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The 2015 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8 and management procedure review

New Zealand Fisheries Assessment Report 2016/27

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This document describes a new stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8 and describes a review of operational management procedures. The work was conducted by a stock assessment team contracted by the New Zealand Rock Lobster Industry Council Ltd.

The stock assessment was made using the length-based multi-stock model MSLM. The Rock Lobster Fishery Assessment Working Group oversaw this work, and data files and all technical decisions were agreed beforehand or subsequently approved (and sometimes changed) by that group. The model was fit to CPUE indices, size frequency data and tag-recapture data. Puerulus settlement indices were not fit. This document describes the procedures used to find acceptable base cases and shows the model fits. The assessments were 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 estimated levels of catch.

The assessment showed that current and projected vulnerable biomasses in both stocks are above the reference levels *Bmsy*, *Bmin* and *Bref*, (*Bref* based on biomass in 1979–81). Spawning stock biomass in CRA 8 is well above the hard and soft limits. Spawning stock biomass in CRA 7 is above the *Bmsy* level, but is low because of the small CRA 7 minimum legal size and because some immature fish migrate from CRA 7 to CRA 8. Overall, the assessments suggest that there are no sustainability concerns for either stock.

The assessment model was used as the basis for an operating model to evaluate the performance of management procedures for CRA 7 and CRA 8, which have had management procedures to determine catch levels since 1996. Each management procedure evaluated was tested with 1000 20-year simulations, based on the McMC posteriors, to address parameter uncertainty, and with stochastic variation in CPUE observation error and in recruitment to address environmental uncertainty. Robustness trials were conducted with alternative operating models.

CRA 7 industry and the NRLMG were satisfied with the existing MP, so this work first evaluated its performance with the base case model and with seven robustness trial versions of the model. The existing rule's performance was satisfactory, so no further work was required.

Performance of the existing CRA 8 management procedure also appeared to be satisfactory with the base case operating model. CRA 8 industry requested design and evaluation of new harvest control rules that were "plateau step" rules rather than "plateau slope", that used CPUE based on the sizes of fish they retain rather than all legal and vulnerable fish, and that included rules that were more aggressive than the existing rule. We developed a way to simulate the "money fish" CPUE ("$CPUE") and tested a set of 180 new rules. Viewers were developed so that stakeholders could explore these rules, and stakeholders chose a small subset of rules as final candidates.

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

1. INTRODUCTION

This work addressed 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 the NZ 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

The National Rock Lobster Management Group (NRLMG) determined that CRA 5, CRA 7 and CRA 8 stocks should be assessed in 2015. Data were compiled for both stocks by a team comprising Paul Starr (Starrfish), D'Arcy Webber (Quantifish) and Paul Breen (Starr et al. 2016). CRA 5 was assessed by Paul Starr and D'Arcy Webber (Starr & Webber 2016) while CRA 7 and CRA 8 were assessed simultaneously by Vivian Haist, Paul Breen and Charles Edwards, with close communication and discussion between the two teams. New graphic routines were developed by D'Arcy Webber and Charles Edwards. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).

The CRA 7 (Figure 1) fishery extends from the Waitaki River south along the Otago coastline to Long Point. The CRA 7 TAC for 2014–15 was 117.72 t. Allowances set by the Minister of Fisheries were 10 t for customary catch, 5 t for recreational catch, 5 t for illegal unreported removals and 97.72 t for the commercial catch. The CRA 7 commercial season previously ran from 1 June through 19 November but is now year-long. The minimum legal size (MLS) is a tail length of 127 mm for both male and female lobsters (roughly equivalent to 47 and 49 mm tail width (TW)). The fishery is open to recreational fishing all year with MLS 54 mm TW for males and 60 mm TW for females. CRA 7 catch is exported or sold to the domestic market by several Dunedin and Christchurch fishing companies. Stock monitoring coverage in CRA 7 comprises 15 observer sampling days across both statistical areas, and has included periodic tagging, with over 2200 tagged lobsters released in 2012 and 1000 in 2013.

The CRA 8 (Figure 1) fishery extends from Long Point south to Stewart Island and the Snares Islands, through the islands and coastline of Foveaux Strait, then north along the Fiordland coastline to Bruce Bay. The CRA 8 TAC for 2014–15 was 1053 t. Allowances set by the Minister of Fisheries were 30 t for customary catch, 33 t for recreational catch, 28 t for illegal unreported removals and 962 t for the commercial catch. The MLS is 54 mm TW for males and 57 mm TW for females. The fishery is open to recreational fishing all year with MLS 54 mm TW for males and 60 mm TW for females. The industry supplies processing and export operations in Te Anau, Riverton, Stewart Island, Invercargill, Bluff, Christchurch, and Wellington. The CRA 8 Management Committee Inc. has developed and implemented codes of practice in relation to use and disposal of fishing gear and refuse, and was a founding member of the Guardians of Fiordland Fisheries.

These are trap or pot fisheries, conducted by small boats, often on day trips, fishing in relatively shallow waters. The rock lobster fishing year runs from April through March; the convention is to name fishing years by the first of the two calendar years, *viz.* 2012-13 is termed 2012. The stock assessment and data preparation separate the autumn-winter (AW, April through September) and spring-summer (SS) seasons. The stocks are managed with operational management procedures (MPs) that determine the total allowable commercial catches (TACCs), the primary management tool. Allowances are added for the non-commercial fisheries to produce total allowable catches (TACs). Other management measures include protection of ovigerous (berried) females, MLS and escape gaps in pots.

The previous stock assessment of CRA 7 and CRA 8 was in 2012: Starr et al. (2013) described the data and Haist et al. (2013) described the stock assessment and management procedure evaluations (MPEs), which used the Bayesian multi-stock length-based model (MSLM) of Haist et al. (2009). This was fitted to CRA 7 and CRA 8 simultaneously and estimated movements between CRA 7 and CRA 8. The model was fitted to tag-recapture data, standardised CPUE from 1979–2006, historical catch rate data from 1963–1973 and length frequency data from voluntary logbooks and observer catch sampling. Changes in MLS and changes in selectivity caused by escape gap regulations were taken into account.

In the 2012 stock assessments, vulnerable biomass was near *Bref* (defined below) in CRA 7 and well above all reference levels in CRA 8. At then-current catch levels, biomass was projected to increase in CRA 7 and to decrease in CRA 8, but projected to remain well above reference levels. MPs were evaluated for both stocks. The MPEs involved analogues of the then-current MPs, but with TACCs as outputs instead of TACs, and they also explored variants requested by industry and MPI.

MPs are extensively simulation-tested decision rules (Butterworth & Punt 1999): see Johnston & Butterworth (2005) and Johnston et al. (2014) for discussion of MPs used to manage rock lobsters in South Africa. MPs are now a major part of New Zealand rock lobster management (Breen 2015; Breen et al. 2016a, 2016b). They were used to rebuild the depleted CRA 8 stock in New Zealand and to manage the volatile CRA 7 stock (Starr et al. 1997; Bentley et al. 2003); a voluntary management procedure was used to govern ACE shelving in CRA 4 to rebuild a badly depleted stock (Breen et al. 2009b); a management procedure was adopted for CRA 5 for the 2012–13 season, after using a voluntary management procedure designed to maintain high abundance (Breen 2009a); a management procedure was adopted for CRA 3 in 2010 (see Breen et al. 2009a). MPs were explored with a surplus-production model for CRA 9 (Breen 2014) and CRA 6 (Breen 2009b) and this approach was compared with length-based models (Breen 2011).

The present document describes new stock assessments for CRA 7 and CRA 8. The work also reviewed the performance of the CRA 7 MP and a small set of alternatives. Explorations were limited because the CRA 7 industry wished to retain their existing rule if the performance was satisfactory in the operating model. For CRA 8, the existing MP was explored and new MPs were developed and evaluated. CRA 8 industry requested some changes to the form of their MP, as described below. For both stocks, evaluation results were presented to the NRLMG.

Management in CRA 7 and CRA 8 and other New Zealand rock lobster stocks is an example of "results-based" management, whereby responsibility for producing specified resource outcomes has been delegated by government to stakeholders (see Neilsen et al. 2015). With some reservations, this approach has been largely successful for New Zealand lobster stocks (Yandle 2008; Miller & Breen 2010; Breen et al. 2016a, 2016b).

Data for this work are described by Starr et al. (2016). This document describes the base case stock assessments, modes of the joint posteriors (MPD) and Markov chain – Monte Carlo (McMC) sensitivity trials, the projection model, MPEs and viewers provided to stakeholders for their choice of suitable rules.

Technical terms used here are defined in the Glossary.

2. BASE CASE MPD AND SENSITIVITY TRIALS

2.1 Model

The Bayesian multi-stock length-based model MSLM was described by Haist et al. (2009). The model is implemented in AD Model Builder (ADMB, Fournier et al. 2012). The model is an integrated model (see Maunder & Punt 2013; Punt et al. 2013) that estimates all structural parameters by fitting to several data sets simultaneously. CPUE is an exception to this: it is standardised outside the model and the model fits to the standardised indices. It might be preferable to estimate the explanatory variables for CPUE along with the other parameters (Maunder 2011) but this is not done for logistic and other reasons.

The model time step can be specified and can vary during the period being simulated. The model's number and width of size bins is specified. Fishing is modelled by taking into account the observed catch, MLS that can change during the period simulated, estimated seasonal vulnerability and estimated size-selectivity of the fishing gear that can vary over time. The model fits the catch that is limited by MLS and a restriction on landing ovigerous females, comprising the commercial and recreational catches, and separately fits the catch not limited by these regulations, comprising the illegal and customary catches.

In each time step, the number of male, immature female and mature female lobsters in each size class is updated as a result of annual recruitment to the model, which occurs to a specified mean size with specified variation. Recruitment can vary over time. Natural mortality is estimated but assumed to be constant over time, sizes and sexes. Handling mortality of returned lobsters (undersized and berried females) is assumed.

A growth transition matrix, based on estimated sex-specific growth parameters, specifies the probability of an individual lobster remaining in the same size bin or growing into each of the other size bins, including smaller ones. Maturation of females is described by a two-parameter logistic curve.

After finding a base case, the stock assessment estimates and their uncertainty are made with Markov chain – Monte Carlo simulations (McMC). Although this is time-consuming, it is recommended as the default method for uncertainty estimates in stock assessments (Magnusson et al. 2012).

Changes to the model for the 2015 stock assessments were minor. Previous stock assessments had used robust normal likelihood when fitting the tag-recapture data. Work by Webber (unpublished data), using the tag-recapture data from all stocks, showed that this likelihood did not perform as well as other choices. The 2015 stock assessments used normal likelihoods and removed tag-recapture records that produced residuals in the 0.2% quantiles of the distribution in a tag-only fit. Webber's work also estimated observation error (*Gobs*, see below) from all data and estimated the posterior distributions of sex-specific shape and variance parameters (*Gshape* and *GCV*) in tag-only fits. These posteriors were used as priors for these parameters. Webber (unpublished data) and Breen (unpublished data) found that the specified minimum standard deviation of the expected growth increment (*Gmin*) could not be estimated and was best fixed to a small value.

For stocks where a substantial weight of legal fish is returned to the sea, the model's *MSY* and B_{msy} calculations were revised. The calculations used the part of the vulnerable biomass that is retained rather than the whole vulnerable biomass.

2.2 Model parameters

Estimated model parameters listed in the tables below and discussed in the text are defined by Haist et al. (2009). Because these definitions are often Greek letters and often superscripted or subscripted, this document uses the set of 'shorthand' notations described in Table 1.

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

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

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

2.3 Model options and fitting

The model was fit to two CPUE indices (the older one is referred to as CR) using lognormal likelihood, to length frequency distributions (LFs) using multinomial likelihood, and to tag-recapture data using normal likelihood.

Model structure was the same as in recent assessments: 31 size bins, each 2 mm wide, with left-hand edges from 30 to 90 mm TW for each of sex groups male, immature females and mature females. Recruitment to the model occurred with a mean of 32 mm TW and standard deviation of 2 mm.

The model was used in multi-stock mode, estimating parameters for both CRA 7 and CRA 8 from the CRA 7 and CRA 8 data simultaneously, and estimating movements from CRA 7 to CRA 8. All parameters were estimated as stock-specific except for maturation. A sensitivity trial was made in which no movements were estimated, approximating separate fits for the two stocks.

Movement from CRA 7 to CRA 8 was assumed to involve fish from 45 to 60 mm TW (both sexes) and was estimated annually for the period 1985 through 2014. A 50% bound was imposed on movement by season (the same estimated movement was used in both seasons for each year) but was not reached in exploratory fits. Movements from the start year through 1984 were based on the mean of estimated movements.

Because the early years of catch data were somewhat suspect, coming from port of landing data and possibly not reflecting catches by stock, we experimented with 1963 and 1974 start years, estimating an initial exploitation rate *Uinit* for each stock. We found little difference between these two choices, and because the earlier start uses the catch rate (CR) estimates of Annala & King (1988), we used 1963 for the base case and explored the sensitivity to this choice.

We used a single annual season until 1979 and then used separate AW and SS seasons (there are no seasonal data before 1979).

The model has several options for population dynamics; we used instantaneous rates, and estimated *F* estimated with Newton-Raphson iterations. Early explorations used three iterations; the work presented is based on four and a sensitivity trial explored the effect of using five.

The model can use either logistic selectivity or a double-normal form; recent stock assessments have used double-normal, with the right-hand limb fixed at 200 to allow only a little decrease in selectivity at large sizes. We followed recent practice. A single set of parameters was estimated for CRA 7, and two sets for CRA 8, the second epoch beginning in 1993 to correspond with changes in the MLS and escape gap regulations.

Growth was estimated with the Schnute-Francis model as in recent stock assessments. The *Gmin* parameter was fixed to a small value. Observation error *Gobs* and sex-specific shape *Gshape* and variance *GCV* parameters were estimated using priors developed by Webber (unpublished) in fits to the entire New Zealand tag-recapture data set. This was a major change to previous assessments, and it resulted in a high proportion of minimisations that had positive definite Hessian matrices, which is a requirement for running McMC simulations in ADMB.

For CRA 8 only, sex-specific retention-at-size was estimated from logbook data (Starr et al. 2016). Inverse logistic curves fitted to the data for each year from 2000 were used to modify the fishing mortality in the assessment years and short-term projections.

Recruitment deviations (*Rdev*s) were estimated from the start year through 2012. Recruitment in short-term projections was randomly re-sampled from the estimates for 2003–12.

Data weighting: for LFs, we used the approach suggested by Francis (2011); weighting of the individual records is described by Starr et al. (2016). For tag-recaptures we set the relative weight to 1, so that the *GCV* prior would remain correct, and we iteratively re-weighted the CPUE, CR and LF data sets to obtain an sdnr close to 1 and a MAR close to 0.67.

Priors: for *M*, recent assessments have used a lognormal prior with a mean of 0.12 and CV of 0.4. We used this initially, but modified the prior to obtain more credible estimates of *M* as described below. Priors for three growth parameters are described above. *Rdev*s were given a normal prior in log space, with a mean of zero and *SigmaR* of 0.4 as in recent previous assessments. Remaining parameters were given uniform priors with wide bounds.

The relation between abundance and CPUE (*CPUEpow*) was fixed to be linear in base case explorations. The model's stock-recruitment option was not used. Puerulus data were explored in the 2012 assessment, but were found to have little predictive value in 2012 (see figure 21 of Haist et al. 2013) and were not used in these assessments. CRA 8 puerulus data available from three locations (Andy McKenzie, NIWA, unpublished data; see Starr et al. 2016) showed markedly different trends.

2.4 Base case MPD

2.4.1 Initial explorations

Between 50 and 75 minimisations were made in choosing a base case. In an initial set of explorations, the major issues explored were a) whether to start in 1963 or 1974 and b) whether to include the SS LFs for CRA 7, because of some uncertainty about their representativeness discussed by the RLFAWG. We ran all four combinations of the two options, doing iterative re-weighting to achieve balanced residual diagnostics, and without density-dependent growth. Because there was little difference among the four trials, we chose to start in 1963 and to include all CRA 7 SS LFs.

A major problem with the results was low estimated *M* in both CRA 7 and CRA 8. When density-dependent growth was estimated, the objective function became lower (better fit) but estimated *M* values were even lower: 0.07 for CRA 7 and 0.03 for CRA 8. These were not considered credible. Increasing the mean of the prior on *M*, based on recent estimates from other lobster stock assessments, had almost no effect on the estimated *M*. Decreasing the CV (without altering the mean) of the prior did give increased *M* estimates, and we chose to use a CV of 0.1 in the *M* prior to force more credible estimates of *M*.

As an alternative to estimating growth density-dependence, we split the CRA 8 tags into two groups: those released in 1986 and before, and those released in 1993 and after; no tags had been released in 1987–92. The two candidate base cases, which we called the Density-dependence (“d-d”) and 2TagFile (“2TF”) options, had very similar parameter estimates except for *Uinit*, which was 0.07–0.11 in the d-d model and zero for both stocks in the 2TF model. The exploitation rate trajectories were very similar after about five years, so the main difference was that early years of the model population had been initialised slightly differently.

We preferred the d-d model option for the base case. However, when we ran preliminary McMC simulations (about 300 000 simulations for the d-d model and about 600 000 from the much faster 2TF model), traces from the d-d model were unacceptable while those from the 2TF model were much better converged and mixed; we chose the 2TF model as the base case and used the d-d model for a sensitivity trial.

2.4.2 Base case

The base case used a 1963 start, used all the SS LFs from CRA 7 catch sampling, used an *M* prior with CV of 0.1, had no growth density-dependence, was weighted iteratively to balance the residuals and used two tag files (1986 and before, 1993 and after) for CRA 8, and estimated two sets of growth parameters *Galpha* and *Gbeta* for CRA 8. The fixed quantities used in the final base cases are shown in Table 2 and the estimation details are shown in Table 3. The organisation of sex- and season-specific vulnerability is shown in Table 4.

Fitting diagnostics, likelihood contributions, parameter estimates and derived parameters from the base case are shown in Table 5. Estimated *M* was close to 0.10 for both stocks as a result of the narrow prior. Initial exploitation rates were zero for both stocks. For CRA 7, *Galpha* and *Gbeta* were the same because of the limited information on larger fish in the tag-recaptures. In CRA 8, growth estimated from the more recent tag data was greater than from the older tag data. In both stocks, male growth was higher than female growth. The time between recruitment to the model and MLS was estimated as 3 years for males and 3.5 to 4 years for females. Estimated *Gshape* was close to the mean of the prior except in the more recent tag data for CRA 8, where it increased somewhat from the prior mean. *GCV* was estimated to be close to the prior mean for both stocks and sexes, and estimated *Gobs* was very close to its prior mean.

The estimated relative vulnerability for males in CRA 7 was at the upper bound of 1 in SS, whereas none of the estimated *vuln*s was at the upper bound for CRA 8. The model has no provision for specifying different stock-specific sex/season cells for the maximum vulnerability.

Movements averaged 0.184 per season (33% annually) and the maximum estimate was 0.42 (66% annually).

In the MPD base case, CRA 7 was estimated to be about twice *Bref* (this is based on the period 1979–81 as in previous stock assessments for these stocks) and four times *Bmsy*. *MSY* was estimated at 197 t, taken with a very high *F* from a small biomass: *Bmsy* was only 230 t. The estimated 2014 total catch in CRA 7 was 74.6 t. The CRA 8 stock was estimated to be 1.3 times *Bref* and 1.7 times *Bmsy*. *MSY* was estimated to be 1103 t, compared with estimated current catch of 1009 t in 2014.

Fits to the AW CPUE were good (Figure 2 and Figure 3); fits to SS were not as good, especially in recent years, but CRA 7 has been historically an AW fishery (see Starr et al. 2016). For both stocks, SS CPUE residuals (Figure 4 and Figure 5) had an increasing trend over time (slopes 0.025 and 0.041 per year respectively); in CRA 7 the AW residuals decreased over time (slope -0.017 per year). The fits to the CR indices (Figure 6 and Figure 7) were reasonably good.

The residual diagnostics for weighting the LFs were based on the residuals from the observed vs. predicted mean lengths (Figure 8 and Figure 9). Fits were much better for CRA 8 than for CRA 7, although for recent years mean size tended to be underestimated for males and mature females in SS. In CRA 7 the data were much more variable, perhaps reflecting less representative catch sampling, and there were seasonal trends that may have reflected some model mis-specification.

Fits to proportion-at-sex in CRA 7 (Figure 10) were good for the increasing trend in males and decreasing trend in mature females in AW, but were less well determined for the SS (with much less catch landed) and for mature females (which had low proportions in most seasons). For CRA 8 (Figure 11), the model caught some but not all of the strong trends reflected in the logbook data. Residuals are shown in Figure 12 and Figure 13.

Fits to the LFs in CRA 7 (Figure 14 through Figure 20) were quite variable, especially in the early years, reflecting the generally low proportions of mature females and the volatile nature of the data (Figure 8 and Figure 10). Mean residuals (Figure 21) showed some trends, especially in AW and for immature females in SS.

Fits to the CRA 8 LFs (Figure 22 through Figure 30) were much better than in CRA 7, but showed some large residuals (Figure 31) and some sex-specific size/seasonal trends (e.g. mature females in SS) that suggested some process that was not captured by the model.

Observed and predicted increments from the tag-recapture data and their Q-Q plots (Figure 32) reflected a better fit for CRA 8, with much more data in both tag-recapture data sets. The second CRA 8 data set was fit better than the first. Residuals by size (Figure 33) were mostly positive for CRA 7, suggesting that the LF data reduced the estimated growth rate from what would be estimated from the tag-recapture data alone. Large fish tended to have negative residuals in both stocks and sexes.

The estimated female maturation curve used for both stocks had 50% maturation just below 60 mm, and the curve was narrow (Figure 34). Selectivity for CRA 7 (Figure 35) was maximum near 54 mm for both sexes. For CRA 8 (Figure 36), selectivity shifted to the right in the second epoch, as would be expected.

The CRA 7 growth curve is shown in Figure 37, and curves for the two CRA 8 growth stanzas in Figure 38 and Figure 39. Growth in the second CRA 8 stanza was faster than in the first.

Recruitment in CRA 7 was estimated to have had a number of strong peaks (Figure 40), while in CRA 8 there was a very strong peak near 1981 and then a much more sedate pattern. Movements are illustrated in Figure 41.

The CRA 7 total biomass trajectories by sex (Figure 42) were dominated by males and immature females; they showed a strong decline from 1963 to 1980, and then a series of fluctuations. CRA 8 total biomass (Figure 43) also showed a strong decline between 1963 and 1980, a minimum in the 1990s and then a recovery. Current total biomass in CRA 8 was dominated by mature females and immature females were a small component.

Vulnerable biomass *Bvulnref*, calculated using the current MLS, and selectivity (Figure 44), showed very steep declines from 1963, minima in the 1990s and then recovery. In CRA 8, AW biomass was higher than in SS because of the restrictions on taking berried females.

Seasonal exploitation rates (Figure 45 and Figure 46) showed peaks at high levels (70%) in the 1980s for the SL stocks, but were in the 10–20% range currently. NSL exploitation rates were small because of the low non-commercial catches (see Starr et al. 2016).

2.5 MPD sensitivity trials

We ran 17 sensitivity trials to various modelling choices: each was run from the base case control and data files except for the change indicated. Results are compared with the base case in Table 5 and Table 6. Most had a positive definite Hessian.

Over all the trials, estimated current and projected biomass remained above both *Bref* and *Bmsy* in 66 out of 68 instances. Except in the trial without tag data, growth parameters did not change more than 30%. Only the trial that changed the *M* prior from the base resulted in a substantial change in estimated *M*.

sens1: the alternative candidate base case d-d described above, using only one CRA 8 tag file and with growth density-dependence estimated. This model had a slightly better fit than the base case by 11 likelihood units. *Uinit* was estimated as 0.17 in CRA 7 and 0.04 in CRA 8 (these were both zero in the base case) and growth parameters *Galpha* and *Gbeta* were higher than in the base case (because they represent growth at zero biomass), but other differences were quite minor.

sens2: with all the SS LFs for CRA 7 removed. This reduced growth in CRA 7 slightly and affected selectivity and vulnerability, but the effects on indicators were small.

sens3: with the model starting in 1974 as in the 2012 assessment. In this model, *Uinit* was estimated at 44% and 16% for CRA 7 and CRA 8 respectively, but effects on indicators were small.

sens4: with the model starting in 1945. In this run, CRA 7 *B2015/Bref* and *B2015/Bmsy* were somewhat smaller; for CRA 8 *B2015/Bref* was larger but *B2015/Bmsy* was smaller and MSY was somewhat larger.

sens5: with *F* estimated with five Newton-Raphson iterations instead of four as in the base case. This had almost no effect, indicating that four iterations were sufficient.

sens6: using raw weights for LF records derived from the numbers of fish measured and the number of days sampled, instead of these weights being truncated between 1 and 10 as in the base case. Although parameter estimates seemed similar, for both stocks the current biomass against reference levels *Bref* and *Bmsy* was lower.

sens7: with the maximum relative sex/season vulnerability set for males in the SS, not AW as in the base case. In this run the CRA 8 male vulnerability went to the upper bound of 1 in AW, suggesting that the original scheme was better for CRA 8.

sens8: using a prior for *M* with mean 0.12 and a standard deviation of 0.4 (as in most recent stock assessments) instead of 0.1 as in the base case. Estimated *M* went down to 0.036 for CRA 7 and to 0.062 for CRA 8, but effects on growth parameters were minimal. CRA 7 was not as far above *Bref* and *Bmsy* as in the base case while for CRA 8 the effects were mixed.

sens9: with wider priors for *GCV*, *Gshape* and *Gobs*: the standard deviations were calculated as 30% of the means. The estimates increased for *Gshape* and *GCV*, decreased for *Gobs*; growth parameters decreased for CRA 7 but increased for CRA 8; movements were higher; indicators were less optimistic for CRA 7 and slightly more positive for CRA 8.

sens10: with the right-hand limb of the selectivity curves estimated rather than fixed at 200 as in the base case. The function value improved by 21 units. *SelRH* decreased to 20 to 55 except for CRA 7 females, where it increased to the upper bound of 250. Effects on indicators were mixed but not large.

sens11: with *CPUEpow* estimated instead of fixed at 1 as in the base case. This improved the fit to CPUE by 12 units but the function value improved only by 3 units. *CPUEpow* was estimated at 2 for CRA 7 (the upper bound, suggesting hyperdepletion) and 0.963 (very slight hyperstability) for CRA 8. Effects on indicators were a slight improvement for CRA 8 and mixed for CRA 8.

sens12: with tag-recapture records removed that were re-releases (fish recaptured more than once might be slower growing than fish captured only once, because many tagged fish are sub-legal at tagging). This produced minor changes to estimated growth parameters but only minor changes in the indicators.

sens13: with CPUE data not fitted. This produced some big implausible decreases in some of the *vuln* estimates and the CRA 8 stock was estimated to be below *Bref* (although still above *Bmsy*).

sens14: with CR data not fitted. This run showed very little change from the base case.

sens15: with LFs data not fitted. In this run there were substantial changes to estimated *vuln*s and selectivity parameters. For the CRA 7 stock, current biomass was estimated to be further above *Bref* and *Bmsy* than in the base case, and CRA 8 was estimated to be further above *Bref* but not as far above *Bmsy*.

sens16: with tag-recapture data not fitted. There were mixed changes in growth parameter estimates, but only in CRA 8 female parameters from the earlier tag data were the changes larger than 25%. Indicators were more optimistic for both stocks.

sens17: with no movements estimated between CRA 7 and CRA 8, making this essentially a separate fit for both stocks, with only maturity parameters estimated in common. The main effect was a huge increase in *Bmsy* for CRA 7 such that *B2015* was less than *Bmsy*. Effects on CRA 8 were minimal.

3. BASE CASE MCMC

The base case McMC was started at the base case MPD and run for 5 million simulations, with 1000 samples saved. As in the base case MPD, simulations used four Newton-Raphson iterations to estimate *F*. Projections were made for three years, to 2018, re-sampling *Rdev*s from 2003–2012 to project recruitments.

Traces (Figure 47) for *Uinit* and some movement parameters were not good because these parameters were at the bound of zero in the MPD, but *Uinit* remained near zero in the McMC. *Gdiff* for CRA 7 males and CRA 7 *vuln2* show similar problems but these result from the MPDs being on the upper bound of 1. *Galpha* and *Gbeta* both show some non-stationarity when estimated from the first tag data file in CRA 8, but traces from the second data file are better behaved. These problems are reflected in the diagnostic plots (Figure 48).

Base case parameter posteriors are summarised in Table 7. For CRA 7, *M* tended to increase slightly from the MPD, but for CRA 8 the median of the posterior was near the MPD. Some growth parameters drifted away from the MPD when estimated from the first tag data file in CRA 8. The vuln2 parameter for CRA 7, already noted above, showed a bimodal distribution but remained close to 1.

Fits to CPUE (Figure 49 and Figure 50) were similar to the MPD fits. Biomass trajectories (Figure 51 and Figure 52) were also similar to the MPD trajectories and recruitment trajectories (Figure 53 and Figure 54) show the same patterns as the MPDs. Selectivity curves are shown in Figure 55 and Figure 56.

4. STOCK ASSESSMENTS

4.1 Assessment indicators

Indicators requested by MPI and the RLFAWG are summarised in Table 8. These included several based on vulnerable biomass: current biomass *B2015*, projected biomass *B2018* and the minimum of the vulnerable biomass trajectory after 1979, *Bmin*. These were all start-of-season AW biomass, which does not include mature females. Vulnerable biomass takes MLS, selectivity and sex/seasonal vulnerability into account, and is the biomass available to the fishery. Vulnerable biomass was calculated with the appropriate MLS: for CRA 7, MLS is 127 mm tail length for both sexes (about 47 or 49 mm TW); for CRA 8, 54 mm for males and 57 mm TW for females.

A minor loss of realism was caused by assuming that the recreational fishery used the same MLS as commercial, whereas in reality the MLS for recreational fishers is 54 mm for males and 60 mm TW for females. Addressing this would involve major recoding. It is not a major problem because the recreational catch is relatively small compared with commercial.

Bmsy and *MSY* were estimated in deterministic 50-year simulations that started at the 2015 biomass estimates. The non-commercial catches were assumed to remain constant at 2014 levels, and the simulations used the 2013 catch splits between AW and SS. Growth for CRA 8 was based on the second growth epoch and recruitment was based on *R0*. A series of multipliers on *F* was applied, and *MSY* was the maximum commercial catch; *Bmsy* was the biomass from which *MSY* was taken. *Fmult* was the multiplier on 2013 *F* that gave *MSY*. *CPUEmsy* was the CPUE associated with *MSY*. For stocks with high-grading, such as CRA 8, these calculations used the part of the vulnerable biomass that is retained rather than the whole vulnerable biomass. The change affected *Fmsy*, *Bmsy* and the relation between 2015 biomass and *Bmsy*.

Spawning stock biomass *SSB* was the biomass of all mature females at start of AW; *SSBmsy* was the biomass associated with *MSY*. *SSB0* was the spawning stock biomass at unfished equilibrium with *R0*.

Biomass and spawning stock biomass were projected for three years using the same assumptions as described for MPD projections: recruitment was based on the most recent 10 years, constant fishing patterns and constant non-commercial catches.

USL was the exploitation rate on the size-limited (SL) stock and *UNSL* was the exploitation rate on the non-size-limited (NSL) stock.

Btot and *Ntot* were the biomass and numbers of all fish without regard to MLS, selectivity or vulnerability.

As well as the simple indicators, the RLFAWG requested the posterior distribution of ratios, for instance the ratio of current biomass to *Bmsy*, and the probabilities that various propositions were true in the McMCs.

4.2 CRA 7 stock assessment

The posteriors of assessment indicators are shown in Table 9. The stock was estimated to be 8 times *Bmin* (5th and 95th quantiles 5.5 to 12 times), four times *Bmsy* (2.8 to 5 times) and twice (1.3 to 2.8 times) *Bref*. Probabilities that current biomass was above these indicators were nearly 1. Spawning stock biomass was 17% of *SSB0* (14% to 21%), less than 20% *SSB0* with 92% probability.

Projected biomass declined with 76% probability by a median 7.5% (21% decrease to 12% increase). Projected biomass remained well above the three indicators *Bmin*, *Bmsy* and *Bref*. Spawning biomass was projected to increase to a median of 23% *SSB0* (17% to 30%) and to have only 21% probability of being less than *SSB0*.

Because of the small MLS, and because of the estimated movements of fish away from CRA 7, yield was maximised at a very high fishing intensity: *MSY* was about 80% *Bmsy* and was achieved with an *F* 15 times the current *F* levels. The proxy *Bref* was about twice *Bmsy* and is therefore a more conservative reference point.

The low indicators based on spawning stock biomass result from the small MLS, which is less than the estimated size at 50% maturation (47 vs. 58 mm TW), and also from the estimated movements of pre-spawning fish out of CRA 7 into CRA 8. The indicators based on vulnerable biomass and exploitation rates suggested that there were no sustainability concerns for this stock.

The phase diagram of fishing intensity vs. biomass is shown in Figure 57. This “snail trail” is a plot developed by the Stock Assessment Methods Working Group, showing the median spawning biomass on the x-axis and median fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery would be likely to go. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock *SSB0*. Estimated *SSB* changes every year; *SSB0* is constant for all years of a simulation, but varies among the 1000 samples from the posterior distribution.

The y-axis is fishing intensity as a proportion of the fishing intensity that would have given *MSY* (*Fmsy*) under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. For CRA 8 the fishing pattern includes retention pattern. *Fmsy* varies among years because the fishing patterns change. It was calculated with a 50-year projection for each year in each simulation, with the NSL catch held constant at that year’s value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually *F*s for two seasons) that gave *MSY* was *Fmsy*, and the multiplier was *Fmult*.

Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

This plot suggests that spawning stock biomass in the CRA 7 stock has never been below the spawning stock biomass associated with *Bmsy*, also suggests that fishing intensity has never reached that which would produce *MSY*. These suggestions must be interpreted cautiously: reasons for low spawning stock biomass and high fishing intensity at *Bmsy* are discussed above.

4.3 CRA 8 stock assessment

The posteriors of assessment indicators are shown in Table 10. The stock was estimated to be four times *Bmin* (5th and 95th quantiles 3.3 to 5.1 times), 1.8 times *Bmsy* (1.5 to 2.2 times) and 1.4 times *Bref* (1.1 to 1.6 times). Probabilities that current biomass was above these indicators were nearly 1. Spawning stock biomass was 44% of *SSB0* (41% to 48%), with no probability of being below 20% *SSB0*. Spawning stock biomass was 1.6 times *SSBmsy* (1.5 to 1.8 times).

Projected biomass increased with 58% probability by a median of 2.4% (16% decrease to 24% increase). Projected biomass remained well above the three indicators *Bmin*, *Bmsy* and *Bref*. Spawning biomass was projected to increase to a median of 46% *SSB0* (40% to 54%) and to zero probability of being less than *SSB0*.

The phase diagram of fishing intensity vs. biomass is shown in Figure 58. In about 1979, the spawning stock biomass became less than that associated with *MSY*, and the fishing intensity exceeded that associated with *MSY*. In this plot, the stock remained overfished and depleted until 2004, when fishing intensity reduced below the MSY level, and the stock increased above the *SSBmsy* level by 2008.

The position of the stock on the phase plot, and the indicators discussed above, suggest that the CRA 8 stock is in a healthy state.

Late in the stock assessment, CRA 8 industry representatives requested new indicators "*relating to ... 'that part of the vulnerable biomass from MLS to 1.5kgs in weight'*". The CRA 8 fishery returns large fish to the sea because they are worth much less than smaller legal fish (see Starr et al. 2016). The industry wanted indicators that related (roughly) to the biomass of lobsters they retain. These were:

- *money fish vulnerable biomass [compared with] vulnerable biomass for the whole stock for both 2015 and 2018*
- *the exploitation rate on that 'cohort'*
- *probability [of] increase or decrease [of] "money fish" biomass between 2015 and 2018*

These were calculated based on "legal biomass", which includes all fish above the MLS except for mature females in AW, and does not consider selectivity or seasonal vulnerability. The seasonal biomass of legal fish between MLS and 1.5 kg weight was calculated as *$BAW* and *$BSS*. Exploitation rate on this biomass was calculated as *$ERateAW* and *$ERateSS*.

These indicators are compared with indicators based on the whole vulnerable biomass in Table 11.

4.4 Comparison with 2012

Key estimates are compared between the 2012 and 2015 stock assessments for each stock in Table 12. This assessment estimated a smaller *Bmin* than in 2012 for both stocks. The 2015 *Bref* was smaller for CRA 7 but larger for CRA 8. Current biomass and current biomass as a proportion of *Bref* were larger in 2015 for both stocks. Current exploitation rates were smaller for both stocks than in 2012 estimates.

4.5 McMC sensitivity trials

Five sensitivity trials were run with McMC. For each, only the change specified was made to the base case; two million simulations were started from the MPD and 1000 samples were saved.

d-d: using the density-dependent model, described above, developed during the search for an appropriate base case

RawLFs: using the raw record weights for LF data, whereas the base case truncates the weights to lie between 1 and 10

WideM: with the prior on *M* with CV 0.4 (as used in previous assessments) instead of the narrower prior used by the base case

WideG: using wider priors (CV 0.3) for the growth parameters *Gobs*, *Gshape* and *GCV*

NoMoves: with no estimated movements from CRA 7 to CRA 8 (virtually separate assessments for these two stocks)

Medians of estimated parameters are compared with the base case in Table 13. Changes involved recruitment, natural mortality and growth parameters, and for CRA 7 the size at maximum selectivity. The WideG trial tended to have the biggest changes, especially in growth and CRA 7 natural mortality, from the base case.

Medians of indicator posteriors, and the probability indicators, are compared for CRA 7 in Table 14. There was little change when comparing current biomass with *Bmin*, *Bmsy* and *Bref*, except that current biomass was only slightly greater than *Bmsy* in the NoMoves trial, and similarly current spawning stock biomass was only slightly higher than *SSBmsy* in the NoMoves trial. Except for the indicators involving *Bmsy*, spawning stock biomass and *SSBmsy*, the conclusions of the base case stock assessment were not challenged in these trials.

Medians of indicator posteriors, and the probability indicators, are compared for CRA 8 in Table 15. Current and projected biomass compared with *Bref* is considerably worse in the RawLF trial and somewhat worse in the NoMoves trial. Except for these indicators, the conclusions of the base case stock assessment were not challenged in these trials.

5. MANAGEMENT PROCEDURE EVALUATIONS

MPs have been in place for CRA 7 and CRA 8 since 1996 (Starr et al. 1997). The current MPs were developed for CRA 7 and CRA 8 in 2012 (Haist et al. 2013). At MPI’s request, we evaluated rules that used standardised CPUE, collated with the F2-LFX procedure (see Starr 2016), to set a TACC. CPUE continues to be the input and TACC the output. For CRA 7 the review looked at performance of the current MP; there was no request for a new rule. For CRA 8 we also looked at performance of the current MP, but a new rule was requested with changes as described below.

5.1 Operating model

The base case stock assessment model was extended to make 20-year projections that set the TACCs. The TACC was set each year under the harvest control rule being tested; non-commercial catches were held at their 2014 estimates. They were:

	CRA 7	**CRA 8**
Customary	1.000	10.000
Recreational	6.688	35.824
Illegal	1.000	3.000

Projected recruitment was based on 2003–2012 means and standard deviations of the *Rdev*s from each stock. Recreational and customary catches were assumed to be taken 90% in SS; illegal catch was assumed to have the same seasonal catch split as the commercial catch in each year. The proportion of commercial catch taken in AW was predicted from a regression based on AW CPUE (Figure 59 and Figure 60) using the model’s predicted AW CPUE for each year.

Real-life MPs are driven by offset-year CPUE, based on the year from 1 October through 30 September. The model estimated projected offset-year CPUE by taking the mean of CPUE from the AW season in the preceding fishing year and from the SS season in the year before that. This procedure appears to be reliable: the relation between the result and the observed CPUE was linear with slope near 1 and intercept near zero (Figure 61). Observation error was added to the model’s predicted offset-year CPUE, based on the residuals in CPUE seen in the minimisation for each sample of the joint posterior.

The operating model comprised all the samples of the joint posterior obtained in the base case stock assessment McMC: each rule was evaluated with each of the 1000 samples of the joint posterior (and with robustness trials as described below).

The operating model evaluated MPs for both stocks simultaneously. The CRA 7 MP will affect the CRA 8 stock because of the migration between CRA 7 and CRA8; it seems unlikely that the CRA 8 MP will affect the CRA 7 stock except at very low CRA 8 spawning stock biomass. When evaluating CRA 7 MPs, we used the current CRA 8 MP and vice versa.

5.2 Performance indicators

Performance was evaluated over 20 years in each of the 1000 runs for each rule evaluated. For biomass, catch and CPUE indicators, the mean, over 20 years, was calculated for each simulation, and the indicator was reported as the median and the 5th and 95th quantiles of the posterior distribution of the 1000 means. Average annual change in TACC was treated similarly, where the percentage of changes was calculated as the change divided by the mean TACC:

$$AAVH = \frac{\sum_{y=2015}^{y=2034} 100 \frac{\left|TACC_y - TACC_{y-1}\right|}{0.5\left(TACC_y + TACC_{y-1}\right)}}{20}$$

Terminal biomass was reported as the median of the posterior distribution of biomass in the last projection year. Minimum commercial and recreational catches were reported as the posterior distribution of the minimum catches during each simulation; similarly minimum CPUE. The 5-year commercial catch was reported as the median of the posterior distribution of commercial catch in the 5th projection year. Indicators related to total biomass and numbers were added at MPI request in 2014.

Probabilities (i.e., the proportion of 20 000 projected years in which the proposition was true) were calculated for biomass being less than a reference level, for CPUE being to the left or right of the plateau and for the TACC being changed.

The complete list of indicators that were output was:

- average biomass (scaled by *Bref*)
- terminal biomass (scaled by *Bref*)
- minimum commercial catch
- average commercial catch
- average 5-year commercial catch
- minimum recreational catch
- average recreational catch
- minimum CPUE
- average CPUE
- AAVH, the average percentage change in TACC
- proportion of years with a change in TACC
- average vulnerable biomass/*Bmsy*
- probability that biomass was less than *Bref*
- probability that biomass was less than *Bmin*
- probability that biomass was less than *Bmsy*
- probability that *SSB* was less than 20% *SSB0*
- probability that *SSB* was less than 10% *SSB0*
- probability that biomass was less than 50% *Bref*
- probability that biomass was less than 25% *Bref*
- probability that CPUE was below the left of the plateau

- probability that CPUE was above the right of the plateau
- minimum CPUE before observation error was applied
- average CPUE before observation error was applied
- total biomass in projection year
- total biomass in projection year divided by *B0*
- total numbers in projection year
- total biomass in projection year divided by *N0*

The total output from each rule was 150 indicator values. Not all of these were considered useful; for instance, 5th and 95th quantiles were not discussed by the RLFAWG. A subset of indicators is provided in tables, and the NRLMG agreed on a much smaller list of key indicators to be shown to stakeholders.

5.3 CRA 7

The current MP was developed in 2012 (Haist et al. 2013) and accepted for the 2013–14 fishing year. The input is standardised offset-year CPUE from the F2-LFX procedure, and the output is TACC. The MP has no latent year, a 10% minimum change threshold and a 50% maximum change threshold. It is a "plateau slope rule" (Breen 2015), illustrated in Figure 62. The intercept is 0.17 kg/potlift, the plateau extends from 1.00 to 1.75 kg/potlift, TACC on the plateau is 80 t. Above the plateau, CPUE increases with a slope such that the TACC is 120 t at CPUE of 3.0 kg/potlift.

The CRA 7 industry expressed a desire to continue with the current MP if its performance were satisfactory in MPEs. Although a small set of alternative rules were explored in MPEs and shown to the RLFAWG, these will not be shown here because the only issue was performance of the current MP.

Productivity of the operating model was explored in constant-TACC runs with a wide range of TACCs (Figure 63). In 20-year runs with a constant TACC, the *MSY* appeared to be about 200 t, although this decreased to round about 160 t if the stock were expected to be above *Bref* 50% of the time.

The current CRA 7 MP was projected to spend most of its time on or above the plateau (Figure 64) and to spend a relatively small proportion of years on the slope below the plateau. The 2015 operating model was more productive than the 2012 operating model, as reflected in key indicators from the current MP (Table 16). These indicators suggested that CPUE would be above the plateau 50% of the time and below the plateau only 5% of the time. Probabilities of biomass falling below all reference levels were low, and CPUE was projected to average 2 kg/potlift. The TACC was changed in 44% of years because of the high proportion of years with CPUE on the upper slope.

Performance was also explored in seven robustness trial versions of the operating model:

- **Density dependence:** with density-dependent growth estimated
- **No moves:** with no movement from CRA 7 to CRA 8.
- **Raw LFs:** using with the raw weights for LF records instead of the truncated weights
- **Wide growth priors:** with the priors for *GCV*, *Gshape* and *Gobs* having standard deviations calculated as 30% of the means instead of the narrower base case priors.
- **Wide *M* prior:** with the CV for the *M* prior 0.4 instead of 0.1 as in the base case
- **High observation error:** with CPUE observation error increased by a factor of two from the base case
- **Low recruitment:** with projected recruitment using the lowest estimated 10-year moving average (Figure 65) estimated by the base case

The first five of these trials were based on the joint posterior distribution samples obtained in the d-d, NoMove, RawLF, WideG and WideM McMc sensitivity trials described above. The last two used the base case joint posterior distribution samples and changed the projections as specified.

The Density-dependence, wide *M* prior, Low recruitment and (with much reduced effect) Raw LFs trials gave lower biomass, catch and CPUE indicators, and consequently spent increased time below the plateau and less time above the plateau (Table 17). The No moves trial and Wide growth prior trial gave converse results, with the Wide growth prior trial being the most extreme of these trials. The main effect of the High observation error trial was to increase the proportion of years with changes, time spent below the plateau, minimum TACC and minimum CPUE. The safety indicators all showed a low probability that biomass would be less than *Bmin*, *Bmsy* or *Bref* in all trials: the highest was 33% for *Bref* in the Wide growth prior trial.

Because the indicators were satisfactory for the current CRA 7 MP, alternative rules were not pursued.

5.4 CRA 8

The current MP was developed in 2012 (Haist et al. 2013) and accepted for the 2013–14 fishing year. This MP was nearly the same as the previous MP (Breen et al. 2008), differing in the input CPUE (using the then-new F2-LFX) and in output (TACC instead of TAC) and was essentially the same if the non-commercial allowances remained unchanged.

The current CRA 8 MP (Figure 66) has no latent year, a 5% minimum change threshold and no maximum change threshold. The intercept is 0.4535 kg/potlift, the plateau extends from 1.9 to 3.7 kg/potlift and TACC on the plateau is 962 t. Above the plateau the TACC rises linearly to reach 1443 t at a CPUE of 8.624 kg/potlift.

Productivity of the operating model was explored with a range of constant-TACC rules and a range of rules that determined TACC with a simple multiplier on CPUE (Figure 67 through Figure 69). These suggested an MSY of almost 1400 t with these rules, but safety indicators become unacceptable above round about 1300 t.

The current management procedure was run with the 2015 operating model. Projected offset-year CPUE (F2-LFX) was calculated from the mean of the projected AW and SS CPUEs with a regression based on the observed values, with intercept 0.8841 and slope 0.0833. When the 2015 results from the current CRA 8 MP were compared with the 2012 results (Table 18), the 2015 indicators showed somewhat higher biomass and CPUE indicators, slightly higher AAV and a higher proportion of TACC changes. Safety indicators showed low risk in all runs. The *Bmsy* indicators could not be compared because of the changed method for calculating *Bmsy* in 2015, taking retention into account. Projected recreational catches were different because of changes to the best available information on recent recreational catches and their trend (see Starr et al. 2016).

5.4.1 CRA 8 New MP

CRA 8 industry representatives requested a new MP with two changes. First, in CRA 8 there is a lot of legal high-grading, where larger legal fish are returned to the water in favour of smaller fish that command a higher price (see Starr et al. 2016). They asked for an MP with input CPUE based on the vulnerable biomass of fish in the sizes they retain instead of the whole vulnerable biomass. CPUE for the “money fish”, in the sizes that are retained, is reflected in landing codes L (landed to a fish receiver) and F (recreational catch from commercial vessels) and not code “X” (returned to the sea). So the CPUE based on “money fish”, or “$CPUE”, can be calculated easily by using the “F2-LF” procedure rather than the F2-LFX procedure (Starr 2016).

There were several ways in which this change could have been approached in MPEs. We chose to let the model predict projected $CPUE from its conventional AW and SS CPUE, based on a regression of the observed values (Figure 70).

Second, CRA 8 industry representatives requested that we explore MPs of the “plateau step” form rather than the “plateau slope” form, and third that we explore rules that were more aggressive (delivering higher average catches) than the current rule. Step rules have the generalised form seen in Figure 71, with the parameter definitions seen in Table 19. Equations for plateau step rules are (Breen 2015):

$$TACC_{y+1} = 0 \qquad \text{for } I_y \le par2$$

$$TACC_{y+1} = par5\left(\frac{I_y - par2}{par3 - par2}\right) \qquad \text{for } par2 < I_y \le par3$$

$$TACC_{y+1} = par5 \qquad \text{for } par3 < I_y \le par4$$

$$TACC_{y+1} = par5\left(\left(1 + par7\right)^{\text{floor}\left(\left(I_y - par4\right)/par6\right)+1}\right) \qquad \text{for } I_y > par4$$

where $TACC_{y+1}$ is the provisional TACC (before thresholds operate) and I_y is the standardised offset-year CPUE in the preceding year.

After some initial explorations, a set of 180 rules were run through the base case and four robustness trials. All combinations of the parameters shown in Table 20 were used, with no latent year, a 5% minimum change threshold and no maximum change threshold. The robustness trials were:

- **Raw LFs:** using with the raw weights for LF records instead of the truncated weights
- **Wide growth priors:** with the priors for *GCV*, *Gshape* and *Gobs* having standard deviations calculated as 30% of the means instead of the narrower base case priors.
- **High observation error:** with CPUE observation error increased by a factor of two from the base case
- **Low recruitment:** with projected recruitment using the lowest estimated 10-year moving average (Figure 72) estimated by the base case

Obvious trade-offs are shown in Figure 73 and Figure 74: between CPUE and catch and between stability and average catch.

Two kinds of viewer were made available to stakeholders for choosing a rule. The spreadsheet-based first version (Figure 75) has evaluation results for each rule in all trials loaded into one line of a large matrix. The user could specify the rule to be viewed, and the Excel viewer used a lookup procedure to find the rule parameters, plot the rule and give base case and robustness trial results for key indicators.

A web-based viewer built by D'Arcy Webber (Figure 76) allowed the user to choose the rule number to be explored or to choose a rule based on a selection of parameters. This viewer showed trade-offs among selected indicators and showed the key performance indicator values for the base case and low recruitment robustness trial if a single rule were specified.

The viewers were made available to stakeholders, who chose rules to take forward to the NRLMG for consultation.

6. DISCUSSION

The MSLM model fit the CRA 7 and CRA 8 data more easily than in most previous stock assessments. The main changes that had been made were: fixing the minimum standard deviation of the growth increment, using priors based on fits to the whole data for three growth parameters and using the normal instead of robust normal likelihood for tag-recaptures. We think it likely that the second change was responsible for the improved performance of the model, and problems finding runs that were pdH were much reduced.

Low estimates of *M* were also a problem for these stocks, as they have been in the past. Our ad hoc fix was to manipulate the prior width so as to obtain credible results. We could also have fixed *M* and then conducted sensitivity trials to this. A better approach would be to use the MSLM model for the seven stocks where it has been used, estimate *M* with a wide uniform prior, then use the posterior distribution of results as an informative prior. For these two stocks, the low estimated *M* may reflect a mis-specification of some kind.

Apart from *M* we had few problems with parameter estimates. Estimated annual movements were reasonable and (except in sensitivity trials) did not approach upper bounds. The CPUE residuals show trends. Our treatment of catchability is somewhat simplistic: we assume a linear relation between abundance and CPUE, and (probably more importantly) we assume that catchability is unchanged throughout the time series. The second assumption is likely to be violated by changes in pot construction and increases in technology. This issue is scheduled for exploration.

The MPD sensitivity trials that involved removing datasets one at a time suggested that stock assessment results were not strongly dependent on any one data set. Even when tag-recapture data were removed, growth parameters were reasonably estimated; recruitment was reasonably estimated even with CPUE removed. The relative insensitivity to results to removal of single data sets suggested a high redundancy in the data.

Both MPD and McMC sensitivity trials suggested that the stock assessment results were robust to modelling choices. However, the base showed much better traces than the density-dependent option that would otherwise have been chosen as the base case. While median assessment results from sensitivity trials were similar to the base case, their credibility is much lower because of the poor McMC performance.

As always, the RLFAWG identified the lack of information on non-commercial catches and their trends as being a substantial source of uncertainty. Non-commercial catches in these two stocks are assumed to be low relative to the commercial catches, but the quality of the estimates or assumptions is low.

The 2015 operating model gave more optimistic results than the 2012 model, partly because the stocks have increased since 2012 relative to *Bref* and exploitation rate has decreased. This stock assessment suggests no sustainability concerns for CRA 7 or CRA 8. The short-term projections suggest that the CRA 7 stock will decline but still remain well above reference levels; CRA 8 is projected to increase. The *Bmsy* reference is suspect for CRA 7: it is affected by the small MLS and the migration from CRA 7 to CRA 8. Spawning stock indicators are not good for CRA 7, but these are also affected by the migration; it is likely in any case that most of the CRA 7 recruitment originates in CRA 8.

With those caveats, MP management for CRA 7 and CRA 8 appears to have been a success: stocks have rebuilt and now appear to be healthy. CRA 8 has the unusual problem that many of the fish are large and consequently have much lower value than smaller fish. This is of course very good for future recruitment, but increasing biomass of larger fish could affect productivity of the “money fish”. CRA 8 has shown good stability under plateau MPs for some time. It seems likely that CRA 7 will remain a volatile stock, vulnerable to fluctuations in recruitment.

MPEs indicated that the current MP for CRA 7 has acceptable performance and could be retained. The new MPs forwarded to the NRLMG for CRA 8 also showed acceptable performance. There will be no logistic problems in calculating offset-year $CPUE, reflecting the abundance of fish that are actually landed. Because the fish returned to the sea are not fully reported under the landing code “X” (Breen, unpublished data), the CPUE from F2-LFX is likely to be an underestimate for recent years, which will cause a distortion of the stock assessment and hence the MPEs. This issue is also scheduled for exploration.

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Table 1: Definitions of parameters discussed in the text.

ln(*R0*)	natural log of initial numbers recruiting
Uinit	initial exploitation rate (first year in equilibrium with this)
M	instantaneous rate of natural mortality
Rdevs	annual recruitment deviations
SigmaR	standard deviation of *Rdevs*
ln(*qCPUE)*	natural log of relation between *Bvuln* and CPUE
CPUEpow	*shape of* relation between *Bvuln* and CPUE (1 implies linear)
ln(*qCR*)	natural log of relation between *Bvuln* and CR index
Mat50	size where 50% of immature females become mature
Mat95Add	difference between *Mat50* and *Mat95*
Galpha	annual growth increment at 50 mm TW
Gbeta	annual growth increment at 80 mm TW (calculated)
Gdiff	the ratio of *Gbeta* to *Galpha*
Gshape	parameter for shape of growth curve: 1 implies vonB straight line; >1 implies concave upwards
GCV	standard deviation of growth-at-size divided by growth-at-size
Gobs	standard deviation of observation error for tag-recaptures
Gmin	minimum standard deviation of growth
Growthd-d	strength of growth density-dependence
SelLH	shape of the LH of selectivity curve (as if it were a standard deviation)
SelMax	size at maximum selectivity
SelRH	shape of the RH of selectivity curve (as if it were a standard deviation)
vuln	relative vulnerability by sex and season
movements	proportion of fish that move from CRA 7 to CRA 8 by season (estimated by year)
Bvuln	start-of-season AW biomass available to be caught legally
B2015	vulnerable biomass at start of AW 2015
B2018	similarly
Bref	mean of AW *Bvuln* for 1979–81
Bmsy	biomass at *MSY*

Table 2: Fixed quantities for the CRA 7/CRA 8 base case.

Stock	**Sex**	**Quantity**	**Value**
		weights	
CRA 7	male	LFs	0.227
CRA 7	immature female	LFs	0.239
CRA 7	mature female	LFs	0.422
CRA 8	male	LFs	1.849
CRA 8	immature female	LFs	5.145
CRA 8	mature female	LFs	1.272
		proportion-at-sex	3.645
		Tags	1
		CPUE	1.251
		CR	1.062
		fixed parameters	
		SigmaR	0.4
		SelRH	200
		CPUEpow	1
		Gmin	0.001
	male	*a* for l-wt	3.39E-06
	male	*b* for l-wt	2.9665
	female	*a* for l-wt	1.04E-05
	female	*b* for l-wt	2.6323
		handling mortality	0.1

Table 3: CRA 7/CRA 8 base case: for estimated parameters, the estimation phases, lower and upper bounds, prior type (0=uniform, 1 = normal, 2 = lognormal), prior mean and standard deviation (n.a. = not applicable), and initial values.

Stock	Sex	Par	Phase	Lower bound	Upper bound	Prior type	Prior mean	Prior std. dev.	Initial value
		ln(*R0*)	1	1	25	0	0	0	18
		Uinit	1	0	0.99	0	0	0	0.3
		M	1	0.01	0.35	2	0.12	0.1	0.12
		Rdevs	2	-2.3	2.3	1	0	0.4	0
		ln(*qCPUE*)	1	-25	0	0	0	0	-6
		ln(*q*CR)	1	-25	2	0	0	0	-3
		Mat50	3	30	80	0	0	0	65
		Mat95Add	3	3	60	0	0	0	10
	males	*Galpha*	2	1	20	0	0	0	4
	males	*Gdiff*	2	0.001	1	0	0	0	0.6
	females	*Galpha*	2	1	20	0	0	0	3.5
	females	*Gdiff*	2	0.001	1	0	0	0	0.6
	males	*Gshape*	3	0.1	15	1	4.812	0.384	4.8
	males	*GCV*	5	0.01	5	1	0.587	0.00756	0.587
	females	*Gshape*	3	0.1	15	1	4.508	0.236	4.5
	females	*GCV*	5	0.01	5	1	0.82	0.0131	0.82
		Gobs	5	0.00001	10	1	1.482	0.0152	1.482
CRA 7		*SelLH*	4	1	50	0	0	0	5
CRA 8		*SelLH*	4	1	50	0	0	0	5
CRA 7		*SelMax*	5	30	70	0	56	2	50
CRA 8		*SelMax*	5	30	70	0	56	2	50
		vuln1	3	0.01	1	0	0	0	0.8
		vuln2	3	0.01	1	0	0	0	0.8
		vuln3	3	0.01	1	0	0	0	0.8
		vuln4	3	0.01	1	0	0	0	0.8
CRA 7		movements	4	0	0.5	0	0	0	0

Table 4: CRA 7/CRA 8 base case: map of *vuln* parameters.

Sex	Season	*vuln*
male	AW	*vuln1*
male	SS	1.0
immature female	AW	*vuln2*
immature female	SS	*vuln3*
mature female	AW	*vuln4*
mature female	SS	*vuln3*

Table 5: CRA 7/8 MPD results from the base case (first column) and the first 8 MPD sensitivity trials; grey cells indicate parameters that were fixed.

Stock	Sex	Quantity	Base	d-d sens1	no7SS sens2	1974 sens3	1945 sens4	NR5 sens5	rawLF sens6	vuln sens7	wideM sens8
		pdH?	yes!	yes!	yes!	yes!	yes!	yes!	no	yes!	no
		LFs-sdnr	0.815	0.826	0.890	0.828	0.950	0.815	1.219	0.858	1.077
		LFs-MAR	0.179	0.176	0.186	0.179	0.181	0.179	0.208	0.182	0.183
		LFs-LL	15388.8	15376.0	14452.8	15390.6	15481.5	15388.8	32493.7	15407.1	15394.4
		Tags-sdnr	0.993	0.991	0.994	0.993	0.993	0.993	0.994	0.993	0.993
		Tags-MAR	0.412	0.407	0.413	0.411	0.411	0.412	0.410	0.412	0.411
		Tags-LL	15580	15569	15579	15579	15581	15580	15586	15581	15581
		CPUE-sdnr	1.001	0.996	0.947	0.981	0.988	1.001	1.064	1.074	0.972
		CPUE-MAR	0.655	0.710	0.606	0.659	0.627	0.655	0.727	0.708	0.651
		CPUE-LL	-152.1	-152.8	-159.7	-155.1	-154.1	-152.1	-142.7	-141.3	-156.3
		CR-sdnr	1.113	1.029	1.034	0.245	0.666	1.113	1.008	0.743	0.710
		CR-MAR	0.541	1.005	0.549	0.000	0.444	0.541	0.542	0.455	0.374
		CR-LL	-14.2	-16.1	-16.0	-2.5	-22.9	-14.2	-16.6	-21.7	-22.2
		SexRatio-sdnr	1.018	1.018	0.847	1.023	1.072	1.018	1.225	1.104	0.997
		SexRatio-MAR	0.460	0.486	0.416	0.439	0.489	0.460	0.536	0.580	0.478
		function	30749.7	30742.7	29799.4	30776.9	30825.5	30749.7	47888.9	30781.6	30753.7
CRA 7		ln(*R0*)	13.76	14.05	13.87	13.74	14.04	13.76	13.99	14.07	13.99
CRA 8		ln(*R0*)	14.18	13.99	14.15	14.18	14.12	14.18	13.81	14.08	13.55
CRA 7		*M*	0.105	0.111	0.105	0.112	0.102	0.105	0.108	0.111	0.036
CRA 8		*M*	0.095	0.072	0.097	0.104	0.077	0.095	0.075	0.102	0.062
CRA 7		*Uinit*	0.000	0.170	0.000	0.443	0.000	0.000	0.037	0.162	0.706
CRA 8		*Uinit*	0.000	0.042	0.000	0.164	0.000	0.000	0.033	0.000	0.070
CRA 7		ln(*qCPUE*)	-5.952	-5.946	-5.938	-5.837	-5.895	-5.952	-5.959	-5.952	-5.284
CRA 8		ln(*qCPUE*)	-6.834	-6.799	-6.842	-6.859	-6.776	-6.835	-6.739	-6.994	-6.740
CRA 7		ln(*qCR*)	-3.136	-2.453	-3.239	-8.886	-2.182	-3.137	-2.917	-2.396	-1.254
CRA 8		ln(*qCR*)	-4.578	-4.052	-4.579	-10.580	-4.091	-4.578	-4.438	-4.658	-4.312
CRA 7		*CPUEpow*	1*	1*	1*	1*	1*	1*	1*	1*	1*
CRA 8		*CPUEpow*	1*	1*	1*	1*	1*	1*	1*	1*	1*
		Mat50	58.13	58.93	58.01	58.08	58.29	58.13	57.94	58.40	58.24
		Mat95Add	6.12	7.15	6.03	6.12	6.69	6.12	5.68	6.26	6.31
CRA 7	male	*Galpha*	3.62	3.63	3.59	3.61	3.67	3.62	3.63	3.66	3.70
CRA 7	male	*Gbeta*	3.62	3.63	3.59	3.61	3.67	3.62	3.63	3.66	3.70
CRA 7	female	*Galpha*	3.50	3.59	3.41	3.57	3.58	3.50	3.55	3.48	3.42
CRA 7	female	*Gbeta*	3.50	3.37	3.23	3.57	3.58	3.50	3.44	3.35	2.73
CRA 8-1	male	*Galpha*	4.15	5.46	4.15	4.14	4.16	4.15	4.12	4.16	4.15
CRA 8-1	male	*Gbeta*	4.01	5.46	4.00	3.98	4.07	4.01	4.12	4.04	3.93

Stock	Sex	Quantity	Base	d-d sens1	no7SS sens2	1974 sens3	1945 sens4	NR5 sens5	rawLF sens6	vuln sens7	wideM sens8
CRA 8-1	female	*Galpha*	2.93	4.24	2.93	2.93	2.95	2.93	2.96	2.93	2.94
CRA 8-1	female	*Gbeta*	1.95	2.95	1.95	1.96	1.94	1.95	1.98	1.94	1.93
CRA 8-2	male	*Galpha*	4.65		4.65	4.65	4.66	4.65	4.59	4.66	4.70
CRA 8-2	male	*Gbeta*	4.079		4.078	4.079	4.086	4.079	4.212	4.085	4.059
CRA 8-2	female	*Galpha*	3.977		3.993	3.991	3.945	3.977	3.883	3.952	3.949
CRA 8-2	female	*Gbeta*	2.57		2.56	2.57	2.56	2.57	2.63	2.57	2.55
CRA 7	male	*Gshape*	4.86	4.80	4.77	4.83	4.78	4.86	4.82	4.85	4.87
CRA 7	male	*GCV*	0.602	0.602	0.602	0.602	0.602	0.602	0.602	0.602	0.602
CRA 7	female	*Gshape*	4.48	4.52	4.53	4.48	4.49	4.48	4.51	4.50	4.50
CRA 7	female	*GCV*	0.830	0.829	0.830	0.830	0.830	0.830	0.829	0.830	0.830
CRA 8	male	*Gshape*	5.35	5.37	5.33	5.32	5.41	5.35	5.45	5.45	5.48
CRA 8	male	*GCV*	0.603	0.599	0.603	0.603	0.602	0.603	0.604	0.602	0.602
CRA 8	female	*Gshape*	5.70	5.55	5.72	5.71	5.68	5.70	5.76	5.66	5.68
CRA 8	female	*GCV*	0.791	0.785	0.790	0.790	0.791	0.791	0.791	0.792	0.792
		Gobs	1.41	1.42	1.41	1.41	1.41	1.41	1.41	1.41	1.41
CRA 7		*Growthd-d*	0*	0.000	0*	0*	0*	0*	0*	0*	0*
CRA 8		*Growthd-d*	0*	0.790	0*	0*	0*	0*	0*	0*	0*
CRA 7		*vuln1*	0.604	0.622	0.485	0.625	0.621	0.604	0.623	1.000	0.607
CRA 7		*vuln2*	1.000	1.000	0.929	0.917	0.936	1.000	1.000	1.000	0.541
CRA 7		*vuln3*	0.732	0.717	1.000	0.652	0.670	0.732	0.730	0.774	0.374
CRA 7		*vuln4*	0.072	0.067	0.138	0.059	0.093	0.072	0.070	0.068	0.033
CRA 8		*vuln1*	0.749	0.766	0.745	0.758	0.734	0.749	0.722	1.000	0.705
CRA 8		*vuln2*	0.862	0.772	0.873	0.871	0.865	0.862	0.879	0.966	0.851
CRA 8		*vuln3*	0.556	0.539	0.555	0.566	0.534	0.556	0.527	0.704	0.514
CRA 8		*vuln4*	0.508	0.522	0.504	0.513	0.491	0.509	0.468	0.583	0.469
CRA 7	male	*SelLH*	7.87	7.71	6.86	8.09	8.16	7.87	7.51	8.25	9.43
CRA 7	male	*SelRH*	200*	200*	200*	200*	200*	200*	200*	200*	200*
CRA 7	male	*SelMax*	55.09	55.67	50.69	56.02	56.24	55.09	54.95	57.64	61.07
CRA 7	female	*SelLH*	7.17	7.61	5.49	7.24	7.14	7.17	7.21	7.13	7.46
CRA 7	female	*SelRH*	200*	200*	200*	200*	200*	200*	200*	200*	200*
CRA 7	female	*SelMax*	54.40	55.82	48.89	54.52	54.56	54.40	54.82	55.30	55.27
CRA 8E1	male	*SelLH*	7.27	7.27	7.24	7.23	7.48	7.27	7.62	7.57	7.92
CRA 8E1	male	*SelRH*	200*	200*	200*	200*	200*	200*	200*	200*	200*
CRA 8E1	male	*SelMax*	54.64	54.64	54.69	54.65	54.72	54.64	55.01	54.93	54.93
CRA 8E1	female	*SelLH*	9.46	8.97	9.47	9.46	9.56	9.46	9.90	9.40	9.99
CRA 8E1	female	*SelRH*	200*	200*	200*	200*	200*	200*	200*	200*	200*
CRA 8E1	female	*SelMax*	58.87	58.12	58.98	58.99	58.75	58.87	59.05	58.54	58.83

Stock	Sex	Quantity	Base	d-d sens1	no7SS sens2	1974 sens3	1945 sens4	NR5 sens5	rawLF sens6	vuln sens7	wideM sens8
CRA 8E2	male	*SelLH*	3.75	3.77	3.75	3.74	3.77	3.75	3.72	3.75	3.80
CRA 8E2	male	*SelRH*	200*	200*	200*	200*	200*	200*	200*	200*	200*
CRA 8E2	male	*SelMax*	54.39	54.58	54.39	54.40	54.38	54.39	54.43	54.33	54.31
CRA 8E2	female	*SelLH*	4.65	4.65	4.66	4.65	4.63	4.65	4.71	4.65	4.68
CRA 8E2	female	*SelRH*	200*	200*	200*	200*	200*	200*	200*	200*	200*
CRA 8E2	female	*SelMax*	57.69	57.88	57.74	57.70	57.64	57.69	57.96	57.69	57.66
CRA 7		*B2015/Bref*	2.167	1.979	2.018	1.975	1.984	2.168	1.512	1.495	1.903
CRA 7		*Bref*	446.2	450.3	471.4	421.8	439.0	446.3	452.8	422.2	259.5
CRA 7		*Bmsy*	230.8	255.3	241.8	198.7	267.5	230.9	240.8	226.0	140.3
CRA 7		*B2015/Bmsy*	4.190	3.491	3.934	4.194	3.256	4.191	2.842	2.792	3.518
CRA 7		*MSY*	197.2	215.4	189.6	188.4	234.0	197.2	205.7	212.9	212.7
CRA 8		*B2015/Bref*	1.280	1.383	1.293	1.221	1.488	1.279	1.203	1.413	1.421
CRA 8		*Bref*	1922.5	1714.9	1946.4	2003.3	1736.6	1923.4	1780.6	1960.0	1743.0
CRA 8		*Bmsy*	1452.6	1199.8	1441.3	1322.0	1889.6	1449.3	1498.4	1522.1	1795.2
CRA 8		*B2015/Bmsy*	1.693	1.977	1.746	1.851	1.367	1.697	1.430	1.819	1.380
CRA 8		*MSY*	1102.9	1152.0	1107.6	1046.3	1288.6	1102.7	1030.1	1133.3	1118.7
CRA 7	male	yrs to MLS	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
CRA 7	female	yrs to MLS	3.5	3	3.5	3.5	3.5	3.5	3.5	3.5	3
CRA 8	male	yrs to MLS	3	4	3	3	3	3	3	3	3
CRA 8	female	yrs to MLS	4.0	6.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
CRA 7		maxMove	0.420	0.448	0.456	0.424	0.441	0.420	0.451	0.457	0.490
CRA 7		meanMoves	0.184	0.226	0.207	0.186	0.209	0.184	0.225	0.230	0.279

Table 6: CRA 7/8 MPD results from the base case (first column) and the last 9 MPD sensitivity trials; grey cells indicate parameters that were fixed.

Stock	Sex	Quantity	Base	wideG sens9	SelRH sens10	pow sens11	Punt sens12	noCPUE sens13	noCR sens14	noLF sens15	noTag sens16	noMoves sens17
		pdH?	yes!	no	yes!	yes!	yes!	no	yes!	yes!	yes!	yes!
		LFs-sdnr	0.815	0.991	0.820	0.805	0.835	0.815	0.830	1.731	0.885	0.814
		LFs-MAR	0.179	0.176	0.176	0.176	0.178	0.171	0.180	0.480	0.173	0.181
		LFs-LL	15388.8	15404.6	15367.3	15385.6	15382.1	15331.8	15389.7	15044.7	15363.8	15391.0
		Tags-sdnr	0.993	1.005	0.993	0.994	0.946	0.992	0.993	0.992	1.061	0.994
		Tags-MAR	0.412	0.423	0.411	0.412	0.423	0.412	0.411	0.412	0.436	0.412
		Tags-LL	15579.6	15409	15580	15580	10595	15575	15579	15577	16707	15580.9
		CPUE-sdnr	1.001	0.966	0.969	0.909	1.013	6.219	0.979	0.848	0.907	1.218
		CPUE-MAR	0.655	0.628	0.602	0.599	0.666	3.462	0.632	0.507	0.570	0.753
		CPUE-LL	-152.1	-157.2	-156.8	-164.8	-150.5	2664.1	-155.2	-172.5	-165.1	-117.5
		CR-sdnr	1.113	0.678	0.953	1.099	1.114	0.968	3.339	0.943	1.028	1.141
		CR-MAR	0.541	0.495	0.495	0.550	0.556	0.474	3.564	0.545	0.594	0.559
		CR-LL	-14.2	-22.7	-17.8	-14.5	-14.1	-17.5	165.0	-18.0	-16.2	-13.5
		SexRatio-sdnr	1.018	0.991	0.989	1.011	1.007	0.896	1.020		0.995	1.012
		SexRatio-MAR	0.460	0.507	0.457	0.506	0.470	0.524	0.445		0.487	0.512
		function	30749.7	30613.9	30720.9	30733.0	25763.8	30822.4	30761.1	15320.3	15088.5	30816.3
CRA 7		ln(R0)	13.76	14.39	13.73	13.83	13.73	13.60	13.77	13.83	13.87	12.82
CRA 8		ln(R0)	14.18	13.18	14.24	14.13	14.25	14.09	14.17	14.83	14.31	14.48
CRA 7		*M*	0.105	0.110	0.097	0.108	0.105	0.103	0.108	0.105	0.107	0.091
CRA 8		*M*	0.095	0.093	0.089	0.094	0.096	0.079	0.095	0.145	0.109	0.097
CRA 7		*Uinit*	0.000	0.349	0.000	0.000	0.000	0.002	0.000	0.001	0.021	0.000
CRA 8		*Uinit*	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.005	0.048	0.000
CRA 7		ln(qCPUE)	-5.952	-5.917	-5.953	-11.849	-5.938	-6*	-5.814	-5.994	-6.013	-5.718
CRA 8		ln(qCPUE)	-6.834	-6.618	-6.878	-6.575	-6.781	-6*	-6.830	-6.824	-7.112	-6.851
CRA 7		ln(qCR)	-3.136	-1.899	-2.797	-3.106	-3.144	-3.471	-3*	-3.655	-3.038	-3.150
CRA 8		ln(qCR)	-4.578	-4.560	-4.006	-4.595	-4.552	-4.267	-3*	-4.283	-4.384	-4.560
CRA 7		*CPUEpow*	1*	1*	1*	2.000	1*	1*	1*	1*	1*	1*
CRA 8		*CPUEpow*	1*	1*	1*	0.963	1*	1*	1*	1*	1*	1*
		Mat50	58.13	58.00	58.14	58.12	58.19	58.17	58.11	52.95	58.47	58.15
		Mat95Add	6.12	5.83	6.10	6.18	6.16	6.18	6.15	4.26	6.34	5.90
CRA 7	male	*Galpha*	3.62	2.80	3.68	3.62	3.68	3.69	3.62	3.53	4.03	3.71
CRA 7	male	*Gbeta*	3.62	2.80	3.68	3.62	3.64	3.69	3.62	3.51	2.85	3.71
CRA 7	female	*Galpha*	3.50	3.11	3.48	3.36	3.55	3.60	3.57	3.63	3.84	3.42
CRA 7	female	*Gbeta*	3.50	3.11	3.48	2.96	3.55	3.60	3.57	3.61	3.20	3.42
CRA 8-1	male	*Galpha*	4.15	4.11	4.15	4.15	3.77	4.15	4.15	4.15	4.94	4.14
CRA 8-1	male	*Gbeta*	4.01	4.11	4.00	4.01	3.77	4.07	4.01	3.81	4.94	4.00

Stock	Sex	Quantity	Base	wideG sens9	SelRH sens10	pow sens11	Punt sens12	noCPUE sens13	noCR sens14	noLF sens15	noTag sens16	noMoves sens17
CRA 8-1	female	*Galpha*	2.93	2.90	2.94	2.93	2.91	2.88	2.93	2.91	4.20	2.93
CRA 8-1	female	*Gbeta*	1.95	2.50	1.91	1.95	2.16	1.89	1.95	1.85	4.20	1.95
CRA 8-2	male	*Galpha*	4.65	4.63	4.68	4.66	4.66	4.73	4.66	4.74	3.43	4.65
CRA 8-2	male	*Gbeta*	4.079	4.556	4.105	4.079	4.660	4.105	4.080	3.974	3.427	4.066
CRA 8-2	female	*Galpha*	3.977	4.434	3.974	3.982	3.884	4.022	3.978	4.105	3.368	3.970
CRA 8-2	female	*Gbeta*	2.57	3.01	2.55	2.57	2.97	2.55	2.57	2.50	2.71	2.57
CRA 7	male	*Gshape*	4.86	6.69	4.83	4.84	4.83	4.69	4.82	4.70	4.99	4.83
CRA 7	male	*GCV*	0.602	1.012	0.602	0.602	0.582	0.602	0.602	0.602	0.587	0.601
CRA 7	female	*Gshape*	4.48	6.26	4.47	4.49	4.48	4.47	4.49	4.51	4.51	4.50
CRA 7	female	*GCV*	0.830	1.068	0.830	0.830	0.813	0.830	0.830	0.829	0.820	0.830
CRA 8	male	*Gshape*	5.35	9.57	5.40	5.34	5.33	5.65	5.35	5.29	4.52	5.26
CRA 8	male	*GCV*	0.603	0.675	0.602	0.603	0.571	0.602	0.603	0.602	0.587	0.603
CRA 8	female	*Gshape*	5.70	11.23	5.65	5.71	5.87	5.65	5.70	5.60	4.60	5.72
CRA 8	female	*GCV*	0.791	0.805	0.791	0.791	0.782	0.793	0.791	0.792	0.816	0.791
		Gobs	1.41	1.15	1.41	1.41	1.42	1.41	1.41	1.41	1.48	1.41
CRA 7		*Growthd-d*	0*	0*	0*	0*	0*	0*	0*	0*	0*	0*
CRA 8		*Growthd-d*	0*	0*	0*	0*	0*	0*	0*	0*	0*	0*
CRA 7		*vuln1*	0.604	0.618	0.612	0.593	0.605	0.835	0.626	0.990	0.615	0.552
CRA 7		*vuln2*	1.000	0.895	1.000	1.000	1.000	1.000	0.903	0.802	1.000	1.000
CRA 7		*vuln3*	0.732	0.638	0.715	0.721	0.736	0.993	0.643	0.105	0.757	0.650
CRA 7		*vuln4*	0.072	0.059	0.067	0.070	0.073	0.061	0.058	1.000	0.075	0.066
CRA 8		*vuln1*	0.749	0.740	0.739	0.757	0.736	0.034	0.748	0.612	0.728	0.750
CRA 8		*vuln2*	0.862	0.903	0.893	0.864	0.849	0.903	0.864	0.884	1.000	0.852
CRA 8		*vuln3*	0.556	0.590	0.576	0.560	0.563	0.027	0.554	0.716	0.709	0.563
CRA 8		*vuln4*	0.508	0.546	0.528	0.505	0.525	0.529	0.505	0.909	0.669	0.516
CRA 7	male	*SelLH*	7.87	8.19	7.85	7.76	7.90	8.03	8.15	29.51	8.21	5.62
CRA 7	male	*SelRH*	200*	200*	23.03	200*	200*	200*	200*	200*	200*	200*
CRA 7	male	*SelMax*	55.09	56.36	55.04	54.33	55.03	54.36	56.20	66.05	54.81	47.56
CRA 7	female	*SelLH*	7.17	7.26	7.14	7.09	7.16	6.86	7.24	31.75	7.04	5.17
CRA 7	female	*SelRH*	200*	200*	250.00	200*	200*	200*	200*	200*	200*	200*
CRA 7	female	*SelMax*	54.40	54.69	54.31	53.67	54.30	52.92	54.54	30.53	53.61	47.96
CRA 8E1	male	*SelLH*	7.27	9.75	7.04	7.29	7.23	7.22	7.28	5.96	6.88	6.80
CRA 8E1	male	*SelRH*	200*	200*	26.21	200*	200*	200*	200*	200*	200*	200*
CRA 8E1	male	*SelMax*	54.64	54.82	54.22	54.64	55.22	54.77	54.68	33.98	54.99	54.54
CRA 8E1	female	*SelLH*	9.46	11.03	9.11	9.49	9.53	8.99	9.47	1.32	8.07	8.89
CRA 8E1	female	*SelRH*	200*	200*	24.33	200*	200*	200*	200*	200*	200*	200*
CRA 8E1	female	*SelMax*	58.87	56.96	58.40	58.86	59.57	58.96	58.90	31.30	59.06	58.44

Stock	**Sex**	**Quantity**	**Base**	**wideG sens9**	**SelRH sens10**	**pow sens11**	**Punt sens12**	**noCPUE sens13**	**noCR sens14**	**noLF sens15**	**noTag sens16**	**noMoves sens17**
CRA 8E2	male	*SelLH*	3.75	3.96	3.66	3.75	3.73	3.81	3.75	39.37	3.68	3.71
CRA 8E2	male	*SelRH*	200*	200*	21.64	200*	200*	200*	200*	200*	200*	200*
CRA 8E2	male	*SelMax*	54.39	54.27	54.20	54.38	54.53	54.43	54.40	31.00	54.60	54.46
CRA 8E2	female	*SelLH*	4.65	4.81	4.64	4.65	4.64	4.73	4.65	49.48	4.52	4.63
CRA 8E2	female	*SelRH*	200*	200*	56.53	200*	200*	200*	200*	200*	200*	200*
CRA 8E2	female	*SelMax*	57.69	57.11	57.69	57.69	57.89	57.83	57.70	46.61	58.10	57.69
CRA 7		*B2015/Bref*	2.167	1.545	2.238	1.266	2.161	2.388	1.986	2.346	2.414	1.806
CRA 7		*Bref*	446.2	439.5	433.3	495.5	443.7	392.1	416.7	507.7	471.3	408.9
CRA 7		*Bmsy*	230.8	252.9	235.8	199.5	228.2	223.8	203.8	202.0	262.4	775.9
CRA 7		*B2015/Bmsy*	4.190	2.685	4.113	3.144	4.201	4.182	4.060	5.896	4.337	0.952
CRA 7		*MSY*	197.2	229.9	201.4	206.5	196.5	209.9	195.2	169.6	204.5	213.3
CRA 8		*B2015/Bref*	1.280	1.389	1.437	1.355	1.333	0.435	1.300	1.469	1.381	1.265
CRA 8		*Bref*	1922.5	1600.0	1576.0	1923.0	1802.8	4292.1	1892.2	2046.2	2237.7	1951.7
CRA 8		*Bmsy*	1452.6	1385.6	1362.9	1418.2	1493.4	1535.5	1447.7	2262.4	1405.0	1476.5
CRA 8		*B2015/Bmsy*	1.693	1.604	1.662	1.838	1.609	1.217	1.699	1.329	2.199	1.672
CRA 8		*MSY*	1102.9	1125.0	1169.9	1070.9	1127.1	1030.8	1103.0	1251.0	1023.7	1127.6
CRA 7	male	yrs to MLS	3.0	2.5	3.0	3.0	3.0	3.0	3.0	3.0	2.0	3.0
CRA 7	female	yrs to MLS	3.5	2.5	3.5	3.5	3.5	3.5	3.5	3.5	3	3.5
CRA 8	male	yrs to MLS	3	2	3	3	3.5	3	3	3	5	3
CRA 8	female	yrs to MLS	4.0	2.0	4.0	4.0	4.0	4.0	4.0	3.5	5.5	4.0
CRA 7		maxMove	0.420	0.500	0.414	0.378	0.415	0.496	0.426	0.442	0.500	
CRA 7		meanMoves	0.184	0.362	0.179	0.193	0.179	0.139	0.189	0.156	0.249	

Table 7: Base case McMC estimated parameters: each line shows the minimum, maximum, median and 5th and 95th quantiles of the posterior distributions. For growth parameters, "8-1" and "8-2" refer to the estimates from the early and later tag-recapture data files; for selectivity, "8E1" and "8E2" refer to the first and second selectivity epochs for CRA 8.

CRA	sex	quantity	min	5%	median	95%
CRA 7		ln(*R0*)	13.53	13.63	13.75	13.88
CRA 8		ln(*R0*)	13.96	14.05	14.16	14.26
CRA 7		*M*	0.085	0.094	0.102	0.113
CRA 8		*M*	0.086	0.090	0.095	0.100
CRA 7		*Uinit*	0.000	0.000	0.002	0.005
CRA 8		*Uinit*	0.000	0.000	0.000	0.001
CRA 7		ln(*qCPUE*)	-6.50	-6.31	-6.09	-5.88
CRA 8		ln(*qCPUE*)	-7.13	-6.99	-6.87	-6.75
CRA 7		ln(*qCR*)	-3.55	-3.36	-3.16	-2.96
CRA 8		ln(*qCR*)	-4.90	-4.74	-4.58	-4.40
		mat50	57.6	57.8	58.2	58.5
		mat95Add	5.13	5.56	6.15	6.87
CRA 7	male	*Galpha*	3.13	3.38	3.65	3.97
CRA 8	male	*Gbeta*	3.12	3.37	3.64	3.96
CRA 7	female	*Galpha*	3.05	3.25	3.45	3.68
CRA 8	female	*Gbeta*	1.83	2.42	3.07	3.49
CRA 8-1	male	*Galpha*	3.98	4.06	4.19	4.35
CRA 8-1	male	*Gbeta*	2.32	2.72	3.68	4.11
CRA 8-1	female	*Galpha*	2.75	2.83	2.94	3.06
CRA 8-1	female	*Gbeta*	1.55	1.78	1.94	2.10
CRA 8-2	male	*Galpha*	4.43	4.52	4.64	4.76
CRA 8-2	male	*Gbeta*	3.70	3.87	4.06	4.24
CRA 8-2	female	*Galpha*	3.68	3.83	3.95	4.09
CRA 8-2	female	*Gbeta*	2.38	2.46	2.57	2.69
CRA 7	male	*Gshape*	3.79	4.39	4.94	5.53
CRA 7	male	*GCV*	0.581	0.590	0.602	0.614
CRA 7	female	*Gshape*	3.58	4.04	4.43	4.80
CRA 7	female	*GCV*	0.788	0.808	0.830	0.851
CRA 8	male	*Gshape*	4.10	4.65	5.19	5.73
CRA 8	male	*GCV*	0.583	0.592	0.603	0.613
CRA 8	female	*Gshape*	5.06	5.42	5.70	5.99
CRA 8	female	*GCV*	0.758	0.774	0.792	0.809
		Gobs	1.36	1.39	1.41	1.44
CRA 7		*vuln1*	0.471	0.520	0.601	0.679
CRA 7		*vuln2*	0.989	0.990	0.995	0.999
CRA 7		*vuln3*	0.499	0.615	0.729	0.860
CRA 7		*vuln4*	0.016	0.042	0.079	0.135
CRA 8		*vuln1*	0.626	0.687	0.752	0.822
CRA 8		*vuln2*	0.663	0.776	0.886	0.984
CRA 8		*vuln3*	0.437	0.495	0.571	0.666
CRA 8		*vuln4*	0.368	0.443	0.520	0.610
CRA 7	male	*SelLH*	4.49	6.05	8.02	10.64
CRA 7	male	*SelMax*	49.4	51.5	54.5	58.7
CRA 7	female	*SelLH*	3.78	5.62	7.21	9.28
CRA 7	female	*SelMax*	47.8	51.0	53.8	56.9
CRA 8 E1	male	*SelLH*	4.27	5.90	7.88	10.76
CRA 8 E1	male	*SelMax*	50.4	52.7	55.3	58.8
CRA 8 E1	female	*SelLH*	6.18	7.86	9.87	12.94
CRA 8 E1	female	*SelMax*	52.8	56.3	59.5	64.3
CRA 8 E2	male	*SelLH*	2.99	3.37	3.76	4.21
CRA 8 E2	male	*SelMax*	53.3	53.8	54.3	55.0
CRA 8 E2	female	*SelLH*	4.24	4.43	4.68	4.93
CRA 8 E2	female	*SelMax*	56.9	57.3	57.7	58.2
CRA 7		maxMove	0.345	0.397	0.460	0.496
CRA 7		meanMove	0.146	0.168	0.19	0.213

Table 8: Indicators used in the assessment.

Indicator	**Median**
Bmin	the lowest estimated vulnerable biomass at the start of the AW season
B2015	estimated vulnerable biomass at the start of the 2015 AW season
Bref	mean vulnerable biomass from the start of the 1979–81 seasons
B2018	estimated vulnerable biomass at the start of the 2018 AW season
Bmsy	vulnerable AW biomass associated with *MSY*
MSY	maximum sustainable yield at current fishing patterns
Fmult	the multiplier on current *F* required to attain *MSY*
SSB2014	biomass of mature females in AW 2014
SSB2018	biomass of mature females in AW 2018
SSBmsy	biomass of mature females associated with *MSY*
CPUE2014	predicted AW CPUE in 2014
CPUE2018	predicted AW CPUE in 2018
CPUEmsy	AW CPUE associated with *MSY*
SSB0	estimated AW biomass of mature females with no fishing
USL2014	exploitation rate in the size-limited fishery in 2014
USL2018	exploitation rate in the size-limited fishery in 2018
Btot2014	total AW biomass at the start of AW 2014
Ntot2014	total numbers at the start of AW 2014
Ntot0	total numbers in the absence of fishing

Table 9: CRA 7 base case McMC: summary of indicator posteriors; for each indicator the table shows the median and 5th and 95th quantiles of the posterior distribution (upper part) and the lower part of the table shows the probability (i.e. proportion of simulations) that the proposition is true. Biomass and *MSY* in t, CPUE in kg per potlift.

CRA 7	**Median**	**5%**	**95%**
Bmin	114.7	87.1	148.1
B2015	965.7	608.5	1424.8
Bref	489.2	414.4	579.8
B2018	905.3	593.9	1282.1
Bmsy	241.1	194.7	303.5
MSY	192.1	174.7	214.5
Fmult	15.2	15.2	15.2
SSB2014	413.5	327.2	518.4
SSB2018	575.1	419.6	769.0
SSBmsy	43.1	26.8	71.6
CPUE2014	2.121	1.750	2.542
CPUE2018	1.900	1.286	2.668
CPUEmsy	0.375	0.310	0.452
B2015/Bmin	8.440	5.490	12.373
B2015/Bref	1.974	1.284	2.834
B2015/Bmsy	4.002	2.848	5.258
B2018/B2015	0.925	0.787	1.122
B2018/Bref	1.833	1.239	2.557
B2018/Bmsy	3.697	2.716	4.852
SSB2014/SSB0	0.167	0.136	0.209
SSB2018/SSB0	0.234	0.171	0.305
SSB2014/SSBmsy	9.577	6.676	13.631
SSB2018/SSBmsy	13.307	10.065	17.375
SSB2018/SSB2014	1.384	1.092	1.754
USL2014	0.048	0.038	0.062
USL2018	0.076	0.053	0.115
USL2018/USL2014	1.575	1.152	2.228
Btot2014	2445.7	1971.9	3029.8
Btot2014/Btot0	0.320	0.260	0.394
Ntot2014	7.7E+06	5.9E+06	1.0E+07
Ntot2014/Ntot0	0.661	0.521	0.869
P(*B2015>Bmin*)	1.000		
P(*B2015>Bref*)	0.998		
P(*B2015>Bmsy*)	1.000		
P(*B2018>Bmin*)	1.000		
P(*B2018>Bref*)	0.991		
P(*B2018>Bmsy*)	1.000		
P(*B2018>B2015*	0.236		
P(*SSB2014>SSBmsy*)	1.000		
P(*SSB2018>SSBmsy*)	1.000		
P(*USL2018>USL2014*)	0.993		
P(SSB2014<0.2SSB0)	0.919		
P(*SSB2018<0.2SSB0*)	0.213		
P(*SSB2014<0.1SSB0*)	0.000		
P(*SSB2018<0.1SSB0*)	0.000		

Table 10: CRA 8 base case McMC: Summary of indicator posteriors; for indicator the tables shows the median and 5th and 95th quantiles of the posterior distribution (upper part) and the lower part of the table shows the probability (i.e. proportion of simulations) that the proposition is true. Biomass and *MSY* in t, CPUE in kg per potlift.

CRA 8	**Median**	**5%**	**95%**
Bmin	658.2	581.3	736.4
B2015	2698.1	2165.4	3392.5
Bref	1983.4	1749.6	2294.9
B2018	2770.6	1951.6	3857.0
Bmsy	1464.9	1333.5	1594.5
MSY	1091.3	1017.6	1166.1
Fmult	1.59	1.3	1.93
SSB2014	5043.3	4642.8	5476.4
SSB2018	5321.6	4581.1	6159.1
SSBmsy	3103.6	2853.0	3339.5
CPUE2014	2.504	2.122	2.917
CPUE2018	2.539	1.762	3.501
CPUEmsy	1.147	1.044	1.265
B2015/Bmin	4.104	3.335	5.072
B2015/Bref	1.352	1.104	1.647
B2015/Bmsy	1.834	1.506	2.247
B2018/B2015	1.024	0.841	1.232
B2018/Bref	1.399	0.985	1.908
B2018/Bmsy	1.889	1.364	2.569
SSB2014/SSB0	0.438	0.405	0.480
SSB2018/SSB0	0.462	0.400	0.535
SSB2014/SSBmsy	1.620	1.484	1.798
SSB2018/SSBmsy	1.711	1.474	2.014
SSB2018/SSB2014	1.055	0.961	1.154
USL2014	0.181	0.150	0.218
USL2018	0.182	0.131	0.258
USL2018/USL2014	1.002	0.800	1.292
Btot2014	9749.9	8670.4	10999.0
Btot2014/Btot0	0.269	0.241	0.304
Ntot2014	1.6E+07	1.4E+07	1.9E+07
Ntot2014/Ntot0	0.415	0.359	0.491
P(*B2015>Bmin*)	1.000		
P(*B2015>Bref*)	0.995		
P(*B2015>Bmsy*)	1.000		
P(*B2018>Bmin*)	1.000		
P(*B2018>Bref*)	0.942		
P(*B2018>Bmsy*)	0.998		
P(*B2018>B2015*	0.575		
P(*SSB2014>SSBmsy*)	1.000		
P(*SSB2018>SSBmsy*)	1.000		
P(*USL2018>USL2014*)	0.510		
P(SSB2014<0.2SSB0)	0.000		
P(*SSB2018<0.2SSB0*)	0.000		
P(*SSB2014<0.1SSB0*)	0.000		
P(*SSB2018<0.1SSB0*)	0.000		

Table 11: CRA 8 base case McMC: summary of new indicators.

Indicator	Median	5%	95%
Blegal AW 2014	2 828.1	2 348.7	3 401.1
Blegal SS2014	7 564.3	6 672.3	8536.1
Blegal AW 2018	2 816.4	1 987.1	3919.4
Blegal SS 2018	8 005.1	6 390.4	9961.8
$B AW 2014	1 833.7	1 506.2	2241.2
$B SS 2014	6 594.1	5 859.4	7427.8
$B AW 2018	2 365.9	1 684.4	3222.5
$B SS 2018	7 586.6	6 178.3	9249.3
$*ERate* AW 2014	0.267	0.219	0.325
$ERate SS 2014	0.075	0.067	0.085
$ERate AW 2018	0.178	0.128	0.253
$*ERate* SS 2018	0.060	0.048	0.076
P(*$B* AW 2018<*$B* AW 2014	4.8%		
P(*$B* AW 2018<*$B* AW 2014	4.8%		

Table 12: Comparison of indicators from the 2012 and 2015 stock assessments for CRA 7 and CRA 8.

	CRA 7						CRA 8					
	2012			2015			2012			2015		
Indicator	**Median**	**5%**	**95%**	**Median**	**5%**	**95%**	**Median**	**5%**	**95%**	**Median**	**5%**	**95%**
Bmin	148	113	188	115	87	148	734	627	848	658	581	736
Bref	616	516	735	489	414	580	1970	1648	2408	1983	1750	2295
B2015	755	537	1061	966	609	1425	2304	1547	3094	2698	2165	3392
SSB2014	138	77	226	414	327	518	4526	3844	5228	5043	4643	5476
CPUE2014	1.29	0.95	1.74	2.12	1.75	2.54	2.00	1.30	2.70	2.50	2.12	2.92
B2015/Bref	1.23	0.91	1.63	1.97	1.28	2.83	1.17	0.81	1.53	1.35	1.10	1.65
SSB14/SSB0	0.16	0.11	0.24	0.17	0.14	0.21	0.71	0.63	0.80	0.44	0.40	0.48
USL2014	7.7%	5.5%	10.9%	4.8%	3.8%	6.2%	28.0%	20.9%	41.7%	18.1%	15.0%	21.8%

Table 13: Medians of estimated parameter posteriors in McMC sensitivity trials.

CRA	Sex	Quantity	base	d-d	WideG	noMoves	rawLFs	wideM
7		ln(*R0*)	13.75	14.03	14.52	12.93	13.65	13.62
8		ln(*R0*)	14.16	13.94	13.16	14.47	14.08	13.83
7		*M*	0.102	0.117	0.144	0.094	0.099	0.084
8		*M*	0.095	0.080	0.091	0.096	0.086	0.054
7		*Uinit*	0.002	0.137	0.230	0.000	0.000	0.032
8		*Uinit*	0.000	0.004	0.000	0.002	0.004	0.070
7		ln(*qCPUE*)	-6.09	-6.13	-6.02	-5.98	-6.05	-5.97
8		ln(*qCPUE*)	-6.87	-6.86	-6.65	-6.89	-6.81	-6.79
7		ln(*qCR*)	-3.16	-2.55	-2.14	-3.21	-3.17	-2.97
8		ln(*qCR*)	-4.58	-4.10	-4.54	-4.56	-4.59	-4.40
		mat50	58.2	58.9	58.0	58.2	58.0	58.4
		mat95Add	6.15	7.19	5.71	5.97	5.68	6.34
7	male	*Galpha*	3.65	3.67	2.60	3.30	3.68	3.59
7	male	*Gbeta*	3.64	3.67	2.59	3.30	3.67	3.59
7	fem.	*Galpha*	3.45	3.53	2.98	3.15	3.47	3.42
7	fem.	*Gbeta*	3.07	3.07	2.98	3.12	3.02	3.07
8-1	male	*Galpha*	4.19	5.39	4.13	4.18	4.23	4.15
8-1	male	*Gbeta*	3.68	5.38	4.13	3.51	3.01	3.88
8-1	fem.	*Galpha*	2.94	4.20	2.89	2.94	2.98	2.95
8-1	fem.	*Gbeta*	1.94	2.93	2.49	1.93	1.94	1.92
8.2	male	*Galpha*	4.64	4.85	4.63	4.64	4.55	4.68
8.2	male	*Gbeta*	4.06	0.60	4.50	4.04	4.15	4.07
8.2	fem.	*Galpha*	3.95	0.83	4.41	3.95	3.84	3.94
8.2	fem.	*Gbeta*	2.57	5.41	3.00	2.57	2.66	2.56
7	male	*Gshape*	4.94	5.56	6.04	5.27	4.98	4.84
7	male	*GCV*	0.602	0.782	1.130	0.602	0.602	0.602
7	fem.	*Gshape*	4.43		5.73	4.56	4.41	4.43
7	fem.	*GCV*	0.830		1.19	0.834	0.828	0.829
8	male	*Gshape*	5.19		9.22	5.11	4.95	5.54
8	male	*GCV*	0.603		0.675	0.603	0.604	0.603
8	fem.	*Gshape*	5.70		11.1	5.73	5.77	5.67
8	fem.	*GCV*	0.792		0.809	0.792	0.793	0.793
7		*Gd-d*	0	0.00	0	0	0	0
8		*Gd-d*	0	0.722	0	0	0	0
		Gobs	1.41	1.419	1.16	1.42	1.41	1.42
7		*vuln1*	0.601	0.60	0.609	0.543	0.609	0.567
7		*vuln2*	0.995	0.986	0.766	0.999	0.999	0.999
7		*vuln3*	0.729	0.734	0.527	0.679	0.722	0.661
7		*vuln4*	0.079	0.07	0.054	0.074	0.082	0.068
8		*vuln1*	0.752	0.777	0.733	0.756	0.743	0.753
8		*vuln2*	0.886	0.809	0.918	0.865	0.896	0.917
8		*vuln3*	0.571	0.558	0.598	0.582	0.557	0.595
8		*vuln4*	0.520	0.550	0.546	0.527	0.485	0.528
7	male	*SelLH*	8.02	7.550	9.32	6.55	7.80	8.56
7	male	*SelMax*	54.5	54.8	59.1	48.4	54.0	55.8
7	fem.	*SelLH*	7.21	7.87	7.62	5.31	7.11	7.12
7	fem.	*SelMax*	53.8	55.7	55.2	47.8	53.3	53.9
8 E1	male	*SelLH*	7.88	7.75	10.97	7.36	7.75	8.00
8 E1	male	*SelMax*	55.3	54.7	56.1	55.4	55.5	55.0
8 E1	fem.	*SelLH*	9.87	9.13	12.14	9.09	9.82	9.85
8 E1	fem.	*SelMax*	59.5	58.2	58.2	58.8	59.4	59.1
8 E2	male	*SelLH*	3.76	3.72	3.96	3.70	3.66	3.81
8 E2	male	*SelMax*	54.3	54.5	54.2	54.4	54.4	54.2
8 E2	fem.	*SelLH*	4.68	4.63	4.82	4.63	4.71	4.70
8 E2	fem.	*SelMax*	57.7	57.8	57.1	57.7	58.0	57.7
7		minMove	0.001	0.000	0.043		0.000	0.001
7		maxMove	0.460	0.466	0.499		0.447	0.451
7		meanMove	0.19	0.221	0.296		0.18	0.188

Table 14: Medians of indicator posteriors for CRA 7 in McMC sensitivity trials.

	base	d-d	wide G prior	no moves	raw LFs	wide M prior
Bmin	114.7	118.3	102.8	125.9	113.2	104.1
B2015	965.7	994.4	755.1	931.2	940.3	962.3
Bref	489.2	510.3	443.3	455.7	477.6	453.1
B2018	905.3	858.7	604.3	1118.5	891.1	916.8
Bmsy	241.1	268.0	265.5	770.9	232.0	223.4
MSY	192.1	208.6	248.7	219.5	187.9	183.6
Fmult	15.2	15.2	15.2	3.25	15.2	15.2
SSB2014	413.5	419.6	464.1	505.7	400.1	427.3
SSB2018	575.1	567.0	541.1	723.0	568.2	636.2
SSBmsy	43.1	50.2	74.9	660.8	39.4	43.3
CPUE2014	2.121	2.172	2.088	1.911	2.112	2.254
CPUE2018	1.900	1.724	1.360	2.658	1.966	2.206
CPUEmsy	0.375	0.412	0.463	1.700	0.367	0.387
B2015/Bmin	8.440	8.251	7.282	7.386	8.374	9.263
B2015/Bref	1.974	1.940	1.712	2.050	1.956	2.130
B2015/Bmsy	4.002	3.719	2.873	1.220	4.042	4.345
B2018/B2015	0.925	0.851	0.789	1.202	0.946	0.948
B2018/Bref	1.833	1.677	1.384	2.463	1.861	2.021
B2018/Bmsy	3.697	3.180	2.300	1.465	3.831	4.126
SSB2014/SSB0	0.167	0.178	0.222	0.191	0.161	0.134
SSB2018/SSB0	0.234	0.244	0.257	0.273	0.229	0.195
SSB2014/SSBmsy	9.577	8.266	6.209	0.760	10.149	10.084
SSB2018/SSBmsy	13.307	10.982	7.276	1.087	14.416	14.905
SSB2018/SSB2014	1.384	1.346	1.153	1.423	1.411	1.513
USL2014	0.048	0.046	0.053	0.060	0.050	0.052
USL2018	0.076	0.080	0.113	0.061	0.077	0.075
USL2018/USL2014	1.575	1.758	2.129	1.030	1.500	1.424
Btot2014	2445.7	2723.1	3561.0	1777.7	2315.2	2343.9
Btot2014/Btot0	0.320	0.369	0.540	0.232	0.304	0.254
Ntot2014	7.7E+06	9.0E+06	1.4E+07	4.4E+06	7.3E+06	7.3E+06
Ntot2014/Ntot0	0.661	0.681	0.815	0.468	0.648	0.581
P(B2015>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000
P(B2015>Bref)	0.998	0.999	0.994	1.000	0.998	1.000
P(B2015>Bmsy)	1.000	1.000	1.000	0.934	1.000	0.997
P(B2018>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000
P(B2018>Bref)	0.991	0.981	0.911	1.000	0.996	0.998
P(B2018>Bmsy)	1.000	1.000	1.000	0.993	1.000	0.997
P(B2018>B2015	0.236	0.101	0.104	0.999	0.327	0.300
P(SSB2014>SSBmsy)	1.000	1.000	1.000	0.007	1.000	0.968
P(SSB2018>SSBmsy)	1.000	1.000	1.000	0.747	1.000	0.982
P(USL2018>USL2014	0.993	0.999	1.000	0.615	0.994	0.987
P(SSB2014<0.2SSB0)	0.919	0.716	0.233	0.674	0.948	0.992
P(SSB2018<0.2SSB0	0.213	0.182	0.069	0.002	0.240	0.536
P(SSB2014<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.274
P(SSB2018<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.120

Table 15: Summary of indicator posteriors for CRA 8 in McMC sensitivity trials.

	base	d-d	wide G prior	no moves	raw LFs	wide M prior
Bmin	658.2	674.2	550.9	651.5	635.9	601.8
B2015	2698.1	2529.9	2362.5	2624.9	2175.2	2506.1
Bref	1983.4	1873.9	1687.1	2024.7	1902.7	1781.7
B2018	2770.6	2383.3	2971.5	2334.1	2004.4	2674.3
Bmsy	1464.9	1170.9	1393.0	1494.3	1410.9	1949.5
MSY	1091.3	1072.6	1104.79	1117.5	1015.5	1047.2
Fmult	1.59	2	1.6	1.57	1.23	1.17
SSB2014	5043.3	4815.6	4631.9	4974.7	4974.5	5525.7
SSB2018	5321.6	4868.4	5345.3	5003.0	4950.2	6176.7
SSBmsy	3103.6	2364.0	2937.370	3093.9	3399.4	4878.0
CPUE2014	2.504	2.468	2.524	2.441	2.173	2.494
CPUE2018	2.539	2.181	3.391	2.075	1.879	2.654
CPUEmsy	1.147	0.867	1.325	1.159	1.185	1.774
B2015/Bmin	4.104	3.772	4.289	3.990	3.399	4.148
B2015/Bref	1.352	1.358	1.389	1.288	1.140	1.404
B2015/Bmsy	1.834	2.161	1.701	1.746	1.536	1.317
B2018/B2015	1.024	0.935	1.257	0.895	0.926	1.071
B2018/Bref	1.399	1.269	1.747	1.159	1.055	1.505
B2018/Bmsy	1.889	2.043	2.140	1.571	1.425	1.421
SSB2014/SSB0	0.438	0.774	0.391	0.432	0.393	0.253
SSB2018/SSB0	0.462	0.789	0.450	0.436	0.391	0.285
SSB2014/SSBmsy	1.620	2.028	1.572	1.611	1.462	1.132
SSB2018/SSBmsy	1.711	2.060	1.812	1.622	1.453	1.270
SSB2018/SSB2014	1.055	1.019	1.152	1.003	0.994	1.115
USL2014	0.181	0.187	0.218	0.183	0.217	0.196
USL2018	0.182	0.211	0.169	0.216	0.251	0.188
USL2018/USL2014	1.002	1.137	0.8	1.184	1.168	0.962
Btot2014	9749.9	9689.3	8030.890	10038.7	9020.7	9729.8
Btot2014/Btot0	0.269	0.403	2.3E-01	0.273	0.235	0.157
Ntot2014	1.6E+07	1.7E+07	1.2E+07	1.8E+07	1.5E+07	1.5E+07
Ntot2014/Ntot0	0.415	0.405	0.352	0.423	0.372	0.294
P(B2015>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000
P(B2015>Bref)	0.995	0.999	0.997	0.975	0.862	0.990
P(B2015>Bmsy)	1.000	1.000	1.000	1.000	1.000	0.954
P(B2018>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000
P(B2018>Bref)	0.942	0.916	0.999	0.724	0.602	0.961
P(B2018>Bmsy)	0.998	1.000	1.000	0.961	0.944	0.932
P(B2018>B2015	0.575	0.203	0.974	0.241	0.275	0.711
P(SSB2014>SSBmsy)	1.000	1.000	1.000	1.000	1.000	0.855
P(SSB2018>SSBmsy)	1.000	1.000	1.000	1.000	1.000	0.970
P(USL2018>USL2014	0.510	0.893	0.045	0.804	0.824	0.395
P(SSB2014<0.2SSB0)	0.000	0.000	0.000	0.000	0.000	0.056
P(SSB2018<0.2SSB0	0.000	0.000	0.000	0.000	0.000	0.017
P(SSB2014<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.000
P(SSB2018<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.000

Table 16: CRA 7: Comparison of key indicators for the current CRA 7 MP between the 2012 and 2015 operating models.

Indicator	2012	2015
mean (*B/Bref*)	1.495	1.882
terminal (*B/Bref*)	-	1.768
minimum commercial catch	67	80
average commercial catch	81	92
average 5-year commercial catch	77	91
minimum CPUE	0.919	1.173
average CPUE	1.571	2.004
%AAV	4.9	8.5
P(*B* < *Bref*)	0.112	0.069
P(*B* < *Bmin*)	0	0
P(*B* < *Bmsy*)	-	0.002
proportion of years with changes	0.312	0.443
P(CPUE < plateau)	0.117	0.056
P(CPUE > plateau)	0.329	0.596

Table 17: CRA 7: comparison of key indicators for the current CRA 7 MP between the base case and robustness trial operating models.

Indicator	Base case	Density dependence	No moves	Raw LF	Wide growth priors	Wide *M* prior	High obs. error	Low rect
mean (*B/Bref*)	1.88	1.57	2.18	1.93	1.28	2.07	1.86	1.30
terminal (*B/Bref*)	1.77	1.40	1.92	1.85	1.14	2.10	1.71	0.94
minimum commercial catch	80	80	80	80	52	80	66	61
average commercial catch	92	86	103	93	78	99	95	82
average 5-yr commercial catch	91	88	103	92	84	96	94	88
minimum CPUE	1.17	0.94	1.38	1.21	0.70	1.36	0.84	0.76
average CPUE	2.00	1.69	2.42	2.08	1.30	2.29	2.08	1.45
%AAV	8.5	8.4	12.3	8.9	9.3	9.7	17.6	7.9
P(*B* < *Bref*)	0.07	0.17	0.03	0.07	0.33	0.04	0.08	0.30
P(*B* < *Bmin*)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P(*B* < *Bmsy*)	0.00	0.01	0.19	0.00	0.05	0.00	0.00	0.04
propn. of years with changes	0.44	0.42	0.57	0.45	0.44	0.49	0.63	0.41
P(CPUE < plateau)	0.06	0.14	0.02	0.05	0.31	0.03	0.12	0.23
P(CPUE > plateau)	0.60	0.44	0.79	0.63	0.21	0.73	0.56	0.31

Table 18: CRA 8: comparison of the current CRA 8 MP results from the 2012 and 2015 operating models.

Indicator	2012	2015
average(*B/Bref*)	1.949	1.795
average(*B/Bmsy*)	2.658	n.a.
minimum commercial catch	961.9	962.0
average commercial catch	1000.9	989.1
average 5-yr commercial catch	962.0	962.0
minimum recreational catch	35.8	86.2
average recreational catch	35.8	99.6
minimum CPUE	2.988	2.610
average CPUE	4.023	3.450
%*AAVH*	1.30	0.7
P(*B*<*Bref*)	0.005	0.014
P(*B*<*Bmin*)	0.000	0.000
P(*B*<*Bmsy*)	0.000	n.a.
propn. of years with TACC changes	0.227	0.159
P(*B*<20% *SSB0*)	0.013	0.000
P(*B*<10% *SSB0*)	0.000	0.000
P(*B*<0.5 *Bref*)	0.000	0.000
P(CPUE<plateau)	0.004	0.008
P((CPUE>plateau)	0.597	0.601

Table 19: Parameters for the generalised plateau step rules.

Parameter	**Function**
*par*2	CPUE at TACC = 0
*par*3	CPUE at plateau left
*par*4	CPUE at plateau right
*par*5	plateau height
*par*6	step width
*par*7	step height

Table 20: CRA 8: parameter set defining 180 plateau step harvest control rules evaluated with the base case and four robustness models.

Function	**Par**	**Values**				
intercept	par2	0.5				
plateau left	par3	1.9				
plateau right	par4	3	3.2	3.4	3.6	3.8
plateau height	par5	962	1012	1062	1112	
step width	par6	0.5	0.4	0.25		
step height	par7	0.055	0.075	0.100		

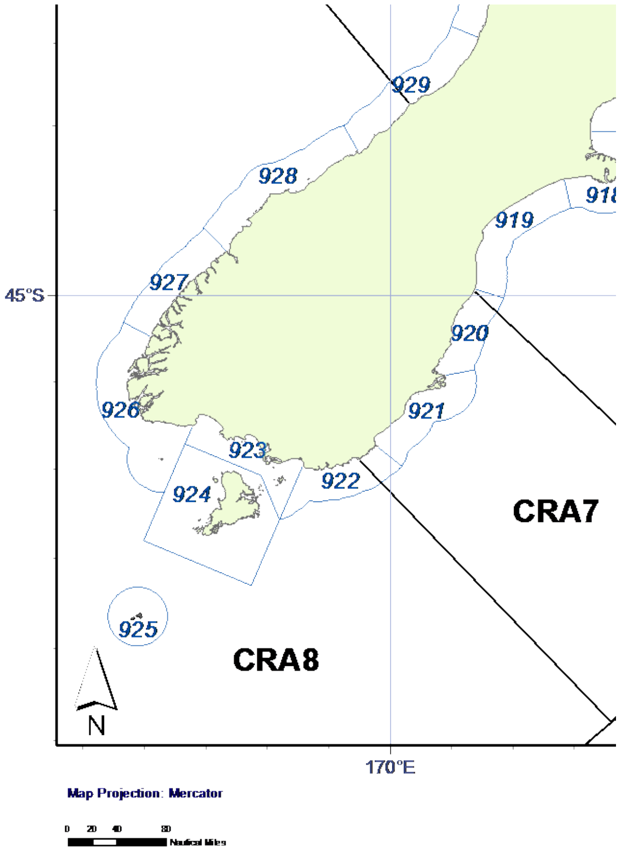


Figure 1: CRA 7 and CRA 8 QMAs on the south of the South Island, and their statistical areas (light blue).

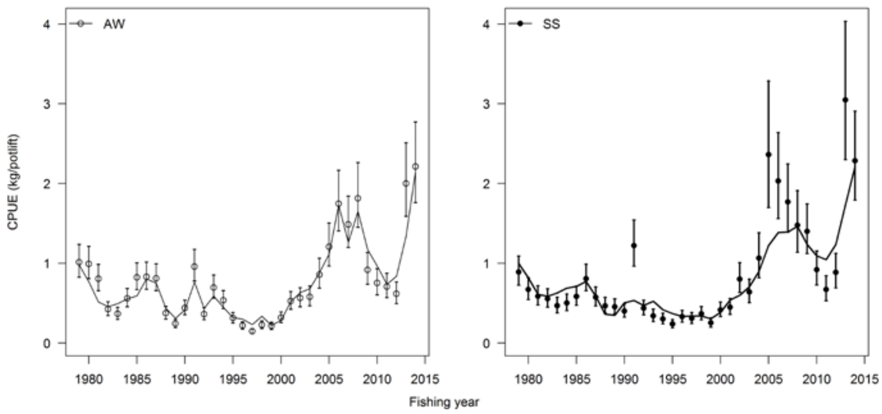


Figure 2: CRA 7: Base case MPD fit to CPUE: points are observations with their standard deviations and the lines are the model's predictions.

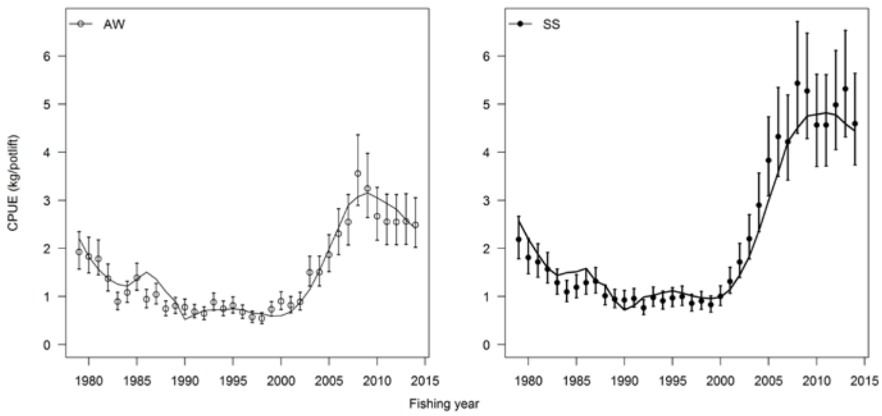


Figure 3: CRA 8: Base case MPD fit to CPUE: points are observations with their standard deviations and the lines are the model's predictions.

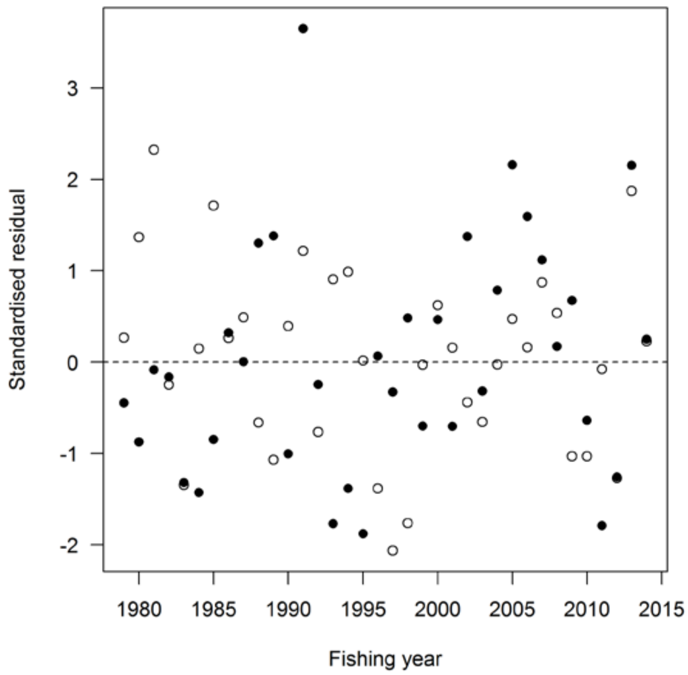


Figure 4: CRA 7: residuals from the fits in Figure 2 (CPUE): closed circles SS, open circles AW.

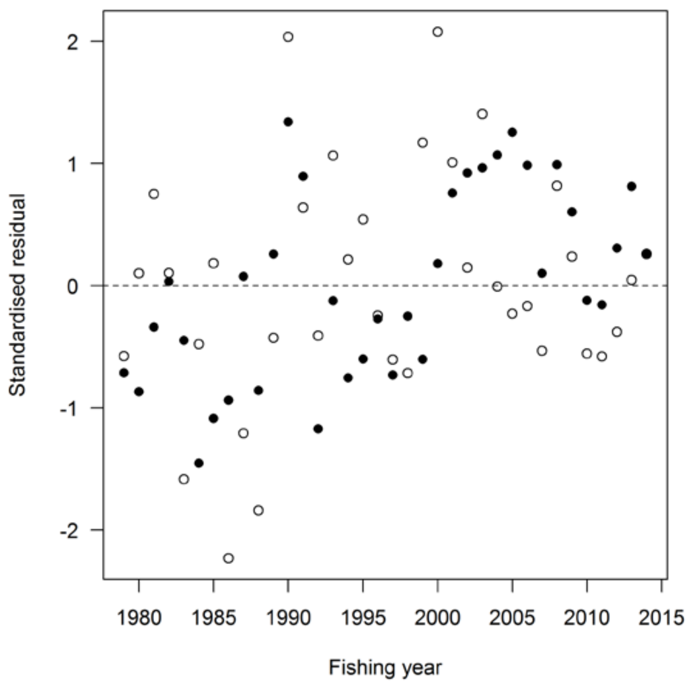


Figure 5: CRA 8: residuals from the fits in Figure 3 (CPUE): closed circles SS, open circles AW.

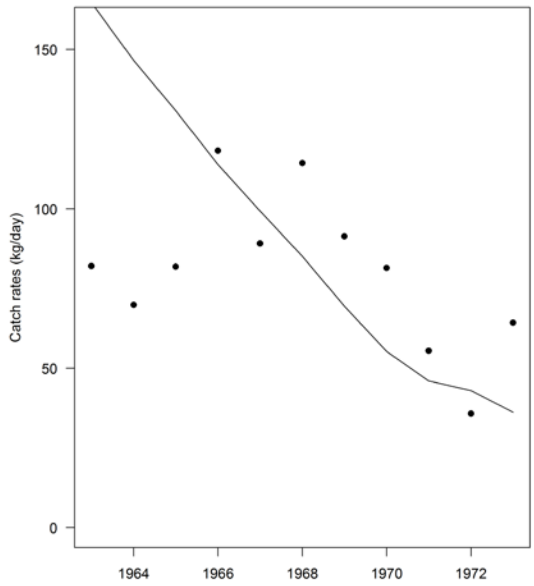


Figure 6: CRA 7: fit to the CR index: points are the observed values and the line connects the predictions.

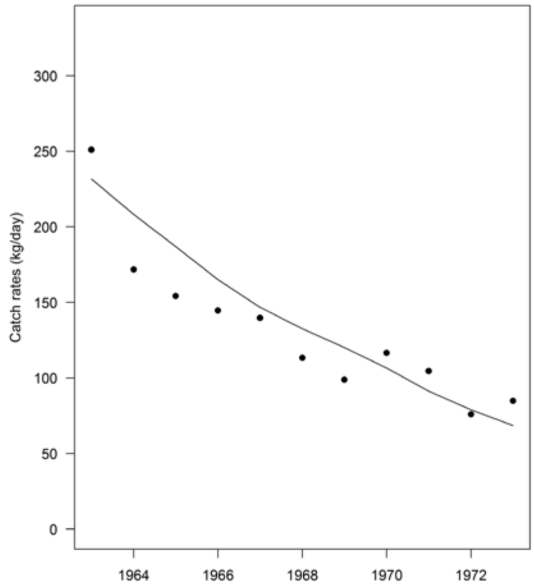


Figure 7: CRA 8: fit to the CR index: points are the observed values and the line connects the predictions.

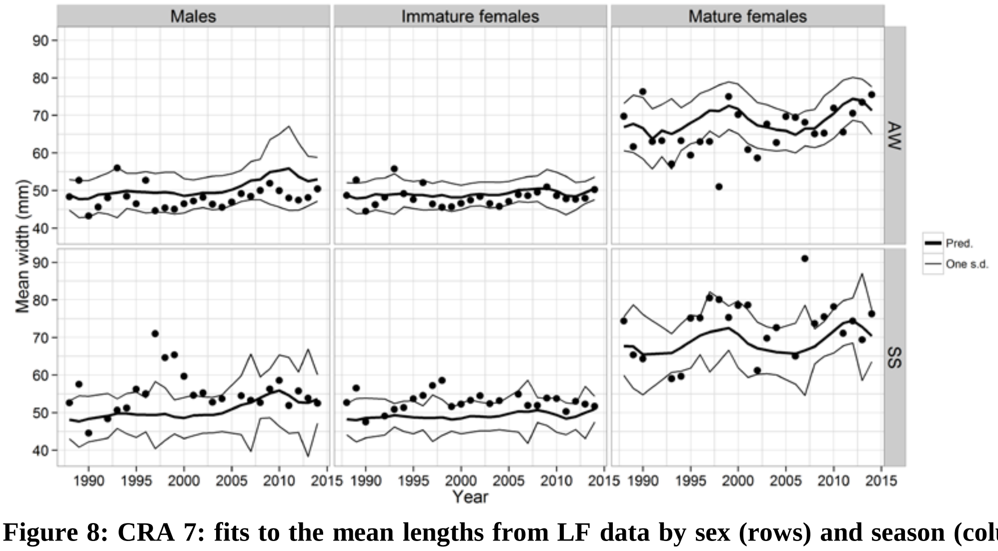


Figure 8: CRA 7: fits to the mean lengths from LF data by sex (rows) and season (columns; AW above): points are the calculated values from the LFs and the heavy lines connect predicted values; lighter lines show one standard deviation.

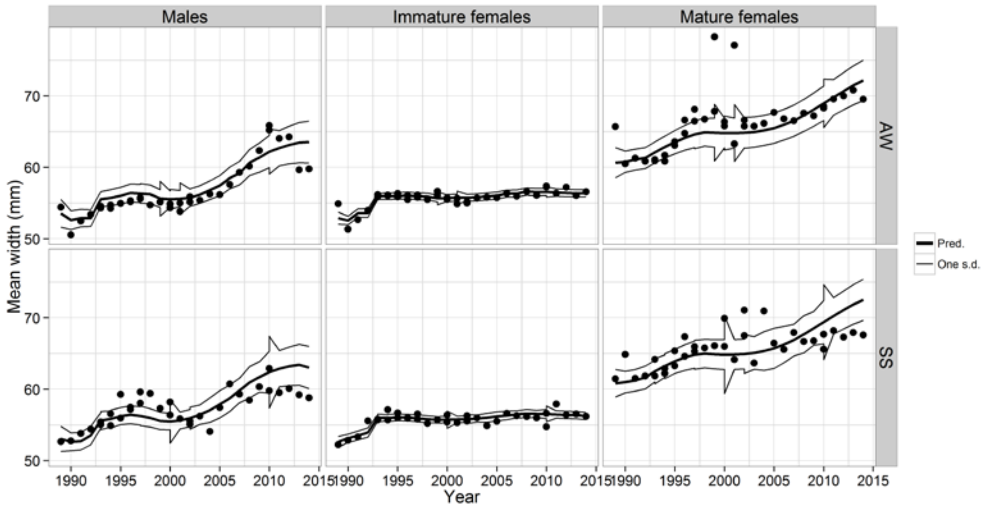


Figure 9: CRA 8: fits to the mean lengths from LF data by sex (rows) and season (columns; AW above): points are the calculated values from the LFs and the heavy lines connect predicted values; lighter lines show one standard deviation.

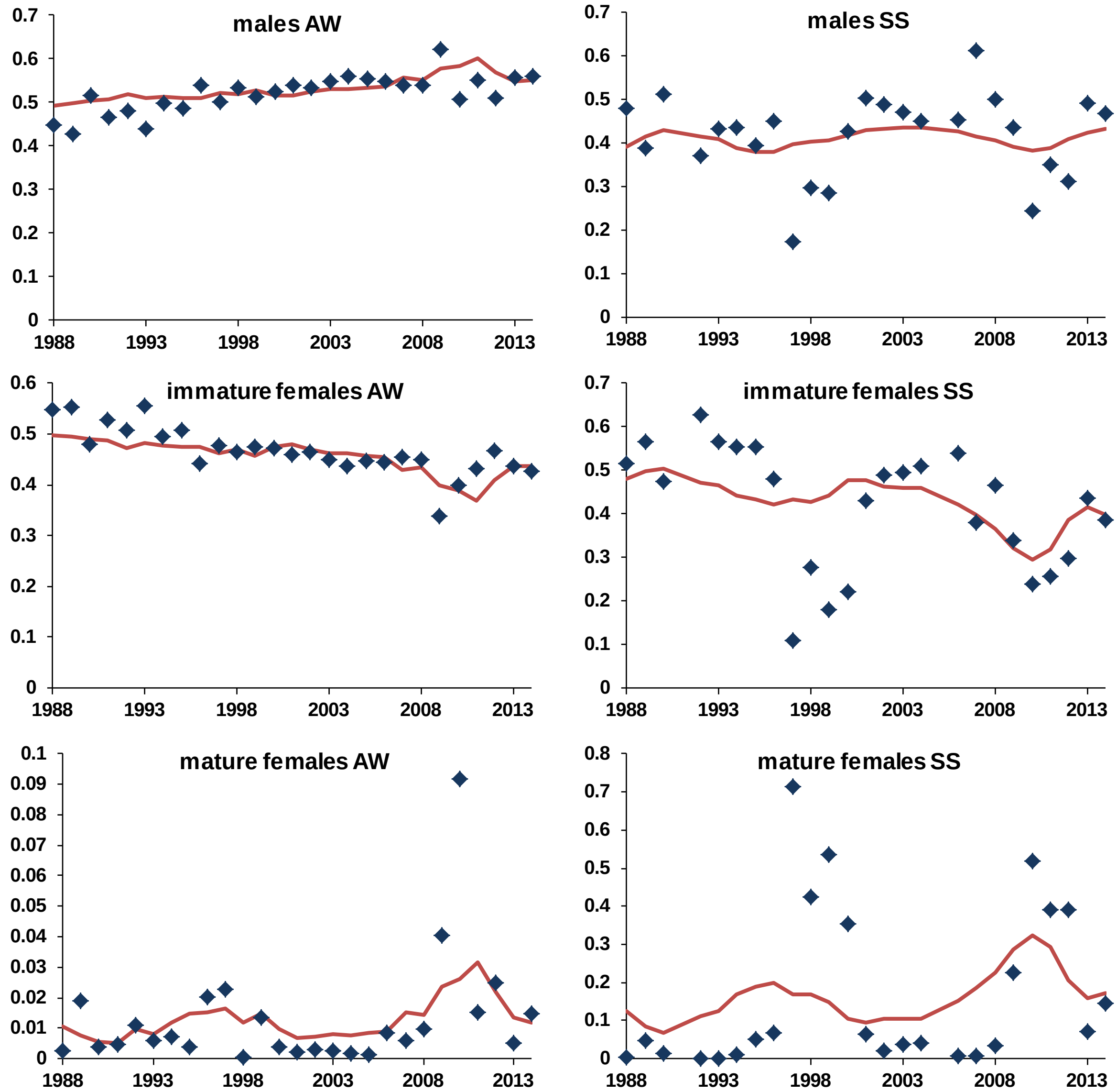


Figure 10: CRA 7: fits to proportions-at-sex by sex, season (AW is the left pair) and source for the base case MPD.

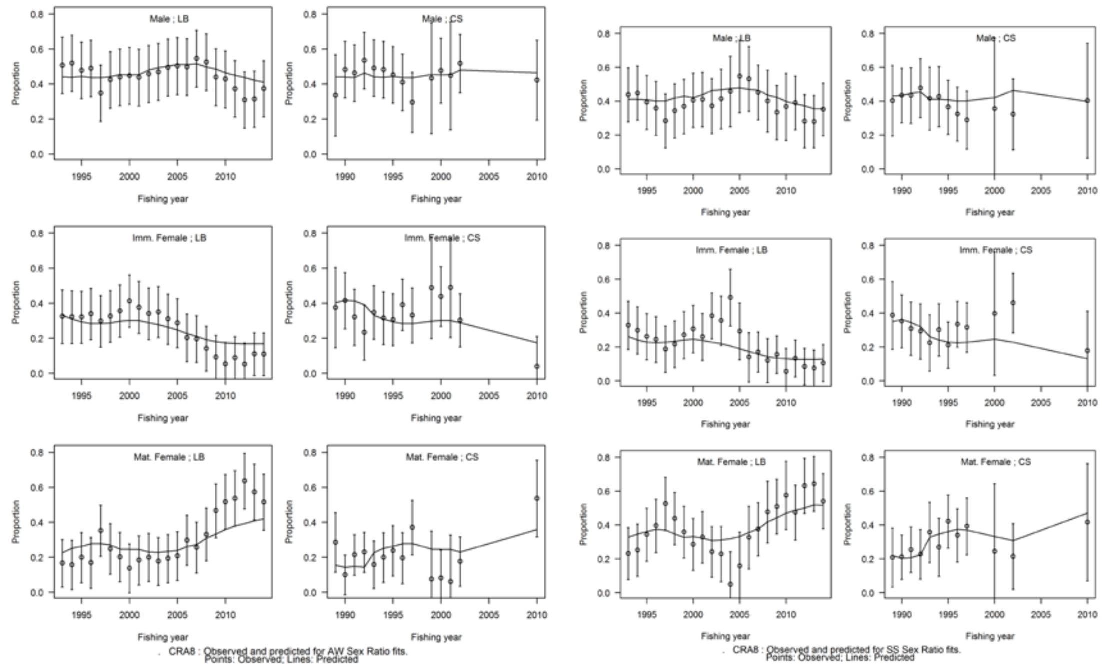


Figure 11: CRA 8: fits to proportions-at-sex by sex, season (AW is the left pair) and source for the base case MPD.

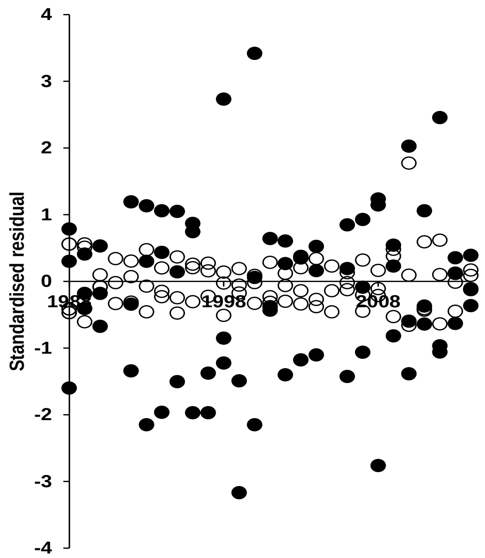


Figure 12: CRA 7: residuals from the fit shown in Figure 10 to proportions-at-sex; open circles are AW and closed circles are SS.

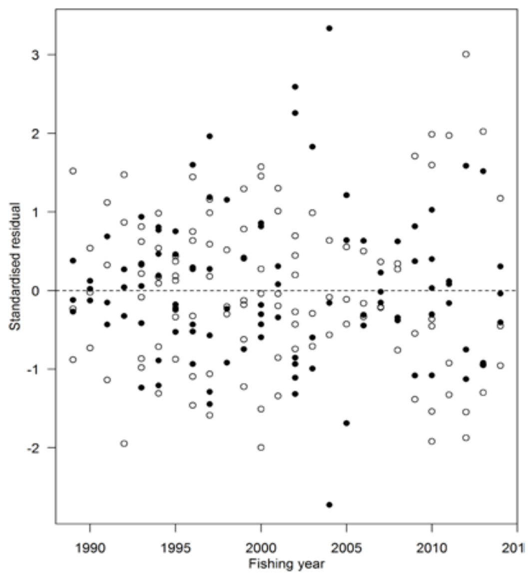


Figure 13: CRA 8: residuals from the fit shown in Figure 11 to proportions-at-sex; open circles are AW and closed circles SS.

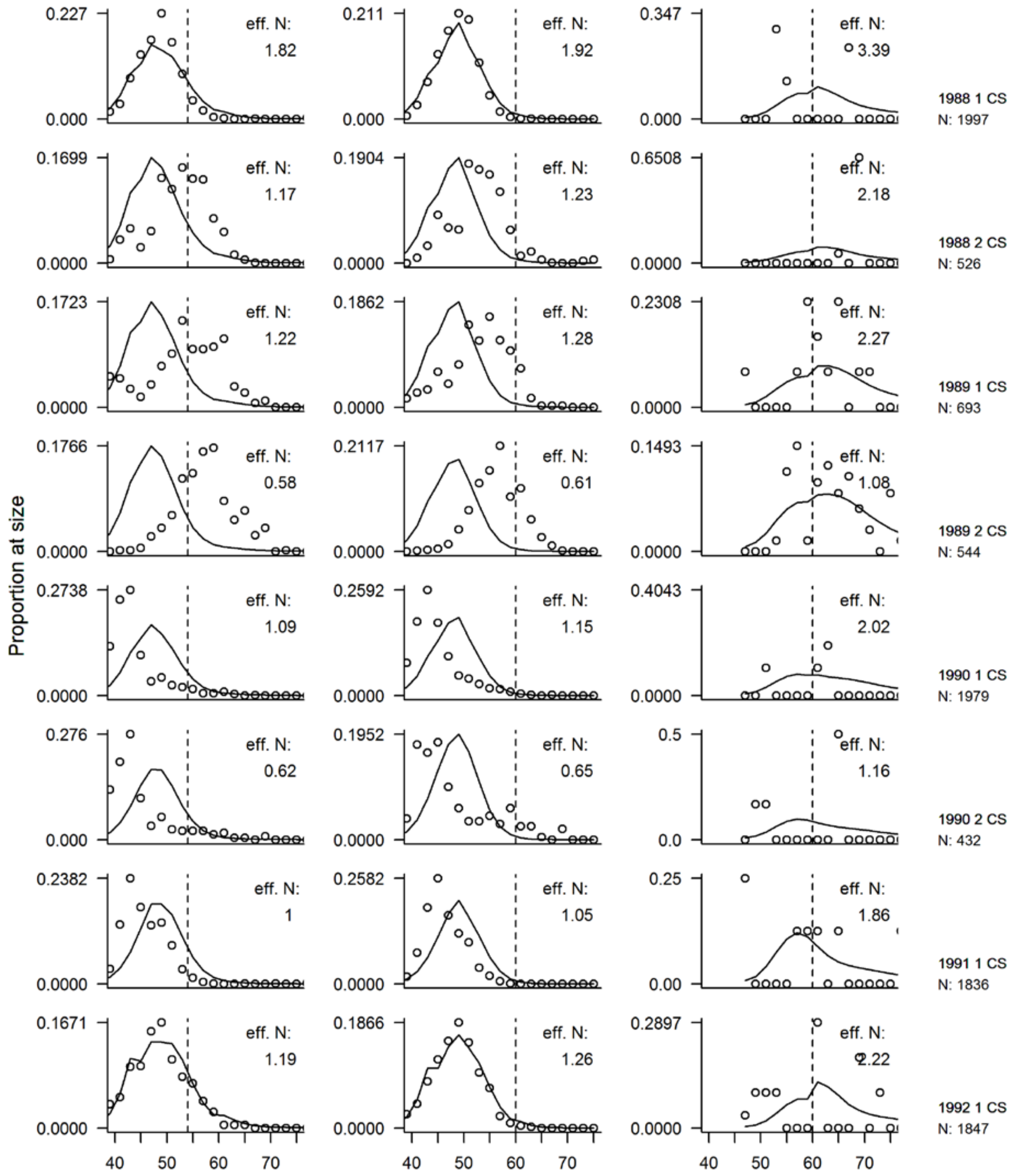


Figure 14: CRA 7: base case MPD fits to the LF data for 1988–92, with males on the left, immature females in the centre and mature females at the right; scales change among plots; numbers at right show the year, season (1 = AW, 2 = SS), source (CS = observer catch sampling, LB = voluntary logbooks) and numbers of fish measured.

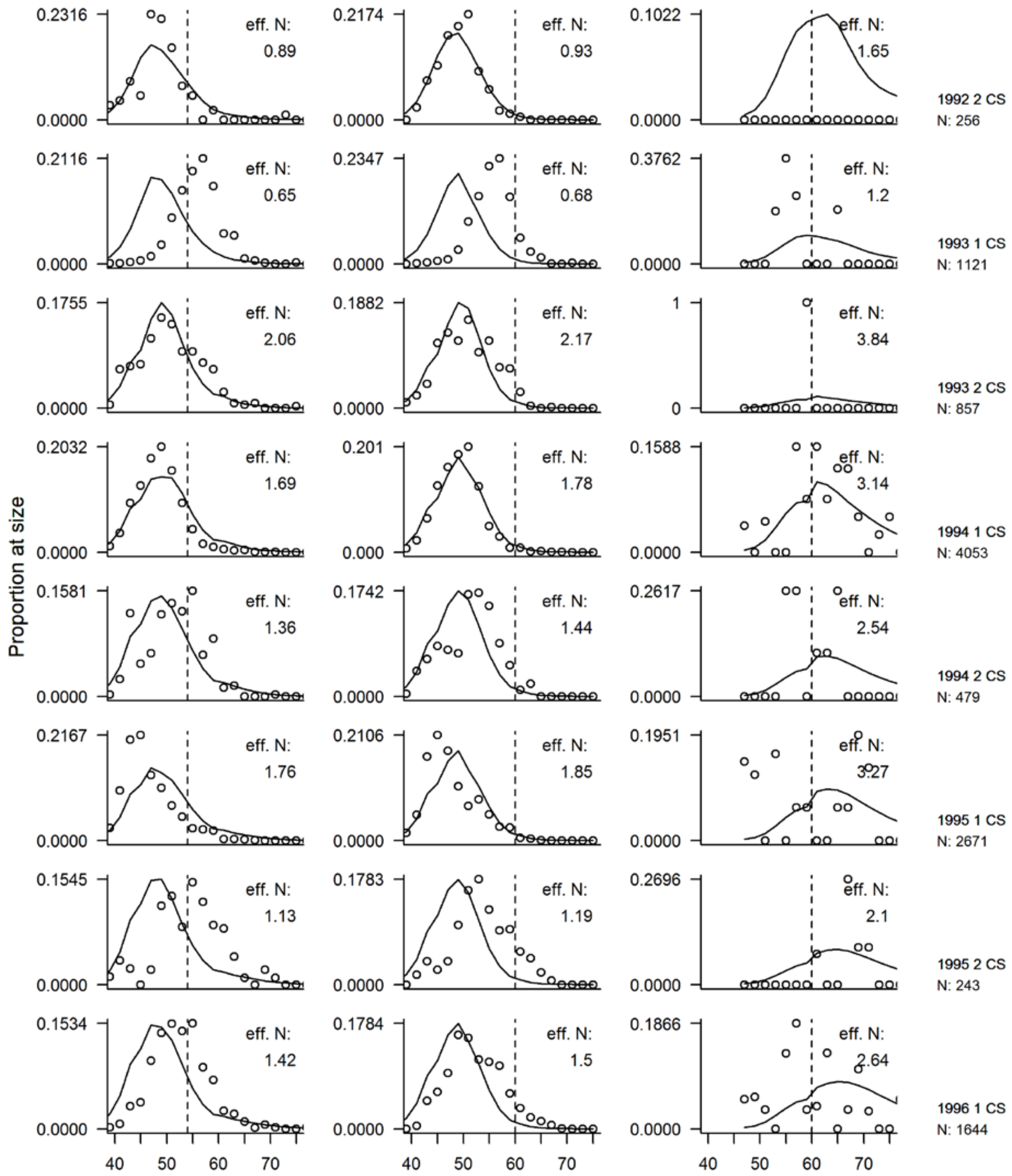


Figure 15: CRA 7: base case MPD fits to the LF data for 1992–96; see caption for Figure 14.

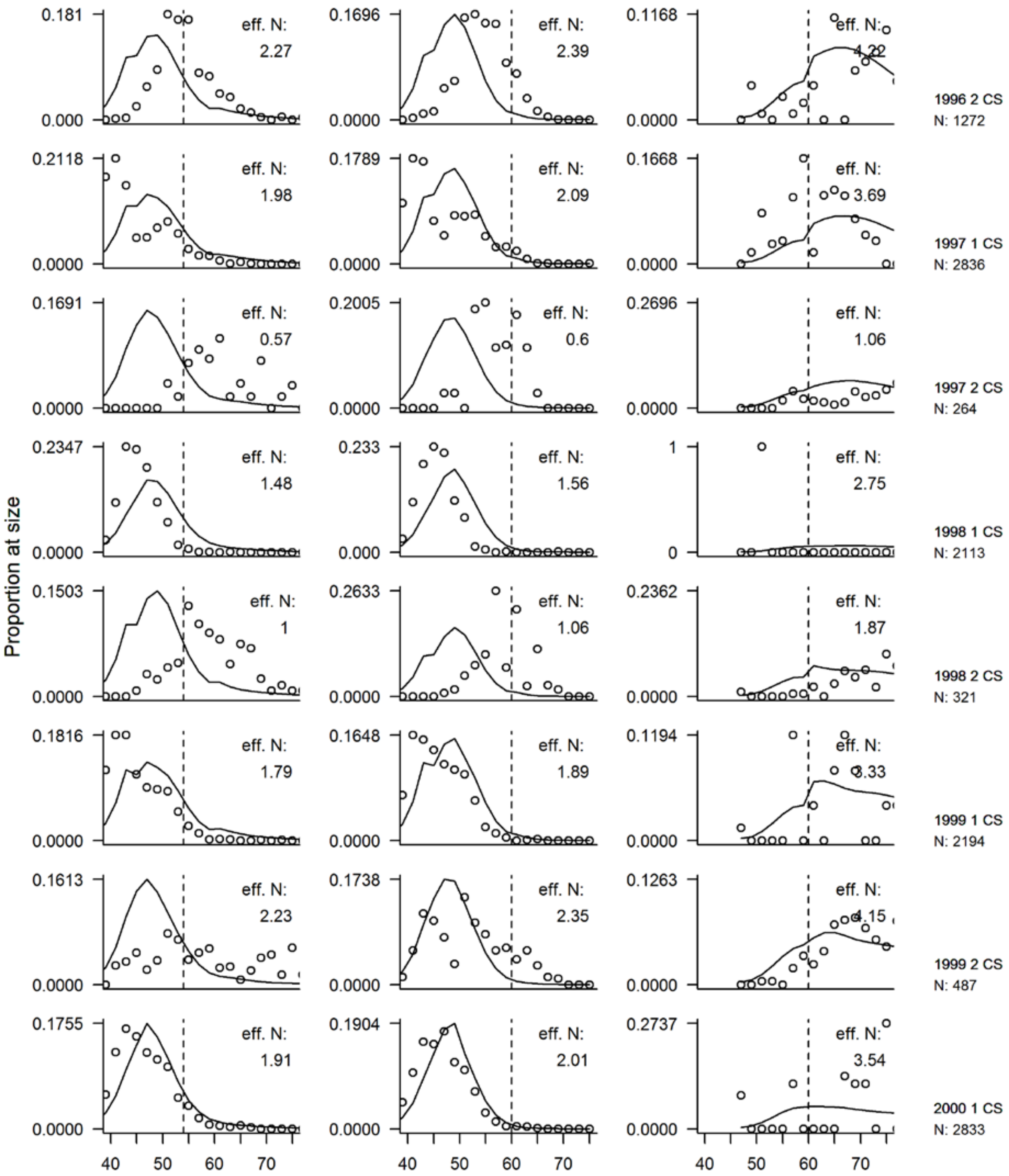


Figure 16: CRA 7: base case MPD fits to the LF data for 1996–2000; see caption for Figure 14.

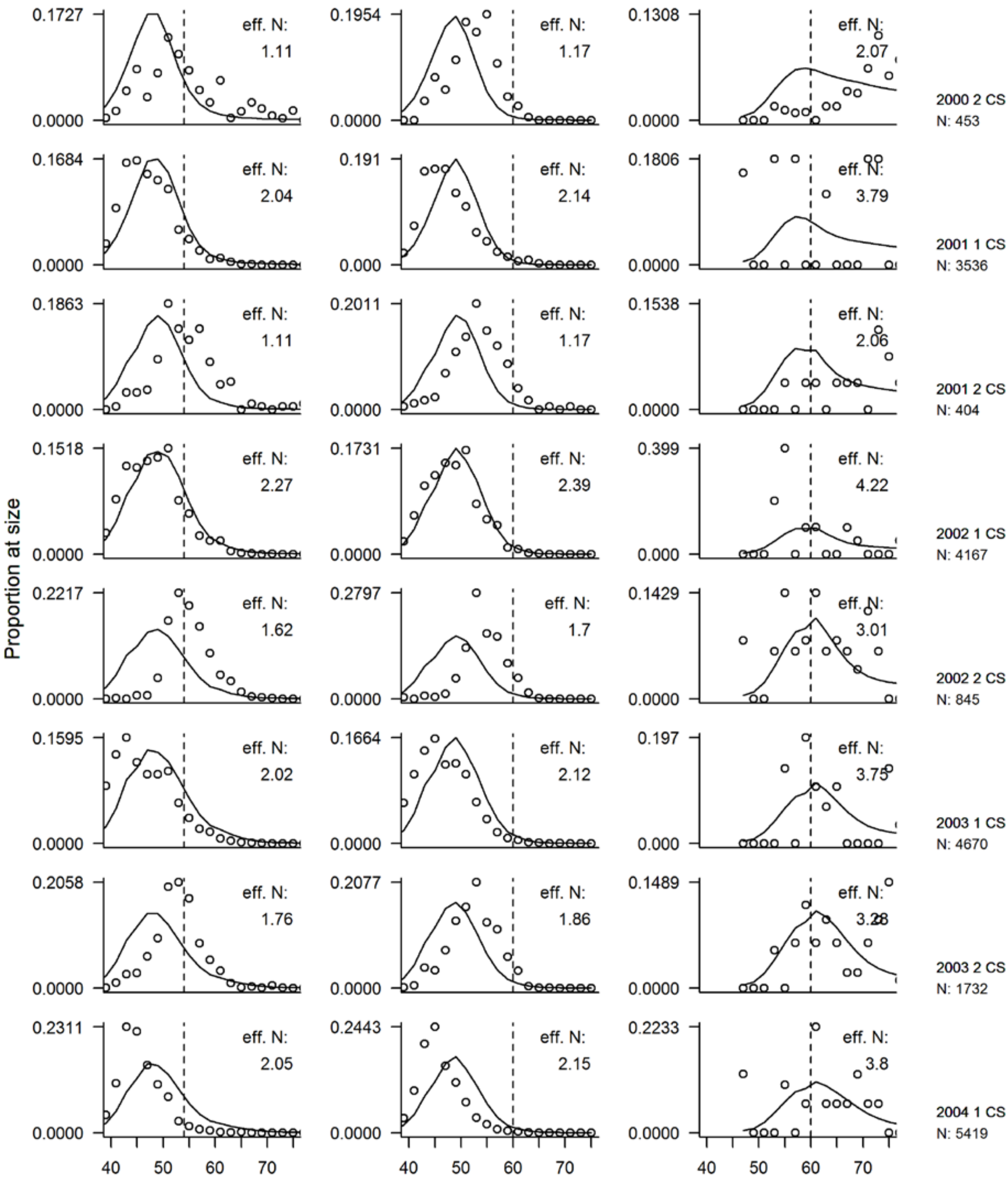


Figure 17: CRA 7: base case MPD fits to the LF data for 2000–04; see caption for Figure 14.

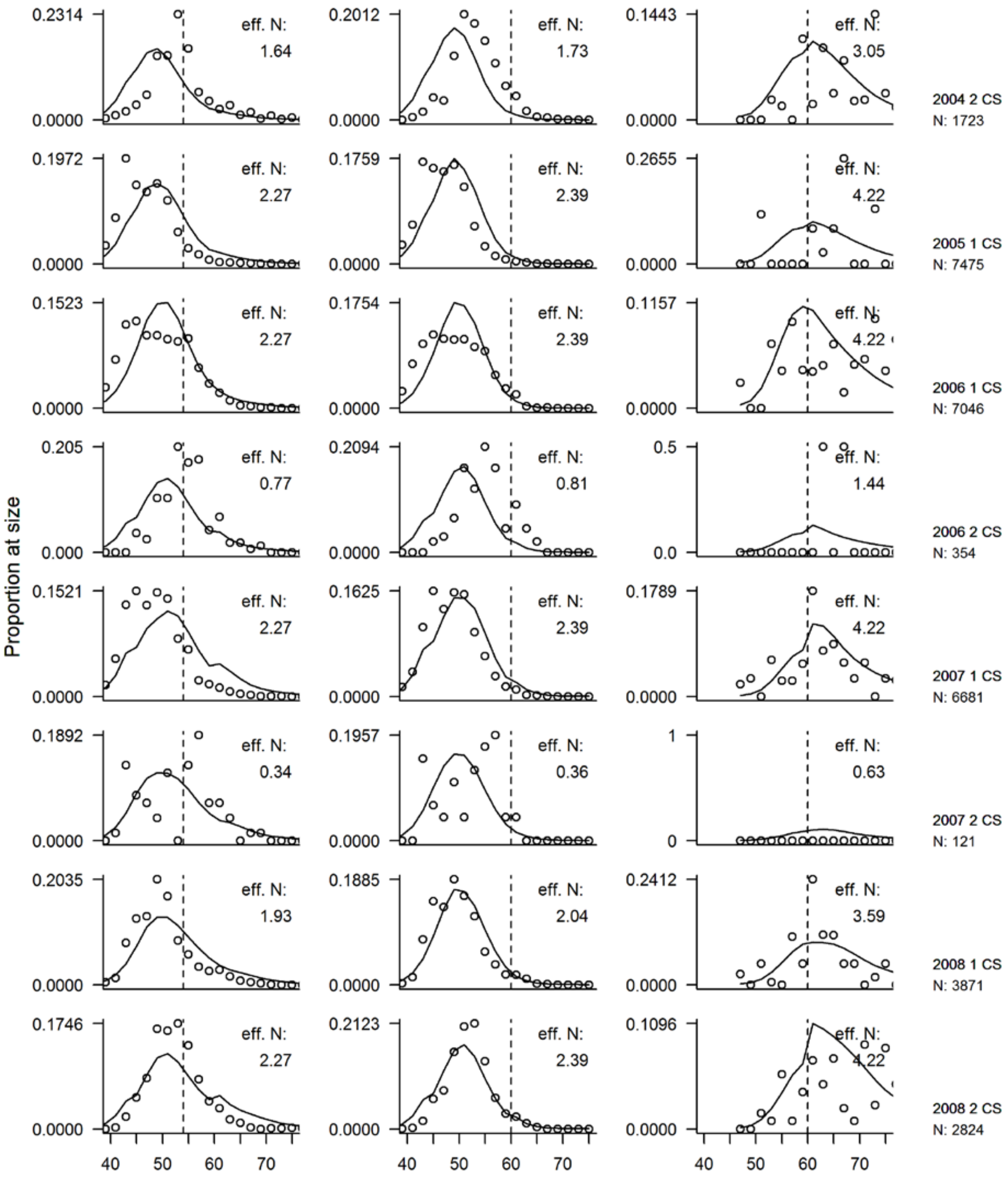


Figure 18: CRA 7: base case MPD fits to the LF data for 2004–08; see caption for Figure 14.

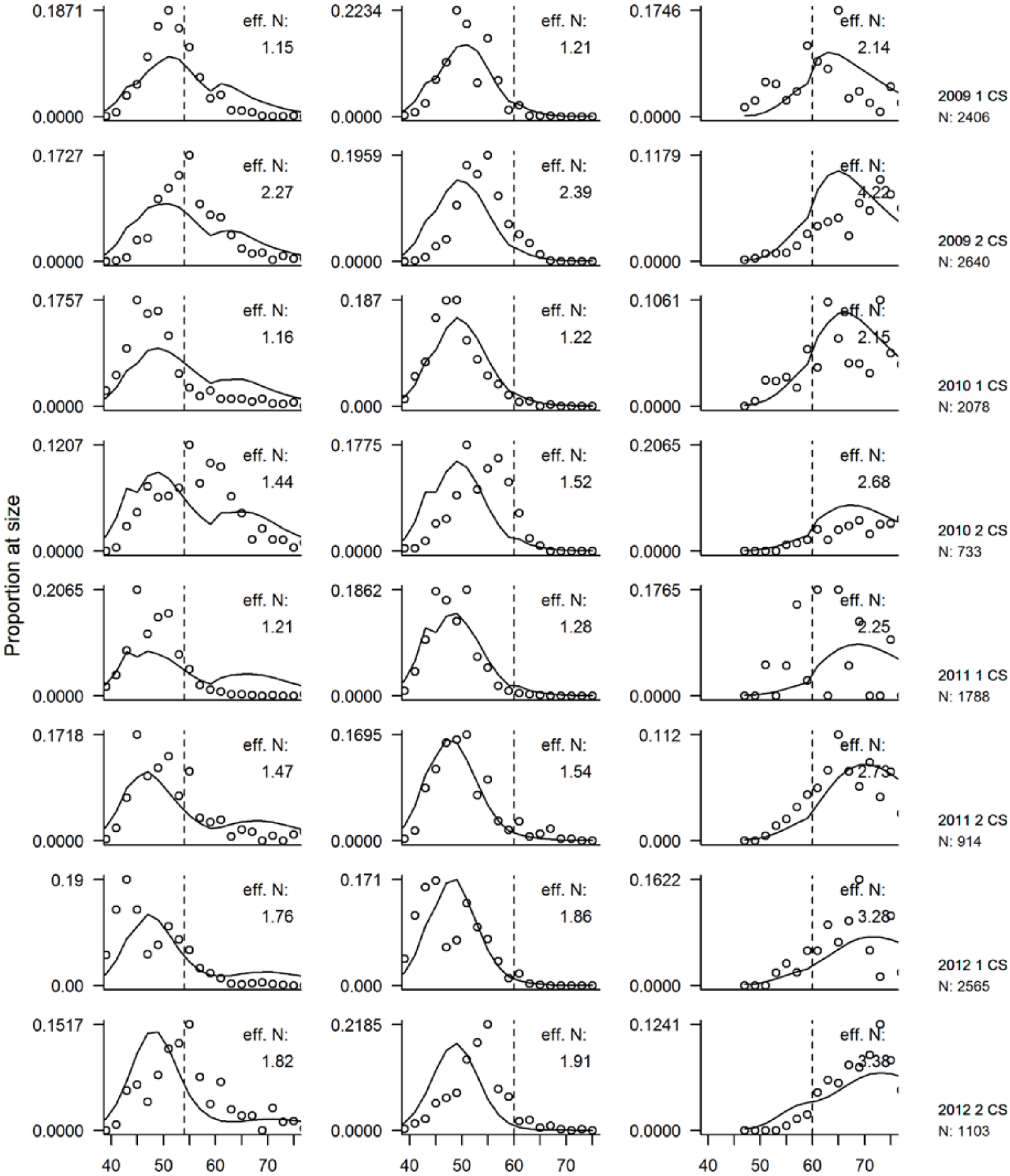


Figure 19: CRA 7: base case MPD fits to the LF data for 2009–12; see caption for Figure 14.

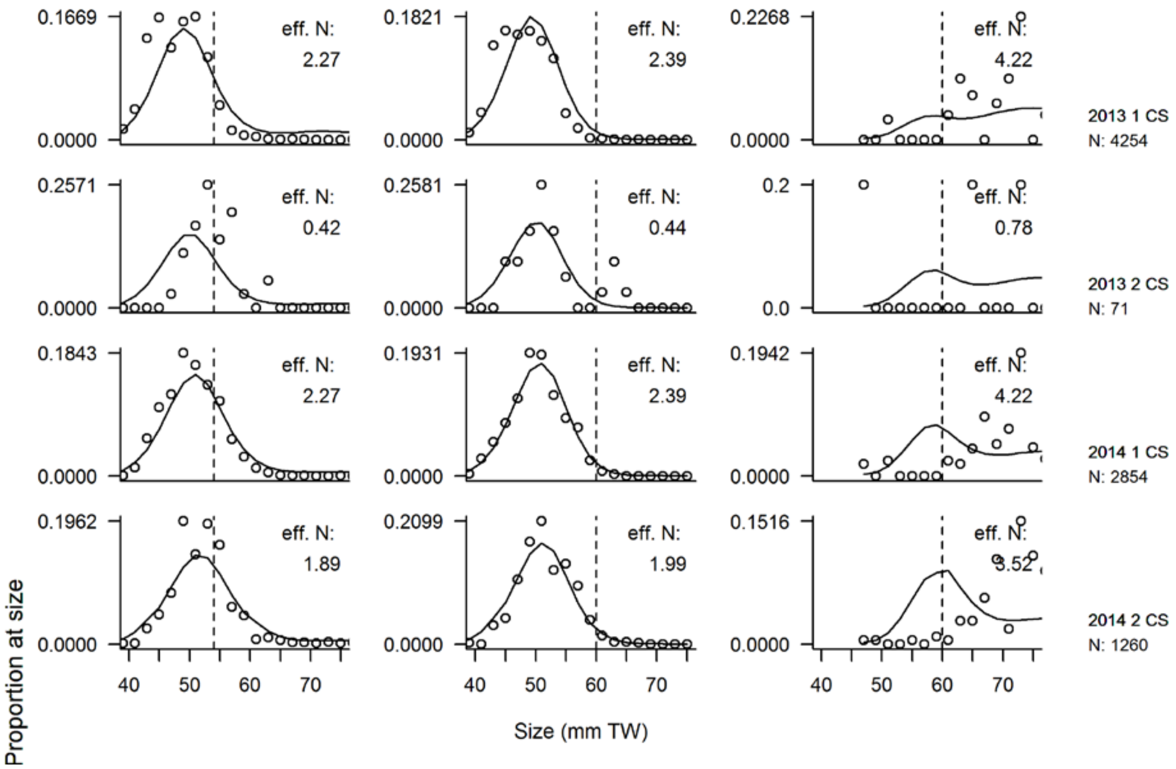


Figure 20: CRA 7: base case MPD fits to the LF data for 2013–14; see caption for Figure 14.

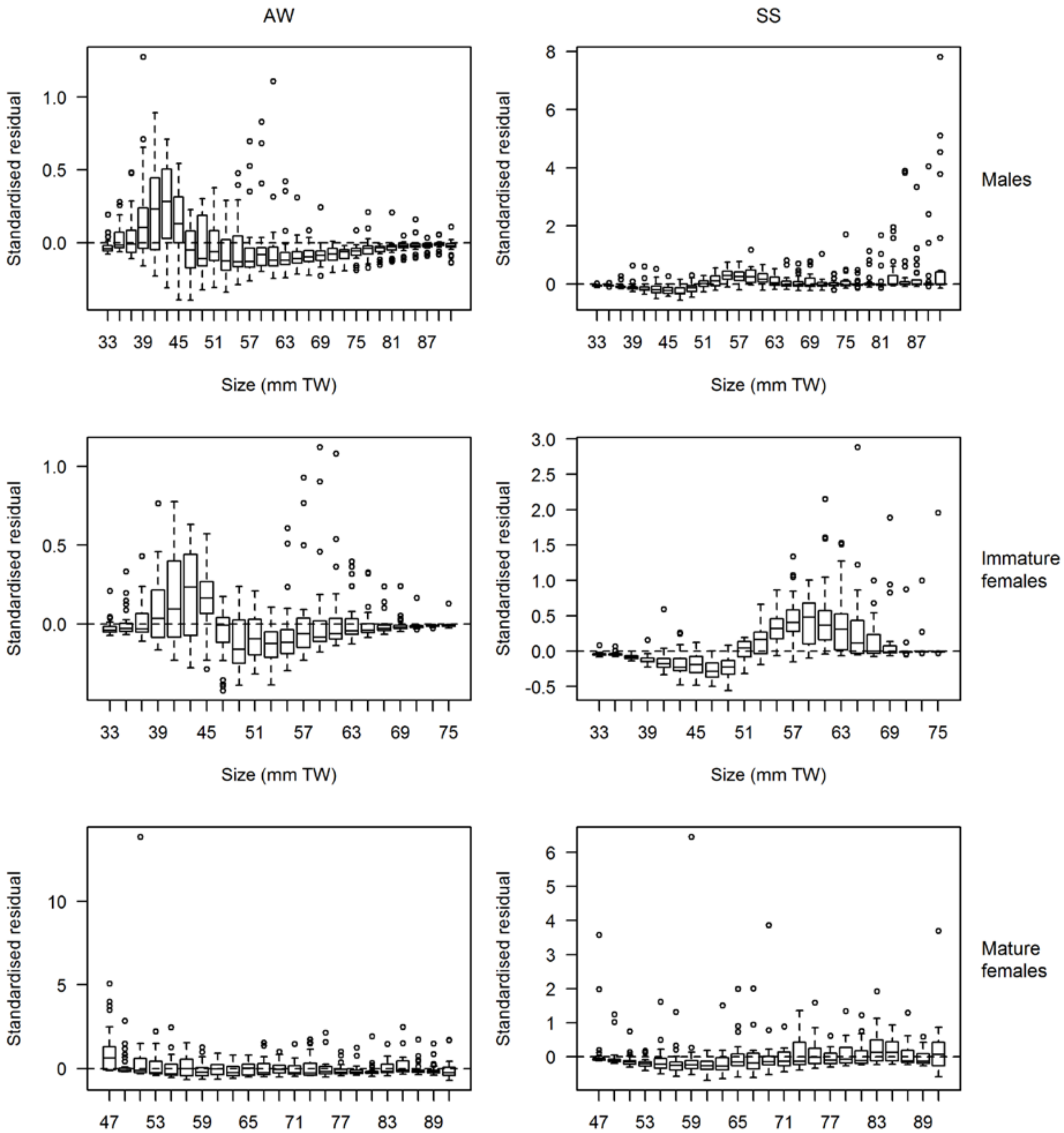


Figure 21: CRA 7: residuals from the fits to LFs (Figure 14 through Figure 20) by size, sex and season.

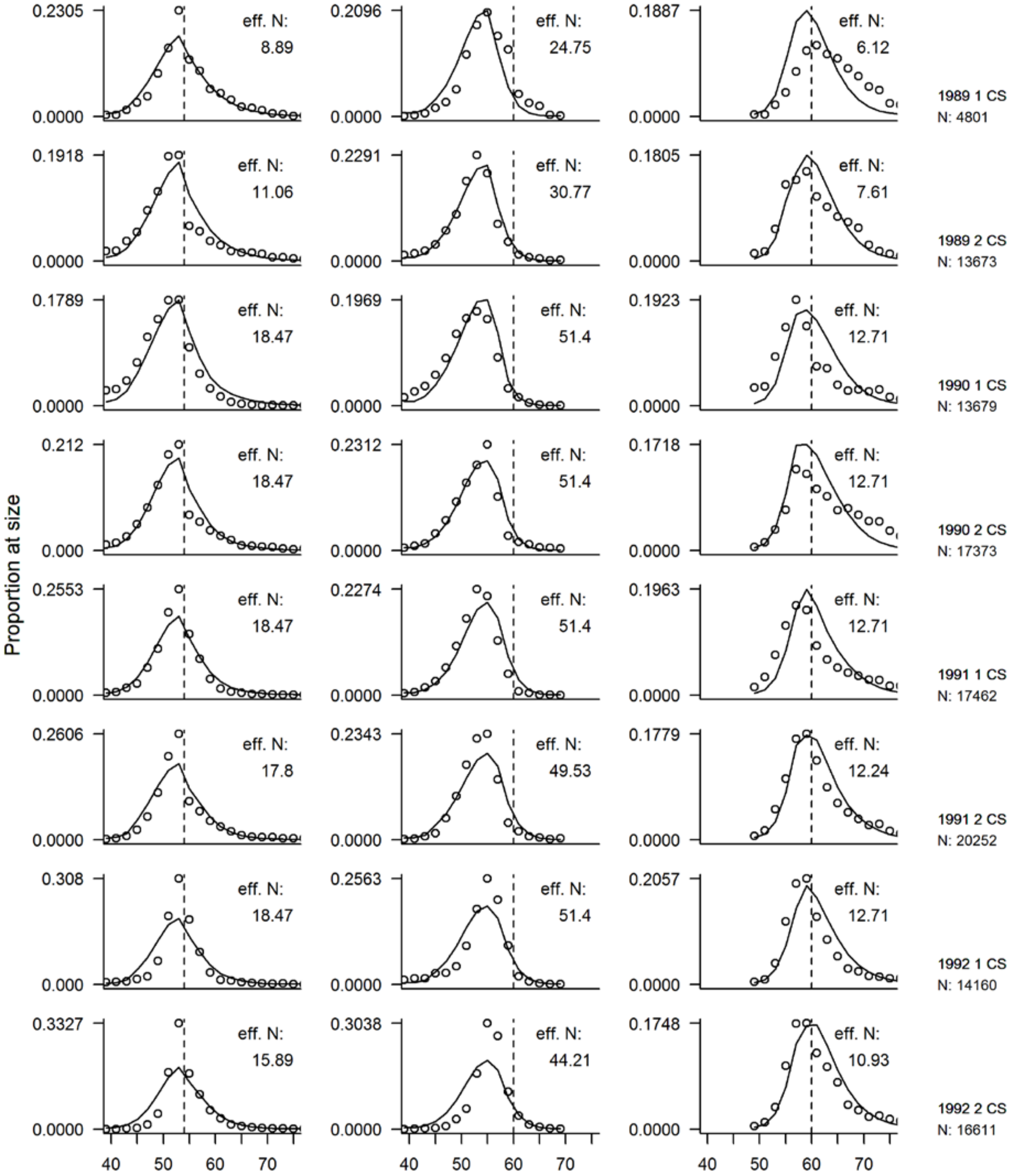


Figure 22: CRA 8: base case MPD fits to the LF data for 1989–92; with males on the left, immature females in the centre and mature females at the right; scales change among plots; numbers at right show the year, season (1 = AW, 2 = SS), source (CS = observer catch sampling, LB = voluntary logbooks) and numbers of fish measured.

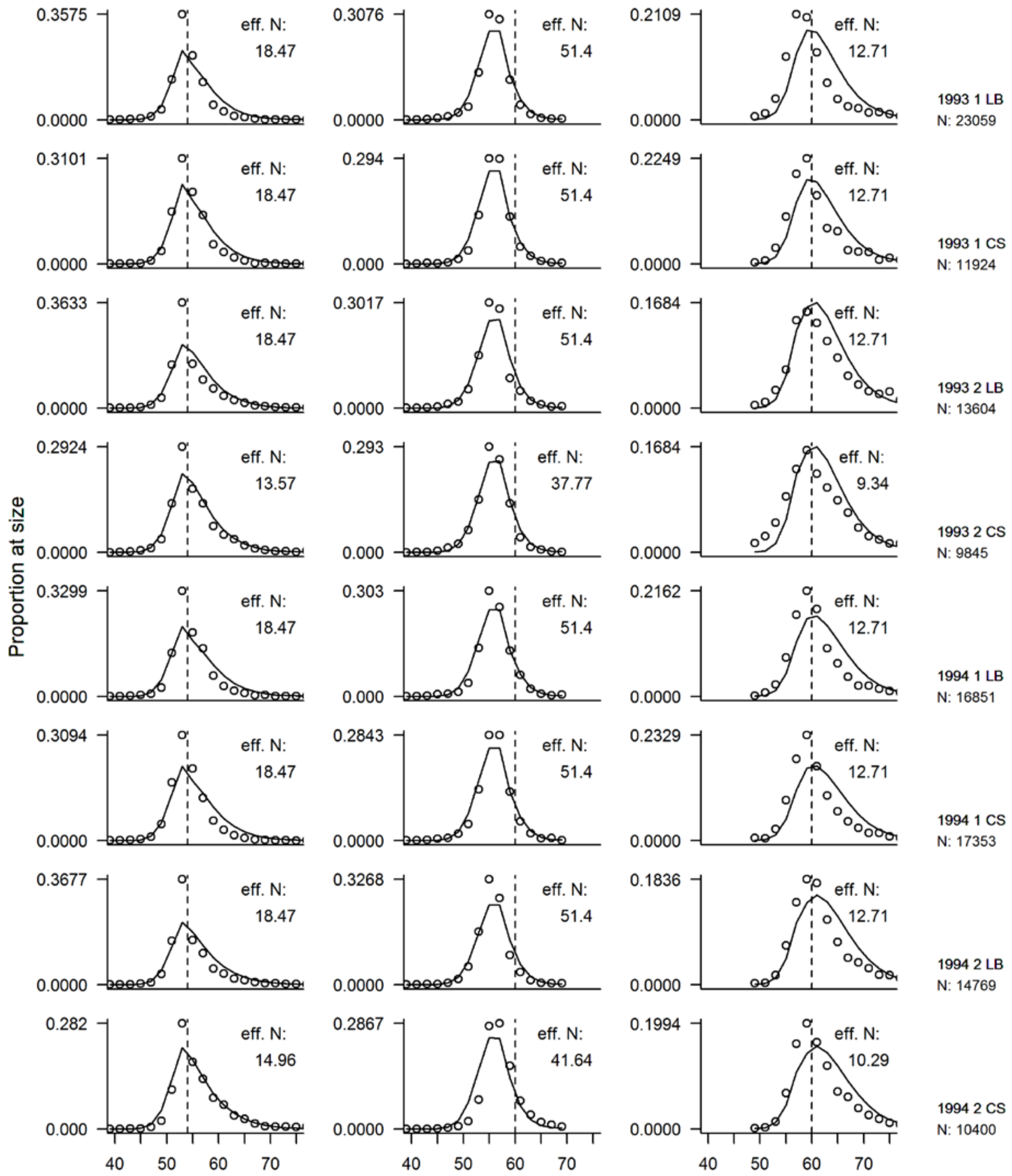


Figure 23: CRA 8: base case MPD fits to the LF data for 1994–94; see caption for Figure 22.

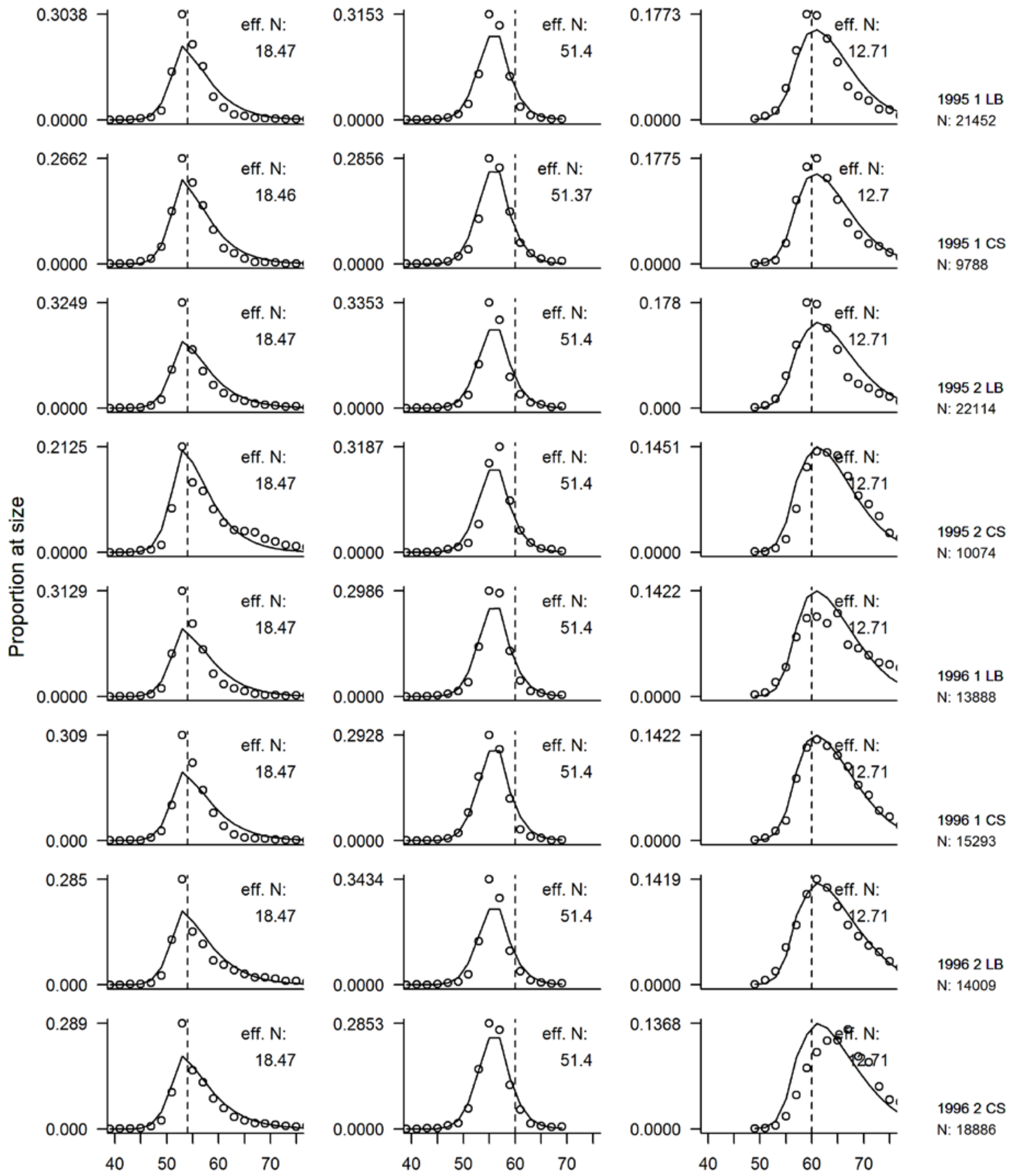


Figure 24: CRA 8: base case MPD fits to the LF data for 1995–96; see caption for Figure 22.

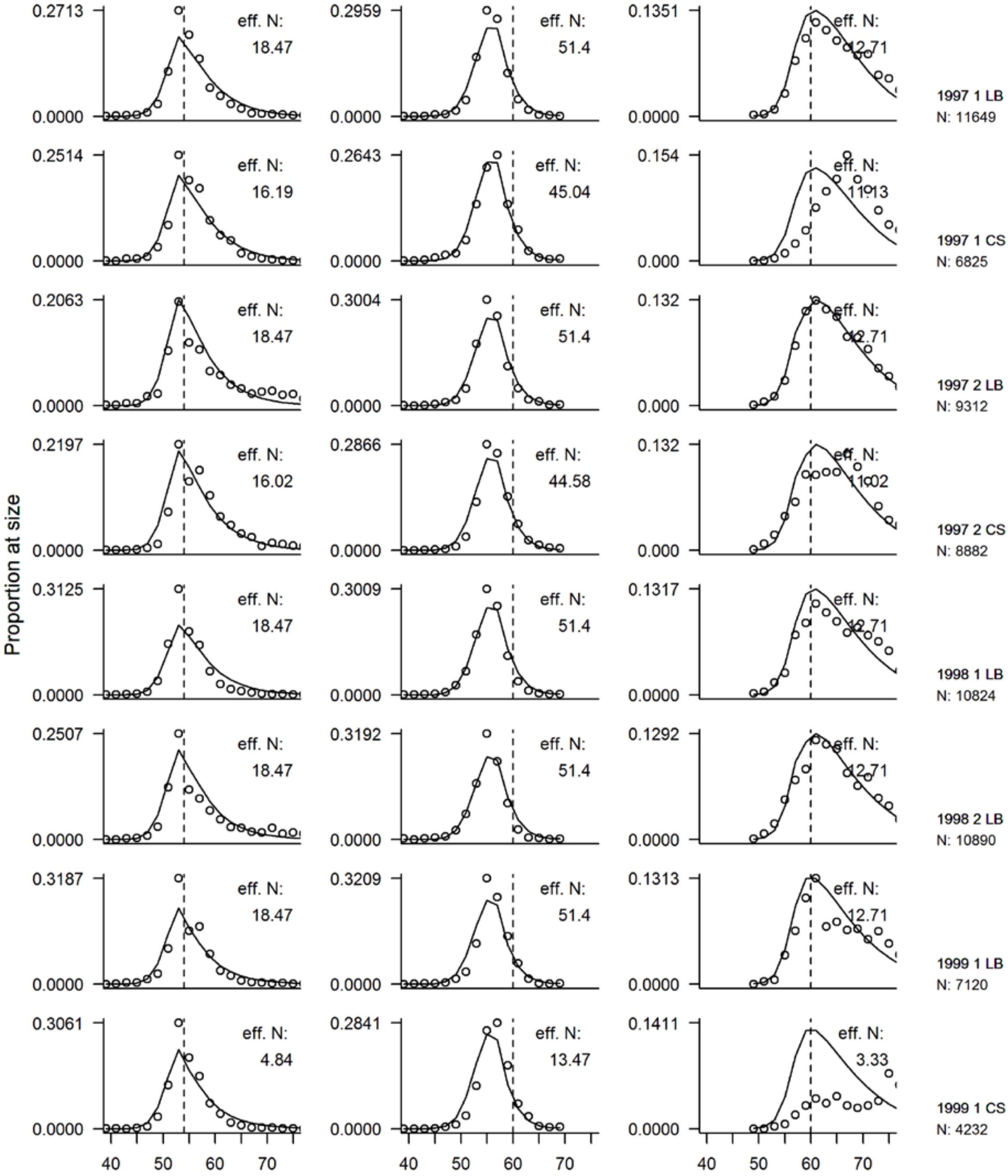


Figure 25: CRA 8: base case MPD fits to the LF data for 1997–99; see caption for Figure 22.

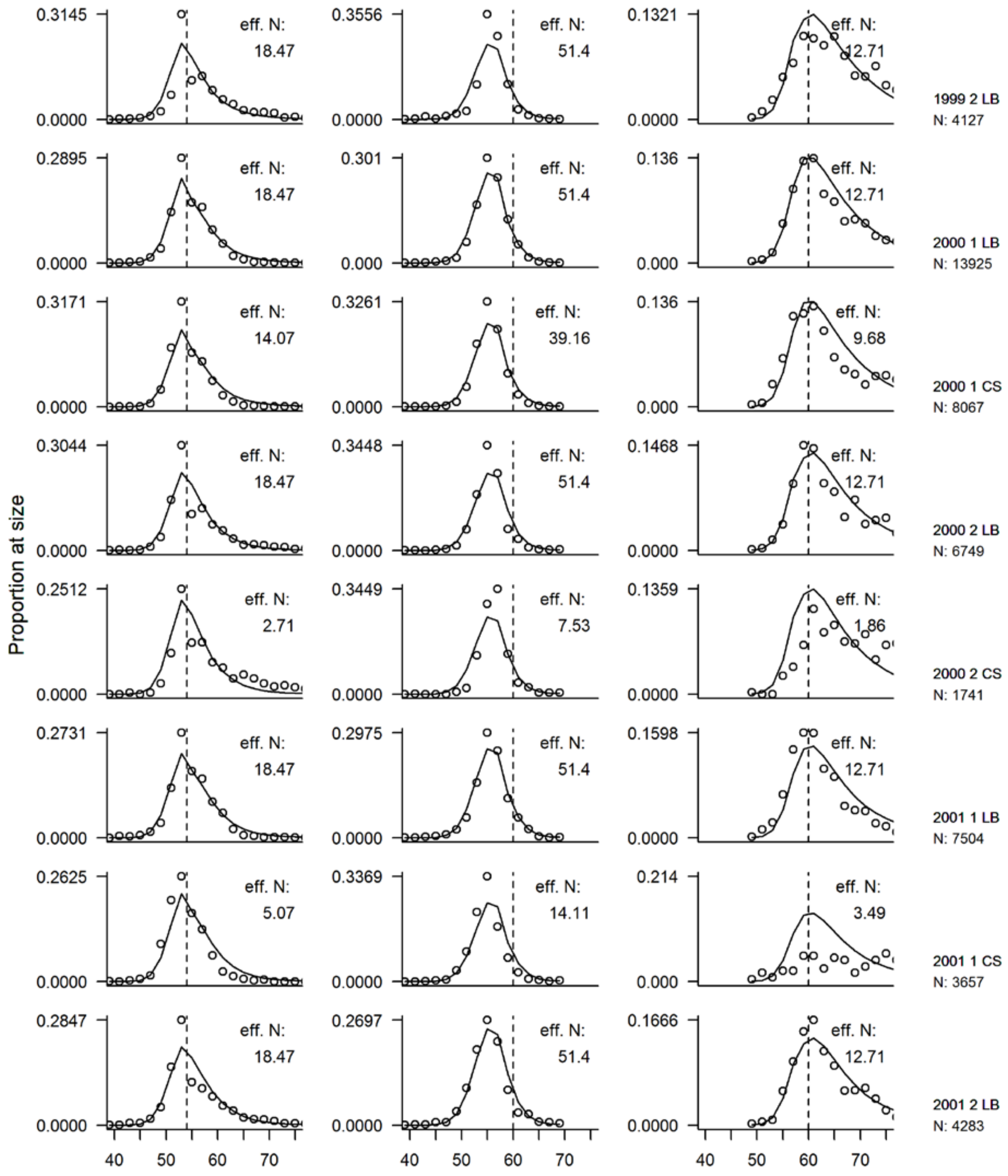


Figure 26: CRA 8: base case MPD fits to the LF data for 1999–2001; see caption for Figure 22.

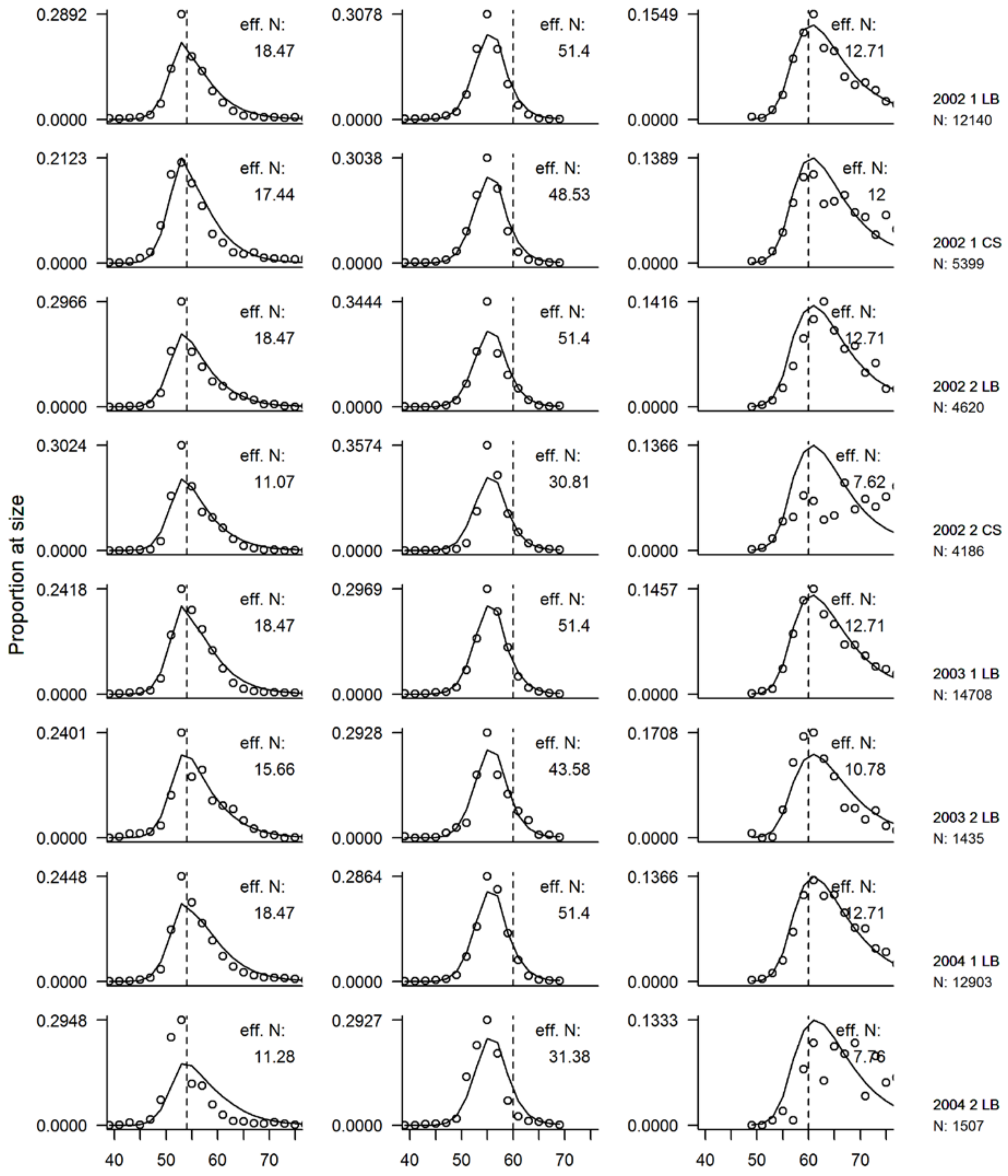


Figure 27: CRA 8: base case MPD fits to the LF data for 2002–04; see caption for Figure 22.

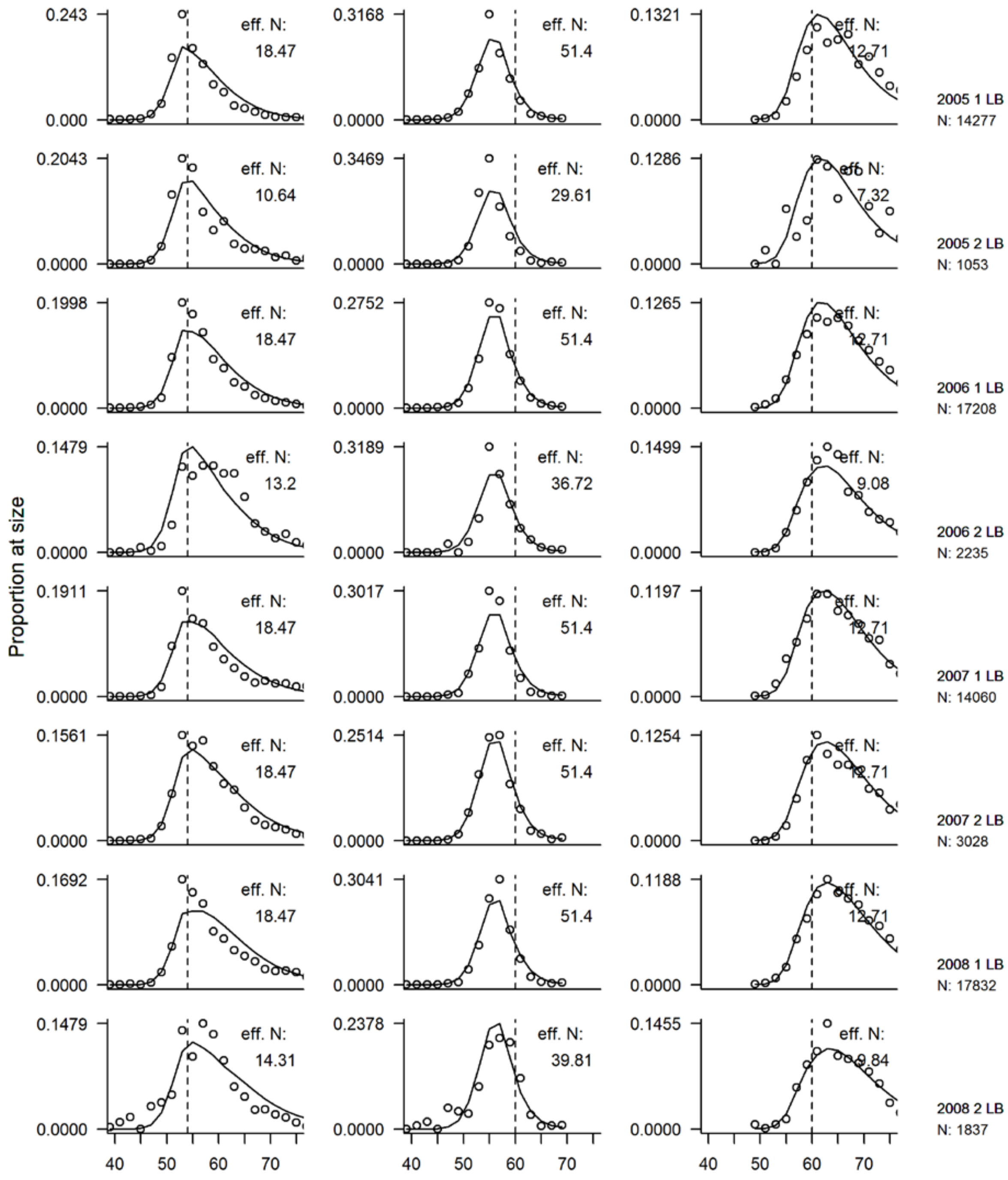


Figure 28: CRA 8: base case MPD fits to the LF data for 2005–08; see caption for Figure 22.

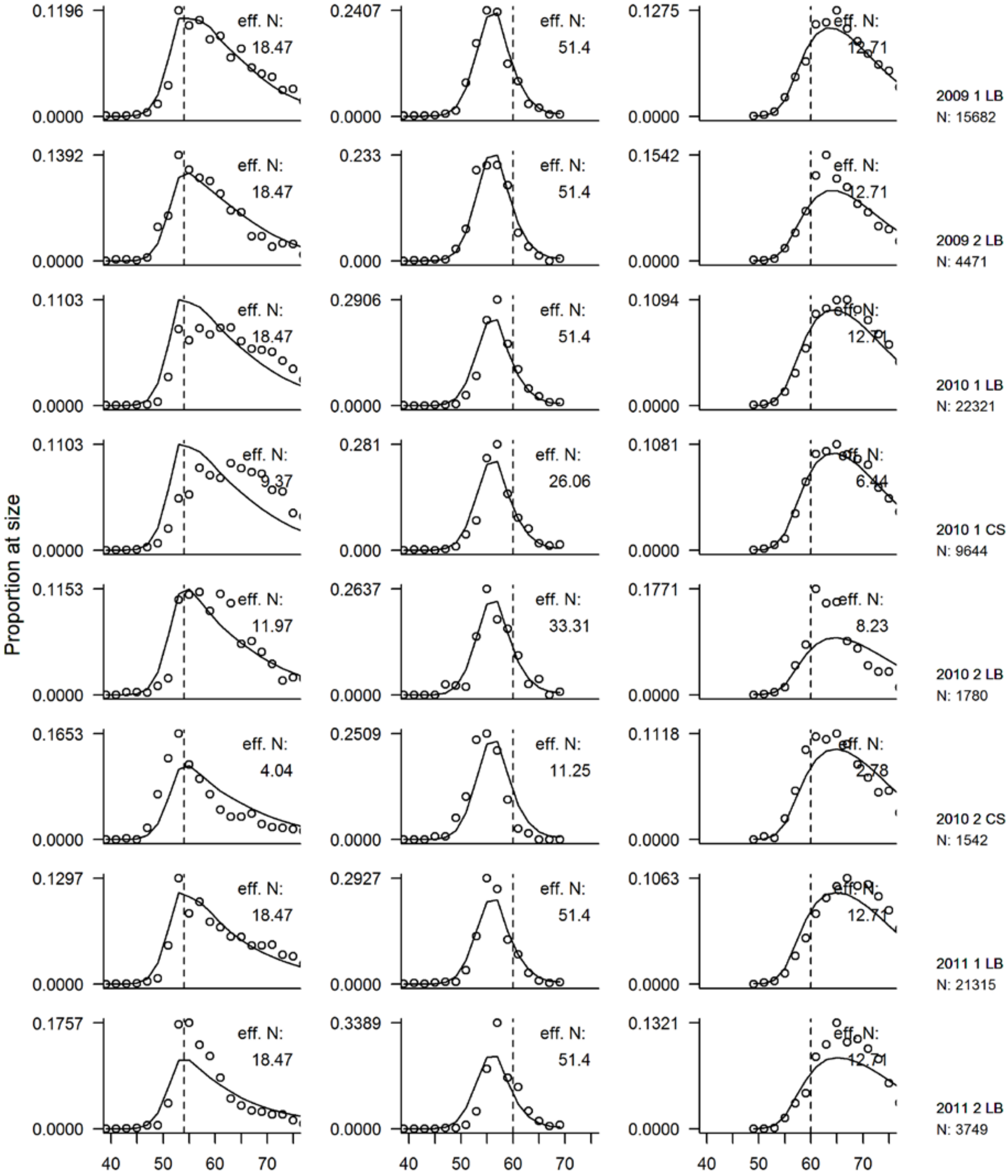


Figure 29: CRA 8: base case MPD fits to the LF data for 2009–11; see caption for Figure 22.

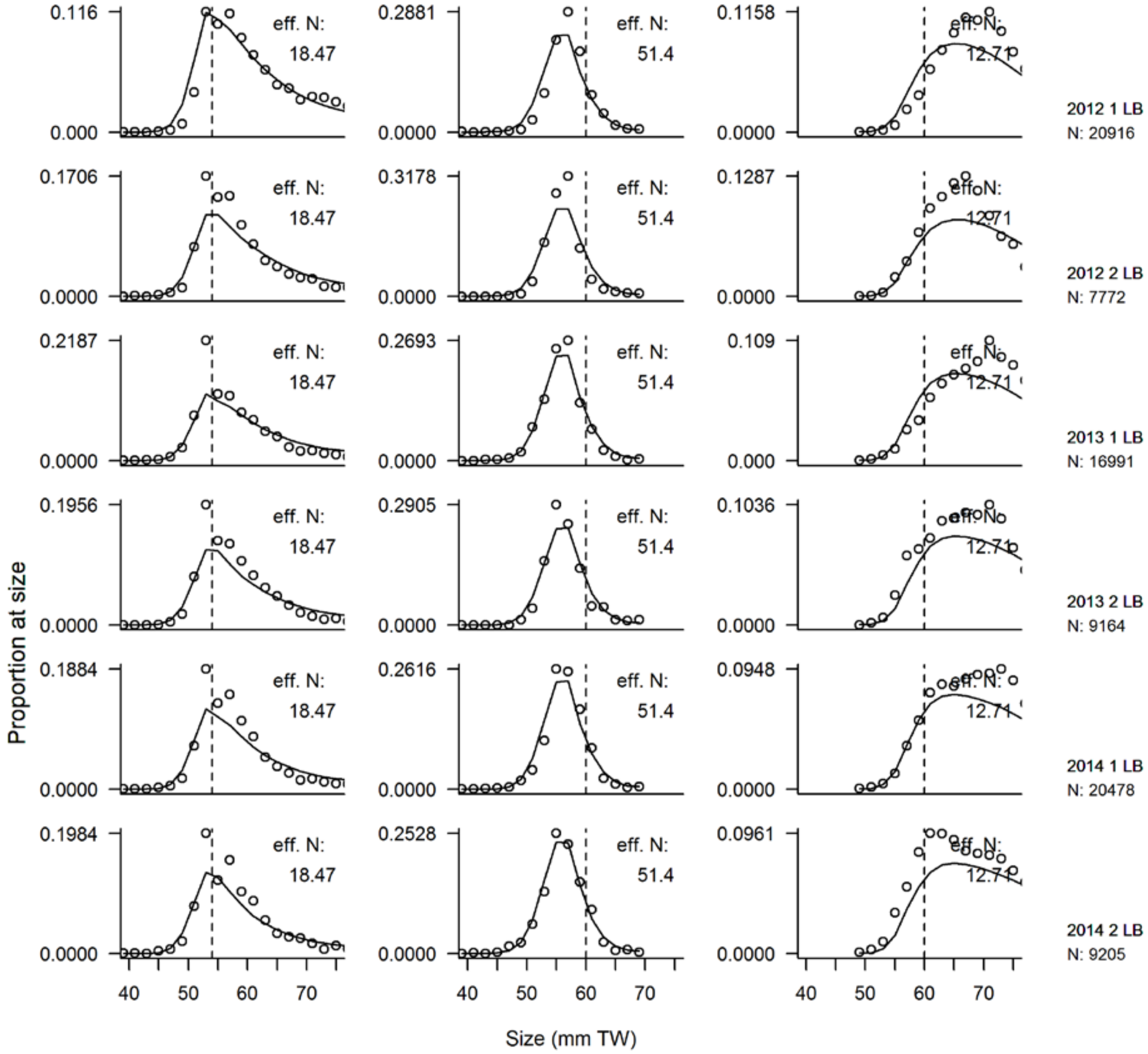


Figure 30: CRA 8: base case MPD fits to the LF data for 2012–14; see caption for Figure 22.

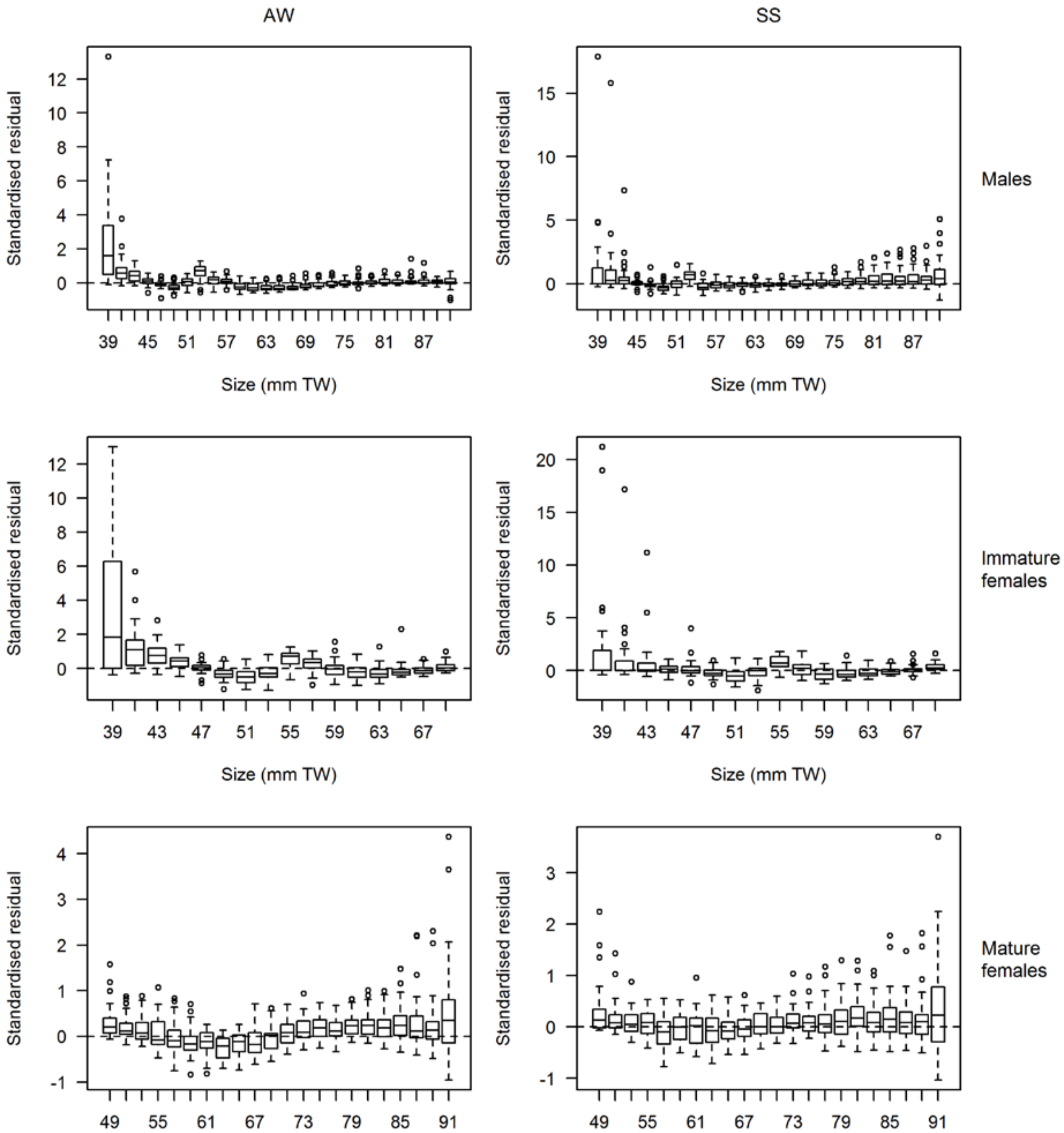


Figure 31: CRA 8: residuals from the fits to LFs (Figure 22 through Figure 30) by size, sex and season.

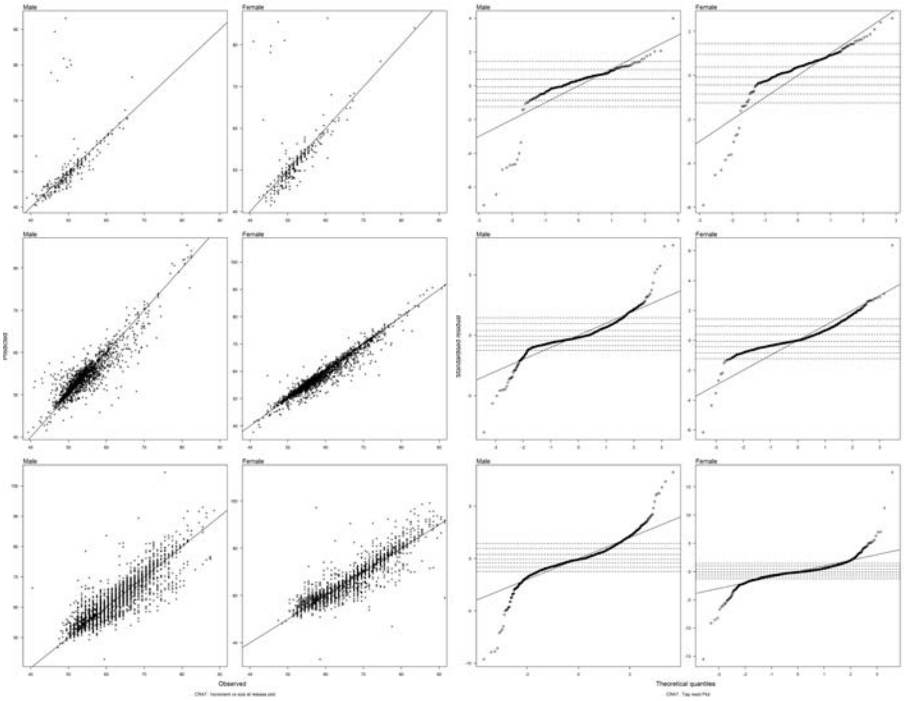


Figure 32: Left column: comparison of observed and predicted increments in the tag-recapture data for CRA 7 males (top), CRA 8 males before 1993 (middle) and CRA 8 males 1993 and after (bottom); second column: same as left for females; third and fourth columns: Q-Q plot from the tag-recapture fits at the left.

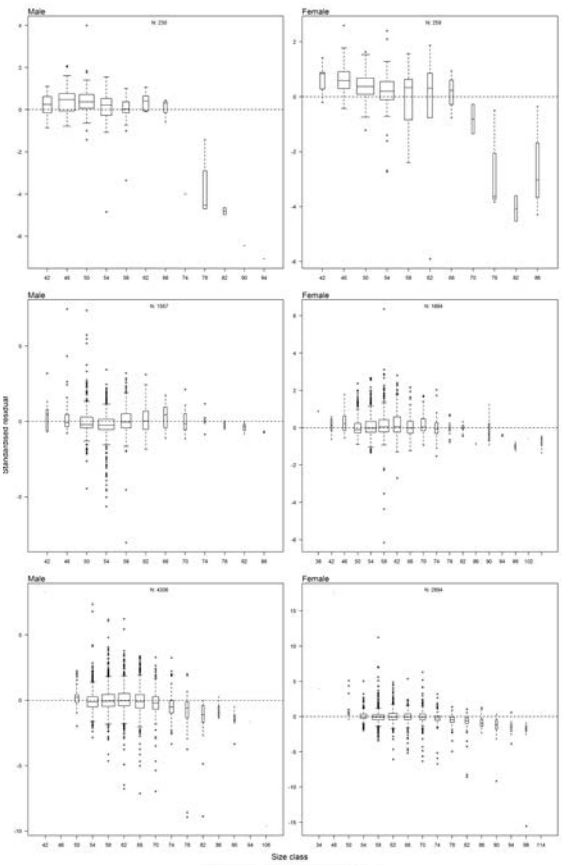


Figure 33: Residuals by size from the tag-recapture fits for CRA 7 (upper), pre-1993 CRA (middle) and later CRA 8 (bottom), males on the left.

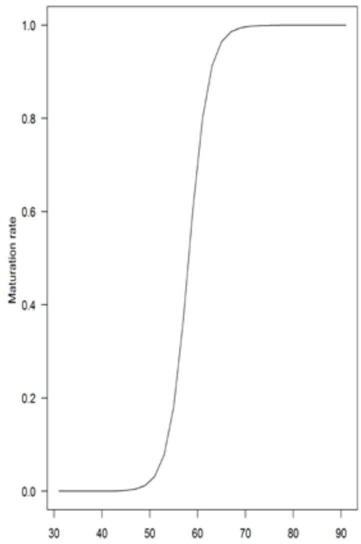


Figure 34: The model's maturation curve for CRA 7 and CRA 8.

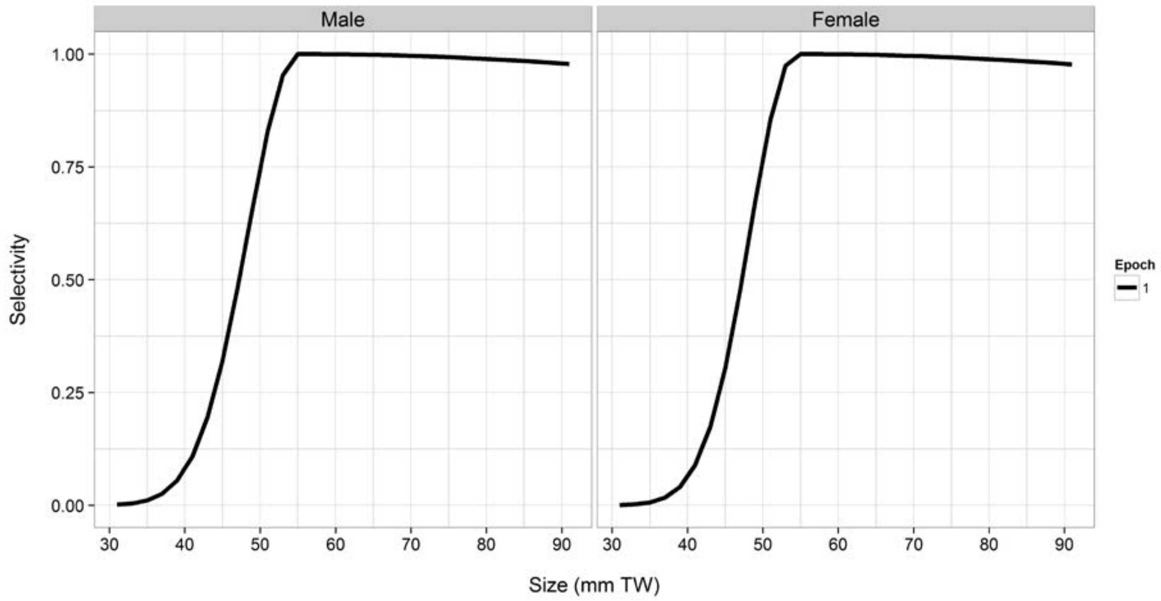


Figure 35: CRA 7: base case MPD selectivity curves for males (left) and females.

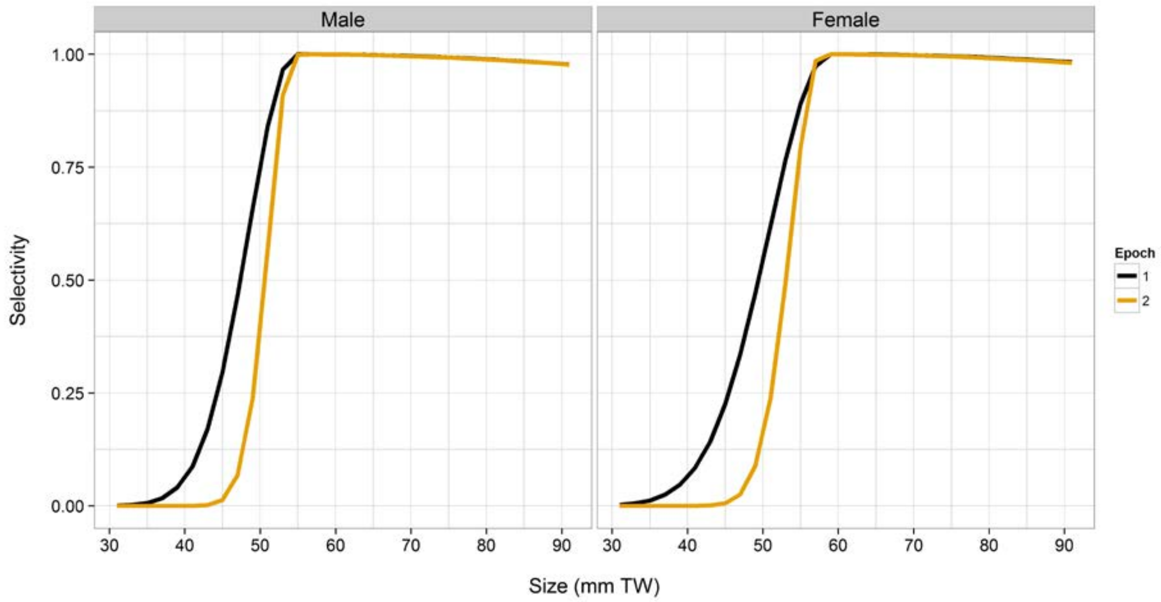


Figure 36: CRA 8: base case MPD selectivity curves for males (left) and females.

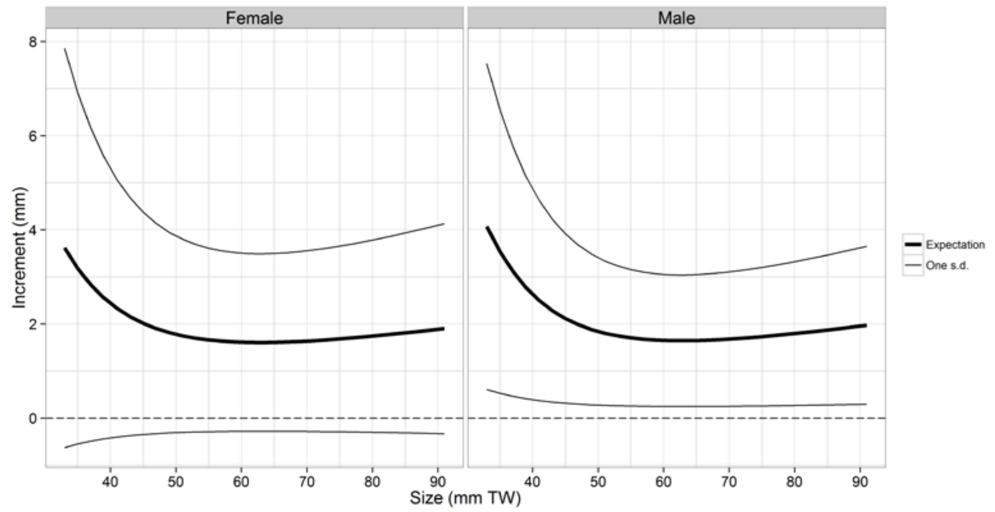


Figure 37: CRA 7: base case MPD growth curves for males (left) and females.

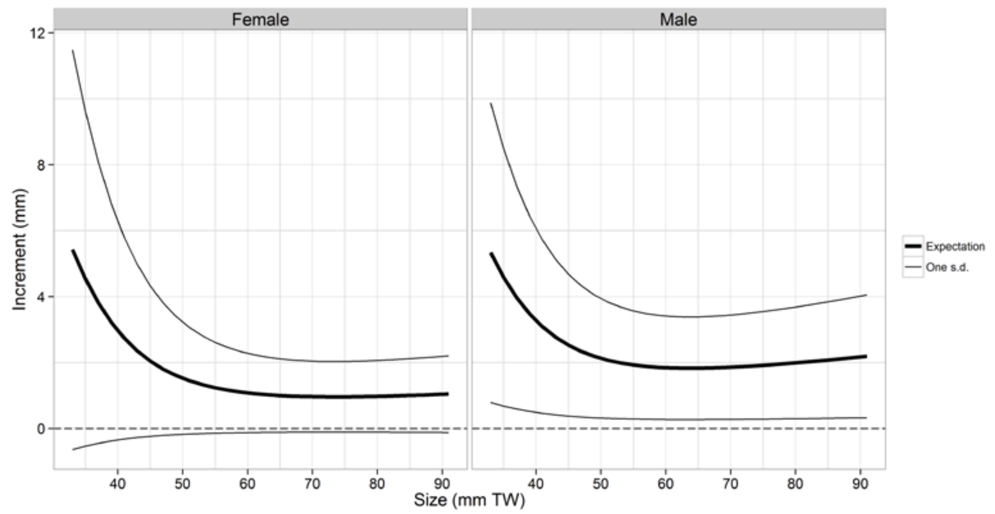


Figure 38: CRA 8: base case MPD growth curves for CRA 8 males (left) and females from the first growth stanza.

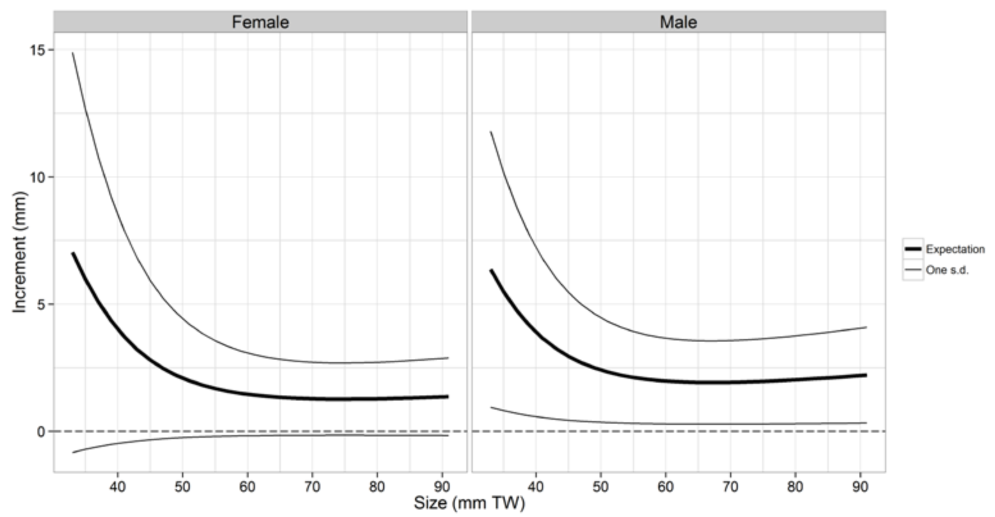


Figure 39: CRA 8: base case MPD growth curves for CRA 8 males (left) and females from the second growth stanza.

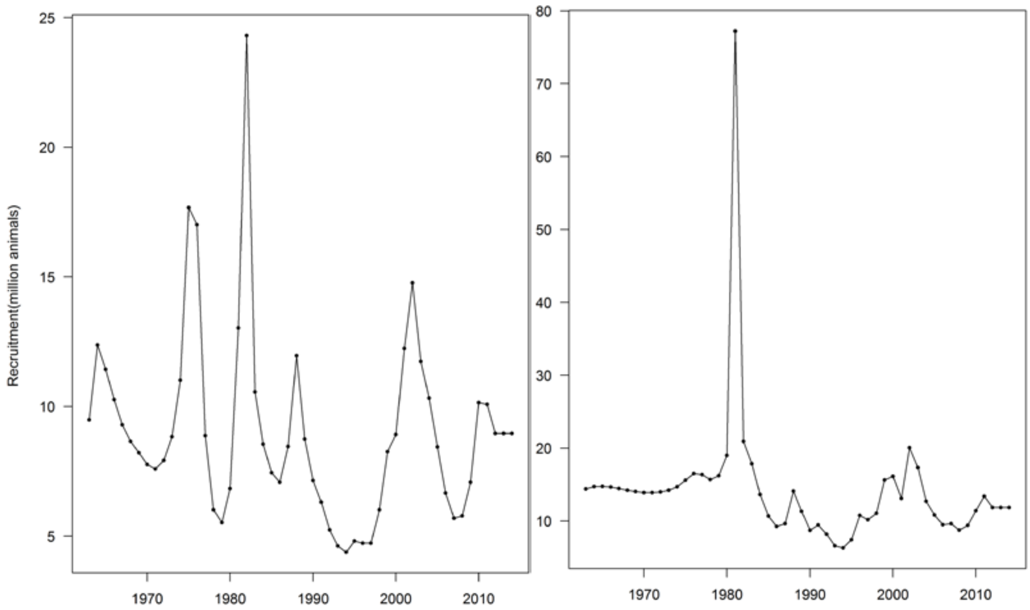


Figure 40: Base case MPD recruitment for CRA 7 (left) and CRA 8.

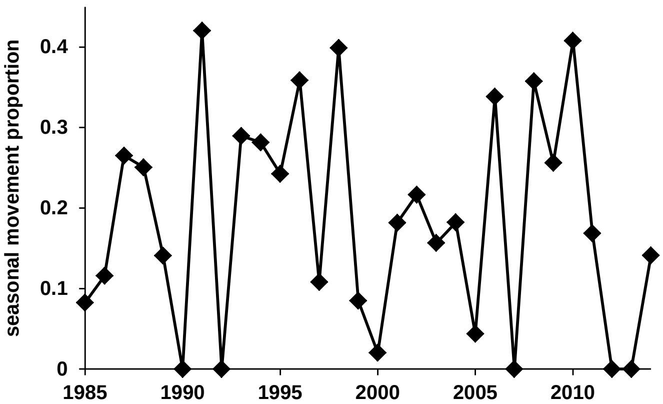


Figure 41: CRA 7: base case MPD estimated movements to CRA 8 as proportion moving in each season of the year indicated.

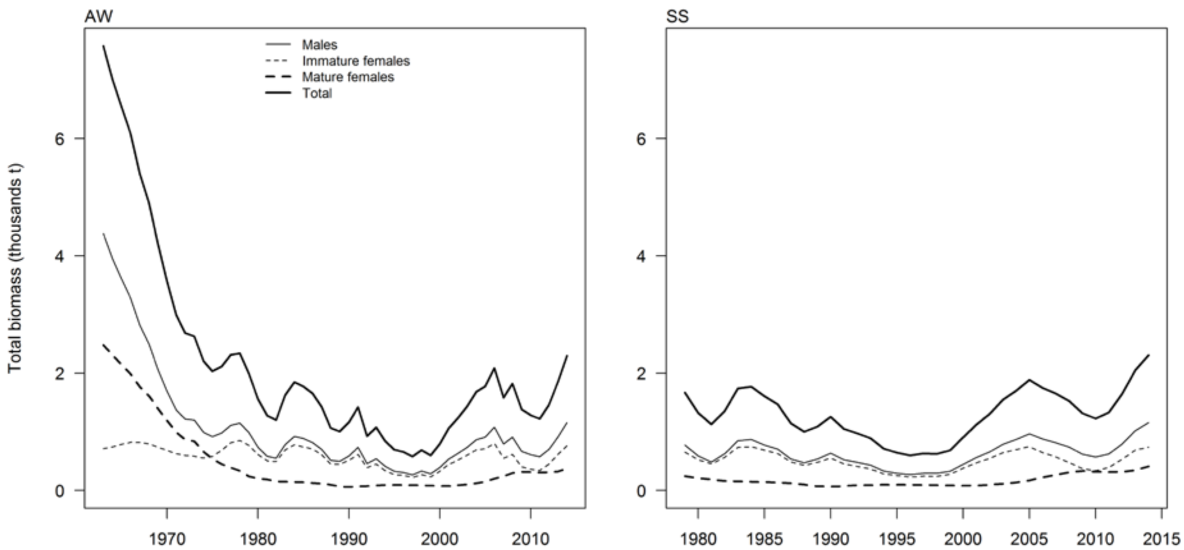


Figure 42: CRA 7: total biomass trajectories and sex-specific biomass from the base case MPD.

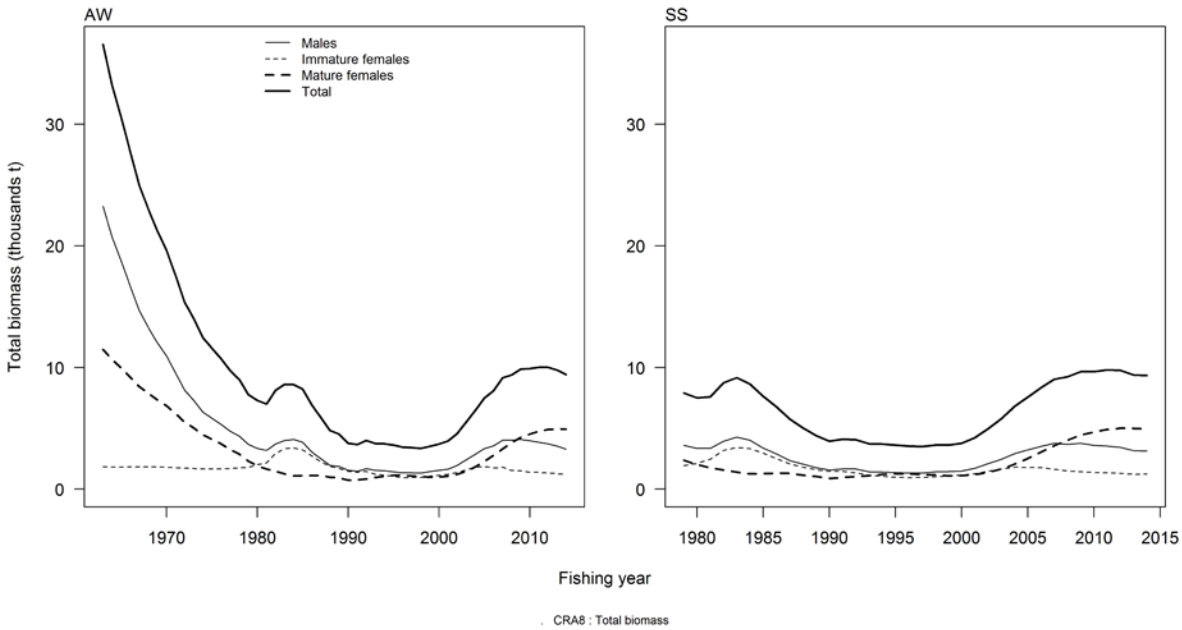


Figure 43: CRA 8: total biomass trajectories and sex-specific biomass from the base case MPD.

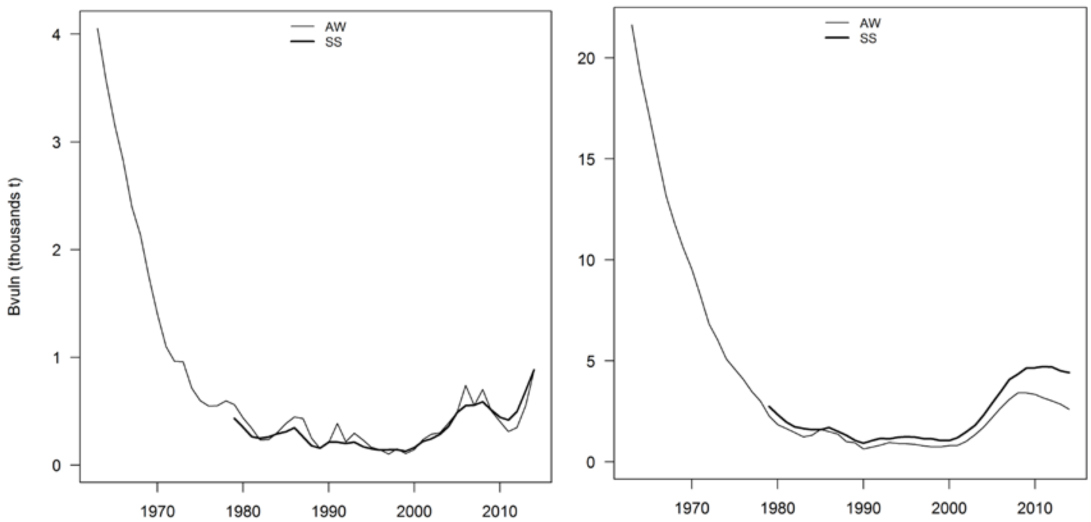


Figure 44: Base case MPD trajectories of *Bvulref* for CRA 7 (left) and CRA 8.

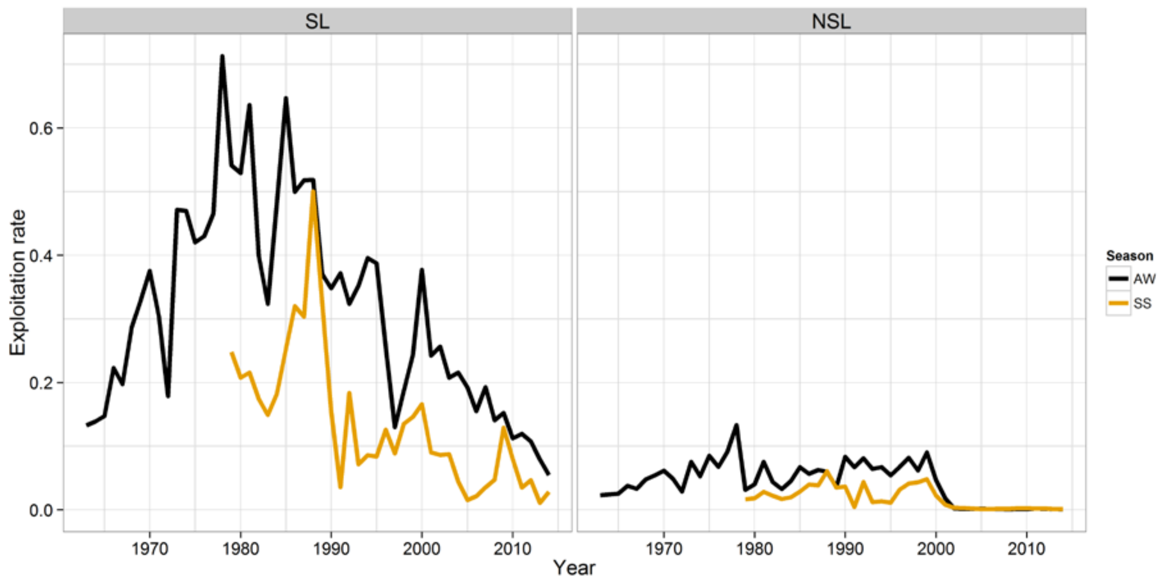


Figure 45: CRA 7: exploitation rate trajectories in the base case MPD.

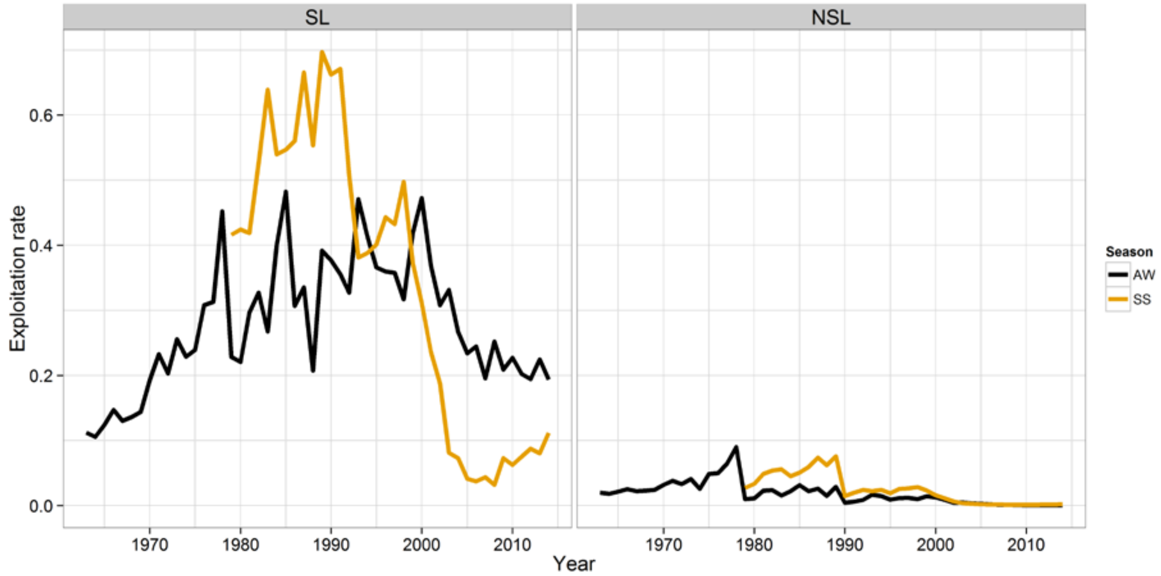


Figure 46: CRA 8: exploitation rate trajectories in the base case MPD.

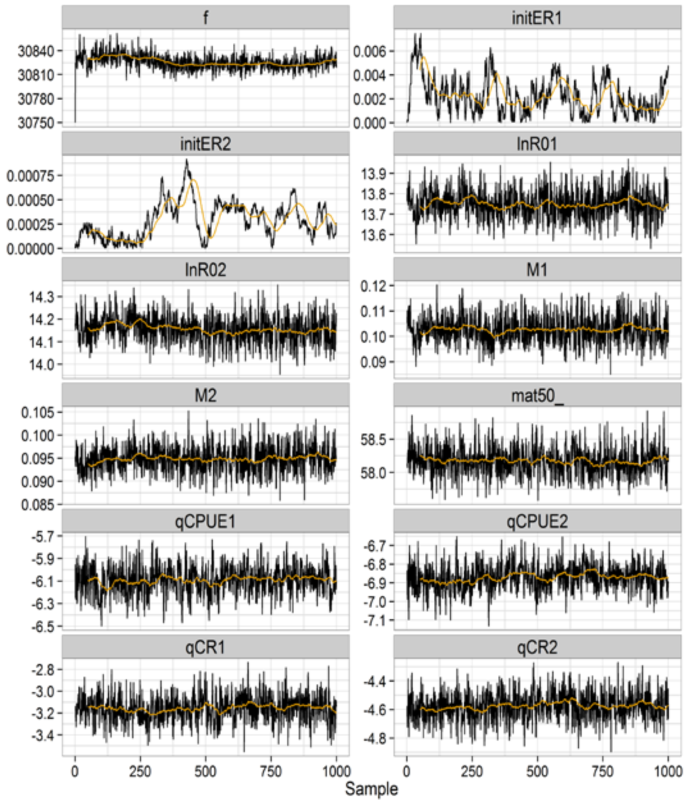


Figure 47: Traces for estimated parameters from the CRA 7/8 base case McMC. In all trace plots, the moving average shown in orange is calculated over 50 samples.

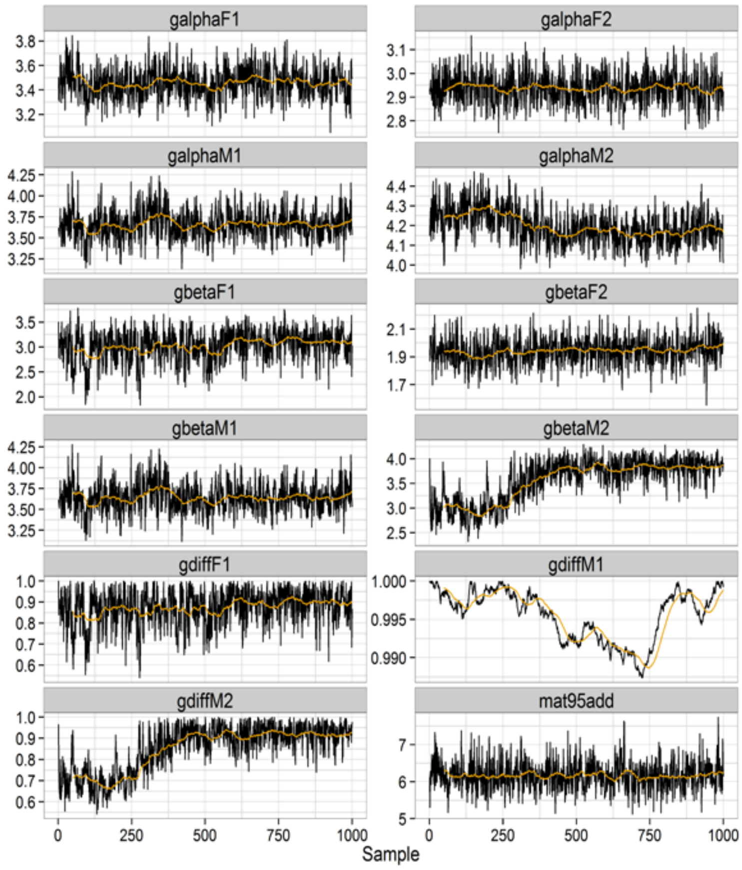


Figure 47 continued.

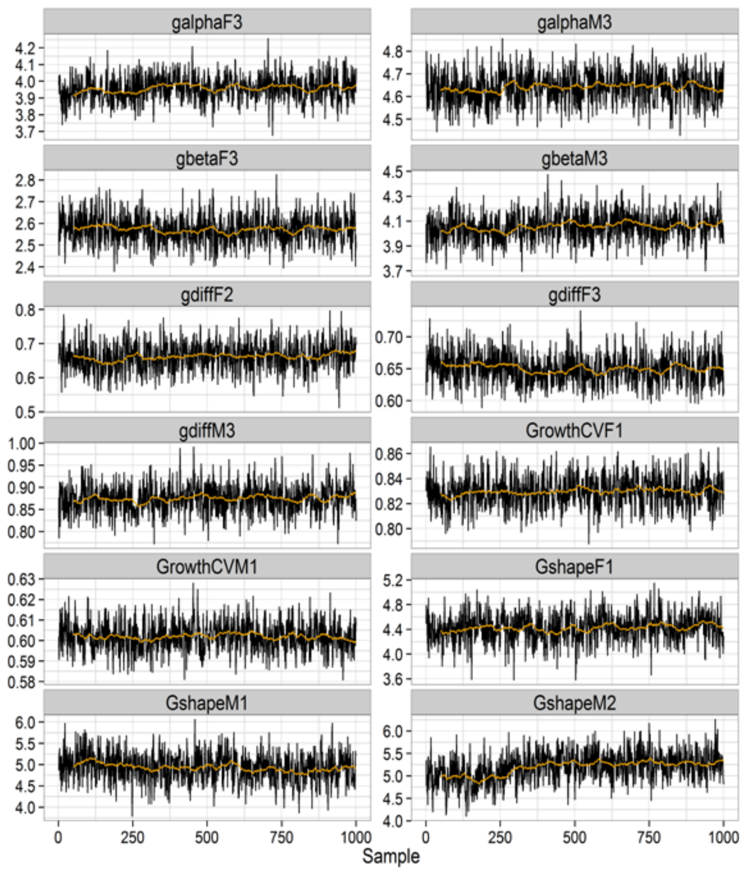


Figure 47 continued.

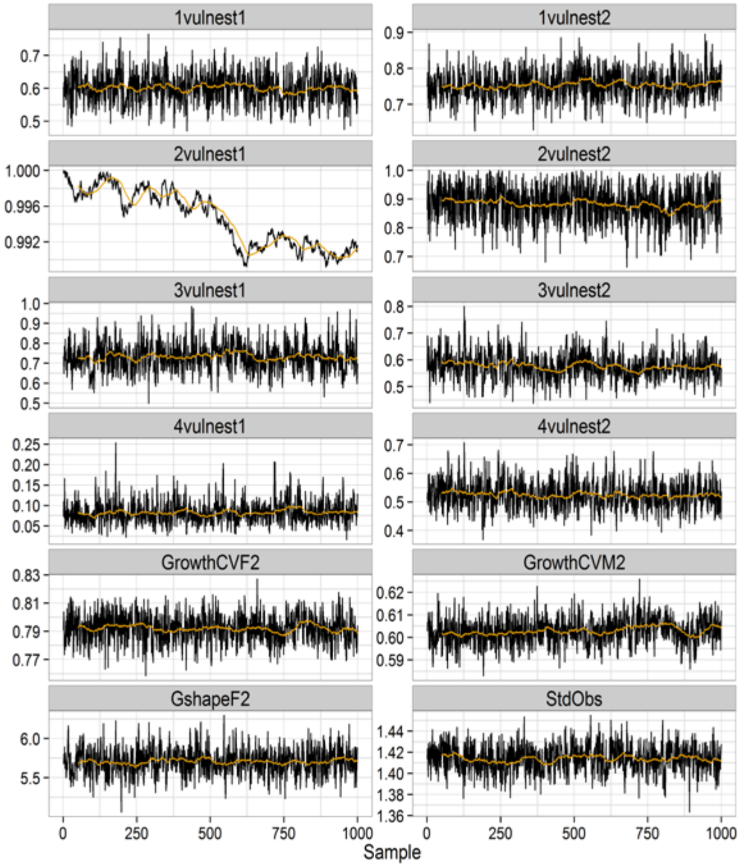


Figure 47 continued.

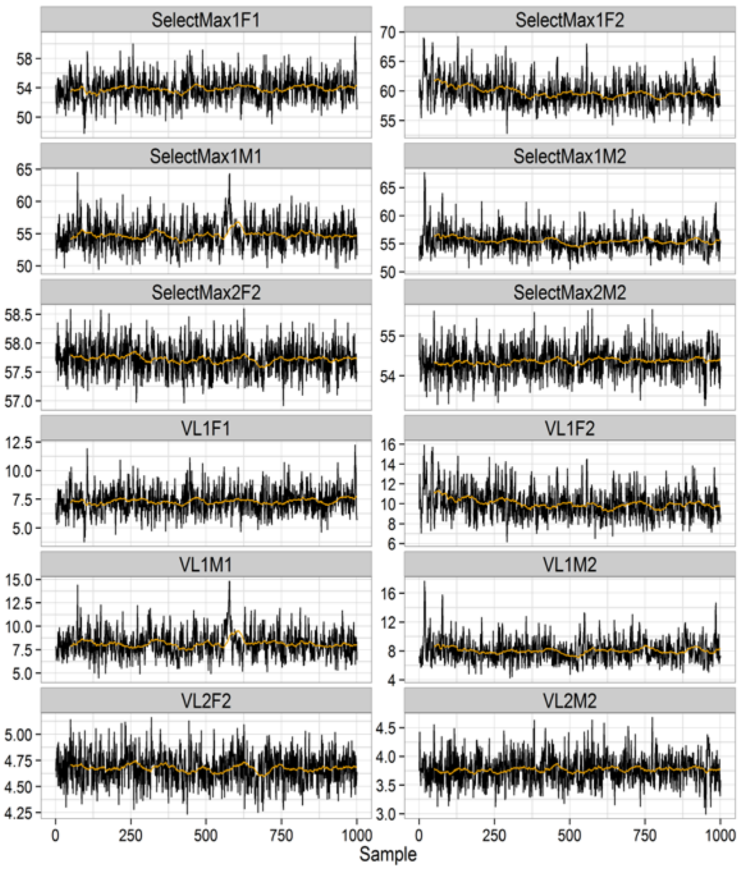


Figure 47 continued.

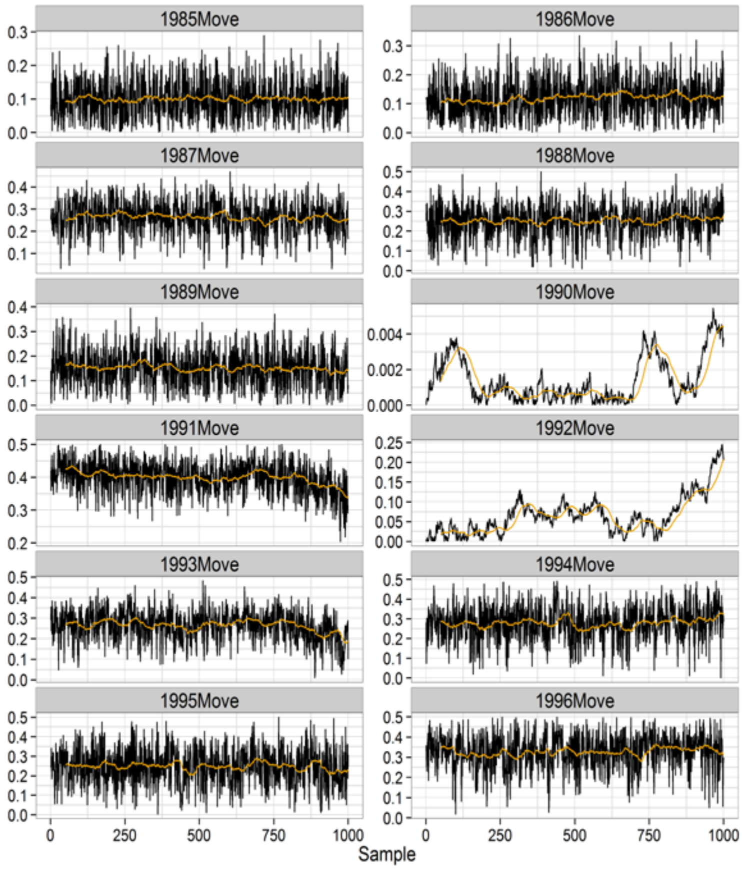


Figure 47 continued.

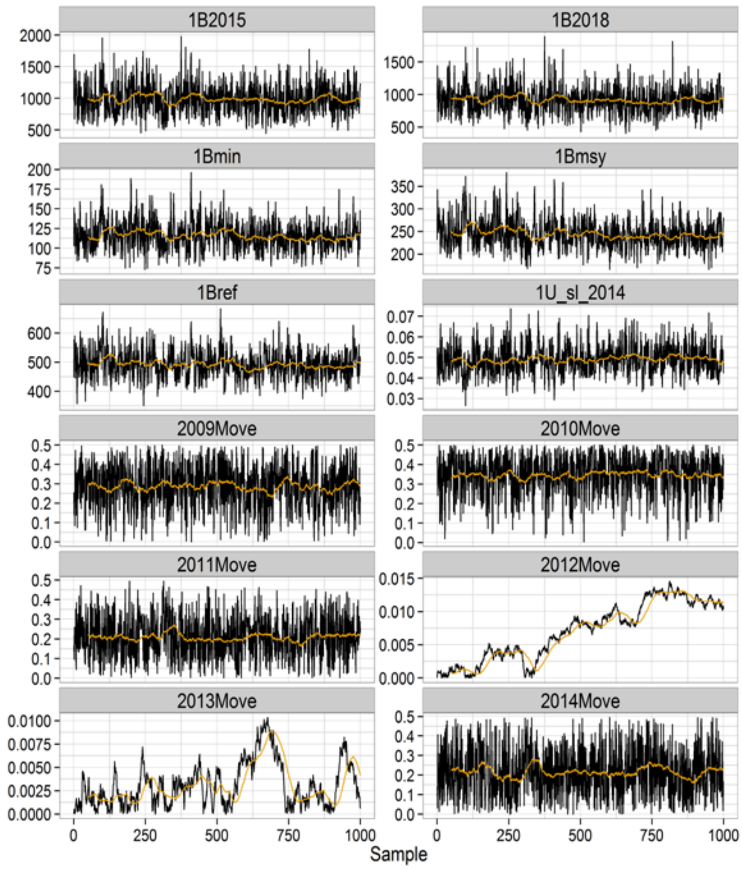


Figure 47 continued.

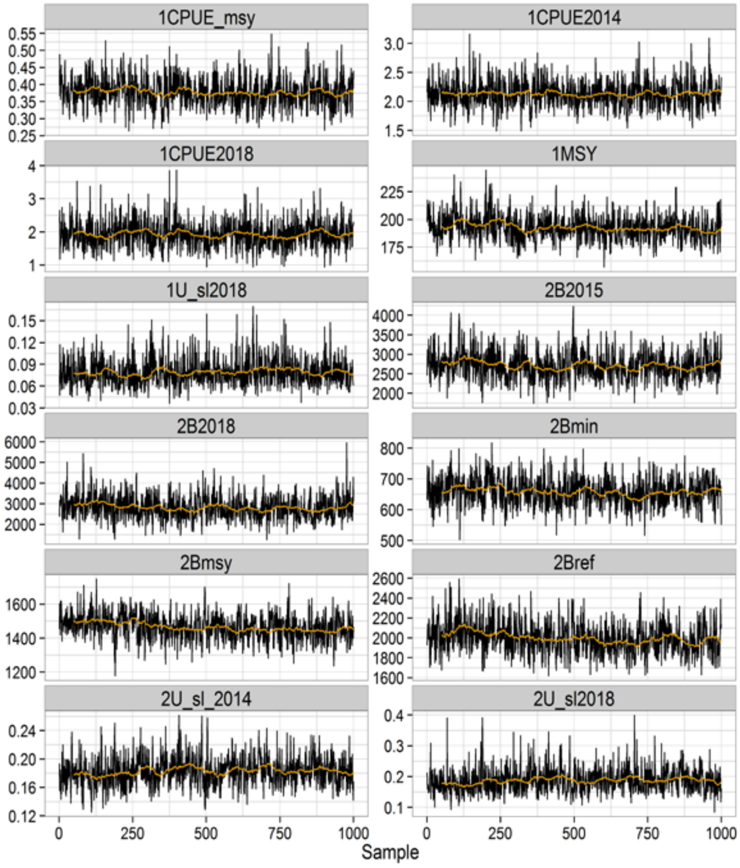


Figure 47 continued.

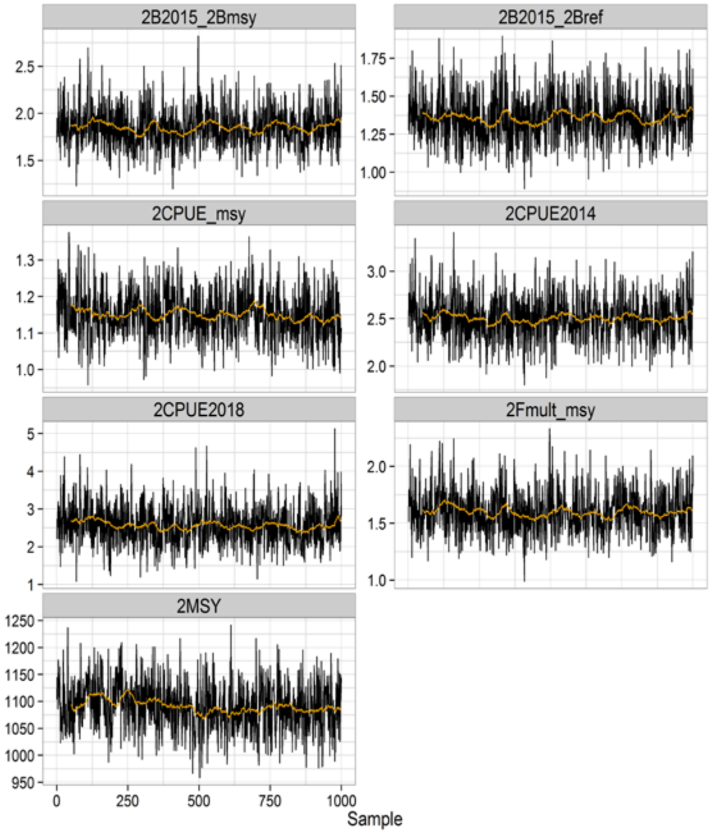


Figure 47 continued.

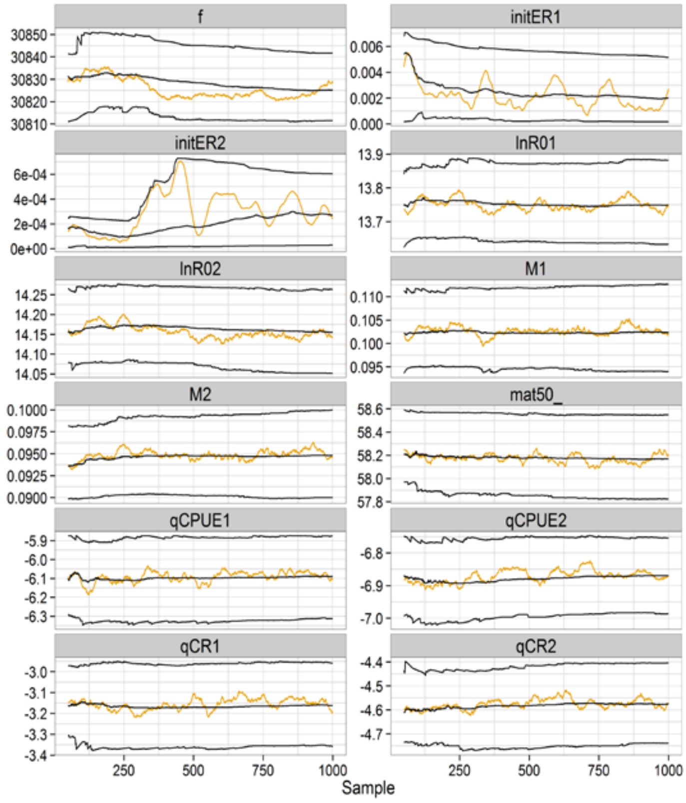


Figure 48: Diagnostic plots (running medians and 5th and 95th quantiles; moving mean over 50 samples)) from the traces shown in ; suffixes refer to stocks: 1 for CRA 7, 2 for CRA 8 from the first tag data file and 3 for CRA 8 from the second tag data file.

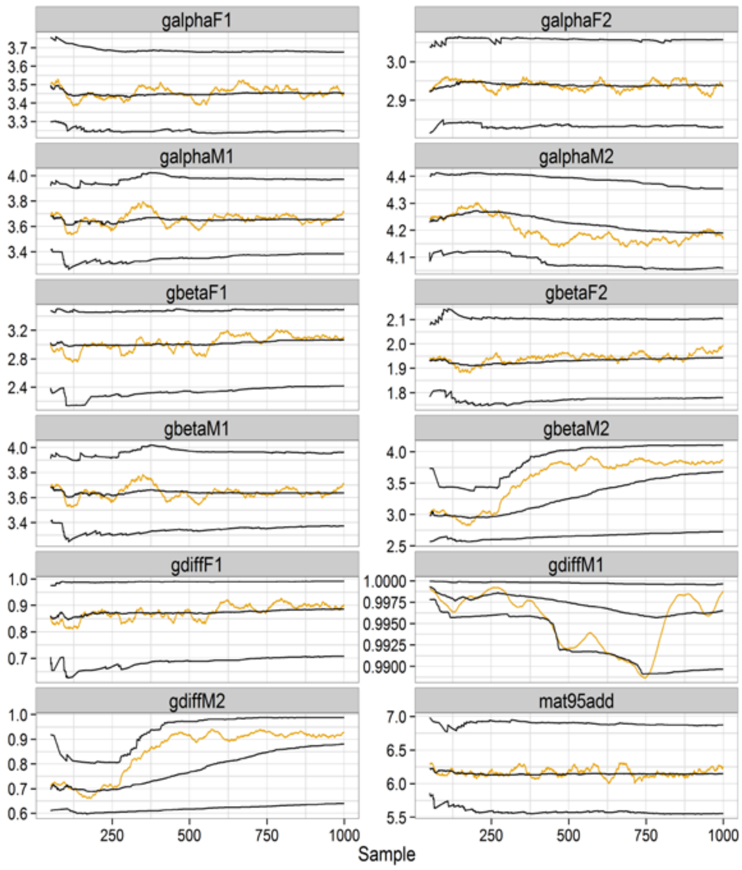


Figure 48 continued.

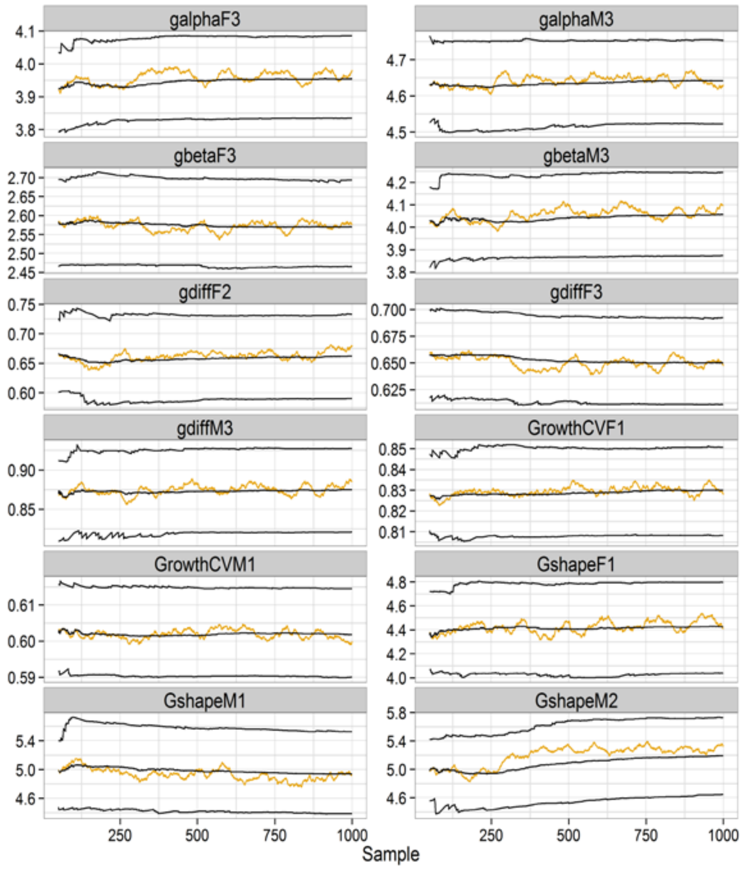


Figure 48 continued.

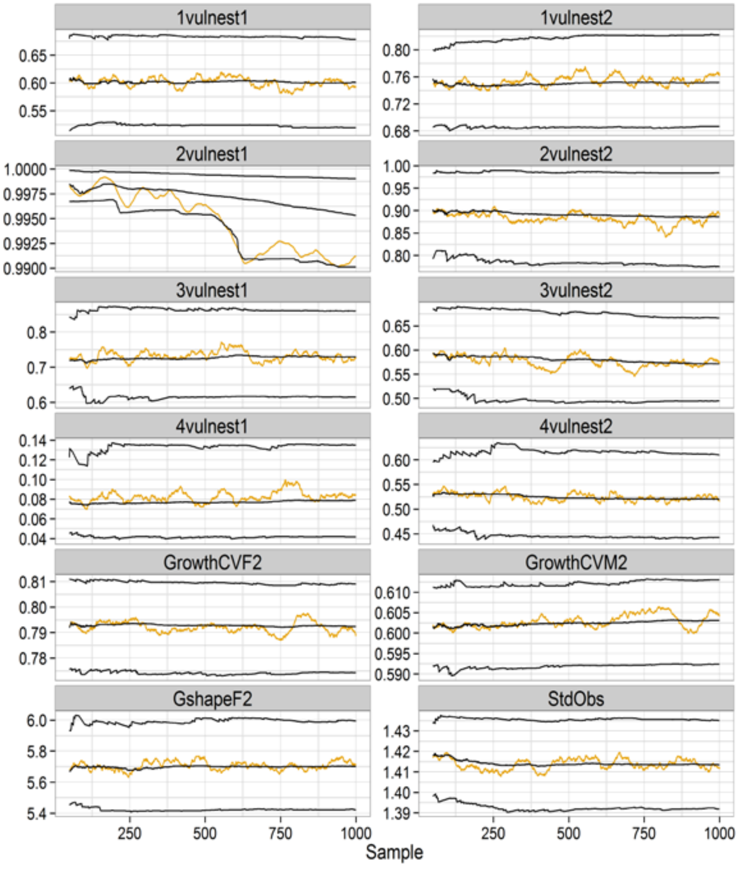


Figure 48 continued.

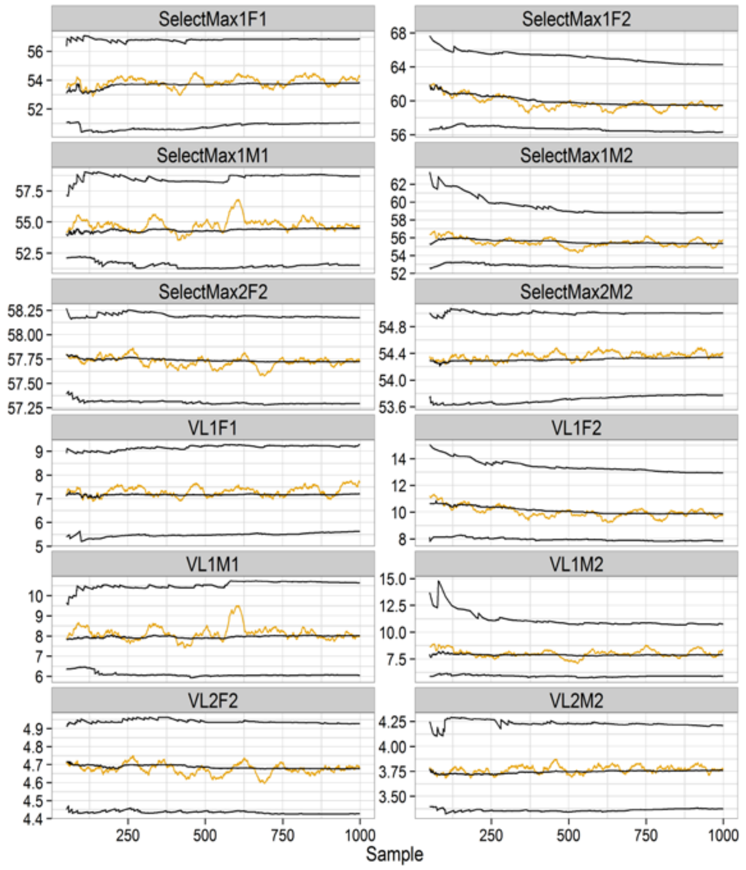


Figure 48 continued.

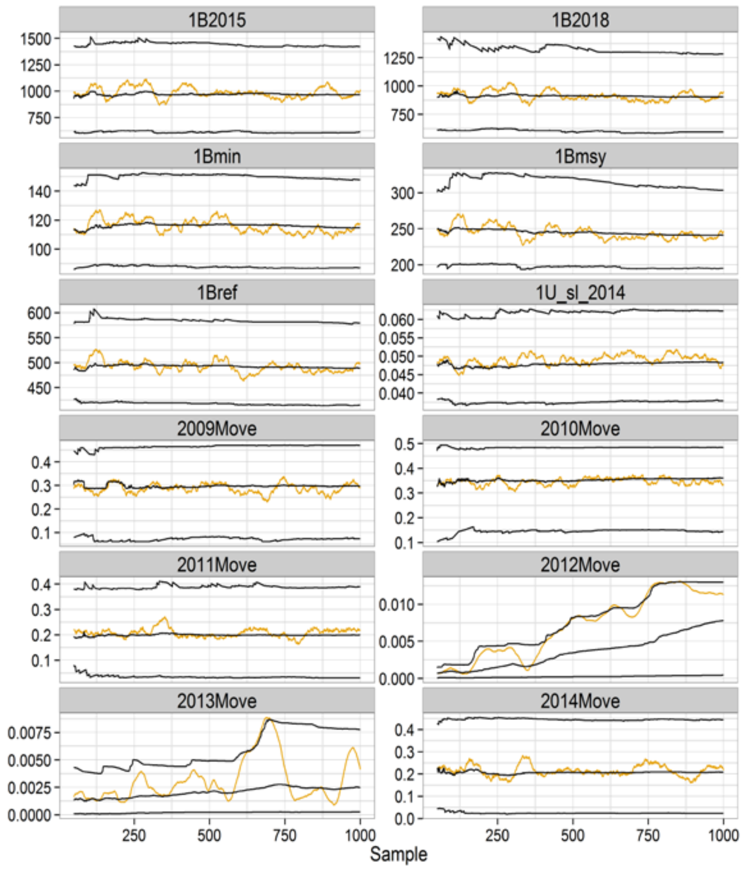


Figure 48 continued.

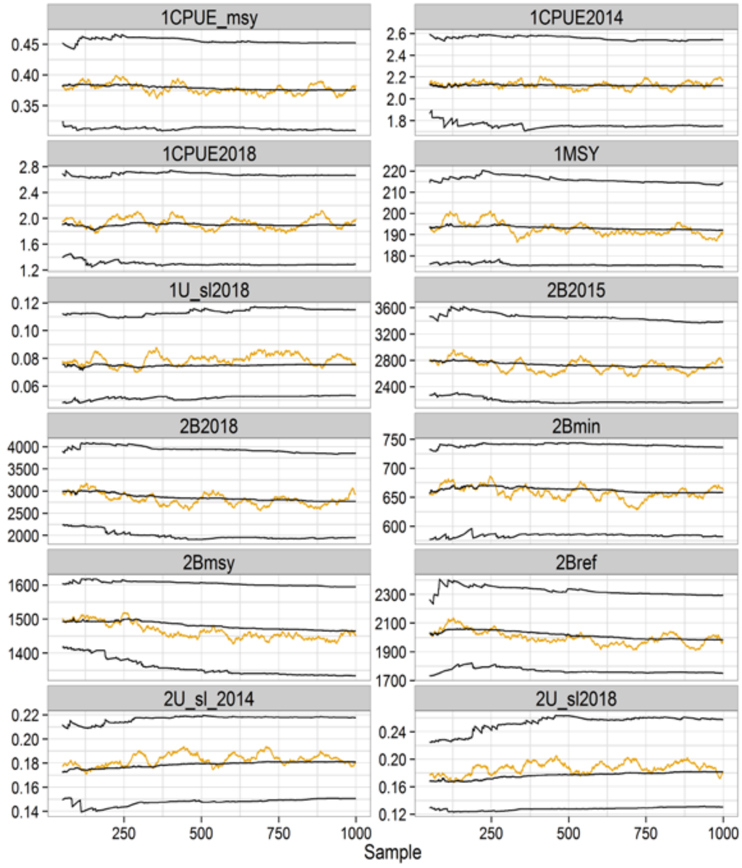


Figure 48 continued.

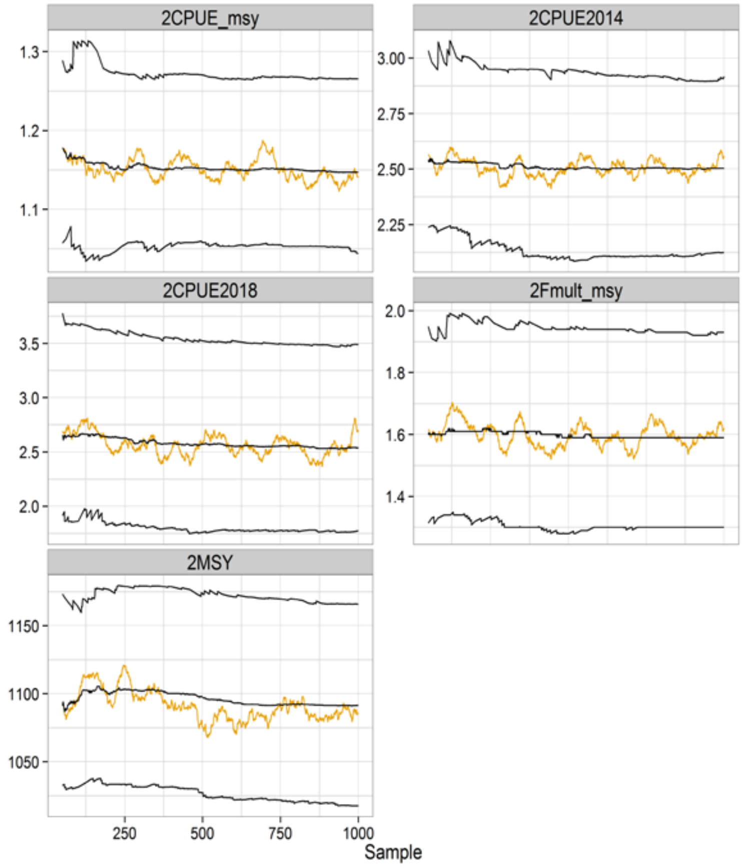


Figure 48 concluded.

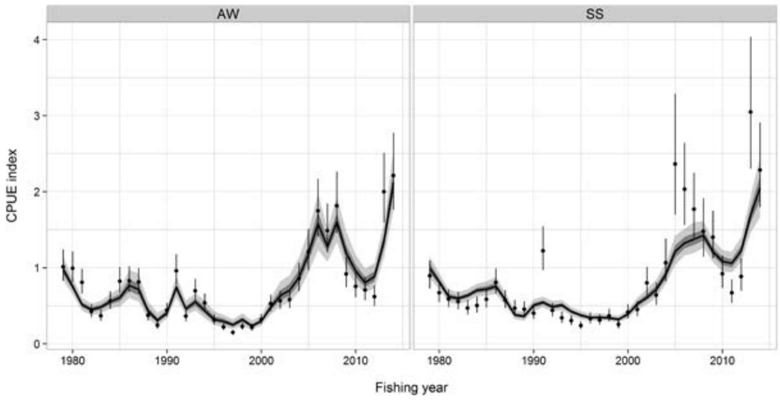


Figure 49: CRA 7 base case McMC: posterior of the fits to CPUE.

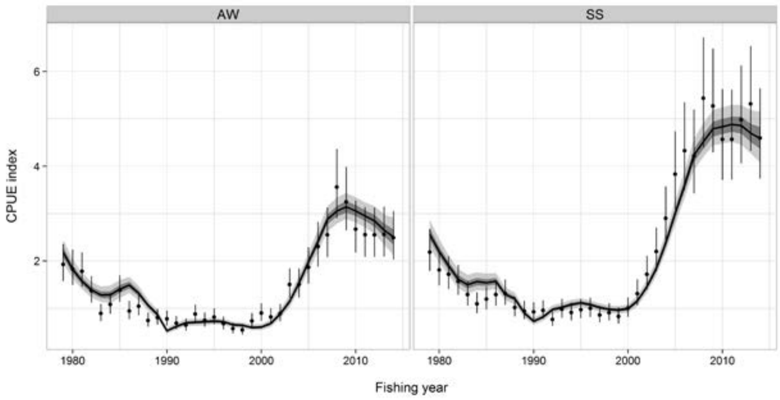


Figure 50: CRA 8 base case McMC: posterior of the fits to CPUE.

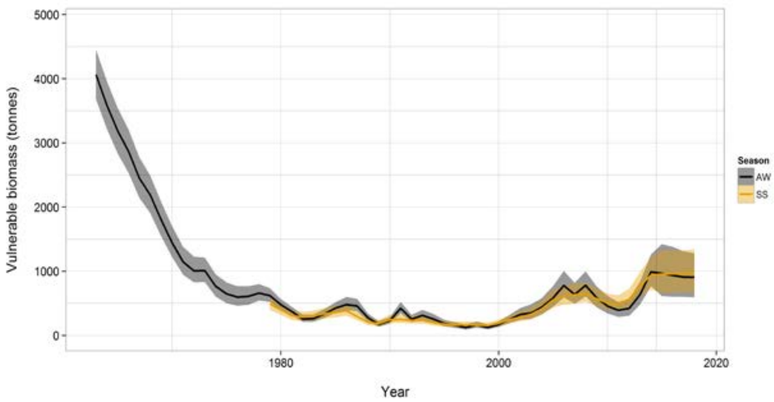


Figure 51: CRA 7 base case McMC: posterior of the vulnerable biomass trajectory.

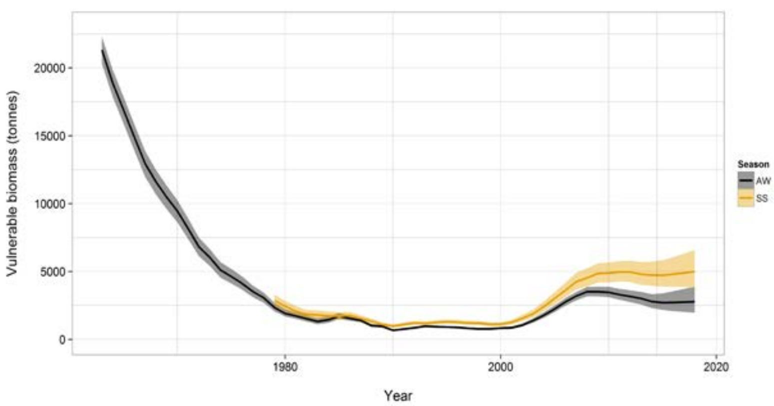


Figure 52: CRA 8 base case McMC: posterior of the vulnerable biomass trajectory.

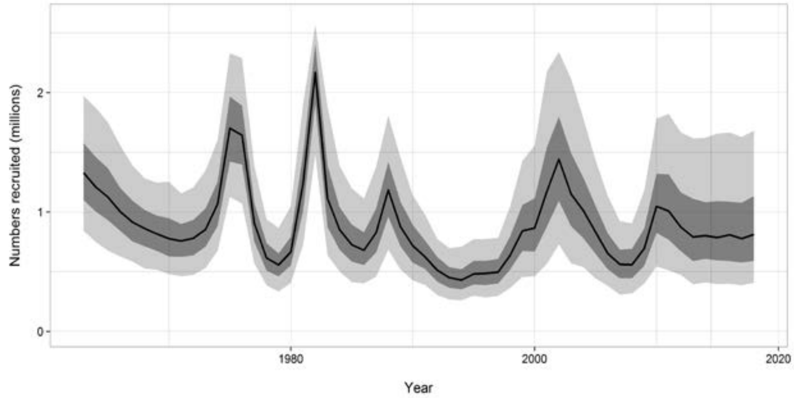


Figure 53: CRA 7 base case McMC: posterior of the recruitment deviations trajectory.

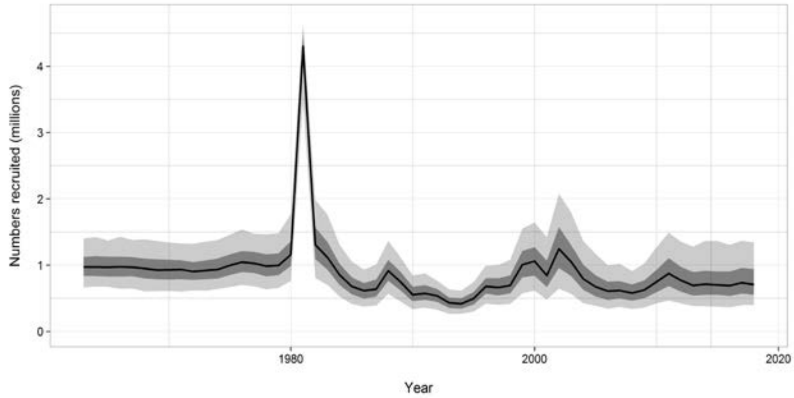


Figure 54: CRA 8 base case McMC: posterior of the recruitment deviations trajectory.

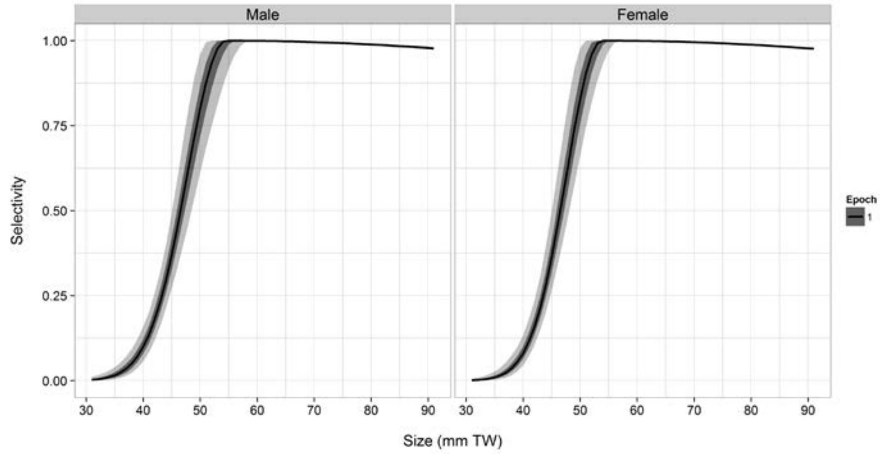


Figure 55: CRA 7 base case McMC: posterior of the selectivity curves; males on left.

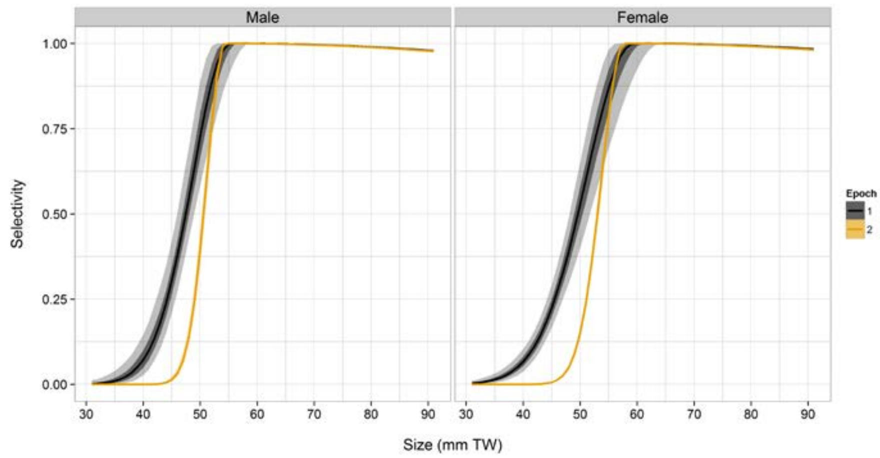


Figure 56: CRA 8 base case McMC: posterior of the selectivity curves; males on left.

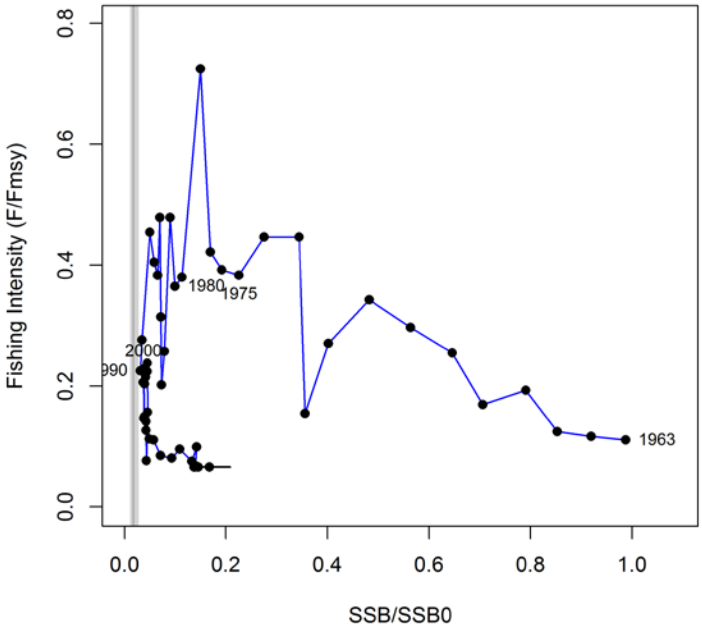


Figure 57: CRA 7 base case McMC snail trail: showing the median spawning biomass on the x-axis and median fishing intensity on the y-axis. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock *SSB0*. Estimated *SSB* changes every year*;* *SSB0* is constant for all years of a simulation, but varies among the 1000 samples from the posterior distribution. The y-axis is fishing intensity as a proportion of the fishing intensity that would have given *MSY* (*Fmsy*) under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. *Fmsy* varies among years because the fishing patterns change. It was calculated with a 50-year projection for each year in each simulation, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually *F*s for two seasons) that gave *MSY* was *Fmsy*, and the multiplier was *Fmult*. Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

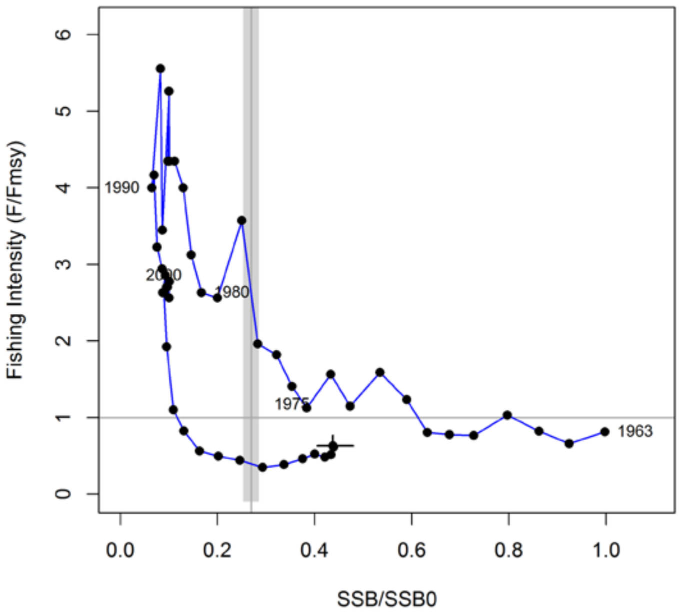


Figure 58: CRA 8 base case McMC snail trail: see the caption for Figure 57 and add "retention" to fishing pattern list.

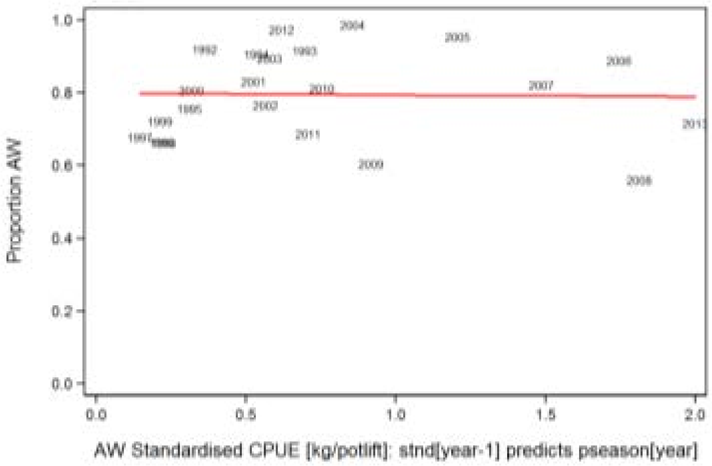


Figure 59: CRA 7: proportion of AW commercial catch as a function of AW CPUE; the fitted regression has intercept 0.800 and slope of -0.0051.

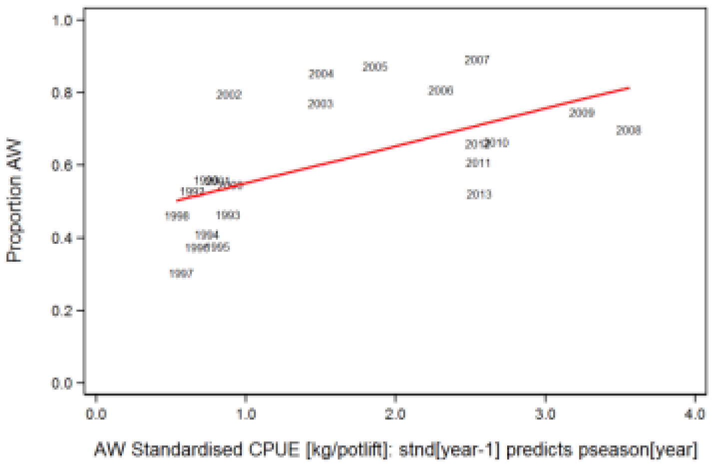


Figure 60: CRA 8: proportion of AW commercial catch as a function of AW CPUE (F2-LFX); the fitted regression has intercept 0.446 and slope of 0.1034.

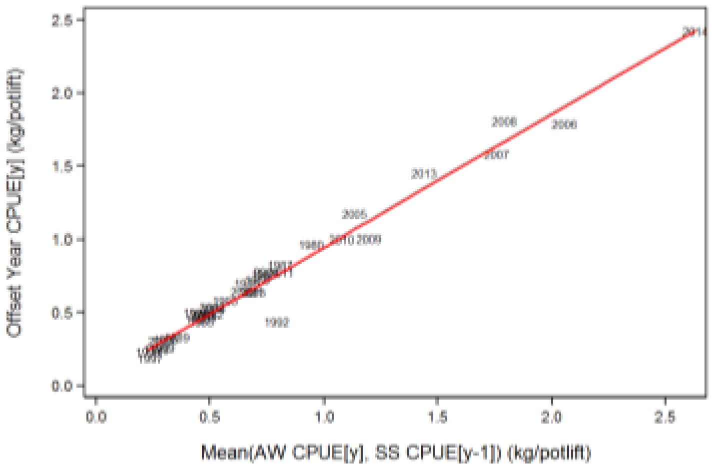


Figure 61: CRA 7: relation between offset-year CPUE and the mean of the component AW and SS CPUE values. The regression has intercept 0.0341 and slope of 0.9108.

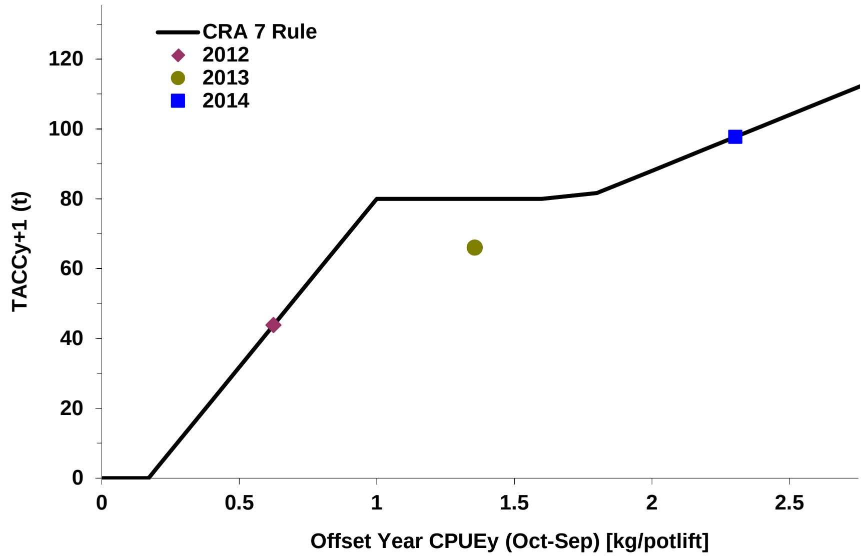


Figure 62: The current CRA 7 management procedure: coloured symbols show the offset-year CPUE and resultant TACC in the year they were calculated.

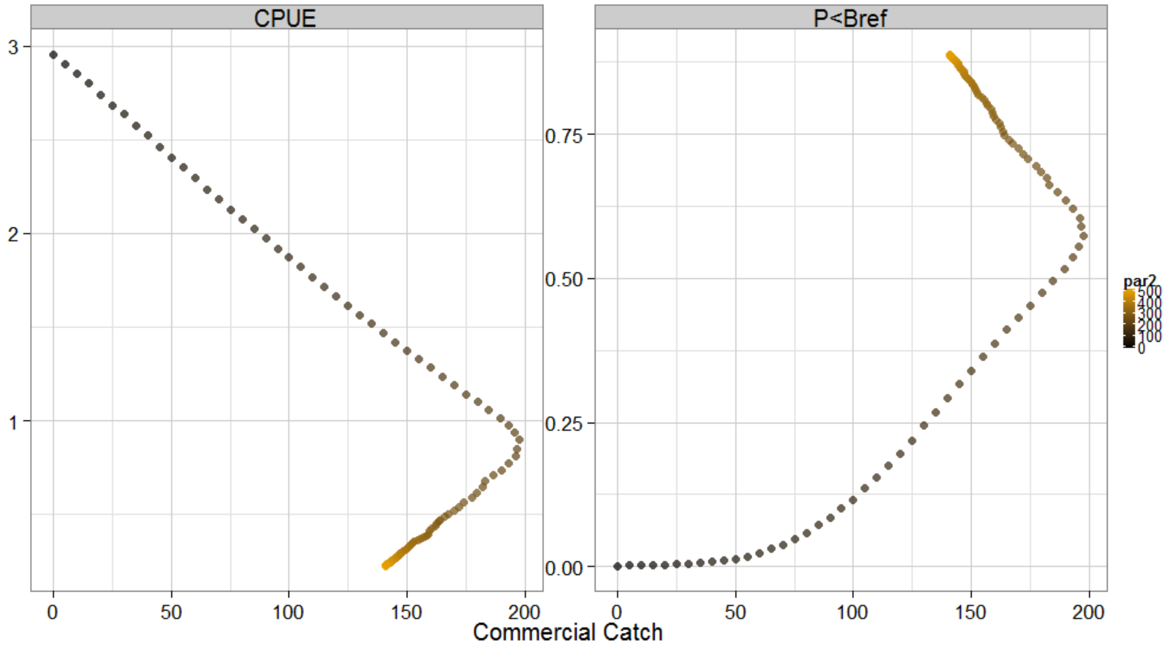


Figure 63: CRA 7: productivity of the operating model under a variety of constant TACCs: left shows average CPUE vs. average commercial catch; right shows the probability that biomass will fall below *Bref* vs. average commercial catch.

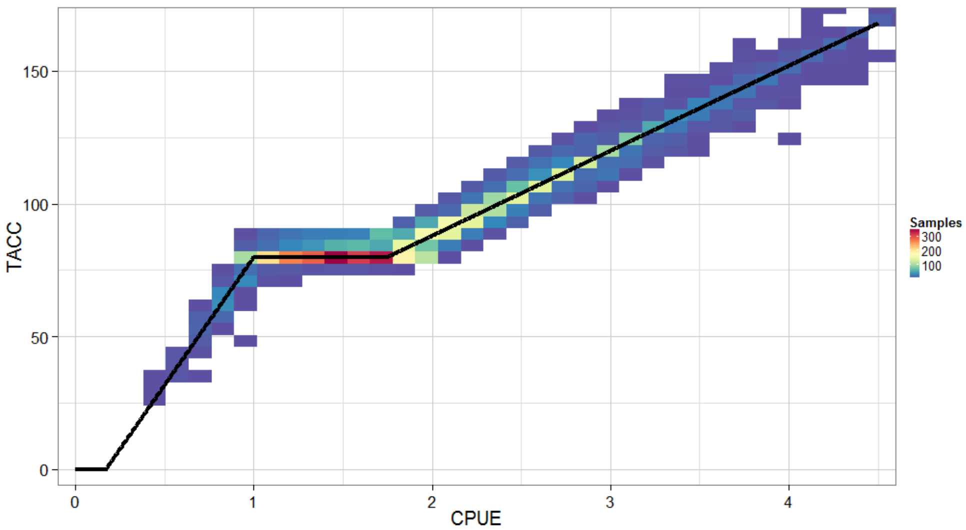


Figure 64: CRA 7: distribution of projected offset-year CPUE and TACC values in 1000 20-year runs of the operating model using the current MP.

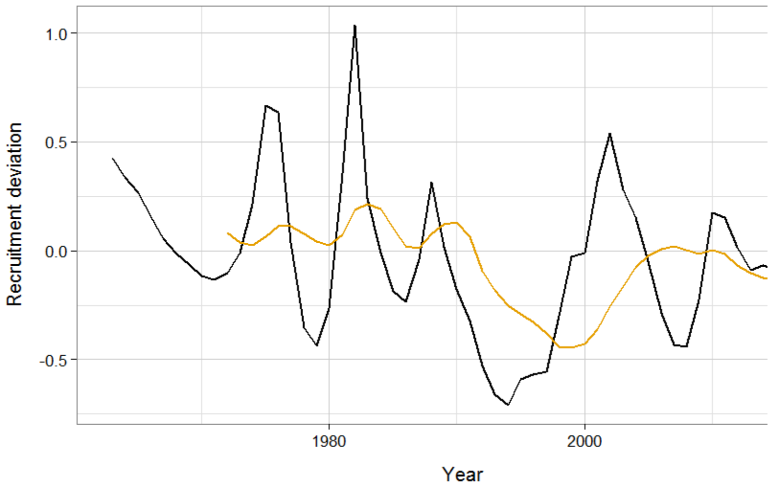


Figure 65: CRA 7: median *Rdevs* (black line) and 10-year moving mean (red line) plotted against the last year of the 10-year period.

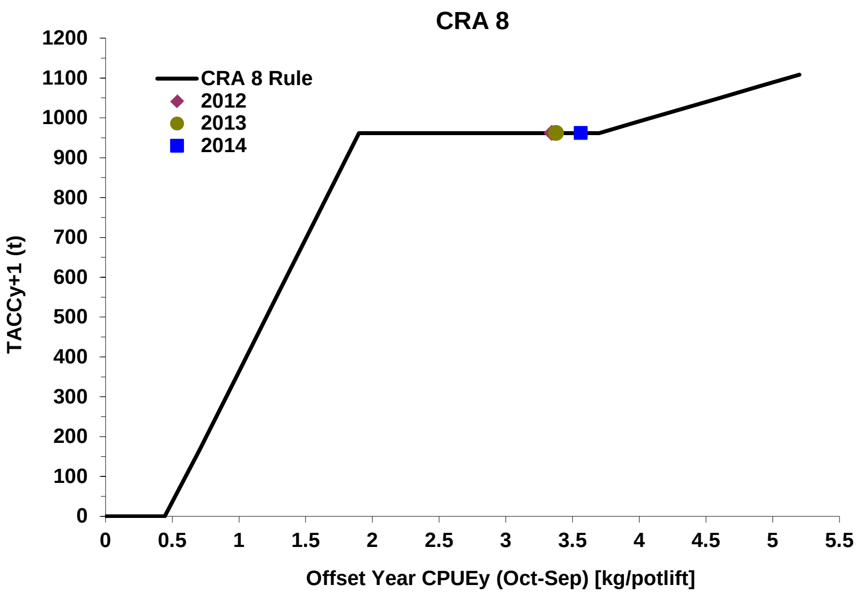


Figure 66: The current CRA 8 management procedure and its recent history; the 2012 point lies under the 2013 point.

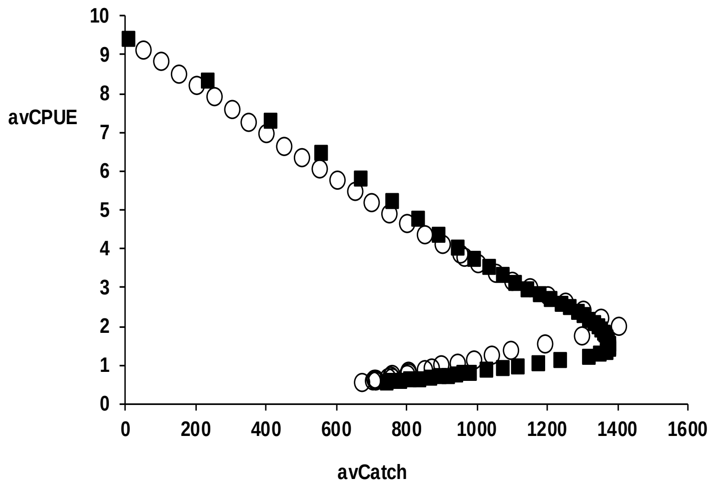


Figure 67: CRA 8 operating model: average CPUE as a function of average catch from a range of rules with constant TACCs (open circles) and constant CPUE multipliers (filled squares).

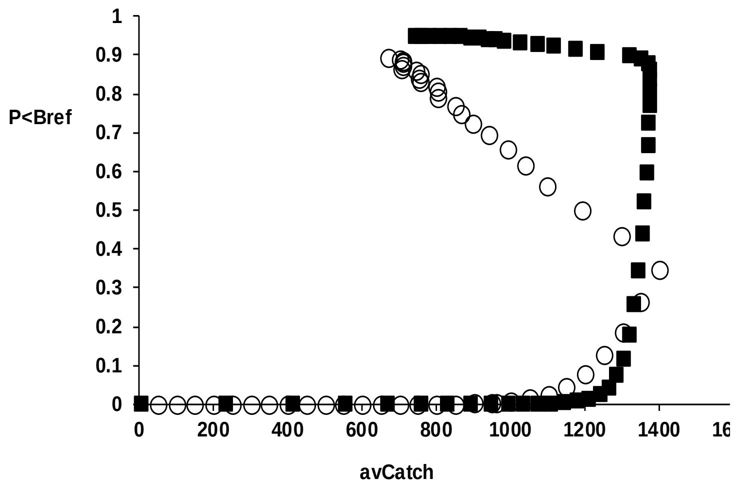


Figure 68: CRA 8 operating model: probability that biomass would be less than *Bref* in a year as a function of average catch from a range of rules with constant TACCs (open circles) and constant CPUE multipliers (filled squares).

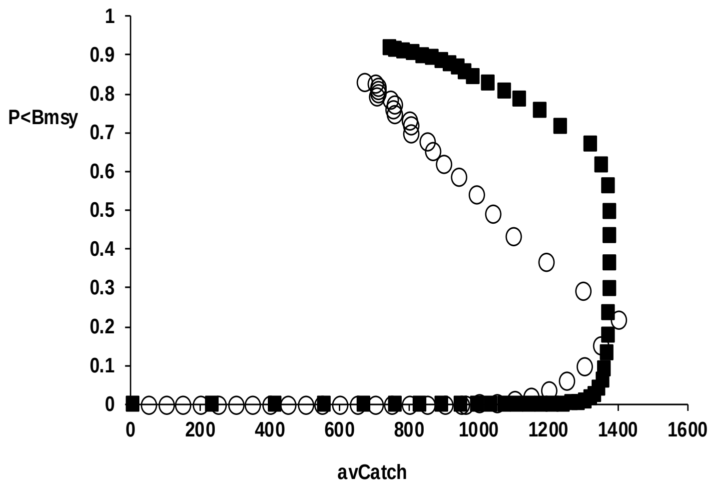


Figure 69: CRA 8 operating model: probability that biomass would be less than *Bmsy* in a year as a function of average catch from a range of rules with constant TACCs (open circles) and constant CPUE multipliers (filled squares).

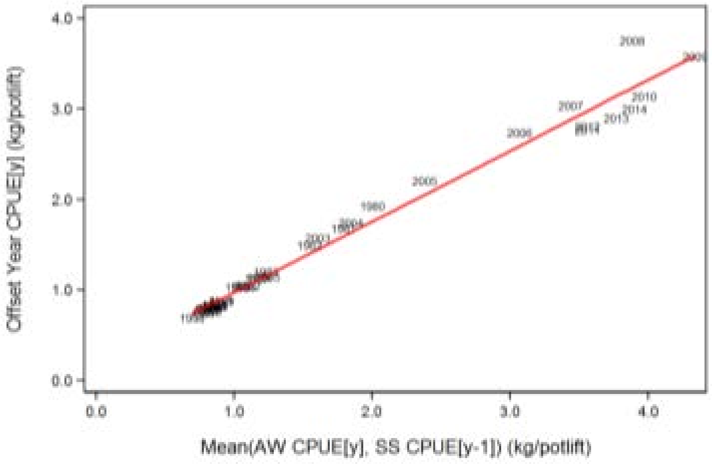


Figure 70: CRA 8: the relation between offset-year $CPUE and the mean of the component AW and SS CPUE values for CRA 7. The regression has intercept 0.1897 and slope of 0.7828.

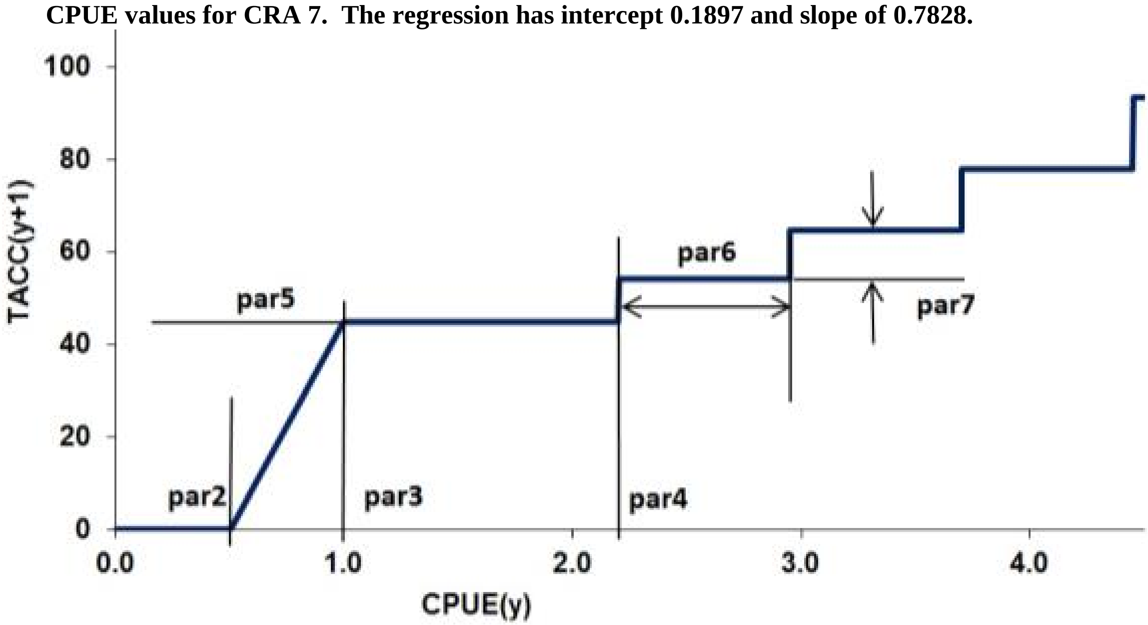


Figure 71: A generalised step rule; see Table 19 for parameter definitions.

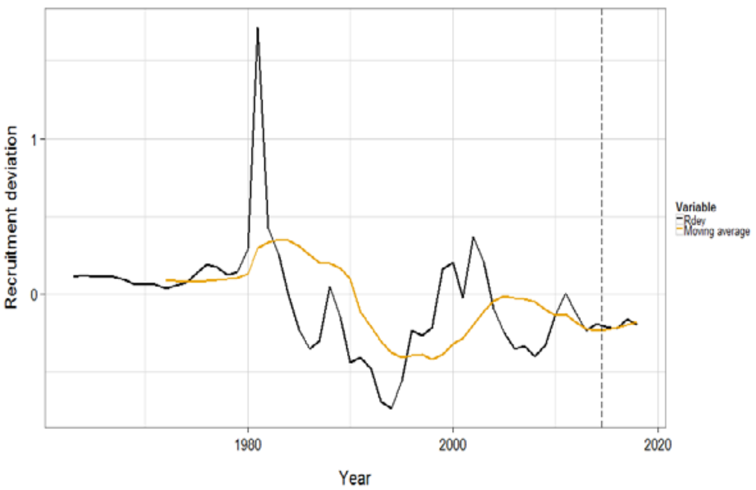


Figure 72: CRA 8: median *Rdevs* (black line) and 10-year moving mean (red line) plotted against the last year of 10-year period.

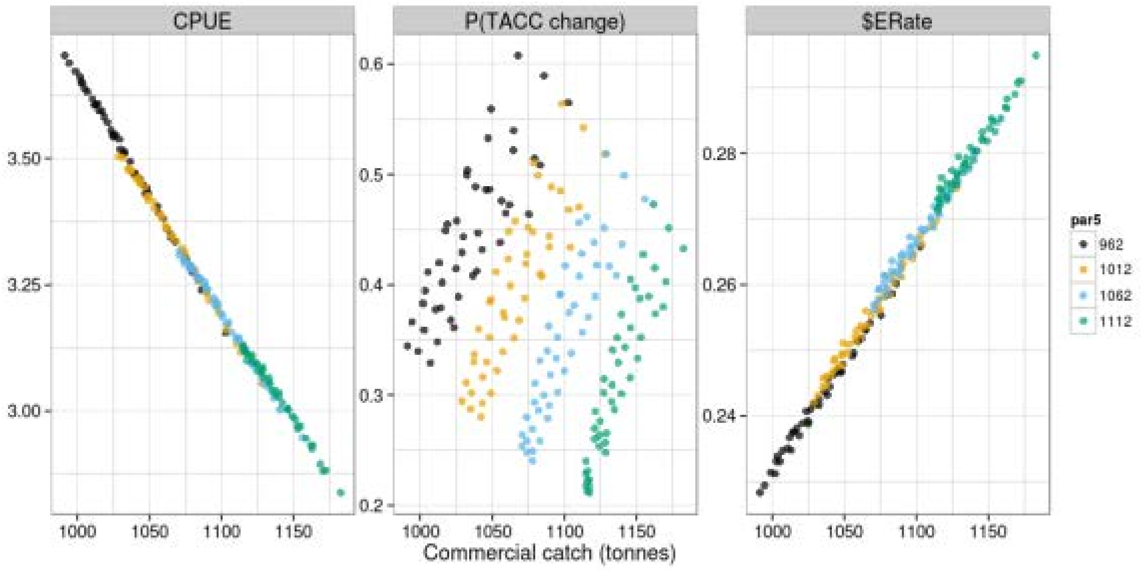


Figure 73: CRA 8: three indicators from the set of 180 rules tested with the base case operating model, all plotted vs. average commercial catch. Plateau heights are coded by colour.

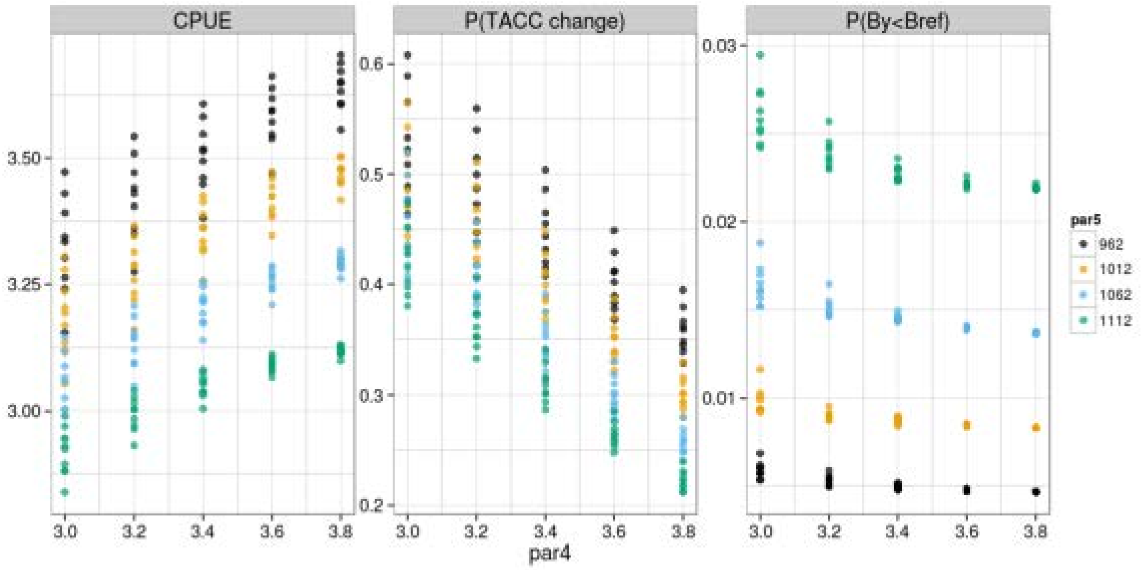
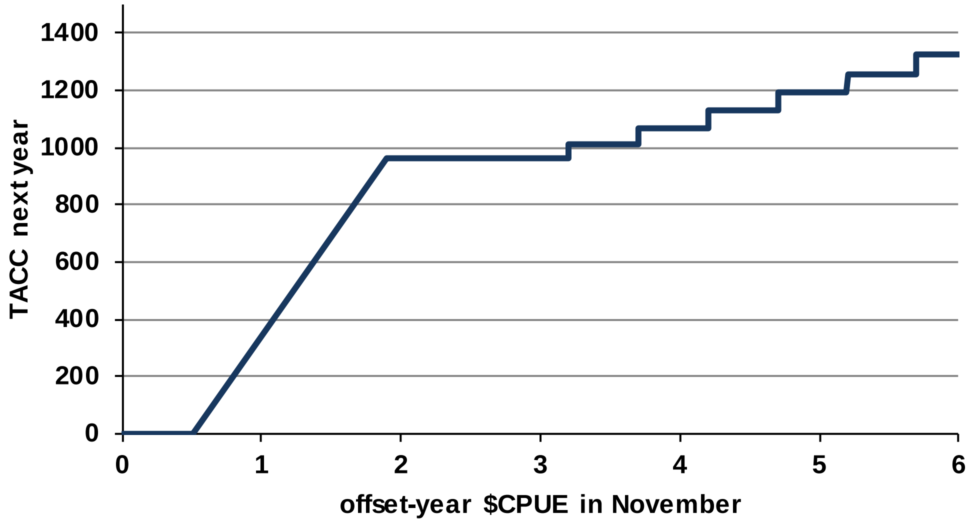


Figure 74: CRA 8: three indicators from the set of 180 rules tested with the base case operating model, all plotted vs. the parameter for plateau right. Plateau heights are coded by colour.

43

rule	par2	par3	par4	par5	par6	par7	par8
43	0.5	1.9	3.2	962	0.5	0.055	0.05



indicator	current	base	hiObs	loRect	rawLFs	wideG
average B/*Bref*	1.917	1.888	1.851	1.367	1.605	2.263
terminal B/*Bref*	2.031	1.986	1.926	1.177	1.690	2.284
min CommCatch	961.9	961.9	961.8	961.7	961.9	962.0
average CommCatch	1013.1	1025.1	1036.4	964.6	991.5	1122.5
average 5-yr Commcatch	972.6	983.1	994.3	972.6	972.5	1048.4
min $CPUE	2.698	2.673	2.227	1.807	2.366	3.080
average $CPUE	3.607	3.542	3.529	2.617	3.131	4.420
%AAV	2.5	2.8	5.1	2.0	2.3	4.2
proportion of changes	42.0%	45.8%	59.5%	32.2%	36.9%	63.1%
P(B<*Bref*)	0.005	0.005	0.006	0.115	0.034	0.003
P(B<*Bmin*)	0.000	0.000	0.000	0.000	0.000	0.000
P(B<*Bmsy*)	0.000	0.000	0.000	99.000	0.003	0.001
P(left of plateau)	0.6%	0.7%	2.9%	15.9%	2.8%	0.3%
P(right of plateau	56.0%	64.5%	58.2%	18.6%	43.2%	87.8%
$B/Blegal SS	66.2%	66.6%	67.0%	67.6%	68.3%	66.9%
$B/Blegal AW	83.4%	83.7%	83.8%	84.5%	85.1%	83.8%
$Exploitation rate	23.5%	23.9%	24.4%	26.7%	26.1%	26.4%

Figure 75: CRA 8: spreadsheet-based viewer, showing harvest control rule parameters for rule 43, comparing results from the base case operating model with those from the current MP and with those from four robustness trial operating models.

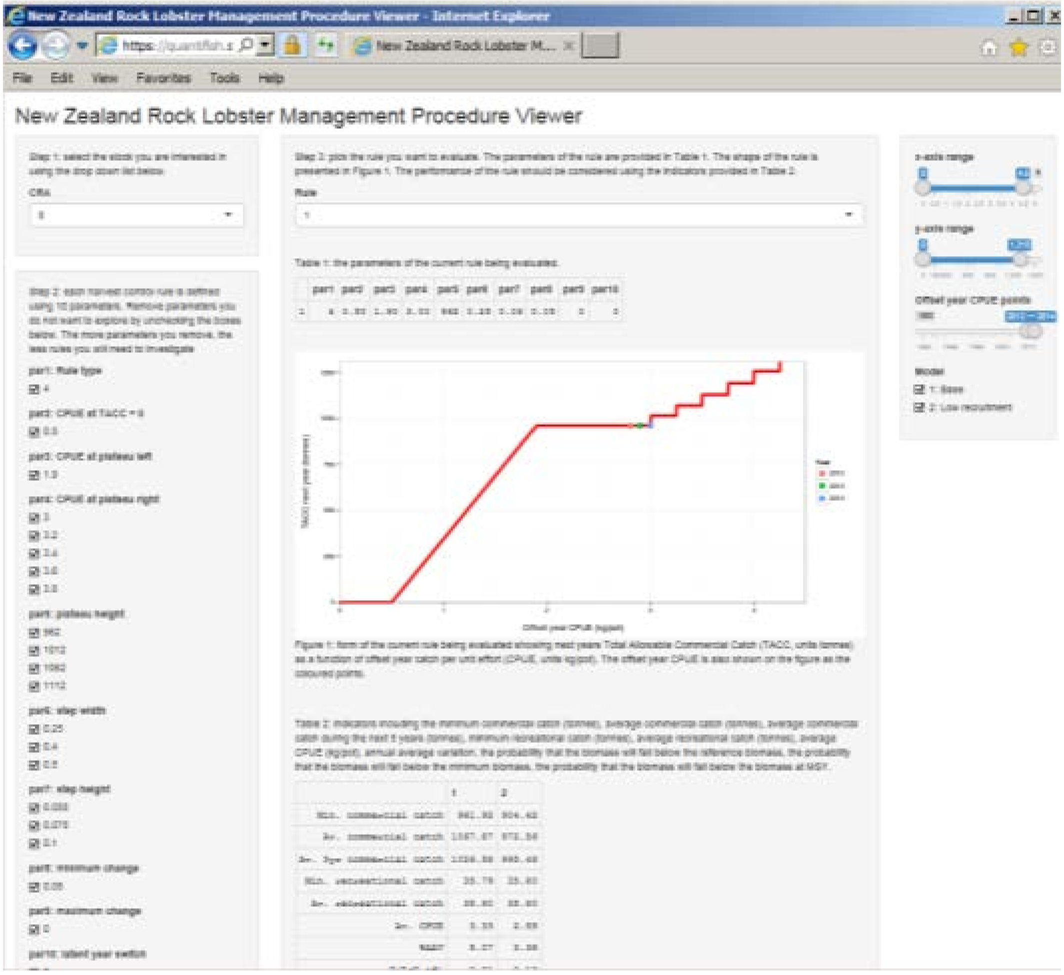


Figure 76: CRA 8: Screenshot of the web-based viewer.

GLOSSARY

This glossary is intended to make the rock lobster stock assessment and MP development processes 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 the multi-stock length-based model (MSLM) and may not be applicable in other contexts.

Underlining indicates a cross-reference to a separate entry.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

catch sampling: see logbooks and observer catch sampling.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

hyperdepletion: see *CPUEpow.*

hyperstability: see *CPUEpow.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

pdH: see Hessian matrix.

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

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

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

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

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

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

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

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

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

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

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

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

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

***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 sdnrs close to 1.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

TW: tail width measured between the second abdominal spines.

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

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

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

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