| *GalphaM* | 2 | 1 | 20 | 0 | – | – | 3.5 |
| *GalphaF* | 2 | 1 | 20 | 0 | – | – | 3.5 |
| *GdiffM* | 2 | 0.001 | 1 | 0 | – | – | 0.8 |
| *GdiffF* | 2 | 0.001 | 1 | 0 | – | – | 0.5 |
| *GshapeM* | 3 | 0.1 | 15 | 1 | 4.81 | 0.38 | 4.8 |
| *GshapeF* | 3 | 0.1 | 15 | 1 | 4.51 | 0.24 | 4.5 |
| *GrowthCVM* | 5 | 0.01 | 2 | 1 | 0.59 | .0076 | 0.59 |
| *GrowthCVF* | 5 | 0.01 | 2 | 1 | 0.82 | .013 | 0.82 |
| *GrowthStdObs* | 5 | 0.00001 | 10 | 1 | 1.48 | 0.015 | 1.5 |
| *GrowthDD* | -5 | 0 | 1 | 0 | – | – | 0 |
| *Sel_L_male* | 4 | 1 | 50 | 0 | – | – | 4.1 |
| *Sel_L_female* | 4 | 1 | 50 | 0 | – | – | 9.2 |
| *Sel_Max_male* | 5 | 30 | 90 | 0 | – | – | 55 |
| *Sel_Max_female* | 5 | 30 | 90 | 0 | – | – | 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 |

[1] 10 used as starting value only for the "base case without puerulus". All other runs started at 3.26, the minimum for that run (sens1).

**Table 3: Fixed quantities in the MPD “base1” base case.**

| Quantity | Value | |
|---|---|---|
| LF: sex proportion dataset weight | 4.0 | |
| LF: male dataset weight | 0.98 | |
| LF: immature female dataset weight | 0.27 | |
| LF: mature female dataset weight | 0.87 | |
| CPUE dataset weight | 2.6 | |
| Tag dataset weight | 1.0 | |
| CR dataset weight | 4.0 | |
| Puerulus dataset weight | 0.3 | |
| **length-weight parameters** | **a** | **b** |
| male | 4.16E-06 | 2.9354 |
| female | 1.30E-05 | 2.5452 |
| Newton-Raphson iterations | 3 | |
| handling mortality | 0.1 | |
| minimum survival | 0.02 | |
| *sigmaR* | 0.4 | |
| *GStdMin* | 0.0001 | |
| *Sel_R* (male & female) | 200 | |

**Table 4: CRA 5 “base1” and “base2” base case MPD results and results from six additional sensitivity trials taken to MCMC level. Grey cells indicate quantities not estimated. Green cells indicate quantities which hit bounds. All model runs had the same relative data weights except for sens6 where the CPUE data weight was doubled relative to the value given in Table 3.**

| Quantity | base1 No density dependence with puerulus (lag=1) | base2 Density dependence with puerulus (lag=1) | sens1 No density dependence and no puerulus | sens2 Density dependence and no puerulus | sens3 Alternative recreational catch | sens4 Estimate right-hand limb | sens5 Growth prior CVs=30% | sens6 Double CPUE data weight |
|---|---|---|---|---|---|---|---|---|
| LFs-sdnr | 1.128 | 1.262 | 1.140 | 1.329 | 1.113 | 1.142 | 0.951 | 1.173 |
| LFs-MAR | 0.177 | 0.179 | 0.179 | 0.180 | 0.177 | 0.167 | 0.185 | 0.185 |
| LFs-LL | 4127.6 | 4153.6 | 4127.4 | 4150.0 | 4126.2 | 4119.1 | 4114.4 | 4145.8 |
| Tags-sdnr | 1.218 | 1.200 | 1.218 | 1.200 | 1.218 | 1.218 | 1.903 | 1.217 |
| Tags-MAR | 0.548 | 0.551 | 0.548 | 0.550 | 0.548 | 0.548 | 0.668 | 0.548 |
| Tags-LL | 7741.6 | 7627.3 | 7741.3 | 7631.6 | 7741.6 | 7742.4 | 7164.4 | 7739.4 |
| CPUE-sdnr | 1.009 | 1.166 | 0.982 | 1.150 | 1.007 | 0.970 | 0.991 | 1.611 |
| CPUE-MAR | 0.633 | 0.621 | 0.630 | 0.657 | 0.640 | 0.596 | 0.576 | 1.167 |
| CPUE-LL | -129.7 | -117.4 | -131.7 | -118.7 | -129.9 | -132.5 | -131.0 | -122.9 |
| CR-sdnr | 0.988 | 1.057 | 0.991 | 1.014 | 1.013 | 0.855 | 1.029 | 0.984 |
| CR-MAR | 0.436 | 0.398 | 0.438 | 0.300 | 0.466 | 0.512 | 0.505 | 0.424 |
| CR-LL | -23.12 | -22.34 | -23.08 | -22.82 | -22.84 | -24.46 | -22.65 | -23.15 |
| Sex prop-sdnr | 1.033 | 1.122 | 1.011 | 1.128 | 1.032 | 1.051 | 0.995 | 1.064 |
| Sex prop-MAR | 0.619 | 0.532 | 0.624 | 0.566 | 0.626 | 0.591 | 0.639 | 0.584 |
| Poo-sndr | 0.926 | 0.991 | – | – | 0.921 | 0.943 | 0.969 | 1.041 |
| Poo-MAR | 0.677 | 0.649 | – | – | 0.655 | 0.680 | 0.660 | 0.745 |
| Poo-LL | 0.113 | 2.231 | – | – | -0.057 | 0.674 | 1.608 | 4.055 |
| Prior LL | -56.37 | -46.98 | -54.46 | -45.03 | -55.88 | -58.56 | -56.22 | -49.07 |
| Function value | 11773.1 | 11718.9 | 11773.1 | 11717.5 | 11772.1 | 11759.7 | 11071.8 | 11808.3 |
| ln(*R0*) | 14.36 | 13.98 | 14.34 | 14.01 | 14.31 | 14.26 | 14.17 | 14.18 |
| *M* | 0.184 | 0.133 | 0.182 | 0.135 | 0.175 | 0.150 | 0.179 | 0.167 |
| ln(*qCPUE*) | -6.990 | -6.663 | -6.932 | -6.674 | -6.972 | -6.930 | -6.773 | -6.809 |
| ln(*qCR*) | -3.385 | -2.974 | -3.382 | -3.089 | -3.435 | -2.946 | -3.253 | -3.232 |
| ln(*qPoo*) | -14.05 | -13.66 | -6* | -6* | -14.01 | -13.92 | -13.84 | -13.85 |
| *CPUEpow* | 1* | 1* | 1* | 1* | 1* | 1* | 1* | 1* |
| *mat50* | 46.45 | 48.20 | 46.40 | 48.09 | 46.47 | 46.30 | 46.70 | 46.52 |

| Quantity | base1 No density dependence with puerulus (lag=1) | base2 Density dependence with puerulus (lag=1) | sens1 No density dependence and no puerulus | sens2 Density dependence and no puerulus | sens3 Alternative recreational catch | sens4 Estimate right-hand limb | sens5 Growth prior CVs=30% | sens6 Double CPUE data weight |
|---|---|---|---|---|---|---|---|---|
| *mat95add* | 3.26* | 3.26* | 3.258 | 3.26* | 3.259 | 3.186 | 3.069 | 3.443 |
| *galphaM* | 3.320 | 5.339 | 3.328 | 5.311 | 3.321 | 3.334 | 3.371 | 3.346 |
| *gbetaM* | 2.463 | 4.379 | 2.469 | 4.378 | 2.465 | 2.484 | 2.865 | 2.440 |
| *gdiffM* | 0.742 | 0.820 | 0.742 | 0.824 | 0.742 | 0.745 | 0.850 | 0.729 |
| *GshapeM* | 5.402 | 5.268 | 5.436 | 5.263 | 5.403 | 5.450 | 6.559 | 5.498 |
| *GCVM* | 0.567 | 0.560 | 0.566 | 0.560 | 0.567 | 0.566 | 0.645 | 0.565 |
| *galphaF* | 3.644 | 5.230 | 3.652 | 5.225 | 3.645 | 3.716 | 3.640 | 3.587 |
| *gbetaF* | 1.484 | 2.690 | 1.484 | 2.682 | 1.483 | 1.412 | 1.690 | 1.518 |
| *gdiffF* | 0.407 | 0.514 | 0.406 | 0.513 | 0.407 | 0.380 | 0.464 | 0.423 |
| *GshapeF* | 5.303 | 4.504 | 5.323 | 4.526 | 5.303 | 5.302 | 6.072 | 5.292 |
| *GCVM* | 0.800 | 0.794 | 0.800 | 0.794 | 0.800 | 0.801 | 0.848 | 0.801 |
| *GstdObs* | 1.251 | 1.240 | 1.251 | 1.240 | 1.251 | 1.252 | 0.385 | 1.251 |
| *GrowthDD* | 0* | 0.624 | 0* | 0.619 | 0* | 0* | 0* | 0* |
| *vulnest1* | 0.564 | 0.561 | 0.560 | 0.538 | 0.562 | 0.560 | 0.564 | 0.557 |
| *vulnest2* | 0.525 | 0.530 | 0.505 | 0.581 | 0.523 | 0.392 | 0.374 | 0.565 |
| *vulnest3* | 0.848 | 0.862 | 0.822 | 0.895 | 0.837 | 0.624 | 0.774 | 0.879 |
| *vulnest4* | 0.830 | 0.823 | 0.807 | 0.855 | 0.822 | 0.635 | 0.767 | 0.849 |
| *VL1M* | 11.63 | 22.59 | 11.18 | 7.917 | 11.80 | 8.692 | 14.60 | 11.49 |
| *VR1M* | 200* | 200* | 200* | 200* | 200* | 12.88 | 200* | 200* |
| *SelectMax1M* | 60.94 | 74.62 | 60.10 | 53.21 | 61.13 | 53.18 | 64.71 | 61.78 |
| *VL1F* | 26.47 | 24.68 | 26.75 | 26.74 | 26.68 | 6.61 | 27.45 | 25.54 |
| *VR1F* | 200* | 200* | 200* | 200* | 200* | 17.27 | 200* | 200* |
| *SelectMax1F* | 90 | 90 | 90 | 90 | 90 | 51.38 | 90 | 90 |
| *VL2M* | 4.505 | 4.631 | 4.525 | 4.557 | 4.520 | 4.480 | 4.713 | 4.606 |
| *VR2M* | 200* | 200* | 200* | 200* | 200* | 16.71 | 200* | 200* |
| *SelectMax2M* | 55.12 | 55.67 | 55.22 | 55.47 | 55.14 | 55.08 | 55.33 | 55.40 |
| *VL2F* | 10.30 | 8.49 | 10.32 | 8.56 | 10.33 | 9.89 | 11.08 | 10.78 |
| *VR2F* | 200* | 200* | 200* | 200* | 200* | 250 | 200* | 200* |
| *SelectMax2F* | 69.11 | 67.14 | 69.12 | 67.41 | 69.14 | 66.91 | 69.27 | 70.49 |
| *Bcurr/Bref* | 2.43 | 1.93 | 2.53 | 2.54 | 2.40 | 2.14 | 2.19 | 2.25 |
| *Bref* | 757.7 | 709.5 | 708.7 | 545.7 | 746.0 | 766.2 | 671.1 | 665.8 |
| *Bmsy* | 499.5 | 479.1 | 499.0 | 490.5 | 514.6 | 560.5 | 469.3 | 489.5 |
| *Bcurr/Bmsy* | 3.69 | 2.86 | 3.59 | 2.83 | 3.48 | 2.92 | 3.14 | 3.07 |
| *MSY* | 541.7 | 576.1 | 542.4 | 583.5 | 546.7 | 588.8 | 512.3 | 493.8 |
| *Fmult* | 5.63 | 4.85 | 5.36 | 4.86 | 4.66 | 4.87 | 4.56 | 4.18 |
| Male yrs to MLS | 4.0 | 4.5 | 4.0 | 4.5 | 4.0 | 4.0 | 3.5 | 4.0 |
| Female yrs to MLS | 5.0 | 6.5 | 5.0 | 6.5 | 5.0 | 5.0 | 4.5 | 5.0 |

**Table 5: Twelve additional CRA 5 MPD sensitivity trials which were not taken to MCMC level. Grey cells indicate quantities not estimated. Grey cells indicate quantities not estimated. Green cells indicate quantities which hit bounds. All model runs had the same relative data weights as given in Table 3 and none of these runs were made using the puerulus data series.**

| Quantity | sens7 N-R 5 | sens8 Half illegal catch | sens9 Double illegal catch | sens10 Only Rel=0 | sens11 Only Rel≠0 | sens12 CPUE pow | sens13 No Trunc | sens14 LF: remove 4 records | sens15 Drop CR data | sens16 Drop CPUE data | sens17 Drop LF data | sens18 Drop tag data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LFs-sdnr | 1.140 | 1.124 | 1.174 | 1.175 | 1.114 | 1.029 | 2.646 | 0.708 | 1.111 | 0.926 | 8.3E+10 | 1.121 |
| LFs-MAR | 0.179 | 0.178 | 0.181 | 0.178 | 0.171 | 0.166 | 0.245 | 0.186 | 0.179 | 0.157 | 0.579 | 0.177 |
| LFs-LL | 4127.4 | 4127.2 | 4127.9 | 4125.4 | 4122.8 | 4110.9 | 11145.9 | 3855.67 | 4127.7 | 4096.6 | 6138.9 | 4110.7 |
| Tags-sdnr | 1.218 | 1.218 | 1.218 | 1.131 | 1.210 | 1.220 | 1.212 | 1.218 | 1.218 | 1.220 | 1.230 | 0.930 |
| Tags-MAR | 0.548 | 0.549 | 0.548 | 0.575 | 0.343 | 0.549 | 0.550 | 0.549 | 0.549 | 0.548 | 0.551 | 0.508 |
| Tags-LL | 7741.3 | 7741.0 | 7741.9 | 6374.1 | 1437.9 | 7742.3 | 7748.2 | 7740.8 | 7741.2 | 7742.4 | 7731.4 | 8811.1 |
| CPUE-sdnr | 0.982 | 0.977 | 0.994 | 0.983 | 1.113 | 0.757 | 1.233 | 0.976 | 0.977 | 19.017 | 0.814 | 0.922 |
| CPUE-MAR | 0.630 | 0.622 | 0.575 | 0.649 | 0.724 | 0.517 | 0.801 | 0.614 | 0.567 | 63.741 | 0.588 | 0.638 |
| CPUE-LL | -131.6 | -132.0 | -130.8 | -131.6 | -121.7 | -145.7 | -111.6 | -132.1 | -132.0 | 218132 | -142.5 | -135.8 |
| CR-sdnr | 0.992 | 0.993 | 0.984 | 0.972 | 1.096 | 0.985 | 1.000 | 0.976 | 1.776 | 1.028 | 0.769 | 0.724 |
| CR-MAR | 0.439 | 0.438 | 0.433 | 0.406 | 0.574 | 0.423 | 0.457 | 0.419 | 3.12 | 0.493 | 0.218 | 0.229 |
| CR-LL | -23.07 | -23.06 | -23.16 | -23.29 | -21.87 | -23.15 | -22.98 | -23.24 | 73.93 | -22.67 | -25.23 | -25.60 |
| Sex prop-sdnr | 1.011 | 1.014 | 1.006 | 1.010 | 1.010 | 1.029 | 1.396 | 1.034 | 1.015 | 1.021 | 2.454 | 0.963 |
| Sex prop-MAR | 0.624 | 0.626 | 0.627 | 0.626 | 0.643 | 0.648 | 0.795 | 0.646 | 0.617 | 0.612 | 1.443 | 0.635 |
| Prior LL | -54.46 | -53.00 | -56.21 | -54.64 | -52.09 | -57.23 | -52.35 | -54.39 | -56.50 | -62.05 | -50.51 | -54.93 |
| Function value | 11773.2 | 11773.8 | 11773.2 | 10314.5 | 5396.88 | 11740.2 | 18835.5 | 11499.7 | 11794.2 | 11867.7 | 7621.5 | 3878.8 |
| ln(*R0*) | 14.35 | 14.28 | 14.47 | 14.34 | 14.44 | 14.33 | 14.33 | 14.38 | 14.25 | 14.16 | 14.55 | 14.25 |
| *M* | 0.182 | 0.182 | 0.183 | 0.182 | 0.170 | 0.180 | 0.187 | 0.187 | 0.167 | 0.158 | 0.216 | 0.234 |
| ln(*qCPUE*) | -6.935 | -6.891 | -7.029 | -6.794 | -7.211 | -15.281 | -6.880 | -6.938 | -6.864 | -12.500 | -6.549 | -6.289 |
| ln(*qCR*) | -3.384 | -3.330 | -3.485 | -3.277 | -3.742 | -3.383 | -3.397 | -3.358 | -3.020 | -3.166 | -2.674 | -2.630 |
| *CPUEpow* | 1* | 1* | 1* | 1* | 1* | 2.250 | 1* | 1* | 1* | 1* | 1* | 1* |
| *mat50* | 46.40 | 46.39 | 46.39 | 46.44 | 46.32 | 46.39 | 46.05 | 46.55 | 46.42 | 46.52 | 48.37 | 45.62 |
| *mat95add* | 3.258 | 3.272 | 3.242 | 3.248 | 3.26* | 3.209 | 3.703 | 2.741 | 3.244 | 3.178 | 3.26* | 3.26* |
| *galphaM* | 3.328 | 3.330 | 3.323 | 3.400 | 2.740 | 3.325 | 3.319 | 3.328 | 3.329 | 3.326 | 3.349 | 4.689 |
| *gbetaM* | 2.469 | 2.472 | 2.461 | 2.845 | 1.925 | 2.457 | 2.618 | 2.468 | 2.478 | 2.476 | 2.376 | 3.479* |
| *gdiffM* | 0.742 | 0.742 | 0.740 | 0.837 | 0.702 | 0.739 | 0.789 | 0.741 | 0.745 | 0.744 | 0.710 | 0.742* |
| *GshapeM* | 5.436 | 5.449 | 5.409 | 5.259 | 5.764 | 5.360 | 5.717 | 5.423 | 5.466 | 5.472 | 5.434 | 4.565 |
| *GCVM* | 0.566 | 0.566 | 0.566 | 0.564 | 0.587 | 0.566 | 0.567 | 0.566 | 0.566 | 0.566 | 0.565 | 0.590 |
| *galphaF* | 3.652 | 3.646 | 3.663 | 3.617 | 3.933 | 3.680 | 3.887 | 3.633 | 3.653 | 3.703 | 3.159 | 4.722 |
| *gbetaF* | 1.484 | 1.483 | 1.487 | 1.518 | 1.441 | 1.429 | 1.498 | 1.484 | 1.479 | 1.415 | 1.450 | 2.361* |
| *gdiffF* | 0.406 | 0.407 | 0.406 | 0.420 | 0.366 | 0.388 | 0.385 | 0.408 | 0.405 | 0.382 | 0.459 | 0.5* |
| *GshapeF* | 5.322 | 5.317 | 5.332 | 5.370 | 4.933 | 5.361 | 6.004 | 5.265 | 5.333 | 5.355 | 4.207 | 4.505 |
| *GCVM* | 0.800 | 0.800 | 0.800 | 0.802 | 0.820 | 0.801 | 0.807 | 0.800 | 0.801 | 0.801 | 0.794 | 0.821 |
| *GstdObs* | 1.251 | 1.251 | 1.251 | 1.371 | 1.341 | 1.252 | 1.251 | 1.251 | 1.251 | 1.252 | 1.253 | 1.480 |
| *GrowthDD* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* | 0* |
| *vulnest1* | 0.560 | 0.558 | 0.564 | 0.558 | 0.507 | 0.509 | 0.554 | 0.562 | 0.556 | 0.013 | 0.850 | 0.565 |
| *vulnest2* | 0.506 | 0.506 | 0.513 | 0.473 | 0.417 | 0.338 | 0.221 | 0.498 | 0.474 | 0.333 | 1.000 | 0.294 |
| *vulnest3* | 0.823 | 0.816 | 0.851 | 0.756 | 0.635 | 0.507 | 0.560 | 0.853 | 0.758 | 0.013 | 0.665 | 0.672 |
| *vulnest4* | 0.808 | 0.802 | 0.830 | 0.746 | 0.684 | 0.603 | 0.566 | 0.816 | 0.748 | 0.567 | 0.133 | 0.677 |
| *VL1M* | 11.189 | 10.758 | 11.369 | 11.011 | 8.291 | 7.521 | 9.395 | 10.983 | 11.686 | 7.184 | 1.000 | 12.107 |
| *VR1M* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* |
| *SelectMax1M* | 60.12 | 58.97 | 61.03 | 60.86 | 53.87 | 51.84 | 55.85 | 59.88 | 60.90 | 49.93 | 53.06 | 62.55 |
| *VL1F* | 26.74 | 27.36 | 25.93 | 26.31 | 9.04 | 25.01 | 7.83 | 26.38 | 27.24 | 9.11 | 50.00 | 25.72 |
| *VR1F* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* |
| *SelectMax1F* | 90 | 90 | 90 | 90 | 55.54 | 78.39 | 52.762 | 90 | 90 | 54.32 | 61.93 | 88.66 |
| *VL2M* | 4.525 | 4.537 | 4.497 | 4.492 | 4.517 | 4.627 | 4.376 | 4.082 | 4.552 | 4.667 | 1.22 | 4.575 |
| *VR2M* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* |
| *SelectMax2M* | 55.22 | 55.25 | 55.15 | 55.37 | 55.15 | 55.54 | 55.11 | 54.84 | 55.24 | 55.49 | 53.00 | 55.46 |
| *VL2F* | 10.32 | 10.31 | 10.36 | 10.38 | 9.74 | 9.82 | 10.80 | 10.01 | 10.22 | 9.79 | 1.00 | 10.05 |
| *VR2F* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* | 200* |
| *SelectMax2F* | 69.12 | 69.11 | 69.25 | 69.41 | 66.43 | 66.72 | 67.60 | 68.94 | 68.59 | 66.38 | 51.19 | 67.59 |
| *Bcurr/Bref* | 2.53 | 2.55 | 2.53 | 2.46 | 2.79 | 1.55 | 2.79 | 2.54 | 2.50 | 1.30 | 2.39 | 2.30 |
| *Bref* | 710.8 | 670.1 | 790.2 | 641.2 | 833.4 | 792.7 | 620.0 | 712.0 | 676.2 | 785.8 | 488.7 | 450.4 |
| *Bmsy* | 499.3 | 471.2 | 553.8 | 469.6 | 494.2 | 454.7 | 417.5 | 496.7 | 511.5 | 464.3 | 440.7 | 397.4 |
| *Bcurr/Bmsy* | 3.60 | 3.63 | 3.61 | 3.36 | 4.71 | 2.71 | 4.15 | 3.64 | 3.31 | 2.21 | 2.65 | 2.61 |
| *MSY* | 543.2 | 519.3 | 592.6 | 527.6 | 583.2 | 532.7 | 549.4 | 548.7 | 532.8 | 503.5 | 519.8 | 514.0 |
| *Fmult* | 5.38 | 5.21 | 5.85 | 4.87 | 7.38 | 3.96 | 6.32 | 5.55 | 4.72 | 3.01 | 4.12 | 3.85 |
| Male yrs to MLS | 4.0 | 4.0 | 4.0 | 4.0 | 4.5 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.0 |
| Female yrs to MLS | 5.0 | 5.0 | 5.0 | 5.0 | 4.5 | 5.0 | 4.5 | 5.0 | 5.0 | 5.0 | 6.5 | 4.0 |

**Table 6: Summaries of estimated parameter posteriors from the two candidate base case MCMC runs. Grey cells indicate fixed parameter values.**

| | | | base1 (no density dependence) | | | | | | base2 (with density dependence) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Epoch** | **Sex** | **Parameter** | **min** | **0.05** | **median** | **0.95** | **max** | **MPD** | **min** | **0.05** | **median** | **0.95** | **max** | **MPD** |
| | | function value | 11804.1 | 11811.1 | 11821.3 | 11833.5 | 11849 | 11773.1 | 11747.9 | 11756.05 | 11766.4 | 11778.65 | 11792.9 | 11718.9 |
| | | ln(*R0*) | 13.98 | 14.13 | 14.35 | 14.59 | 14.86 | 14.36 | 13.67 | 13.78 | 13.94 | 14.13 | 14.25 | 13.98 |
| | | *M* | 0.140 | 0.159 | 0.184 | 0.214 | 0.244 | 0.184 | 0.100 | 0.113 | 0.132 | 0.155 | 0.172 | 0.133 |
| | | ln(*qCPUE*) | -7.44 | -7.30 | -7.11 | -6.90 | -6.73 | -6.99 | -7.00 | -6.87 | -6.72 | -6.56 | -6.45 | -6.66 |
| | | ln(*qPoo*) | -14.55 | -14.35 | -14.05 | -13.77 | -13.51 | -14.05 | -14.10 | -13.86 | -13.62 | -13.39 | -13.02 | -13.66 |
| | | *mat50* | 41.98 | 44.44 | 46.26 | 47.69 | 48.75 | 46.45 | 44.21 | 46.74 | 48.12 | 49.22 | 50.30 | 48.20 |
| | | *mat95add* | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 |
| | male | *Galpha* | 3.189 | 3.247 | 3.316 | 3.384 | 3.436 | 3.320 | 4.812 | 5.029 | 5.309 | 5.615 | 5.850 | 5.339 |
| | male | *Gbeta* | 2.101 | 2.241 | 2.439 | 2.651 | 2.853 | 2.463 | 3.554 | 3.943 | 4.336 | 4.745 | 5.105 | 4.379 |
| | male | *Gdiff* | 0.627 | 0.671 | 0.737 | 0.804 | 0.868 | 0.742 | 0.684 | 0.749 | 0.818 | 0.886 | 0.963 | 0.820 |
| | male | *Gshape* | 4.416 | 4.972 | 5.452 | 6.007 | 6.482 | 5.402 | 4.240 | 4.768 | 5.352 | 5.882 | 6.440 | 5.268 |
| | male | *GCV* | 0.546 | 0.556 | 0.567 | 0.579 | 0.593 | 0.567 | 0.539 | 0.549 | 0.561 | 0.573 | 0.583 | 0.560 |
| | female | *Galpha* | 3.364 | 3.515 | 3.648 | 3.790 | 3.952 | 3.644 | 4.774 | 4.952 | 5.210 | 5.457 | 5.725 | 5.230 |
| | female | *Gbeta* | 1.306 | 1.386 | 1.479 | 1.574 | 1.664 | 1.484 | 2.172 | 2.444 | 2.668 | 2.908 | 3.122 | 2.690 |
| | female | *Gdiff* | 0.346 | 0.370 | 0.405 | 0.443 | 0.474 | 0.407 | 0.425 | 0.466 | 0.513 | 0.557 | 0.600 | 0.514 |
| | female | *Gshape* | 4.717 | 5.021 | 5.319 | 5.611 | 5.955 | 5.303 | 3.870 | 4.162 | 4.538 | 4.874 | 5.272 | 4.504 |
| | female | *GCV* | 0.758 | 0.781 | 0.800 | 0.820 | 0.844 | 0.800 | 0.748 | 0.776 | 0.795 | 0.815 | 0.837 | 0.794 |
| | | *GStdObs* | 1.212 | 1.228 | 1.251 | 1.275 | 1.306 | 1.251 | 1.194 | 1.217 | 1.239 | 1.263 | 1.286 | 1.240 |
| | | *GDD* | 0 | 0 | 0 | 0 | 0 | 0 | 0.425 | 0.521 | 0.609 | 0.682 | 0.744 | 0.624 |
| | | *vulnest1* | 0.500 | 0.533 | 0.569 | 0.606 | 0.651 | 0.564 | 0.492 | 0.529 | 0.565 | 0.602 | 0.628 | 0.561 |
| | | *vulnest2* | 0.187 | 0.333 | 0.564 | 0.874 | 0.989 | 0.525 | 0.226 | 0.335 | 0.564 | 0.863 | 0.998 | 0.530 |
| | | *vulnest3* | 0.614 | 0.736 | 0.886 | 0.988 | 1.000 | 0.848 | 0.637 | 0.731 | 0.890 | 0.986 | 1.000 | 0.862 |
| | | *vulnest4* | 0.538 | 0.703 | 0.861 | 0.977 | 1.000 | 0.830 | 0.537 | 0.690 | 0.842 | 0.972 | 0.999 | 0.823 |
| 1 | male | *Sel_VL* | 3.281 | 7.077 | 13.75 | 24.72 | 44.94 | 11.63 | 6.78 | 17.61 | 29.19 | 38.55 | 46.79 | 22.59 |
| 1 | male | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| 1 | male | *Sel_max* | 45.83 | 53.08 | 62.89 | 74.20 | 86.57 | 60.94 | 52.17 | 67.42 | 82.40 | 89.36 | 89.96 | 74.62 |
| 1 | female | *Sel_VL* | 22.04 | 24.20 | 27.15 | 31.10 | 42.62 | 26.47 | 20.71 | 22.36 | 24.54 | 27.64 | 31.07 | 24.68 |
| 1 | female | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| 1 | female | *Sel_max* | 89.78 | 89.79 | 89.84 | 89.94 | 89.96 | 90.00 | 89.94 | 89.94 | 89.97 | 89.99 | 90.00 | 90.00 |
| 2 | male | *Sel_VL* | 3.643 | 3.965 | 4.567 | 5.234 | 6.094 | 4.505 | 3.665 | 4.107 | 4.648 | 5.350 | 6.180 | 4.631 |
| 2 | male | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| 2 | male | *Sel_max* | 53.48 | 54.19 | 55.07 | 56.08 | 57.25 | 55.12 | 53.93 | 54.70 | 55.61 | 56.69 | 58.19 | 55.67 |
| 2 | female | *Sel_VL* | 8.292 | 9.301 | 10.290 | 11.574 | 13.107 | 10.301 | 7.303 | 7.755 | 8.517 | 9.378 | 10.05 | 8.489 |
| 2 | female | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| 2 | female | *Sel_max* | 65.72 | 66.93 | 68.96 | 71.24 | 73.36 | 69.11 | 64.48 | 65.56 | 67.07 | 68.84 | 70.79 | 67.14 |

**Table 7: Summaries of indicator posteriors from the two candidate base case MCMC runs.**

| **Quantity** | **base1 (no density dependence)** | | | **base2 (with density dependence)** | | |
|---|---|---|---|---|---|---|
| **CRA 5** | **5%** | **median** | **95%** | **5%** | **median** | **95%** |
| *Bmin* | 365.2 | 438.8 | 532.2 | 279.9 | 323.9 | 373.7 |
| *Bcurr* | 1679.3 | 2070.0 | 2566.5 | 1204.3 | 1428.8 | 1674.4 |
| *Bref* | 719.6 | 871.0 | 1051.8 | 649.3 | 788.6 | 923.0 |
| *Bproj* | 1478.1 | 1935.6 | 2491.6 | 1074.8 | 1290.3 | 1531.2 |
| *Bmsy* | 443.0 | 505.2 | 576.7 | 437.6 | 483.6 | 537.7 |
| *MSY* | 475.1 | 536.6 | 608.2 | 513.9 | 560.1 | 610.7 |
| *Fmult* | 4.565 | 6.180 | 8.130 | 3.920 | 4.780 | 5.910 |
| *SSBcurr* | 2572.5 | 2926.2 | 3425.7 | 2045.4 | 2250.3 | 2465.9 |
| *SSBproj* | 2211.9 | 2669.6 | 3224.0 | 1798.7 | 2018.0 | 2249.6 |
| *SSBmsy* | 1335.9 | 1500.4 | 1671.3 | 994.9 | 1094.2 | 1203.8 |
| *CPUEcurrent* | 1.424 | 1.542 | 1.671 | 1.431 | 1.544 | 1.656 |
| *CPUEproj* | 1.131 | 1.401 | 1.740 | 1.190 | 1.358 | 1.519 |
| *CPUEmsy* | 0.209 | 0.267 | 0.334 | 0.302 | 0.362 | 0.426 |
| *Bcurr/Bmin* | 4.098 | 4.742 | 5.517 | 3.945 | 4.404 | 4.868 |
| *Bcurr/Bref* | 1.980 | 2.402 | 2.812 | 1.522 | 1.822 | 2.266 |
| *Bcurr/Bmsy* | 3.377 | 4.107 | 5.061 | 2.571 | 2.943 | 3.437 |
| *Bproj/Bcurr* | 0.815 | 0.923 | 1.078 | 0.829 | 0.903 | 0.981 |
| *Bproj/Bref* | 1.736 | 2.217 | 2.798 | 1.349 | 1.653 | 2.057 |
| *Bproj/Bmsy* | 2.991 | 3.836 | 4.854 | 2.278 | 2.666 | 3.107 |
| *SSBcurr/SSB0* | 0.676 | 0.781 | 0.906 | 0.913 | 0.970 | 1.028 |
| *SSBproj/SSB0* | 0.594 | 0.707 | 0.853 | 0.796 | 0.871 | 0.945 |
| *SSBcurr/SSBmsy* | 1.723 | 1.957 | 2.266 | 1.881 | 2.047 | 2.255 |
| *SSBproj/SSBmsy* | 1.499 | 1.785 | 2.129 | 1.671 | 1.842 | 2.030 |
| *SSBproj/SSBcurr* | 0.811 | 0.905 | 1.030 | 0.845 | 0.897 | 0.949 |
| *USLcurrent* | 0.092 | 0.113 | 0.139 | 0.139 | 0.164 | 0.192 |
| *USLproj* | 0.096 | 0.123 | 0.161 | 0.155 | 0.184 | 0.221 |
| *USLproj/USLcurrent* | 0.918 | 1.100 | 1.288 | 1.027 | 1.125 | 1.244 |
| *Btotcurrent* | 5922 | 6987 | 8451 | 4619 | 5194 | 5834 |
| *Btotcurrent/Btot0* | 0.555 | 0.673 | 0.810 | 0.610 | 0.668 | 0.734 |
| *Ntotcurrent* | 13 680 700 | 16 854 400 | 21 293 200 | 10 950 250 | 12 830 400 | 15 069 450 |
| *Ntotcurrent/Ntot0* | 0.697 | 0.832 | 1.017 | 0.595 | 0.698 | 0.817 |

**Table 8: Indicator posterior probabilities from the two candidate base case MCMC runs.**

| **Probability** | **base1 (no DD)** | **base2 (with DD)** |
|---|---|---|
| P(*Bcurr>Bmin*) | 1 | 1 |
| P(*Bcurr>Bref*) | 1 | 1 |
| P(*Bcurr>Bmsy*) | 1 | 1 |
| P(*Bproj>Bmin*) | 1 | 1 |
| P(*Bproj>Bref*) | 1 | 0.999 |
| P(*Bproj>Bmsy*) | 1 | 1 |
| P(*Bproj>Bcurr*) | 0.188 | 0.026 |
| P(*SSBcurr>SSBmsy*) | 1 | 1 |
| P(*SSBproj>SSBmsy*) | 1 | 1 |
| P(*USLproj>USLcurr*) | 0.822 | 0.985 |
| P(*SSBcurr<0.2SSB0*) | 0 | 0 |
| P(*SSBproj<0.2SSB0*) | 0 | 0 |
| P(*SSBcurr<0.1SSB0*) | 0 | 0 |
| P(*SSBproj<0.1SSB0*) | 0 | 0 |

**Table 9: Description of base and sensitivity runs made for the CRA 5 stock assessment. All runs include puerulus with lag year=1 unless indicated otherwise. DD: density dependence; R-H: right-hand limb of selectivity function. Mat95Add: second parameter of the logistic maturation rate function.**

| Run | Description | Fix Mat95Add? | Length of MCMC chain (-burn in) | MCMC convergence |
|---|---|---|---|---|
| **base1: no DD** | no DD estimate | Yes | 4 150 000–1 150 000 | good: see Figure 31A, Figure 32A, Figure 47A |
| **base2: with DD** | estimate DD | Yes | 3 150  000–150 000 | good: see Figure 31B, Figure 32B, Figure 47B |
| **sens1: no DD and no puerulus** | do not include puerulus data series; no DD estimate | Yes | 3 150 000–150 000 | acceptable: see Figure 44A, Figure 48A, Figure 51A |
| **sens2: with DD and no puerulus** | estimate DD without puerulus data series | Yes | 6 150 000–3 150 000 | poor: see Figure 44B, Figure 48B, Figure 51B |
| **sens3: alternative recreational catch** | fit power function to 2011 recreational catch estimate of 140 t | Yes | 3 150  000–150 000 | acceptable: see Figure 45A, Figure 49A, Figure 52A |
| **sens4: estimate R-H selectivity** | alternative hypothesis to account for lack of large lobsters | Yes | 3 150  000–150 000 | poor: see Figure 45B, Figure 49B, Figure 52B |
| **sens5: growth prior CV=30%** | widen CVs on informed priors estimating *Gshape*, *GCV* and *GStdObs* | No | 3 150  000–150 000 | poor: see Figure 46A, Figure 50A, Figure 53A |
| **sens6: double weight to CPUE series** | attempt to improve fit to CPUE data series | Yes | 3 150  000–150 000 | poor: see Figure 46B, Figure 50B, Figure 53B |

**Table 10: Medians of estimated parameter posteriors from the two candidate base case MCMC runs and all sensitivity runs. All runs include puerulus with one year lag unless indicated otherwise. Grey cells indicate fixed parameter values. DD: density dependence; R-H: right-hand limb of selectivity function.**

| epoch | sex | parameter | base1 no DD | base2 with DD | sens1 no DD and no puerulus | sens2 with DD and no puerulus | sens3 alternative recrea-tional catch | sens4 estimate R-H selectivity | sens5 growth prior CV=30% | sens6 double weight to CPUE series |
|---|---|---|---|---|---|---|---|---|---|---|
| | | function value | 11821.3 | 11766.4 | 11818.1 | 11763.35 | 11820.4 | 11811.5 | 11121.9 | 11852.8 |
| | | ln(*R0*) | 14.35 | 13.94 | 14.38 | 13.95 | 14.31 | 14.33 | 14.15 | 14.19 |
| | | *M* | 0.184 | 0.132 | 0.188 | 0.133 | 0.177 | 0.162 | 0.179 | 0.171 |
| | | ln(*qCPUE*) | -7.11 | -6.72 | -7.09 | -6.69 | -7.09 | -7.14 | -6.89 | -6.93 |
| | | ln(*qPoo*) | -14.05 | -13.62 | -6.00 | -6.00 | -14.01 | -14.02 | -13.82 | -13.87 |
| | | *mat50* | 46.26 | 48.12 | 46.16 | 48.03 | 46.22 | 45.91 | 46.17 | 46.32 |
| | | *mat95add* | 3.26 | 3.26 | 3.26 | 3.26 | 3.26 | 3.19 | 4.483 | 3.44 |
| | male | *Galpha* | 3.316 | 5.309 | 3.319 | 5.363 | 3.317 | 3.326 | 3.359 | 3.335 |
| | male | *Gbeta* | 2.439 | 4.336 | 2.448 | 4.380 | 2.439 | 2.470 | 2.880 | 2.411 |
| | male | *Gdiff* | 0.737 | 0.818 | 0.739 | 0.816 | 0.736 | 0.742 | 0.858 | 0.723 |
| | male | *Gshape* | 5.452 | 5.352 | 5.479 | 5.415 | 5.474 | 5.568 | 6.804 | 5.570 |
| | male | *GCV* | 0.567 | 0.561 | 0.568 | 0.560 | 0.567 | 0.567 | 0.647 | 0.566 |
| | female | *Galpha* | 3.648 | 5.210 | 3.657 | 5.256 | 3.653 | 3.707 | 3.642 | 3.602 |
| | female | *Gbeta* | 1.479 | 2.668 | 1.483 | 2.686 | 1.476 | 1.417 | 1.691 | 1.508 |
| | female | *Gdiff* | 0.405 | 0.513 | 0.406 | 0.511 | 0.404 | 0.383 | 0.464 | 0.419 |
| | female | *Gshape* | 5.319 | 4.538 | 5.329 | 4.557 | 5.319 | 5.315 | 6.101 | 5.286 |
| | female | *GCV* | 0.800 | 0.795 | 0.800 | 0.795 | 0.800 | 0.801 | 0.849 | 0.800 |
| | | *GStdObs* | 1.251 | 1.239 | 1.251 | 1.240 | 1.252 | 1.252 | 0.386 | 1.252 |
| | | *GDD* | 0 | 0.609 | 0 | 0.616 | 0 | 0 | 0 | 0 |
| | | *vulnest1* | 0.569 | 0.565 | 0.566 | 0.564 | 0.567 | 0.573 | 0.572 | 0.563 |
| | | *vulnest2* | 0.564 | 0.564 | 0.577 | 0.556 | 0.570 | 0.475 | 0.424 | 0.598 |
| | | *vulnest3* | 0.886 | 0.890 | 0.894 | 0.885 | 0.886 | 0.725 | 0.846 | 0.928 |
| | | *vulnest4* | 0.861 | 0.842 | 0.863 | 0.842 | 0.859 | 0.723 | 0.823 | 0.879 |
| 1 | male | *Sel_VL* | 13.75 | 29.19 | 12.67 | 28.40 | 14.16 | 8.52 | 18.64 | 12.81 |
| 1 | male | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 19.05 | 200 | 200 |
| 1 | male | *Sel_max* | 62.89 | 82.40 | 61.13 | 80.72 | 63.27 | 50.90 | 68.15 | 63.20 |
| 1 | female | *Sel_VL* | 27.15 | 24.54 | 27.21 | 24.83 | 27.31 | 6.25 | 28.03 | 26.05 |
| 1 | female | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 18.64 | 200 | 200 |
| 1 | female | *Sel_max* | 89.84 | 89.97 | 89.95 | 89.99 | 89.91 | 50.11 | 89.97 | 89.97 |
| 2 | male | *Sel_VL* | 4.567 | 4.648 | 4.557 | 4.692 | 4.576 | 4.498 | 4.772 | 4.621 |
| 2 | male | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 18.83 | 200 | 200 |
| 2 | male | *Sel_max* | 55.07 | 55.61 | 55.13 | 55.66 | 55.04 | 54.95 | 55.18 | 55.27 |
| 2 | female | *Sel_VL* | 10.29 | 8.52 | 10.30 | 8.51 | 10.34 | 10.05 | 11.18 | 10.62 |
| 2 | female | *Sel_VR* | 200 | 200 | 200 | 200 | 200 | 142.6 | 200 | 200 |
| 2 | female | *Sel_max* | 68.96 | 67.07 | 69.06 | 67.09 | 68.98 | 67.45 | 69.35 | 69.94 |

**Table 11: Median indicator estimates from the two candidate base case MCMC runs and all sensitivity runs. All runs include puerulus with one year lag unless indicated otherwise. DD: density dependence; R-H: right-hand limb of selectivity function.**

| Indicator | base1<br>no DD | base2<br>with DD | sens1<br>no DD and no puerulus | sens2<br>with DD and no puerulus | sens3<br>alternative recrea-tional catch | sens4<br>estimate R-H selectivity | sens5<br>growth prior CV=30% | sens6<br>double weight to CPUE series |
|---|---|---|---|---|---|---|---|---|
| *Bmin* | 438.8 | 323.9 | 425.9 | 319.1 | 431.6 | 450.3 | 370.3 | 378.0 |
| *Bcurr* | 2070.0 | 1428.8 | 2086.2 | 1373.1 | 2019.0 | 2020.2 | 1650.7 | 1686.0 |
| *Bref* | 871.0 | 788.6 | 841.2 | 744.7 | 857.5 | 903.6 | 760.2 | 755.2 |
| *Bproj* | 1935.6 | 1290.3 | 2250.7 | 1257.9 | 1844.6 | 1869.0 | 1548.4 | 1594.4 |
| *Bmsy* | 505.2 | 483.6 | 503.8 | 481.9 | 517.1 | 568.3 | 474.6 | 498.1 |
| *MSY* | 536.6 | 560.1 | 545.3 | 564.5 | 540.2 | 591.6 | 504.2 | 494.5 |
| *Fmult* | 6.18 | 4.78 | 6.30 | 4.72 | 5.17 | 6.01 | 4.93 | 4.66 |
| *SSBcurr* | 2926.2 | 2250.3 | 3022.4 | 2195.8 | 2867.6 | 3556.2 | 2406.1 | 2541.6 |
| *SSBproj* | 2669.6 | 2018.0 | 3139.5 | 2016.8 | 2574.5 | 3313.0 | 2218.0 | 2335.5 |
| *SSBmsy* | 1500.4 | 1094.2 | 1511.8 | 1086.8 | 1456.2 | 1736.2 | 1267.6 | 1411.4 |
| *CPUEcurrent* | 1.54 | 1.54 | 1.54 | 1.52 | 1.53 | 1.49 | 1.50 | 1.46 |
| *CPUEproj* | 1.40 | 1.36 | 1.68 | 1.35 | 1.34 | 1.33 | 1.36 | 1.36 |
| *CPUEmsy* | 0.267 | 0.362 | 0.266 | 0.364 | 0.291 | 0.296 | 0.311 | 0.318 |
| *Bcurr/Bmin* | 4.74 | 4.40 | 4.90 | 4.27 | 4.65 | 4.47 | 4.43 | 4.42 |
| *Bcurr/Bref* | 2.40 | 1.82 | 2.51 | 1.84 | 2.36 | 2.25 | 2.16 | 2.22 |
| *Bcurr/Bmsy* | 4.11 | 2.94 | 4.14 | 2.85 | 3.89 | 3.57 | 3.46 | 3.41 |
| *Bproj/Bcurr* | 0.92 | 0.90 | 1.07 | 0.92 | 0.91 | 0.92 | 0.93 | 0.94 |
| *Bproj/Bref* | 2.22 | 1.65 | 2.69 | 1.68 | 2.12 | 2.05 | 2.02 | 2.11 |
| *Bproj/Bmsy* | 3.84 | 2.67 | 4.46 | 2.62 | 3.53 | 3.27 | 3.25 | 3.20 |
| *SSBcurr/SSB0* | 0.781 | 0.970 | 0.805 | 0.965 | 0.751 | 0.779 | 0.701 | 0.702 |
| *SSBproj/SSB0* | 0.707 | 0.871 | 0.837 | 0.888 | 0.668 | 0.720 | 0.649 | 0.642 |
| *SSBcurr/SSBmsy* | 1.96 | 2.05 | 2.00 | 2.02 | 1.97 | 2.05 | 1.89 | 1.81 |
| *SSBproj/SSBmsy* | 1.78 | 1.84 | 2.08 | 1.86 | 1.75 | 1.90 | 1.74 | 1.66 |
| *SSBproj/SSBcurr* | 0.905 | 0.897 | 1.032 | 0.918 | 0.889 | 0.928 | 0.921 | 0.916 |
| *USLcurrent* | 0.113 | 0.164 | 0.115 | 0.170 | 0.118 | 0.115 | 0.142 | 0.140 |
| *USLproj* | 0.123 | 0.184 | 0.106 | 0.189 | 0.132 | 0.127 | 0.154 | 0.149 |
| *USLproj/USLcurrent* | 1.10 | 1.12 | 0.93 | 1.11 | 1.12 | 1.11 | 1.10 | 1.07 |
| *Btotcurrent* | 6986.9 | 5193.8 | 7448.8 | 5109.5 | 6835.4 | 8463.3 | 5558.3 | 5952.1 |
| *Btotcurrent/Btot0* | 0.673 | 0.668 | 0.720 | 0.667 | 0.645 | 0.668 | 0.577 | 0.588 |
| *Ntotcurrent* | 16 854 400 | 12 830 400 | 19 078 650 | 12 767 250 | 16 562 000 | 18 648 300 | 13 185 100 | 14 581 600 |
| *Ntotcurrent/Ntot0* | 0.832 | 0.698 | 0.927 | 0.699 | 0.823 | 0.829 | 0.771 | 0.781 |

**Table 12: Indicator posterior probabilities from the two candidate base case MCMC runs. All runs include puerulus with one year lag unless indicated otherwise.**

| Probability | base1 no DD | base2 with DD | sens1 no DD and no puerulus | sens2 with DD and no puerulus | sens3 alternative recrea-tional catch | sens4 estimate R-H selectivity | sens5 growth prior CV=30% | sens6 double weight to CPUE series |
|---|---|---|---|---|---|---|---|---|
| P(*Bcurr*>*Bmin*) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*Bcurr*>*Bref*) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*Bcurr*>*Bmsy*) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*Bproj*>*Bmin*) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*Bproj*>*Bref*) | 1 | 0.999 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*Bproj*>*Bmsy*) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*Bproj*>*Bcurr*) | 0.188 | 0.026 | 0.726 | 0.081 | 0.133 | 0.189 | 0.24 | 0.281 |
| P(*SSBcurr*>*SSBmsy*) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*SSBproj*>*SSBmsy*) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P(*USLproj*>*USLcurr*) | 0.822 | 0.985 | 0.281 | 0.956 | 0.871 | 0.833 | 0.788 | 0.705 |
| P(*SSBcurr*<*0.2SSB0*) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P(*SSBproj*<*0.2SSB0*) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P(*SSBcurr*<*0.1SSB0*) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| P(*SSBproj*<*0.1SSB0*) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 13: Base case and robustness trial models described below.**

| Model | Code | Description |
|---|---|---|
| base1 | 11 | use puerulus without density dependence |
| base2 | 29 | use puerulus with density dependence |
| altrec | 23 | alternative recreational catch trajectory, with 2011=140 t (no DD) |
| hiStdObs | 30 | double observation error on CPUE indices (no DD) |
| lowrecruit | 31 | from base1: set mean recruitment to lowest 10 year average (=0.227 from 0.0333 or –23%) |
| lowrecruitDD | 32 | from base2: set mean recruitment to lowest 10 year average (=0.398 from -0.0809 or –27%) |
| nopoo | 3 | base1 without puerulus index series |

**Table 14: Values used for each rule parameter in runs. A total of 216 rules were evaluated.**

| Function | Par | existing rule | trial value 1 | trial value 2 | trial value 3 | trial value 4 |
|---|---|---|---|---|---|---|
| Rule type (4=step rule) | *par1* | 4 | 4 | | | |
| CPUE@TACC=0 | *par2* | 0.3 | 0.3 | 0.4 | 0.5 | |
| plateau left | *par3* | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| plateau right | *par4* | 2.0 | 2.0 | 2.2 | 2.4 | |
| plateau height | *par5* | 350 | 325 | 350 | 375 | |
| step width | *par6* | 0.2 | 0.2 | | | |
| step height | *par7* | 0.05 | 0.055 | | | |
| minimum change threshold | *par8* | 0 | 0.05 | 0.10 | | |
| maximum change threshold | *par9* | 0 | 0 | | | |
| latent year | *par10* | no | no | | | |

**Table 15: Detailed results for the two base case runs across the 216 rules defined in Table 14.**

| | Median value across all 216 rules | | | | | | 95th quantile value across all 216 rules | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | base1 | | | base2 | | | base1 | | | base2 | | |
| **Indicator** | **p=0.05** | **Median** | **p=0.95** | **p=0.05** | **Median** | **p=0.95** | **p=0.05** | **Median** | **p=0.95** | **p=0.05** | **Median** | **p=0.95** |
| AW average vulnerable biomass (B/Bref) | 1.513 | 1.958 | 2.650 | 1.147 | 1.425 | 1.816 | 1.645 | 2.102 | 2.785 | 1.254 | 1.541 | 1.945 |
| AW terminal vulnerable biomass (B/Bref) | 1.270 | 1.859 | 2.755 | 1.014 | 1.319 | 1.752 | 1.486 | 2.065 | 2.961 | 1.154 | 1.483 | 1.925 |
| Minimum commercial catch (t) | 223.9 | 324.9 | 349.9 | 249.4 | 324.9 | 349.9 | 324.9 | 374.9 | 374.9 | 349.6 | 374.8 | 374.9 |
| Average commercial catch (t) | 318.0 | 349.9 | 350.4 | 325.5 | 349.9 | 349.9 | 360.6 | 374.9 | 379.1 | 367.8 | 374.8 | 374.9 |
| Average commercial catch (t) in 1st 5 ye | 349.9 | 349.9 | 350.0 | 349.9 | 349.9 | 349.9 | 374.9 | 374.9 | 379.1 | 374.8 | 374.9 | 379.0 |
| Minimum recreational catch (t) | 50.80 | 59.86 | 71.12 | 52.29 | 58.64 | 65.14 | 54.87 | 62.63 | 72.24 | 55.65 | 62.01 | 67.30 |
| Average recreational catch (t) | 57.39 | 64.80 | 75.52 | 58.40 | 63.06 | 67.93 | 60.09 | 66.85 | 77.32 | 60.96 | 65.27 | 69.53 |
| Minimum offset CPUE (kg/potlift) | 0.852 | 1.161 | 1.596 | 0.952 | 1.189 | 1.476 | 0.999 | 1.258 | 1.668 | 1.077 | 1.306 | 1.569 |
| Average offset CPUE (kg/potlift) | 1.163 | 1.443 | 1.902 | 1.273 | 1.478 | 1.716 | 1.278 | 1.530 | 1.988 | 1.380 | 1.582 | 1.811 |
| Average annual variation in TACC (%) | 0.000 | 0.000 | 5.436 | 0.000 | 0.000 | 3.688 | 0.000 | 3.620 | 9.317 | 0.000 | 3.528 | 8.003 |
| AW average vulnerable biomass (B/Bmsy) | 2.552 | 3.373 | 4.584 | 1.906 | 2.309 | 2.792 | 2.810 | 3.620 | 4.801 | 2.109 | 2.502 | 2.961 |
| Average predicted CPUE (kg/pot) | 1.168 | 1.450 | 1.923 | 1.287 | 1.483 | 1.688 | 1.275 | 1.543 | 2.022 | 1.402 | 1.588 | 1.784 |
| Minimum predicted CPUE (kg/pot) | 0.911 | 1.230 | 1.715 | 1.028 | 1.282 | 1.568 | 1.072 | 1.346 | 1.781 | 1.172 | 1.430 | 1.680 |
| AW terminal total biomass | 4484.9 | 6057.2 | 8374.2 | 3239.9 | 4095.5 | 5294.8 | 4801.5 | 6349.7 | 8618.3 | 3495.5 | 4347.0 | 5499.1 |
| AW terminal total biomass/total B0 | 0.433 | 0.586 | 0.807 | 0.425 | 0.529 | 0.672 | 0.465 | 0.611 | 0.829 | 0.455 | 0.562 | 0.698 |
| AW terminal total numbers | 1.150E+07 | 1.540E+07 | 2.160E+07 | 7.939E+06 | 1.050E+07 | 1.430E+07 | 1.180E+07 | 1.570E+07 | 2.190E+07 | 8.304E+06 | 1.090E+07 | 1.460E+07 |
| AW terminal total numbers/total N0 | 0.597 | 0.766 | 1.022 | 0.436 | 0.574 | 0.768 | 0.613 | 0.781 | 1.033 | 0.459 | 0.595 | 0.788 |
| P(B[y]<Bref) | | 0.003 | | | 0.033 | | | 0.022 | | | 0.126 | |
| P(B[y]<Bmin) | | 0.000 | | | 0.000 | | | 0.000 | | | 0.000 | |
| P(B[y]<Bmsy) | | 0.000 | | | 0.000 | | | 0.000 | | | 0.003 | |
| P(TACC change) | | 0.127 | | | 0.086 | | | 0.335 | | | 0.277 | |
| P(SSB[y]<20%B0) | | 0.000 | | | 0.000 | | | 0.000 | | | 0.000 | |
| P(SSB[y]<10%B0) | | 0.000 | | | 0.000 | | | 0.000 | | | 0.000 | |
| P(B[y]<0.5*Bref) | | 0.000 | | | 0.000 | | | 0.000 | | | 0.000 | |
| P(B[y]<0.25*Bref) | | 0.000 | | | 0.000 | | | 0.000 | | | 0.000 | |
| P(B[y]<left_plateau height) | | 0.112 | | | 0.061 | | | 0.463 | | | 0.461 | |
| P(B[y]>right_plateau height) | | 0.016 | | | 0.001 | | | 0.070 | | | 0.022 | |

**Table 16: Comparison of median indicator values for the two base case and five robustness trials described in Table 13.**

| | base or robustness model | | | | | | |
|---|---|---|---|---|---|---|---|
| | base1 | base2 | altrec | hiStdObs | lowrecruit | lowrecruitDD | nopoo |
| AW average vulnerable biomass (B/Bref) | 1.958 | 1.425 | 1.969 | 1.966 | 1.634 | 1.236 | 2.750 |
| AW terminal vulnerable biomass (B/Bref) | 1.859 | 1.319 | 1.872 | 1.887 | 1.295 | 0.973 | 2.800 |
| Minimum commercial catch (t) | 324.9 | 324.9 | 325.6 | 324.9 | 218.6 | 238.6 | 349.9 |
| Average commercial catch (t) | 349.9 | 349.9 | 349.9 | 346.1 | 315.2 | 324.9 | 351.4 |
| Average commercial catch (t) in 1st 5 ye | 349.9 | 349.9 | 349.9 | 350.0 | 350.0 | 349.9 | 350.0 |
| Minimum recreational catch (t) | 59.86 | 58.64 | 67.63 | 60.03 | 49.91 | 49.90 | 71.01 |
| Average recreational catch (t) | 64.80 | 63.06 | 76.56 | 64.90 | 58.43 | 58.68 | 76.85 |
| Minimum offset CPUE (kg/potlift) | 1.161 | 1.189 | 1.180 | 1.048 | 0.836 | 0.895 | 1.592 |
| Average offset CPUE (kg/potlift) | 1.443 | 1.478 | 1.471 | 1.454 | 1.221 | 1.303 | 1.967 |
| Average annual variation in TACC (%) | 0.000 | 0.000 | 0.000 | 1.267 | 4.878 | 3.761 | 0.843 |
| AW average vulnerable biomass (B/Bmsy) | 3.373 | 2.309 | 3.299 | 3.386 | 2.827 | 1.990 | 4.580 |
| Average predicted CPUE (kg/pot) | 1.450 | 1.483 | 1.458 | 1.454 | 1.228 | 1.309 | 1.968 |
| Minimum predicted CPUE (kg/pot) | 1.230 | 1.282 | 1.259 | 1.242 | 0.885 | 0.948 | 1.699 |
| AW terminal total biomass | 6057.2 | 4095.5 | 6098.2 | 6089.3 | 4415.6 | 2906.5 | 8124.5 |
| AW terminal total biomass/total B0 | 0.586 | 0.529 | 0.578 | 0.588 | 0.426 | 0.374 | 0.782 |
| AW terminal total numbers | 1.540E+07 | 1.050E+07 | 1.550E+07 | 1.540E+07 | 1.160E+07 | 7.206E+06 | 1.990E+07 |
| AW terminal total numbers/total N0 | 0.766 | 0.574 | 0.772 | 0.768 | 0.572 | 0.393 | 0.972 |
| P(B[y]<Bref) | 0.003 | 0.033 | 0.002 | 0.003 | 0.034 | 0.245 | 0.000 |
| P(B[y]<Bmin) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(B[y]<Bmsy) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 |
| P(TACC change) | 0.127 | 0.086 | 0.122 | 0.191 | 0.304 | 0.249 | 0.165 |
| P(SSB[y]<20%B0) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(SSB[y]<10%B0) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(B[y]<0.5*Bref) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(B[y]<0.25*Bref) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(B[y]<left_plateau height) | 0.112 | 0.061 | 0.100 | 0.137 | 0.449 | 0.348 | 0.005 |
| P(B[y]>right_plateau height) | 0.016 | 0.001 | 0.016 | 0.036 | 0.002 | 0.000 | 0.270 |

**Table 17: Comparison of 95th quantile indicator values for the two base case and five robustness trials described in Table 13.**

| | base or robustness model | | | | | | |
|---|---|---|---|---|---|---|---|
| | base1 | base2 | altrec | hiStdObs | lowrecruit | lowrecruitDD | nopoo |
| AW average vulnerable biomass (B/Bref) | 2.102 | 1.541 | 2.113 | 2.128 | 1.776 | 1.357 | 2.884 |
| AW terminal vulnerable biomass (B/Bref) | 2.065 | 1.483 | 2.069 | 2.094 | 1.553 | 1.182 | 2.999 |
| Minimum commercial catch (t) | 374.9 | 374.8 | 374.9 | 374.9 | 324.9 | 324.8 | 374.9 |
| Average commercial catch (t) | 374.9 | 374.8 | 374.9 | 374.9 | 356.4 | 359.7 | 381.3 |
| Average commercial catch (t) in 1st 5 ye | 374.9 | 374.9 | 374.9 | 374.9 | 374.9 | 374.9 | 375.0 |
| Minimum recreational catch (t) | 62.63 | 62.01 | 72.44 | 63.05 | 54.42 | 54.73 | 72.10 |
| Average recreational catch (t) | 66.85 | 65.27 | 80.39 | 67.25 | 60.87 | 61.32 | 78.57 |
| Minimum offset CPUE (kg/potlift) | 1.258 | 1.306 | 1.277 | 1.143 | 0.990 | 1.064 | 1.637 |
| Average offset CPUE (kg/potlift) | 1.530 | 1.582 | 1.556 | 1.558 | 1.311 | 1.419 | 2.050 |
| Average annual variation in TACC (%) | 3.620 | 3.528 | 3.425 | 7.314 | 7.646 | 6.738 | 2.253 |
| AW average vulnerable biomass (B/Bmsy) | 3.620 | 2.502 | 3.526 | 3.661 | 3.071 | 2.189 | 4.805 |
| Average predicted CPUE (kg/pot) | 1.543 | 1.588 | 1.544 | 1.561 | 1.318 | 1.428 | 2.055 |
| Minimum predicted CPUE (kg/pot) | 1.346 | 1.430 | 1.371 | 1.368 | 1.059 | 1.140 | 1.743 |
| AW terminal total biomass | 6349.7 | 4347.0 | 6388.2 | 6374.6 | 4758.1 | 3217.0 | 8404.2 |
| AW terminal total biomass/total B0 | 0.611 | 0.562 | 0.605 | 0.615 | 0.456 | 0.413 | 0.807 |
| AW terminal total numbers | 1.570E+07 | 1.090E+07 | 1.580E+07 | 1.570E+07 | 1.190E+07 | 7.629E+06 | 2.010E+07 |
| AW terminal total numbers/total N0 | 0.781 | 0.595 | 0.786 | 0.783 | 0.591 | 0.416 | 0.986 |
| P(B[y]<Bref) | 0.022 | 0.126 | 0.023 | 0.020 | 0.204 | 0.484 | 0.001 |
| P(B[y]<Bmin) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 |
| P(B[y]<Bmsy) | 0.000 | 0.003 | 0.000 | 0.000 | 0.001 | 0.068 | 0.000 |
| P(TACC change) | 0.335 | 0.277 | 0.330 | 0.464 | 0.520 | 0.459 | 0.397 |
| P(SSB[y]<20%B0) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(SSB[y]<10%B0) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(B[y]<0.5*Bref) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.012 | 0.000 |
| P(B[y]<0.25*Bref) | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| P(B[y]<left_plateau height) | 0.463 | 0.461 | 0.449 | 0.449 | 0.734 | 0.673 | 0.070 |
| P(B[y]>right_plateau height) | 0.070 | 0.022 | 0.069 | 0.108 | 0.014 | 0.013 | 0.500 |

**Table 18: Median values for the three probability safety indicators across the four *par3* (left-hand inflection point) values investigated while holding *par2* (CPUE value when TACC=0) constant at a single value. There are 72 rules in each subtable.**

*par2*=0.3

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.010 | 0.006 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.050 | 0.047 | 0.035 | 0.015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| altrec | 0.012 | 0.006 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.009 | 0.005 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.143 | 0.072 | 0.025 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.369 | 0.349 | 0.276 | 0.160 | 0.000 | 0.000 | 0.000 | 0.000 | 0.032 | 0.008 | 0.001 | 0.000 |
| nopoo | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

*par2*=0.4

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.010 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.050 | 0.047 | 0.034 | 0.013 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| altrec | 0.011 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.009 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.135 | 0.062 | 0.020 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.368 | 0.343 | 0.262 | 0.145 | 0.000 | 0.000 | 0.000 | 0.000 | 0.029 | 0.007 | 0.001 | 0.000 |
| nopoo | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

*par2*=0.5

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.009 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.050 | 0.046 | 0.032 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| altrec | 0.011 | 0.004 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.008 | 0.004 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.124 | 0.053 | 0.015 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.366 | 0.336 | 0.247 | 0.129 | 0.000 | 0.000 | 0.000 | 0.000 | 0.025 | 0.005 | 0.001 | 0.000 |
| nopoo | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Table 19: Median values for the three probability safety indicators across the four *par3* (left-hand inflection point) values investigated while holding *par5* (plateau height) constant at a single value. There are 72 rules in each subtable.**

*par5*=325

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.004 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.016 | 0.016 | 0.011 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| altrec | 0.004 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.004 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.075 | 0.035 | 0.011 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.232 | 0.215 | 0.161 | 0.082 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.002 | 0.000 | 0.000 |
| nopoo | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

*par5*=350

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.010 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.050 | 0.047 | 0.034 | 0.013 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| altrec | 0.011 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.009 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.135 | 0.062 | 0.020 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.368 | 0.343 | 0.262 | 0.145 | 0.000 | 0.000 | 0.000 | 0.000 | 0.029 | 0.007 | 0.001 | 0.000 |
| nopoo | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

*par5*=375

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.022 | 0.011 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.126 | 0.113 | 0.076 | 0.031 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.001 | 0.000 | 0.000 |
| altrec | 0.023 | 0.012 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.020 | 0.010 | 0.003 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.204 | 0.101 | 0.033 | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.484 | 0.450 | 0.357 | 0.218 | 0.001 | 0.000 | 0.000 | 0.000 | 0.069 | 0.018 | 0.003 | 0.000 |
| nopoo | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Table 20: Median values for the three indicators across the four *par3* (left-hand inflection point) values investigated while holding *par2* (CPUE value when TACC=0) constant at a single value. There are 72 rules in each subtable.**

*par2*=0.3

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 349.94 | 344.89 | 327.69 | 327.69 | 64.76 | 64.77 | 64.84 | 65.37 | 0.00 | 0.00 | 0.42 | 2.24 |
| base2 | 349.89 | 349.89 | 341.21 | 324.94 | 63.04 | 63.06 | 63.08 | 63.57 | 0.00 | 0.00 | 0.00 | 1.83 |
| altrec | 349.94 | 346.07 | 327.69 | 327.67 | 76.55 | 76.55 | 76.61 | 77.54 | 0.00 | 0.00 | 0.28 | 2.06 |
| histdobs | 349.94 | 341.03 | 335.06 | 332.36 | 64.73 | 64.78 | 65.01 | 65.81 | 0.00 | 0.56 | 2.32 | 5.14 |
| lowrecruit | 324.96 | 324.96 | 311.63 | 294.20 | 56.53 | 57.19 | 58.34 | 59.65 | 1.31 | 3.27 | 4.52 | 5.31 |
| lowrecruitdd | 331.30 | 324.93 | 324.92 | 312.02 | 56.93 | 57.52 | 58.55 | 59.77 | 0.19 | 2.33 | 3.66 | 4.58 |
| nopoo | 369.80 | 369.80 | 369.56 | 356.56 | 76.85 | 76.85 | 76.85 | 76.85 | 0.56 | 0.56 | 0.70 | 1.13 |

*par2*=0.4

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 349.94 | 342.07 | 327.69 | 327.68 | 64.76 | 64.77 | 64.86 | 65.43 | 0.00 | 0.00 | 0.48 | 2.57 |
| base2 | 349.89 | 349.89 | 339.13 | 324.94 | 63.04 | 63.06 | 63.08 | 63.63 | 0.00 | 0.00 | 0.00 | 2.10 |
| altrec | 349.94 | 343.37 | 327.69 | 327.67 | 76.55 | 76.55 | 76.64 | 77.64 | 0.00 | 0.00 | 0.28 | 2.28 |
| histdobs | 349.94 | 339.04 | 334.97 | 331.17 | 64.73 | 64.78 | 65.05 | 65.87 | 0.00 | 0.56 | 2.62 | 5.77 |
| lowrecruit | 324.96 | 324.96 | 308.86 | 290.84 | 56.60 | 57.34 | 58.53 | 59.86 | 1.73 | 4.01 | 5.36 | 6.16 |
| lowrecruitdd | 328.65 | 324.93 | 323.38 | 310.14 | 56.98 | 57.58 | 58.68 | 59.95 | 0.28 | 2.87 | 4.34 | 5.32 |
| nopoo | 369.80 | 369.80 | 369.16 | 355.54 | 76.85 | 76.85 | 76.85 | 76.85 | 0.56 | 0.56 | 0.71 | 1.13 |

*par2*=0.5

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 349.94 | 340.06 | 327.69 | 327.68 | 64.76 | 64.77 | 64.89 | 65.48 | 0.00 | 0.00 | 0.62 | 3.00 |
| base2 | 349.89 | 349.89 | 337.33 | 324.94 | 63.04 | 63.06 | 63.08 | 63.70 | 0.00 | 0.00 | 0.00 | 2.42 |
| altrec | 349.94 | 341.14 | 327.69 | 327.66 | 76.55 | 76.55 | 76.67 | 77.73 | 0.00 | 0.00 | 0.28 | 2.69 |
| histdobs | 349.94 | 336.78 | 334.93 | 330.02 | 64.73 | 64.79 | 65.08 | 65.98 | 0.00 | 0.56 | 2.86 | 6.62 |
| lowrecruit | 324.96 | 323.92 | 305.58 | 287.31 | 56.64 | 57.49 | 58.77 | 60.12 | 2.47 | 5.23 | 6.59 | 7.25 |
| lowrecruitdd | 325.63 | 324.93 | 321.61 | 307.94 | 57.02 | 57.68 | 58.84 | 60.13 | 0.76 | 3.64 | 5.20 | 6.27 |
| nopoo | 369.80 | 369.80 | 368.50 | 353.99 | 76.85 | 76.85 | 76.85 | 76.85 | 0.56 | 0.56 | 0.84 | 1.13 |

**Table 21: Median values for three indicators across the four *par3* (left-hand inflection point) values investigated while holding *par5* (plateau height) constant at a single value. There are 72 rules in each subtable.**

*par5*=325

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 324.95 | 324.95 | 324.95 | 320.83 | 66.51 | 66.51 | 66.55 | 66.85 | 0.00 | 0.00 | 0.00 | 1.52 |
| base2 | 324.92 | 324.92 | 324.92 | 324.12 | 65.09 | 65.09 | 65.11 | 65.28 | 0.00 | 0.00 | 0.00 | 0.67 |
| altrec | 324.95 | 324.95 | 324.95 | 321.26 | 79.93 | 79.93 | 79.95 | 80.40 | 0.00 | 0.00 | 0.00 | 1.36 |
| histdobs | 324.96 | 324.95 | 324.93 | 314.45 | 66.50 | 66.53 | 66.63 | 67.25 | 0.00 | 0.00 | 1.69 | 4.41 |
| lowrecruit | 324.92 | 312.88 | 296.83 | 279.87 | 58.42 | 58.77 | 59.69 | 60.89 | 0.00 | 2.59 | 4.35 | 5.51 |
| lowrecruitdd | 324.88 | 322.52 | 311.34 | 299.02 | 59.55 | 59.71 | 60.30 | 61.32 | 0.00 | 0.90 | 2.83 | 4.31 |
| nopoo | 329.93 | 329.93 | 329.93 | 329.93 | 78.23 | 78.23 | 78.23 | 78.25 | 0.84 | 0.84 | 0.98 | 1.24 |

*par5*=350

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 349.94 | 349.94 | 349.92 | 338.31 | 64.76 | 64.77 | 64.86 | 65.43 | 0.00 | 0.00 | 0.32 | 2.56 |
| base2 | 349.89 | 349.89 | 349.87 | 341.76 | 63.04 | 63.06 | 63.08 | 63.64 | 0.00 | 0.00 | 0.00 | 2.11 |
| altrec | 349.94 | 349.94 | 349.93 | 339.54 | 76.55 | 76.55 | 76.61 | 77.64 | 0.00 | 0.00 | 0.00 | 2.34 |
| histdobs | 349.94 | 349.93 | 345.57 | 332.27 | 64.73 | 64.78 | 65.04 | 65.87 | 0.00 | 0.28 | 2.46 | 5.99 |
| lowrecruit | 344.26 | 326.81 | 308.86 | 290.84 | 56.60 | 57.34 | 58.53 | 59.86 | 1.73 | 4.01 | 5.36 | 6.15 |
| lowrecruitdd | 348.49 | 336.34 | 323.38 | 310.14 | 56.98 | 57.58 | 58.68 | 59.95 | 0.56 | 2.87 | 4.34 | 5.34 |
| nopoo | 351.88 | 351.88 | 351.88 | 351.43 | 76.85 | 76.85 | 76.85 | 76.85 | 0.56 | 0.70 | 0.84 | 1.13 |

*par5*=375

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 374.92 | 374.91 | 369.85 | 353.63 | 62.92 | 62.96 | 63.28 | 64.15 | 0.00 | 0.00 | 1.46 | 3.73 |
| base2 | 374.84 | 374.83 | 370.13 | 356.39 | 60.85 | 60.88 | 61.22 | 62.17 | 0.00 | 0.00 | 1.38 | 3.62 |
| altrec | 374.92 | 374.92 | 371.30 | 355.07 | 73.05 | 73.15 | 73.58 | 75.30 | 0.00 | 0.00 | 1.25 | 3.50 |
| histdobs | 374.92 | 374.90 | 364.34 | 347.86 | 62.91 | 63.04 | 63.54 | 64.66 | 0.00 | 1.09 | 3.96 | 7.51 |
| lowrecruit | 356.44 | 338.97 | 319.44 | 301.14 | 54.93 | 56.09 | 57.51 | 58.93 | 3.85 | 5.46 | 6.31 | 6.83 |
| lowrecruitdd | 359.83 | 347.46 | 333.80 | 319.66 | 54.68 | 55.85 | 57.22 | 58.70 | 3.39 | 4.82 | 5.73 | 6.33 |
| nopoo | 375.47 | 375.47 | 375.46 | 375.46 | 75.35 | 75.35 | 75.35 | 75.37 | 0.28 | 0.28 | 0.42 | 0.99 |

**Table 22: Median values for the three probability safety indicators across the four *par3* (left-hand inflection point) values while holding *par8* (threshold for minimum change) constant at a single value. There are 108 rules in each subtable.**

*par*8=0.05

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.009 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.050 | 0.046 | 0.033 | 0.013 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| altrec | 0.011 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.009 | 0.005 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.134 | 0.061 | 0.020 | 0.004 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.368 | 0.343 | 0.261 | 0.143 | 0.000 | 0.000 | 0.000 | 0.000 | 0.029 | 0.007 | 0.001 | 0.000 |
| nopoo | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

*par*8=0.1

| | P(B[y]<Bref) | | | | P(B[y]<Bmin) | | | | P(B[y]<Bmsy) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 0.010 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| base2 | 0.050 | 0.047 | 0.035 | 0.014 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| altrec | 0.011 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| histdobs | 0.009 | 0.005 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruit | 0.135 | 0.063 | 0.021 | 0.005 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| lowrecruitdd | 0.368 | 0.343 | 0.263 | 0.148 | 0.000 | 0.000 | 0.000 | 0.000 | 0.029 | 0.007 | 0.001 | 0.000 |
| nopoo | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Table 23: Median values for three indicators across the four *par3* (left-hand inflection point) values while holding *par8* (threshold for minimum change) constant at a single value. There are 108 rules in each subtable.**

Par8=0.05

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 349.94 | 342.60 | 328.58 | 328.57 | 64.76 | 64.77 | 64.86 | 65.45 | 0.00 | 0.00 | 0.68 | 2.95 |
| base2 | 349.89 | 349.89 | 339.13 | 324.94 | 63.04 | 63.06 | 63.08 | 63.68 | 0.00 | 0.00 | 0.00 | 2.41 |
| altrec | 349.94 | 343.38 | 328.58 | 328.54 | 76.55 | 76.55 | 76.67 | 77.64 | 0.00 | 0.00 | 0.56 | 2.63 |
| histdobs | 349.94 | 339.81 | 333.15 | 330.74 | 64.73 | 64.78 | 65.06 | 65.89 | 0.00 | 0.59 | 2.82 | 6.18 |
| lowrecruit | 324.96 | 324.96 | 308.57 | 290.47 | 56.60 | 57.35 | 58.56 | 59.89 | 1.83 | 4.23 | 5.60 | 6.55 |
| lowrecruitdd | 328.97 | 324.93 | 323.31 | 309.90 | 56.98 | 57.60 | 58.72 | 59.99 | 0.56 | 3.03 | 4.64 | 5.66 |
| nopoo | 370.24 | 370.24 | 369.16 | 356.46 | 76.78 | 76.78 | 76.78 | 76.79 | 1.13 | 1.13 | 1.13 | 1.41 |

Par8=0.1

| | Average commercial catch | | | | Average recreational catch | | | | Average annual variation | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Par3 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 | 0.8 | 1.0 | 1.2 | 1.4 |
| base1 | 349.94 | 341.54 | 326.80 | 326.79 | 64.76 | 64.77 | 64.86 | 65.41 | 0.00 | 0.00 | 0.00 | 2.15 |
| base2 | 349.89 | 349.89 | 338.23 | 324.94 | 63.04 | 63.06 | 63.08 | 63.59 | 0.00 | 0.00 | 0.00 | 1.78 |
| altrec | 349.94 | 343.36 | 326.80 | 326.80 | 76.55 | 76.55 | 76.61 | 77.64 | 0.00 | 0.00 | 0.00 | 1.90 |
| histdobs | 349.94 | 341.03 | 336.78 | 330.16 | 64.74 | 64.78 | 65.01 | 65.87 | 0.00 | 0.00 | 2.25 | 5.28 |
| lowrecruit | 324.96 | 324.96 | 309.09 | 291.11 | 56.60 | 57.34 | 58.53 | 59.84 | 1.59 | 3.75 | 4.89 | 5.72 |
| lowrecruitdd | 328.34 | 324.93 | 323.39 | 310.37 | 56.96 | 57.56 | 58.67 | 59.91 | 0.00 | 2.69 | 4.04 | 4.97 |
| nopoo | 369.35 | 369.35 | 368.61 | 355.82 | 76.92 | 76.92 | 76.92 | 76.92 | 0.00 | 0.00 | 0.56 | 1.13 |

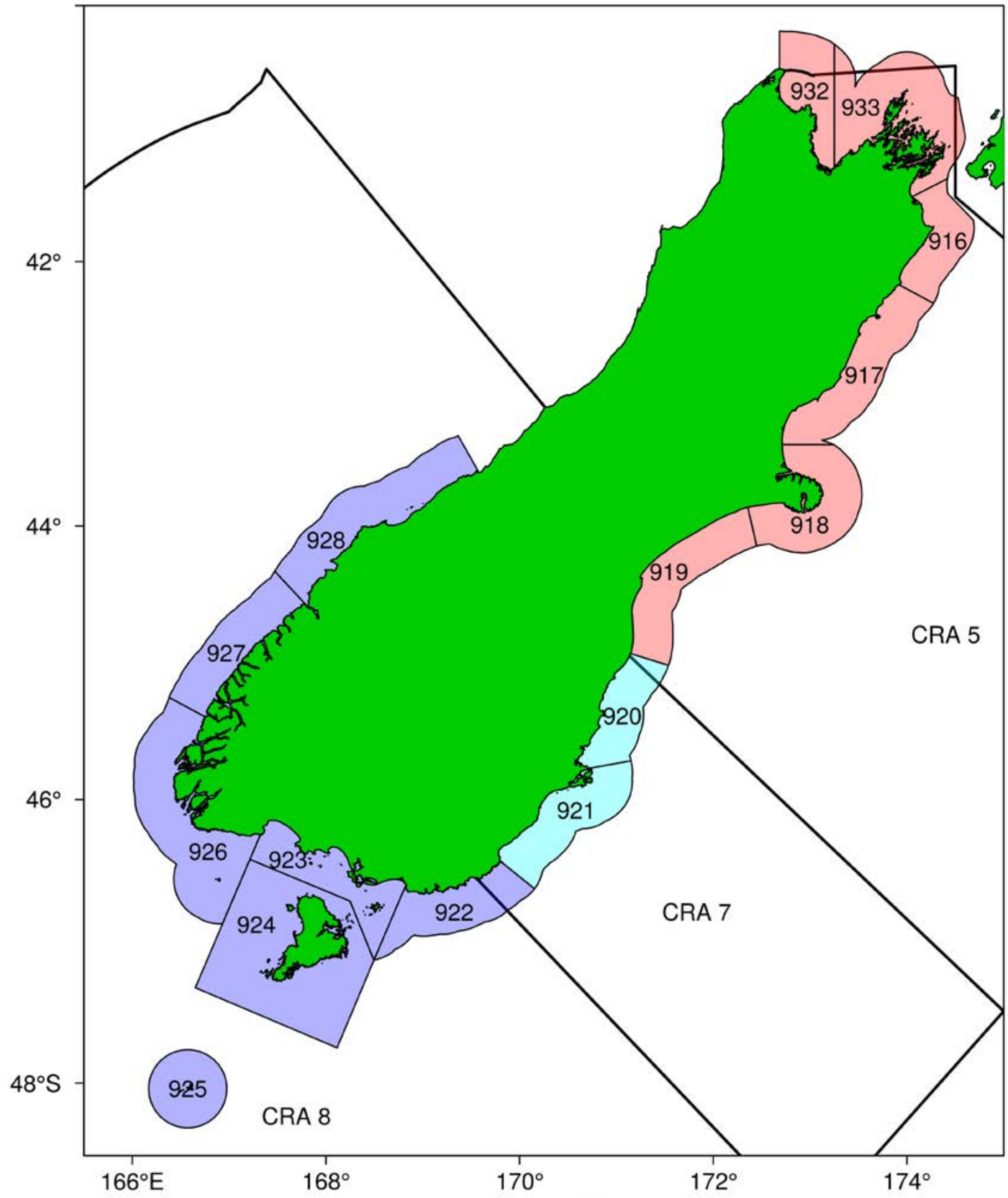



**Figure 1: CRA 5 (pink statistical areas), CRA 7 (blue statistical areas) and CRA 8 (purple statistical areas) stock areas on the South Island.**

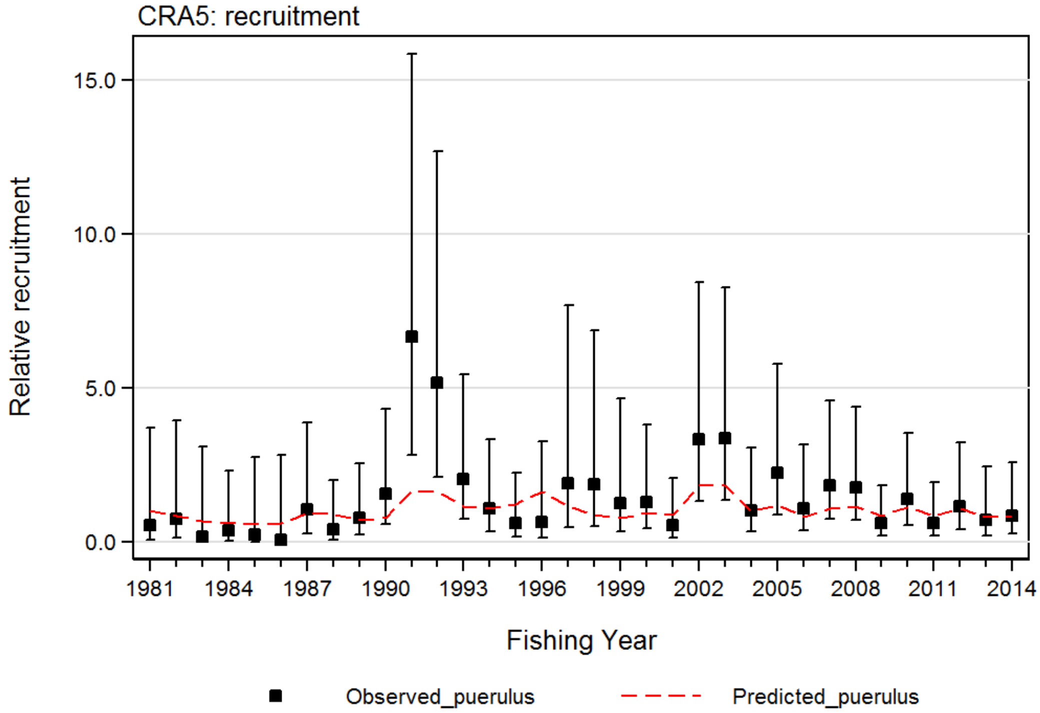



**Figure 2: Plot of fitted puerulus indices from 1981 to 2014 for the CRA 5 "base1" base case model.**

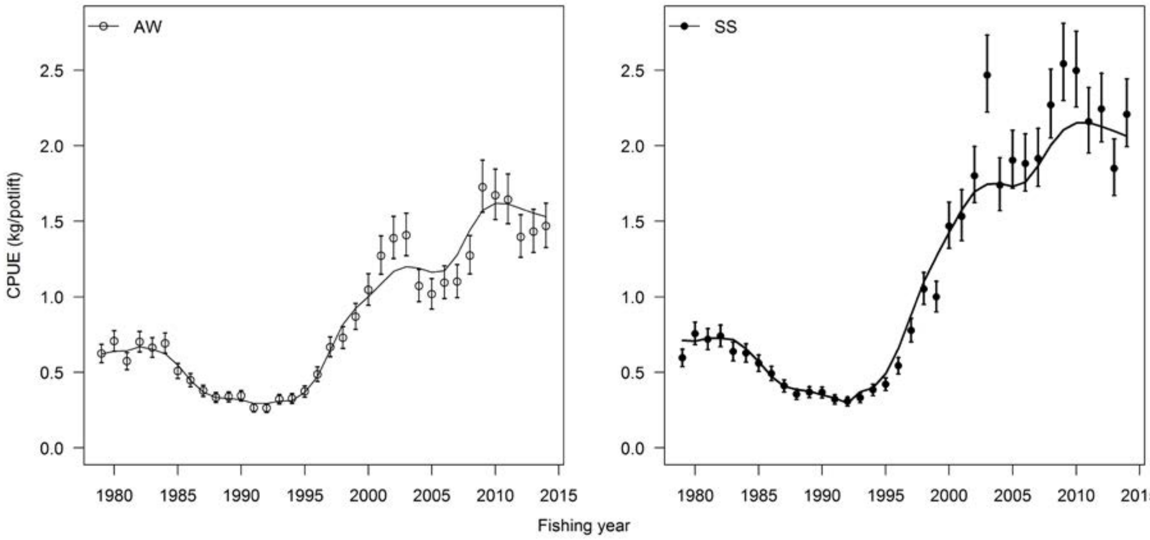



**Figure 3: Fit to catch per unit effort (CPUE) by year and season (AW = autumn-winter, SS = spring-summer) in the CRA 5 "base1" base case. Circles show observed values, bars show one standard deviation, and lines show predicted values.**

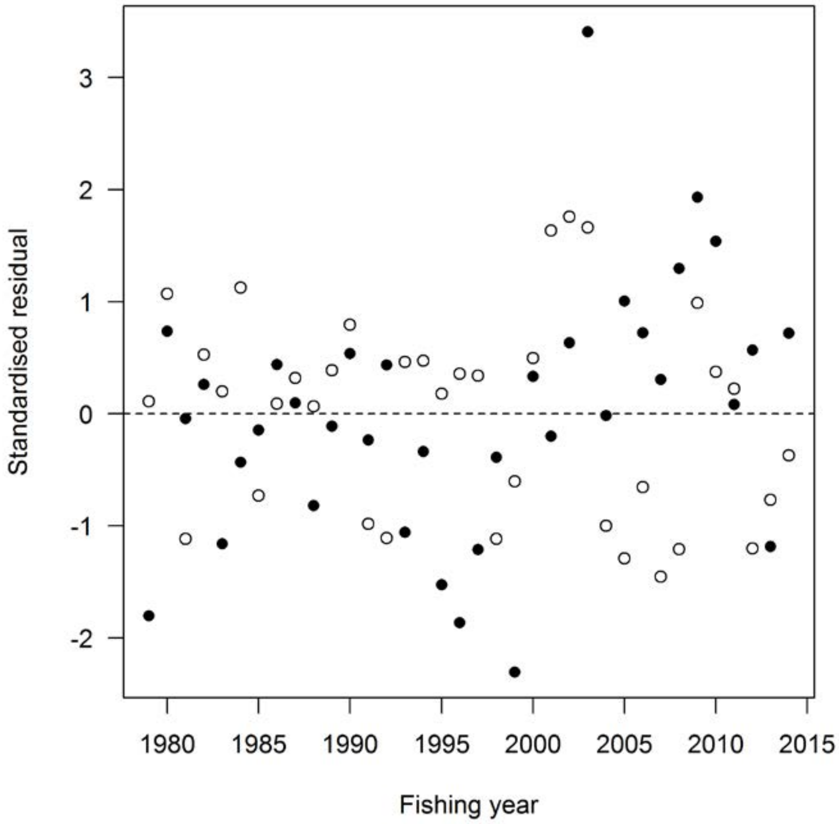



**Figure 4:** **Residuals from the fit to CPUE by year and season for the CRA 5 "base1" base case. Open circles are autumn-winter (AW), closed are spring-summer (SS).**

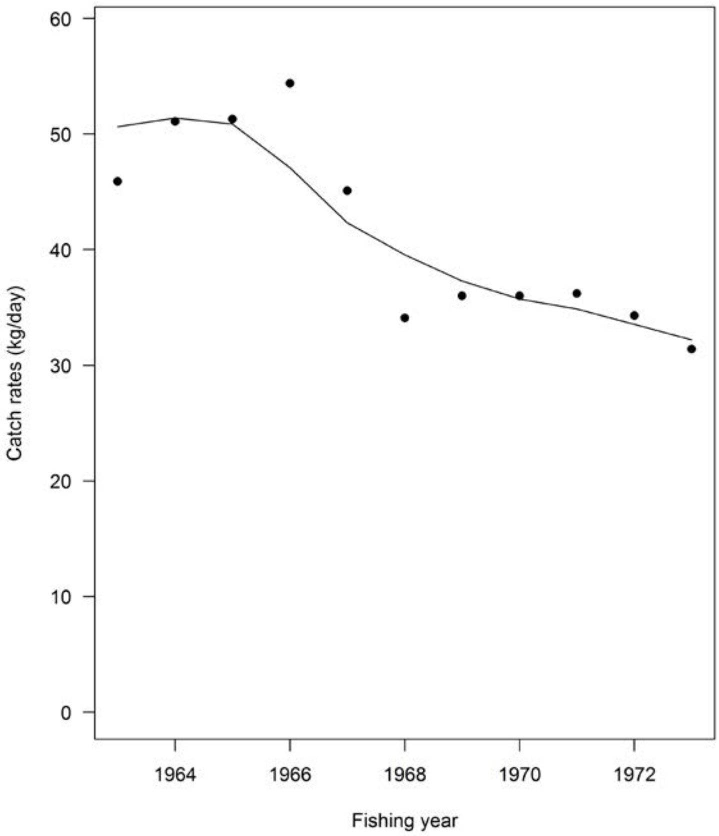



**Figure 5:** **Predicted (line) and observed (points) CR by year for the CRA 5 "base1" base case.**

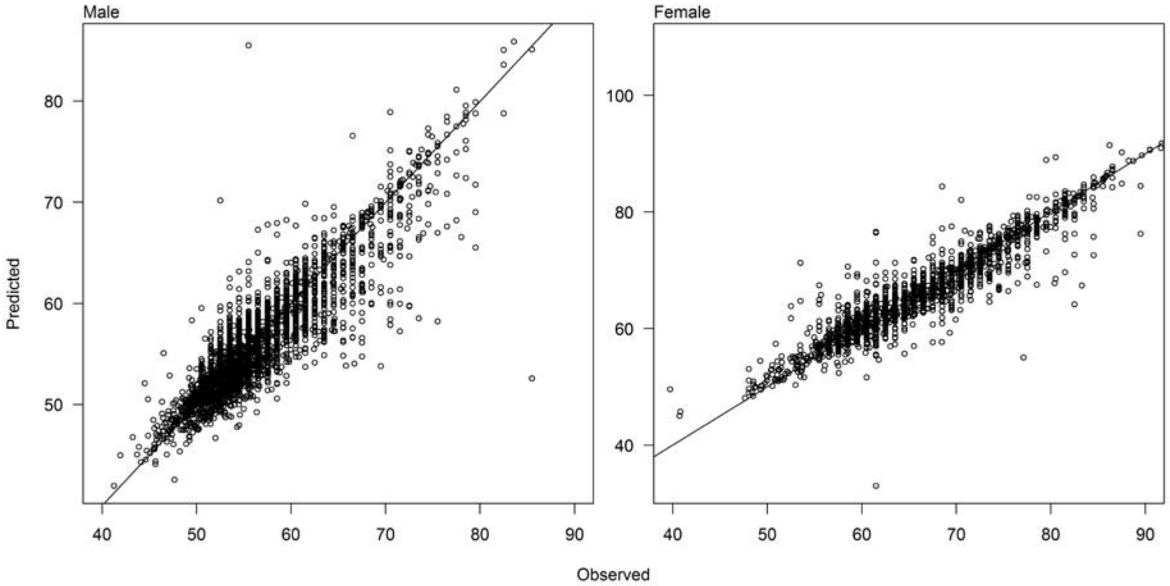



**Figure 6: Predicted versus observed increments for the CRA 5 “base1” base case tag-recapture data by sex.**

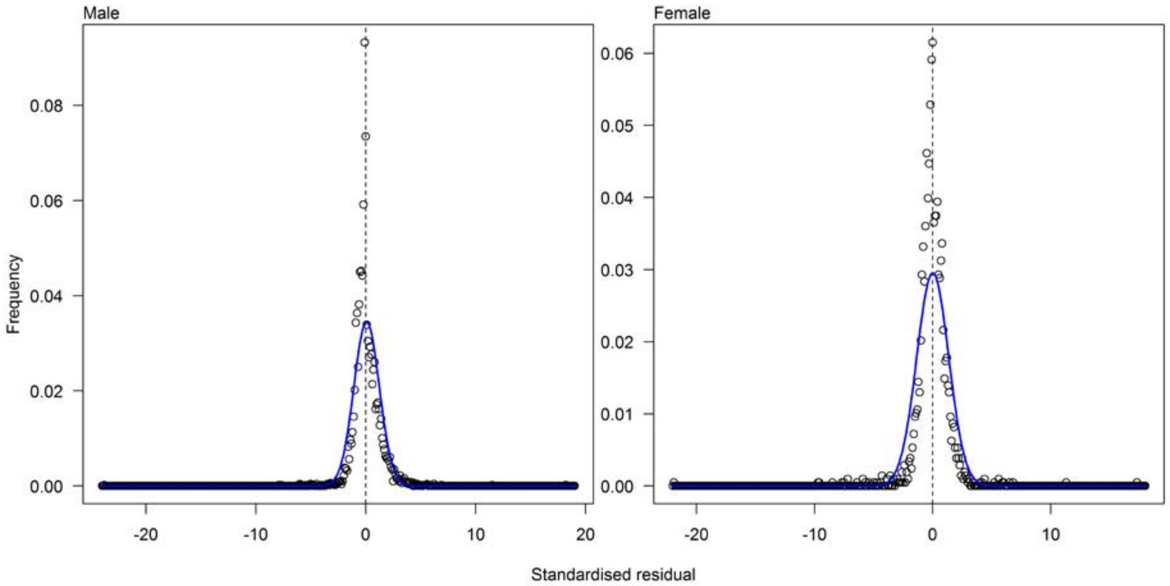



**Figure 7: Distributions of normalised residuals from the fit to the tag-recapture data for the CRA 5 “base1” base case.**

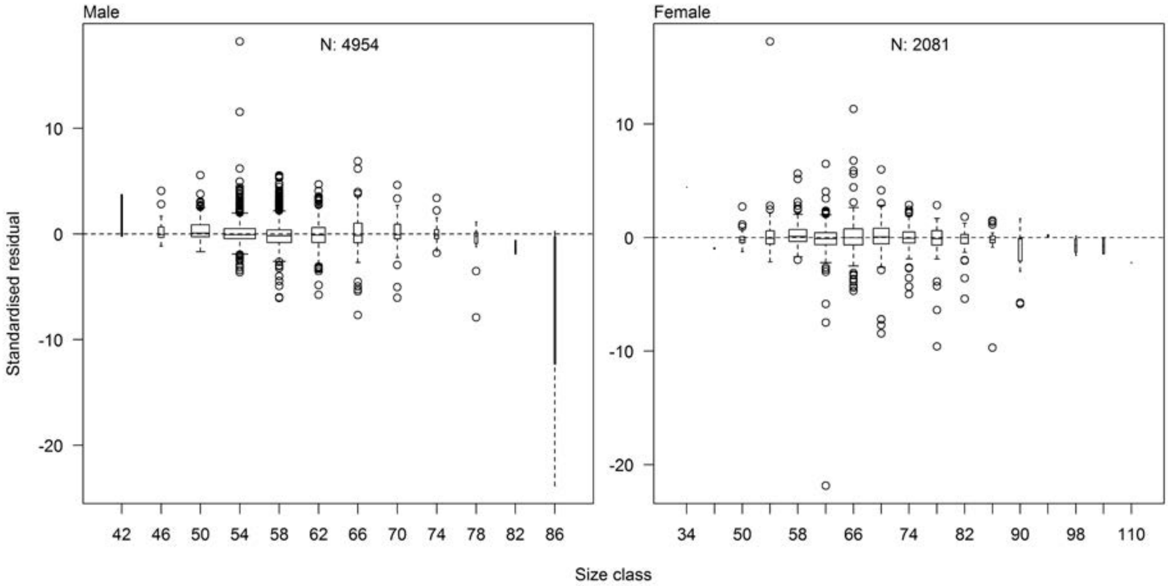



**Figure 8: Distributions of residuals to the tag-recapture data by sex and size for the CRA 5 "base1" base case. The width of each box is proportional to the number of observations in the category. The total number of observations by sex is shown at the top of each panel.**

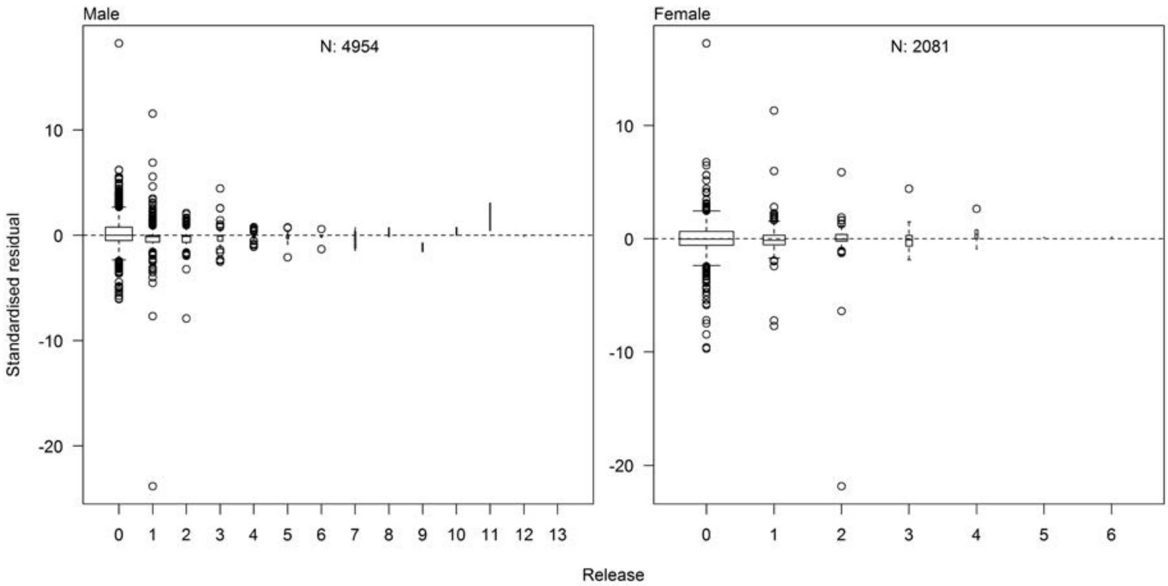



**Figure 9: Distributions of residuals to the tag-recapture data by sex and release event for the CRA 5 "base1" base case. The width of each box is proportional to the number of observations in the category.**

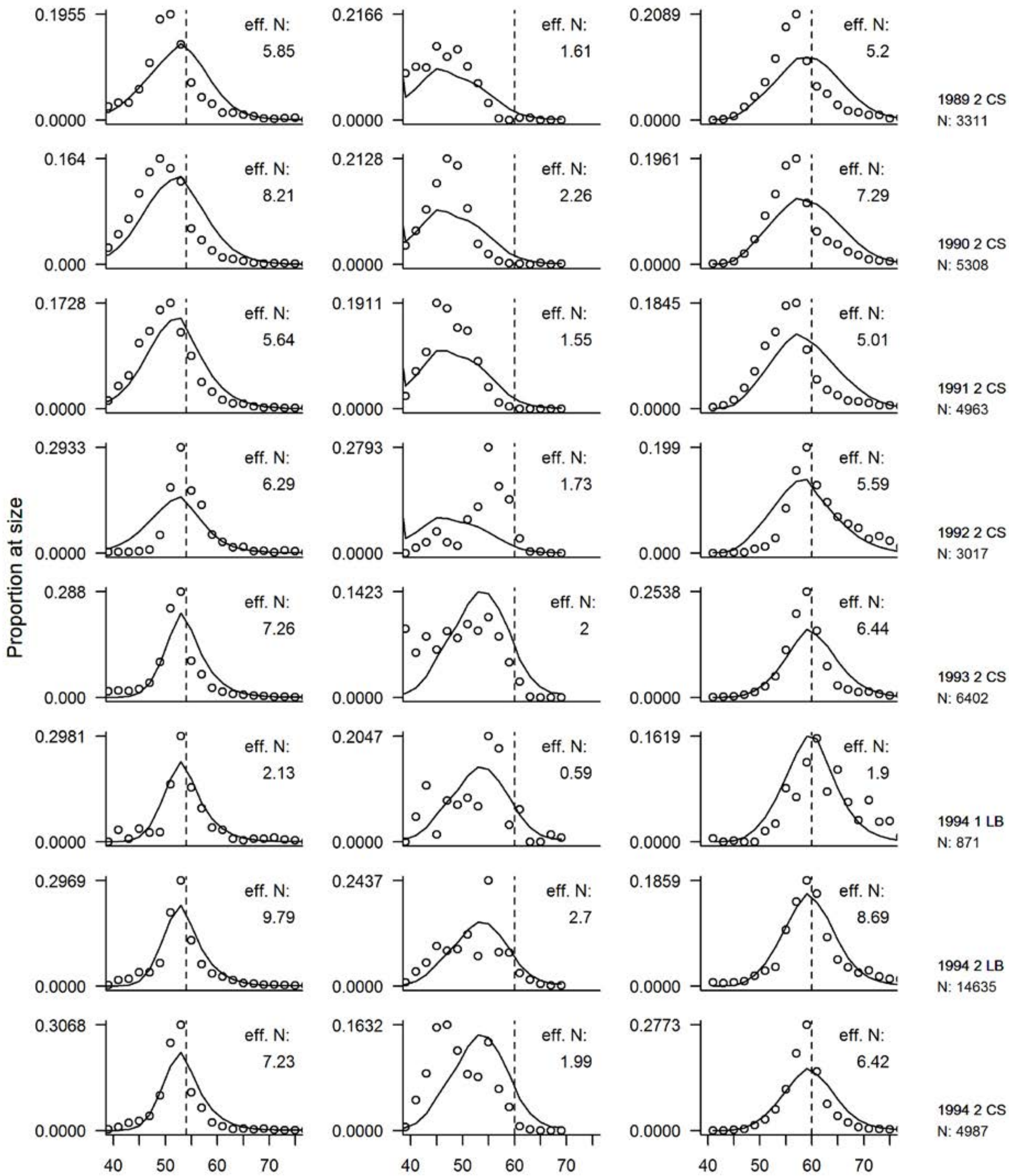



**Figure 10A: Fit to the LFs (1989 SS CS to 1994 SS CS) for the CRA 5 “base1” base case.**

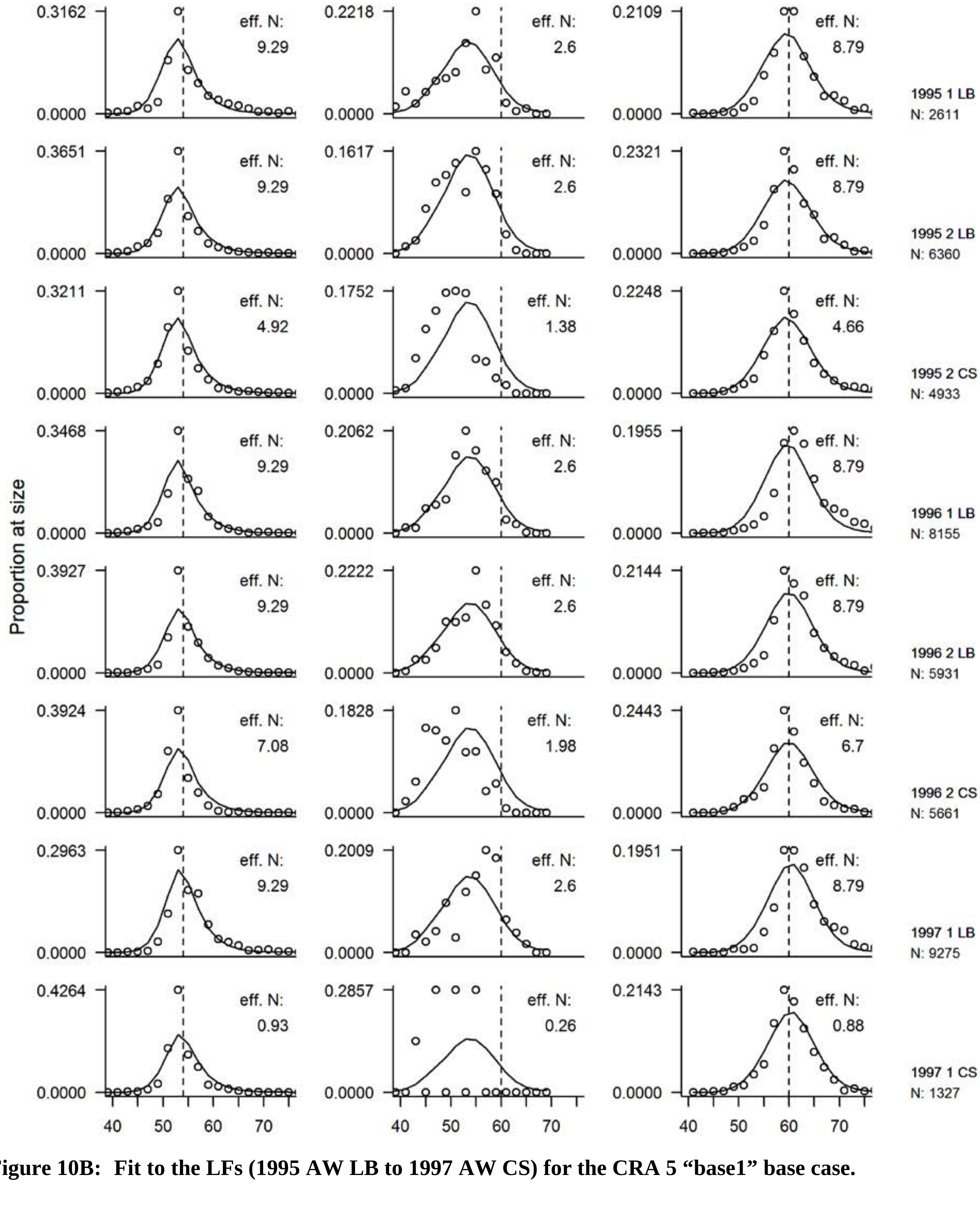



**Figure 10B: Fit to the LFs (1995 AW LB to 1997 AW CS) for the CRA 5 “base1” base case.**

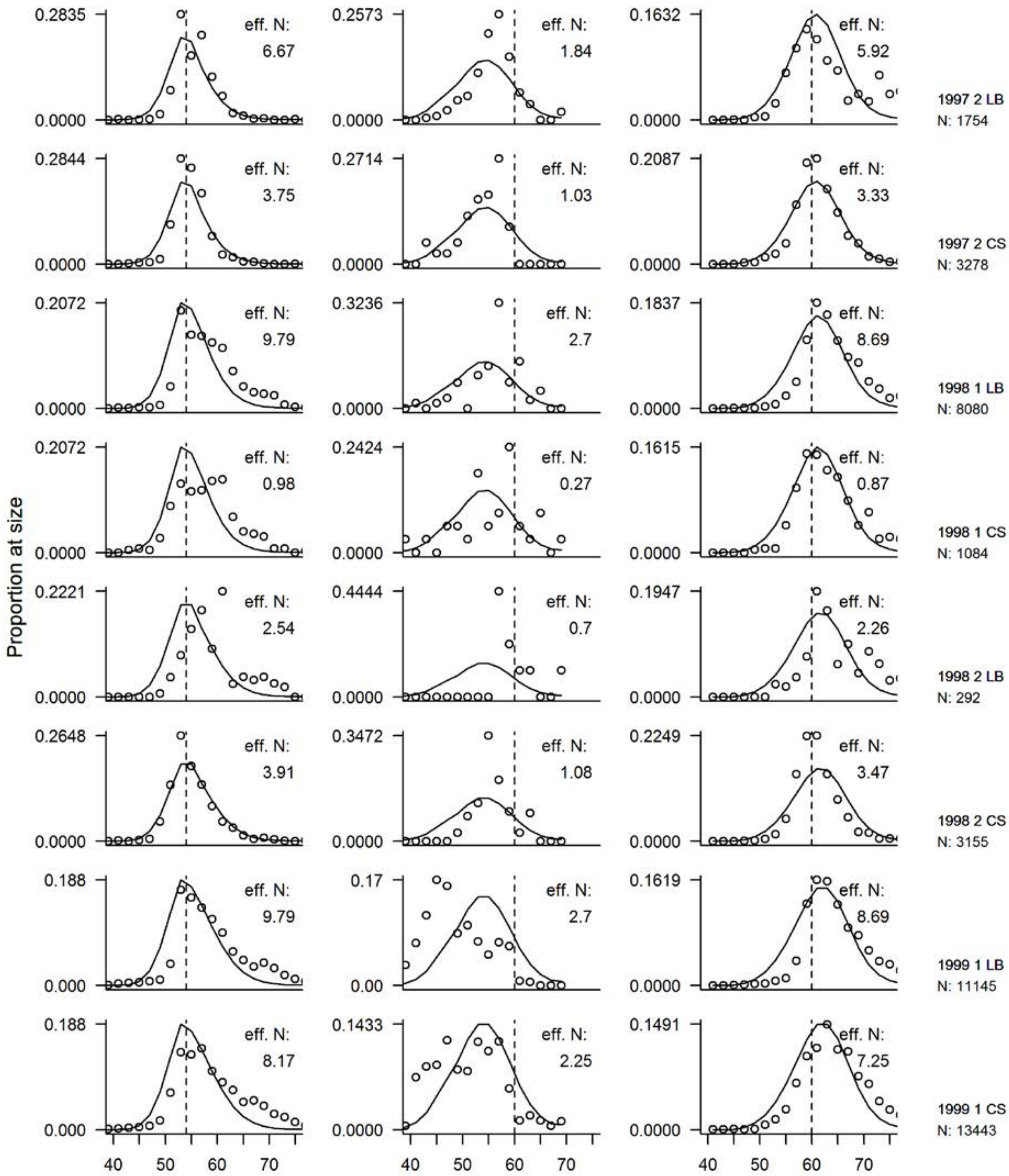



**Figure 10C: Fit to the LFs (1997 SS CS to 1999 AW CS) for the CRA 5 "base1" base case.**

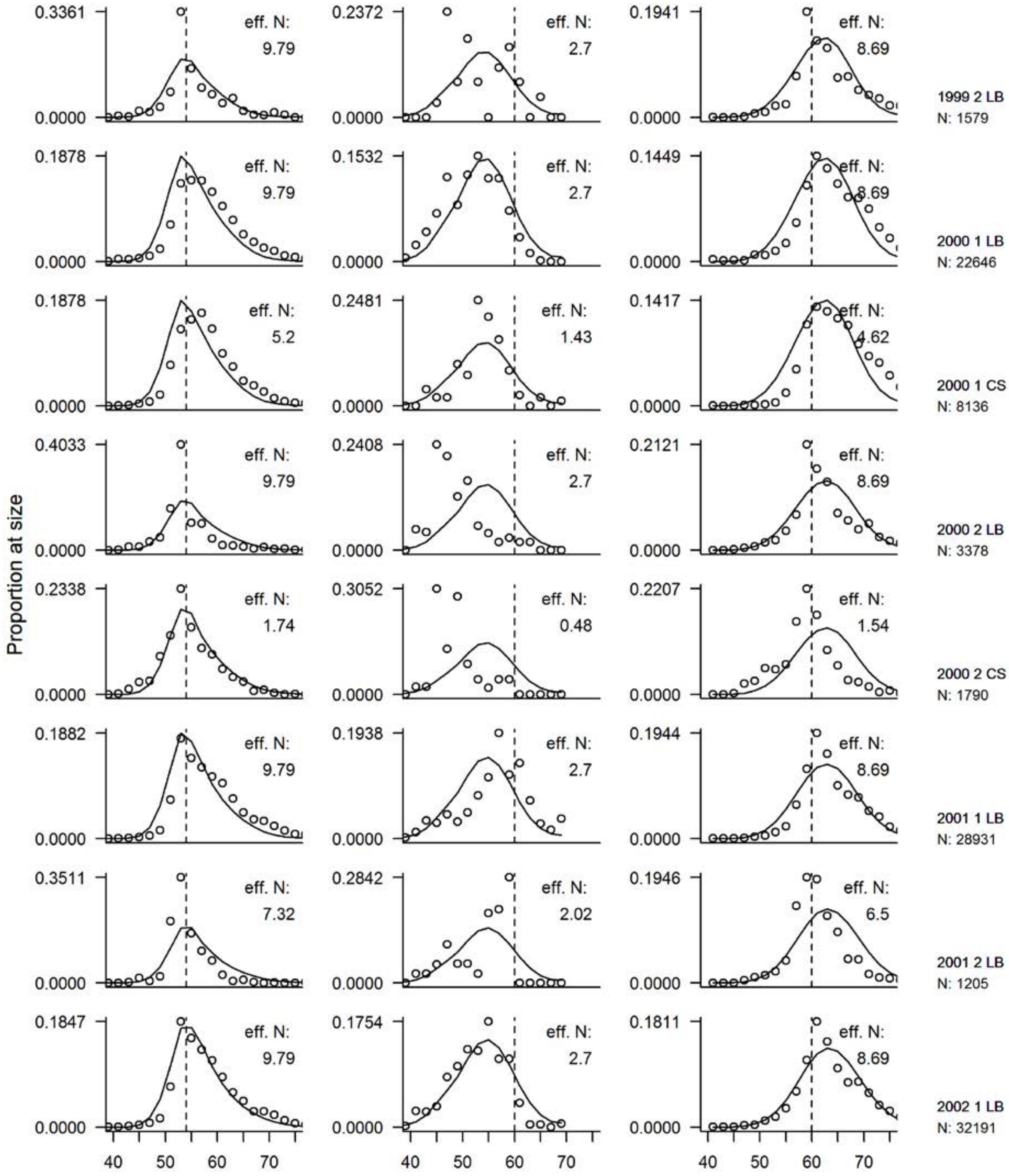



**Figure 10D: Fit to the LFs (1999 SS LB to 2002 AW LB) for the CRA 5 "base1" base case.**

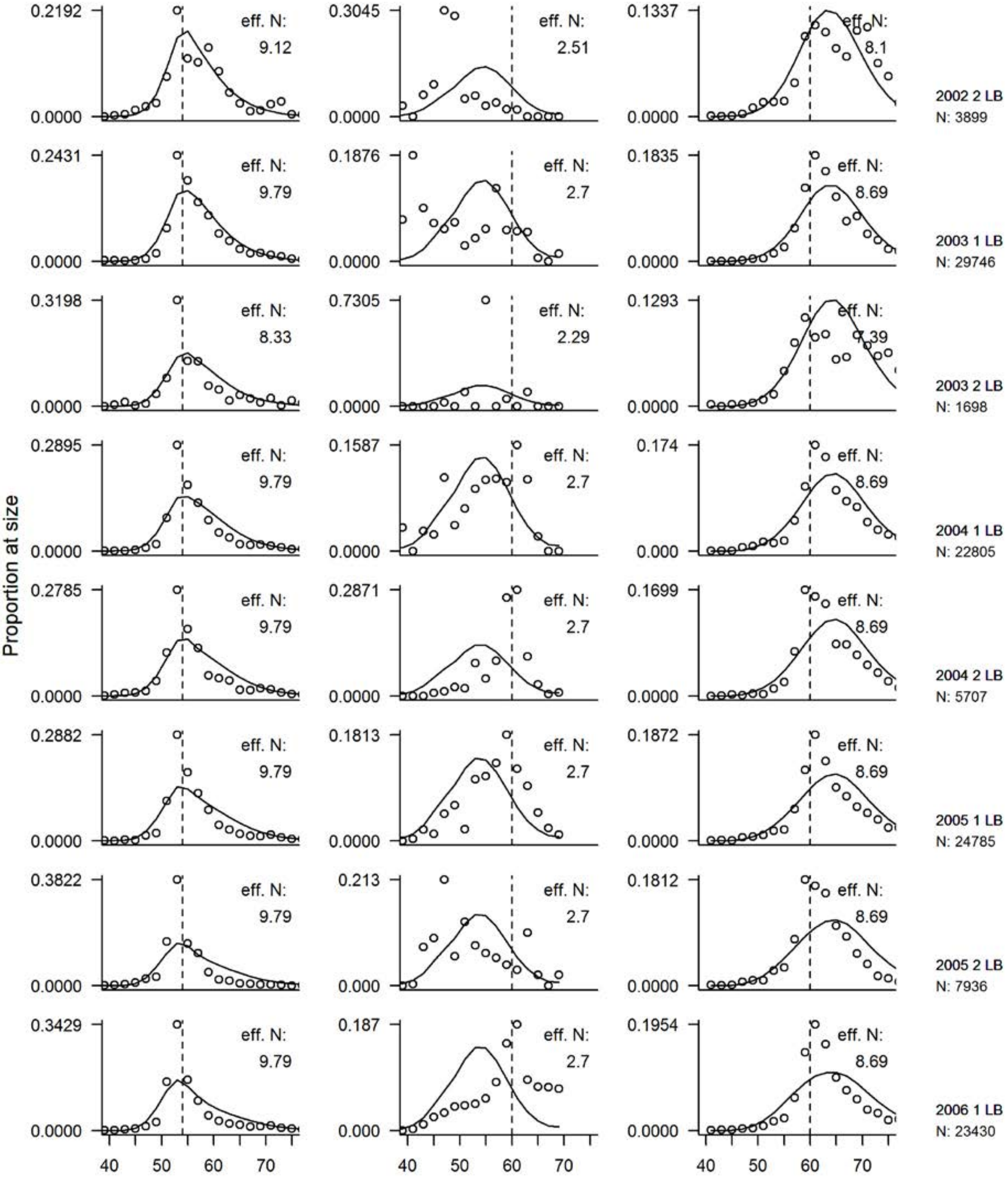



**Figure 10E: Fit to the LFs (2002 SS LB to 2006 AW LB) for the CRA 5 "base1" base case.**

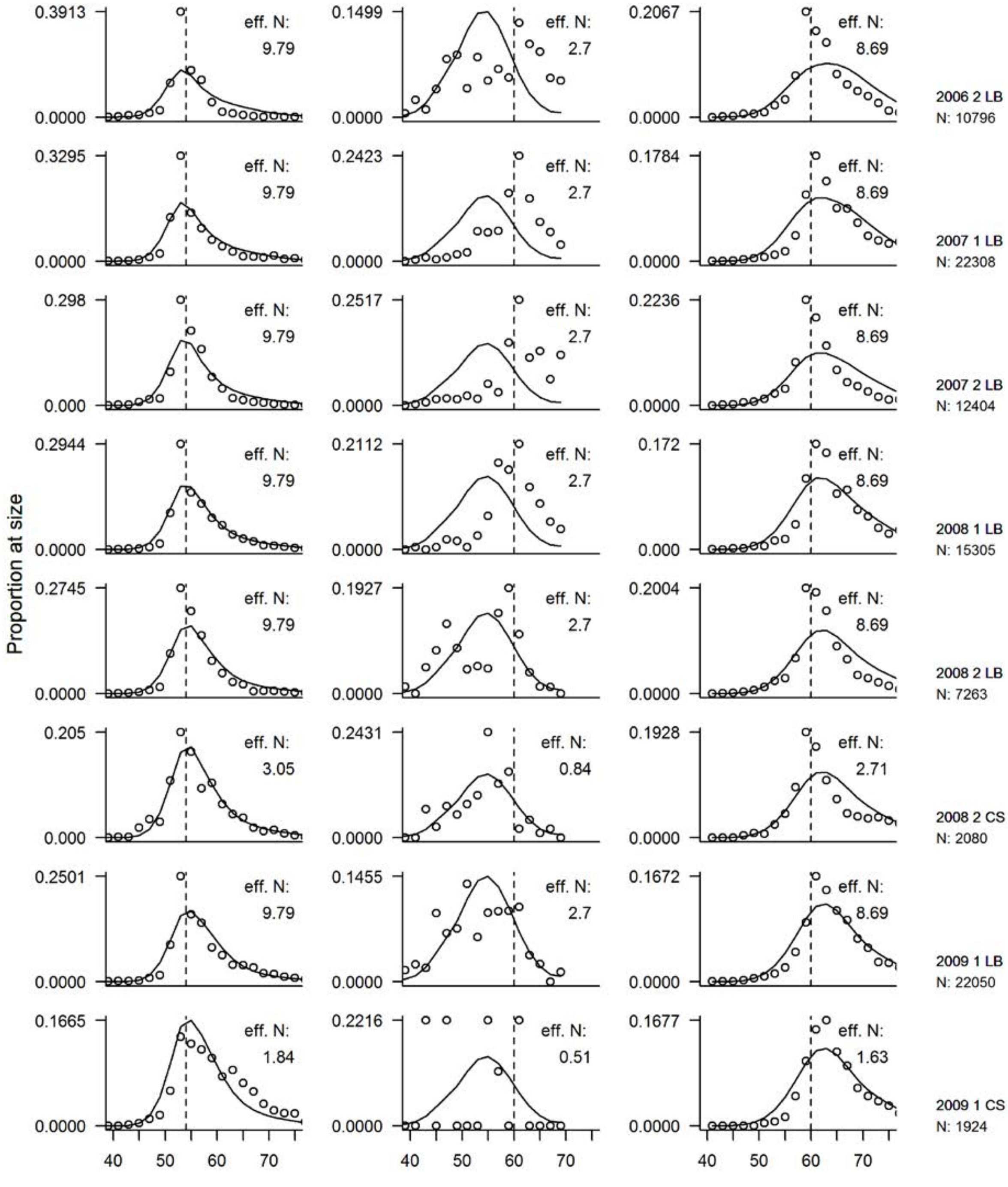



**Figure 10F: Fit to the LFs (2006 SS LB to 2009 AW CS) for the CRA 5 "base1" base case.**

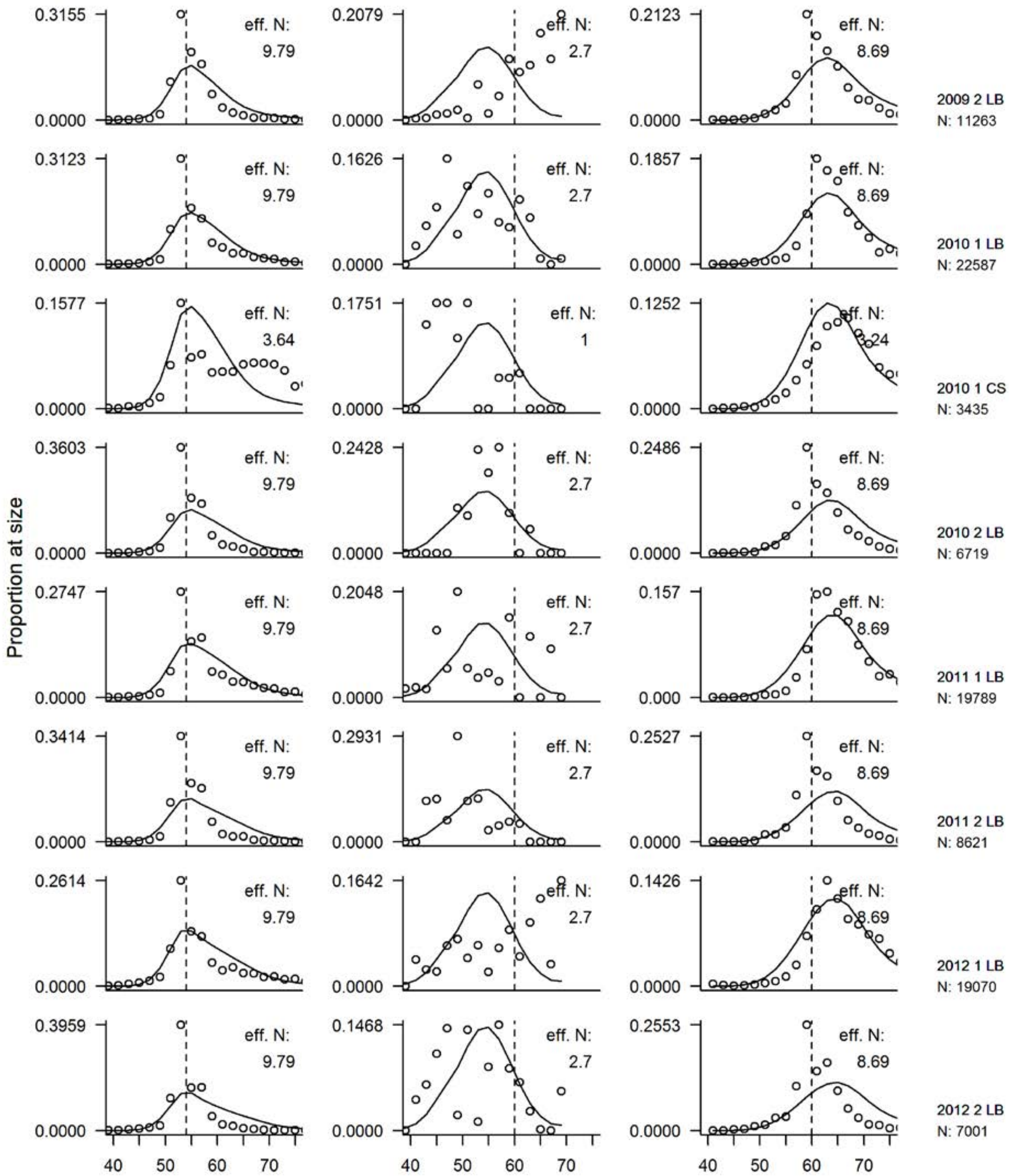



**Figure 10G: Fit to the LFs (2009 SS LB to 2012 SS LB) for the CRA 5 "base1" base case.**

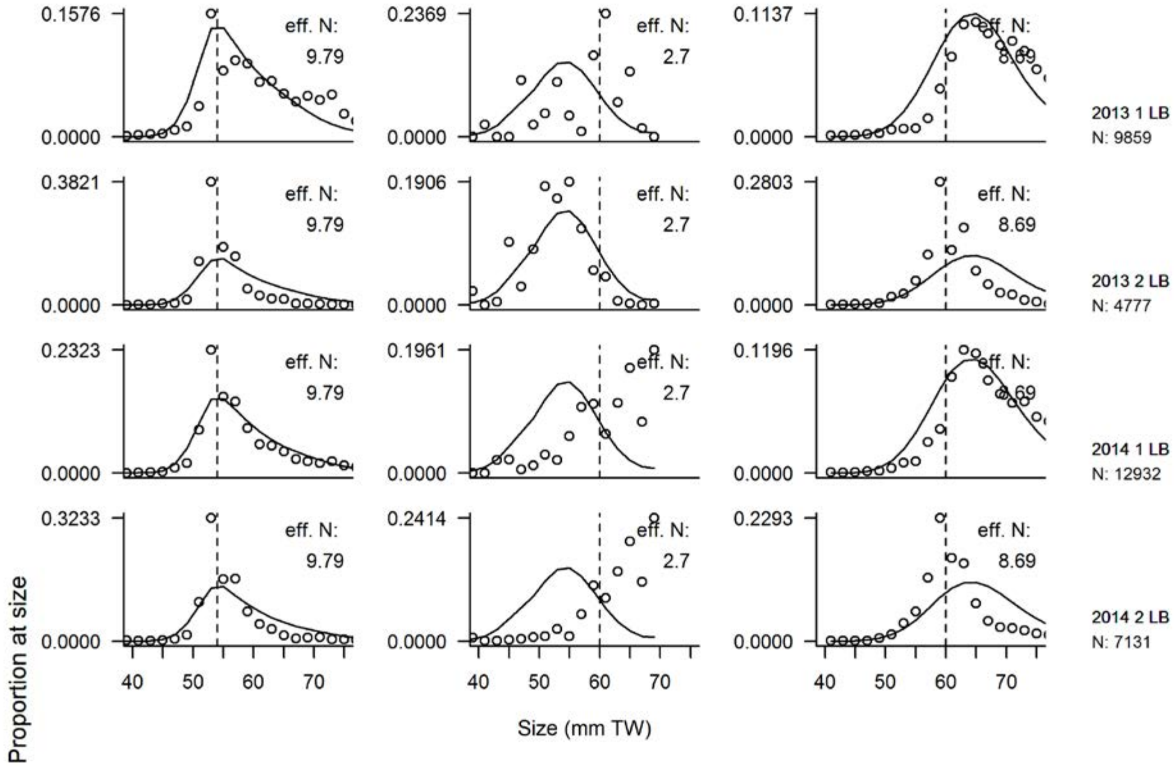



**Figure 10H: Fit to the LFs (2013 AW LB to 2014 SS LB) for the CRA 5 “base1” base case.**

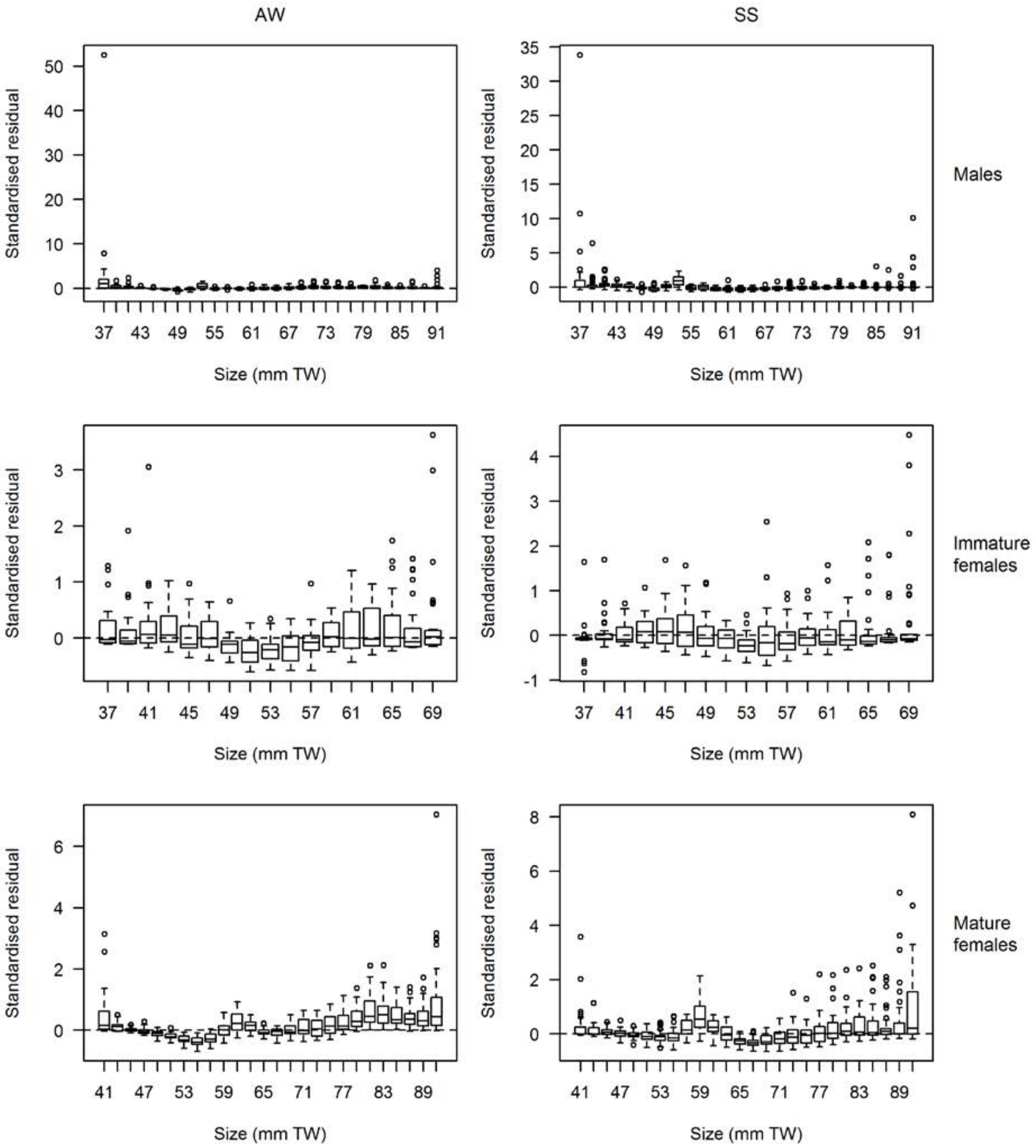


**Figure 11: Residuals from the fits to the LFs by sex, size and season for the CRA 5 "base1" base case.**

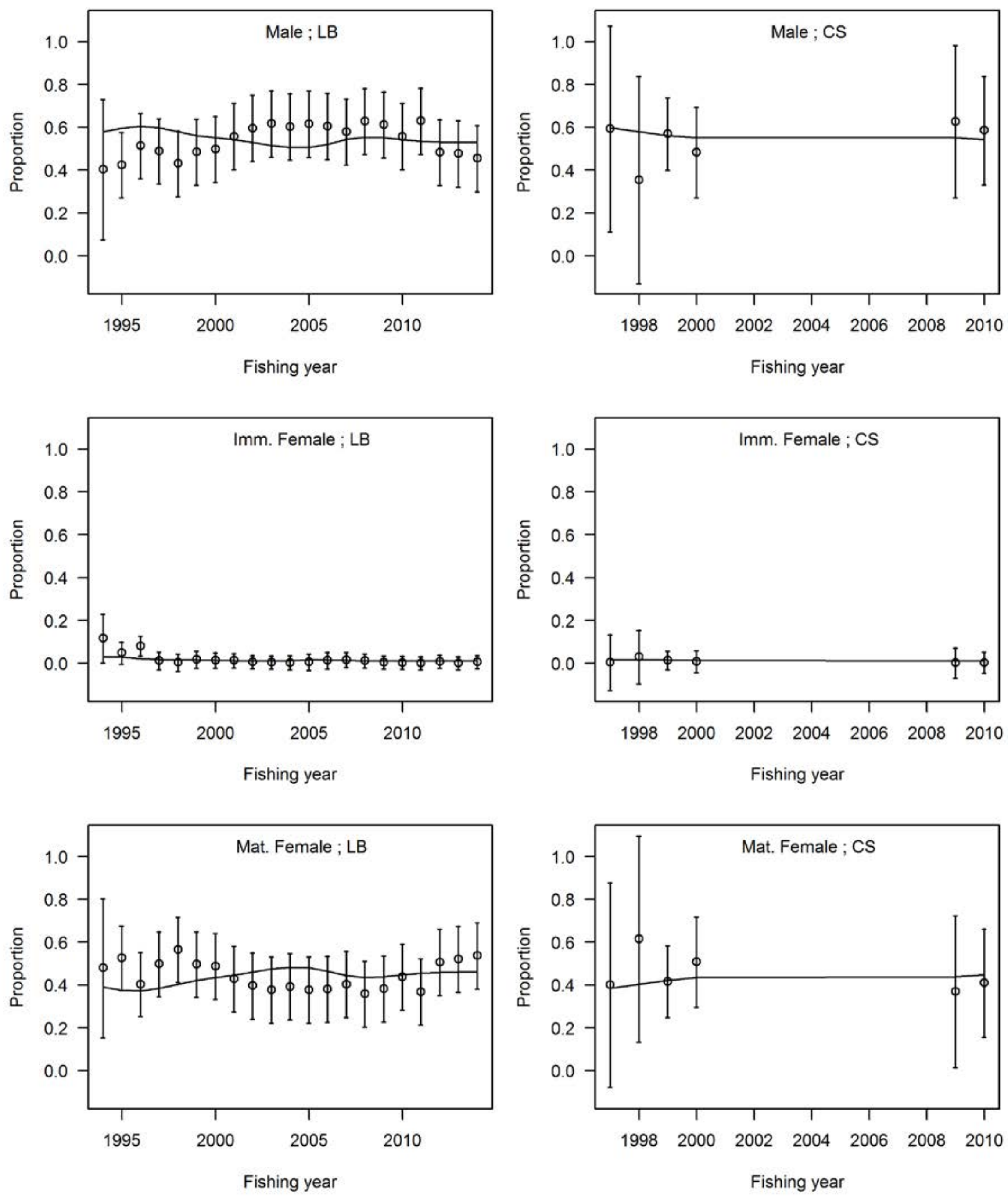



**Figure 12: Observed (circles) and predicted sex (lines) proportion fits in AW by sex and data source for the CRA 5 "base1" base case.**

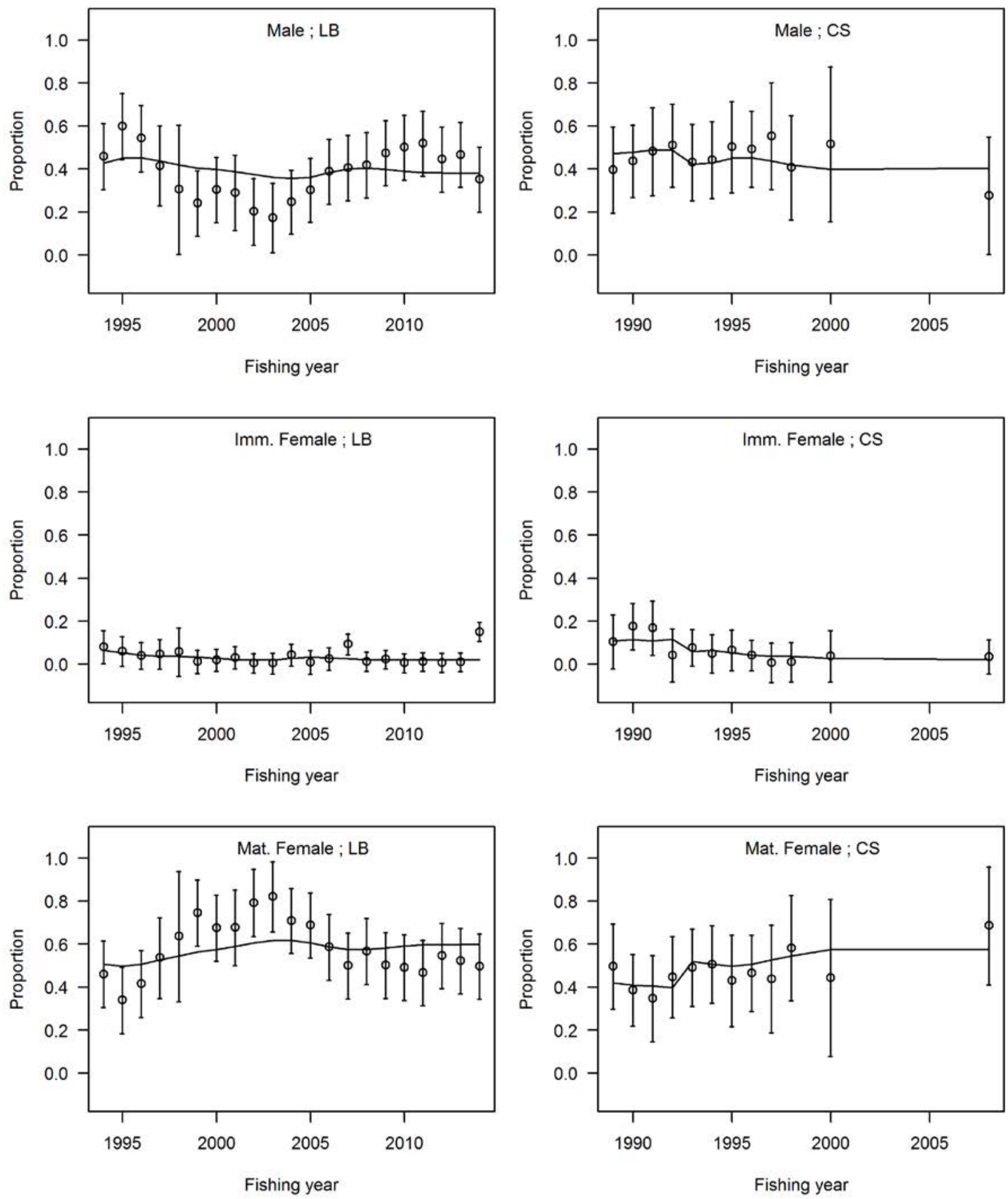



**Figure 13: Observed (circles) and predicted sex (lines) proportion fits in SS by sex and data source for the CRA 5 "base1" base case.**

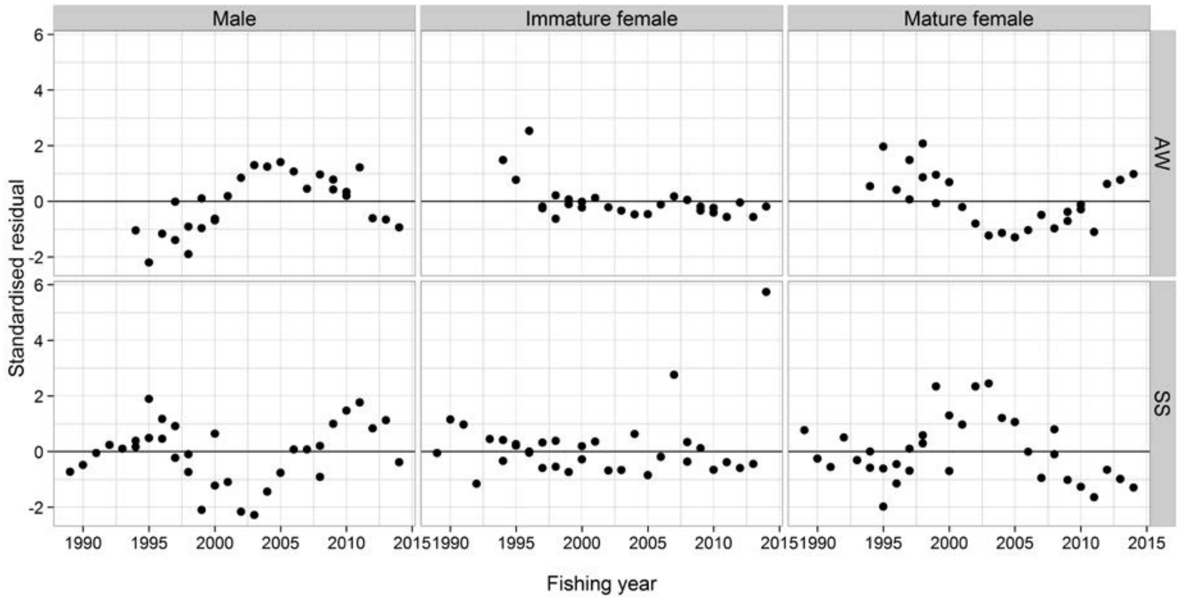



**Figure 14:** **Residuals from the fits to sex proportions by year, season (AW = autumn-winter, SS = spring-summer) and sex category for the CRA 5 “base1” base case.**

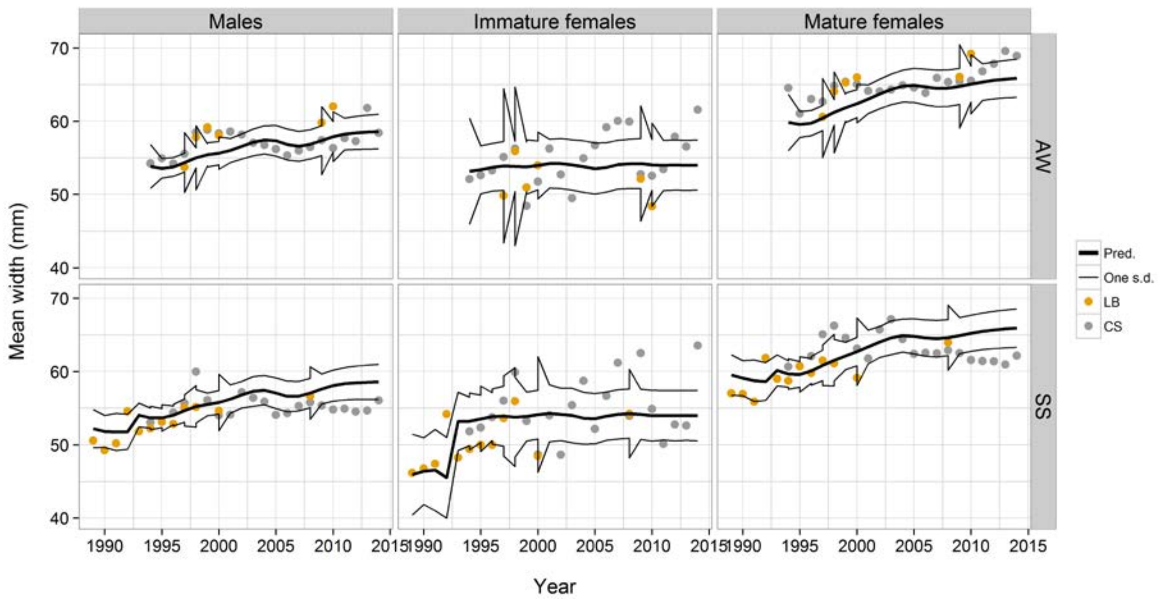



**Figure 15:** **Predicted (solid line) and observed (filled circles) mean length by year, data source, sex category and season (AW = autumn-winter, SS = spring-summer) for the CRA 5 “base1” base case. Thinner lines show one standard deviation from the predicted mean.**

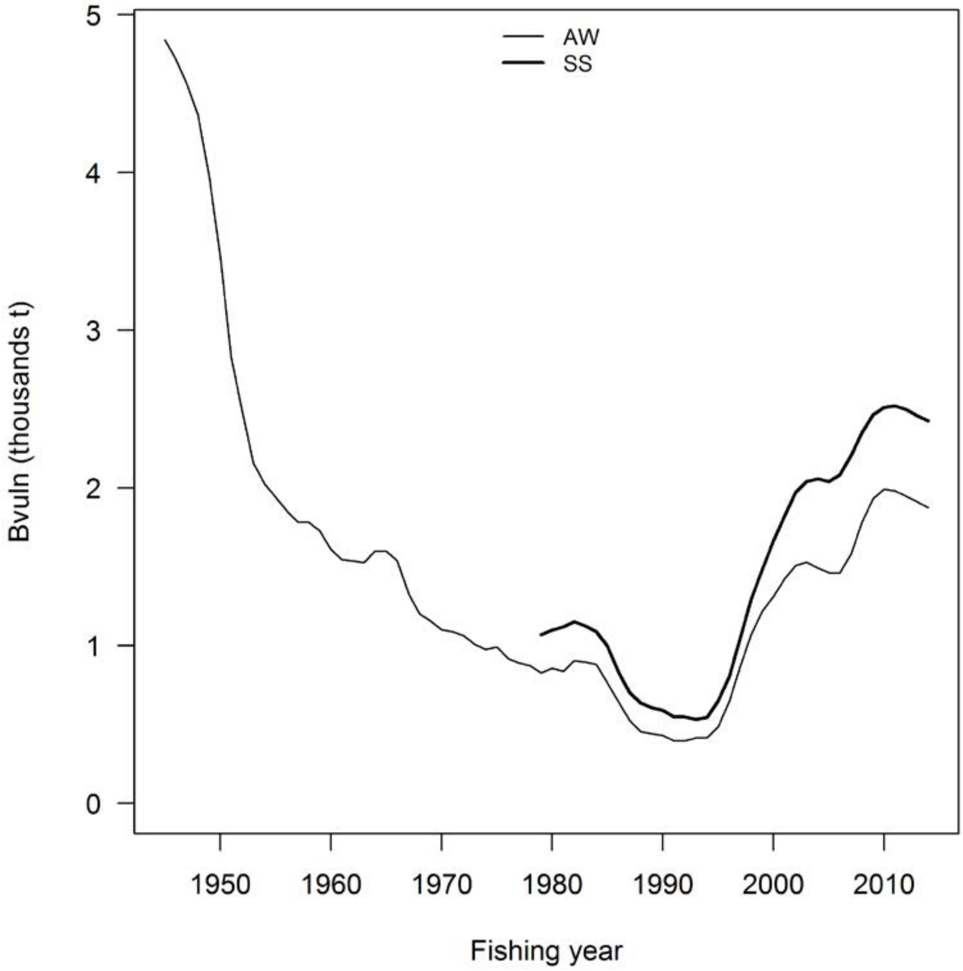



**Figure 16: Vulnerable biomass trajectory by season for the CRA 5 "base1" base case MPD. The model used a yearly time step before 1979 that is shown as "AW".**

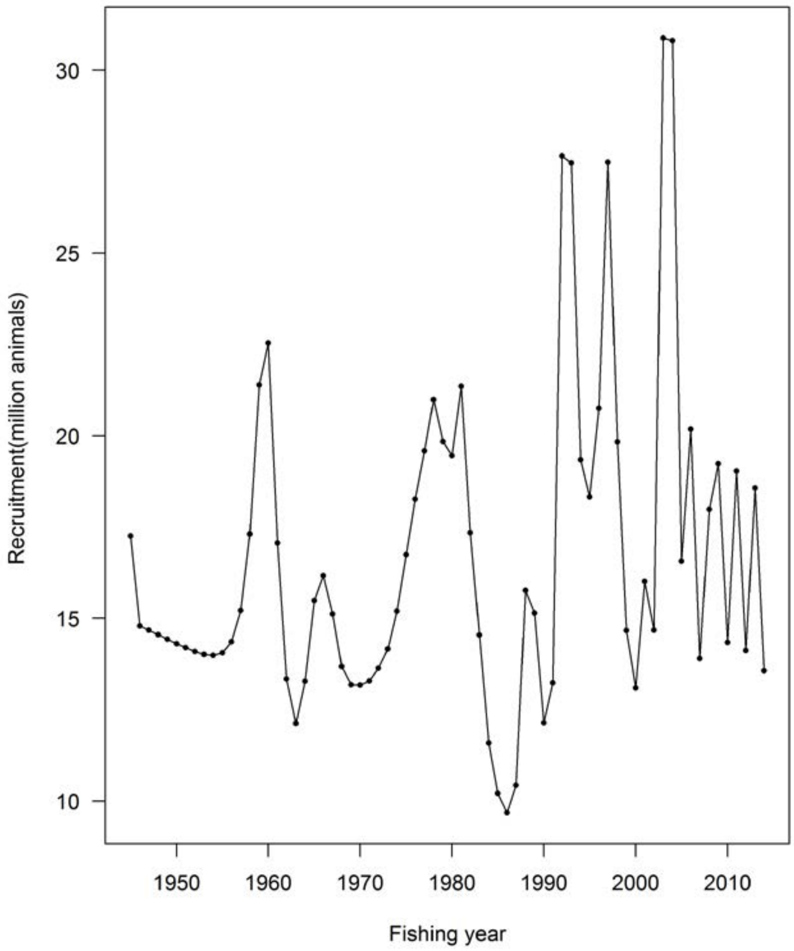



**Figure 17: Annual recruitment from the MPD fit for the CRA 5 "base1" base case. Note that recruitments are estimated up to 2014 because of the availability of puerulus information.**

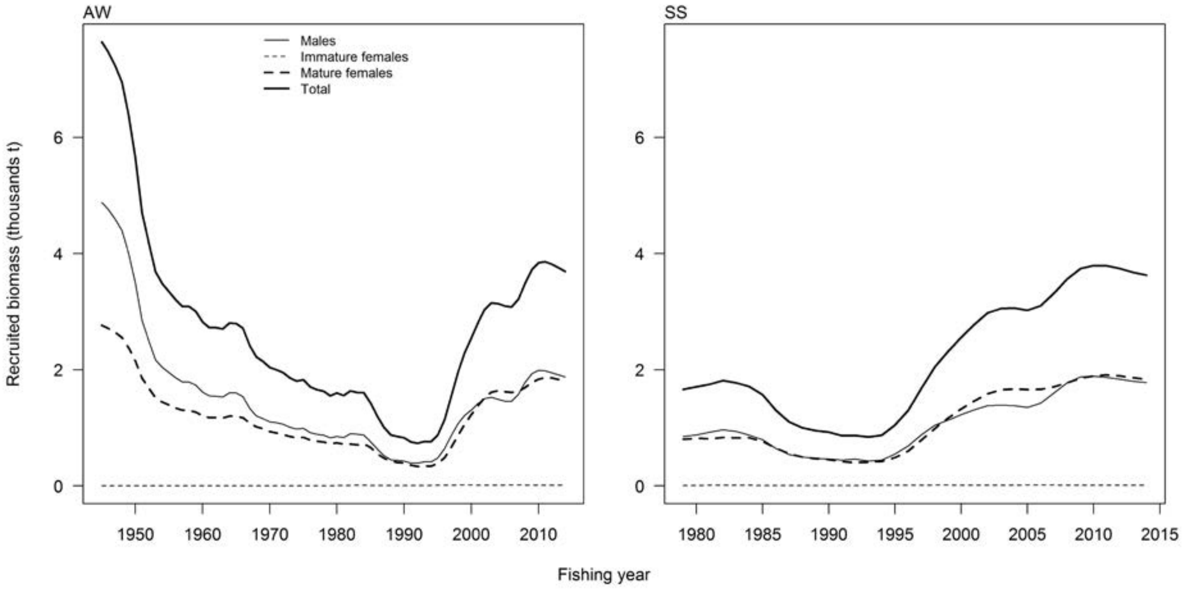



**Figure 18: Seasonal trajectories of recruited biomass by sex category and total recruited biomass for the CRA 5 "base1" base case MPD fit. The model used a yearly time step before 1979 that is shown in the AW panel.**

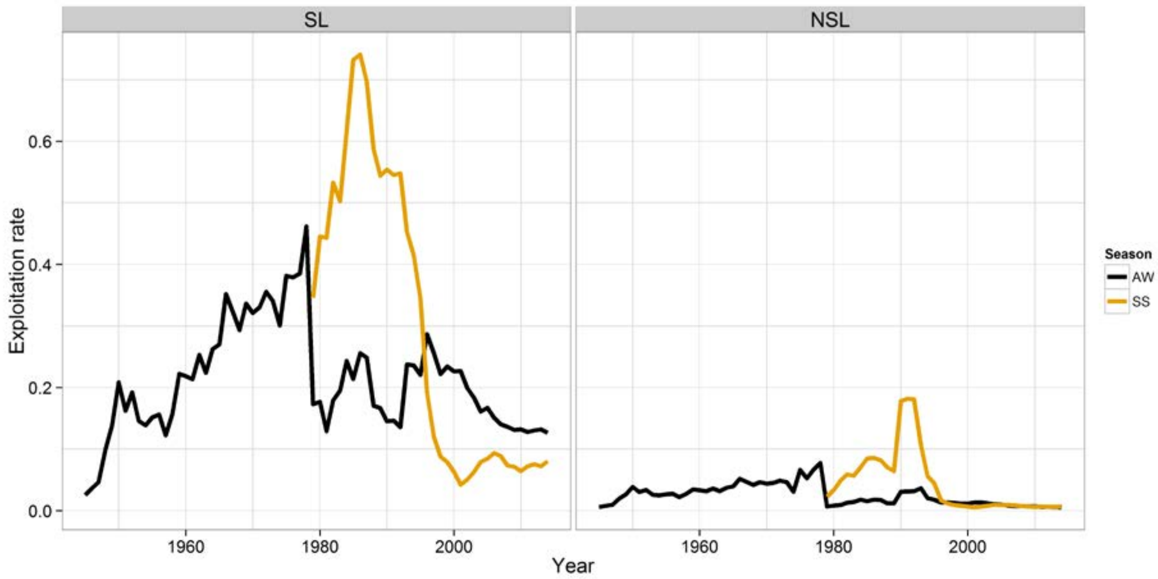



**Figure 19: Seasonal trajectories of exploitation rate for the SL and NSL fisheries for the CRA 5 “base1” base case MPD fit.**

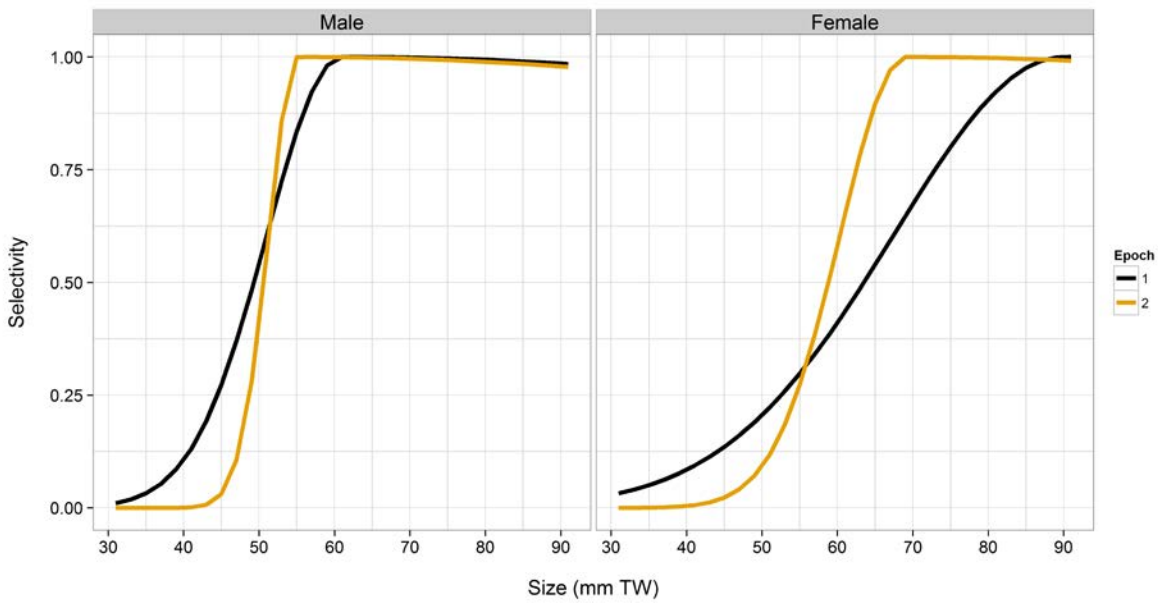



**Figure 20: Selectivity-at-size for males and females in two epochs for the CRA 5 “base1” base case. The second epoch began in 1993.**

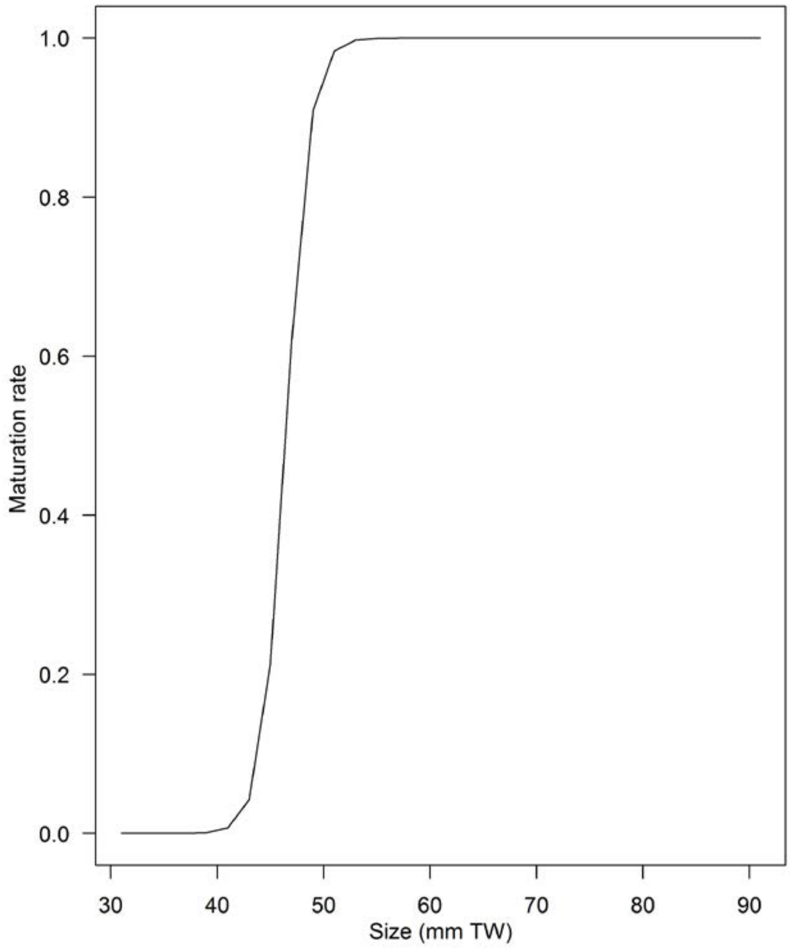



**Figure 21: Maturation rate at length for the CRA 5 “base1” base case MPD fit.**

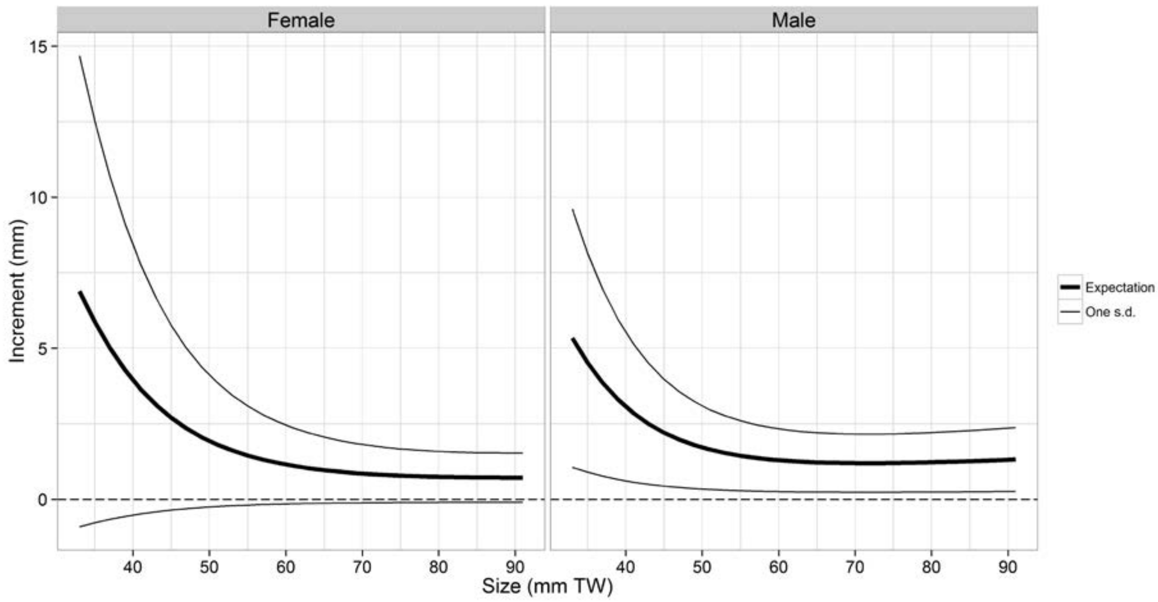



**Figure 22: Predicted increments against initial size by sex for the CRA 5 “base1” base case MPD fit. Thinner lines show one standard deviation from the predicted mean.**

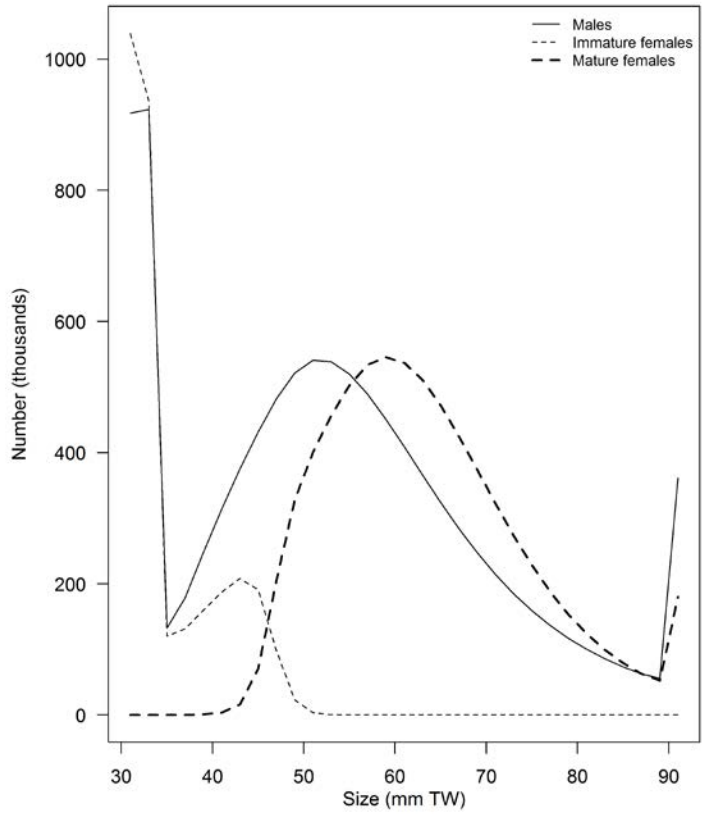



**Figure 23: The predicted size distributions by sex in the absence of fishing and with constant recruitment for the CRA 5 “base1” base case MPD fit.**

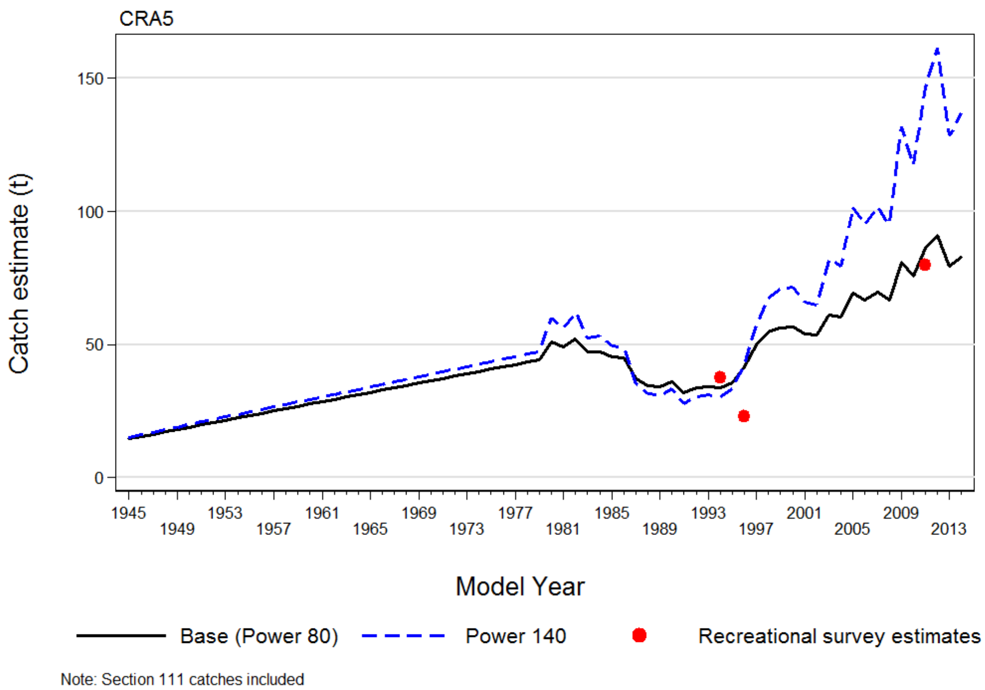



**Figure 24: Two alternative recreational catch trajectories: (A) the base case used the “Power 80” trajectory, where the Area 917 CPUE was scaled to the 1994/1996/2011 recreational survey estimates using an exponential power function (accepted by RLFAWG at 22 Sep meeting) with the final recreational estimate set=80 t in 2011; (B) the “Power 140” trajectory uses the same exponential power function, CPUE data and 1994/1996 recreational survey estimates, but uses 140 t for the recreational survey estimate in 2011.**

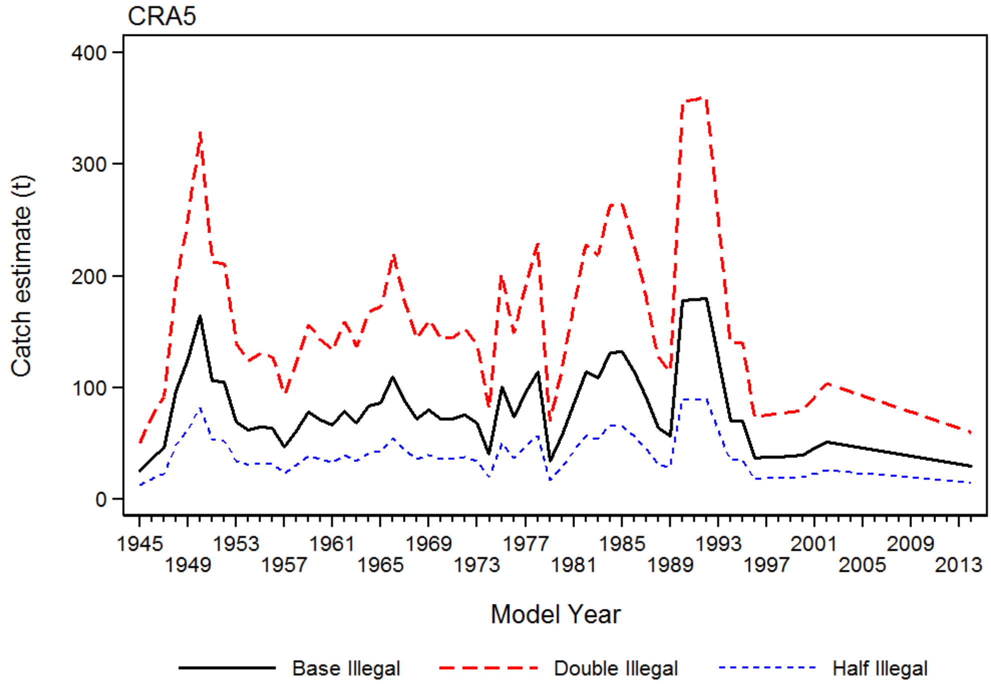



**Figure 25: Three alternative illegal catch trajectories: the base case trajectory based on export discrepancy information up to 1990 and fishery officer estimates afterward. The other two trajectories are double and half of the base case trajectory.**

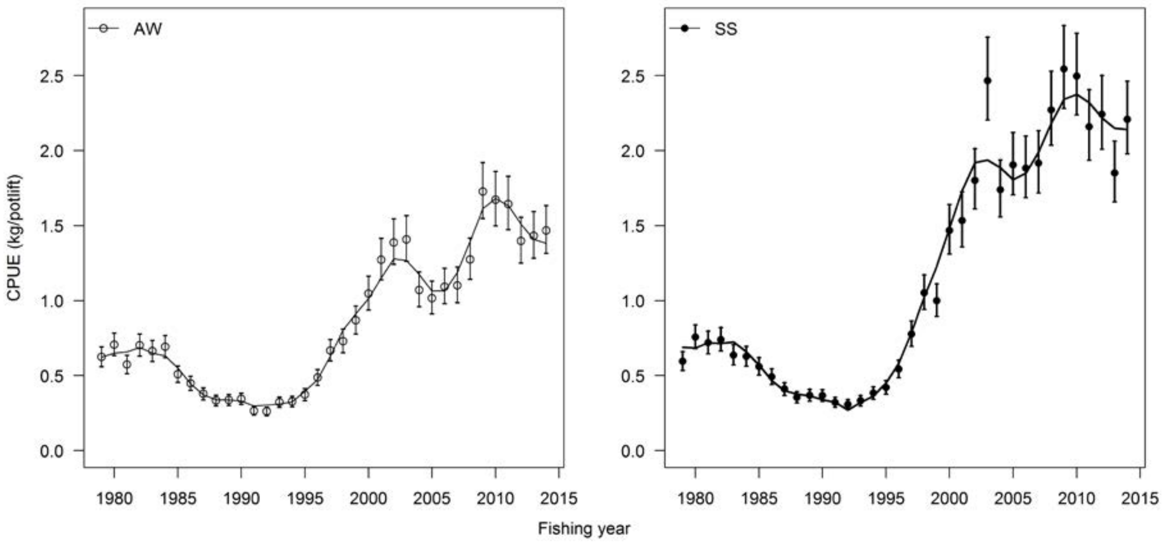



**Figure 26: The fit to CPUE in the CPUEpow sensitivity trial (sens12; Table 5).**

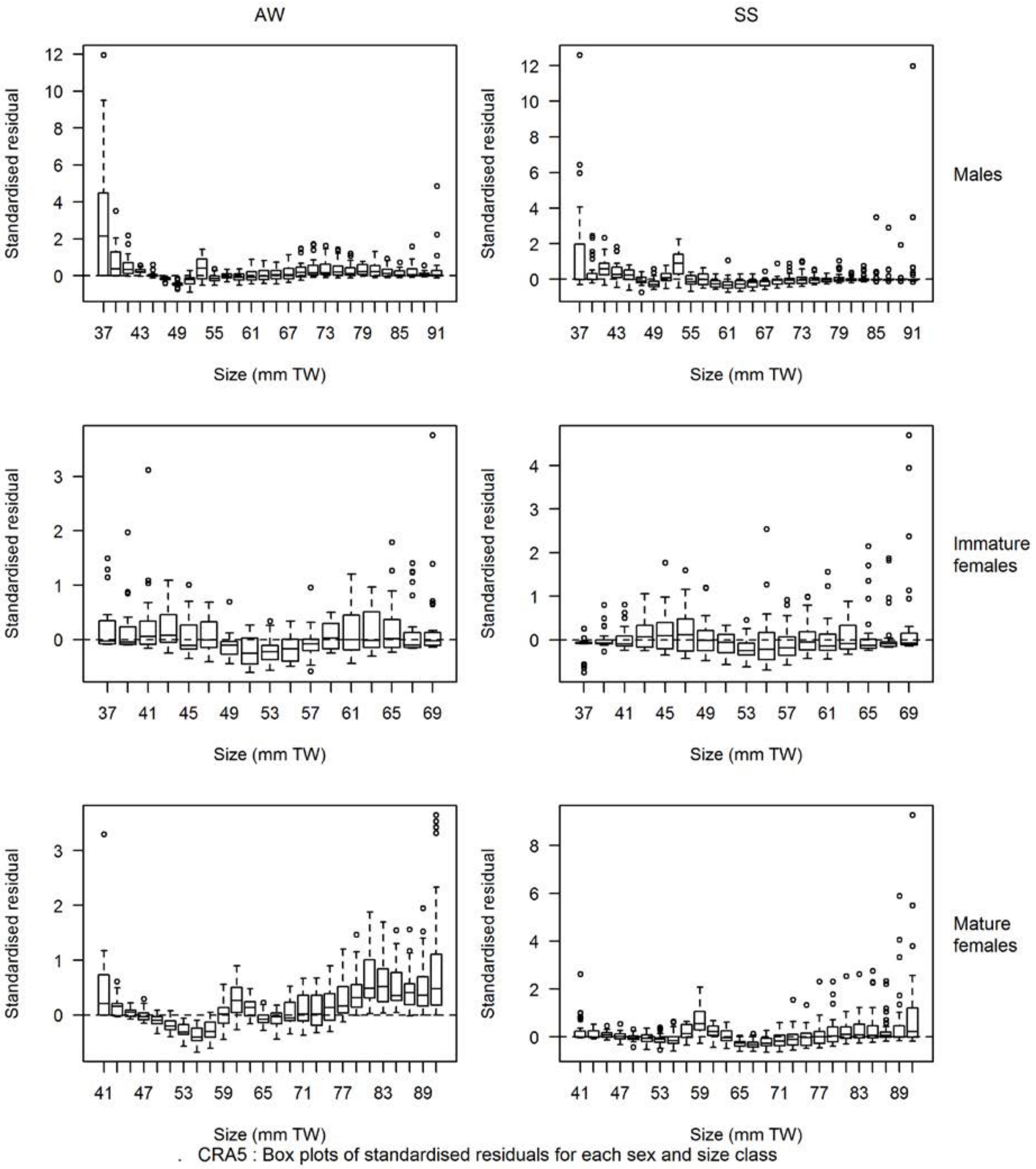



**Figure 27: Residuals from the fits to the LFs by sex, size and season for the CRA 5 sens14 (Table 5) sensitivity run which dropped the four LF samples which were causing large standardised residuals in both base case runs (see Figure 11).**

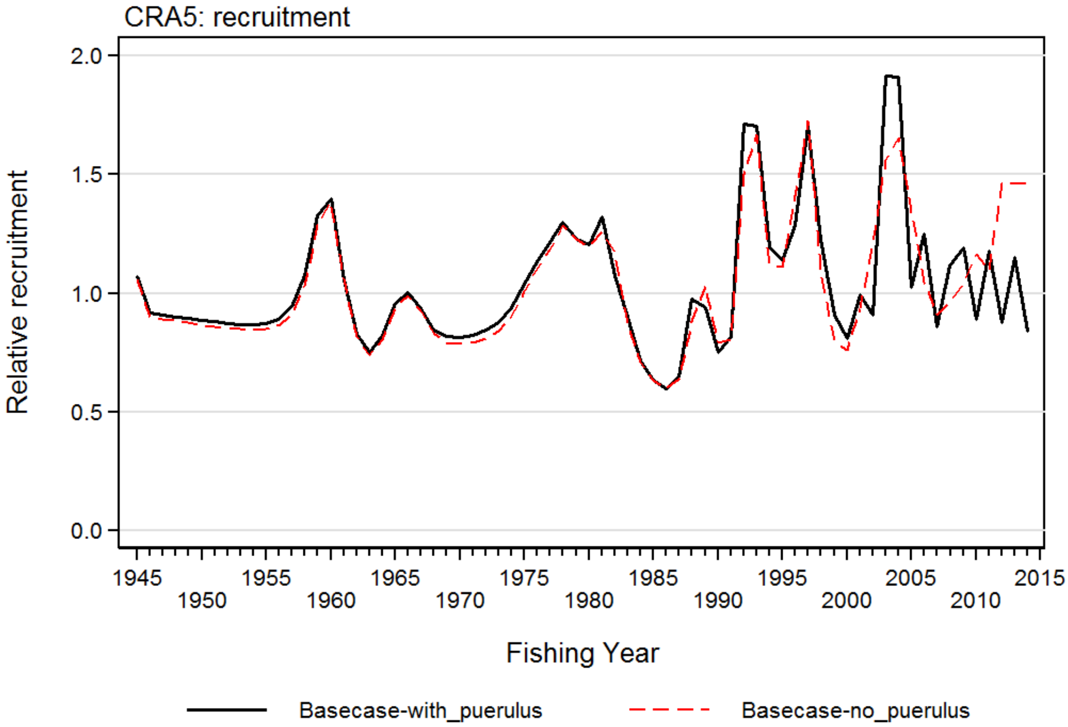



**Figure 28: Relative recruitment trajectories for the "base1" base case (with puerulus) and the same run (sens1, Table 4) which omits the puerulus series.**

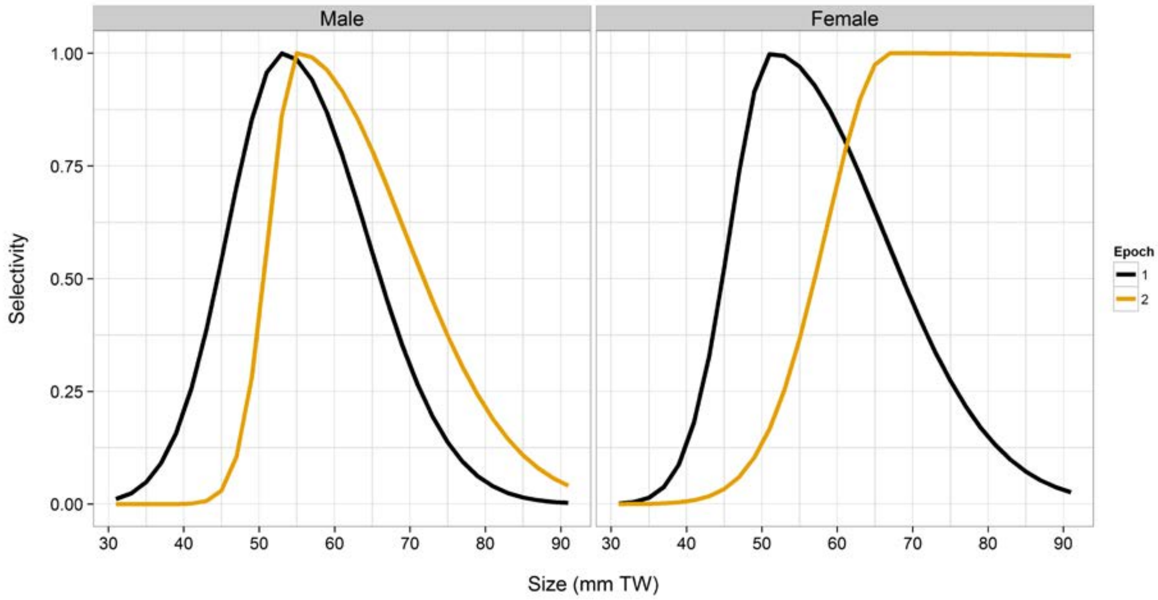



**Figure 29: Selectivity functions by sex and epoch (sens4, est right-hand limb).**

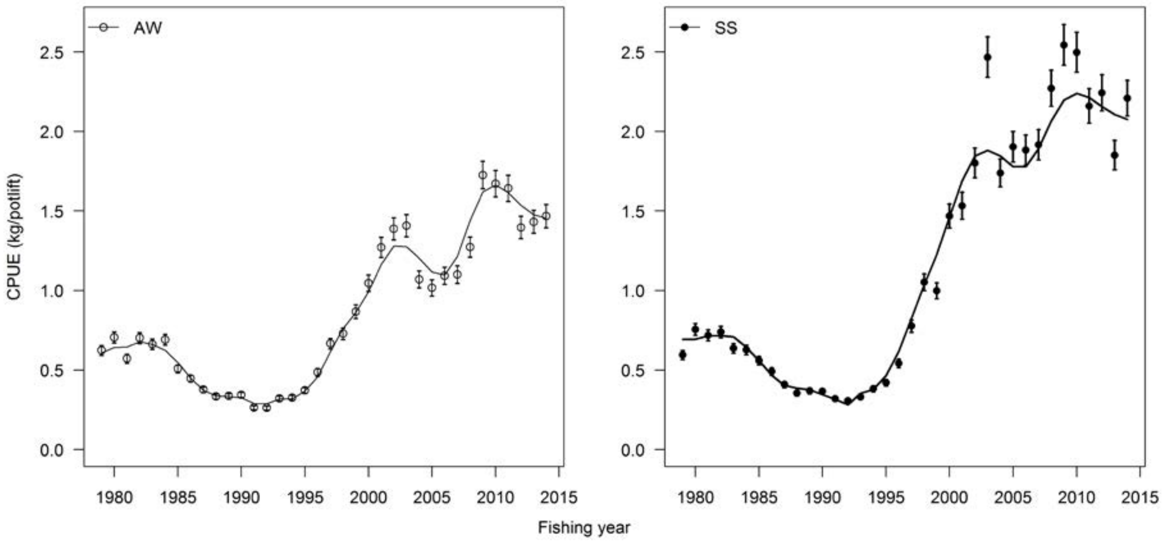



**Figure 30: Fits to the CPUE data series for sens6 (Table 4) where the weight on the CPUE data has been arbitrarily doubled relative to the base case.**

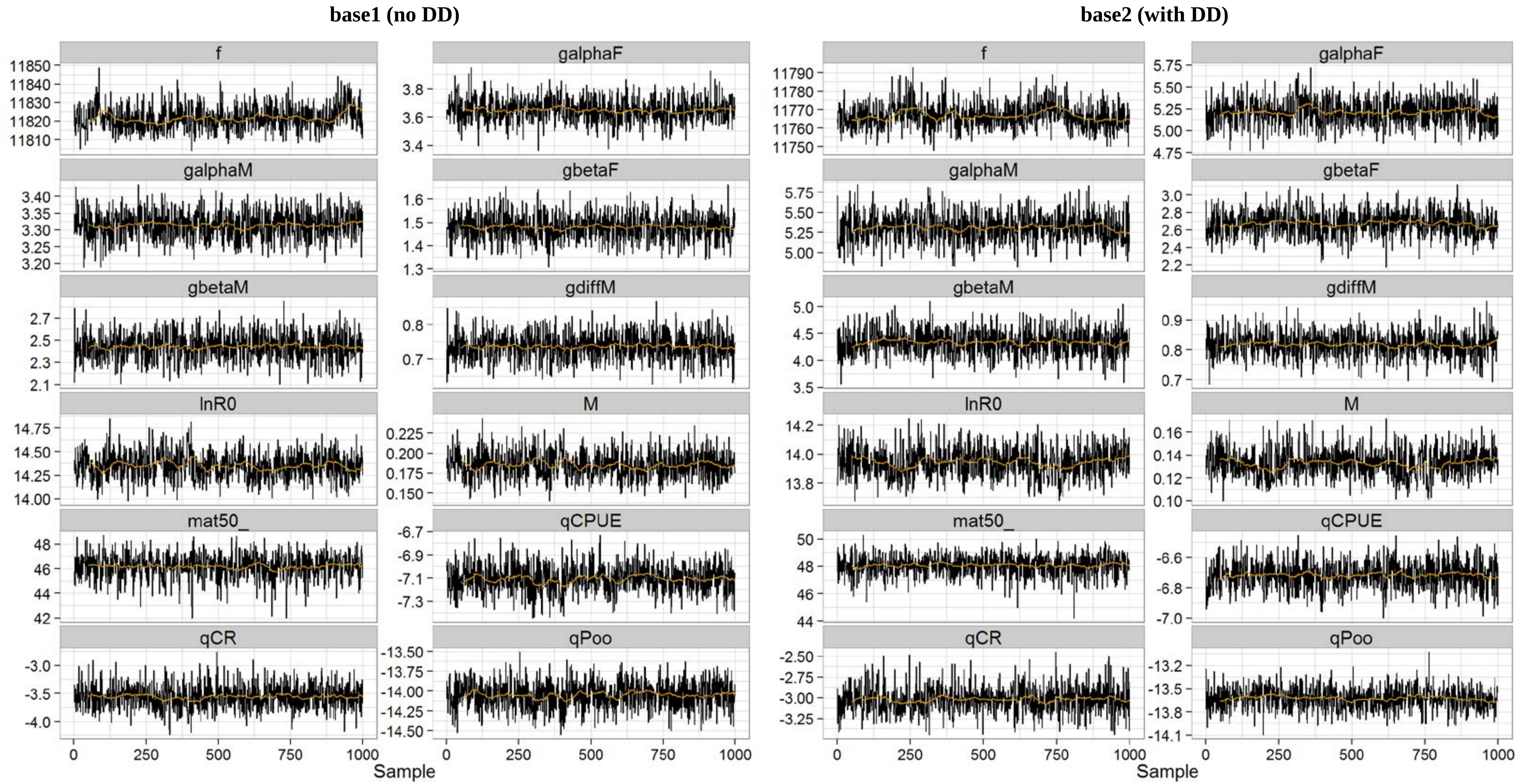



**Figure 31A: MCMC trace plots for estimated and derived parameters from the base1 (left panels) and base2 (right panels) models. The gold line is a moving mean over 50 samples.**

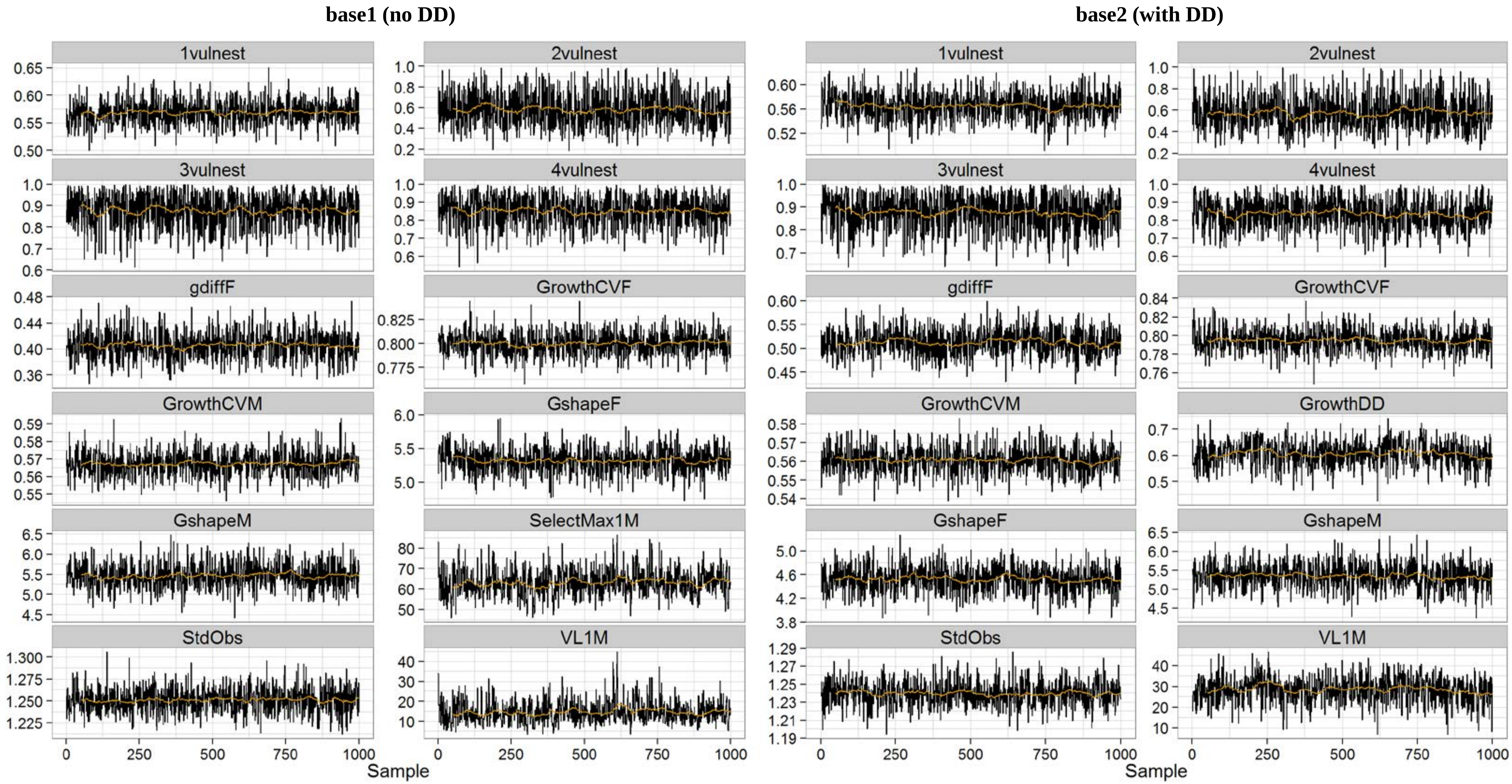



**Figure 31B: MCMC trace plots for estimated and derived parameters from the base1 (left panels) and base2 (right panels) models. The gold line is a moving mean over 50 samples.**

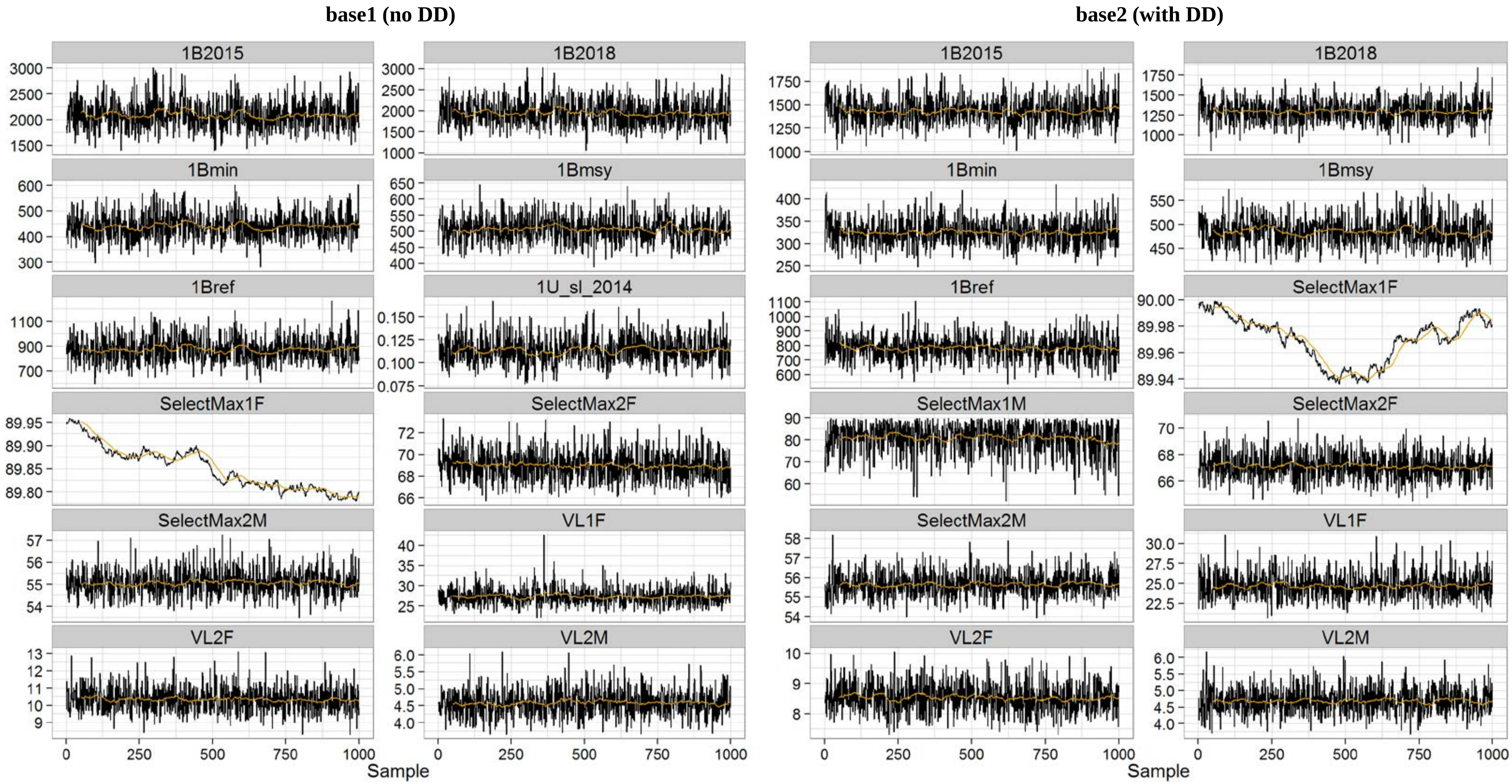



**Figure 31C: MCMC trace plots for estimated and derived parameters from the base1 (left panels) and base2 (right panels) models. The gold line is a moving mean over 50 samples.**

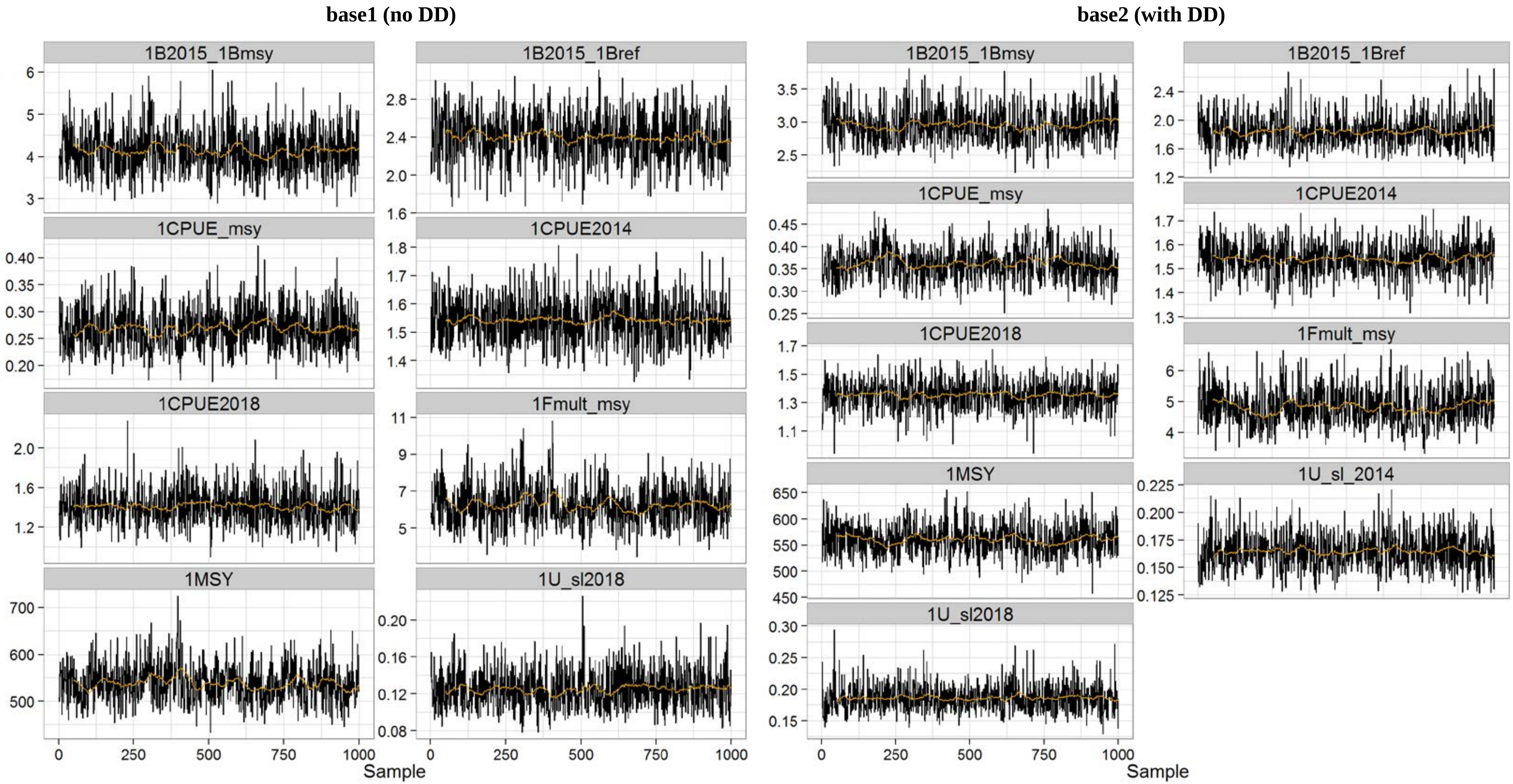



**Figure 31D: MCMC trace plots for estimated and derived parameters from the base1 (left panels) and base2 (right panels) models. The gold line is a moving mean over 50 samples. Included in this plot is the panel showing the trace of $B_{2015}/B_{ref}$ for each of the models. $B_{ref}$ is defined as the mean AW beginning year vulnerable biomass from 1979–1988. $B_{curr}$ or $B_{2015}$ is the AW beginning year vulnerable biomass in 2013.**

base1 (no DD) base2 (with DD)

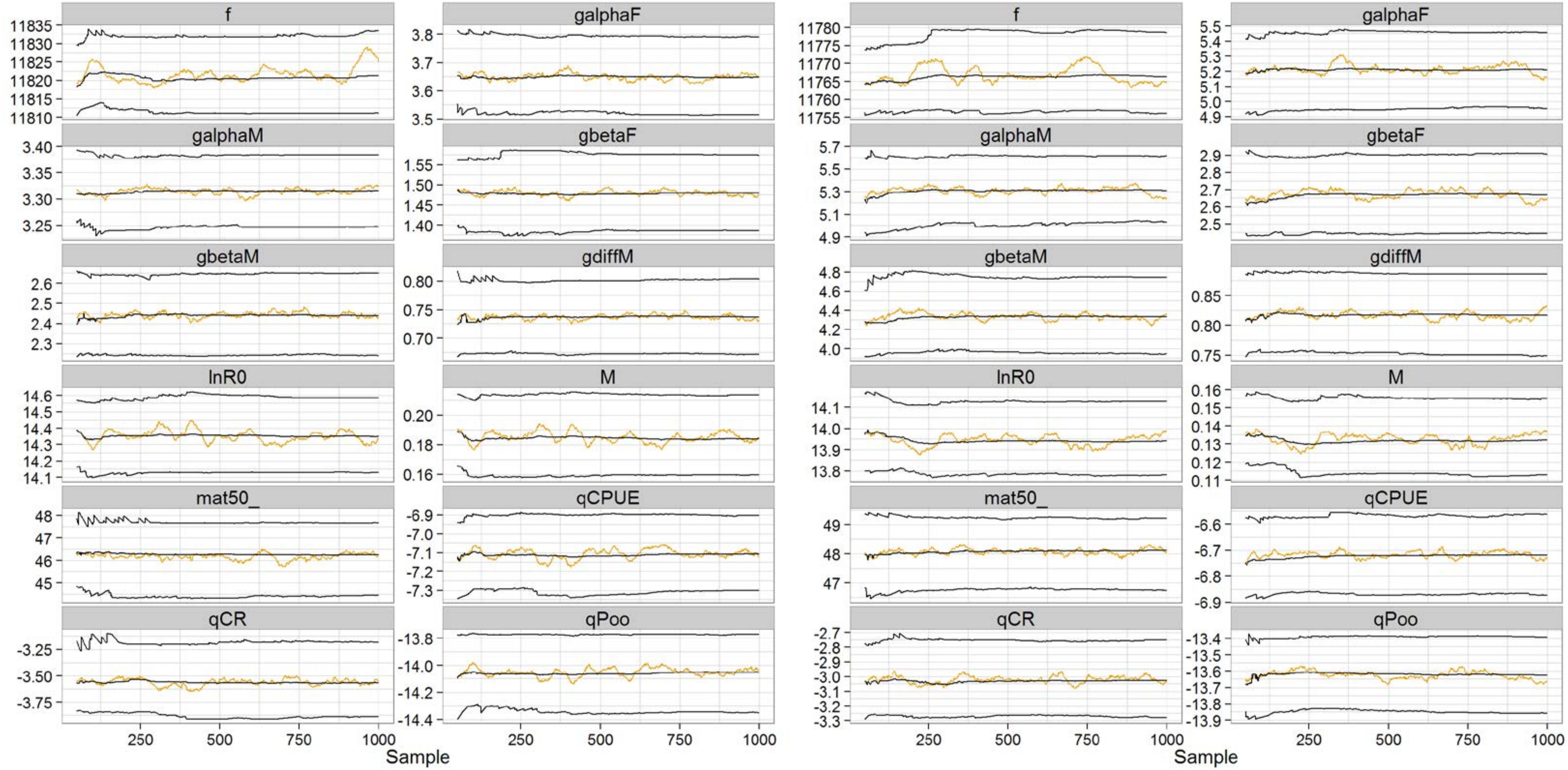



**Figure 32A: Diagnostic plots for the traces seen in Figure 31A for the base1 (left panels) and base2 (right panels) models. The solid black lines are the running median and the 5th and 95th quantiles. The gold line is a moving mean over 50 samples.**

**base1 (no DD)** **base2 (with DD)**

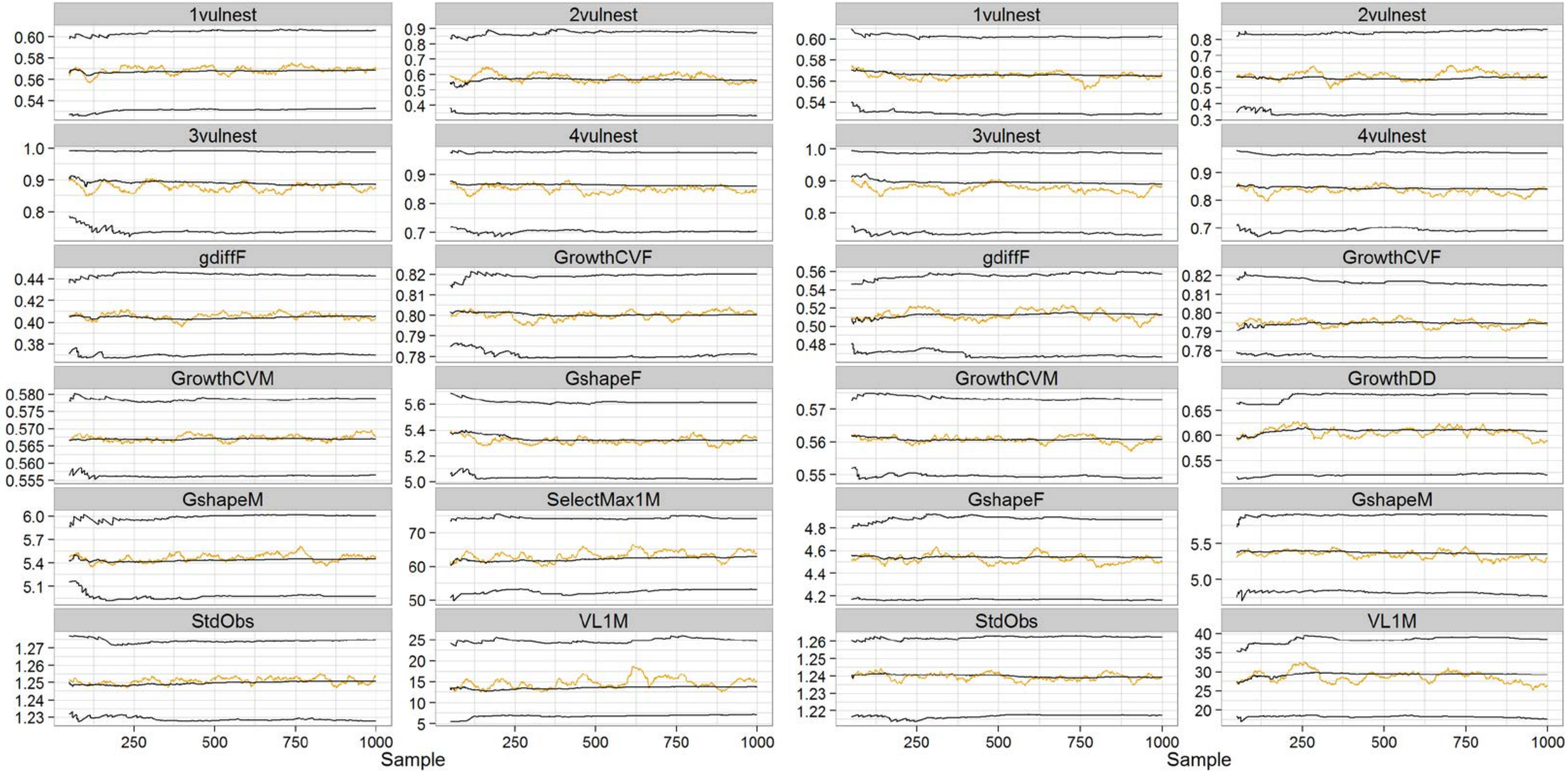



**Figure 32B: Diagnostic plots for the traces seen in Figure 31B for the base1 (left panels) and base2 (right panels) models.**

**base1 (no DD)** **base2 (with DD)**

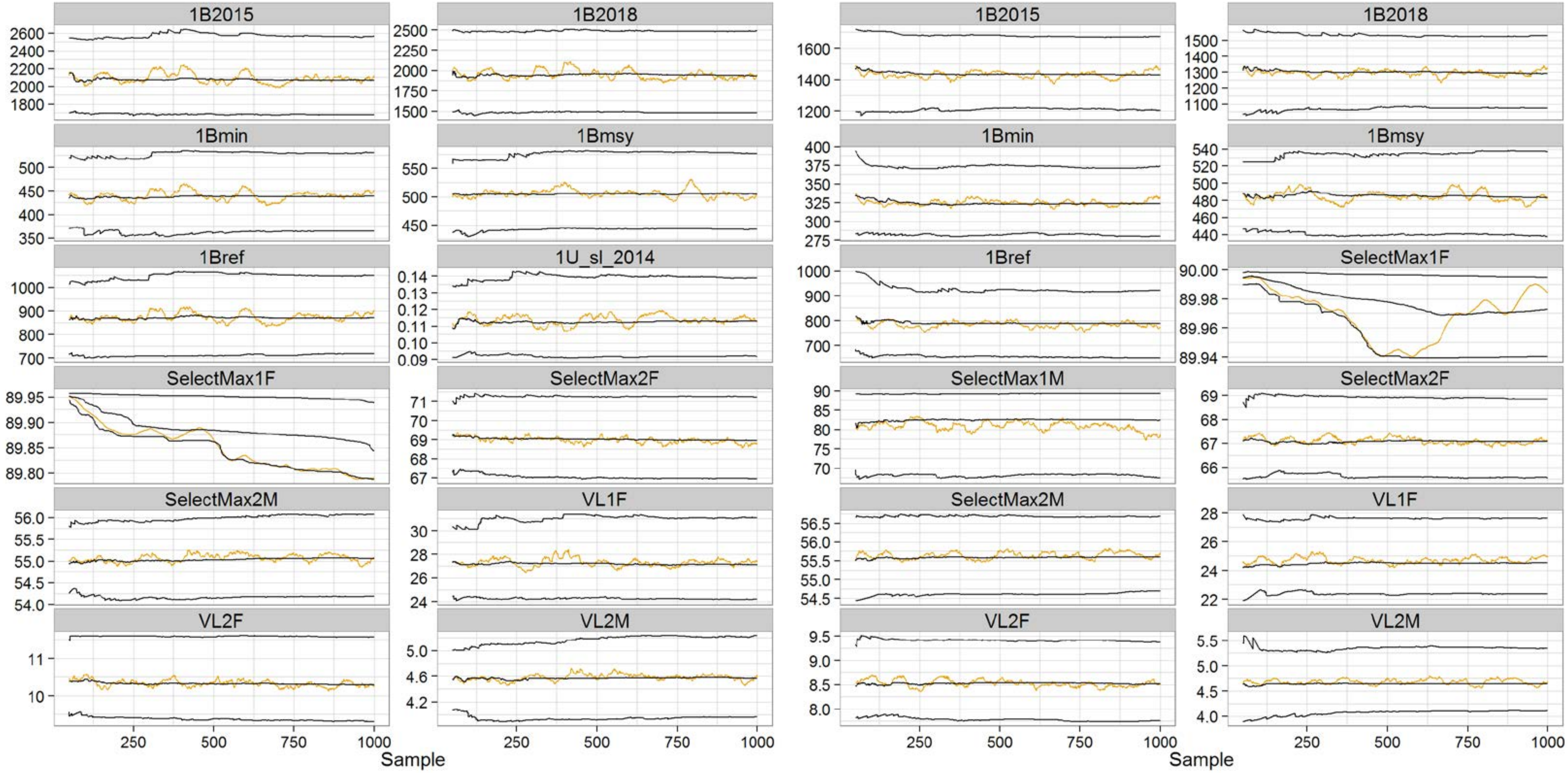



**Figure 32C: Diagnostic plots for the traces seen in Figure 31C for the base1 (left panels) and base2 (right panels) models.**

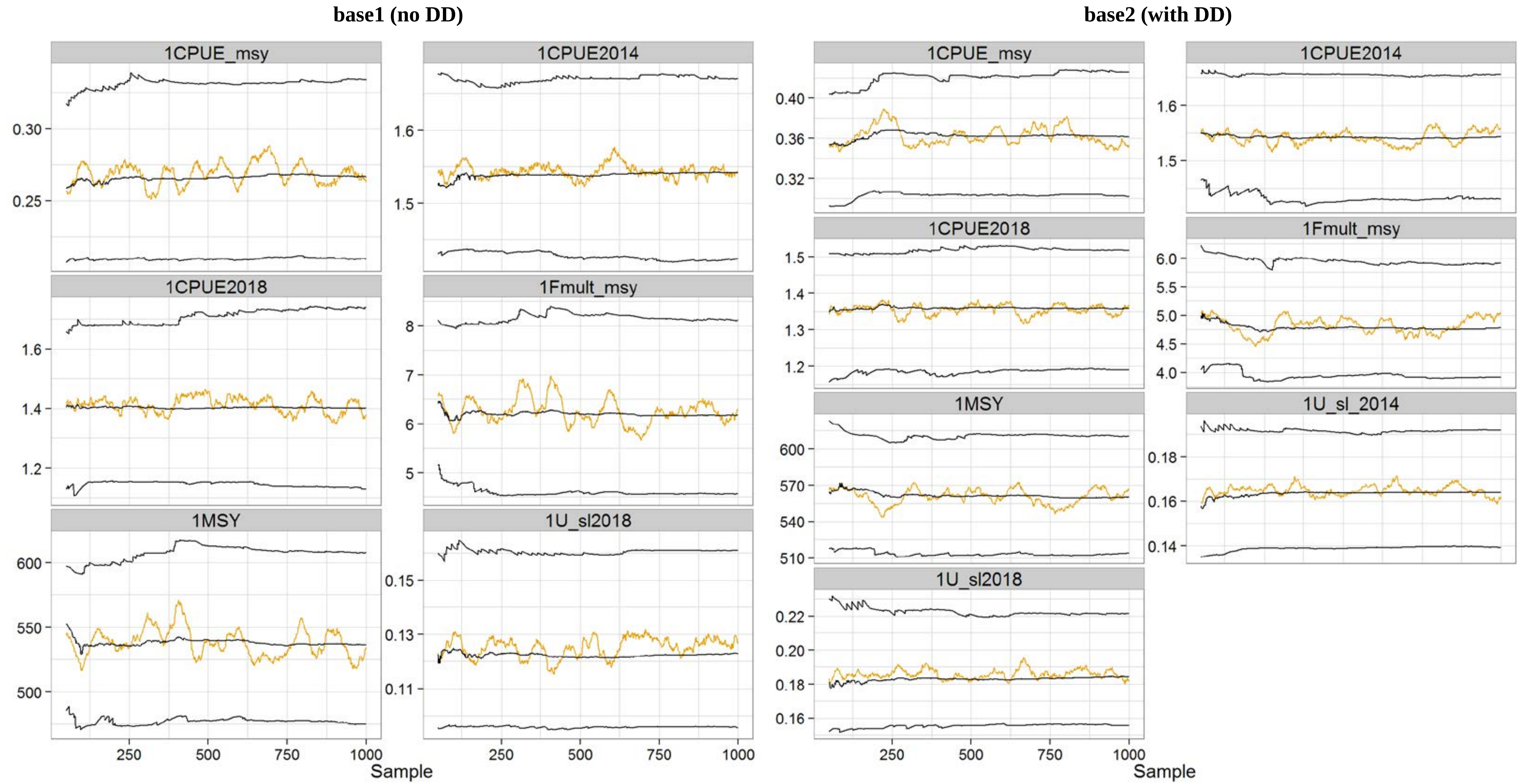



**Figure 32D: Diagnostic plots for the traces seen in Figure 31D for the base1 (left panels) and base2 (right panels) models.**

**base1 (no DD)** **base2 (with DD)**

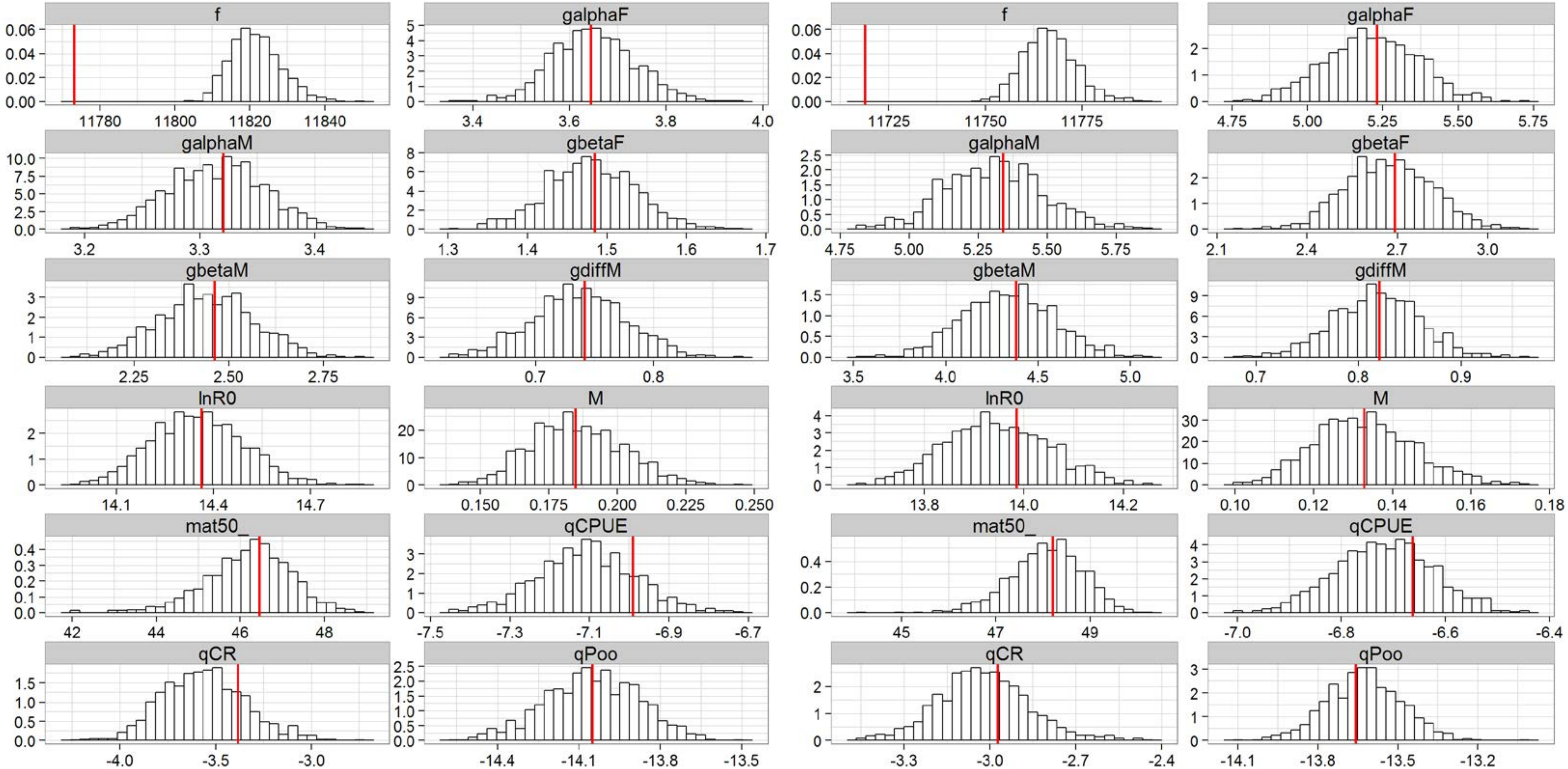



**Figure 33A: Posterior distributions of estimated parameters from the base1 (left panels) and base2 (right panels) models.**

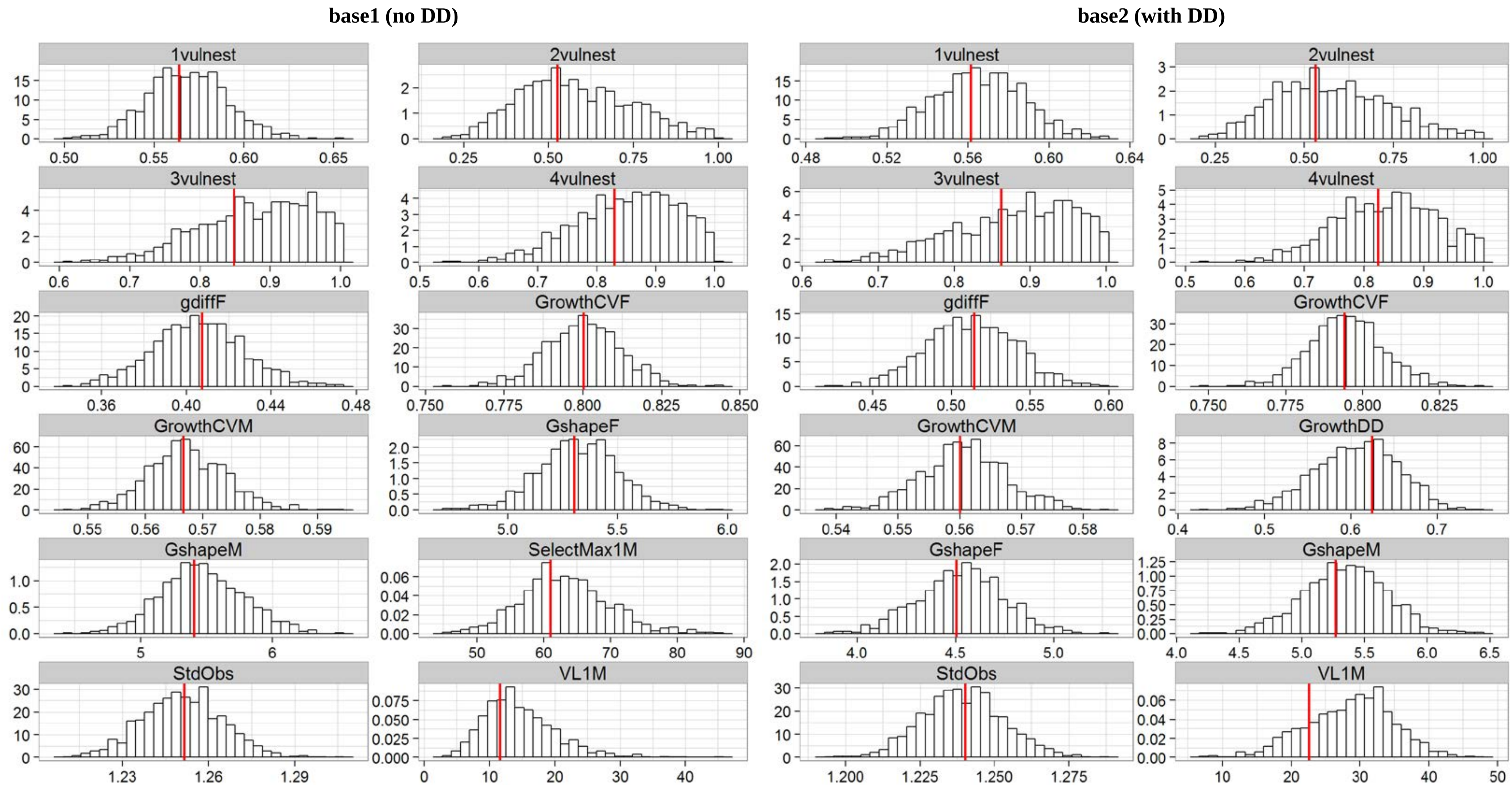



**Figure 33B: Posterior distributions of estimated parameters from the base1 (left panels) and base2 (right panels) models.**

**base1 (no DD)** **base2 (with DD)**

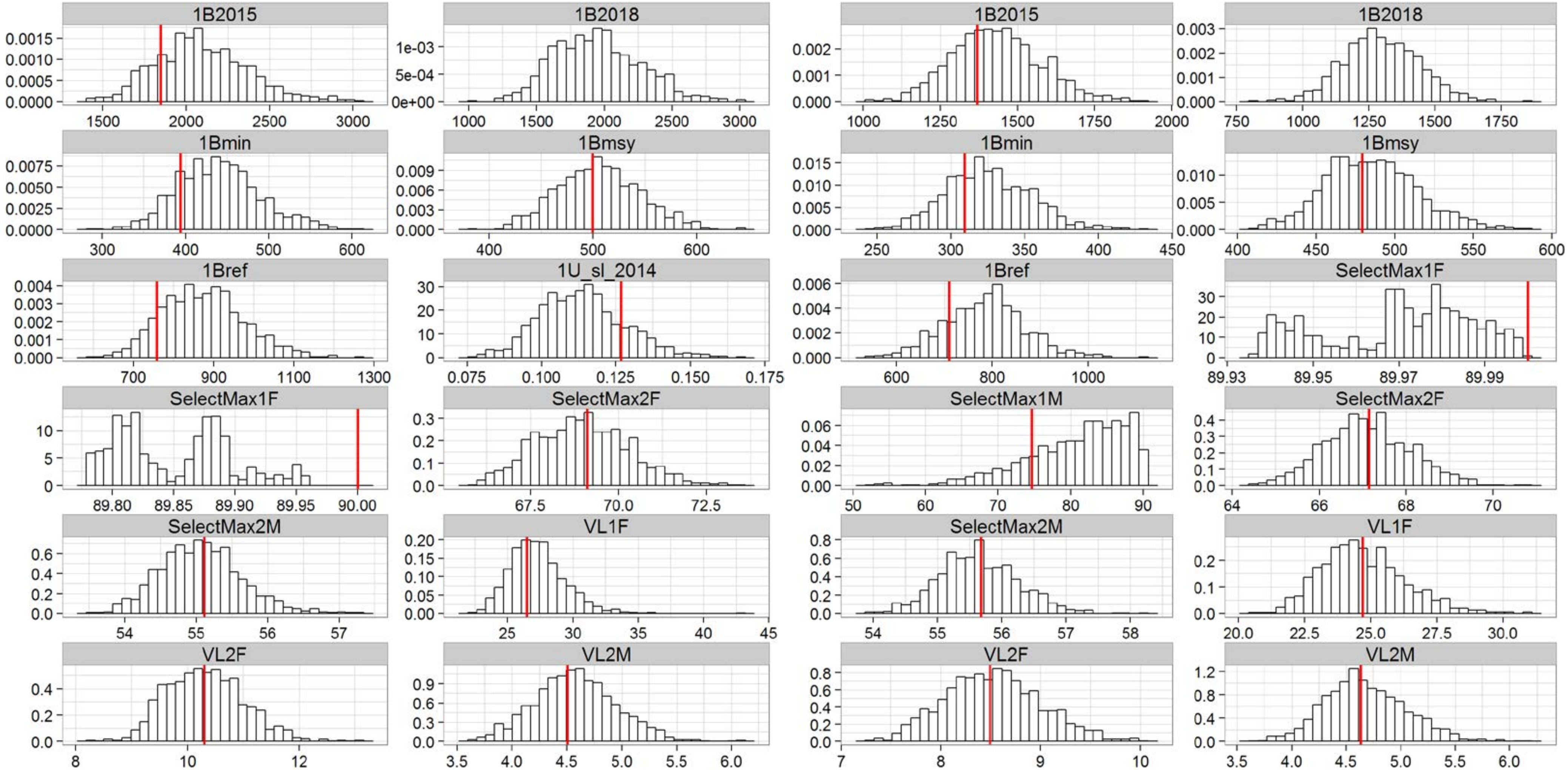



**Figure 33C: Posterior distributions of estimated parameters from the base1 (left panels) and base2 (right panels) models.**

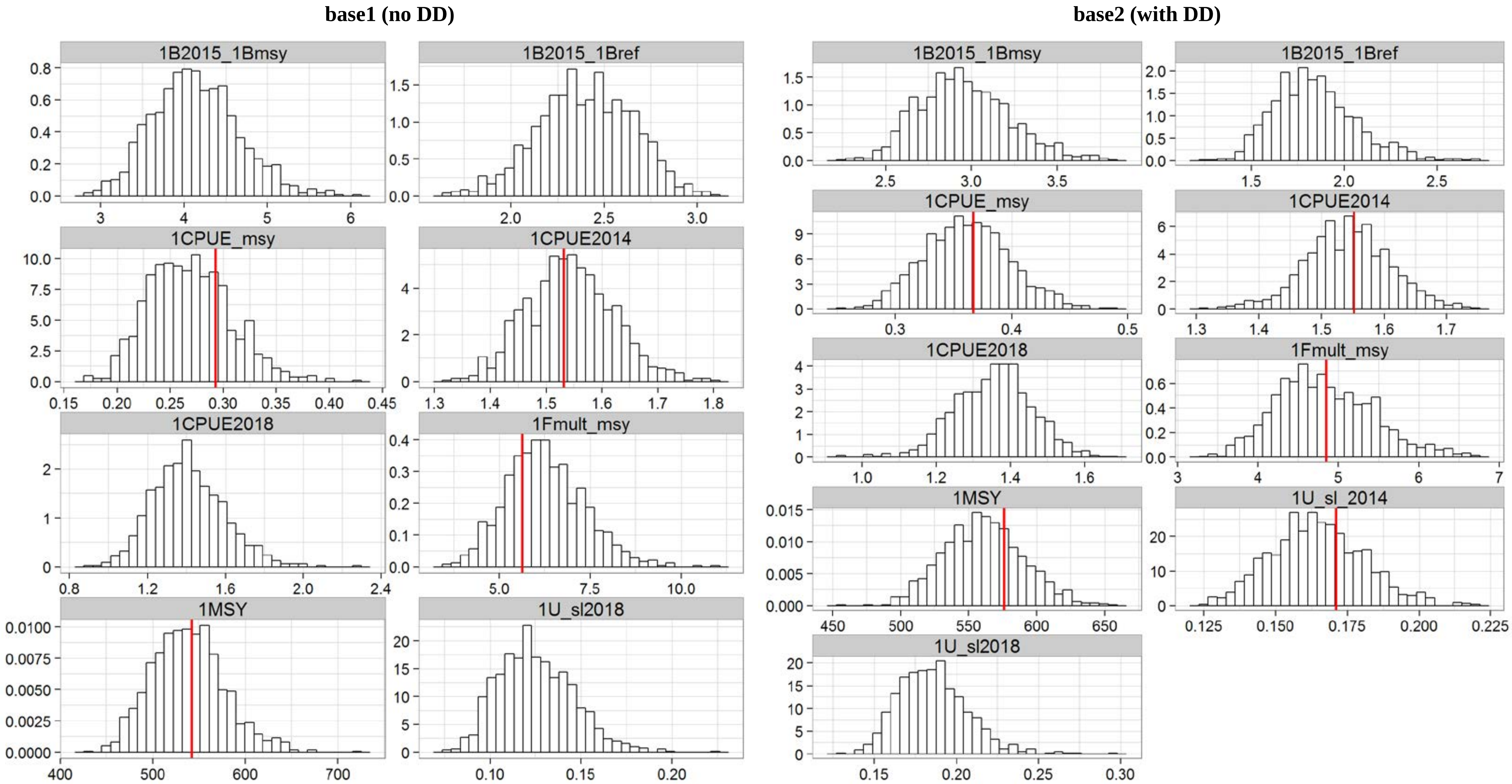



**Figure 33D: Posterior distributions of estimated parameters from the base1 (left panels) and base2 (right panels) models.**

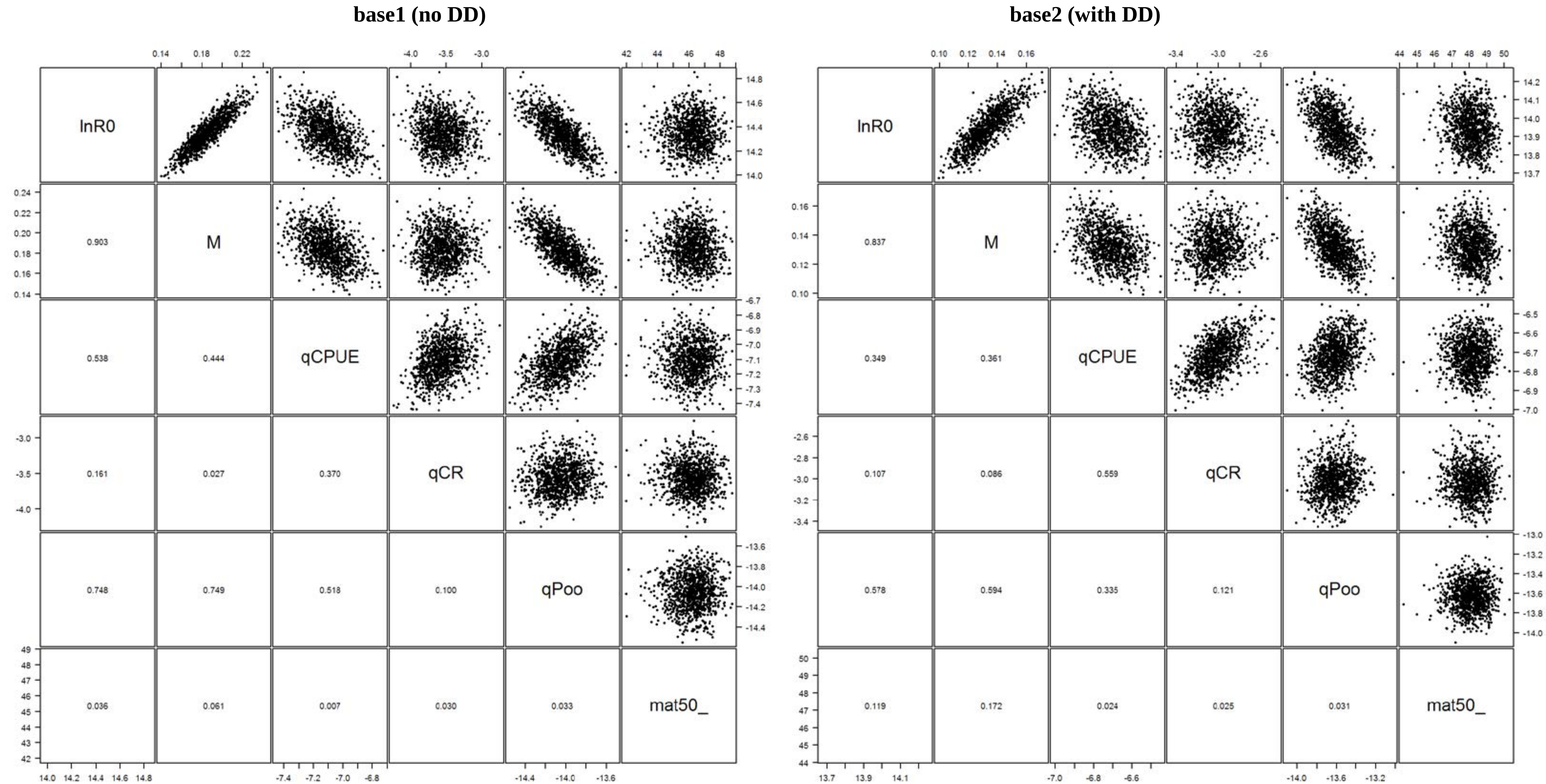



**Figure 34A: Paired correlation plots for the indicated base1 (left panels) and base2 (right panels) model parameters, with correlation coefficients provided in the mirrored cells.**

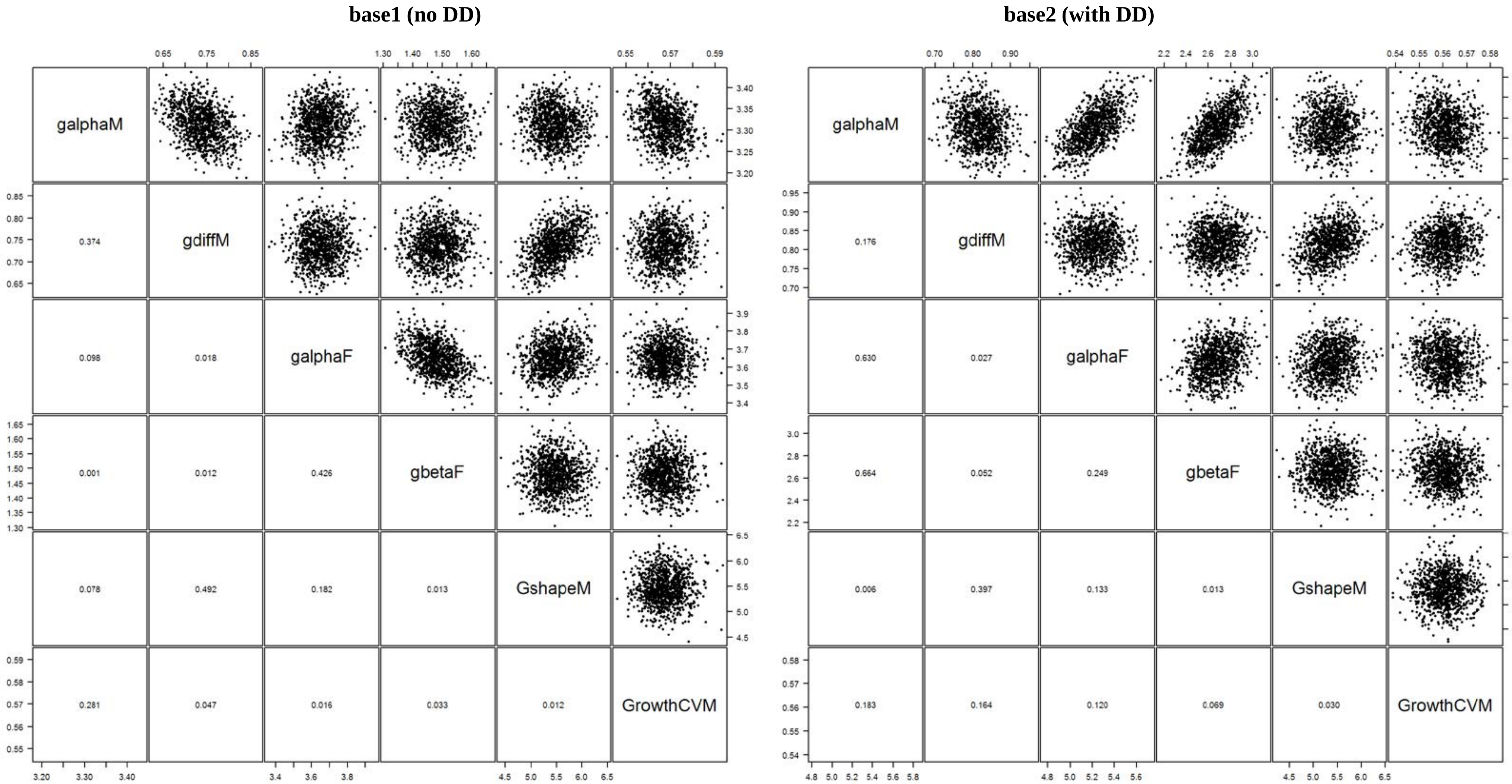



**Figure 34B: Paired correlation plots for the indicated base1 (left panels) and base2 (right panels) model parameters.**

**base1 (no DD)** **base2 (with DD)**

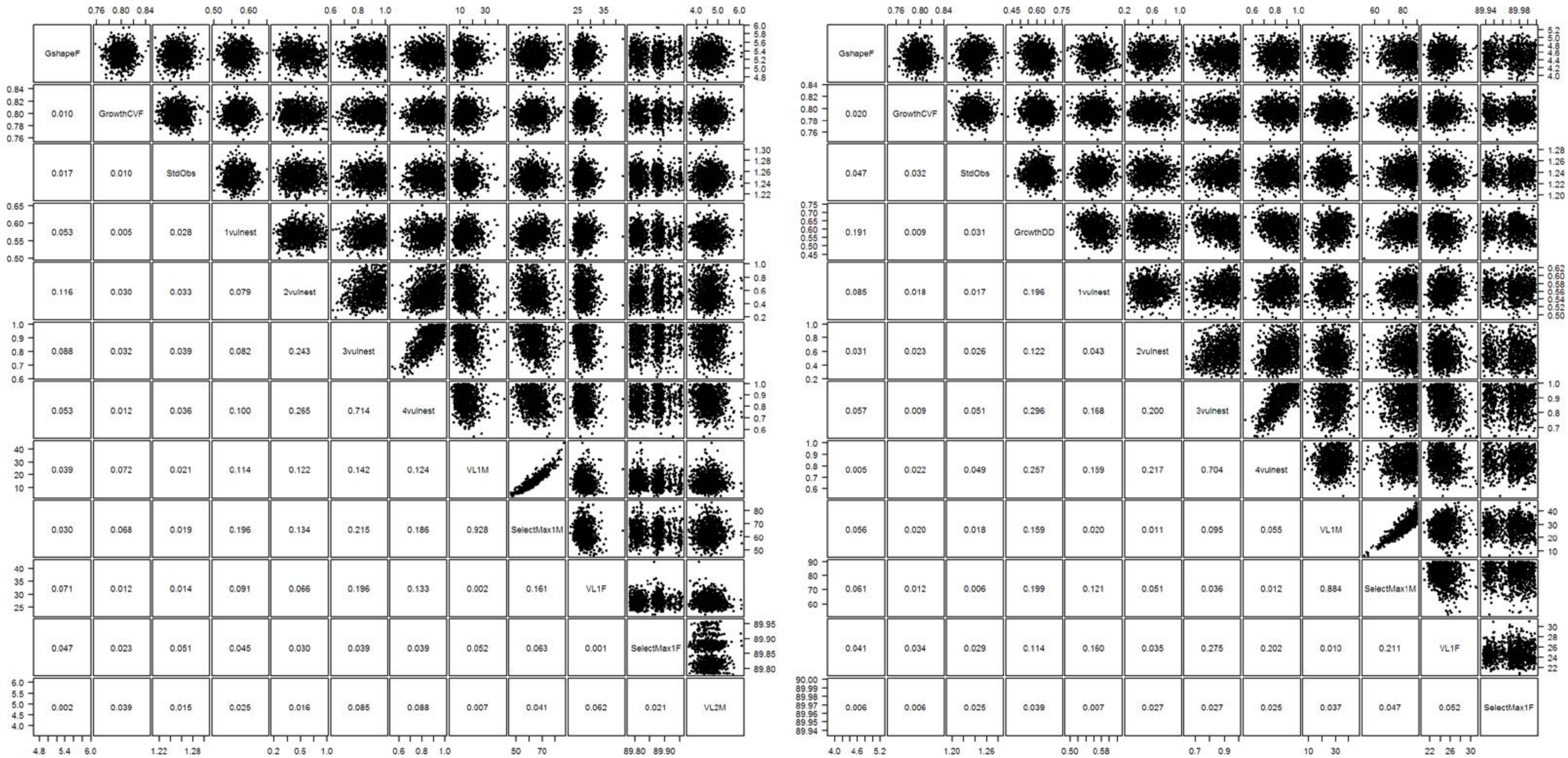


**Figure 34C: Paired correlation plots for the indicated base1 (left panels) and base2 (right panels) model parameters.**

**base1 (no DD)** **base2 (with DD)**

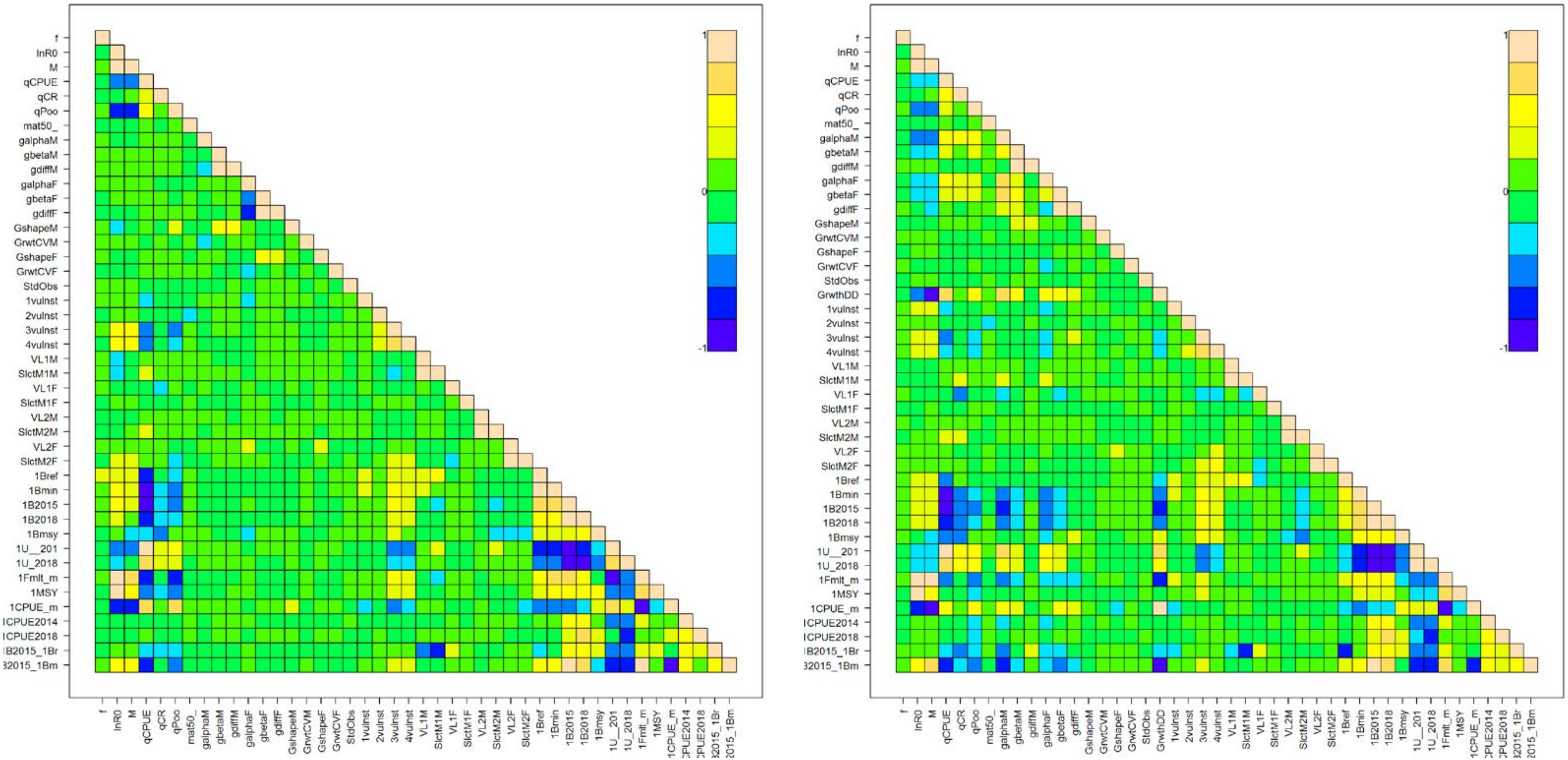
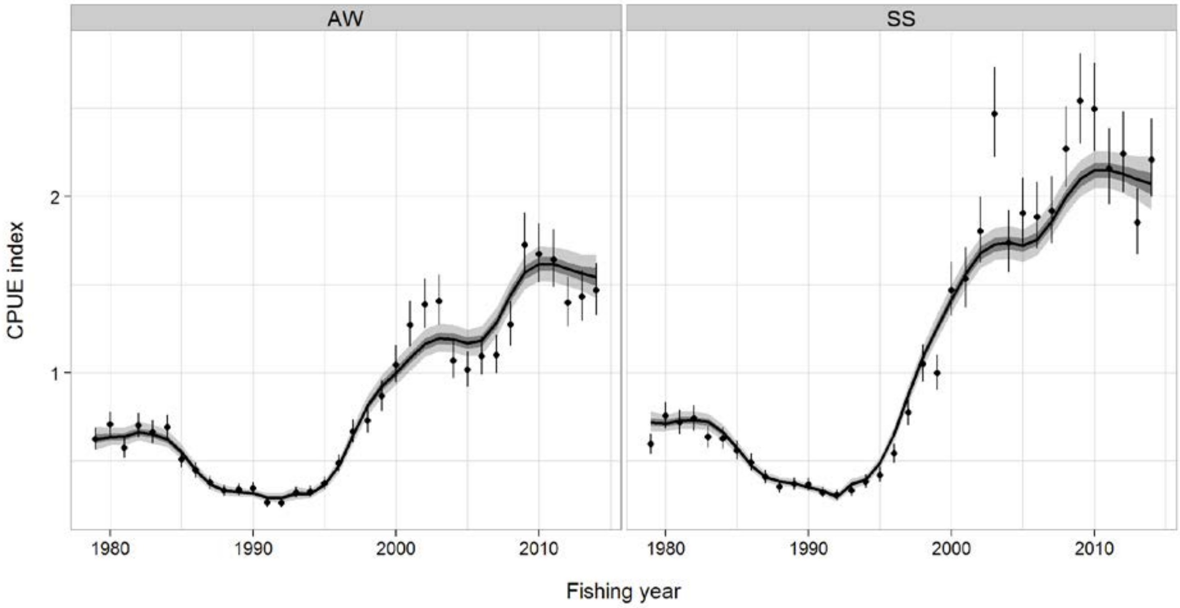



**Figure 35:** **Paired correlation plots for all base1 (left panels) and base2 (right panels) model parameters with level of correlation indicated by colour code.**

(a) base1 (no DD)




(a) base2 (with DD)

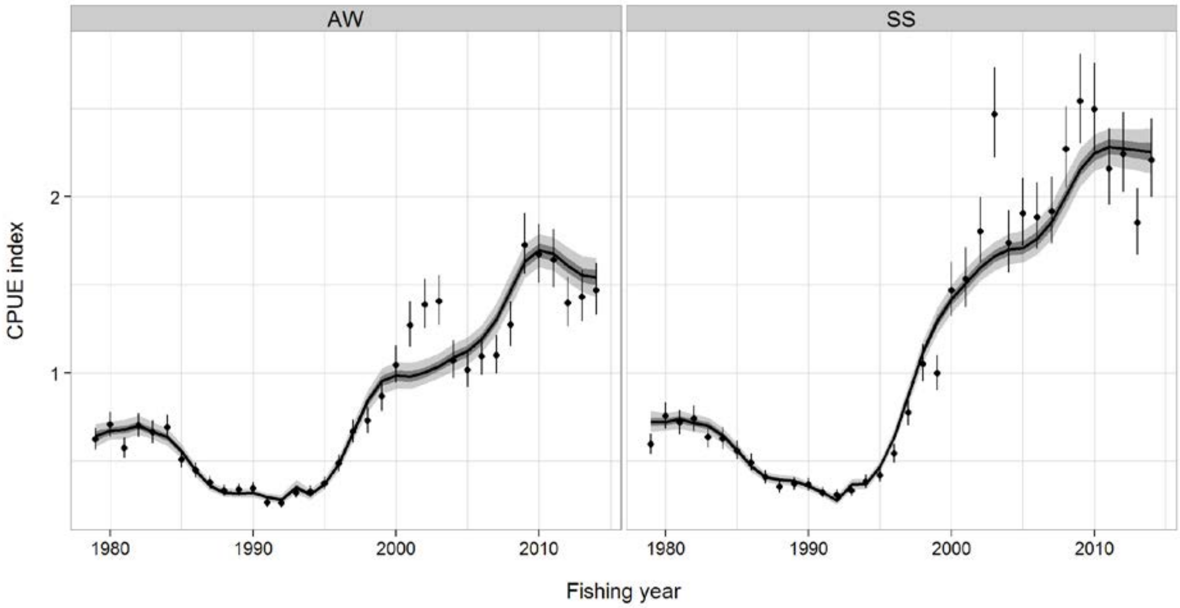
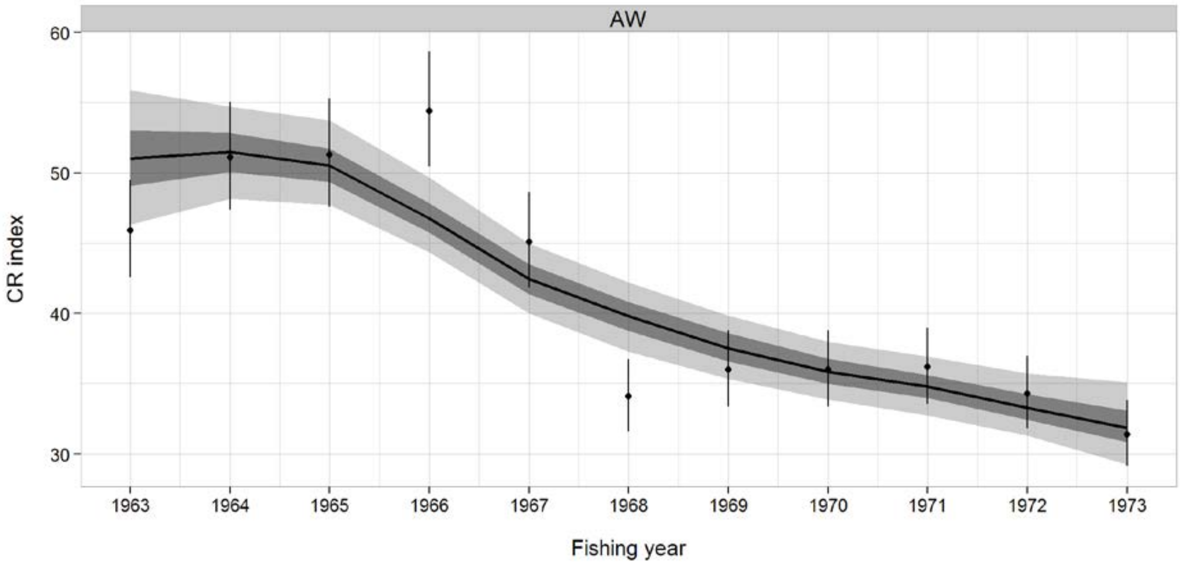



**Figure 36: Posterior of the fit to CPUE for CRA 5 by season for the base1 (top panels) and base2 (bottom panels) models. Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution. Error bars on the CPUE index values are one standard deviation.**

**(a) base1 (no DD)**




**(b) base2 (with DD)**

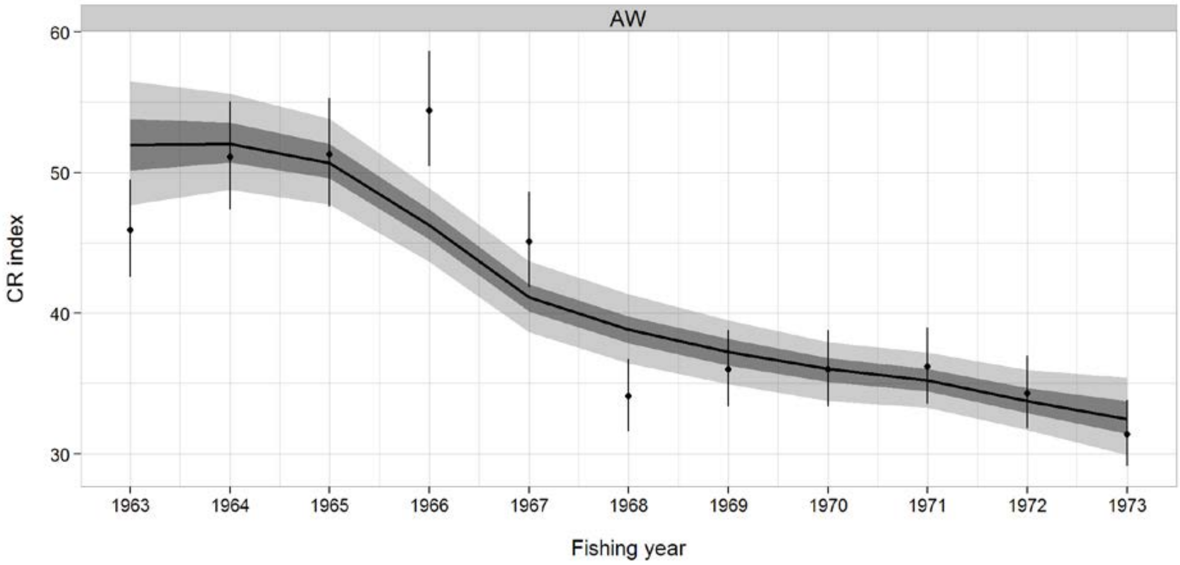
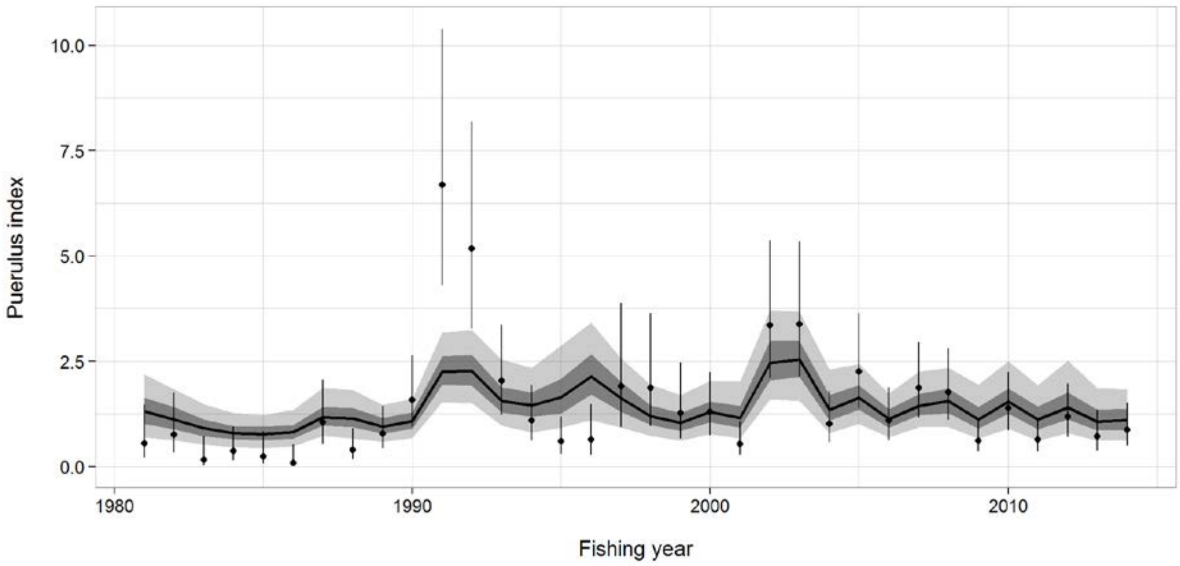



**Figure 37: Posterior of the fit to catch rate (CR) index for CRA 5 in autumn-winter (AW) for the base1 (top panels) and base2 (bottom panels) models. Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution. Error bars on the CPUE index values are one standard deviation.**

**(a) base1 (no DD)**




**(b) base2 (with DD)**

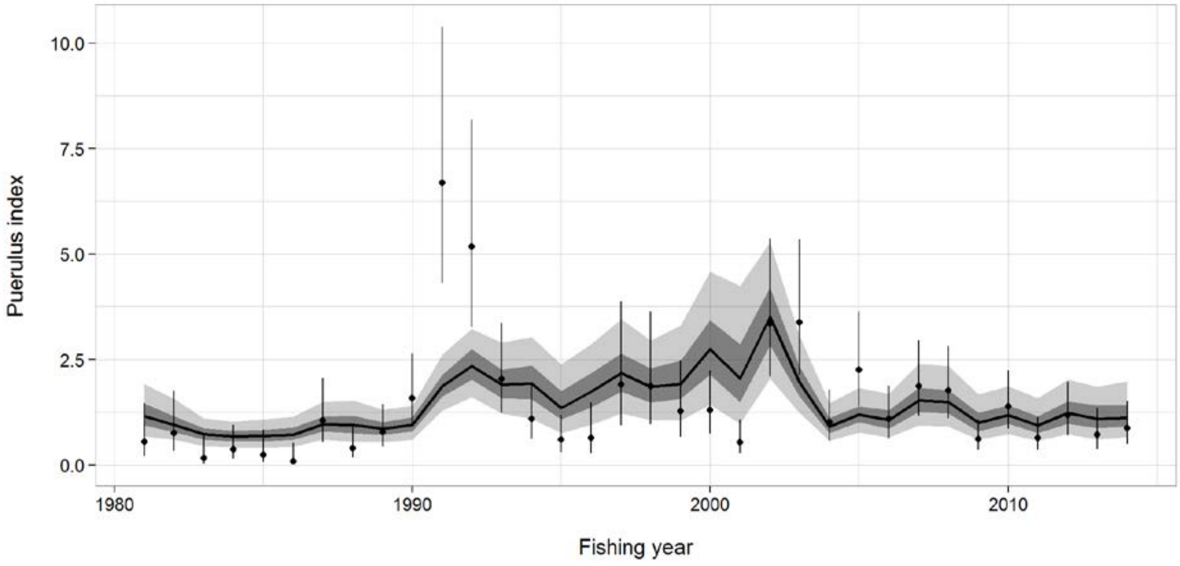



**Figure 38: Posterior of the fit to Puerulus index for CRA 5 for the base1 (top panels) and base2 (bottom panels) models. Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution. Error bars on the CPUE index values are one standard deviation.**

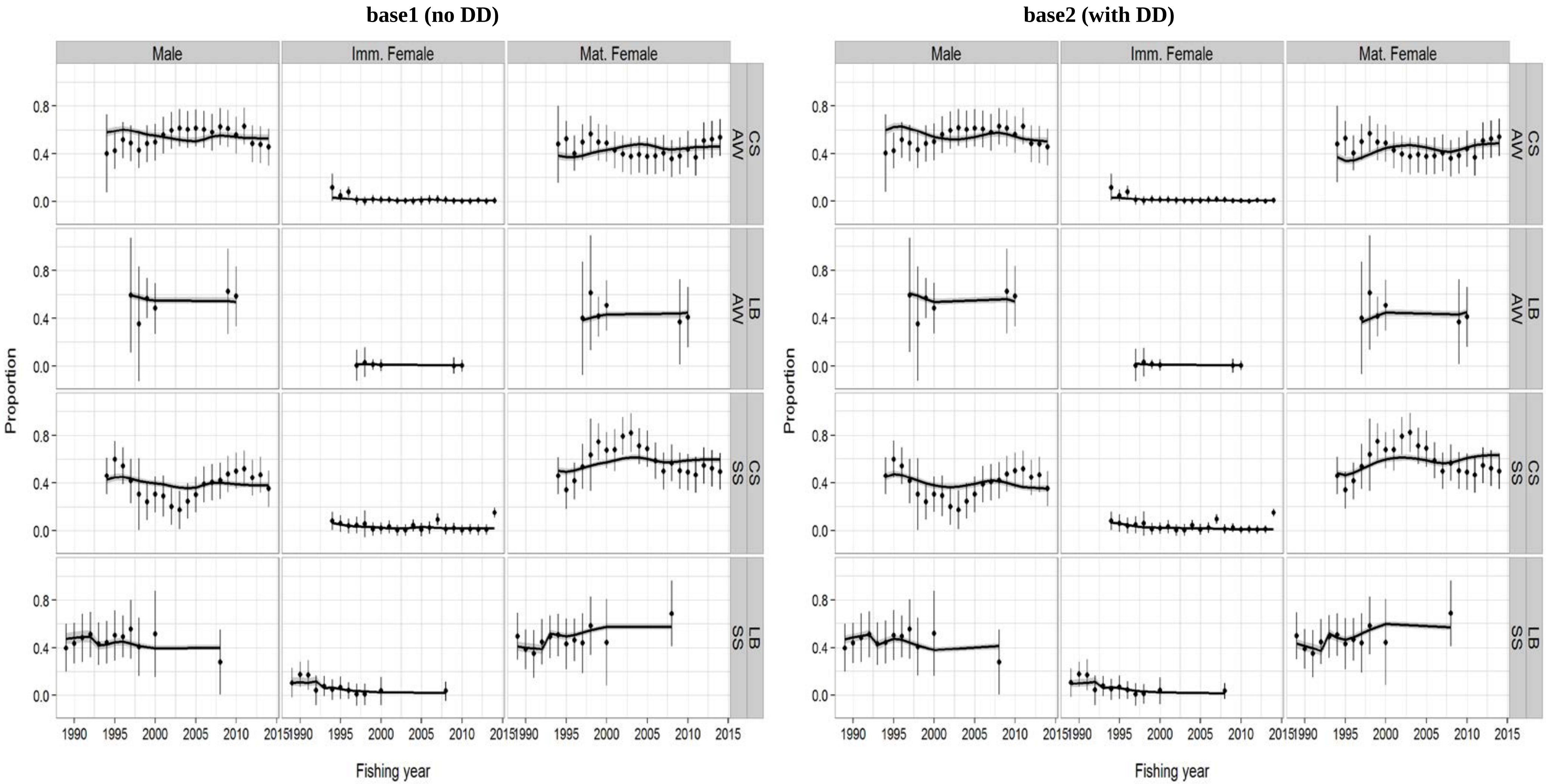
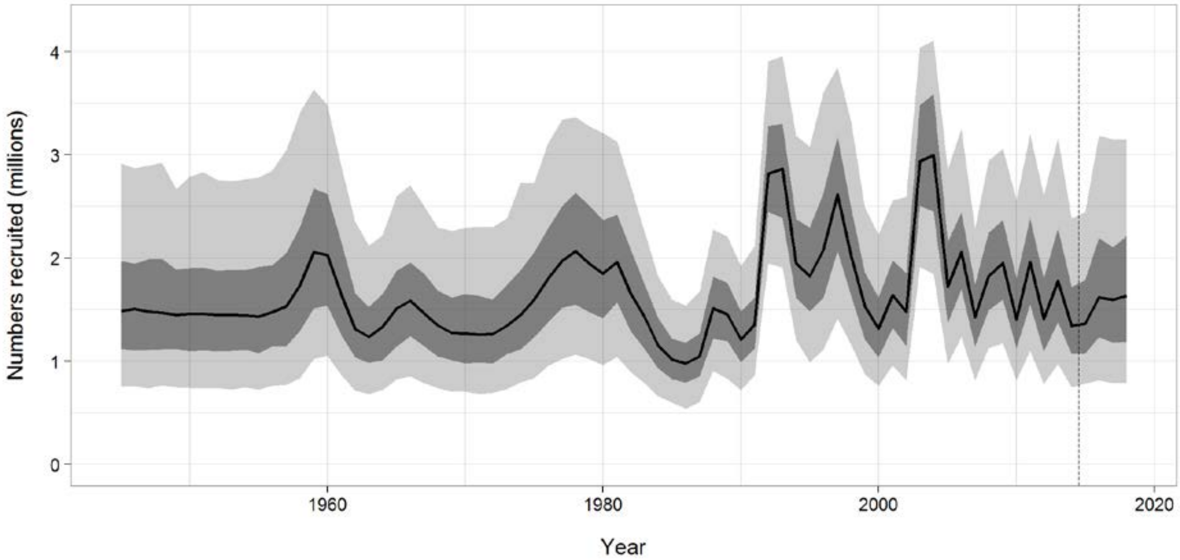



**Figure 39: Posterior of the fit to the sex ratios for CRA 5 by season, sex and data source for the base1 (top panels) and base2 (bottom panels) models. Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution. Error bars on the CPUE index values are one standard deviation.**

**(a) base1 (no DD)**




**(b) base2 (with DD)**

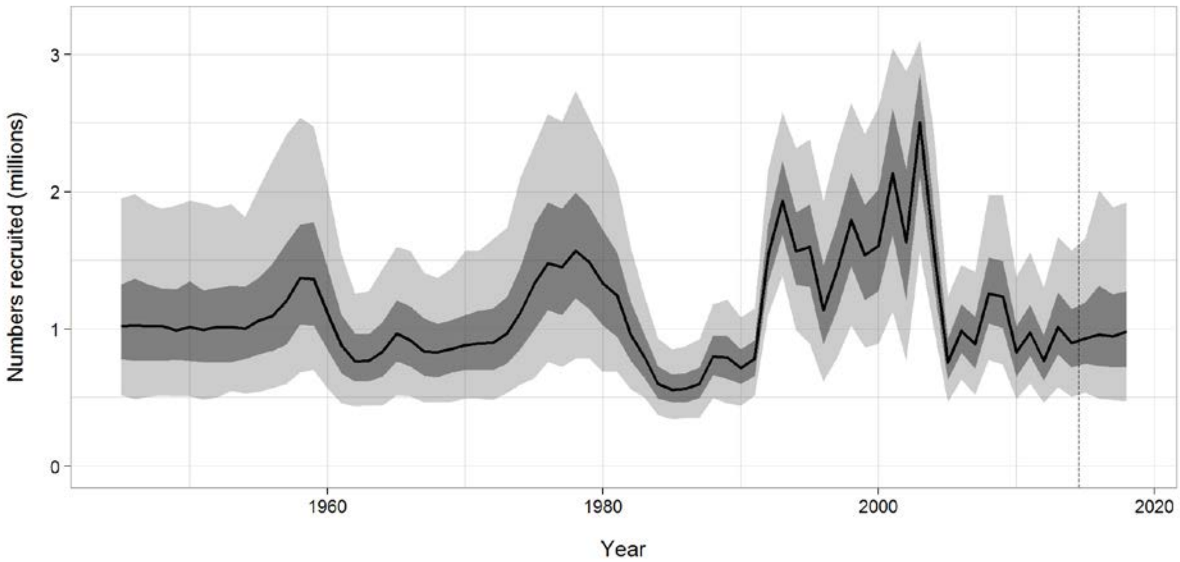
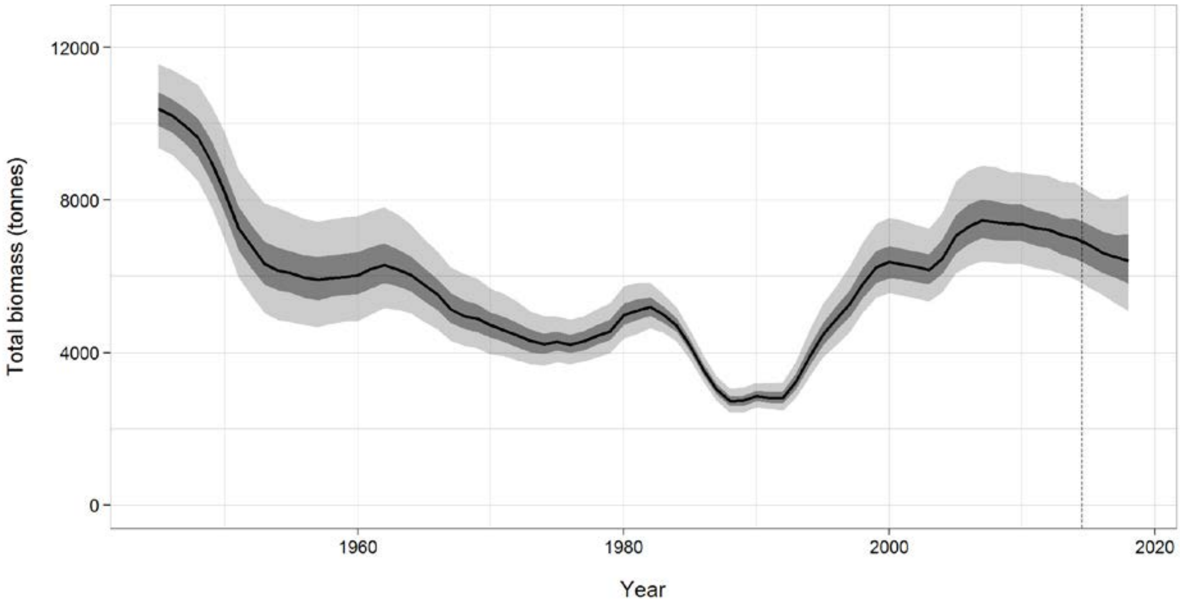



**Figure 40: Number of recruits from 1945 to 2015 and projected recruits from 2015 to 2018 for the CRA 5 base1 (top panel) and base2 (bottom panel) models. Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution. The vertical line shows 2014, the final fishing year of the model reconstruction.**

**(a) base1 (no DD)**




**(b) base2 (with DD)**

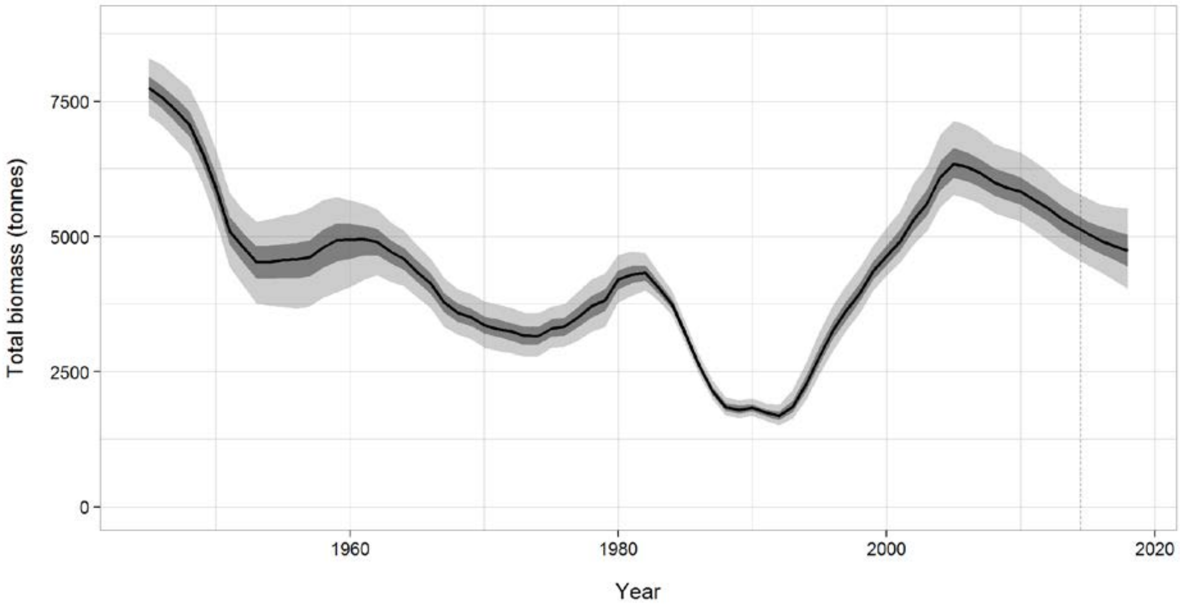
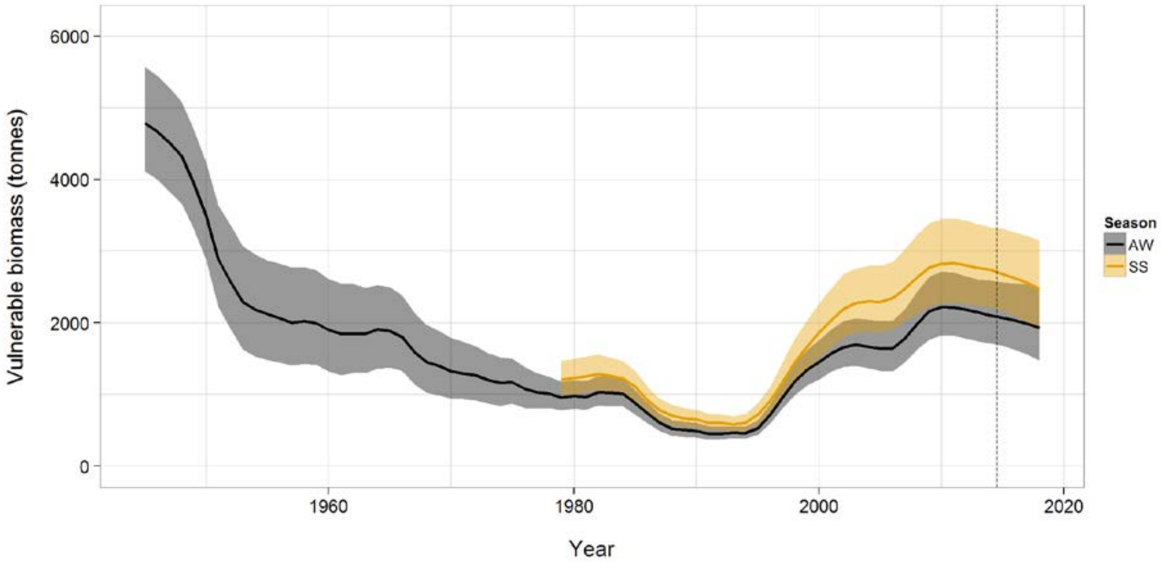



**Figure 41: Total biomass from 1945 to 2015 and projected biomass from 2015 to 2018, based on the 2014 catch distribution for the CRA 5 base1 (top panel) and base2 (bottom panel) models. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The vertical line shows 2014, the final fishing year of the model reconstruction.**

**(a) base1 (no DD)**




**(b) base2 (with DD)**

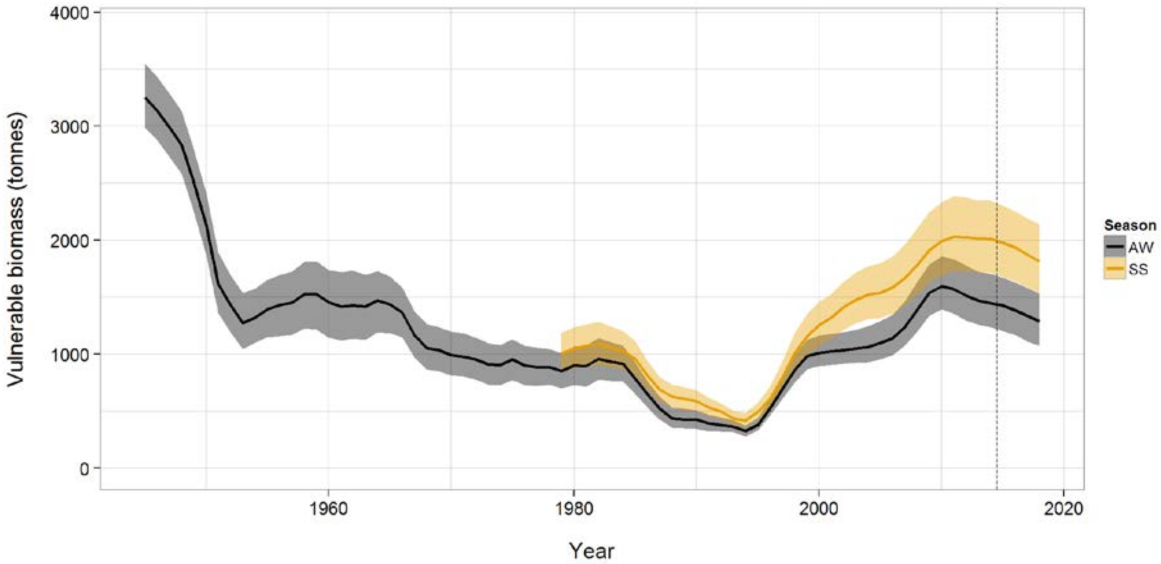



**Figure 42: Vulnerable [reference] biomass from 1945 to 2013 by season and projected vulnerable biomass by season from 2015 to 2018 for the CRA 5 base1 (top panel) and base2 (bottom panel) models, assuming the 2014 catch distribution. Shaded areas show the 90% credibility intervals and the heavy solid line is the median of the posterior distributions. The vertical line shows 2014, the final fishing year of the model reconstruction. Biomass before 1979 is annual, but is plotted using the AW coding.**

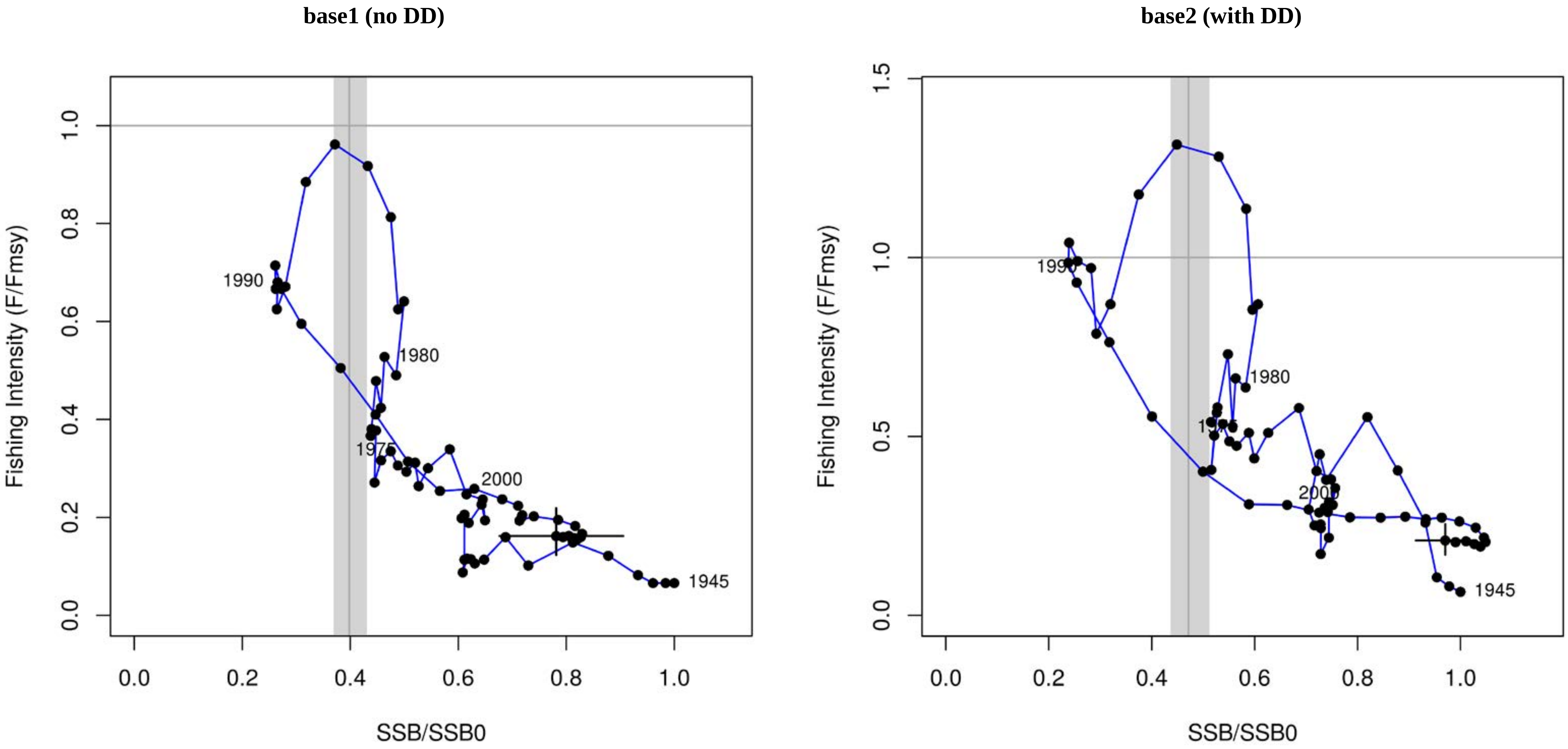



**Figure 43: Snail trail for the CRA 5 base1 (left panel) and base2 (right panel) models. The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval in both directions for the final model year (2014).**

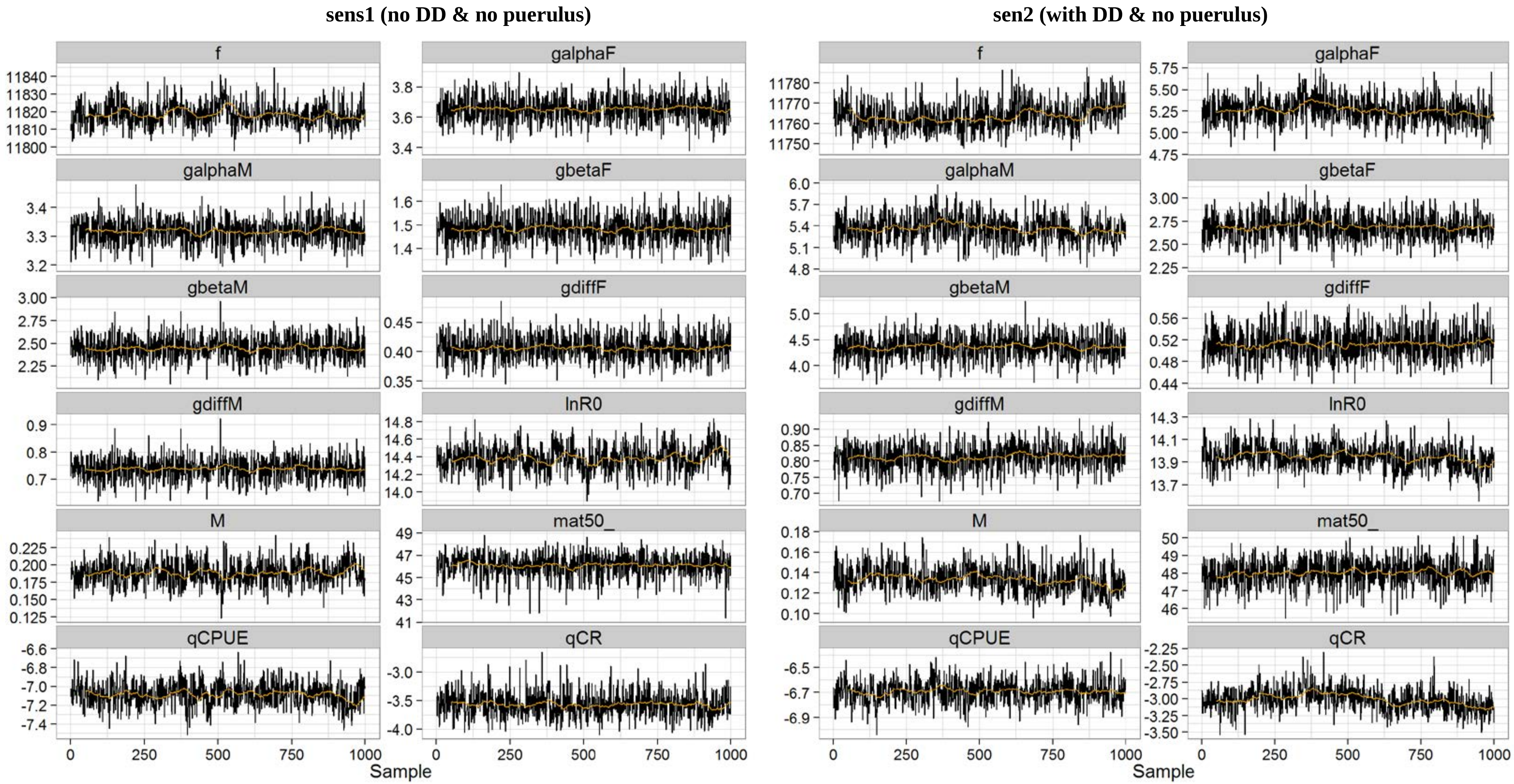



**Figure 44: MCMC trace plots for leading estimated parameters from sensitivity model runs: (A) sens1 (no DD and no puerulus; left panels) and (B) sens2 (with DD and no puerulus; right panels). The gold line is a moving mean over 50 samples.**

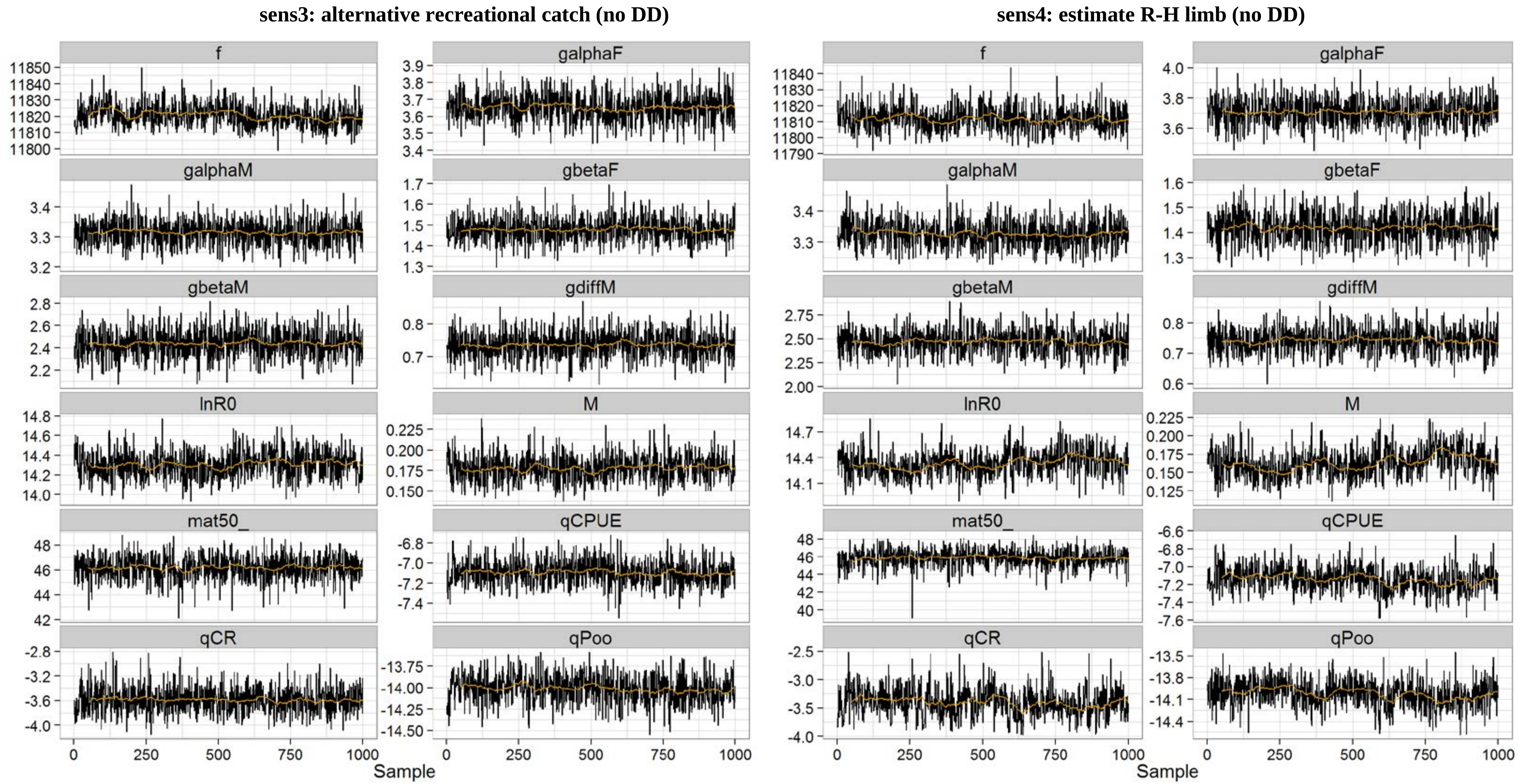



**Figure 45: MCMC trace plots for leading estimated parameters from sensitivity model runs: (A) alternate recreational catch (left panels) and (B) estimate right hand selectivity parameter (right panels). The gold line is a moving mean over 50 samples.**

**sens5: growth prior CV=30% (no DD)** **sens6: double CPUE weight (no DD)**

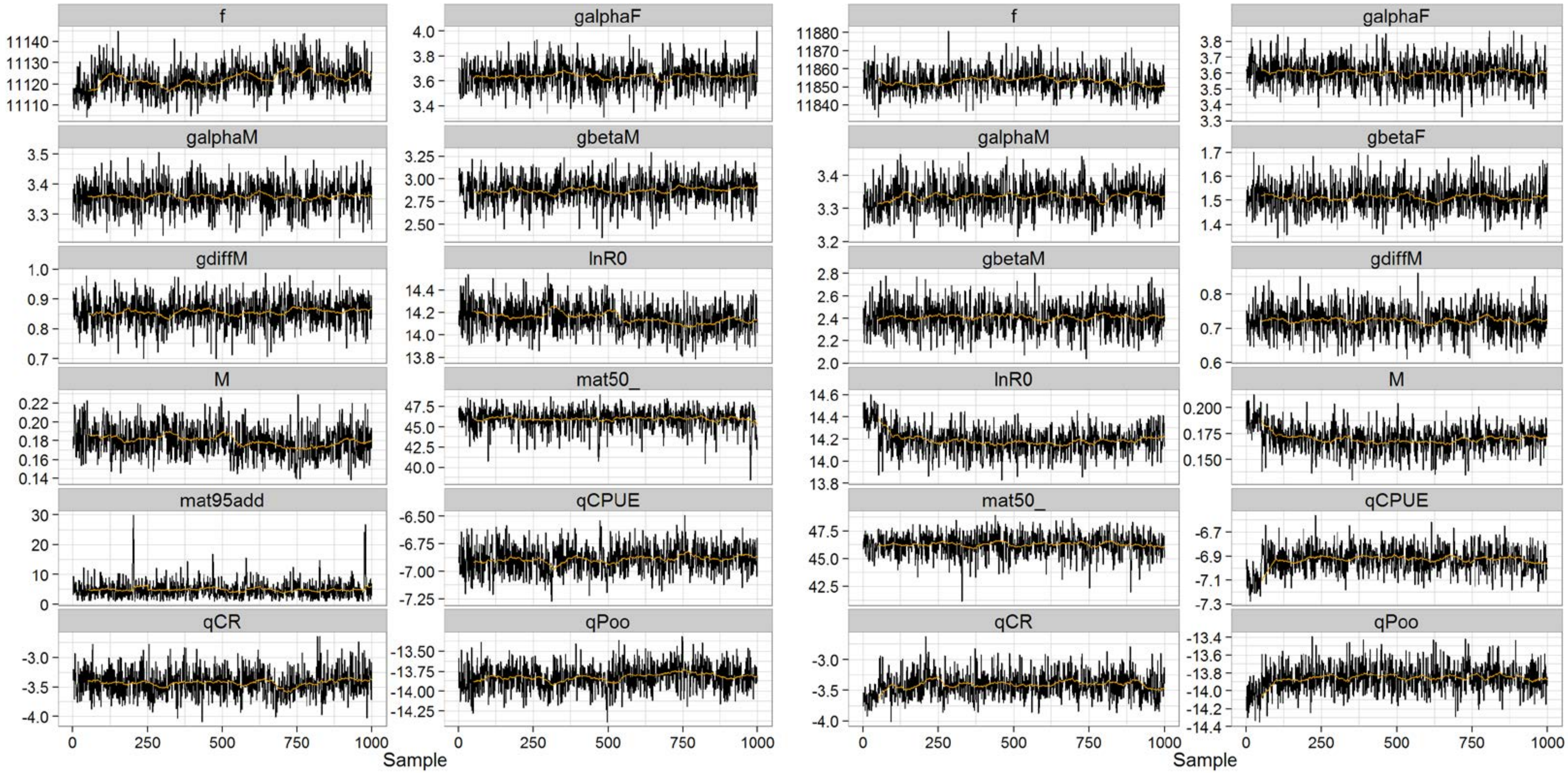



**Figure 46: MCMC trace plots for leading estimated parameters from sensitivity model runs: (A) increased CV on the growth priors (left panels) and (B) double relative weight on the CPUE series (right panels). The gold line is a moving mean over 50 samples.**

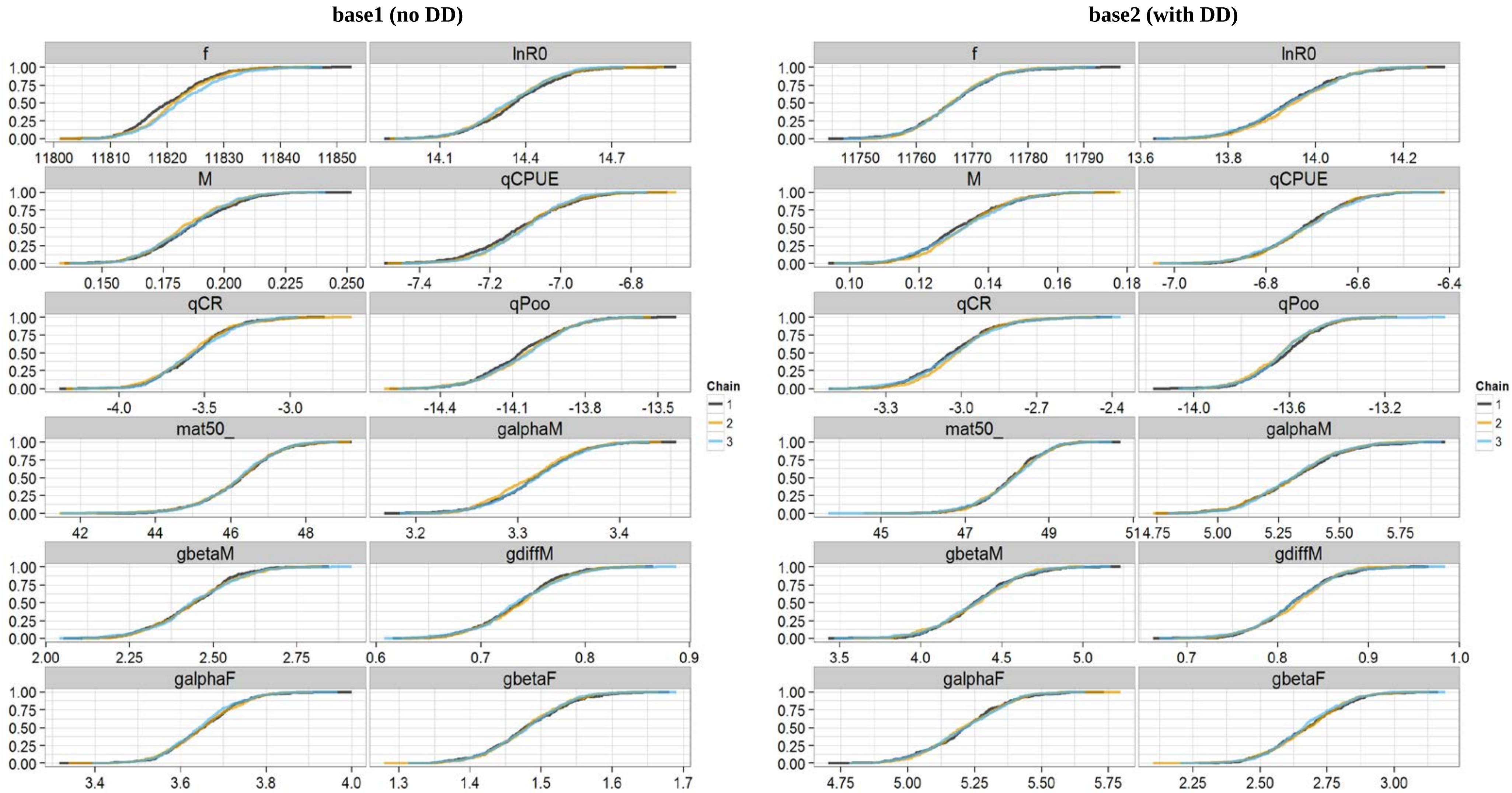



**Figure 47:** **Empirical cumulative frequency distributions for successive thirds of the posterior distributions for leading estimated parameters from (A) base1 (no DD; left panels) and (B) base2 (with DD; right panels) models.**

**sens1 (no DD & no puerulus)** **sens2 (with DD & no puerulus)**

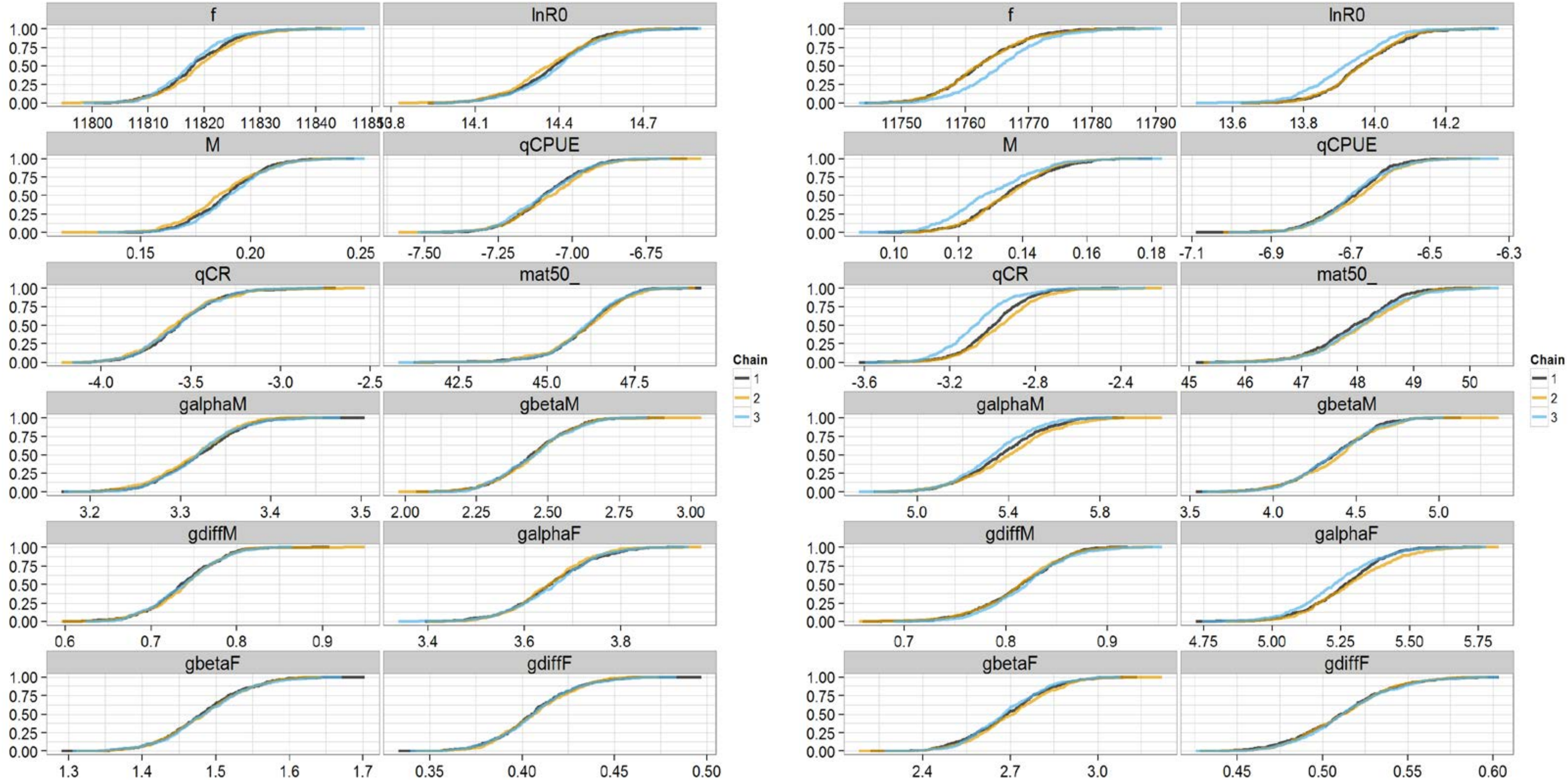



**Figure 48: Empirical cumulative frequency distributions for successive thirds of the posterior distributions for leading estimated parameters from sensitivity model runs: (A) sens1 (no DD and no puerulus; left panels) and (B) sens2 (with DD and no puerulus; right panels).**

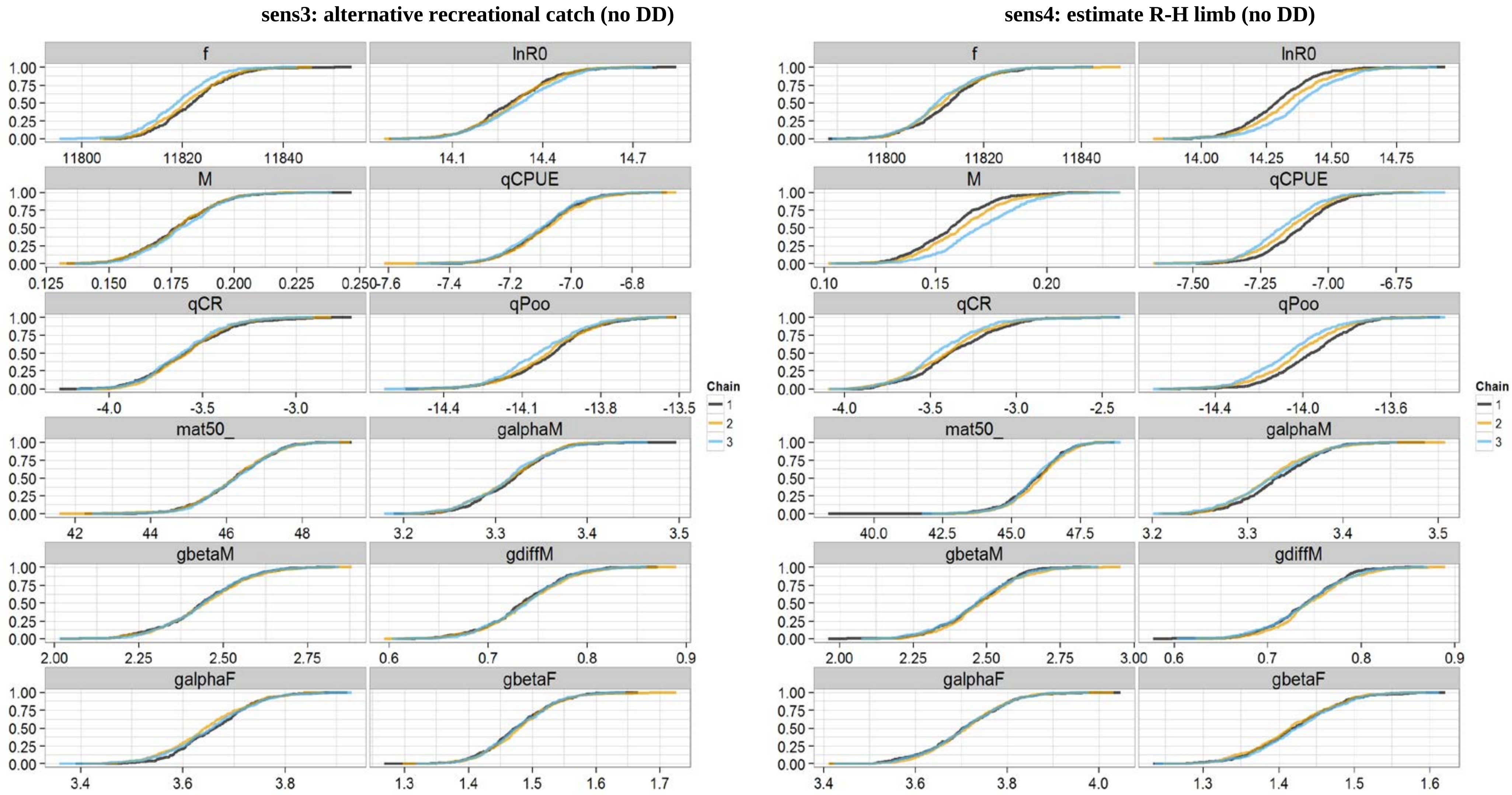



**Figure 49: Empirical cumulative frequency distributions for successive thirds of the posterior distributions for leading estimated parameters from sensitivity model runs: (A) alternate recreational catch (left panels) and (B) estimate right hand selectivity parameter (right panels).**

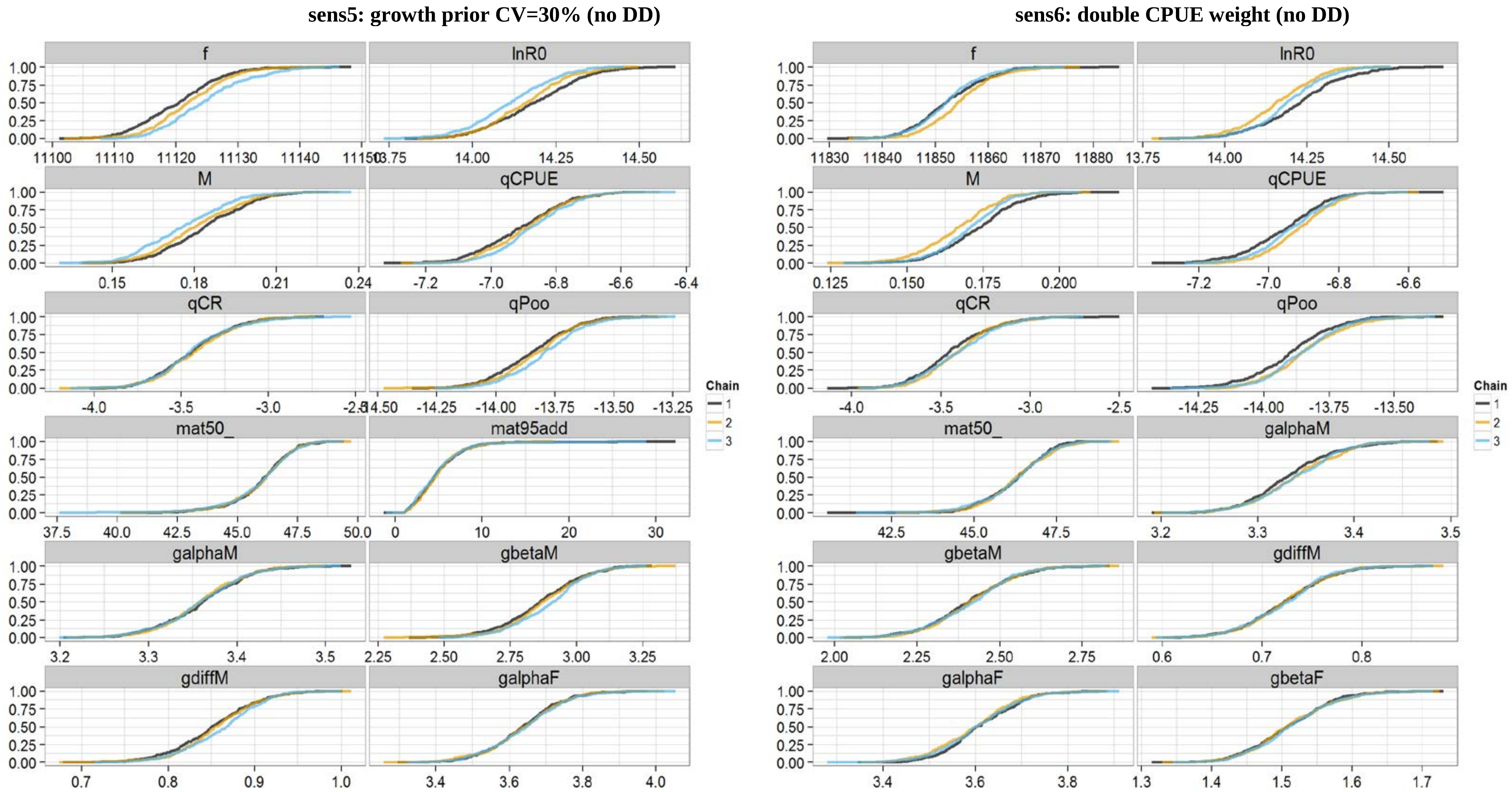



**Figure 50: Empirical cumulative frequency distributions for successive thirds of the posterior distributions for leading estimated parameters from sensitivity model runs: (A) increased CV on the growth priors (left panels) and (B) double relative weight on the CPUE series (right panels).**

**sens1 (no DD & no puerulus)** **sens2 (with DD & no puerulus)**

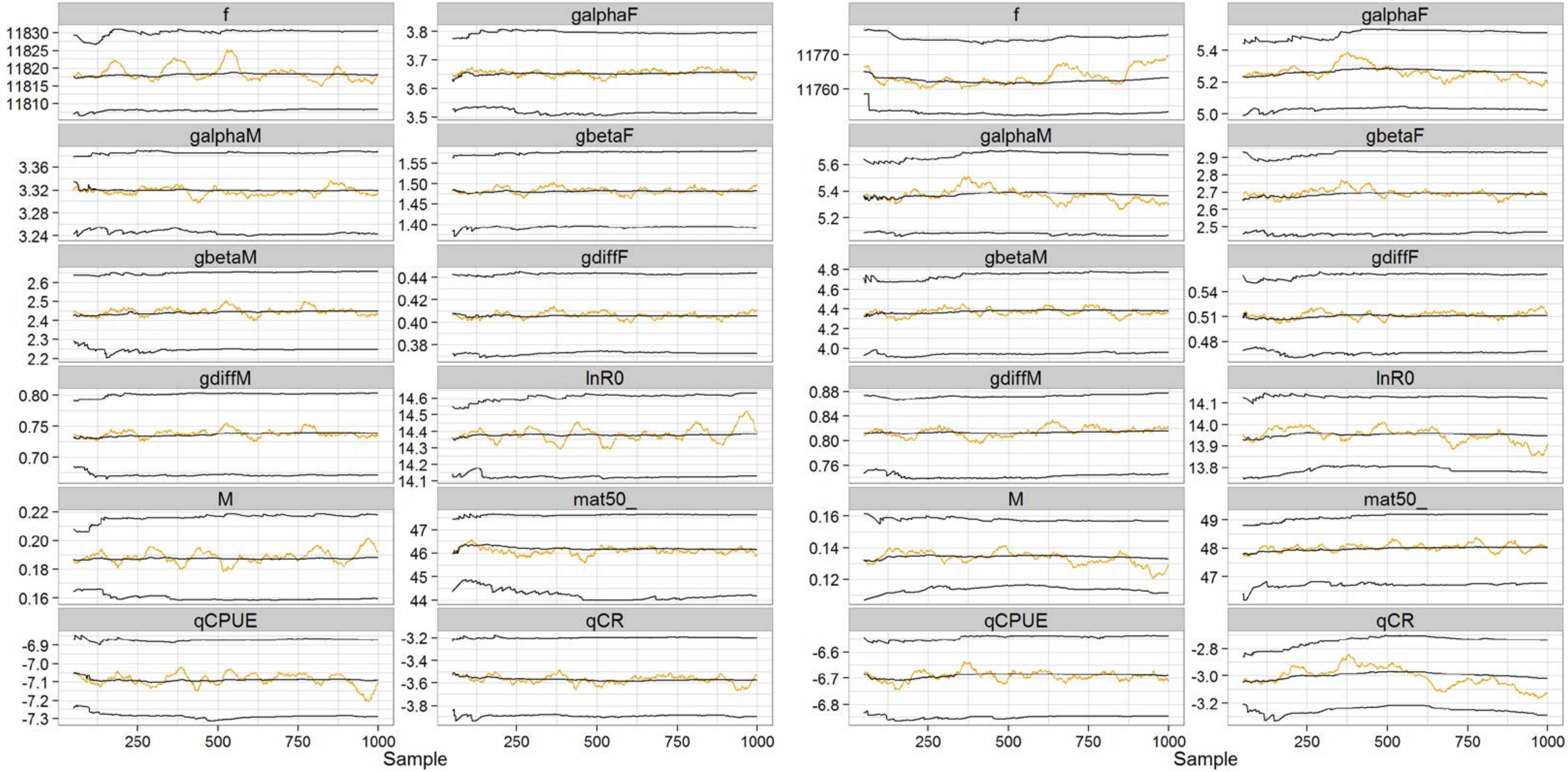



**Figure 51: Diagnostic plots for the traces seen in Figure 44A & B for the sensitivity model runs: (A) sens1 (no DD and no puerulus; left panels) and (B) sens2 (with DD and no puerulus; right panels). The gold line is a moving mean over 50 samples.**

**sens3: alternative recreational catch (no DD)** **sens4: estimate R-H limb (no DD)**

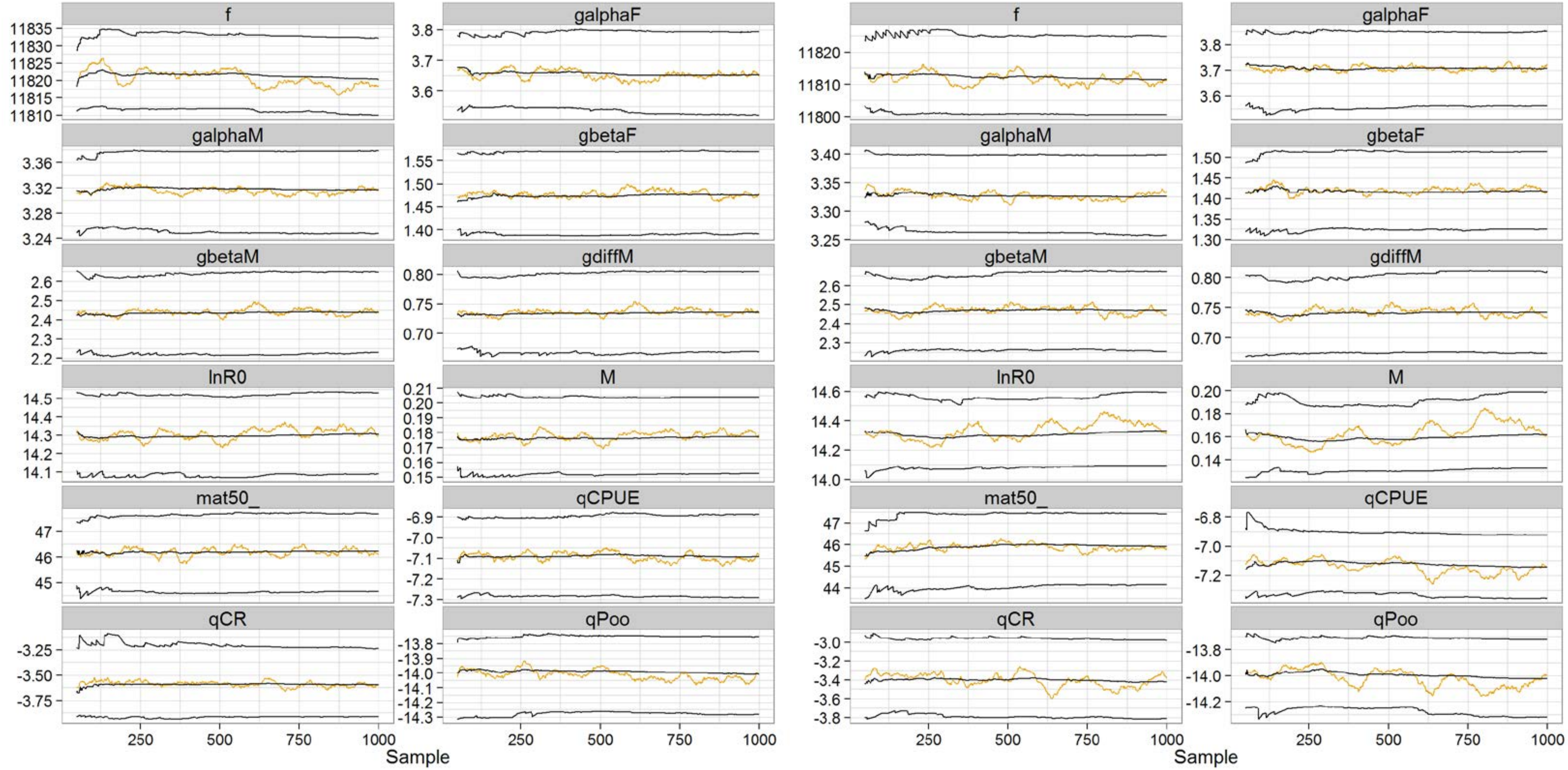



**Figure 52: Diagnostic plots for the traces seen in Figure 45A & B for the sensitivity model runs: (A) alternate recreational catch (left panels) and (B) estimate right hand selectivity parameter (right panels). The gold line is a moving mean over 50 samples.**

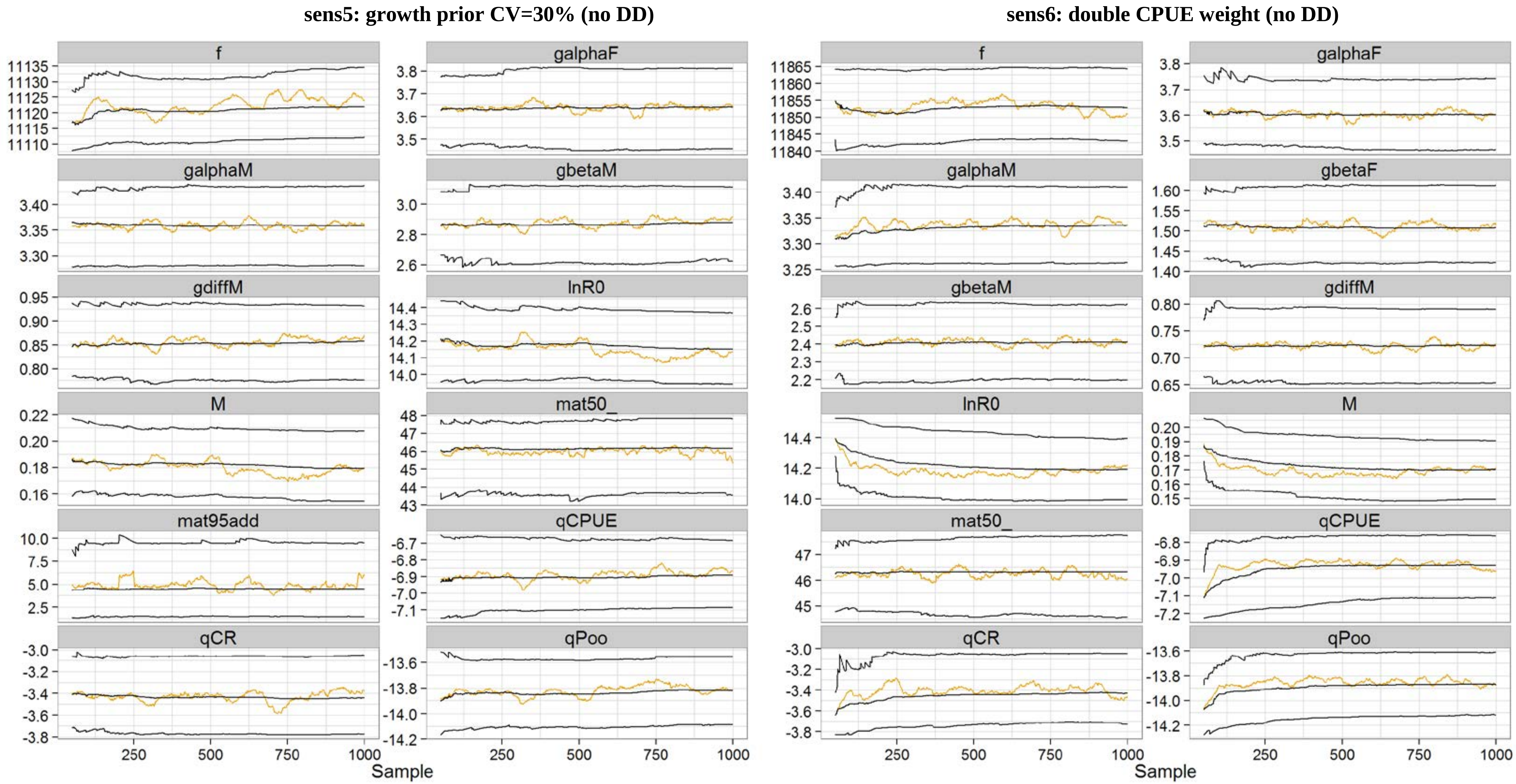



**Figure 53: Diagnostic plots for the traces seen in Figure 46A & B for the sensitivity model runs: (A) increased CV on the growth priors (left panels) and (B) double relative weight on the CPUE series (right panels). The gold line is a moving mean over 50 samples.**

**sens1 (no DD & no puerulus)** **sens2 (with DD & no puerulus)**

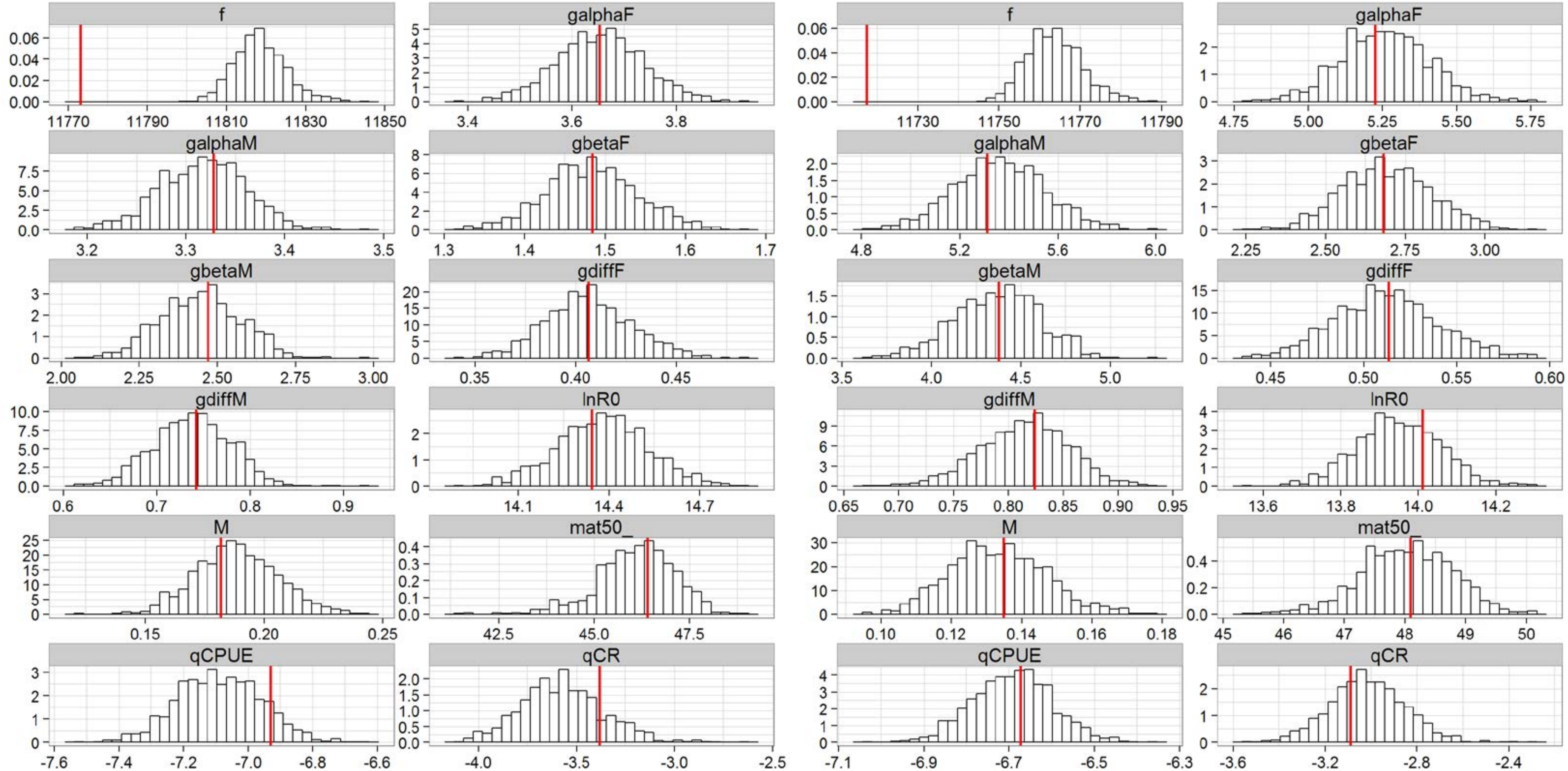



**Figure 54: Posterior distributions for leading estimated parameters from sensitivity model runs: (A) sens1 (no DD and no puerulus; left panels) and (B) sens1 (with DD and no puerulus; right panels). The vertical bar shows the associated MPD value.**

**sens3: alternative recreational catch (no DD)** **sens4: estimate R-H limb (no DD)**

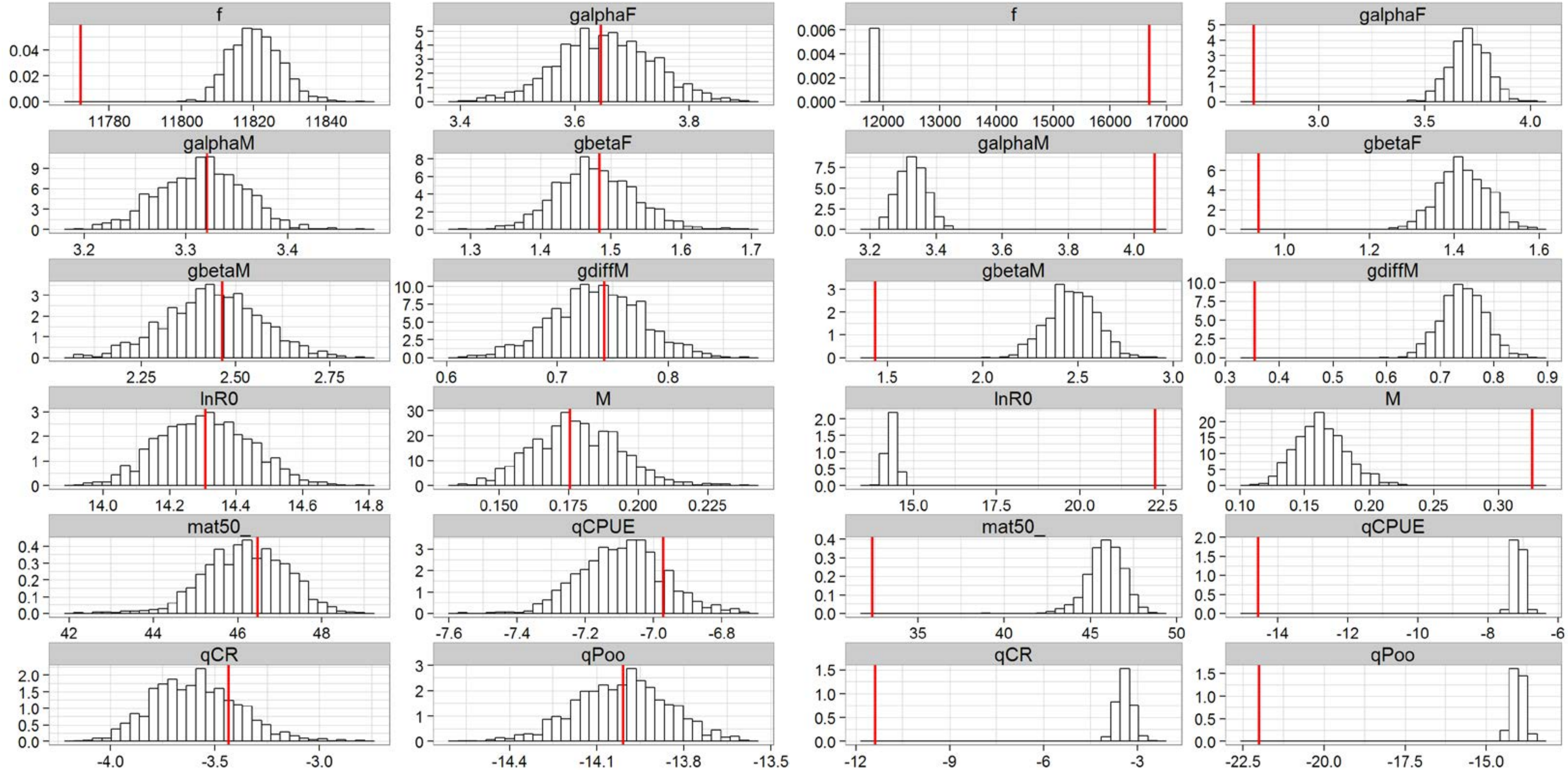



**Figure 55: Posterior distributions for leading estimated parameters from sensitivity model runs: (A) alternate recreational catch (left panels) and (B) estimate right hand selectivity parameter (right panels). The vertical bar shows the associated MPD value.**

**sens5: growth prior CV=30% (no DD)** **sens6: double CPUE weight (no DD)**

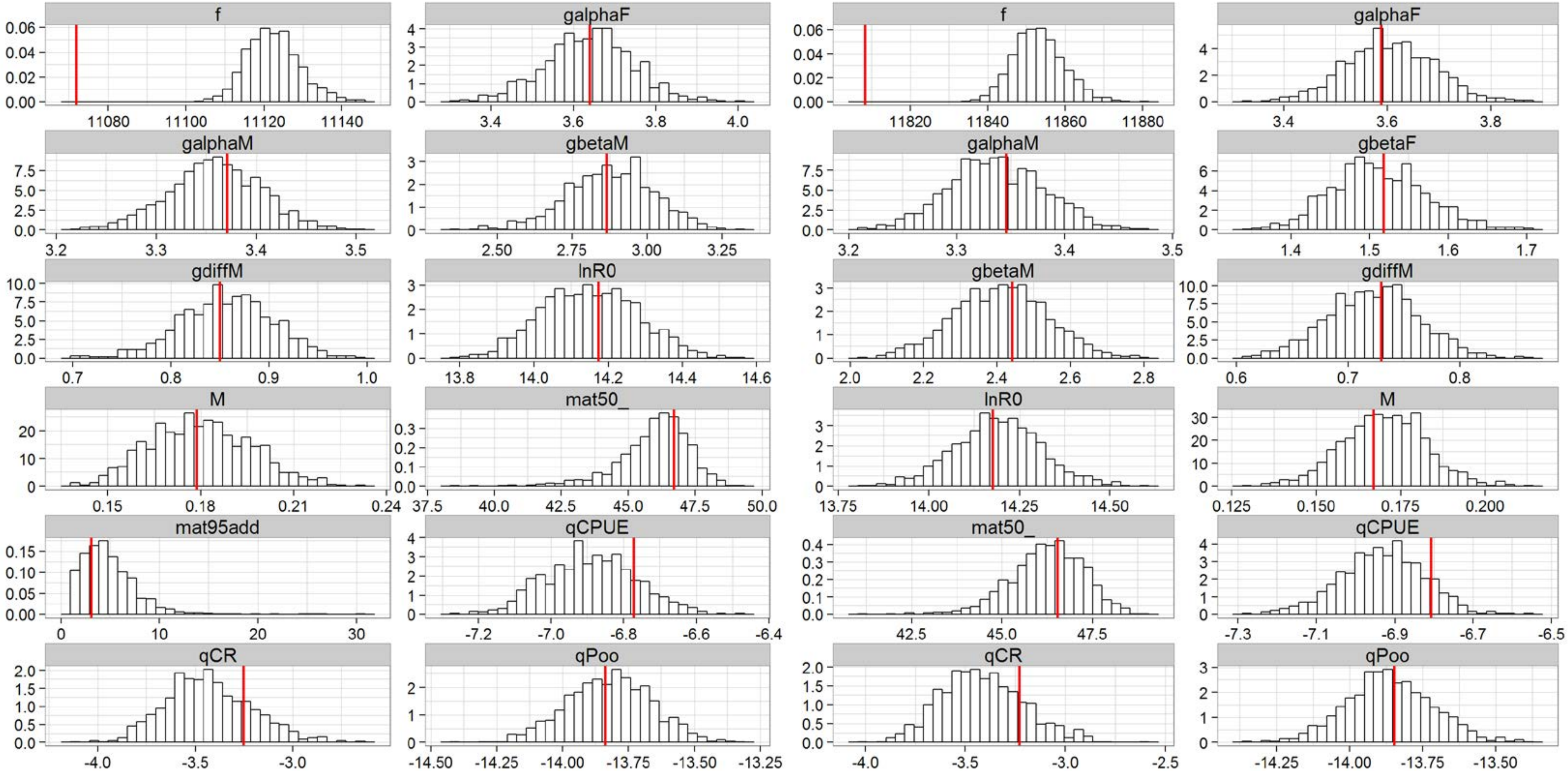
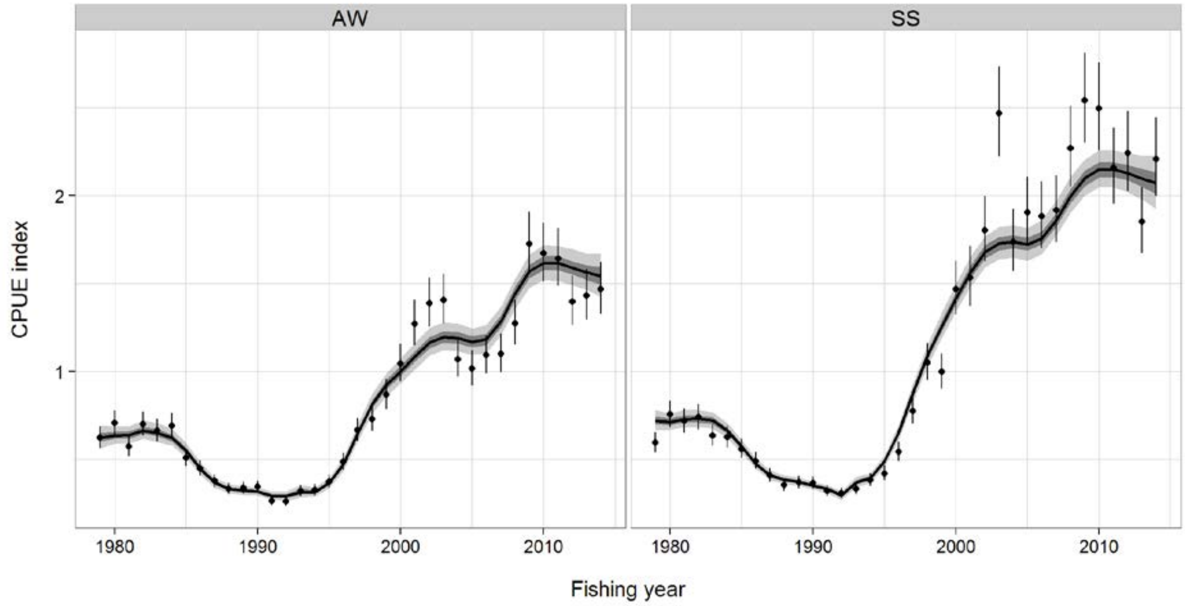



**Figure 56: Posterior distributions for leading estimated parameters from sensitivity model runs: (A) increased CV on the growth priors (left panels) and (B) double relative weight on the CPUE series (right panels). The vertical bar shows the associated MPD value.**

(a) base1 (no DD)




(b) sens6: double CPUE weight (no DD)

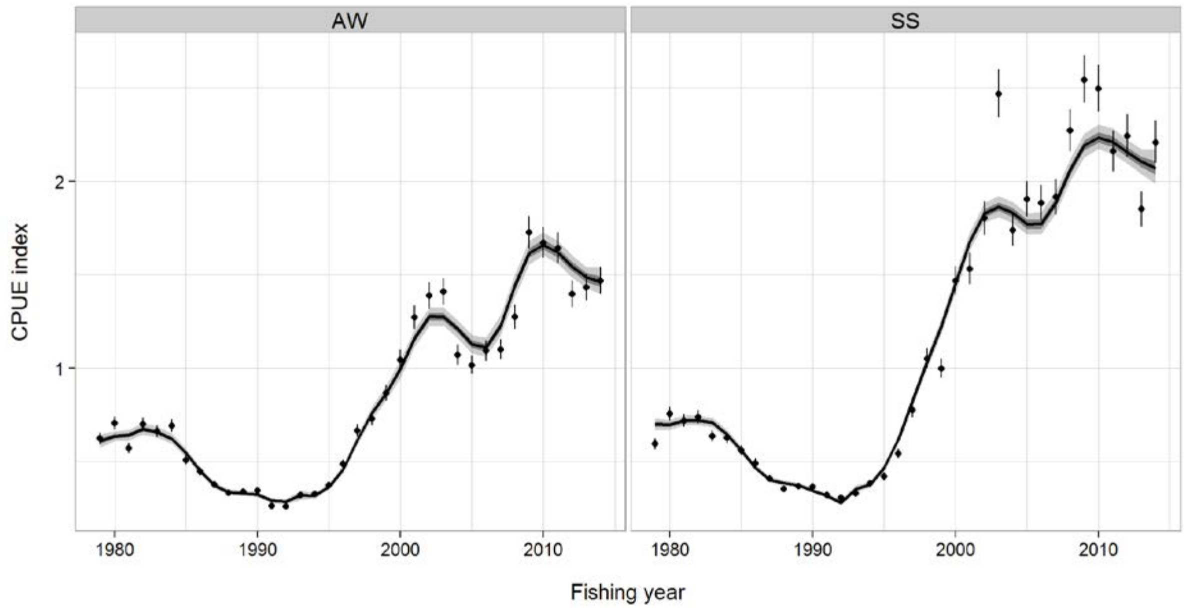



**Figure 57: Posterior of the fit to CPUE for CRA 5 by season for the base1 (no DD, top panels) and double CPUE weight (no DD, bottom panels) models. Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution. Error bars on the CPUE index values are one standard deviation.**

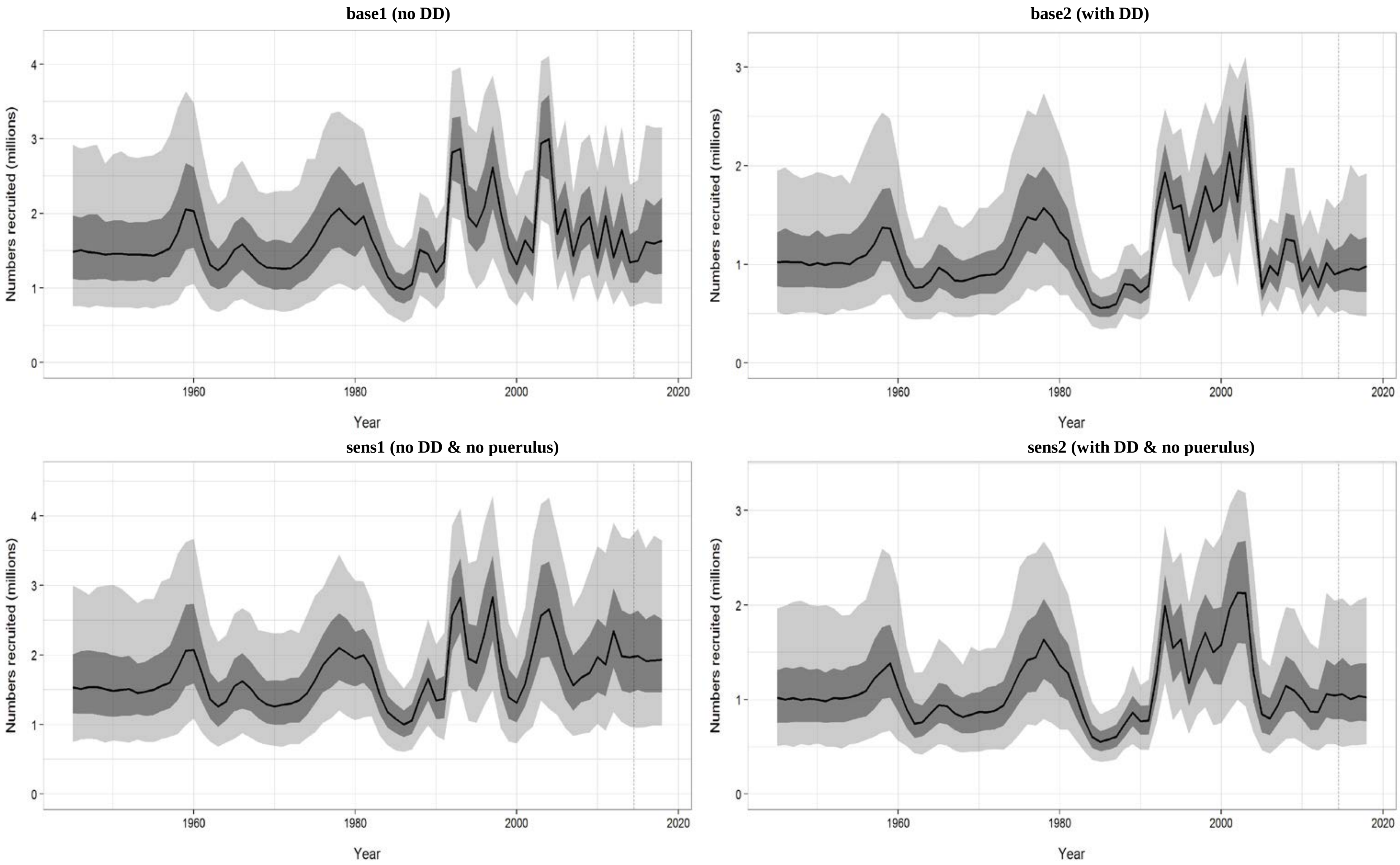



**Figure 58: Recruitment from 1945 to 2015 and projected recruits from 2016 to 2018 for the first four CRA 5 models (Table 9). Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution and the vertical line shows 2014.**

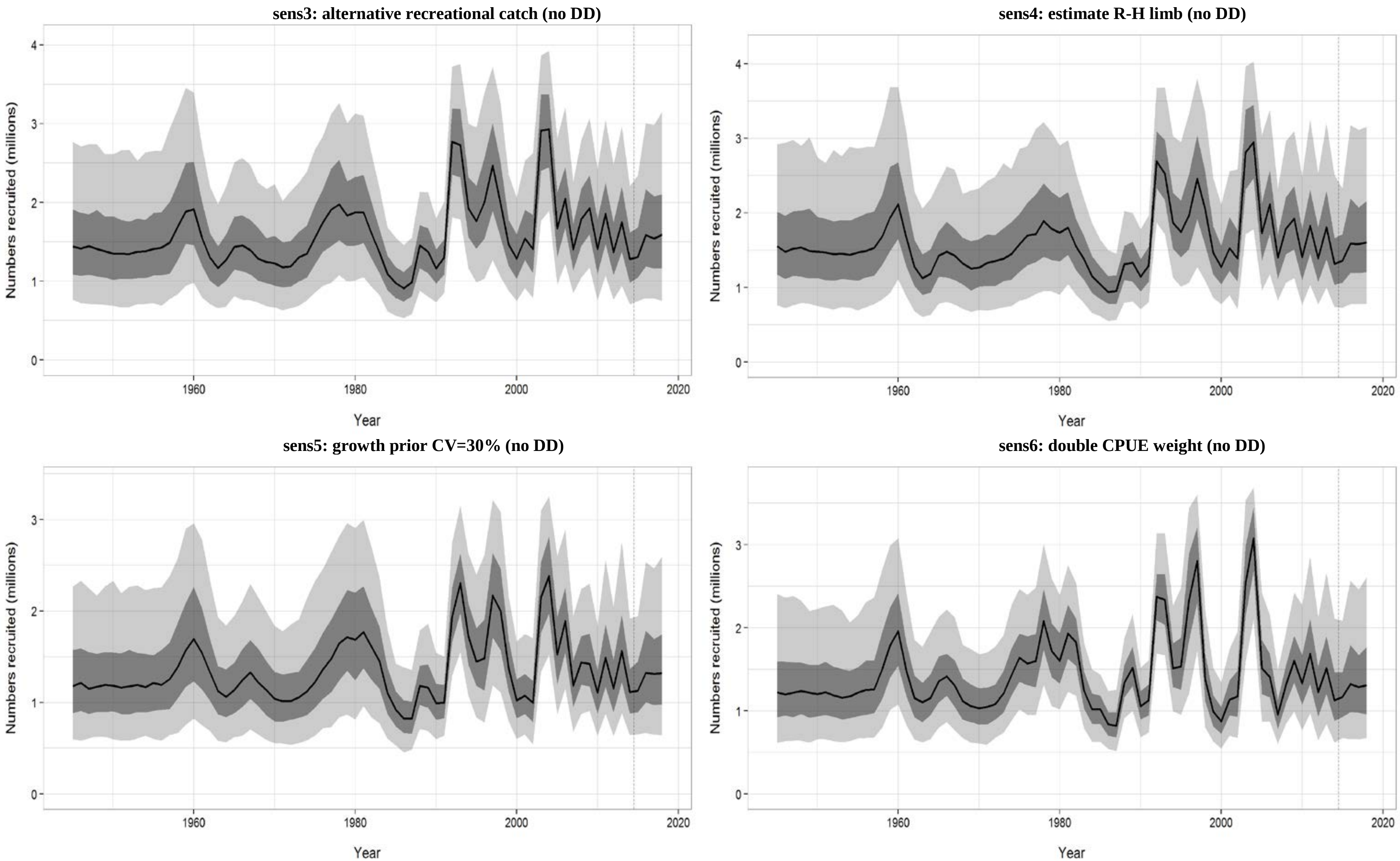



**Figure 59: Recruitment from 1945 to 2015 and projected recruits from 2016 to 2018 for the last four CRA 5 models (Table 9). Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution and the vertical line shows 2014.**

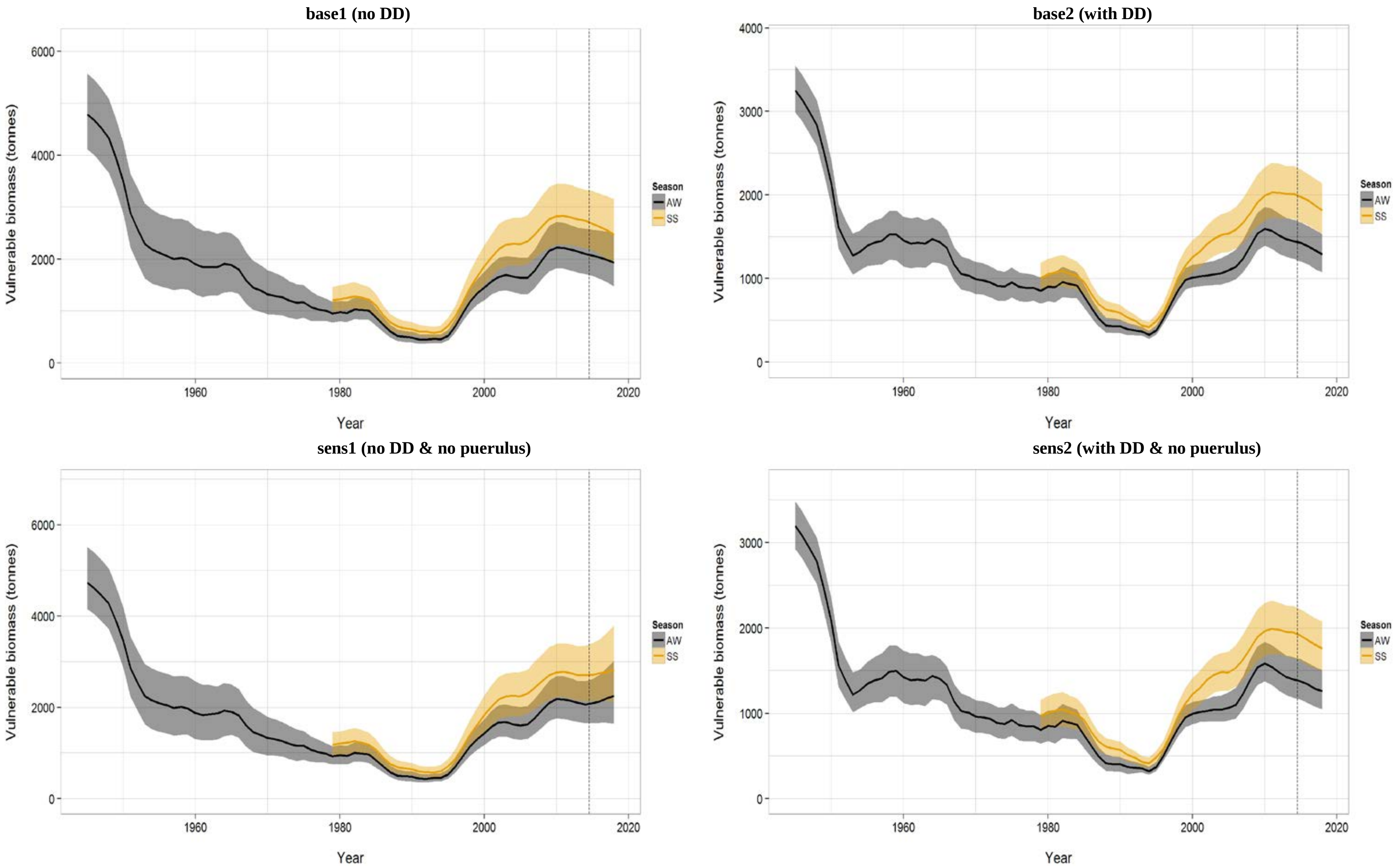



**Figure 60: Vulnerable [reference] biomass from 1945 to 2014 by season and projected vulnerable biomass by season from 2015 to 2018 for the first four CRA 5 models (Table 9). Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution and the vertical line shows 2014. Biomass before 1979 is annual, but is plotted using the AW coding.**

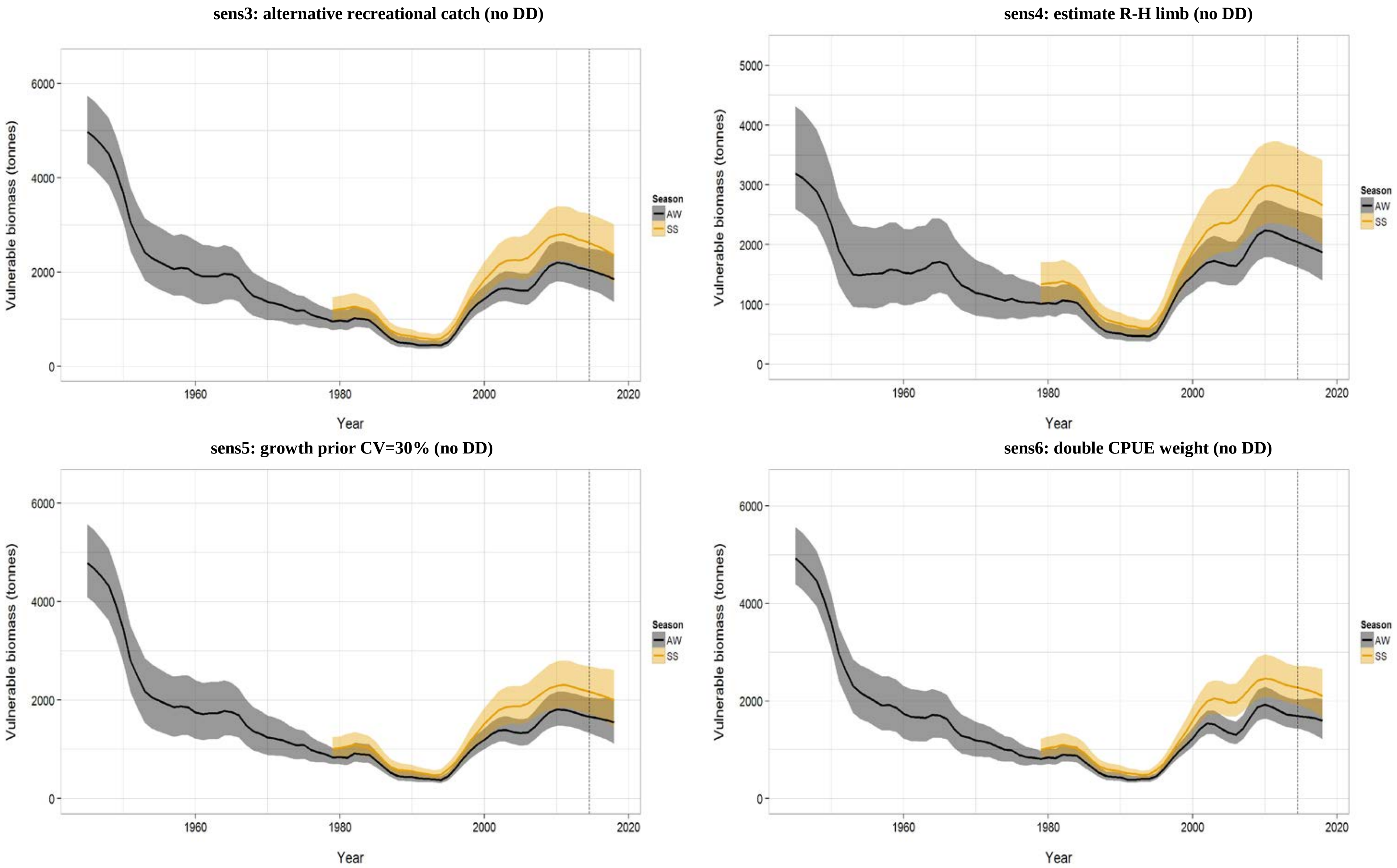



**Figure 61: Vulnerable [reference] biomass from 1945 to 2014 by season and projected vulnerable biomass by season from 2015 to 2018 for the last four CRA 5 models (Table 9). Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution and the vertical line shows 2014. Biomass before 1979 is annual, but is plotted using the AW coding.**

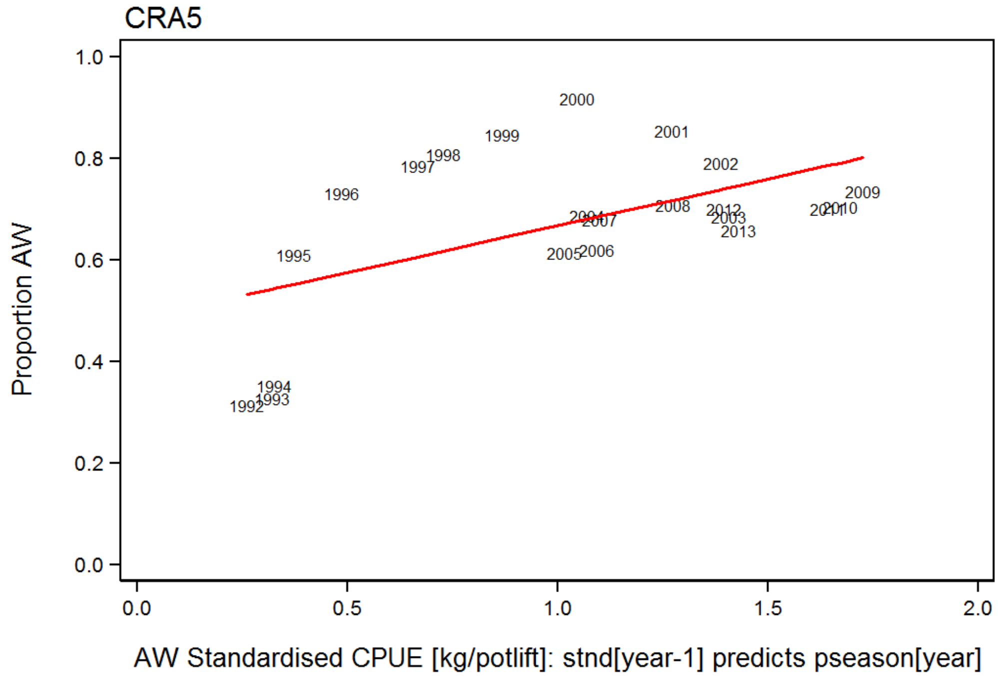



**Figure 62: CRA 5: Observed and predicted (line) AW catch proportions; intercept=0.484 and slope=0.184, with $R^2$ = 0.283.**

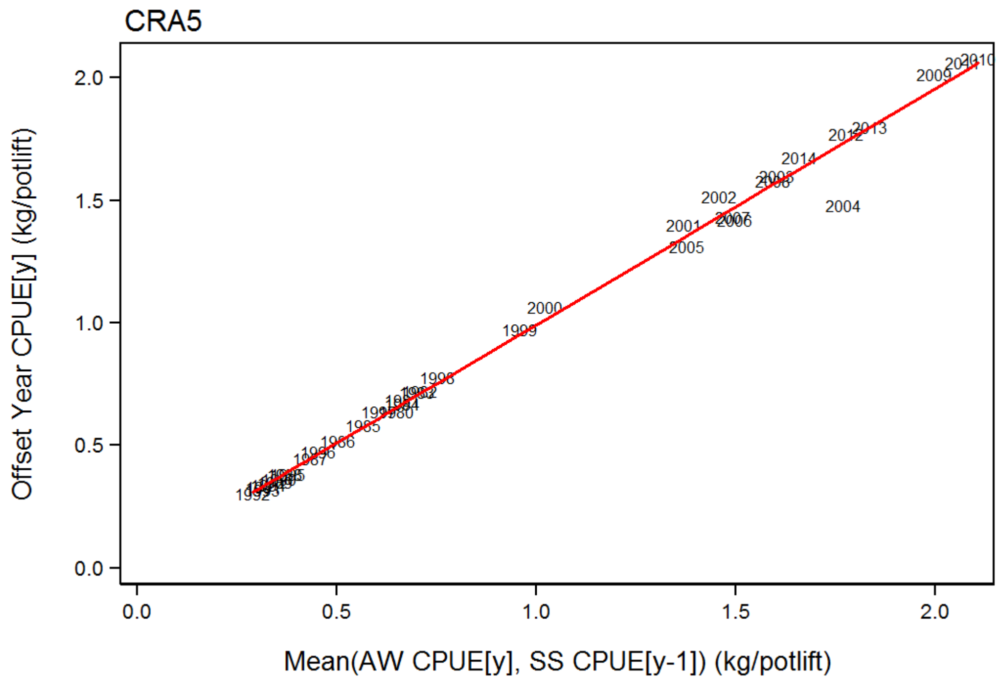



**Figure 63: CRA 5: Observed and predicted (line) Standardised offset-year CPUE versus the mean of the preceding AW and SS CPUE; intercept=0.0277 and slope=0.963, with $R^2$ = 0.992.**

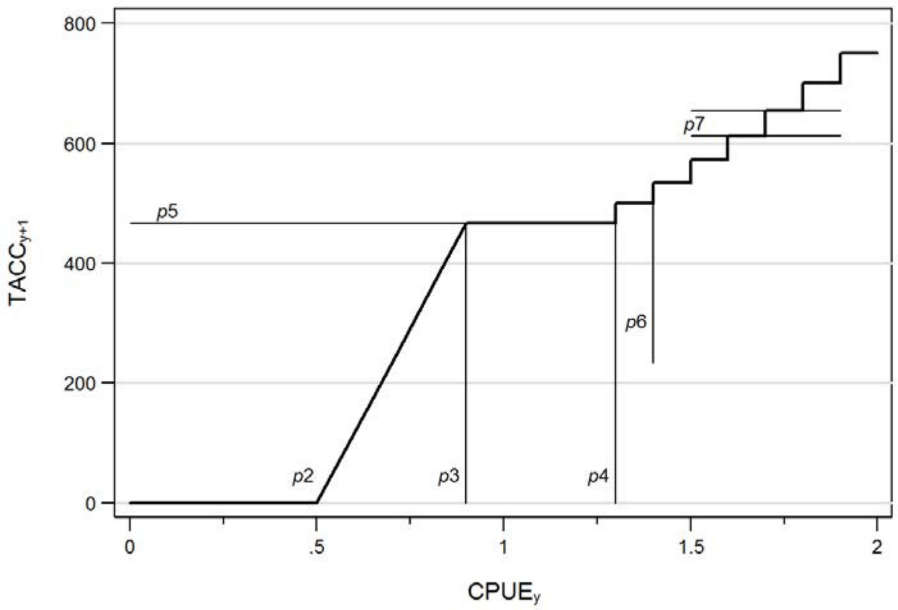
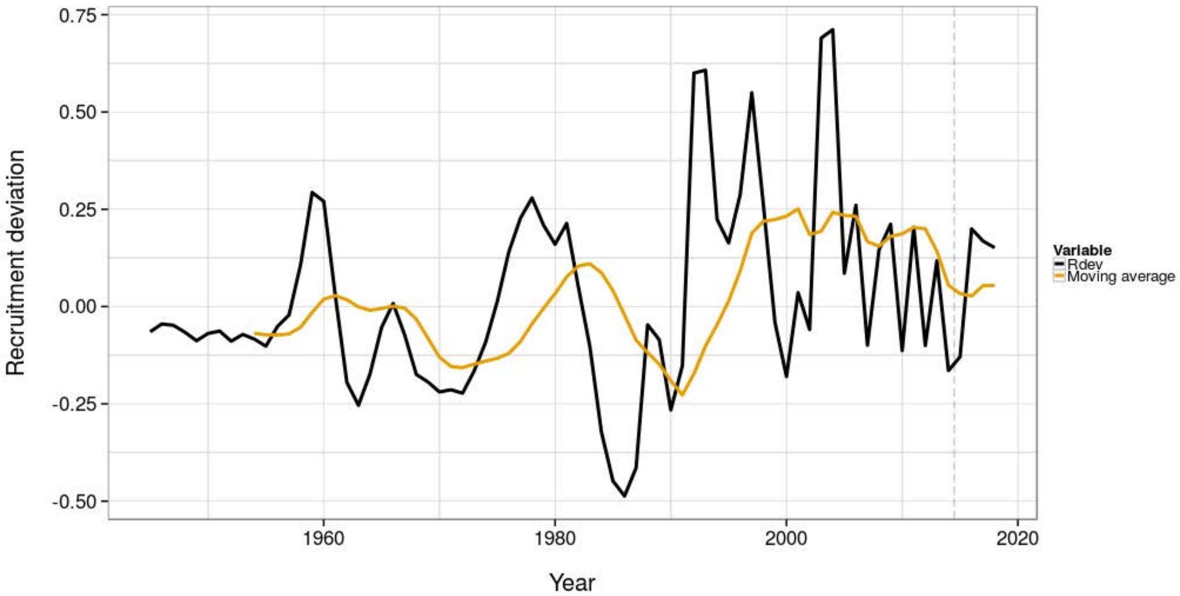



**Figure 64: Generalised harvest control rule.**

**(a) base1:**




**(b) base2:**

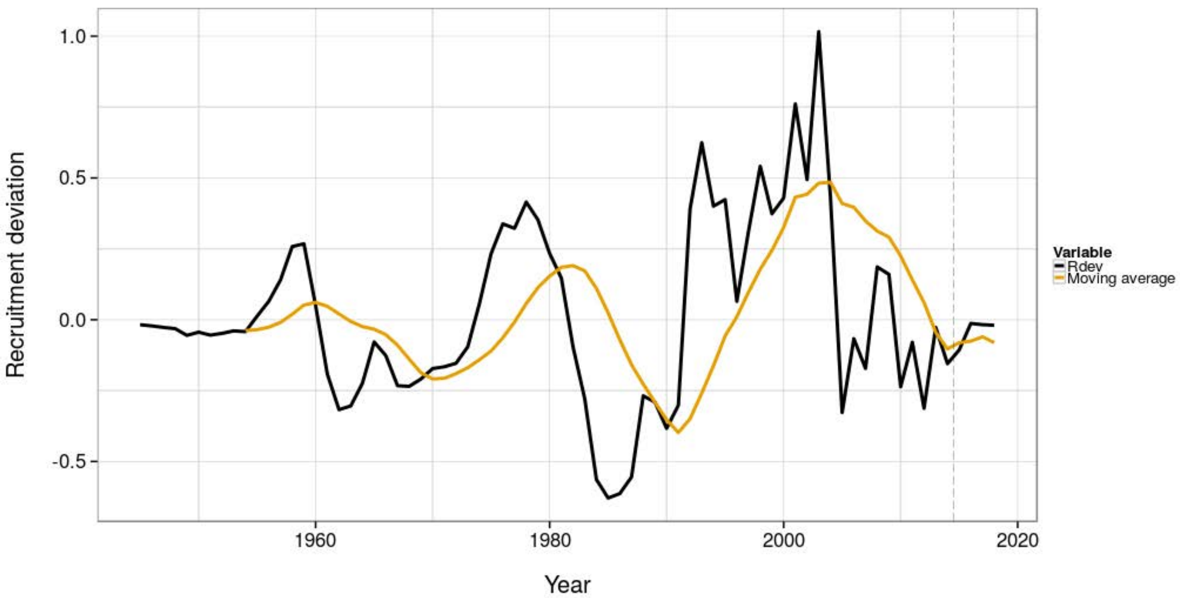



**Figure 65: Running 10-year medians of the posterior of absolute recruitment deviations for the two CRA 5 base cases plotted against the final year used in the mean. The mean 2006–2015 recruitment deviation is 0.0333 for base1 and –0.0809 for base2. The lowest 10-year mean recruitment is –0.227 (1982–1991) for base1 and –0.398 (1982–1991) for base2.**

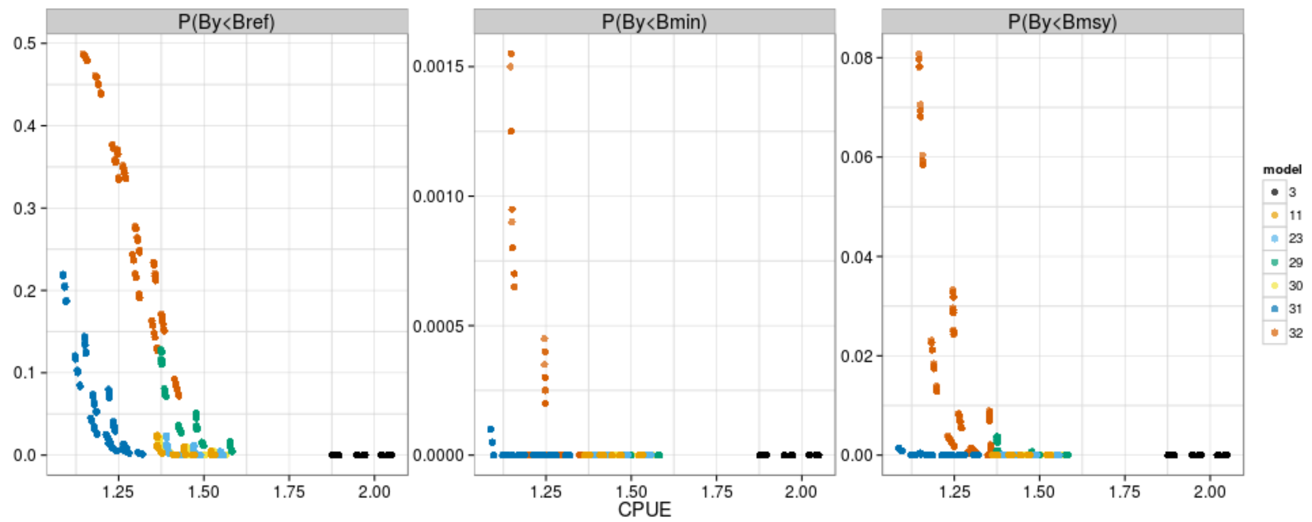



**Figure 66:** **Relationship of the mean CPUE against three probability safety indicators: [left panel] less than *Bref*; [centre panel] less than *Bmin*; [right panel] less than *Bmsy*. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates a base or robustness trial as coded in Table 13.**

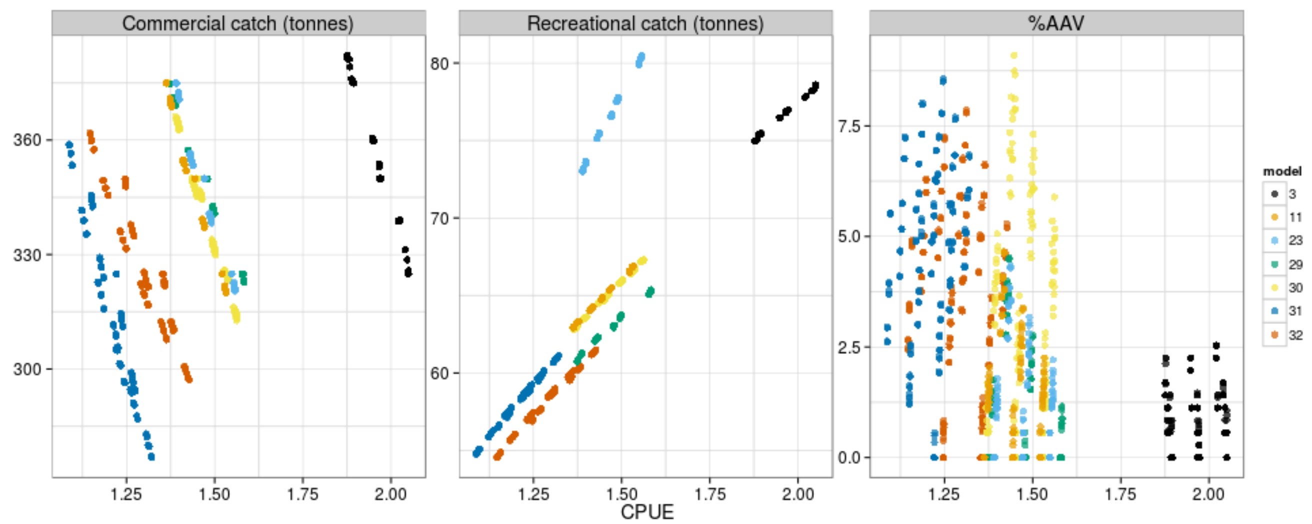



**Figure 67:** **Relationship of the mean CPUE against three performance indicators: [left panel] average commercial catch; [centre panel] average recreational catch; [right panel] mean AAV%. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates a base or robustness trial as coded in Table 13.**

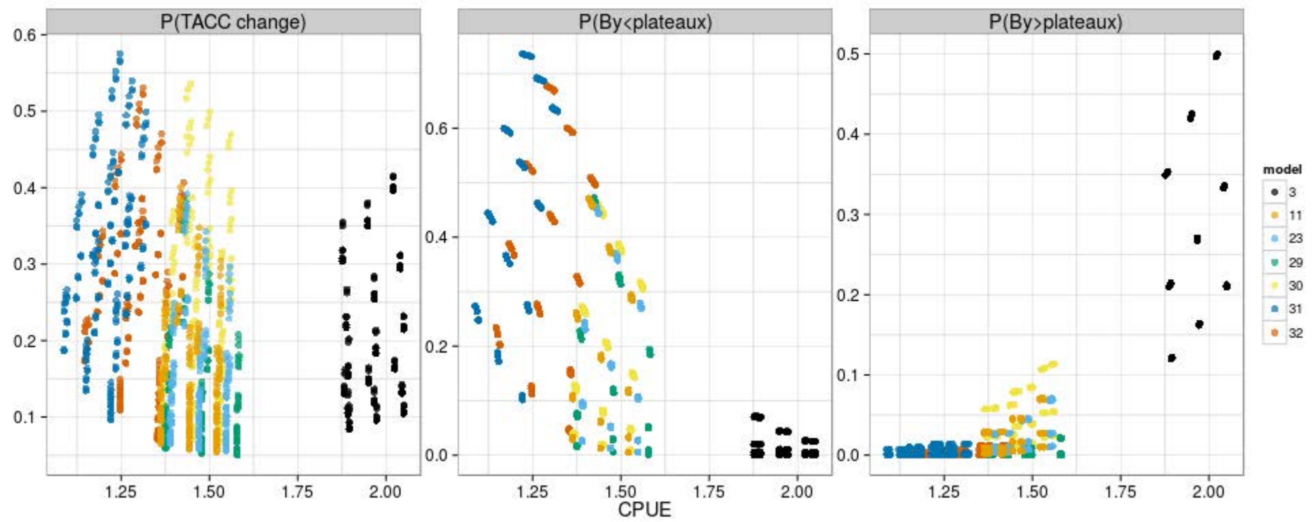



**Figure 68: Relationship of the mean CPUE against three indicators: [left panel] probability of a TACC change; [centre panel] probability of going below the left inflection point; [right panel] probability of exceeding the right inflection point. Each symbol shows the result from one harvest control rule, summarised as the median over 1000 runs. The colour code indicates a base or robustness trial as coded in Table 13.**

## 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; $Z = F + M$.