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The 2017 stock assessment and management procedure evaluation for rock lobsters (*Jasus edwardsii*) in CRA 2

New Zealand Fisheries Assessment Report 2018/17

D.N. Webber
P.J. Starr
V. Haist
M.B. Rudd
C.T.T. Edwards

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This document describes a new stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2 and a review of operational management procedure evaluations.

The stock assessment was done using the lobster stock dynamics (LSD) model. The Rock Lobster Fishery Assessment Working Group oversaw this work: data files and all technical decisions were agreed by that group. The model was fit to standardised catch per unit effort (CPUE) indices, size frequency data, sex ratio data, and tag-recapture data. This document describes the procedures used to find an acceptable base case and shows the model fits.

This stock assessment was fitted to two standardised CPUE series, each characterised by its data source. The second series used a *vessel* explanatory variable in the standardisation procedure. Initial model fits to the CPUE series without a *vessel* variable were improved by estimating an additional parameter which relaxed the assumption that CPUE is strictly proportional to vulnerable biomass. The need for this additional parameter disappeared after adding the *vessel* variable to the standardisation model. The two CPUE series had been combined as a single series and did not use a *vessel* explanatory variable in the 2013 CRA 2 stock assessment.

Model inference for this assessment was based on maximum a posteriori (MAP) fits and Markov chain Monte Carlo (MCMC) simulations. The document describes the diagnostics for each and shows the results of MAP and MCMC sensitivity trials.

The stock assessment showed a stock depleted below B_{REF} (the average vulnerable biomass from 1979–1981) along with low estimates of spawning stock (mature female) biomass (SSB) relative to the unfished stock level (SSB_0) in spite of the small size at maturity. Depletion of the stock was recognised by all stakeholders even before the stock assessment.

The assessment model was used as the basis for an operating model to evaluate the performance of alternative management procedures for CRA 2, which has used management procedures to determine catch levels since 2014. To address parameter uncertainty, each management procedure candidate was tested with 1000 20-year simulations, based on each of the 1000 MCMC posterior samples. To address environmental uncertainty, each of the 1000 simulations included stochastic variation in CPUE observation error and recruitment.

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

1. INTRODUCTION

This work addressed Objectives 4 and 5 of the Ministry for Primary Industries (MPI) contract CRA2015-01A. This three-year contract, which began in April 2016, was awarded to the NZ Rock Lobster Industry Council Ltd. (NZ RLIC), 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 MPI and the National Rock Lobster Management Group (NRLMG) determined that the CRA 2 stock (Figure 1) should be assessed a year ahead of schedule in 2017. Data used in this model are documented in Starr & Webber (2018). CRA 2 was assessed assuming a single homogeneous stock across the four statistical areas (i.e. 905, 905, 907, and 908), using the lobster stock dynamics (LSD) model (Webber et al. 2018). This work was done by a team sub-contracted to the NZ RLIC: Vivian Haist (Haist Consultancy), Merrill Rudd (University of Washington), Paul Starr (Starrfish), D'Arcy Webber (Quantifish), and Charles Edwards (NIWA). At the same time, an experimental multi-area assessment of CRA 2 was conducted which was based on data specific to the four CRA 2 statistical areas. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).

The CRA 2 fishery extends from Te Arai Point, south of Whangarei, to East Cape at the easternmost end of the Bay of Plenty (Figure 1). This quota management area (QMA) includes the Hauraki Gulf, both sides of the Coromandel, and all of the Bay of Plenty. Commercial fishing is mainly confined to the Bay of Plenty, extending from the eastern side of the Coromandel Peninsula to East Cape. Lobster potting also occurs around Little Barrier Island and Great Barrier Island. There were 33 vessels operating in CRA 2 in 2015–16, a total that has been relatively constant since the mid-1990s (Starr 2017). This fishery supports processing and export operations primarily in Tauranga, Whitianga, and Auckland.

The current 416.5 tonne total allowable catch (TAC) for the fishery was set in 2014. In addition to the 200 tonne total allowable commercial catch (TACC), the TAC comprises 140 tonnes for recreational catch, 16.5 tonnes for customary harvest, and 60 tonnes for illegal removals. The amount of shelving was increased to 49 tonnes in 2016–17 and this amount of shelving has been carried forward into 2017–18.

Potting and hand gathering are the preferred methods for recreational fishers in this area. As in most QMAs, the majority of the recreational catch is taken during the summer months. The region also sustains a recreational fishing and dive charter industry during summer. Lobsters are very important to Maori in this area, and the customary allowance allows lobsters to be taken under permit for use by the marae.

The CRA 2 commercial fishery is open all year. This is a trap or pot fishery, conducted by small boats on day trips fishing in relatively shallow waters. The stock assessment and data preparation separate the autumn-winter (AW, April through September) and spring-summer (SS, October through March) seasons. The stock is managed with an operational MP that determines the TACC, the primary management tool. Allowances are added by the Minister for the non-commercial fisheries to produce a TAC. Other management measures include protection of ovigerous (berried) females, minimum legal size (MLS) by sex, and escape gaps in pots. The MLS is 54 mm tail width (TW) for males and 60 mm TW for females for both the commercial and recreational fisheries. CRA 2 currently has the lowest catch per unit effort (CPUE) of all nine CRA QMAs. The scaled standardised CRA 2 CPUE was below 0.6 kg/potlift from 2001–02, dropping below 0.4 kg/potlift in 2010–11, and below 0.3 kg/potlift in 2014–15 (Starr 2017).

A previous stock assessment of CRA 2 was conducted in 2013, with Starr et al. (2014a) describing the data and Starr et al. (2014b) describing the stock assessment and management procedure evaluations (MPEs), generated from the multi-stock length-based model (MSLM, Haist et al. 2009). The 2013 stock assessment was informed by tag-recapture data, standardised CPUE from 1979–2010, historical catch rate data from 1963–1973, and length frequency and sex ratio data from voluntary logbooks and observer catch sampling. Changes in MLS and changes in selectivity caused by escape gap regulations were modelled by estimating separate fishing selectivity periods. MPs were evaluated using an operating model based on the 2013 CRA 2 base case stock assessment.

Technical terms used here are defined in the Glossary.

2. CRA 2 STOCK ASSESSMENT

This document describes a new stock assessment and MPE for CRA 2. The data used in this stock assessment are described in Starr & Webber (2018). A major change in this stock assessment compared to the 2013 stock assessment was the inclusion of a *vessel* explanatory variable in the CPUE standardisation procedure (see Starr & Webber, in prep., for documentation of this additional step) and splitting the CPUE series into two series: one associated with the 1979–1988 data stored in the Fisheries Statistics Unit (FSU) database and the other associated with the post-1989 Catch Effort Landing Return (CELR) data stored in the Warehou database. This was done as initial model fits to a CPUE series without a *vessel* variable were improved by estimating an additional parameter which relaxed the assumption that CPUE is strictly proportional to vulnerable biomass.

Both frequentist inference and Bayesian inference were used: specifically maximum a posteriori (MAP) estimation and Markov chain Monte Carlo (MCMC) sampling. A series of MAP sensitivity trials were investigated and the most plausible of these were extended by MCMC simulation.

The stock assessment was completed in a workshop held in Wellington from 18 September to 20 October 2017 and was presented to the MPI Mid-year Plenary on 30 October 2017.

2.1 Stock assessment approach

This stock assessment treats CRA 2 as a single homogeneous area, as was done in the previous stock assessment conducted in 2013 (Starr et al. 2014b). This stock assessment represents a transition from the previously used MSLM of Haist et al. (2009) to the new LSD model (Webber et al in prep.) written in Stan (Stan Development Team 2016, 2017). This transition was extensively tested to determine that the two models provided equivalent results.

It became apparent while conducting this stock assessment that the estimated CPUE series was not proportional to stock abundance, with fits to the data improving with the addition of a q-drift parameter (δ) which estimated improvement in potting "efficiency". But this additional parameter became unnecessary when a CPUE series which included a *vessel* explanatory variable was used instead of the standardisation model which omitted this variable. Examination of the standardisation model diagnostics showed that the apparent efficiency improvement occurred because vessels with lower catch rates were leaving the fishery while those with higher catch rates remained, leading to an observed increase in CPUE that was independent of a biomass increase (see Appendix D in Starr & Webber, in prep.). The lack of continuity in vessel codes between the FSU and Warehou databases was overcome by keeping the two CPUE series separate and estimating a q-scaling parameter for each series. While the FSU standardisation model did not include a *vessel* variable, the Warehou model was constrained to use vessels with at least five years of experience in the fishery, to allow for sufficient time series observations to estimate a vessel coefficient that was not unduly confounded with the time series coefficient. Two other experience levels were investigated (three and ten years) without much affecting the resulting time series sequence: the primary difference among the estimated series being in the use or non-use of a *vessel* explanatory variable (see Appendices C and D in Starr & Webber, in prep.).

When the series which included the *vessel* explanatory variable in the standardisation procedure was incorporated into the model, the estimate of δ dropped considerably and the improvement in the likelihood disappeared. Consequently the RLFAWG selected the model which used the CPUE series with the *vessel* variable but did not estimate δ as the base case and now reports a model which estimates δ as a sensitivity run.

2.2 Major model options and the choices made

Major model options and choices included:

- first year: 1979 (by WG agreement)
    - explored starting in 1945 (see sensitivities below)
- end year: 2016, i.e. the 2016–17 fishing year
    - because this is the last period with data
- seasons: one per year until 1979, then AW and SS seasons
- size structure:
    - 31 2-mm wide bins from 30 mm to 92 mm tail width (last bin is a “plus” bin)
- recruitment: mean 32 mm with standard deviation 2 mm
- 3-sexes: male, immature female and mature female
- mature females: allowed to be caught in SS but not in AW
- likelihoods:
    - lognormal for two CPUE series (FSU and CELR)
    - robust normal for tags
    - multinomial for LFs, fitted to proportions for males, immature females and mature females, with each sex category normalised separately
    - multinomial for sex ratio
- data weighting: determined iteratively unless stated otherwise (Francis 2011)
- fishing mortality dynamics: instantaneous using Newton-Raphson algorithm
- growth model: Schnute-Francis
- *Rdev*s: estimated annually 1979–2014 (final two years not estimated, given no real information in data for these recruitments and lack of puerulus data)
- selectivity: “double normal”
- two selectivity periods: 1979–1992 and 1993–2016. These periods indirectly model changes in escape gap regulations that occurred between 1992 and 1993
- two handling mortality periods: 1979–1989 and 1990–2016
- no density-dependent growth
- two CPUE series:
    - FSU q is constant over 1979–1988 and no vessel explanatory variable
    - CELR CPUE standardised with a vessel explanatory variable (5 years minimum in the fishery)
- q-drift parameter: option to estimate annual proportional increase of the CPUE q with parameter δ (run as a sensitivity to the base case)

2.3 Major modelling changes for 2017

2.3.1 Standardising the CELR CPUE series with a vessel variable

Starr & Webber (in prep.) describe a standardisation of the CELR CPUE data which included a categorical variable that estimates a *vessel* “effect”. They also show that there is very little difference in the estimated series among the three vessel restrictions investigated (a minimum of three, five, or ten years in the fishery). There needs to be such a restriction because there must be a reasonable number of observations for each vessel so that a coefficient estimating the relative vessel CPUE can be estimated. The stock assessment team selected the five-year restriction option as a compromise between having a sufficient number of annual observations in the data set for every vessel while keeping the data set large enough to estimate the remaining model coefficients.

2.3.2 Changes in applying size distribution weights

Previous stock assessments calculated a sample weight for each record based on the number of fish measured and the number of sampling days, where a record was a year, season (AW or SS), and sampling source (LB or CS). This weight was applied to each sex category (males, immature females, and mature females). In some cases, this procedure resulted in very high weights being given to the immature female category, a category which tends to have relatively few observations in the North Island QMAs. This year, the weights were partitioned by sex category so that each category would get a weight that was appropriate to the actual number of lobsters measured. Although it is likely that this change will have only small effects on the stock assessment, it was felt that weighting each sex category appropriately was the better way to analyse these data.

2.3.3 Estimating an increasing CPUE *q* parameter (δ)

Improvements in fishing technology and gear can lead to changes in fishing efficiency which can result in a non-constant relationship between CPUE and stock biomass. To date, the rock lobster stock assessment has assumed a constant catchability $\left(q^{CPUE}\right)$ between CPUE and mid-season vulnerable biomass $\left(B_y^{vul}\right)$:

Eq. 1 $$CPUE_y = q^{CPUE} B_y^{vul}$$

An alternative to the constant catchability assumption, that catchability changes at a constant rate, was investigated in the context of the CRA 2 stock assessment. This is parameterised as:

Eq. 2 $$CPUE_y = q_y^{drift} q^{CPUE} B_y^{vul}$$

where

Eq. 3 $$q_y^{drift} \begin{cases} =1 & y=1989 \\ =q_{y-1}^{drift}\left(1+\delta\right) & y>1989 \end{cases}$$

Initially a prior based on published data from the Western Australia (WA) rock lobster fishery (de Lestang et al. 2012) was used (normal distribution with mean = 0.02 and standard deviation = 0.0051). Estimates for δ using this prior seemed aggressive and some members of the RLFAWG suggested that the WA rock lobster fishery was not an appropriate match for CRA 2. For many years, the WA fishery used effort limitation to constrain catch and it generally operates in deeper water than the CRA 2 fishery. A replacement prior centred around zero was developed with a reasonably small standard deviation (i.e. a normal distribution with mean = 0 and standard deviation = 0.005). The aim of this prior was to pull δ towards zero unless the data provide support for higher or lower δ values. Initial model fits to the revised CELR CPUE series using a vessel explanatory variable estimated δ using the normal prior (mean = 0; standard deviation = 0.005). These showed a large likelihood contribution from the prior and little or no improvement to the model fits. Consequently the *q*-drift sensitivity run fitted to the revised CELR CPUE placed a uniform prior on δ.

2.4 MAP stock assessment

Frequentist inference is used for exploring potential model options for closer examination without committing the computing time involved in Bayesian inference.

2.4.1 Searching for a base case

Searching for a base case for CRA 2 involved:

- determining LF bins for fitting (see Table 13 in Starr & Webber [2018])
- checking the season and sex used to set the vulnerability to 1 to ensure that no estimated sex- and seasonal-specific vulnerability was on the upper bound of 1
- adjusting dataset weights iteratively until the SDNRs were close to 1 and/or the MARs were close to 0.67

Once these tasks were completed, the parameter estimates were checked against the estimates from the previous CRA 2 stock assessment as well as other rock lobster stock assessments. This comparison indicated that most estimates were similar to previous CRA 2 estimated values, particularly R_0

(average recruitment which determines the stock size) and *M*. The growth parameter estimates changed (dropped a bit) because we are using different priors than in 2013 and there are 800 more tag recoveries than we had in 2013, but the estimates themselves remained credible. The only major difference was for the parameters estimating male selectivity in the first epoch, *SelLH* and *SelMax*, with the latter estimate on the lower bound of 1 and an estimate of 40 mm or less for the size at maximum selectivity. This compares to the estimated maximum selectivity at 49 mm from the previous stock assessment. However there are very little data to support estimation of this parameter with only three SS length frequency samples for the entire period. The stock assessment team agreed that, given this parameter has minor impact on the stock reconstruction, there was no need to constrain it.

As the analysis progressed, several other changes were implemented to the stock assessment that represent changes from previous approaches (e.g., Starr et al. 2014b):

- start the model in 1979 instead of 1945
- use separate *q*-parameters for the FSU and CELR data
- *q* is constant for both the FSU and CELR CPUE series (no drift parameter)
- only use first time tag recaptures: there seemed to be a negative growth bias in the tag re-recaptures
- although density-dependence was included in the base case in the last CRA 2 stock assessment, this was not included in this stock assessment because there was insufficient time to validate this code in the LSD model.

Model parameters, including fixed and derived parameters, are defined in Table 1. Parameter bounds, priors, and initial values are given in Table 2. Fixed values used in the model, including relative weights, are given in Table 3. The selection definitions for the *vuln* parameters are provided in Table 4.

2.4.2 Base case results

Diagnostic plots for the base case are presented from Figure 2 to Figure 15, consisting of model predictions relative to observed data or the standardised residuals of the model fits to the data. These include:

- the fit to the two AW and SS CPUE series (Figure 2)
- the residuals to CPUE indices (Figure 3)
- example fits to the observer and logbook LF data by sex (Figure 4 and Figure 5)
- residuals to the LF fits by sex, size, and data source (observer or logbook) (Figure 6)
- residuals to the LF fits by sex, year, and data source (observer or logbook) (Figure 7)
- unfished size distribution by sex (Figure 8)
- estimated and observed sex ratios, by sex, year, and data source (Figure 9)
- predicted growth increments, with standard deviation, at length, and sex (Figure 10)
- residuals to the fit to the tag-recovery data by sex, and statistical area of release (Figure 11)
- residuals to the fit to the tag-recovery data by sex, size class, and statistical area of release (Figure 12)
- residuals to the fit to the tag-recovery data by sex, and year of release (Figure 13)
- selectivity function by selectivity period and sex (Figure 14)
- estimated female maturity function (Figure 15)

Annual plots of important derived parameters for the base case can be found in Figure 16 (recruitment), Figure 17 (fishing mortality), Figure 18 (recruited biomass), and Figure 19 (vulnerable biomass). Parameter estimates, likelihoods, and indicators for the base case can be found in the table which also reports the sensitivity runs (see Table 6).

2.4.3 MAP sensitivity trials

A reduced number of sensitivity trials were made as single variants relative to the base case. These are listed in Table 5.

Sensitivity runs which dropped data sets were not repeated except for a run which dropped the FSU data. A sensitivity run which assumed density dependent growth was not run because the density-dependence code in the LSD model has not yet been validated. We investigated density dependence in the MSLM model (Haist et al. 2009) with the 2017 data set. This showed a moderate improvement in the likelihood (two units) in a *q*-drift model which used a single CPUE series without an explanatory variable. This test was not run with the CELR CPUE series using a *vessel* explanatory variable. Given the limited available time, combined with the small amount of improvement from this additional process, it was opted to drop density dependence from this CRA 2 stock assessment. The effect on the estimated stock status was small in these initial trials.

There was only a small effect of the sensitivity runs on many of the major parameters (see Table 6). All runs returned an M estimate between 0.142 and 0.176 while R_0 varied from 571 000 to 656 000, with the higher estimate resulting from the "2 × recreational" run. Similarly *Galpha* varied from 4.58 to 4.76 mm for females and from 6.57 to 6.87 mm for males, with the lower estimates occurring for the "all tags" sensitivity run. The other growth parameters behaved similarly. *Mat50* only ranged from 49.9 mm to 50.1 mm while *Mat95* went from 10.0 to 10.3 mm. The *q-drift* parameter (δ), using the revised CELR CPUE series, was estimated at 0.0045, with no improvement in the total likelihood.

There was very little difference between the vulnerable biomass trajectories from the base case using the CELR CPUE series with a vessel effect and the sensitivity run that estimated δ (Figure 20).

Figure 21 shows a negative bias in the growth residuals after the first recapture event, leading to the decision to discard tag recapture recoveries after the first recapture for the base case. The "all tags" sensitivity run, which included all tag recapture recoveries, led to an estimated biomass trajectory above the base case run (Figure 22), but there is no difference in the stock status estimates compared to the base case run (Table 6).

The effect of changing the non-commercial catch history was relatively small, except when doubling the recreational catch (Figure 23). The model estimates for B_{REF} dropped for the "half-illegal" run, increased for the "constant illegal" run and increased again for the "2 × recreational" run (Table 6). The vulnerable biomass trajectories of the two sensitivity runs which varied the illegal catch closely resemble the base case run, while the sensitivity run which doubled the recreational catch lies above the base case (Figure 23).

Stock status varied little among all sensitivity runs tested, with B_{2017}/B_{REF} ratios ranging between 0.18 and 0.21 for all runs except "drop FSU", where B_{2017}/B_{REF} = 0.13 (Table 6). The reason the "drop FSU" returned the lowest stock status relative to B_{REF} can be seen in Figure 24, with that run completely equivalent to the base case during the time period when the CELR CPUE data are used, but the lack of the FSU data caused the model to estimate higher early biomass levels and consequently a higher B_{REF} and lower stock status.

The sensitivity run which started in 1945 shows a steeply descending vulnerable biomass trajectory until biomass converged in 1979 (Figure 25). After than point, six of the eight runs reported in Table 6 estimated very similar trajectories, with exceptions being the "drop FSU" and "2 × recreational" sensitivity runs (Figure 25).

2.5 Bayesian stock assessment

Bayesian inference was used to estimate parameter uncertainty in this stock assessment. LSD uses Stan to run MCMC simulations using the Hamiltonian Monte Carlo (HMC) algorithm, starting with the values in Table 6. A total of 1000 samples from the posterior distribution were obtained by combining samples across four chains, with each chain consisting of a burn-in period of 500 discarded samples and then extracting 250 samples from the remaining 500 samples by discarding every second sample.

2.5.1 Assessment indicators

Stock assessment indicators requested by MPI and the RLFAWG are summarised in Table 7. These included several based on vulnerable biomass such as current biomass (B_{2017}), and the minimum of the vulnerable biomass trajectory after 1979 (B_{MIN}). 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 reference biomass was calculated by applying the MLS and selectivity from the second selectivity period to all years.

The most important indicator was B_{REF}, the mean of AW vulnerable reference biomass in 1979–1981. The period used for B_{REF} was selected by the RLFAWG in 2013 because it was deemed at the time to be a period when the stock was in a relatively good position and above a level from which the stock subsequently recovered. B_{REF} is used as a B_{MSY} proxy reference point (see Ministry of Fisheries 2011). Estimated B_{MSY} is sensitive to growth and mortality estimates and the assumptions under which it is estimated. The RLFAWG and the 2017 Plenary concluded that more work was needed to evaluate how this quantity is determined for rock lobsters, therefore MSY-related quantities are not reported here.

Spawning stock biomass (*SSB*) was the biomass of all mature females at the start of AW. SSB_0 was the spawning stock biomass at unfished equilibrium with R_0.

Handling mortality was assumed to be 5% for all lobsters returned to the sea from 1990 and 10% before 1990. This mortality was applied to undersized lobsters of both sexes taken in either season by the SL fishery as well as to mature females taken in the AW SL fishery. It was assumed that there were no discards in the NSL fishery. H_{2016} is the model estimate of the quantum of handling mortality in the final (2016) fishing year.

In addition to the reference point indicators, the RLFAWG requested the posterior distribution of ratios, for instance the ratio of current biomass to B_{REF} and B_{MIN}, along with the probability of each ratio being below specific levels important for management, calculated from the MCMC posteriors.

2.5.2 Base case MCMC

MCMC was used to obtain samples from the posterior distribution for the base case model described in Section 2.4.2. Diagnostic traces are shown for estimated parameters in Figure 26, cumulative density diagnostic plots are shown in Figure 27, and density plots of the posterior distributions of estimated parameters and important derived quantities are shown in Figure 28. Posterior distributions of parameter estimates and derived quantities are summarised in Table 8.

Traces for important estimated parameters such as M and R_0 show reasonable stability. MCMC chains for most parameters stayed away from the bounds with the exception of some of the selectivity parameters during the first selectivity period (Figure 28). Trace and cumulative density plots indicate that MCMC chains are well-mixed, suggesting that the base model is likely to have converged. Density plots demonstrate that the posterior distributions are consistent with the prior distributions. In some instances (e.g., *par_grow_sd_i*[1], Figure 28), there is little overlap between the prior and the posterior distributions. However, there is no cause for concern in these instances as the growth priors were developed using data from all of New Zealand and growth in CRA 2 may not be consistent with other New Zealand QMAs.

A set of base case MCMC diagnostic plots consisting of posterior distributions of the model predictions relative to the observed data, or the standardised residuals to model fits to the data, can be found in Figure 29 through to Figure 41. These are comparable to those provided for the base case MAP results:

- the fit to the two AW and SS CPUE series, along with standardised residuals (Figure 29, Figure 30)
- example fits to the observer and logbook LF data by sex (Figure 31 and Figure 32)
- residuals to the LF fits by sex, size, and data source (observer or logbook) (Figure 33)
- residuals to the LF fits by sex, year, and data source (observer or logbook) (Figure 34)
- predicted growth increments, with standard deviation, at length, and sex (Figure 35)
- residuals to the fit to the tag-recovery data by sex, and statistical area of release (Figure 36)
- residuals to the fit to the tag-recovery data by sex, size class, and statistical area of release (Figure 37)
- residuals to the fit to the tag-recovery data by sex, and year of release (Figure 38)
- estimated and observed sex ratios, by sex, year, and data source (Figure 39)
- selectivity function by selectivity period and sex (Figure 40)
- estimated female maturity function (Figure 41)

The model fits the CPUE time series reasonably well, with acceptable residual patterns (Figure 29, Figure 30). These CPUE fits were similar to the equivalent MAP fits (Figure 2, Figure 3). The fit to the proportions-at-sex showed good agreement with the observations (Figure 39). Maturation was estimated to be well below the female MLS (Figure 40) with most females maturing by 50 mm TW. Estimated selectivity appeared consistent with the shift in regulations between periods (Figure 41).

Recruitment was estimated to peak in the early 1990s, oscillating around the estimate of R_0 since 2000 but then dropping below R_0 consistently in recent years (Figure 42). Fishing mortality (F) has followed an increasing trend in both seasons, with a dip in the spring/summer in the late 1990s but consistently increasing in recent years (Figure 43). Vulnerable reference biomass was estimated to have decreased steadily over time, with the exception of a peak in estimated vulnerable reference biomass in the 1990s following the recruitment peak (Figure 44). Vulnerable reference biomass in the spring/summer and autumn/winter periods were estimated to be far below the B_{REF} reference point (median B_{2017}/B_{REF} = 0.21, 95% credible intervals 0.17–0.26; Table 8).

The posteriors of assessment indicators are summarised in Table 8. Median base case estimates suggest that B_{2017} was 2% above B_{MIN} (i.e. 102% of B_{MIN} with 5th and 95th quantiles 92% to 117%) and 21% of B_{REF} (17% to 26%). There was zero probability that B_{2017} was above B_{REF}.

The 2016 spawning stock biomass (SSB) was 19% of SSB_0 (16% to 21%) with 82% probability that it was below the soft limit of 20% SSB_0 and zero probability that it was below the hard limit of 10% SSB_0.

The historical sequence of biomass versus fishing intensity is shown in Figure 45. The plot shows relative spawning biomass on the x-axis and relative 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 is likely to go.

Relative spawning biomass on the x-axis was calculated as spawning stock biomass (SSB) in year y as a proportion of the unfished spawning stock (SSB_0). SSB_0 is constant for all years of a run, but varies through the 1000 samples from the posterior distribution.

Relative fishing intensity on the y-axis is fishing intensity in year y as a proportion of the fishing intensity (F_{REF}) that results in SSB_{REF} under the fishing pattern in year y. Fishing patterns account for MLS, selectivity, the seasonal catch split, and the balance between SL and NSL catches. F_{REF} varies among years because fishing patterns change in each year and is calculated by projecting deterministically for 50 years to reach equilibrium. Each projection is done by holding the NSL catch constant, assuming recruitment at R_0, and applying a range of stepped multipliers to the AW and SS SL fishing mortalities (F_y). The F that results in SSB_{REF} at the end of the projection is F_{REF}. This projection procedure is followed in every year for each sample in the MCMC posterior.

The median track in Figure 45 suggests that fishing intensity has exceeded F_{REF} in every year starting in 1979, the first model year. The only years that the SSB was above SSB_{REF} were 1979 and 1980. The fishing intensity increased from 1979 to 1990 as the stock declined because of poor recruitment. Fishing intensity declined from 1990 as stock abundance increased as a result of improved recruitment. Fishing intensity and relative biomass neared the centre of the figure from 1996 to 1998, as abundance peaked near SSB_{REF} and fishing mortality approached F_{REF}. The trend reversed after 1998, with the stock dropping below 20% SSB_0 in 2015 and fishing mortality exceeding three times F_{REF} after 2001. Fishing intensity began to drop after 2013 in response to drops in the SL catch but has stayed well above three times F_{REF}. Stock status has continued to decline despite the decline in fishing mortality, with the median estimate of SSB_{2016} at 19% SSB_0 (90% credibility interval from 16%–21% SSB_0; Table 8).

2.5.3 MCMC sensitivity trials

Posterior distributions were sampled for three sensitivity trials using MCMC. Each trial only made the single change to the base case specified below. The trials were:

- **Start 1945** – starting the model in 1945, rather than 1979, as done in the previous CRA 2 stock assessment
- **2 × recreational catch** – double the recreational catch during all model years
- **q-drift** – estimate an additional multiplicative parameter (q-drift: see Section 2.3.3) which models an increase in fishing efficiency over time

Results from the base case and the three sensitivity trials are compared in Table 8. Differences were minor. Trace plots for a selection of parameters for each sensitivity are shown in Figure 46 (Start 1945), Figure 47 (2 × recreational), and Figure 48 (q-drift). Trace plots (along with cumulative density plots not presented here) show that all MCMC chains were well-mixed, indicating that the sensitivity models are likely to have converged.

Starting the model in 1945 did not have a significant effect on recent population estimates. Beginning in 1979, the first year in the base model, the posterior distributions of vulnerable biomass and recruitment overlap (Figure 49, Figure 50). The natural mortality rate estimates were very similar, with a median of 0.164 in the base model and 0.172 beginning in 1945, with overlapping posterior distributions (95% credible interval (CI) = 0.150-0.179 for the base model and 0.158–0.189 starting in 1945, Table 8). The ratio of current biomass in 2017 compared to B_{REF} were also very similar (median B_{2017}/B_{REF} = 0.211 in the base case vs. 0.195 starting in 1945; Table 8). These overlapping posterior distributions indicate that the catch rates from 1945–1979 are not informative for recent years, and support our decision to begin the base model in 1979.

The 2 × recreational catch scenario represents a likely upper bound on potential harvest from non-commercial sectors, mainly recreational fishing, but could theoretically include unaccounted illegal or customary catch. The 2 × recreational catch scenario estimated vulnerable biomass to be higher than the base model (Figure 51) but does not impact estimates of recruitment (Figure 52). While vulnerable biomass is estimated to be higher because of the larger amount of recreational catch, estimates of B_{REF} are also higher than the base model (Table 8). This results in estimated current biomass relative to the reference point similar to the base model (median B_{2017}/B_{REF} = 0.211 in the base case vs. 0.214 2 × recreational catch; Table 8). Thus, estimates of stock status would be similar between the base model and the 2 × recreational catch sensitivity. The 2 × recreational catch scenario estimated natural mortality lower than the base model, there the upper 95% CI is close to the median in the base model (base model: median = 0.164, 95% CI = 0.150-0.179; 2 × recreational: median = 0.146, 95% CI = 0.132–0.161, Table 8).

Because δ was estimated to be very close to zero, with a lower 95% CI less than zero (median = 0.0043, 95% CI -0.0006–0.0089, Table 8), the change in catchability over time was small (Figure 53). This resulted in the *q*-drift scenario being very similar to the base case (Table 8, Figure 54).

Finally, we compared vulnerable reference biomass in the start 1945 MCMC sensitivity with the previous CRA 2 stock assessment (Figure 55) and note that the new assessment is very similar to the old assessment from 1990 onwards, which is the period with the greatest concentration of data. However, the new assessment estimated a higher unfished and historic biomass from 1945–1970, and a different biomass trajectory from 1971–1989.

3. MANAGEMENT PROCEDURE EVALUATIONS

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 2017; 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. 2009a); 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 2009); a management procedure was adopted for CRA 3 in 2010 (see Breen et al. 2009b); and an MP was also developed for CRA 1 in 2014 (Webber & Starr 2015).

An operating model based on this 2017 stock assessment was used to explore the existing 2013 MP and evaluate new MPs. This MP evaluation was used to inform managers and stakeholders of the likely consequences of a range of management choices. This evaluation was aided by the availability of an interactive user interface. These results were presented to the NRLMG, who chose four final candidates and engaged in formal consultation on them.

3.1 The 2013 CRA 2 management procedure

An MP has been in place for CRA 2 since 2014 (Starr et al. 2014b), which was the first MP for this stock. This MP used an operating model based on the 2013 CRA 2 stock assessment. The rules evaluated were generalised plateau step rules (see Breen 2017), with the Minister adopting the step rule illustrated in Figure 56.

The existing 2013 MP used standardised CPUE (kg/potlift) based on the offset year (1 October through to 30 September) as the input variable, prepared using the F2-LFX algorithm (see Starr 2017), to determine the output variable TACC (tonnes). When CPUE was between 0 and 0.3 kg/potlift the TACC increased linearly with CPUE to a plateau of 200 tonnes, which extended to a CPUE of 0.5 kg/potlift. As CPUE increased above 0.5 kg/potlift, TACC increased in steps with a width of 0.1 kg/potlift and a height of 10% of the preceding TACC. There was no latent year (TACC could be changed every year if necessary) and no maximum change threshold. A minimum change threshold of 5% was specified.

The history of the operation of this rule is given in Table 9 and Figure 56. In November 2013, standardised offset-year CPUE was 0.367 kg/potlift, which gave a suggested TACC of 200 tonnes. The Minister accepted this rule and assigned the current allowances (customary 16.5 tonnes, recreational 140 tonnes, and other mortality 60 tonnes). In November 2014, CPUE was 0.3361 kg/potlift, which gave a TACC that remained on the plateau. In November 2015, standardised F2-LFX offset-year CPUE again decreased and was just below the plateau. The preliminary rule result was a TACC of 199.397 tonnes. Because this would be a change of only 0.3%, below the minimum change threshold of 5%, the MP result was no change to the TACC. The Minister accepted this result and retained the current allowances. However, more than 95% of the quota held by CRA 2 industry voted in favour of a 49 tonne quota shelving, so the functional TACC for 2016 was 151 tonnes. In November 2016, standardised F2-LFX offset-year CPUE again decreased slightly and was just below the plateau. The preliminary rule result was a TACC of 196.884 tonnes. Because this would be a TACC change of only 2%, which is below the minimum change threshold of 5%, the MP result was no change to the TACC. The Minister accepted this result and retained the current allowances. However, as they had done in 2016, CRA 2 industry voted in favour of a 25% quota shelving, so the functional TACC for 2017 was 151 tonnes.

3.2 Developing the 2018 CRA 2 operating model

The suite of stock assessment models (including the base case and sensitivity trials) was projected for 20-years by setting TACCs in each year based on a harvest control rule. Recreational catch was projected using an estimated exploitation rate from 1979–2016. Using the discrete exploitation rate assumes that recreational catch is proportional to the amount of vulnerable biomass, rather than a specific amount annually. Other non-commercial catches were held at their 2016 estimates.

Projected recruitment, from 2015–2038 was based on recruitment deviations (*Rdev*s) sampled from a normal distribution with mean and standard deviation calculated from estimated recruitment deviations from 2005–2014 (2014 is the last year that recruitment deviations are estimated in the model). Autocorrelation, based on recruitment deviations from 1986–2014 (1986 is the first year that we have length frequency data), was also applied to these recruitment deviations. This was a new addition to the MP process.

Fishing took place every six months. Recreational catches were assumed to be taken 79% in SS while the customary catches were 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 logistic regression based on AW CPUE (Figure 57) using the previous year predicted AW CPUE.

When MPs are operated annually, they are driven by offset-year CPUE, which is calculated from AW data from the year in which the MP is operated and from SS in the preceding fishing year. This process is simulated in the model by estimating projected offset-year CPUE with the mean AW CPUE in the year for which the MP was calculated and from the SS season in the preceding year. This procedure appears to be reliable: the relationship between the result and the observed offset-year CPUE was log-log linear (Figure 58). Observation error was added to the model-predicted offset-year CPUE based on the residuals in CPUE seen in each sample of the posterior.

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

Performance of MPs was evaluated over the entire projection period using a combination of tables and figures in an interactive user interface. This differs to MPE in previous years where performance indicators over 5 and 20 years were used to evaluate the performance of rules. Performance was evaluated for three classes:

- abundance: vulnerable reference biomass and offset year CPUE
- yield: recreational and commercial catch
- safety and rebuilding: the probabilities that biomass would be greater or less than reference points

Initially the probability that the projected vulnerable reference biomass exceeded the reference biomass $P(B_y > B_{REF})$ was investigated for each rule. However, the probability of rebuilding to B_{REF} within 20 years was generally very low. Therefore the RLFAWG suggested an intermediate target of twice the current biomass ($2 \times B_{2018}$), and the focus during MPE became the probability that the projected vulnerable reference biomass exceeds twice the current biomass $P(B_y > 2 \times B_{2018})$.

3.3 Robustness trials

Along with the base case and three sensitivity trials (start 1945, 2 × recreational catch, and q-drift), the RLFAWG suggested that three additional robustness trials should be run, giving a total of six robustness trials and the base case:

- *low recruitment*: this trial used projected recruitment based on 2011–2014 (rather than 2005–2014), which was a period of low recruitment
- *base fix*: same as base but recreational catch fixed at 34 tonnes (the estimated 2016 catch) each year in projections
- *2 × fix*: same as the 2 × recreational catch sensitivity but recreational catch fixed at 68 tonnes (twice the estimated 2016 catch) each year in projections

The low recruitment robustness trial projected recruitment from 2015 to 2037 using recruitment deviations (*Rdev*s) sampled from a normal distribution with mean and standard deviation calculated from the 2011–2014 base case recruitment deviations. These four years represented the lowest recruitment deviations in the time series of the CRA 2 stock reconstruction. Autocorrelation was also applied to these recruitment deviations and was based on recruitment deviations from 1986–2014 (as in the base case).

The "*base fix*" and "*2 × fix*" robustness trials were developed to test rebuilding in CRA 2 if input controls were applied to the recreational fishery such that the catch would remain at the 2016 level.

3.4 Development of a new CRA 2 MP

Initially a suite of exploratory plateau step MPs (see Breen 2017) were tested and presented to stakeholders (e.g. Figure 59). We evaluated rules that used vessel-standardised offset-year CPUE as input, collated with the F2-LFX procedure (see Starr 2017), to set a TACC. This preliminary set of rules was evaluated with the base case and seven robustness trials. A strong decrease in commercial catch in the first five years was common among these rules (e.g. Figure 60).

After looking at the set of initial exploratory MPs, stakeholders were asked for their views about the form of a new CRA 2 MP. There was general agreement among stakeholders that it was important to start to rebuild CRA 2 within the five-year time horizon that is usual before revisiting the stock assessment and its associated MPE. With this in mind, twice the 2018 vulnerable reference biomass was selected as an intermediate target that was potentially achievable within the five-year time period. In addition, constant catch MP rules were favoured because they would avoid the large drops in commercial catch that were being observed in the initial plateau step rules (e.g. Figure 60). Therefore a range of constant catch rules were tested including 0 tonnes, then 50 tonnes to 200 tonnes in 10 tonne increments. The 0 tonne and several of the lower constant catch rules were purely exploratory to see how the stock responded to different catch levels, as were the constant catch rules above 150 tonnes.

There was little contrast between the base case and the robustness trials based on the MCMC sensitivity trials (*start 1945*, *2 x recreational*, *q-drift*, Figure 61). There were several important differences between these four runs and the robustness trials with fixed recreational catch or the low recruitment run. The low recruitment robustness trial resulted in much more pessimistic projections (Figure 61), while the fixed recreational catch robustness trials resulted in much more optimistic projections (Figure 62). The fixed TACC rules resulted in a wide range of different rebuilding speeds and final biomass levels (Table 10). The 80, 100, 120, and 140 tonnes fixed TACC rules were presented to the NRLMG, representing the spectrum of rules that displayed rebuild probabilities that spanned the stakeholder expectations (Figure 63, Table 10). The NRLMG went to consultation on these four rules.

4. DISCUSSION

The stock assessment showed a stock depleted below B_{REF}, along with low estimates of spawning stock biomass relative to the unfished stock level (SSB_0), despite the large proportion of mature females below the MLS. Depletion of the stock was recognised even before the stock assessment by all stakeholders.

The LSD model fit the CRA 2 data with little difficulty, with acceptable fits to the CPUE, LF, sex ratio, and tagging data. Estimates of growth, maturity, and selectivity (particularly in the second period) were credible with tight posterior distributions.

This stock assessment used a CPUE series with a *vessel* explanatory variable. This was done as initial model fits to a CPUE series without a *vessel* variable were improved by estimating the additional q-drift parameter (δ) that relaxes the assumption that CPUE is strictly proportional to vulnerable biomass (see Section 2.3.3). The improvement in model fit when δ was estimated dropped to low levels when the CPUE with the added *vessel* explanatory factor was substituted for the standardised CPUE series estimated as done in the previous CRA 2 stock assessment (Starr et al. 2014a). The model which estimated δ was taken to MCMC and used as a robustness trial in the MP evaluations, but its results were similar to those in the base case (Table 8, Table 10).

Figure 55 compares the vulnerable biomass trajectories from this year's "*start 1945*" MCMC sensitivity run with the 2013 stock assessment base case run. This plot shows that the trajectories in the period following 1990 are largely the same, with some possible divergence at the end of the series because of the difference in CPUE series used. The main difference between the two series is in the period associated with the FSU data (1979–1988), where the 2013 assumption of *q*-equivalency between the FSU and Warehou databases forced the model to estimate low biomass levels during that period. Once this constraint was removed, the present model estimated much higher biomass levels during this period. This in turn resulted in a much higher estimate for the biomass level associated with B_{REF} (1979–1981) and higher levels of pre-1979 stock reconstruction.

As always, the RLFAWG identified the lack of information on non-commercial catches and their trends as being a substantial source of uncertainty.

A major concern must be the apparent declining productivity of the CRA 2 stock, which can be seen in the time series of the base case recruitment deviations (Figure 42). Recent recruitments are well below those seen in the 1980s and the first half of the 1990s. More worrisome is the declining trend from the mid-2000s, with the four most recent years (2011–2014) having the lowest recruitment estimates in the series. Recruitment is estimated by the model to have declined and this is the likely cause of the low productivity. Possible causes of this decline may include direct or indirect effects of climate change, or ecological changes in the near shore habitat, such as increased siltation from agricultural runoff.

The base case model and all robustness trials predict that substantial cuts to the overall levels of removals are required to rebuild the stock to B_{REF}. These rebuilding scenarios indicate that there is a trade-off between the commercial and recreational fisheries, depending on how the latter catch category is modelled. Rebuilding occurs much more quickly when the recreational fishery catches are capped at current levels, while rebuilding is delayed if it is assumed that recreational fishing removal rates are fixed at current levels.

The "low recruitment" robustness trial is particularly pessimistic, with recruitment levels set at the mean 2011–2014 recruitment, the lowest level in the time series. While this scenario may be relatively unlikely, it does show that the prognosis for the CRA 2 stock is poor if current levels of low recruitment persist.

Twice the 2018 vulnerable reference biomass was selected by stakeholders as an intermediate target that was potentially achievable within the five year time period between stock assessments. This was done so that a rebuilding trajectory for CRA 2 would be started as soon as possible.

5. FUTURE RESEARCH RECOMMENDATIONS

The RLWG and Plenary identified a number of potentially useful avenues of exploration to evaluate or improve this assessment in the future. Improvements related to the development of the CPUE standardisation (GLM) and its use in the stock assessment model include:

- Include alternative CPUE formulations as sensitivity analyses in the stock assessment model itself to more fully evaluate their consequences.
- Develop logbook CPUE series where possible. Display comparisons of this series with the current CPUE series. Include the logbook series in the model as well.
- Implement vessel as an explanatory variable in all future rock lobster CPUE standardisations. Investigate sequential coding of the same vessel in the model to determine whether there are 'learning' effects, or examine individual vessels for trends in residuals over time.
- Investigate the distribution of the vessel correction factors (VCF) that scale estimated catch into landed green weight in the F2_LFX algorithm.
- Use a smoother to determine the minimum amount of process error to add and use this (to avoid overfitting) instead of the arbitrary 25% process error that is added at present.

Other suggested improvements include:

- Explore alternative reference points (targets and limits) for CRA 2 (and rock lobster stocks in general). For example, evaluate the consistency and efficacy of B_{REF} targets, and develop a dynamic B_{MSY}.
- Examine the effects of including a stock-recruitment relationship in the model.
- Investigate the implications of not estimating recruitment deviations for the period with no relevant data or, alternatively, the implications of estimating recruitment deviations for all years.
- Investigate the effects of changing the definition of new recruits from 32 mm, with a standard deviation of 2 mm; for example, what would be the effect of an increase in the standard deviation?
- Develop and test the LSD computer code to include the effects of density-dependent growth and environmental effects.
- Develop and evaluate alternative growth models.
- Re-evaluate the method used to determine length-frequency weights.
- Develop an option for including random effects for certain parameters (e.g. selectivity parameters) in the model.
- Continue development of the spatial model and develop spatial model management procedures.
- Explore new ways to "search" for management procedures (e.g. basic optimisation routines, genetic algorithms).

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D'Arcy Webber is at Quantifish, 72 Haukore Street, Hairini, Tauranga 3112, New Zealand
Paul Starr is at Starrfish, 61A Rhine St., Island Bay, Wellington 6023, New Zealand
Vivian Haist is at Haist Consultancy, 1262 Marina Way, Nanoose Bay, B.C., Canada V9P 9C1
Merrill Rudd is at University of Washington, 1122 NE Boat Street, Seattle, W.A. 98195, USA
Charles Edwards is at NIWA, P.O. Box 14901, Wellington 6021, New Zealand

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Table 1: Definitions of parameters and derived quantities discussed in the text.

Estimated parameters	
R_0	initial numbers recruiting
U_{init}	initial exploitation rate (first year is in equilibrium using this estimate)
M	instantaneous rate of natural mortality
Rdevs	annual recruitment deviations
qCR	relation between B_{vuln} and 1963–1973 CR index
qFSU	relation between B_{vuln} and 1979–1988 (FSU) CPUE index
qCELR	relation between B_{vuln} and 1989–2016 (CELR) CPUE index
qdrift (δ)	annual proportional change in CPUE *q*
Mat50	size where 50% of immature females become mature
Mat95	difference between *Mat50* and *Mat95*
Galpha	annual growth increment at 50 mm TW
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
SelLH	shape of the LH of selectivity curve (as if it were a standard deviation)
SelMax	size at maximum selectivity
vuln	relative vulnerability by sex and season
Fixed parameters	
SigmaR	standard deviation of *Rdevs*
SelRH	shape of the RH of selectivity curve (as if it were a standard deviation)
Derived parameters	
Gbeta	annual growth increment at 80 mm TW where *Gbeta* = *Galpha* × *Gdiff*
B_{2017}	vulnerable biomass at start of AW 2017
B_{REF}	mean of AW *Bvuln* for 1979-1981 in CRA 2 (reference biomass)
B_{MIN}	minimum CRA 2 AW vulnerable biomass from 1979 to 2016

Table 2: Specifications for estimated parameters in the CRA 2 models including the upper and lower bounds, prior type (0: uniform, 1: lognormal, 2: normal), prior mean and standard deviation (SD), and the initial values.

Season	Sex	Parameter	Lower bound	Upper bound	Prior type	prior mean	Prior SD	Initial value
		R_0	1	7e10				6e5
		M	0.01	0.35	2	0.12	0.4	0.12
		U_{init}	0	1	0			0
		Rdevs[1]	-2.3	2.3	1	0	*sigmaR*	0
		qFSU	1.4e-11	1	0			1e-4
		qCELR	1.4e-11	1	0			1e-4
		qdrift	-0.08	0.08	0			0
		mat50	30	80	1	50	15	50
		mat95	1	60	1	10	10	5
	male	*Galpha*	1	20	0			3.5
	male	*Gdiff*	0.001	1	0			0.8
	female	*Galpha*	1	20	0			3.5
	female	*Gdiff*	0.001	1	0			0.5
	male	*Gshape*	0.1	15	1	4.81	1.0	4.8
	male	*GCV*	0.01	2	1	0.59	0.3	0.59
	female	*Gshape*	0.1	15	1	4.51	1.0	4.5
	female	*GCV*	0.01	2	1	0.82	0.3	0.82
		Gobs	0.00001	10	1	1.48	0.074	0.4
	male	*SelLH*	1	50	0			4.1
	female	*SelLH*	1	50	0			9.2
	male	*SelMax*	30	90	0			55
	female	*SelMax*	30	90	0			64
SS	male	*vuln1*	0.01	1	0			0.8
AW	immafem	*vuln2*	0.01	1	0			0.8
SS	imma & matfem	*vuln3*	0.01	1	0			0.8
AW	matfem	*vuln4*	0.01	1	0			0.8

[1] Normal in log space = lognormal (bounds equivalent to –10 to 10)

Table 3: Fixed quantities used in the CRA 2 models.

Quantity	Value
weights	
tags	1
CELR CPUE	2.7
FSU CPUE	3
sex ratio	22.0
LFs	7.3
process error FSU/CELR 1979-2016	0.25
Newton-Raphson iterations	3
last year of estimated *Rdevs*	2014
years for *Rdev* projections	2005–2014
years for *Rdev* autocorrelation	1986–2014

Quantity	Value
fixed parameters	
sigmaR	0.4
SelRH	200
male length-weight *a*	4.16E-06
male length-weight *b*	2.9354
female length-weight *a*	1.30E-05
female length-weight *b*	2.5452
other	
handling mortality, 1979–89	0.10
handling mortality, 1990–2016	0.05
min survival proportion	0.02
CRA 2 reference years	1979-81
projected SL catch	184
projected NSL catch	45
male bins	4 to 31
female immature bins	4 to 20
female mature bins	6 to 31

Table 4: CRA 2 base case: map of vulnerability (*vuln*) parameters. Note that the vulnerability for males in AW is fixed at 1.

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

Table 5: List of CRA 2 MAP sensitivity runs.

start 1945	start the model in 1945
q-drift	estimate *q*-drift parameter (δ) using updated CELR CPUE series (used a uniform prior for this parameter)
half illegal	illegal catch vector reduced by half
constant illegal	set a constant illegal catch vector from 1945–2016, using the mean estimate from the 1990, 1992, 1994–1996 CRA 2 estimates in table 3 of RLFAWG 2017/10 (=65 t)
2 × recreational	double the recreational catch vector
all tags	use all tagging data
drop FSU	drop the FSU CPUE indices (1979–1988)

Table 6: CRA 2 stock assessment: MAP base case and sensitivity trial results. Grey indicates quantities not fitted. Growth increment values in mm TW, biomass values in tonnes and R_0 in numbers.

	Base	1945 start	*q*-drift	Half illegal	Constant illegal	2×recreational	All tags	Drop FSU
LFs-sdnr	0.76	0.76	0.76	0.76	0.76	0.75	0.78	0.75
LFs-MAR	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
LFs-LL	22 994	22 994	22 992	22 991	22 998	22 987	23 004	22 993
Tags-sdnr	1.42	1.42	1.42	1.42	1.42	1.42	1.82	1.42
Tags-MAR	0.68	0.68	0.68	0.68	0.68	0.68	0.66	0.68
Tags-LL	4 439	4 440	4 438	4 439	4 439	4 438	5 539	4 438
CELR-sdnr	1.11	1.10	1.10	1.12	1.14	1.10	1.15	1.11
CELR-MAR	0.61	0.59	0.55	0.65	0.61	0.65	0.63	0.63
CELR-LL	- 98	- 99	- 98	- 97	- 96	- 98	- 95	- 98
FSU-sdnr	1.23	1.06	1.24	1.28	1.26	1.21	1.25	0
FSU-MAR	0.76	0.82	0.76	0.73	0.74	0.77	0.78	0
FSU-LL	- 35	- 39	- 35	- 34	- 34	- 36	- 35	0
CR-sdnr	0	1.02	0	0	0	0	0	0
CR-MAR	0	0.49	0	0	0	0	0	0
CR-LL	0	- 26	0	0	0	0	0	0
Sex-sdnr	1.06	1.07	1.07	1.08	1.05	1.08	1.07	1.07
Sex-MAR	0.60	0.60	0.60	0.60	0.61	0.61	0.60	0.60
Sex-LL	7 886	7 886	7 887	7 889	7 884	7 889	7 886	7 887
Prior	0.48	-25.12	0.85	1.53	0.63	-0.07	65.13	-0.67
Function value	35 186	35 132	35 185	35 190	35 191	35 180	36 364	35 219
R_0	624 266	592 674	629 594	628 795	656 009	634 731	616 987	571 033
M	0.161	0.171	0.164	0.176	0.166	0.142	0.158	0.165
qdrift	0	0	0.0045	0	0	0	0	0
qCELR	0.00145	0.00142	0.00136	0.00150	0.00143	0.00129	0.00136	0.00144
qFSU	0.00064	0.00064	0.00061	0.00065	0.00061	0.00058	0.00059	0
qCR	0	0.0321	0	0	0	0	0	0
mat50	50.0	49.9	49.9	49.9	49.9	50.0	50.1	50.0
mat95	10.3	10.1	10.2	10.3	10.2	10.3	10.1	10.2
GalphaM	6.87	6.85	6.86	6.86	6.86	6.86	6.57	6.86
GbetaM	2.85	2.83	2.83	2.86	2.85	2.84	2.47	2.82
GshapeM	2.48	2.35	2.42	2.46	2.43	2.47	2.69	2.39
GCVM	0.43	0.43	0.43	0.43	0.43	0.43	0.49	0.43

	Base	1945 start	q-drift	Half illegal	Constant illegal	2×recreational	All tags	Drop FSU
GalphaF	4.73	4.76	4.75	4.73	4.74	4.76	4.58	4.75
GbetaF	1.19	1.22	1.18	1.20	1.19	1.19	1.16	1.18
GshapeF	4.42	4.46	4.43	4.43	4.45	4.40	4.34	4.39
GCVF	0.77	0.77	0.77	0.78	0.77	0.77	0.83	0.77
StdObs	1.01	1.01	1.01	1.01	1.01	1.01	0.52	1.01
vuln1	0.66	0.68	0.67	0.67	0.67	0.65	0.66	0.67
vuln2	0.58	0.58	0.58	0.58	0.57	0.58	0.62	0.58
vuln3	0.56	0.57	0.56	0.57	0.55	0.56	0.59	0.56
vuln4	0.51	0.51	0.51	0.51	0.50	0.50	0.54	0.50
SelLH1M	1.0	3.3	3.6	3.5	3.5	3.6	3.6	3.5
SelMax1M	38.4	43.3	43.4	44.4	43.2	39.3	41.1	42.4
SelLH1F	7.1	6.5	6.1	7.1	5.6	5.8	6.3	6.5
SelMax1F	58.6	58.2	57.3	58.7	56.7	57.0	57.9	58.1
SelLH2M	4.7	4.7	4.7	4.7	4.7	4.7	4.6	4.7
SelMax2M	55.9	55.9	55.9	55.9	55.9	55.8	55.7	55.9
SelLH2F	7.25	7.26	7.26	7.24	7.23	7.32	7.23	7.24
SelMax2F	63.1	63.1	63.1	63.1	63.1	63.2	63.1	63.1
SSB_0	1 778	1 611	1 756	1 559	1 791	2 222	1 783	1 577
B_{REF}	949	950	979	930	988	1022	1009	1425
B_{MIN}	196	198	186	189	199	220	207	196
B_{2017}	194	193	180	189	189	219	208	192
SSB_{2016}/SSB_0	0.18	0.20	0.18	0.20	0.18	0.16	0.18	0.21
B_{2017}/B_{REF}	0.20	0.20	0.18	0.20	0.19	0.21	0.21	0.13
B_{2017}/B_{MIN}	0.99	0.98	0.97	1.00	0.95	0.99	1.00	0.98
F_{mult}	1.06	1.20	1.03	1.29	1.08	0.78	1.17	1.09
U_{init}	0.162	0.000	0.153	0.148	0.154	0.172	0.145	0.076

Table 7: Reference points, performance indicators, and stock status probabilities for the CRA 2 stock assessment. Note that B_{MSY} has been removed from this table as the RLWG and Plenary determined that more work needed to be conducted to evaluate how this quantity is determined for rock lobsters.

Type	*Description*
Reference Points	
H_{2016}	Handling mortality (tonnes) in final fishing year
SSB_0	Female spawning stock biomass during AW season associated with unfished equilbrium
SSB_{2016}	Female spawning stock biomass at end of 2016 AW season
B_{REF}	Beginning of AW season mean vulnerable reference biomass for the 1979–1981
B_{MIN}	The lowest beginning AW vulnerable biomass in the series
B_{2017}	Beginning of season AW vulnerable biomass for 2017
Performance indicators	
SSB_{2016} / SSB_0	ratio of SSB_{2016} to SSB_0
B_{2017} / B_{REF}	ratio of B_{2017} to B_{REF}
B_{2017} / B_{MIN}	ratio of B_{2017} to B_{MIN}
Probabilities	
P($SSB_{2016} < 0.2\ SSB_0$)	soft limit CRA 2: probability $SSB_{2016} < 20\%\ SSB_0$
P($SSB_{2016} < 0.1\ SSB_0$)	hard limit CRA 2: probability $SSB_{2016} < 10\%\ SSB_0$
P($B_{2017} > B_{REF}$)	probability $B_{2017} > B_{REF}$
P($B_{2017} > B_{MIN}$)	probability $B_{2017} > B_{MIN}$

Table 8: CRA 2 base case and sensitivity run MCMC outputs, reporting the 5%, 50% (median), and 95% quantiles of the posterior distributions. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers, '–': not applicable.

			Base			*Start 1945*			*2× recreational catch*			*q-drift*
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods and diagnostic statistics												
LFs- SDNR	0.613	0.772	1.126	0.616	0.773	1.143	0.604	0.760	1.053	0.614	0.772	1.091
LFs-MAR	0.101	0.104	0.106	0.101	0.104	0.106	0.101	0.104	0.106	0.101	0.104	0.107
LFs-LL	22 990	23 010	23 020	23 000	23 010	23 020	22 990	23 000	23 010	22 990	23 010	23 020
Tags-SDNR	1.373	1.418	1.467	1.371	1.417	1.463	1.372	1.417	1.462	1.374	1.418	1.465
Tags-MAR	0.662	0.679	0.698	0.662	0.680	0.698	0.663	0.680	0.698	0.662	0.680	0.700
Tags-LL	4 430	4 442	4 455	4 430	4 442	4 456	4 430	4 442	4 456	4 430	4 441	4 453
CELR-SDNR	1.078	1.173	1.274	1.065	1.162	1.270	1.060	1.160	1.261	1.066	1.163	1.266
CELR-MAR	0.589	0.734	0.876	0.560	0.704	0.841	0.599	0.735	0.883	1.012	1.504	2.289
CELR-LL	-99.44	-93.58	-86.34	-100.20	-94.21	-86.91	-100.40	-94.26	-87.44	-100.10	-94.15	-87.17
FSU-SDNR	1.188	1.307	1.436	1.048	1.199	1.382	1.179	1.281	1.408	1.198	1.301	1.438
FSU-MAR	0.660	0.873	1.133	0.665	0.875	1.118	0.656	0.869	1.124	0.662	0.873	1.132
FSU-LL	-35.79	-32.84	-29.20	-38.67	-35.27	-30.70	-36.06	-33.41	-29.84	-35.64	-32.93	-29.32
CR-SDNR	–	–	–	0.969	1.206	1.484	–	–	–	–	–	–
CR-MAR	–	–	–	0.432	0.717	1.091	–	–	–	–	–	–
CR-LL	–	–	–	-25.86	-23.12	-19.19	–	–	–	–	–	–
Sex-SDNR	1.035	1.070	1.112	1.037	1.071	1.109	1.054	1.086	1.121	1.045	1.078	1.118
Sex-MAR	0.566	0.595	0.628	0.565	0.596	0.630	0.573	0.604	0.635	0.569	0.598	0.631
Sex-LL	7 882	7 888	7 894	7 882	7 888	7 894	7 885	7 890	7 895	7 883	7 888	7 895
Prior	-1.77	7.68	19.40	-15.53	-4.43	9.18	-1.74	7.48	18.75	-1.72	8.18	19.09
Function value	35 210	35 220	35 230	35 170	35 180	35 190	35 200	35 210	35 220	35 210	35 220	35 230
Model parameters												
R_0	559 600	633 000	730 400	522 300	594 200	669 900	571 700	653 300	739 200	564 600	643 500	725 000
M	0.150	0.164	0.179	0.158	0.172	0.189	0.132	0.146	0.161	0.152	0.167	0.182
U_{init}	0.118	0.157	0.203	–	–	–	0.130	0.169	0.216	0.108	0.149	0.192
q-CR	–	–	–	0.0207	0.0278	0.0382	–	–	–	–	–	–
q-FSU	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007
q-CELR	0.0013	0.0014	0.0015	0.0013	0.0014	0.0015	0.0012	0.0013	0.0014	0.0012	0.0013	0.0015
qdrift	–	–	–	–	–	–	–	–	–	-0.0006	0.0043	0.0089
mat50	48.96	49.88	50.71	48.82	49.79	50.60	49.05	49.95	50.82	48.92	49.85	50.65
mat95	8.46	10.50	13.41	8.18	10.46	13.18	8.30	10.61	13.48	8.35	10.42	13.45
GalphaM	6.65	6.82	7.00	6.64	6.80	6.97	6.63	6.81	6.99	6.64	6.81	6.99
GbetaM	2.62	2.88	3.20	2.61	2.84	3.15	2.61	2.87	3.17	2.60	2.85	3.13
GshapeM	2.02	2.55	3.18	1.93	2.457	3.11	1.96	2.53	3.15	1.95	2.51	3.10
GCVM	0.42	0.44	0.46	0.42	0.44	0.46	0.42	0.44	0.46	0.42	0.44	0.46
GalphaF	4.55	4.72	4.88	4.59	4.74	4.90	4.57	4.74	4.90	4.57	4.73	4.89
GbetaF	1.12	1.19	1.27	1.13	1.21	1.30	1.12	1.20	1.28	1.12	1.19	1.28
GshapeF	4.12	4.43	4.71	4.17	4.47	4.77	4.12	4.42	4.69	4.15	4.45	4.74
GCVF	0.74	0.78	0.82	0.73	0.77	0.82	0.73	0.77	0.82	0.73	0.77	0.82
StdObs	0.90	1.00	1.11	0.90	1.01	1.11	0.91	1.01	1.10	0.90	1.01	1.11
vuln1	0.63	0.66	0.69	0.65	0.68	0.71	0.63	0.65	0.68	0.64	0.67	0.70
vuln2	0.51	0.60	0.70	0.50	0.59	0.71	0.49	0.59	0.70	0.50	0.59	0.71

	Base			Start 1945			2× recreational catch			q-drift		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
vuln3	0.52	0.56	0.62	0.52	0.57	0.63	0.51	0.56	0.62	0.52	0.57	0.62
vuln4	0.47	0.51	0.56	0.47	0.51	0.56	0.46	0.51	0.56	0.47	0.51	0.56
SelLH1M	2.78	23.42	46.67	2.60	22.04	47.32	3.30	26.39	47.55	3.02	23.20	47.29
SelMax1M	32.00	45.48	67.63	31.64	45.77	67.00	31.16	44.01	67.09	31.97	46.07	66.32
SelLH1F	3.26	11.65	33.01	2.60	11.03	31.90	2.85	12.05	34.28	2.34	10.10	30.87
SelMax1F	49.19	61.77	78.41	48.28	61.20	77.83	48.44	63.15	80.68	47.37	60.22	76.62
SelLH2M	4.38	4.67	4.96	4.38	4.67	4.95	4.42	4.67	4.95	4.41	4.66	4.96
SelMax2M	55.38	55.87	56.37	55.44	55.90	56.40	55.42	55.84	56.33	55.44	55.88	56.39
SelLH2F	6.89	7.26	7.66	6.89	7.26	7.68	6.91	7.35	7.73	6.89	7.27	7.69
SelMax2F	62.51	63.15	63.79	62.52	63.14	63.85	62.53	63.22	63.88	62.50	63.15	63.82
Derived quantities												
H_{2016}	2.251	2.424	2.618	2.213	2.396	2.588	2.586	2.782	3.011	2.272	2.463	2.676
SSB_0	1 582	1 763	1 966	1 444	1 588	1 753	1 954	2 191	2 442	1 555	1 743	1 935
SSB_{REF}	922	999	1 086	813	903	1 006	1 048	1 139	1 234	936	1 017	1 098
SSB_{2016}	306	328	353	304	327	350	344	369	400	293	316	342
B_0	3 391	3 798	4 299	2 883	3 217	3 604	4 149	4 743	5 345	3 283	3 733	4 173
B_{REF}	831	965	1 125	882	1 005	1 160	896	1 044	1 210	864	1 007	1 183
B_{MIN}	182	199	217	182	201	221	203	223	243	171	190	211
B_{2017}	173	203	242	167	197	232	186	222	265	152	184	222
Ratios												
SSB_{2016}/SSB_0	0.163	0.185	0.211	0.183	0.205	0.231	0.148	0.168	0.194	0.162	0.182	0.207
SSB_{2016}/SSB_{REF}	0.297	0.326	0.357	0.322	0.362	0.403	0.294	0.324	0.356	0.283	0.311	0.345
SSB_{REF}/SSB_0	0.503	0.567	0.637	0.489	0.567	0.661	0.452	0.522	0.594	0.517	0.584	0.656
B_{2017}/B_O	0.042	0.052	0.064	0.049	0.061	0.075	0.038	0.047	0.058	0.040	0.049	0.061
B_{2017}/B_{REF}	0.171	0.211	0.261	0.160	0.195	0.240	0.172	0.214	0.264	0.141	0.183	0.234
B_{2017}/B_{MIN}	0.917	1.020	1.174	0.872	0.978	1.118	0.883	0.994	1.135	0.847	0.965	1.107
B_{REF}/B_0	0.204	0.253	0.318	0.260	0.313	0.374	0.174	0.219	0.280	0.215	0.271	0.345
Probabilities												
$P(SSB_{2016}<0.2SSB_0)$		0.816			0.340			0.970			0.893	
$P(SSB_{2016}<0.1SSB_0)$		0			0			0			0	
$P(SSB_{2016} > SSB_{REF})$		0			0			0			0	
$P(B_{2017} > B_{REF})$		0			0			0			0	
$P(B_{2017} > B_{MIN})$		0.614			0.391			0.473			0.323	

Table 9: History of the CRA 2 management procedure. "Rule result" is the result of the management procedure after operation of all its components including thresholds. * indicates that the TACC was functionally 175 tonnes after voluntary shelving. † indicates that the TACC was functionally 151 tonnes after voluntary shelving.

Year	Offset year CPUE (kg/potlift)	Applied to fishing year	Rule result TACC (tonnes)	Applied TACC (tonnes)	Applied TAC (tonnes)
2013	0.3668	2013–14	200	200	416.5
2014	0.3361	2014–15	200	200*	416.5
2015	0.2991	2015–16	200	200†	416.5
2016	0.2953	2016–17	200	200†	416.5

Table 10: Probability that $B_y > 2 \times B_{2018}$ for the base case and each of the robustness trials. Cells with P>0.5 are coloured.

Model	Year	base	1945	2×rec	qdrift	basefix	2×fix	lowrec
80 t TACC	2018	0	0	0	0	0	0	0
	2019	0.001	0.001	0	0.003	0.002	0.001	0
	2020	0.140	0.157	0.089	0.199	0.196	0.152	0.031
	2021	0.413	0.424	0.311	0.488	0.530	0.445	0.160
	2022	0.631	0.625	0.496	0.684	0.740	0.691	0.301
	2023	0.741	0.756	0.604	0.803	0.869	0.832	0.399
	2024	0.814	0.828	0.689	0.864	0.933	0.908	0.479
	2025	0.877	0.867	0.748	0.898	0.970	0.950	0.543
100 t TACC	2018	0	0	0	0	0	0	0
	2019	0	0	0	0.001	0.001	0.001	0
	2020	0.083	0.090	0.047	0.107	0.121	0.089	0.017
	2021	0.262	0.284	0.189	0.335	0.349	0.298	0.066
	2022	0.454	0.460	0.331	0.502	0.556	0.503	0.147
	2023	0.559	0.584	0.439	0.614	0.699	0.674	0.219
	2024	0.649	0.667	0.509	0.719	0.814	0.777	0.275
	2025	0.713	0.727	0.575	0.763	0.870	0.847	0.317
	2026	0.761	0.780	0.628	0.806	0.912	0.896	0.353
	2027	0.816	0.798	0.651	0.828	0.943	0.927	0.392
	2028	0.838	0.821	0.672	0.852	0.959	0.948	0.437
	2029	0.838	0.852	0.682	0.881	0.973	0.962	0.449
	2030	0.862	0.878	0.691	0.900	0.981	0.975	0.475
	2031	0.875	0.885	0.710	0.905	0.985	0.981	0.486
	2032	0.881	0.904	0.725	0.916	0.990	0.986	0.502
120 t TACC	2018	0	0	0	0	0	0	0
	2019	0	0	0	0	0	0	0
	2020	0.041	0.043	0.031	0.064	0.080	0.055	0.007
	2021	0.155	0.181	0.111	0.201	0.221	0.190	0.026
	2022	0.274	0.294	0.205	0.327	0.376	0.326	0.058
	2023	0.376	0.420	0.292	0.422	0.500	0.465	0.091
	2024	0.451	0.507	0.362	0.503	0.609	0.568	0.111
	2025	0.525	0.570	0.406	0.573	0.681	0.676	0.137
	2026	0.581	0.614	0.445	0.631	0.746	0.742	0.157
	2027	0.620	0.650	0.479	0.670	0.797	0.788	0.186
	2028	0.652	0.678	0.495	0.694	0.821	0.829	0.203
	2029	0.687	0.706	0.524	0.715	0.859	0.872	0.217
	2030	0.698	0.714	0.536	0.758	0.876	0.884	0.223
	2031	0.714	0.746	0.543	0.771	0.894	0.901	0.245
	2032	0.724	0.767	0.560	0.776	0.915	0.917	0.246
	2033	0.745	0.774	0.551	0.796	0.924	0.932	0.238
	2034	0.758	0.771	0.572	0.812	0.931	0.941	0.245
	2035	0.770	0.790	0.579	0.816	0.943	0.953	0.253
	2036	0.783	0.794	0.581	0.809	0.952	0.961	0.250
	2037	0.781	0.809	0.607	0.812	0.963	0.966	0.251
140 t TACC	2018	0	0	0	0	0	0	0
	2019	0	0	0	0	0	0	0
	2020	0.016	0.025	0.019	0.036	0.044	0.037	0.002
	2021	0.090	0.104	0.059	0.112	0.135	0.115	0.014
	2022	0.147	0.194	0.119	0.192	0.243	0.212	0.023
	2023	0.229	0.253	0.171	0.268	0.344	0.291	0.035
	2024	0.280	0.335	0.210	0.314	0.395	0.382	0.034
	2025	0.326	0.385	0.234	0.364	0.482	0.453	0.041
	2026	0.374	0.430	0.259	0.428	0.525	0.529	0.048
	2027	0.415	0.470	0.298	0.459	0.584	0.600	0.061
	2028	0.434	0.491	0.332	0.492	0.625	0.652	0.074
	2029	0.458	0.507	0.349	0.503	0.664	0.691	0.081
	2030	0.491	0.515	0.356	0.534	0.704	0.716	0.082
	2031	0.493	0.513	0.356	0.555	0.732	0.739	0.085
	2032	0.512	0.522	0.377	0.574	0.748	0.757	0.072
	2033	0.527	0.554	0.396	0.586	0.761	0.776	0.076
	2034	0.543	0.576	0.380	0.589	0.780	0.785	0.085
	2035	0.559	0.591	0.371	0.593	0.794	0.812	0.089
	2036	0.565	0.612	0.372	0.603	0.818	0.829	0.090
	2037	0.567	0.615	0.404	0.608	0.831	0.846	0.085

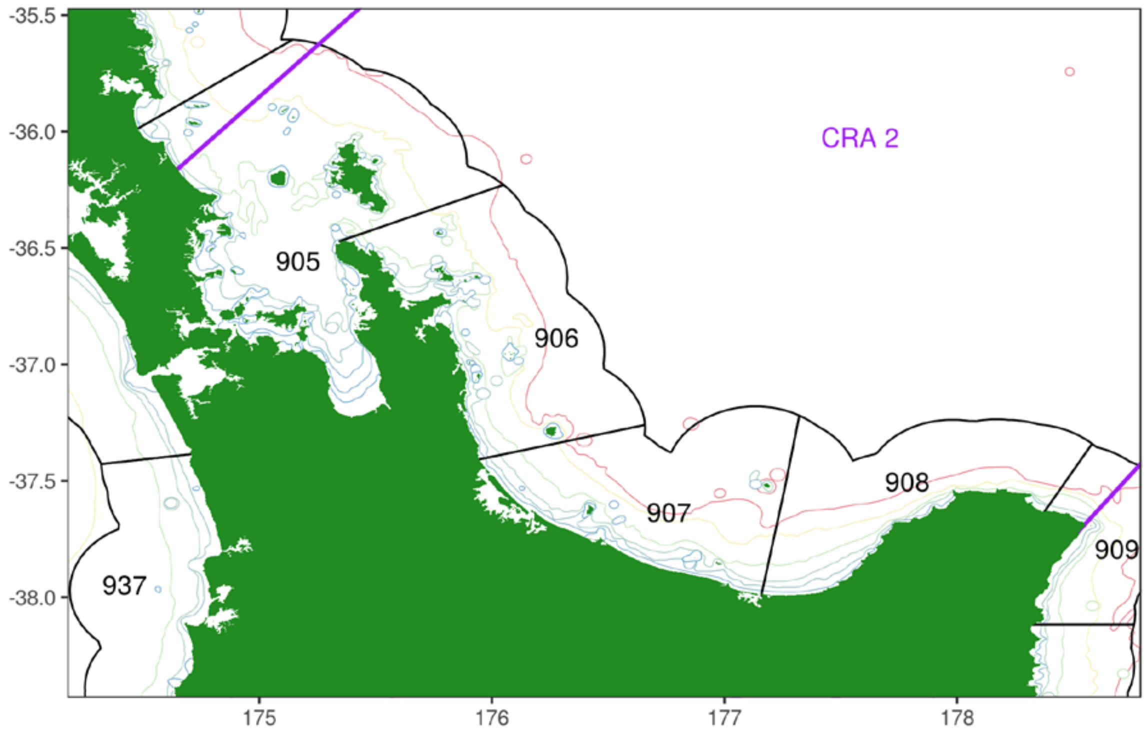


Figure 1: Map of the upper North Island, showing location of CRA 2 and its statistical areas.

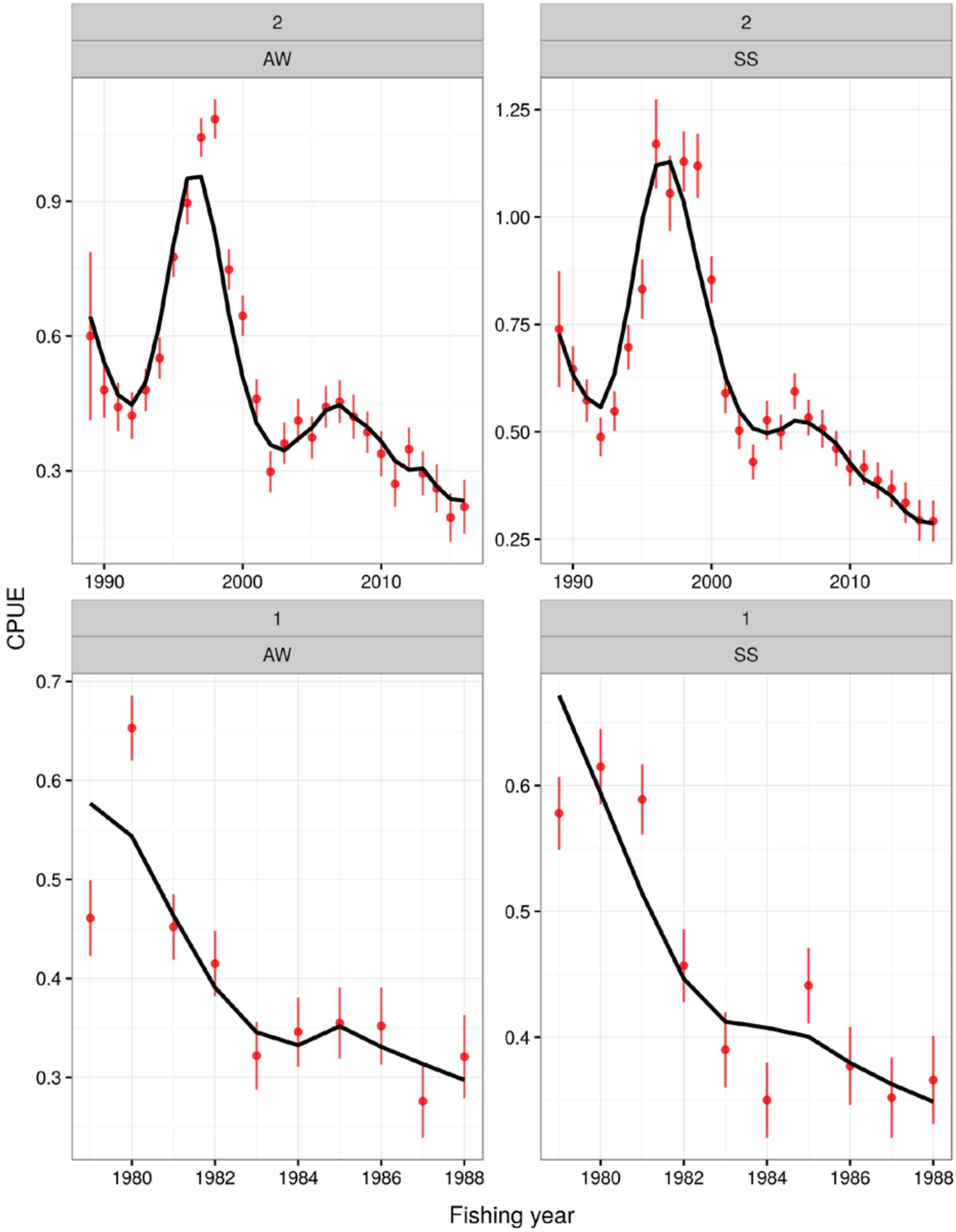


Figure 2: CRA 2 base case MAP: fit to CPUE during autumn-winter (AW, left panels) and spring-summer (SS, right panels) for 1979–1988 (the FSU data, bottom panels) and 1989–2016 (the CELR data, top panels).

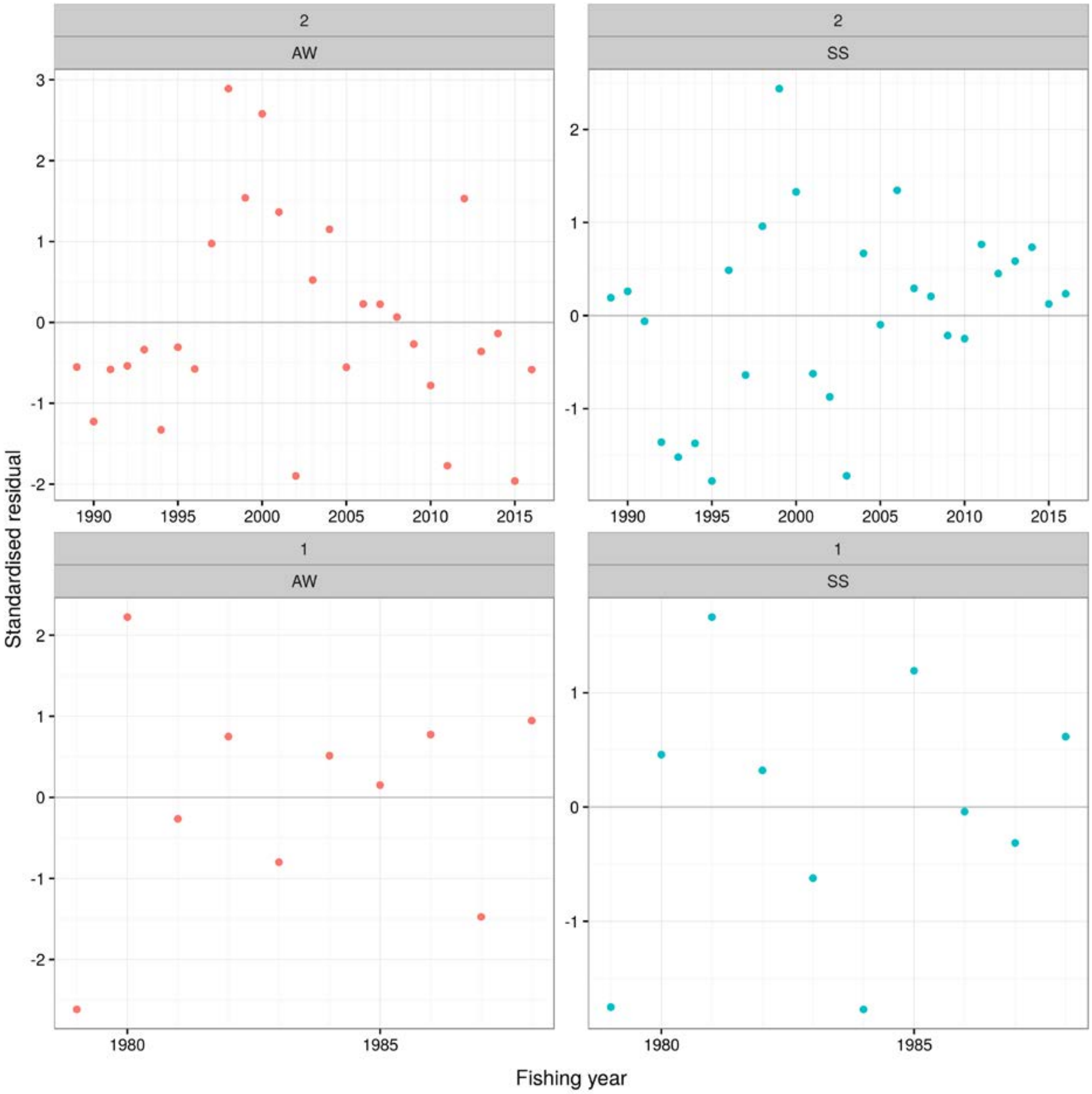


Figure 3: CRA 2 base case MAP: CPUE residuals during autumn-winter (AW, left panels) and spring-summer (SS, right panels) for 1979–1988 (the FSU data, bottom panels) and 1989–2016 (the CELR data, top panels).

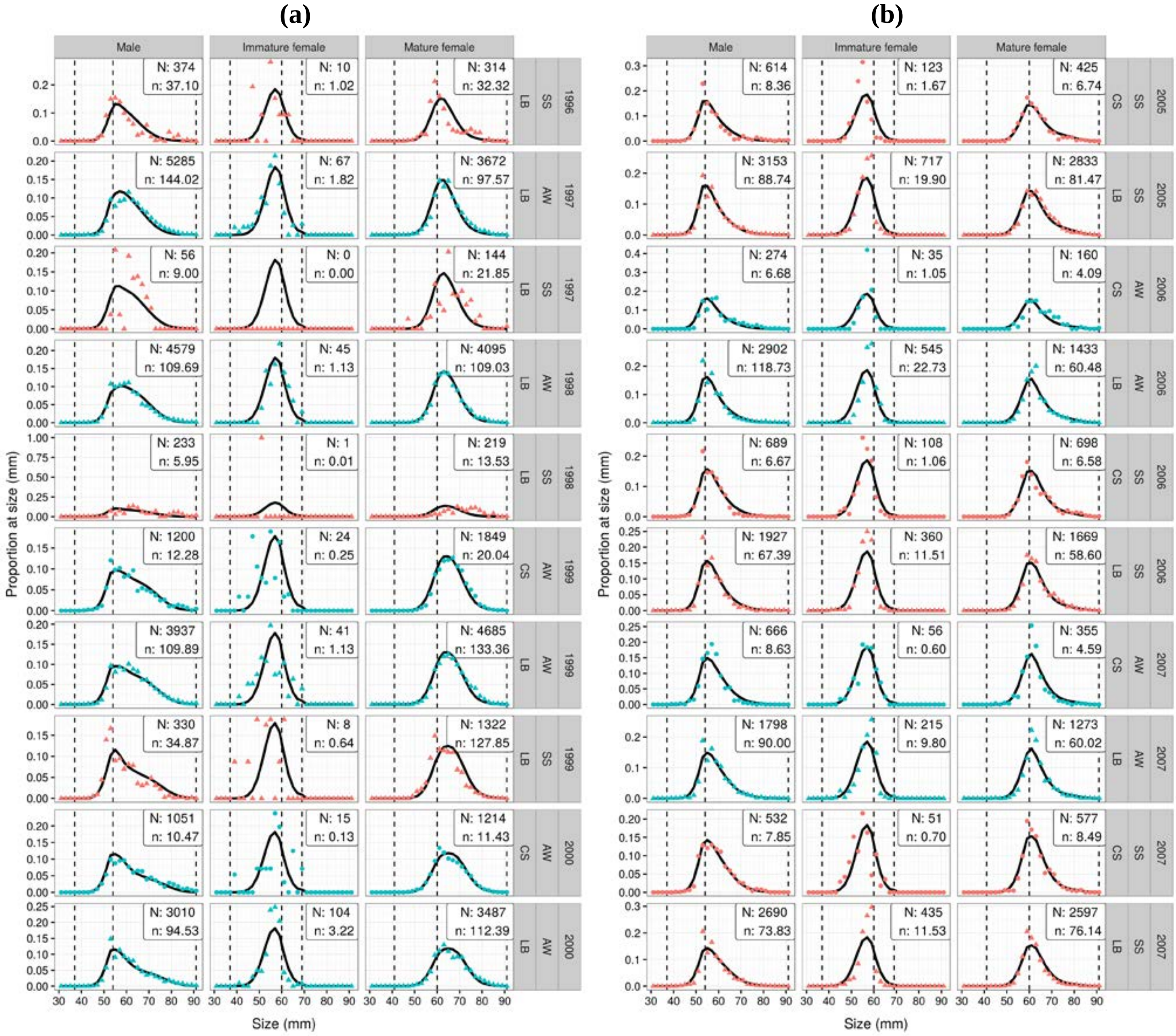


Figure 4: CRA 2 base case MAP: model fits to LFs for each sex category from (a) 1996 SS LB – 2000 AW LB; (b) 2005 SS CS – 2007 SS LB. For each panel "N" is the number of individuals measured and "n" is the effective sample size used in the stock assessment model.

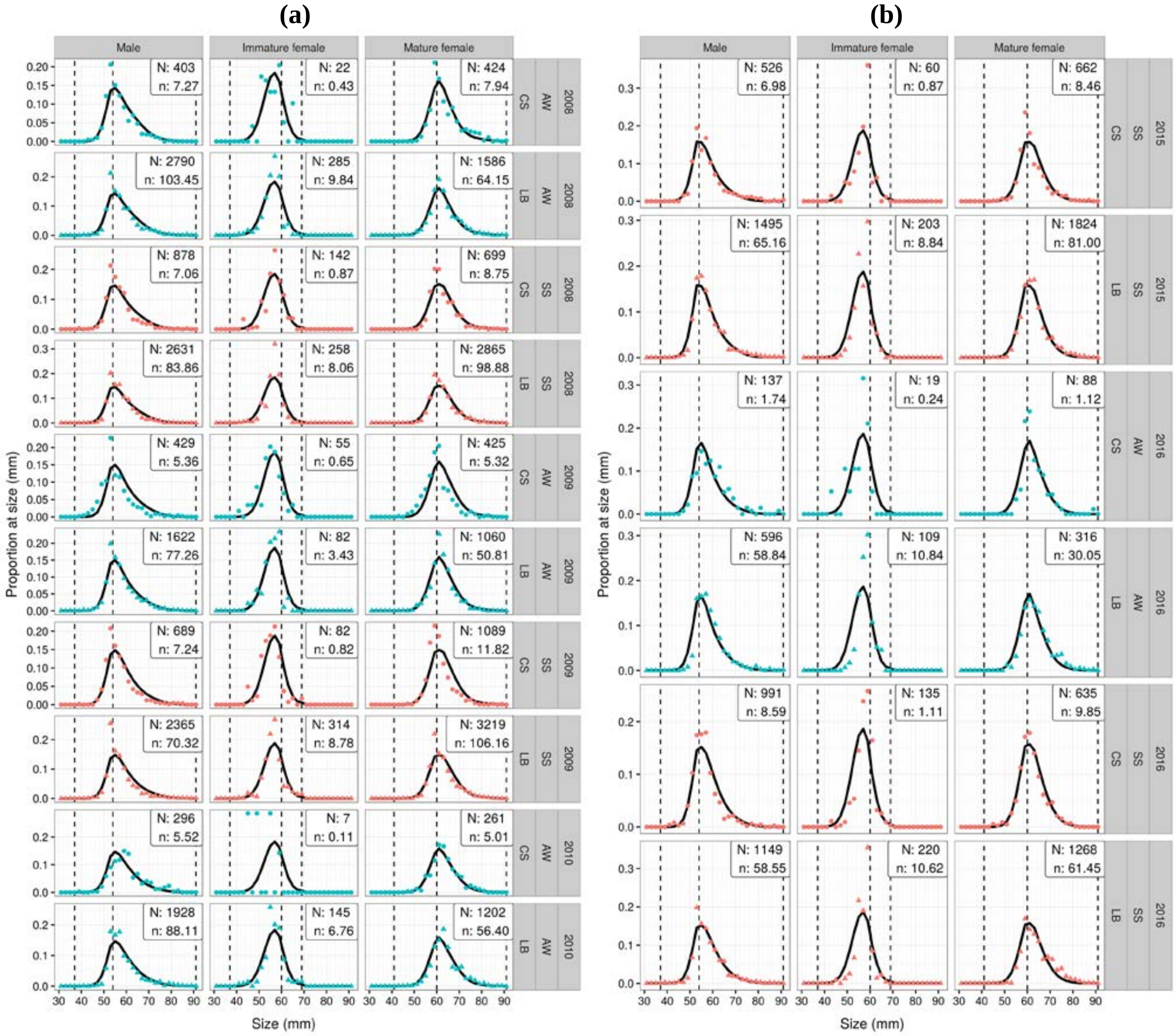


Figure 5: CRA 2 base case MAP: Model fits to LFs from (a) 2008 AW CS – 2010 AW LB; (b) 2015 SS CS – 2016 SS LB.

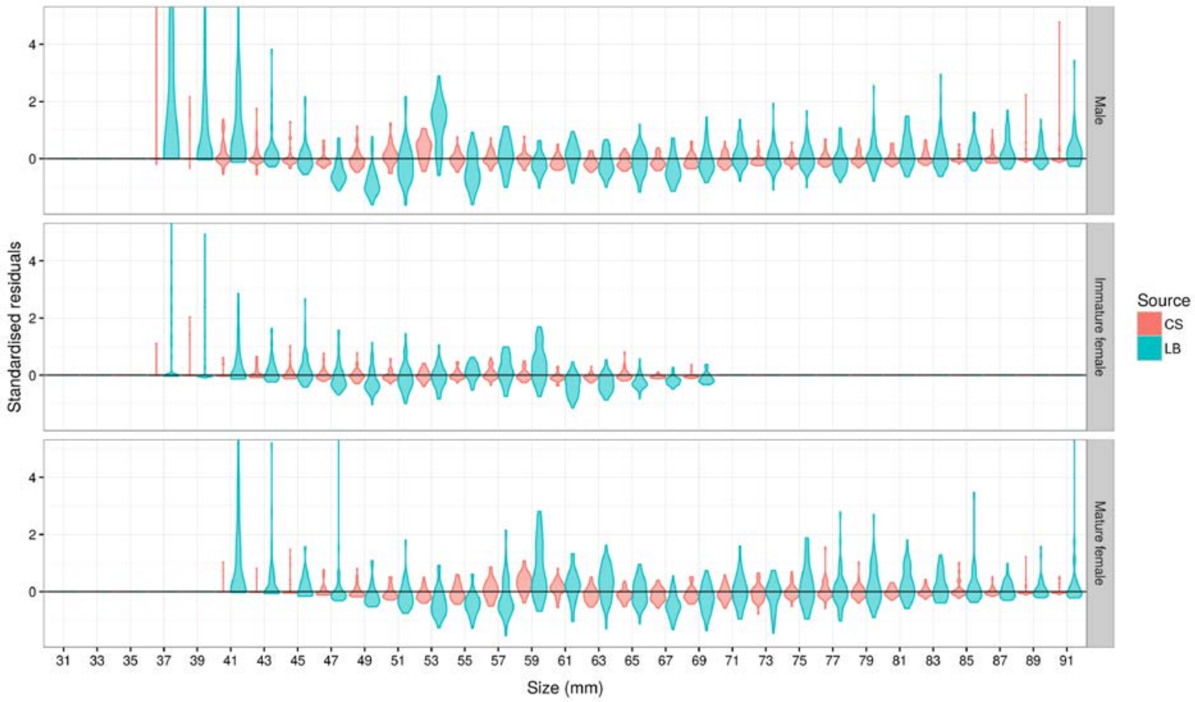


Figure 6: CRA 2 base case: MAP residuals from fit to the LF data, showing residuals by sex, 2 mm size bin and sampling source.

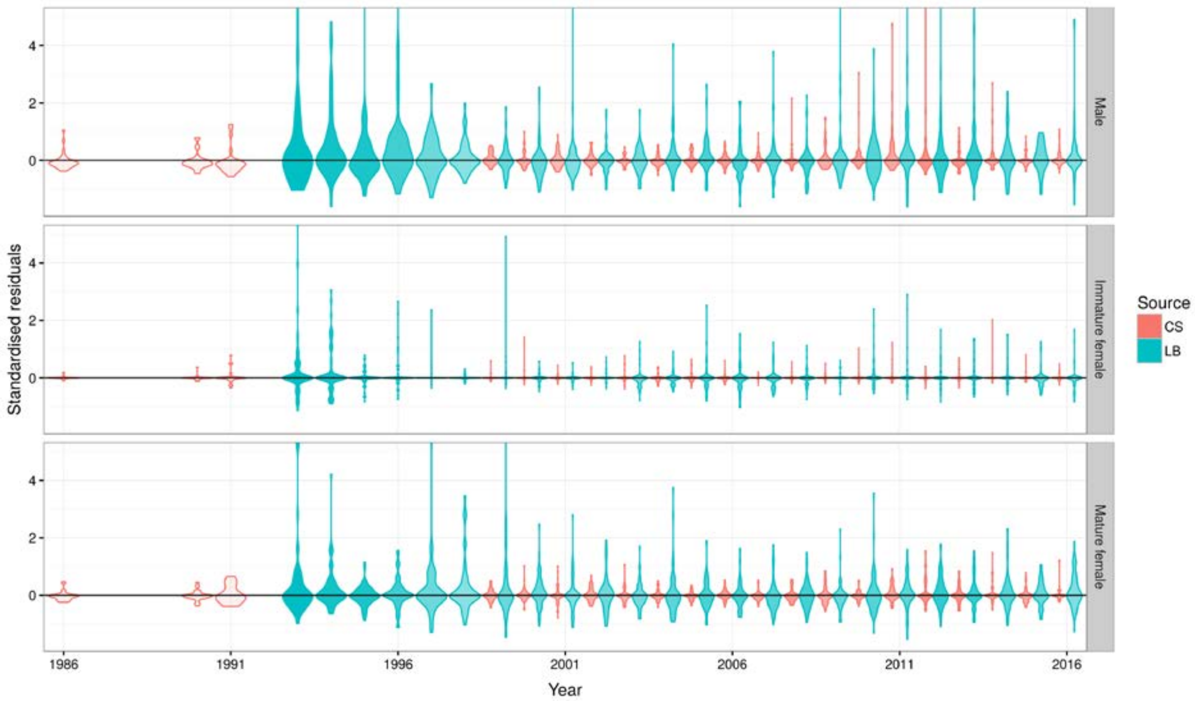


Figure 7: CRA 2 base case: MAP residuals from fit to the LF data, showing residuals by sex, year and sampling source.

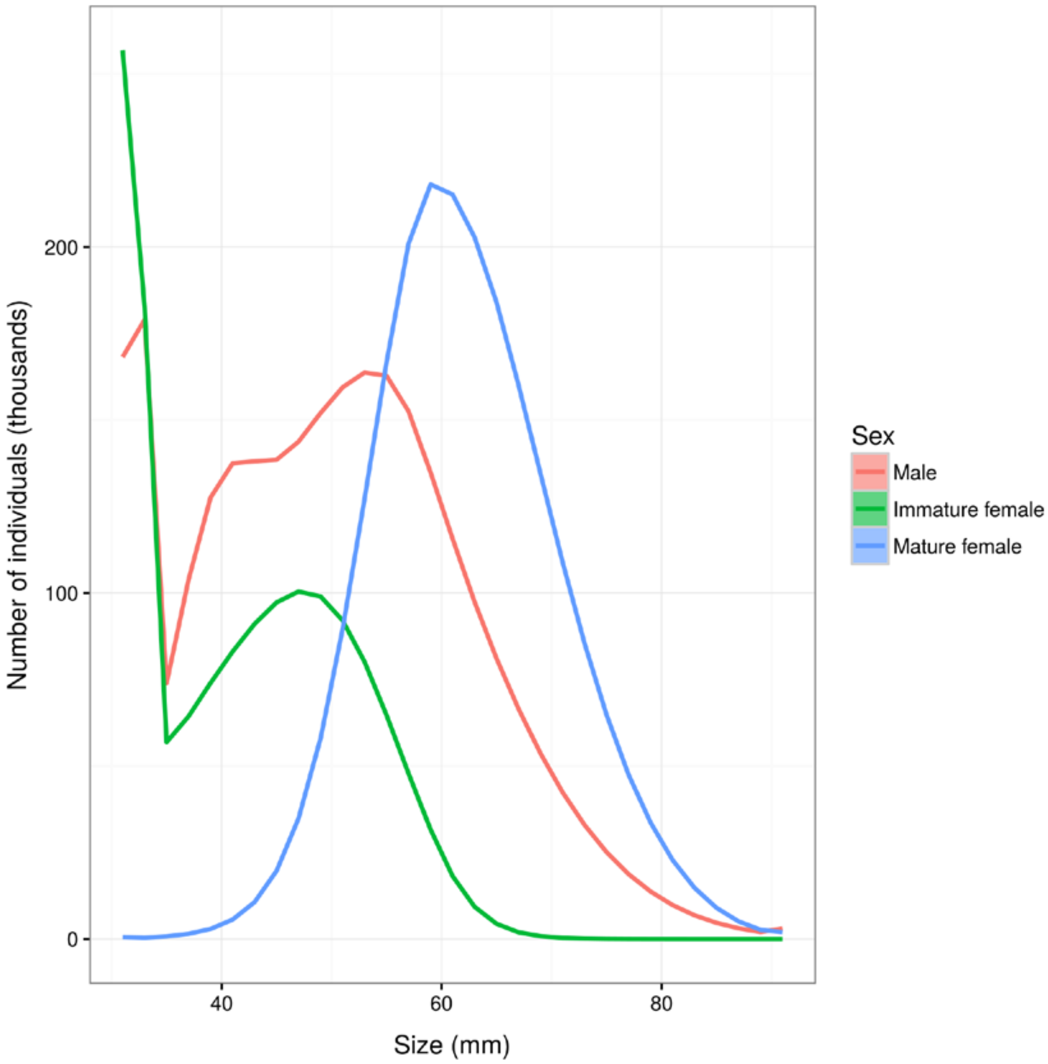


Figure 8: CRA 2 base case MAP: size distributions of the unfished stock by sex category.

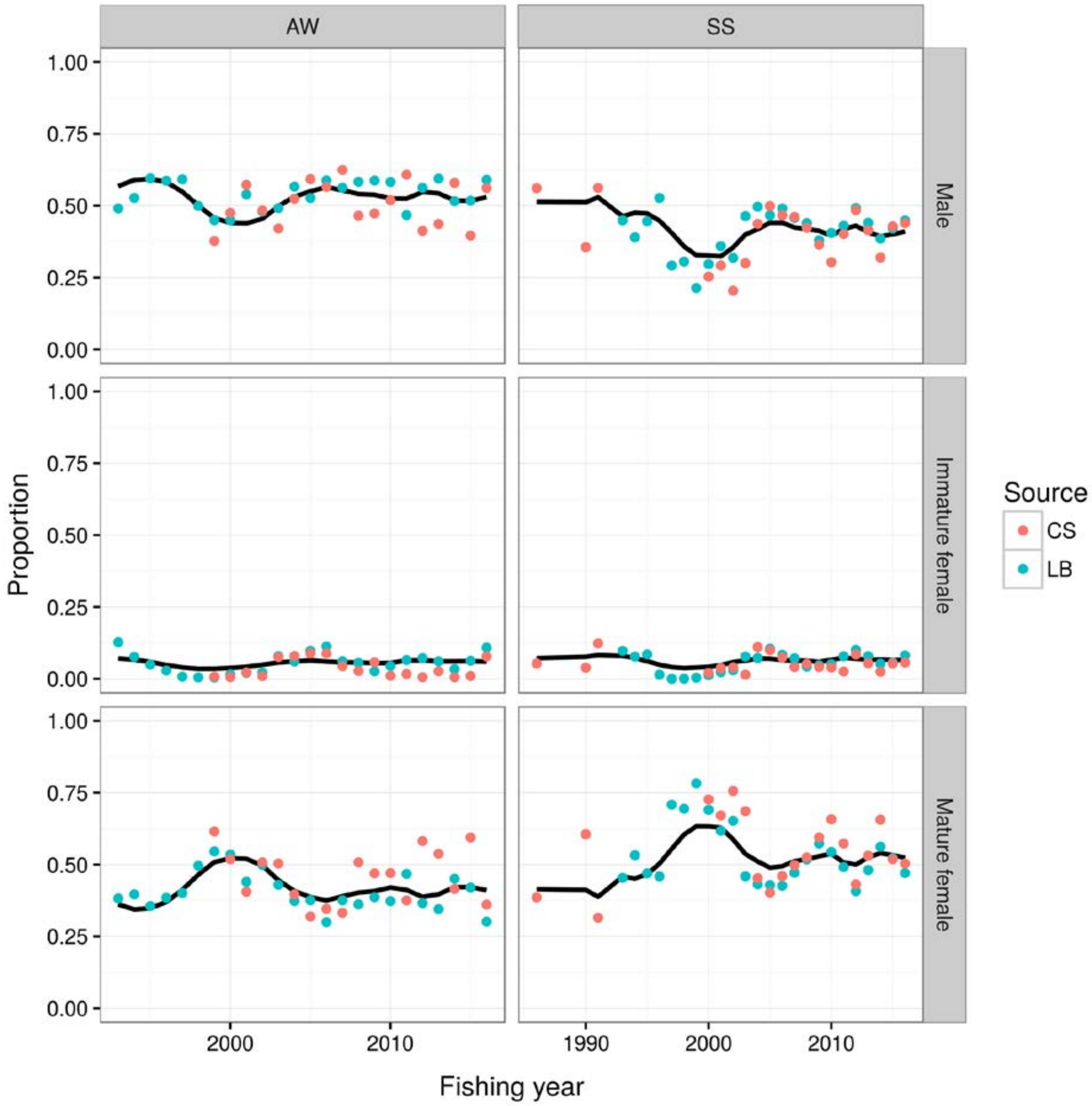


Figure 9: CRA 2 base case MAP: model predictions to proportion-at-sex in AW and SS by sampling source: LB – logbooks, CS – observer catch sampling.

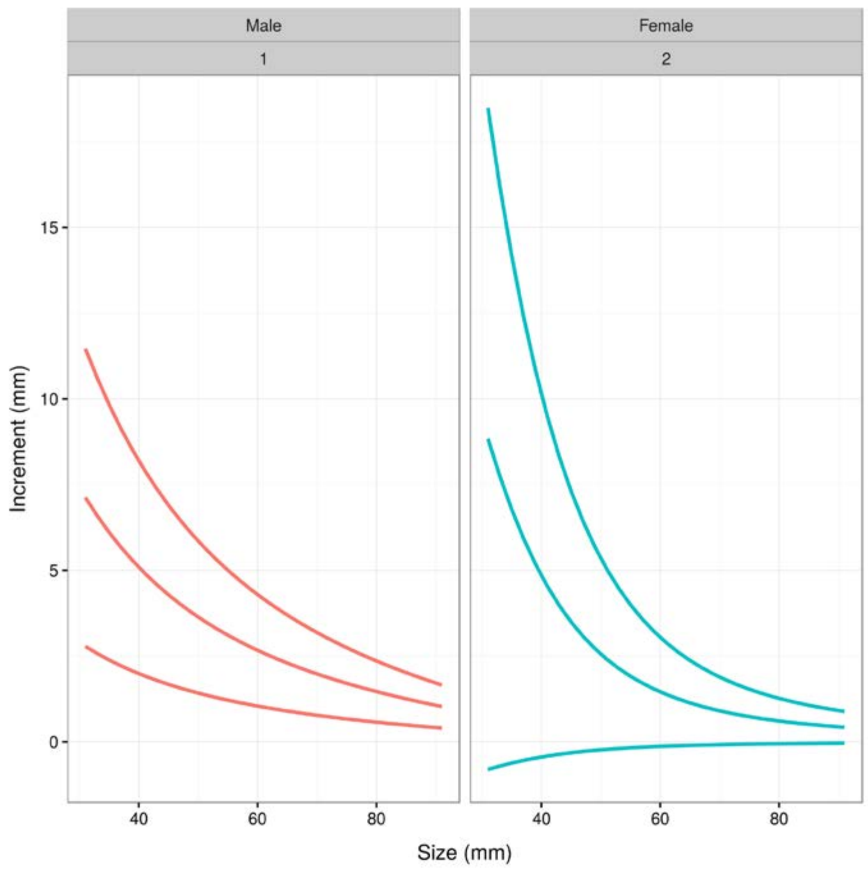


Figure 10: CRA 2 base case MAP: predicted increments-at-length and their standard deviations.

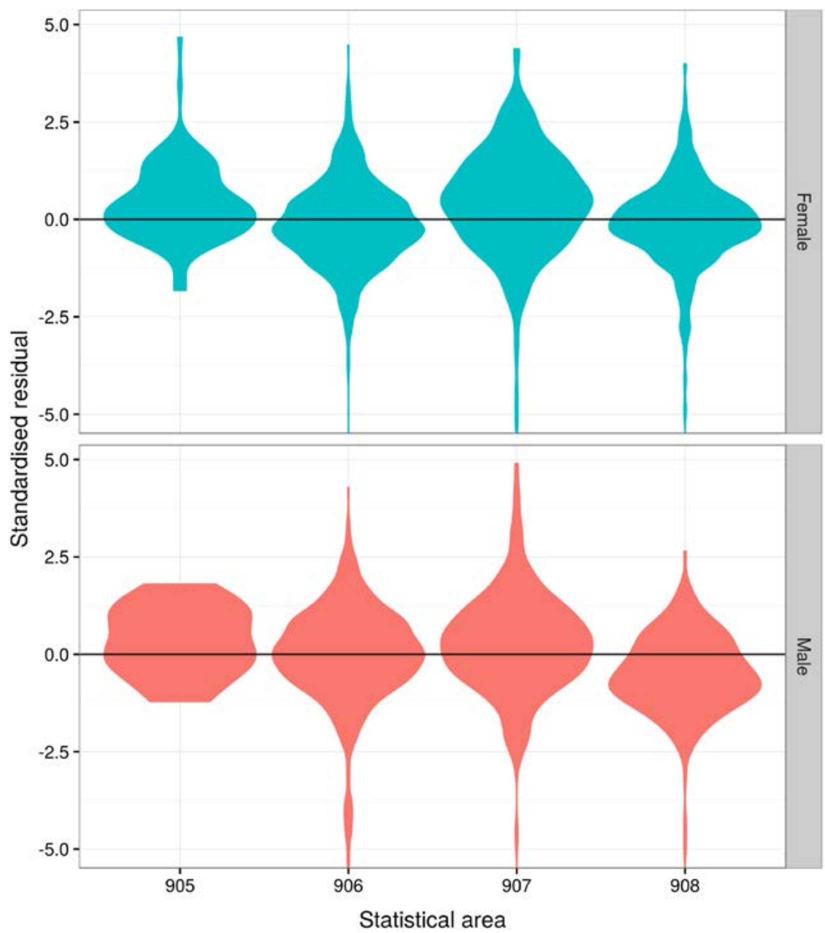


Figure 11: CRA 2 base case MAP: distribution of standardised residuals from the fit to tag data by sex and statistical area of release.

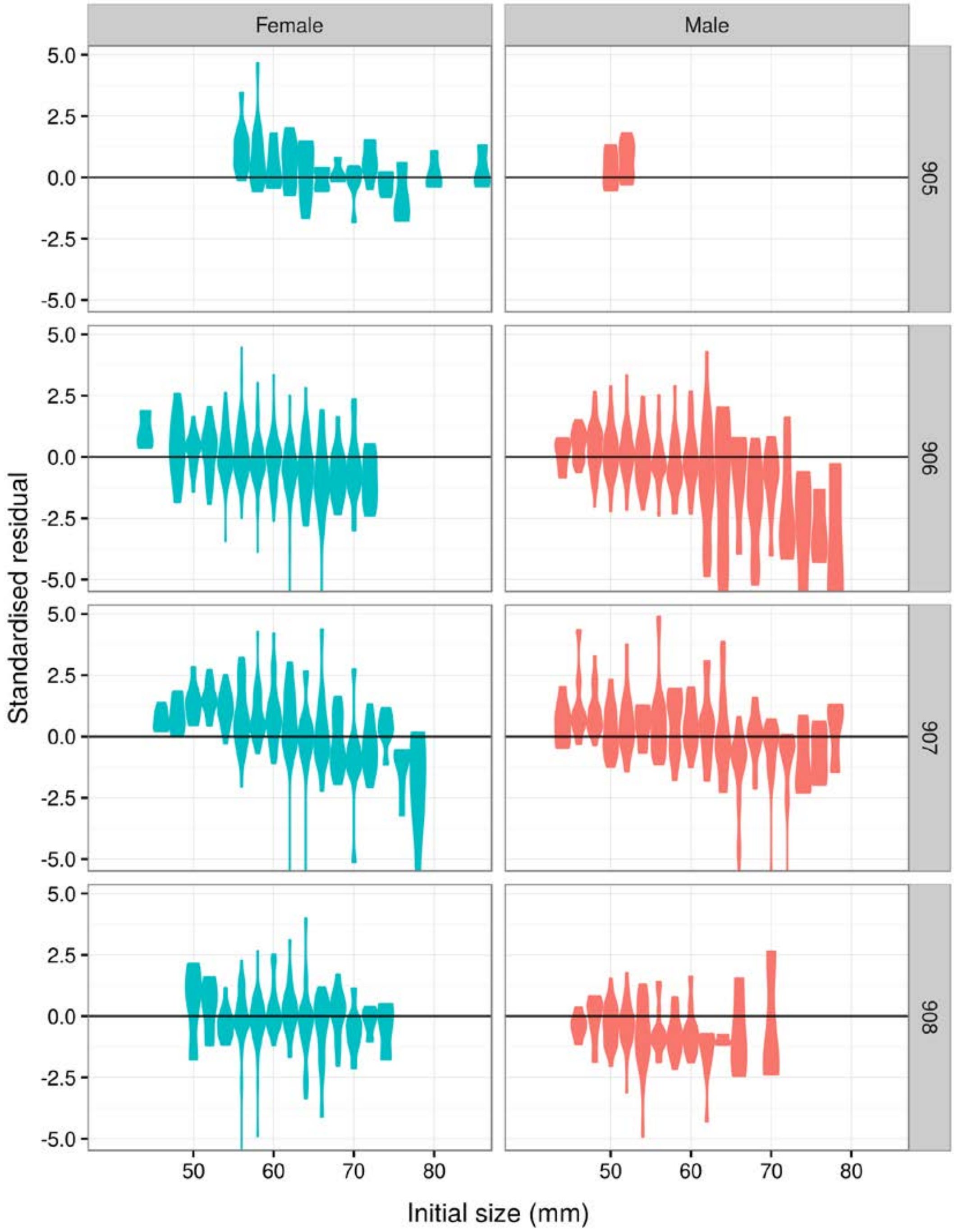


Figure 12: CRA 2 base case MAP: distribution of standardised residuals from the fit to tags by sex, size class and statistical area of release.

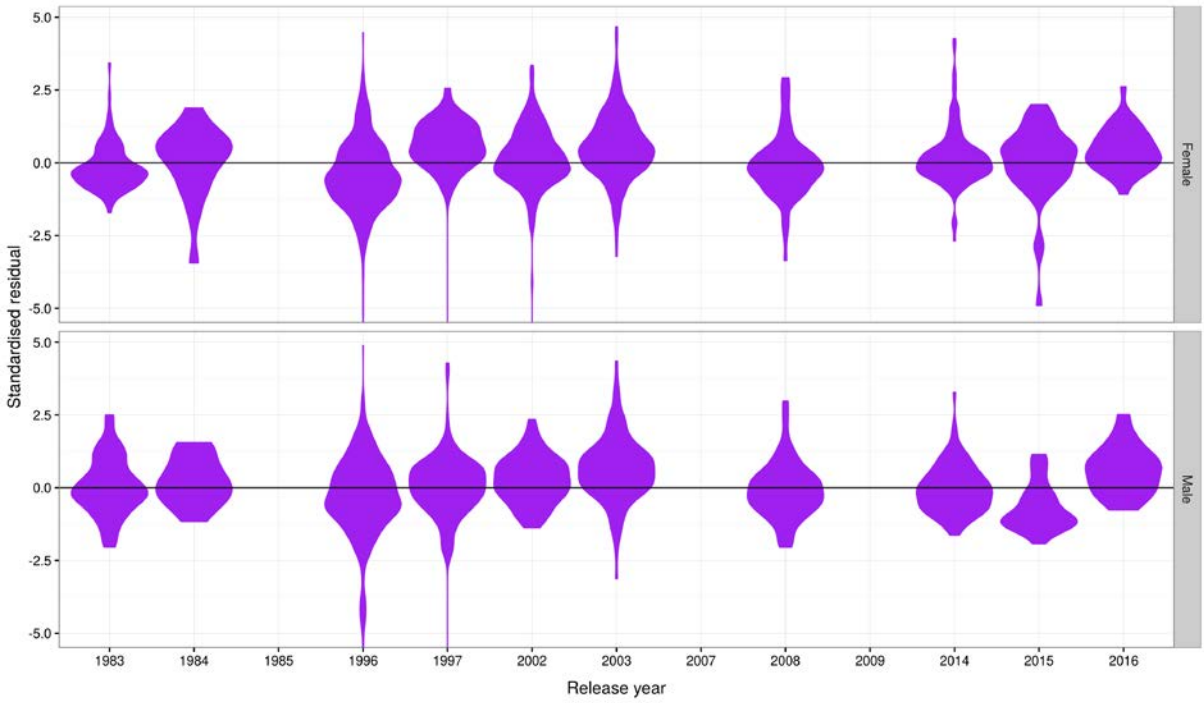


Figure 13: CRA 2 base case MAP: distribution of standardised residuals from the fit to tags by sex and release year.

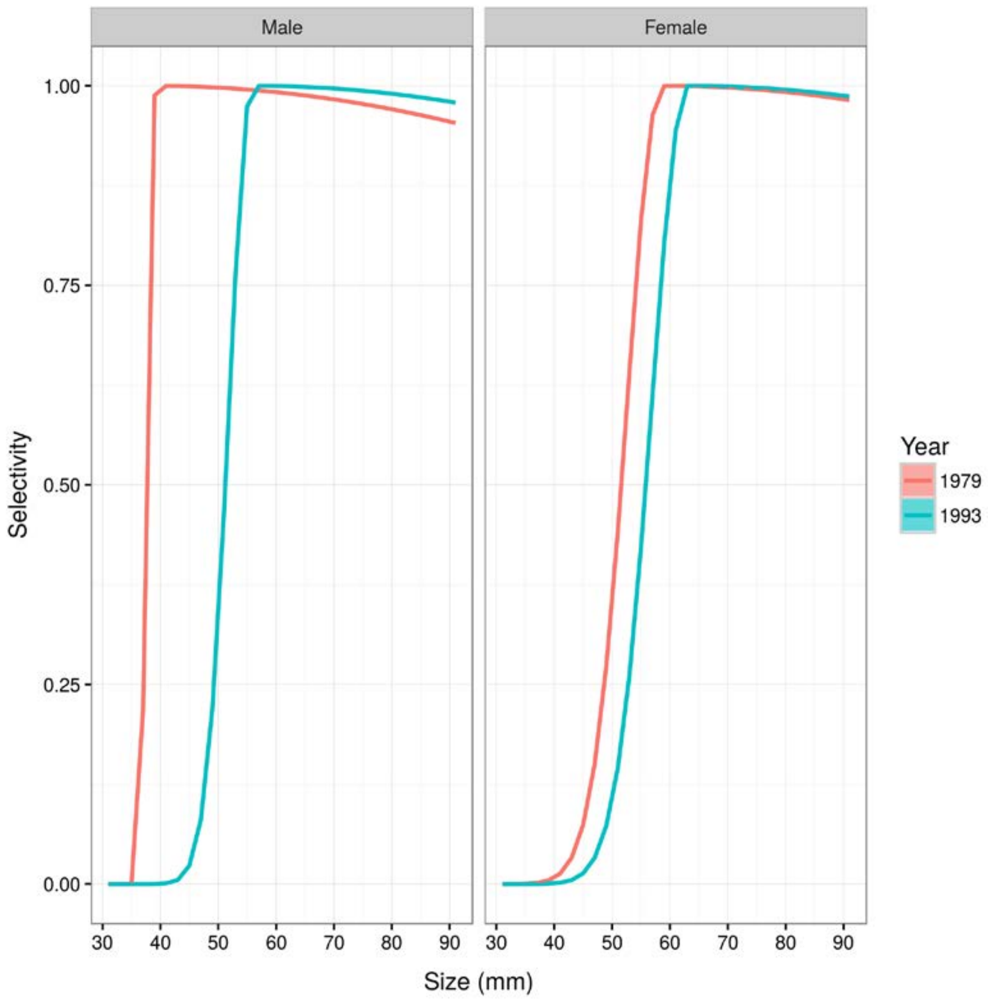


Figure 14: CRA 2 base case MAP: selectivity by sex during two periods.

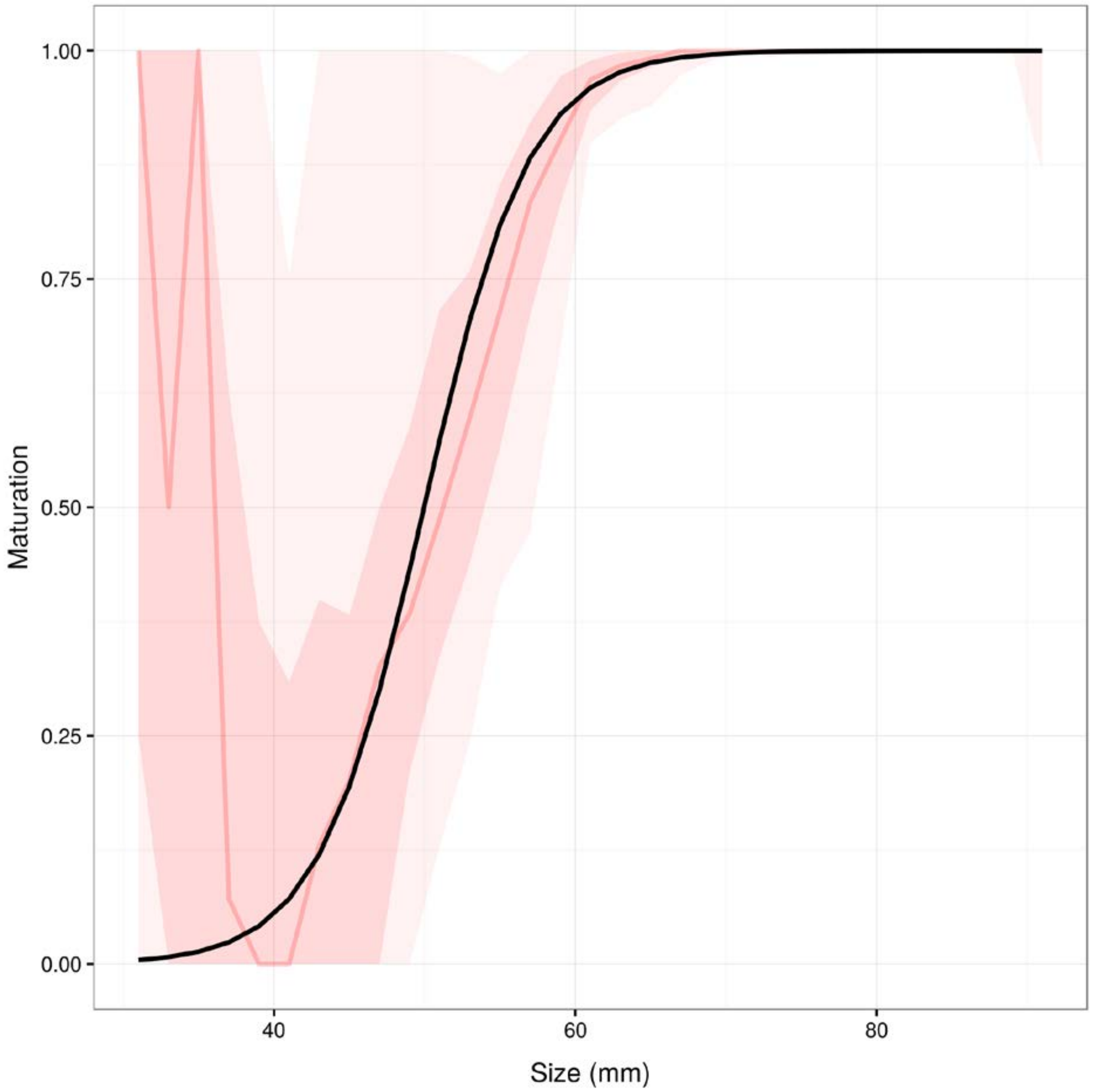


Figure 15: CRA 2 base case MAP: female maturity with model fit plotted as a black line and the empirical proportion mature at size in pink (there are very few data records below 40 mm). Bands delimit 95% confidence interval of empirical proportion mature.

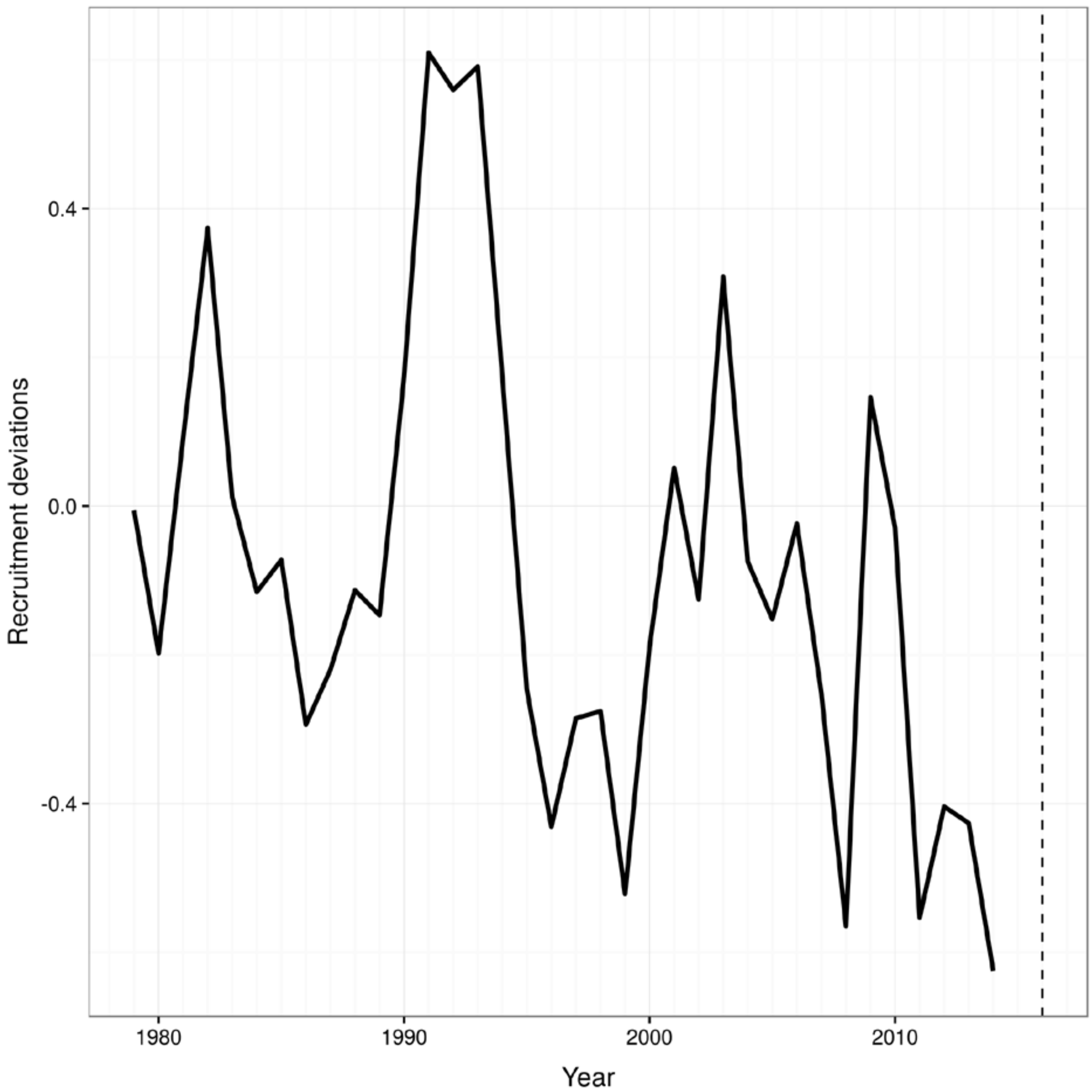


Figure 16: CRA 2 base case MAP: recruitment deviations to the model in each year. The dashed vertical line represents the start of the projection period.

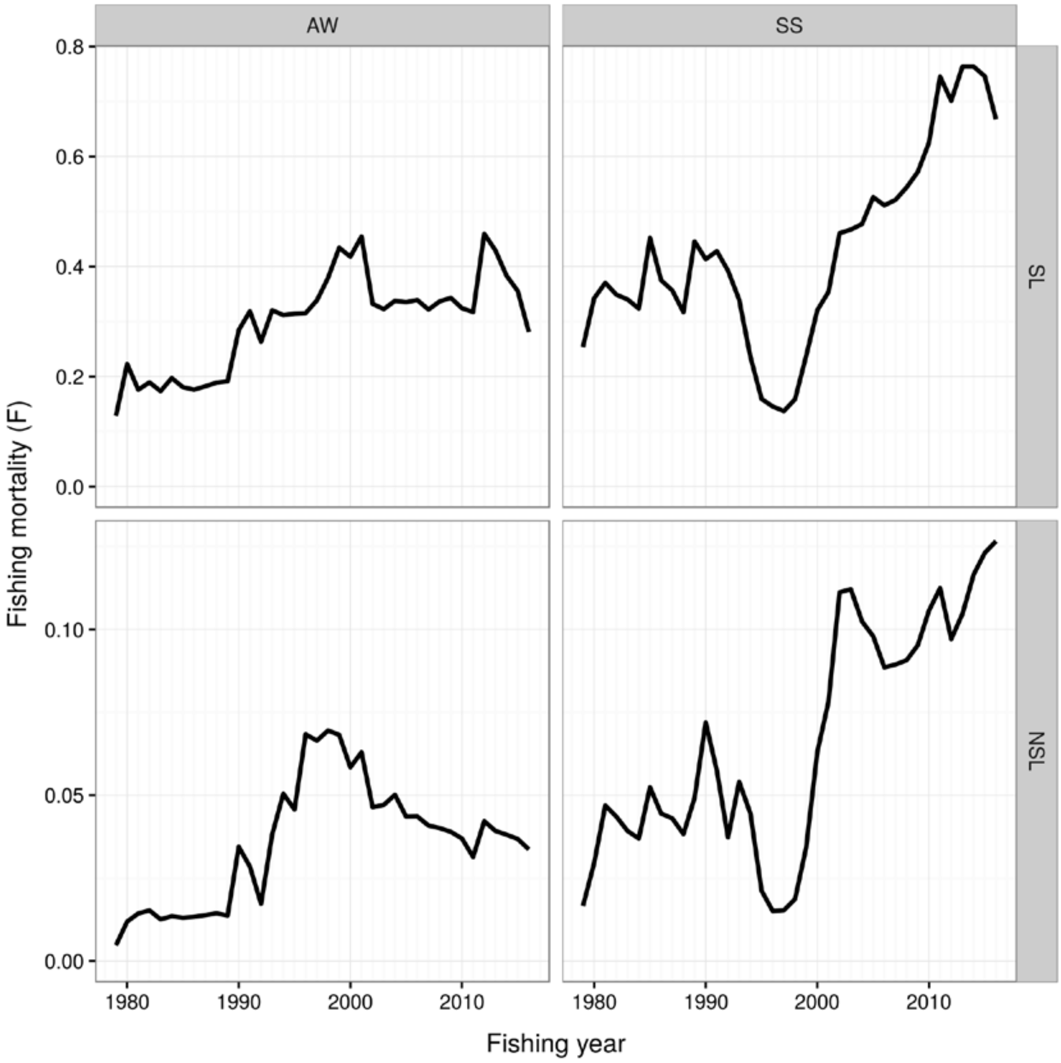


Figure 17: CRA 2 base case MAP: fishing mortality (F) in the size limited (SL) and non-size limited (NSL) fisheries during the autumn-winter (AW) and spring-summer (SS).

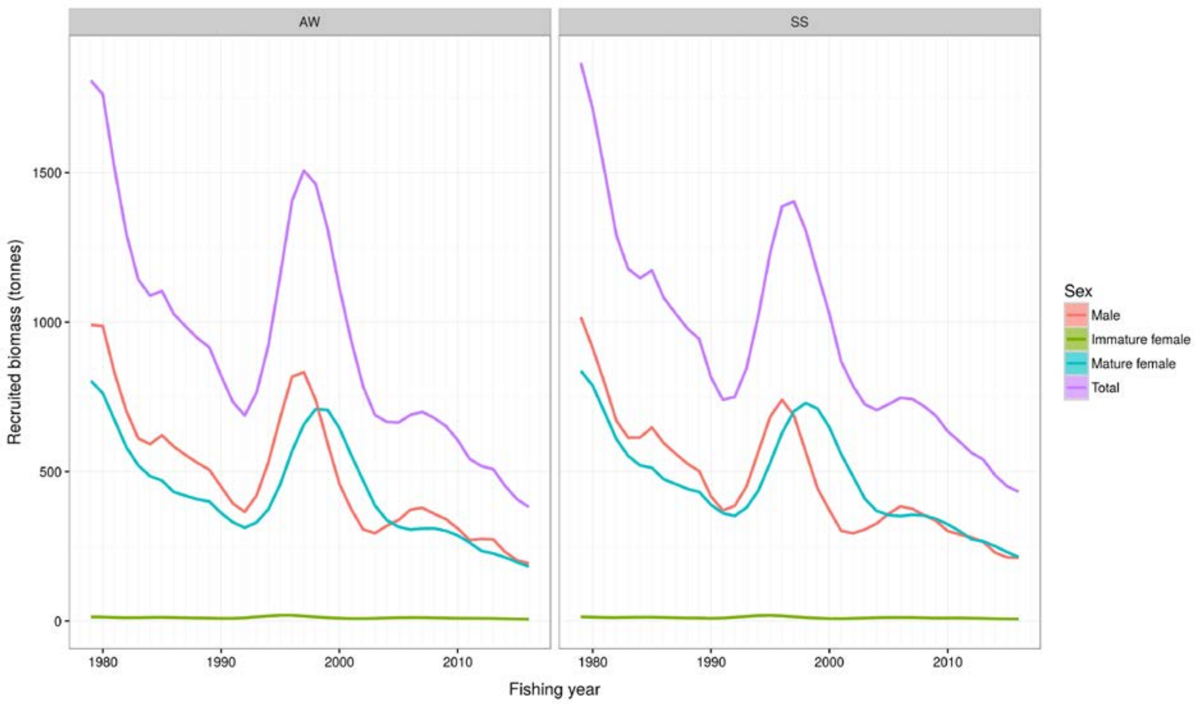


Figure 18: CRA 2 base case MAP: trajectory of recruited biomass by sex category and season. The total biomass across all three sex categories is shown as a purple line.

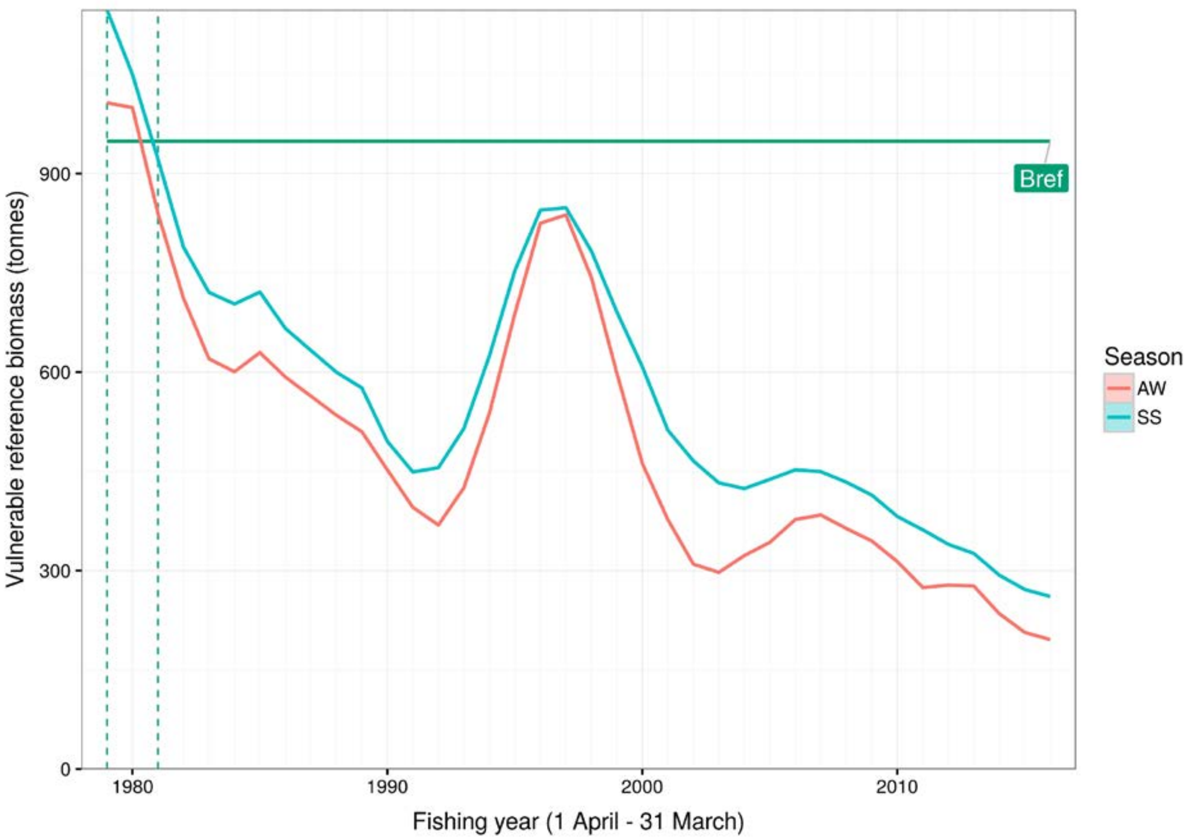


Figure 19: CRA 2 base case MAP: reference biomass over model reconstruction period and season. Upper horizontal line is *B_{REF}* (average AW vulnerable biomass during 1979–1981 reference period, identified using green vertical lines). The biomass in each year uses the selectivities and MLS appropriate to period 2.

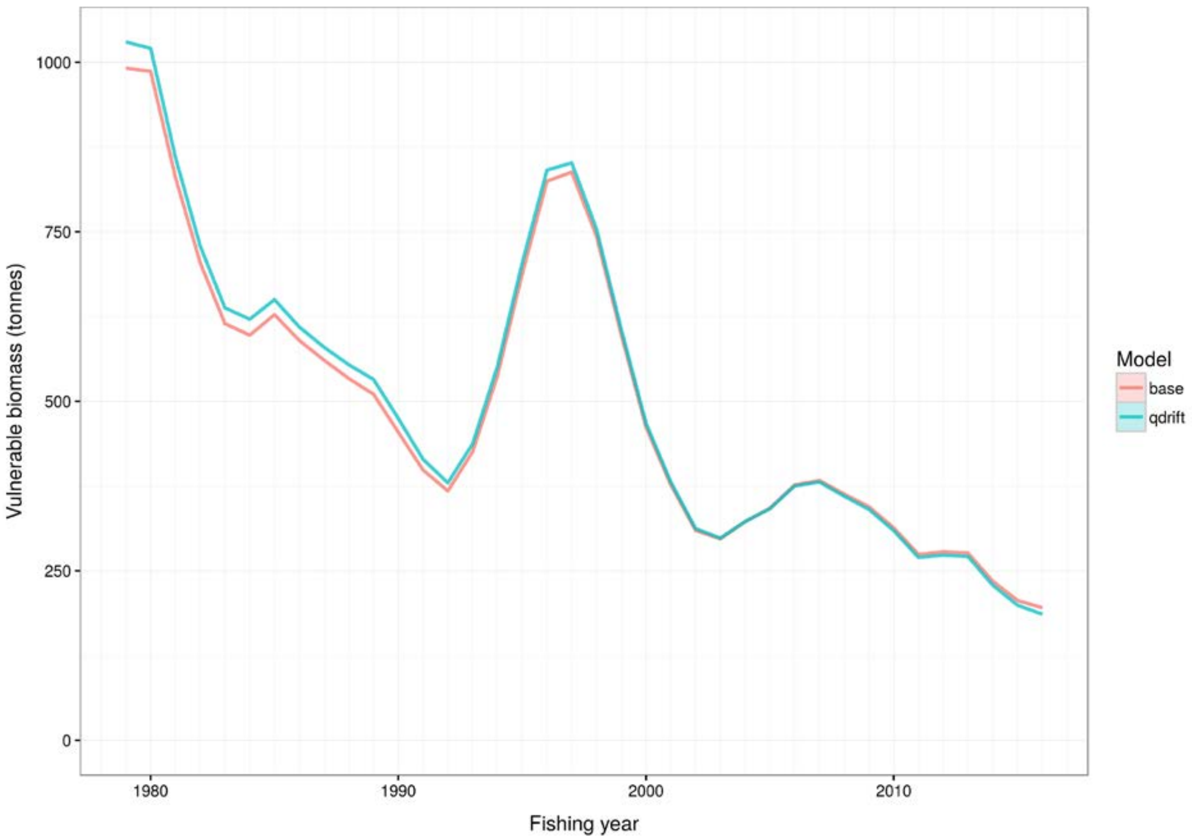


Figure 20: Comparison of two MAP runs: base case using revised CELR CPUE series with *q*-drift sensitivity run which also used the revised CELR CPUE series.

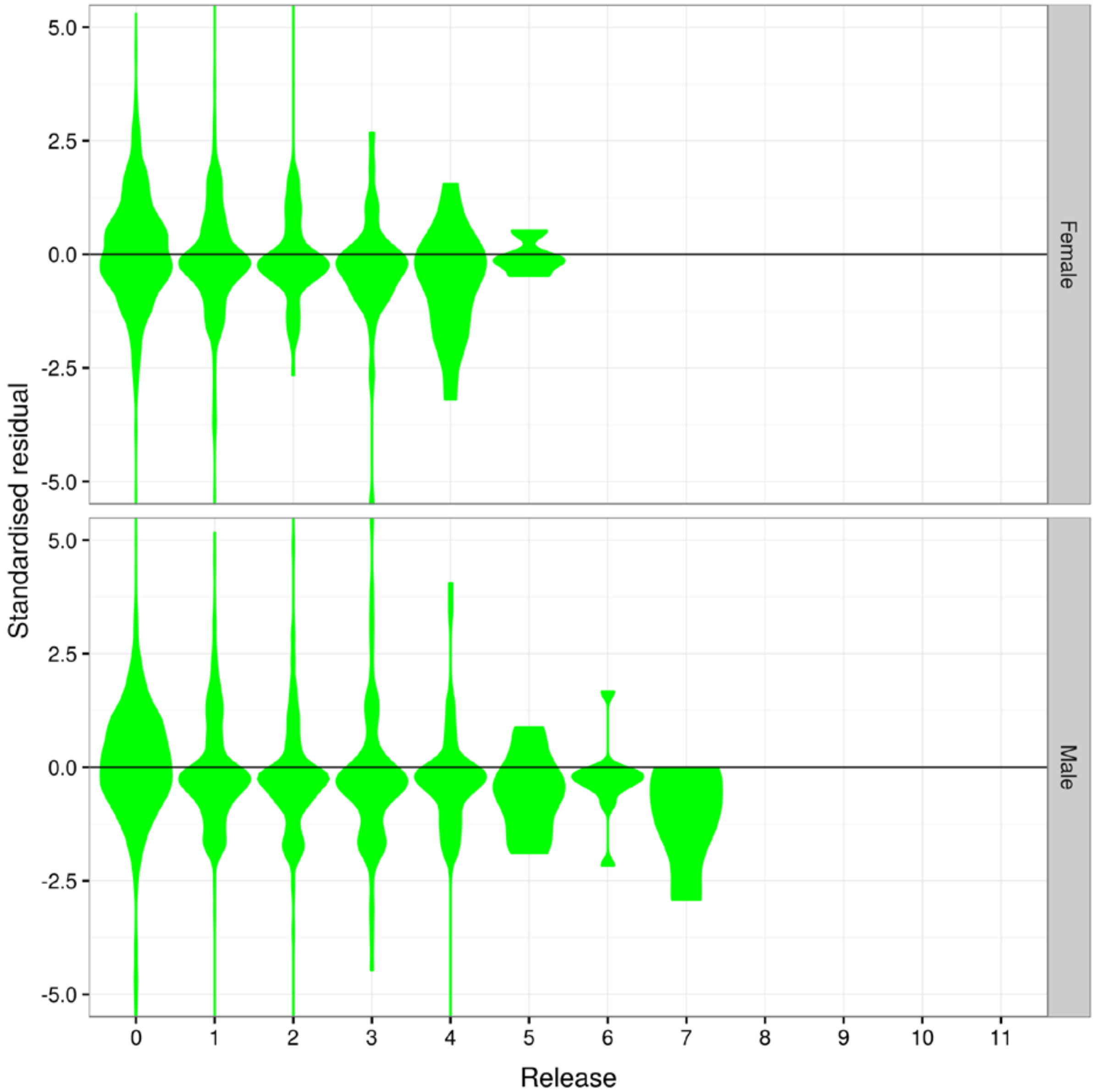


Figure 21: CRA 2 “all tags” MAP sensitivity: tag residuals by re-release number.

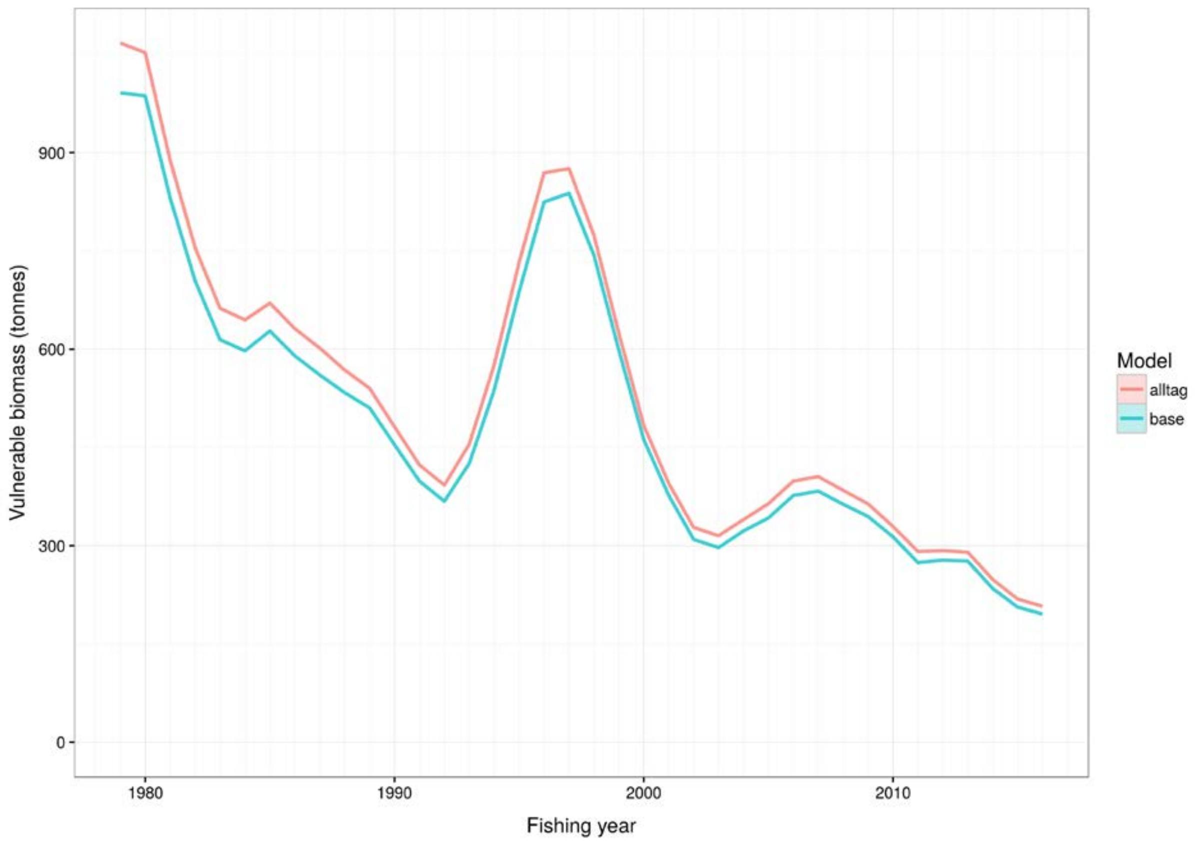


Figure 22: Comparison of the vulnerable biomass trajectories between the base case model and the model based on all tag releases (not just the initial release).

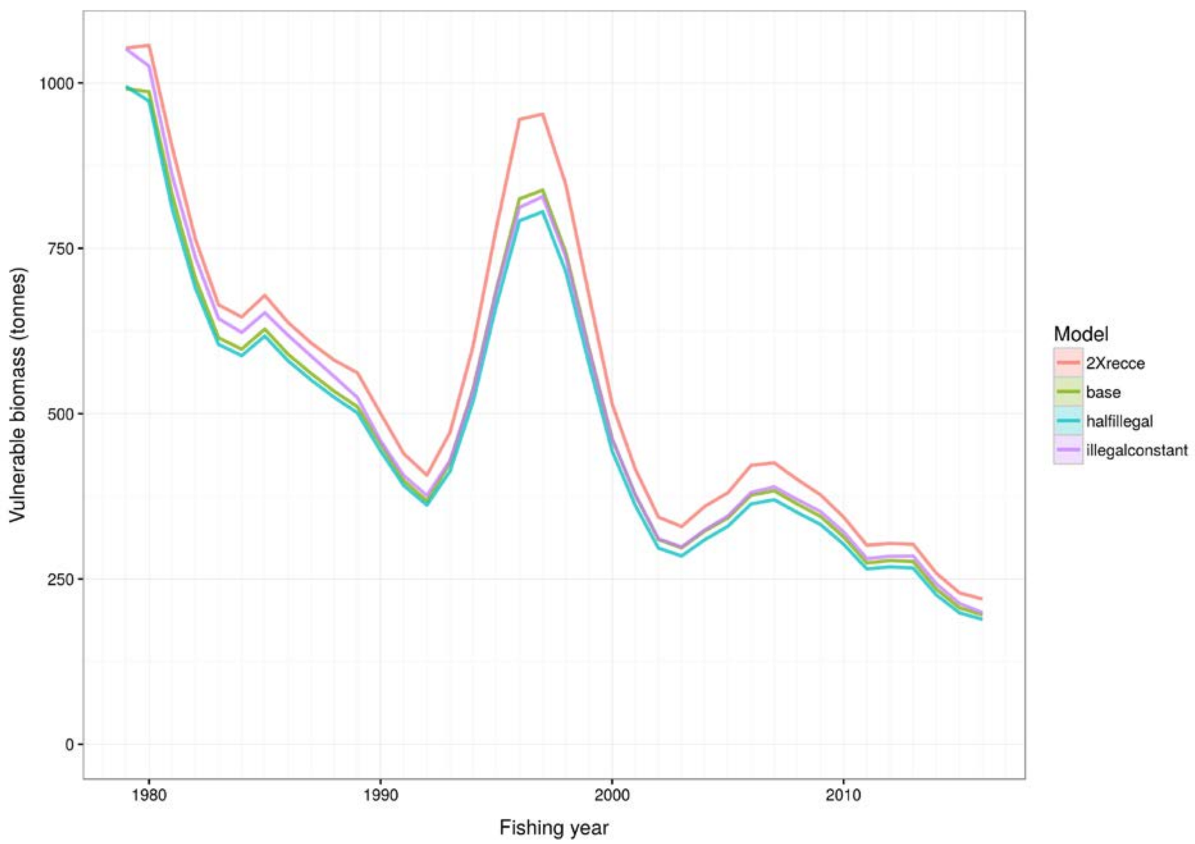


Figure 23: Comparison of the vulnerable biomass trajectories for the base case and three sensitivity runs which altered the underlying catch history.

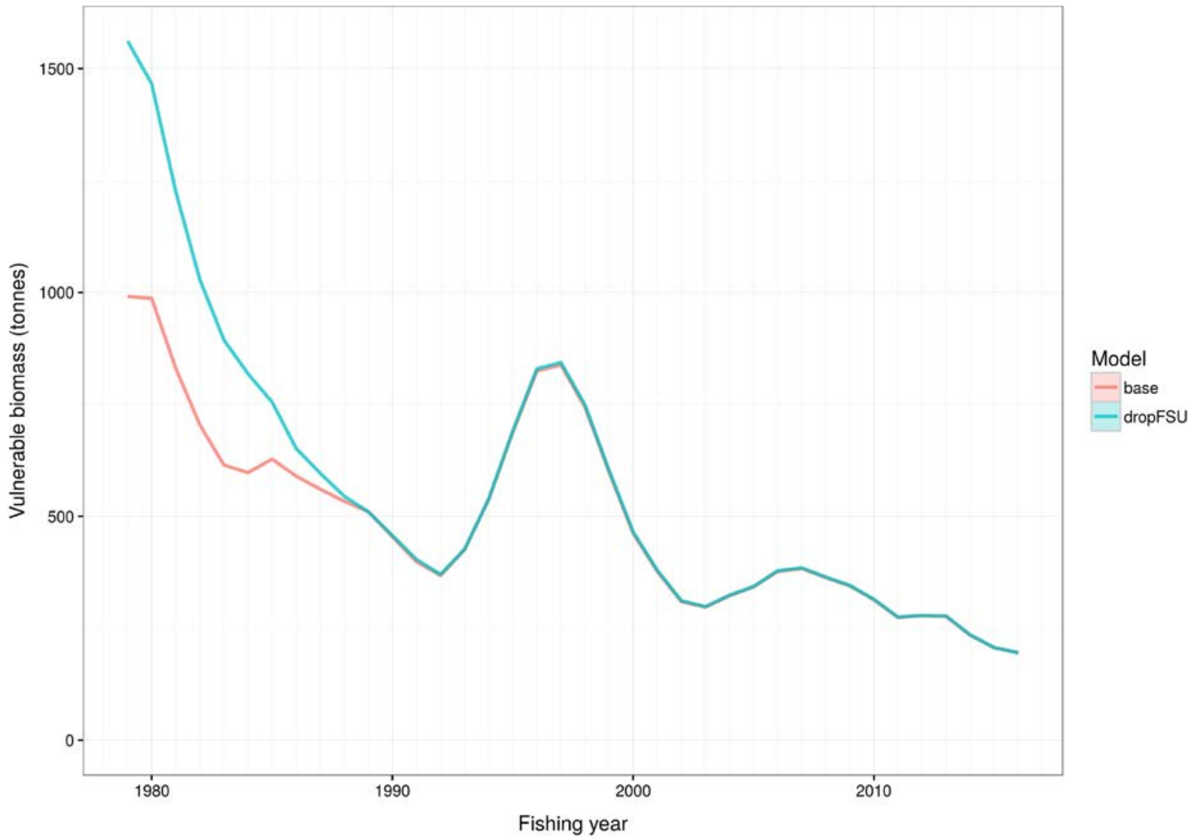


Figure 24: Comparison of the base case run and "drop FSU" where the model did not fit to the FSU CPUE time series.

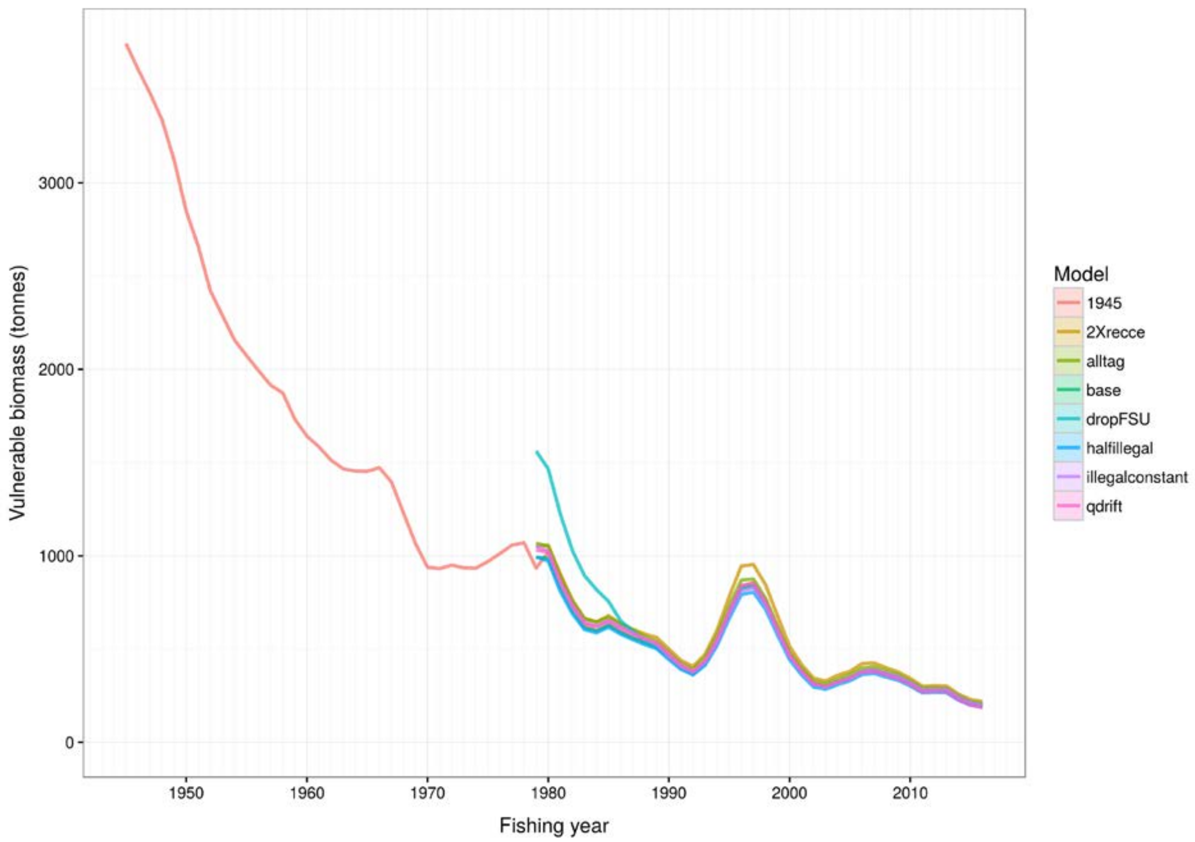


Figure 25: Comparison of vulnerable biomass for the base case and all sensitivity runs.

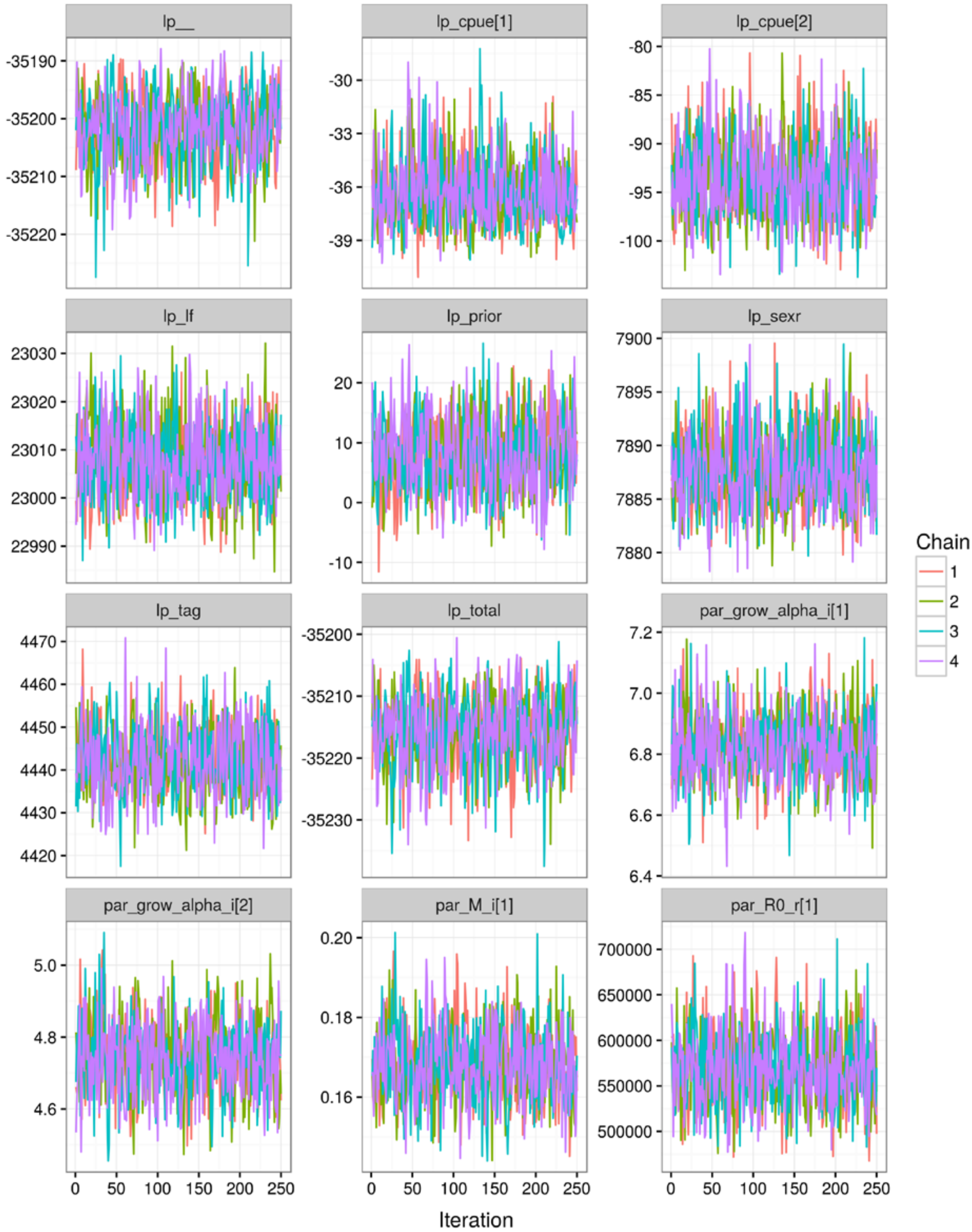


Figure 26: Traces for components of the likelihood (total objective function = lp__; likelihood for 1979–1988 CPUE data = lp_cpue[1]; likelihood for 1989–2016 CPUE data = lp_cpue[2]; likelihood for length-frequency data = lp_lf; likelihood for sex-ratio data = lp_sexr; likelihood for tag data = lp_tag; prior = lp_prior) and estimated parameters from the base case MCMC.

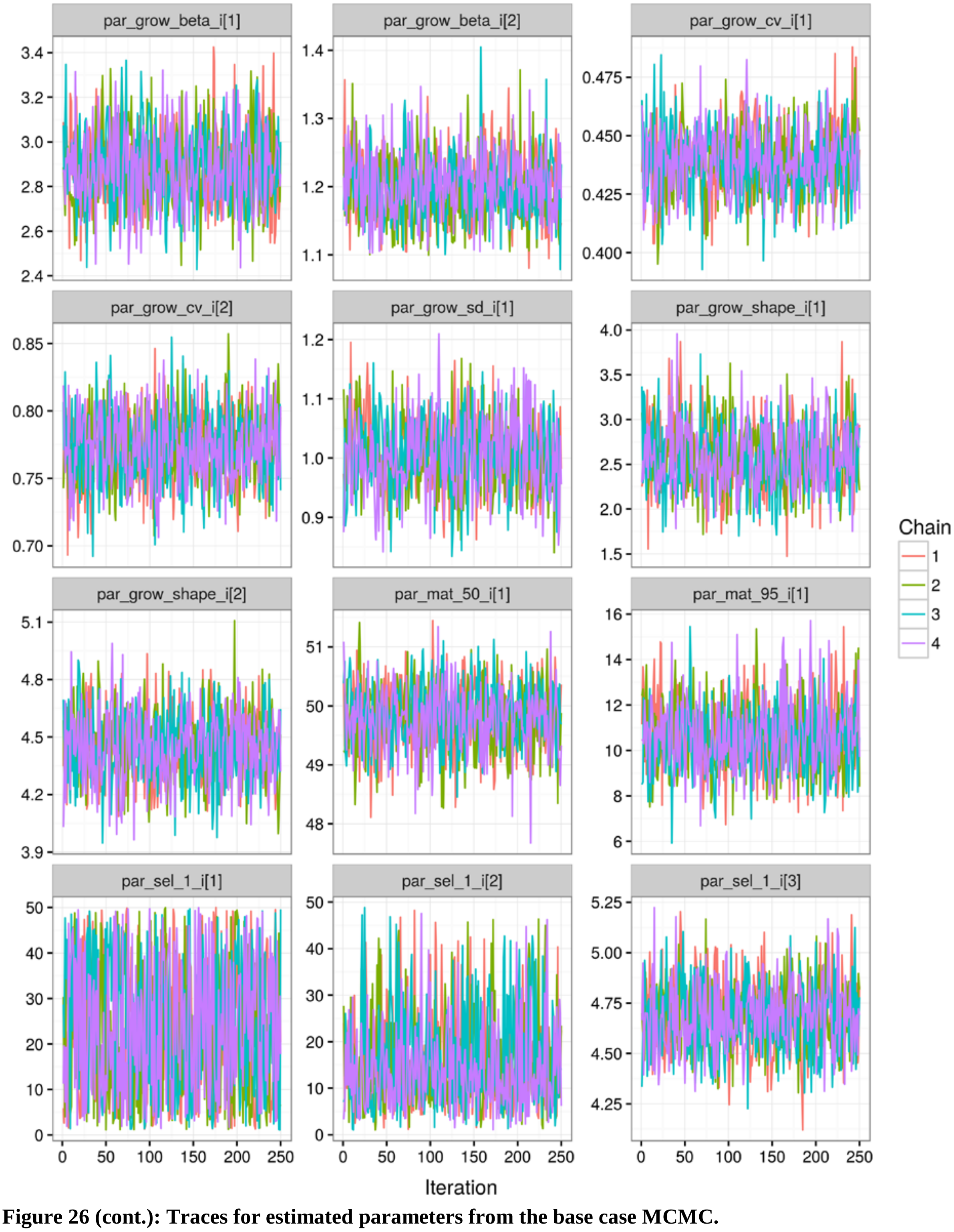


Figure 26 (cont.): Traces for estimated parameters from the base case MCMC.

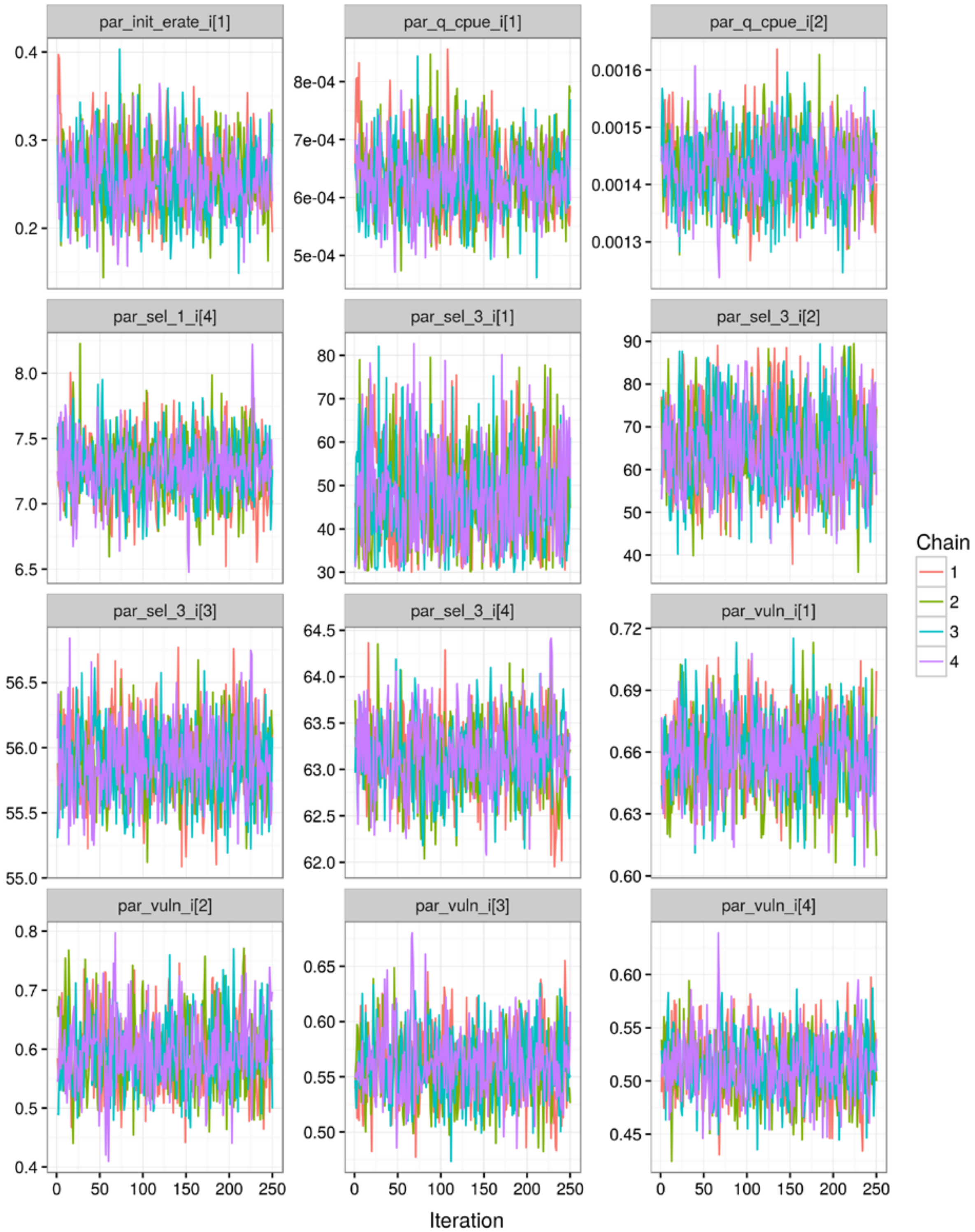


Figure 26 (cont.): Traces for estimated parameters from the base case MCMC.

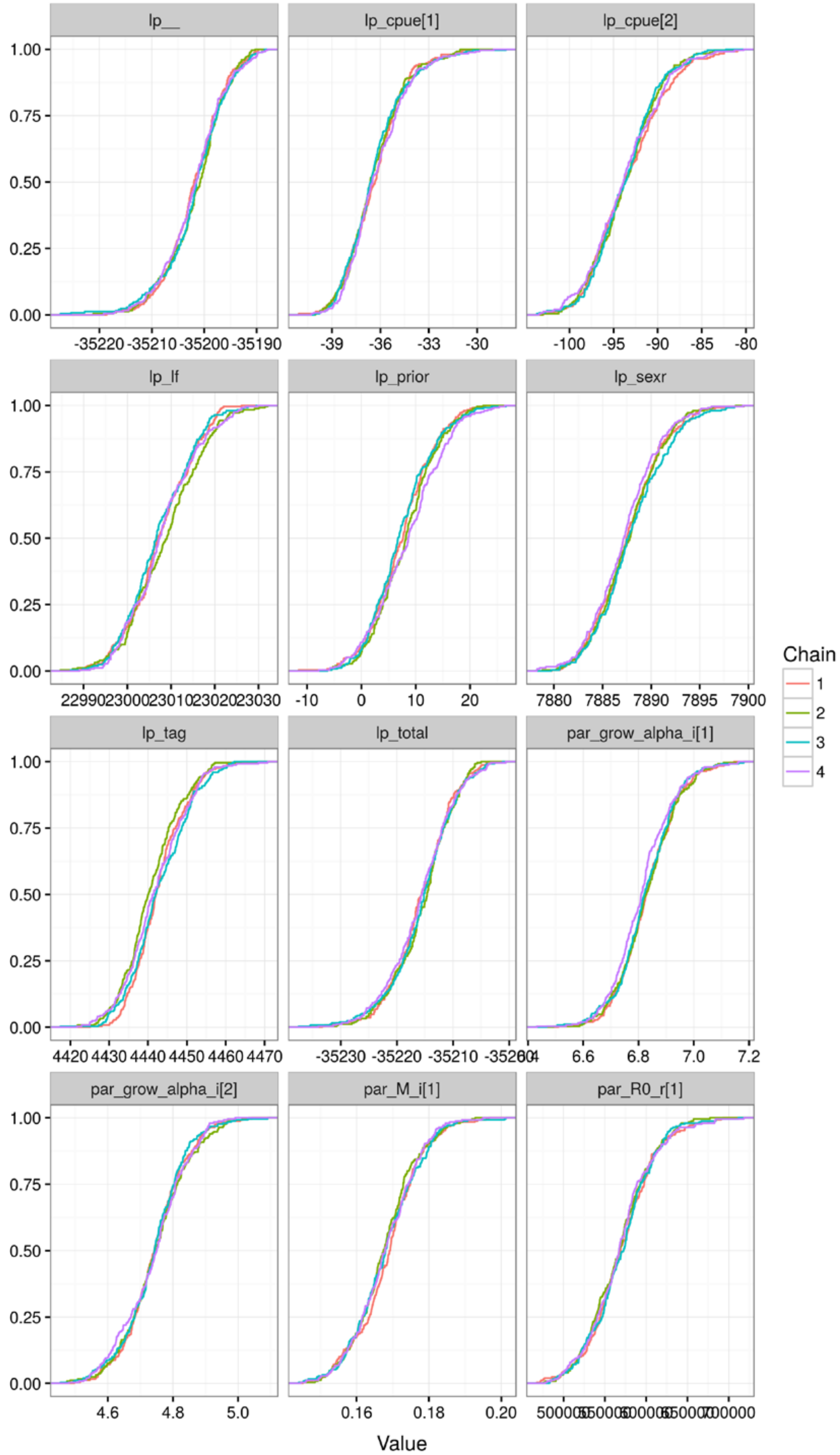


Figure 27: Cumulative density plots comparing each chain for the traces in Figure 26 from the base case MCMC.

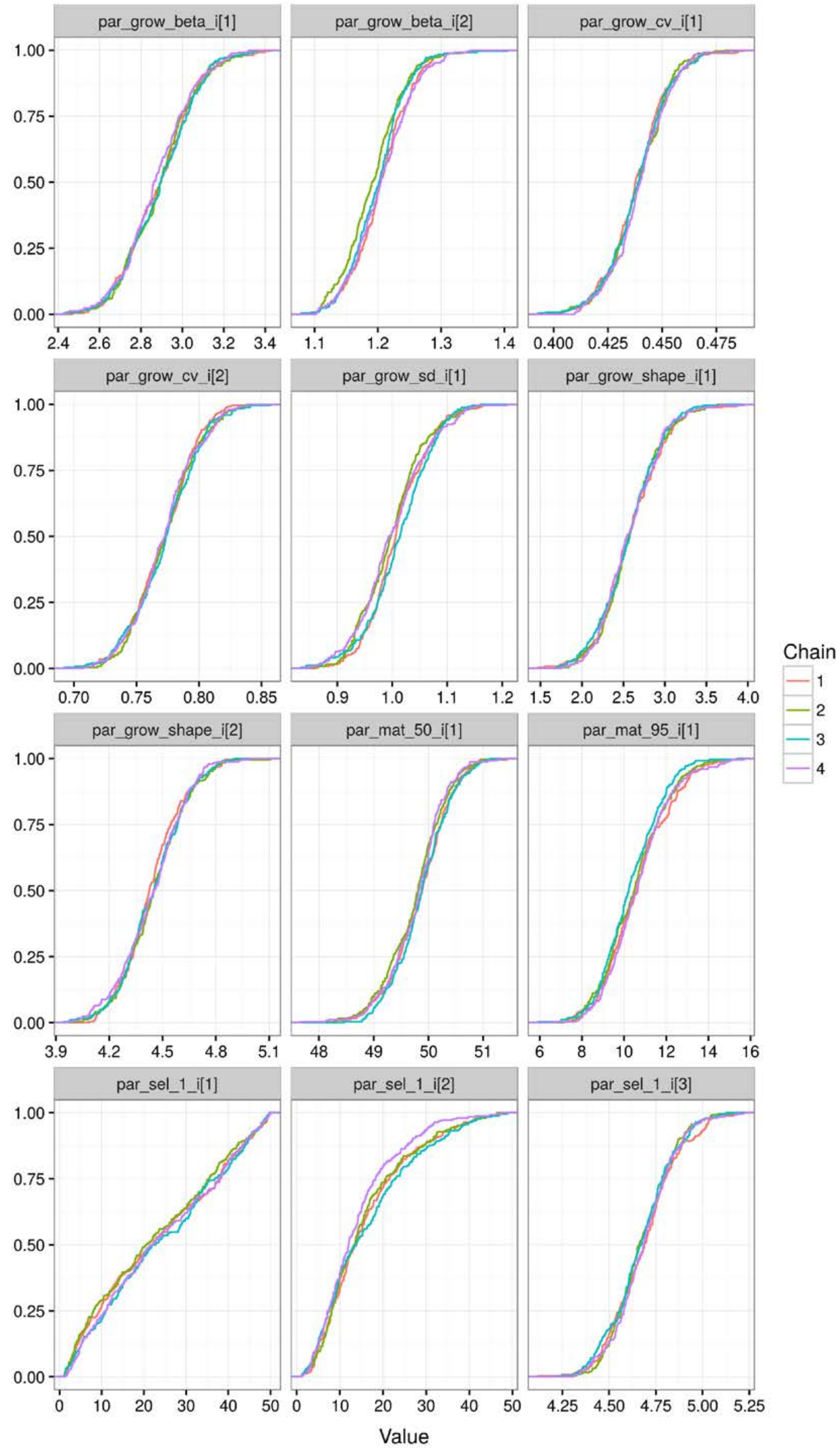


Figure 27 (cont.): Cumulative density plots comparing each chain for the traces in Figure 26 from the base case MCMC.

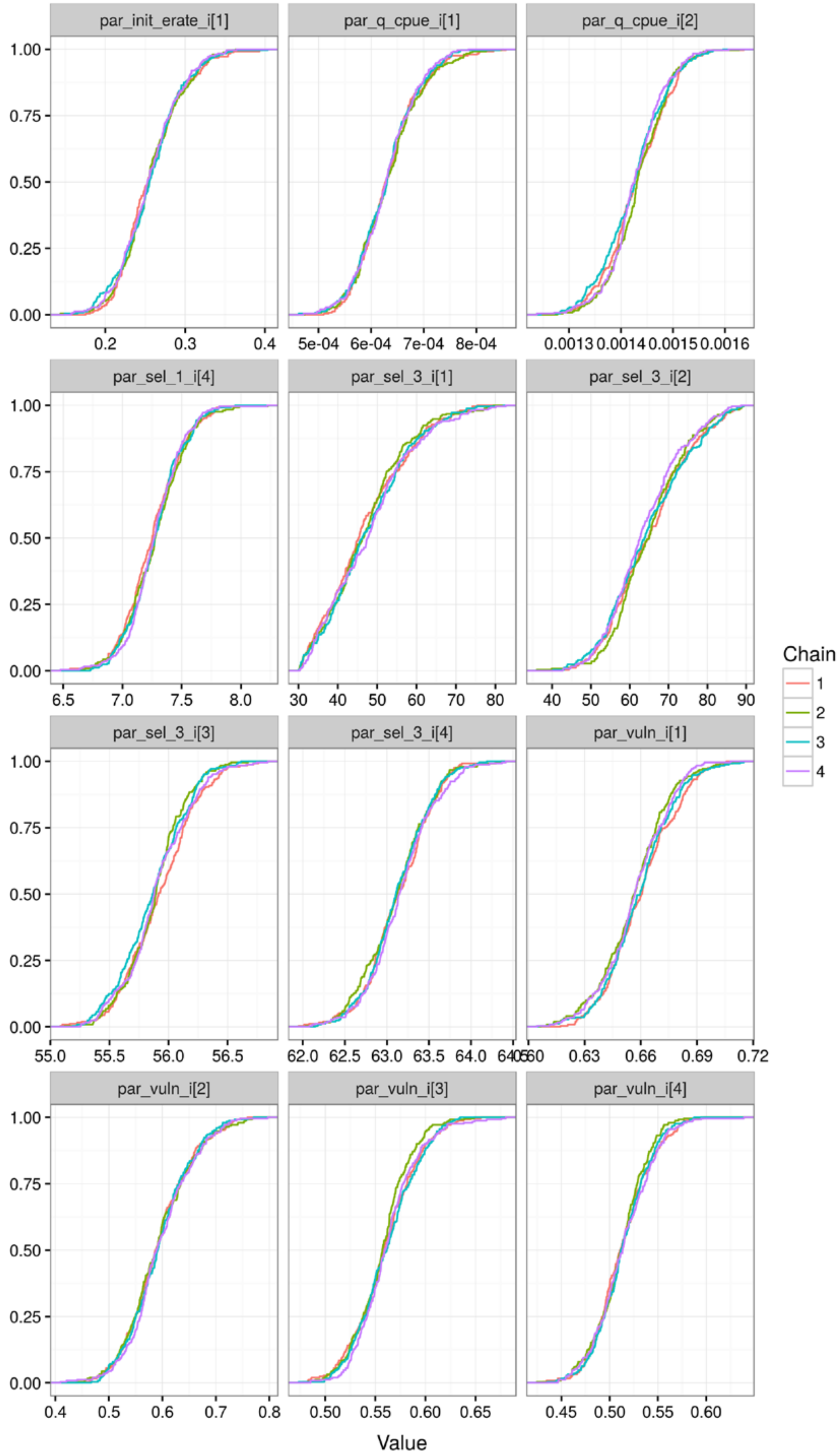


Figure 27 (cont.): Cumulative density plots comparing each chain for the traces in Figure 26 from the base case MCMC.

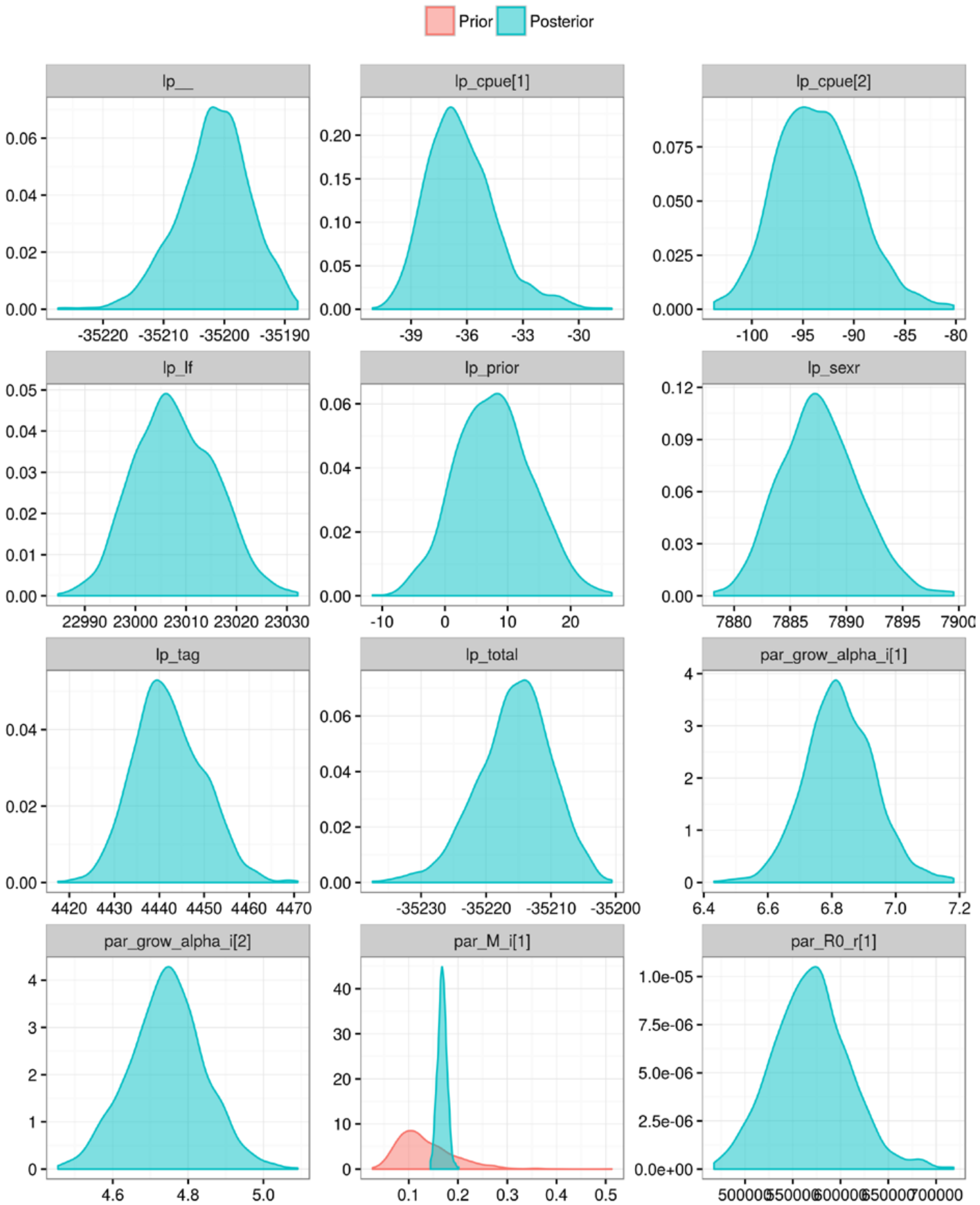


Figure 28: Prior and posterior density distributions of estimated parameters and derived quantities from the base case MCMC.

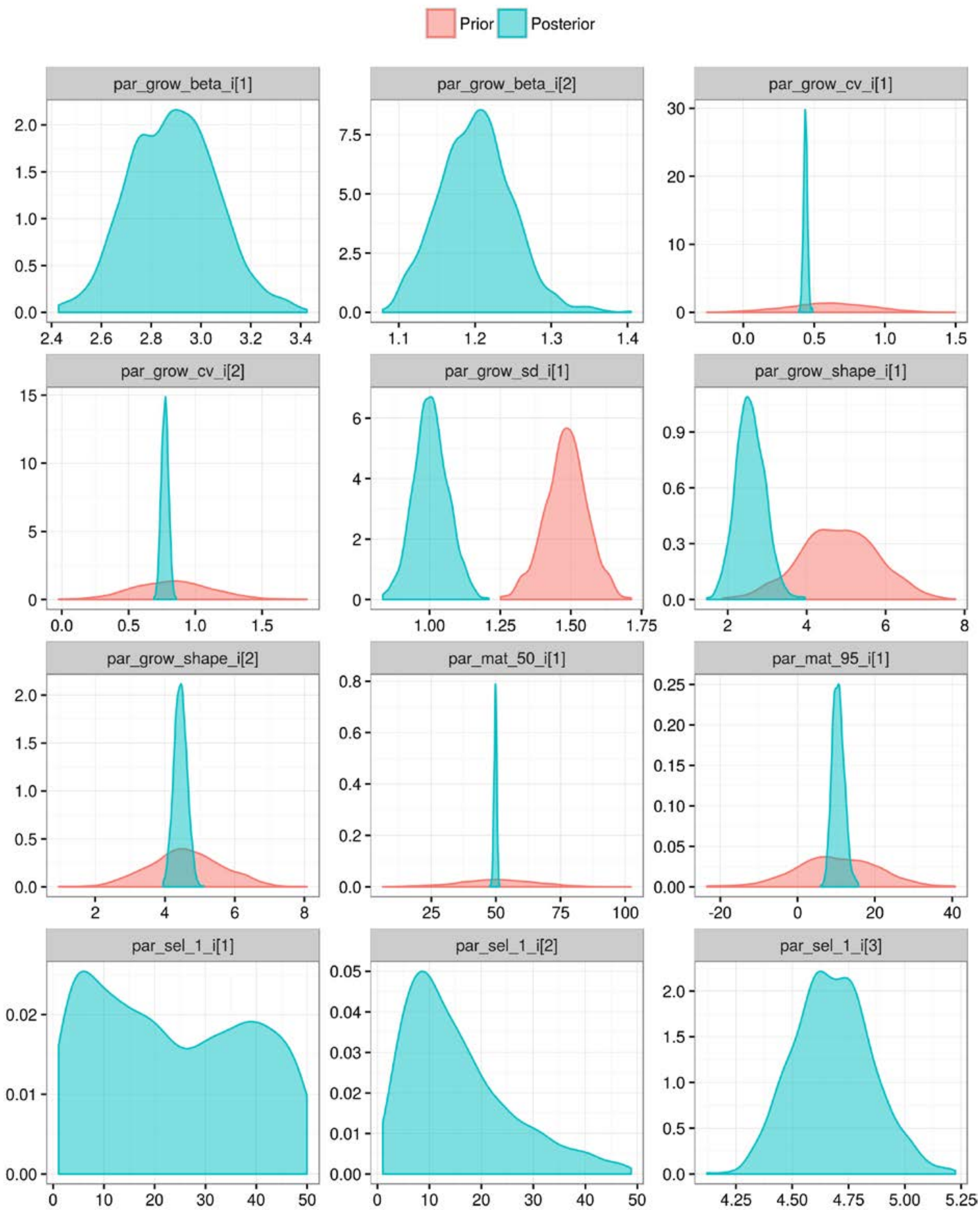


Figure 28 (cont.): Prior and posterior density distributions of estimated parameters and derived quantities from the base case MCMC.

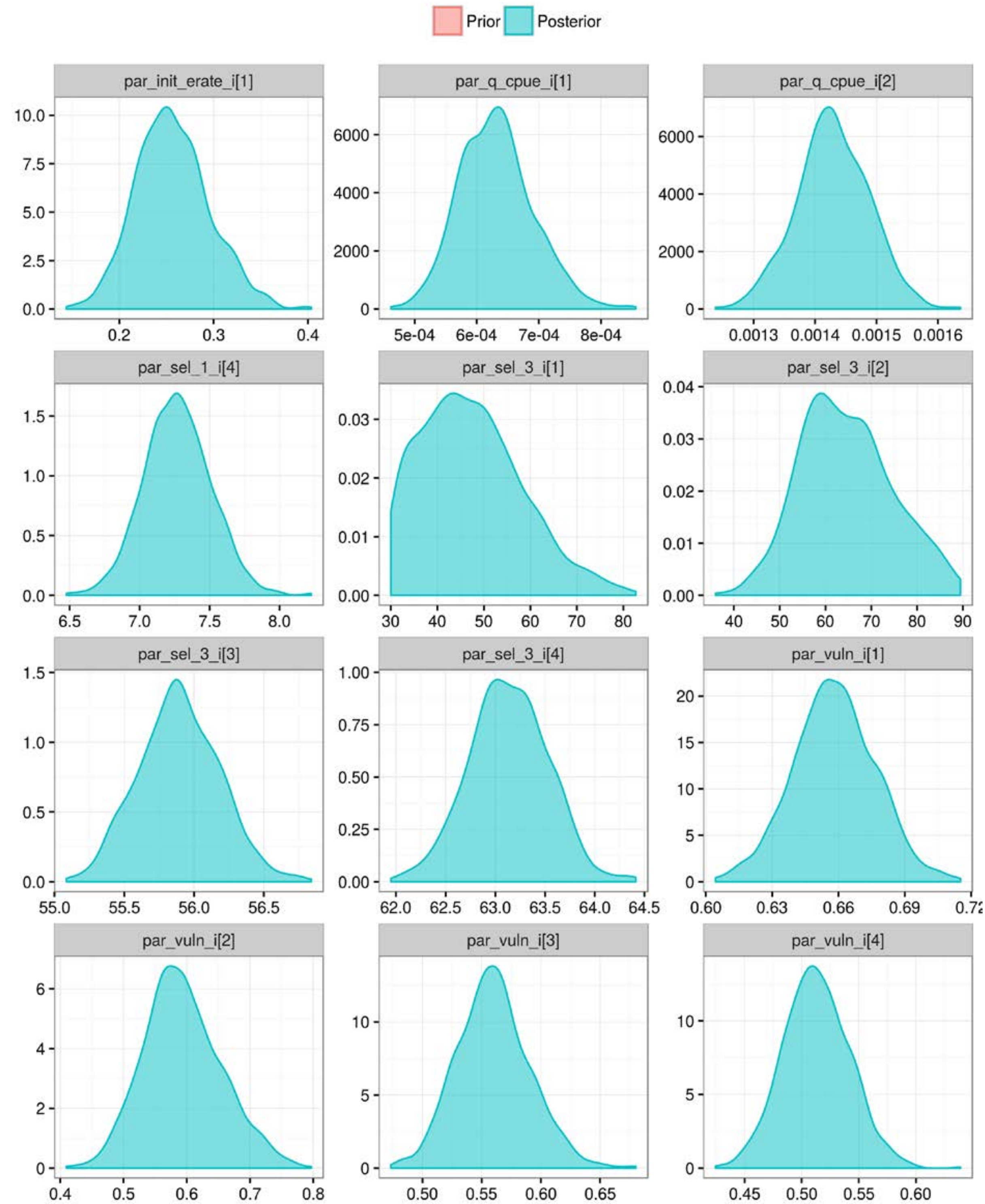


Figure 28 (cont): Prior and posterior distributions of estimated and derived parameters and derived quantities from the base case MCMC.

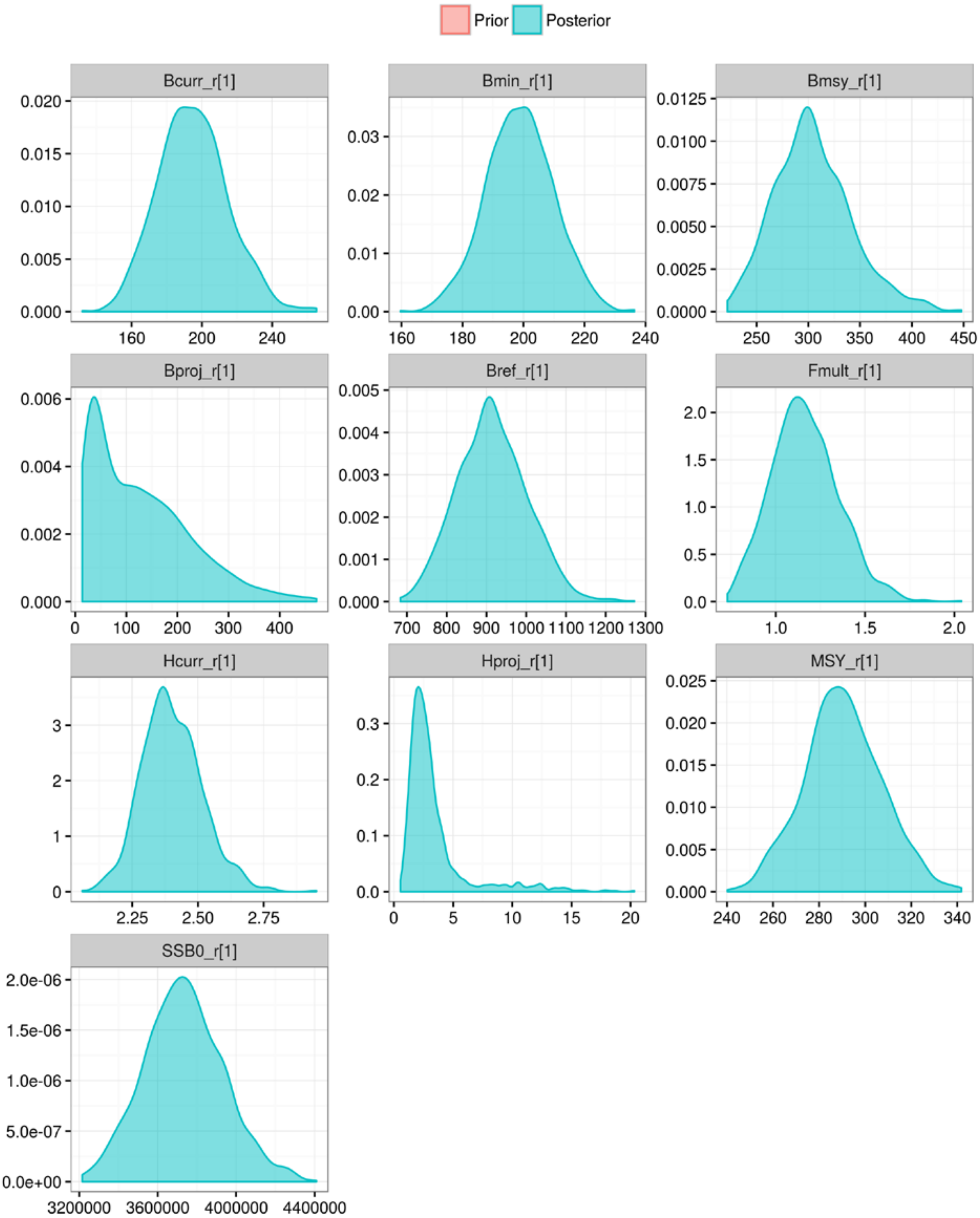


Figure 28 (cont.): Posterior distributions of derived quantities from the base case MCMC.

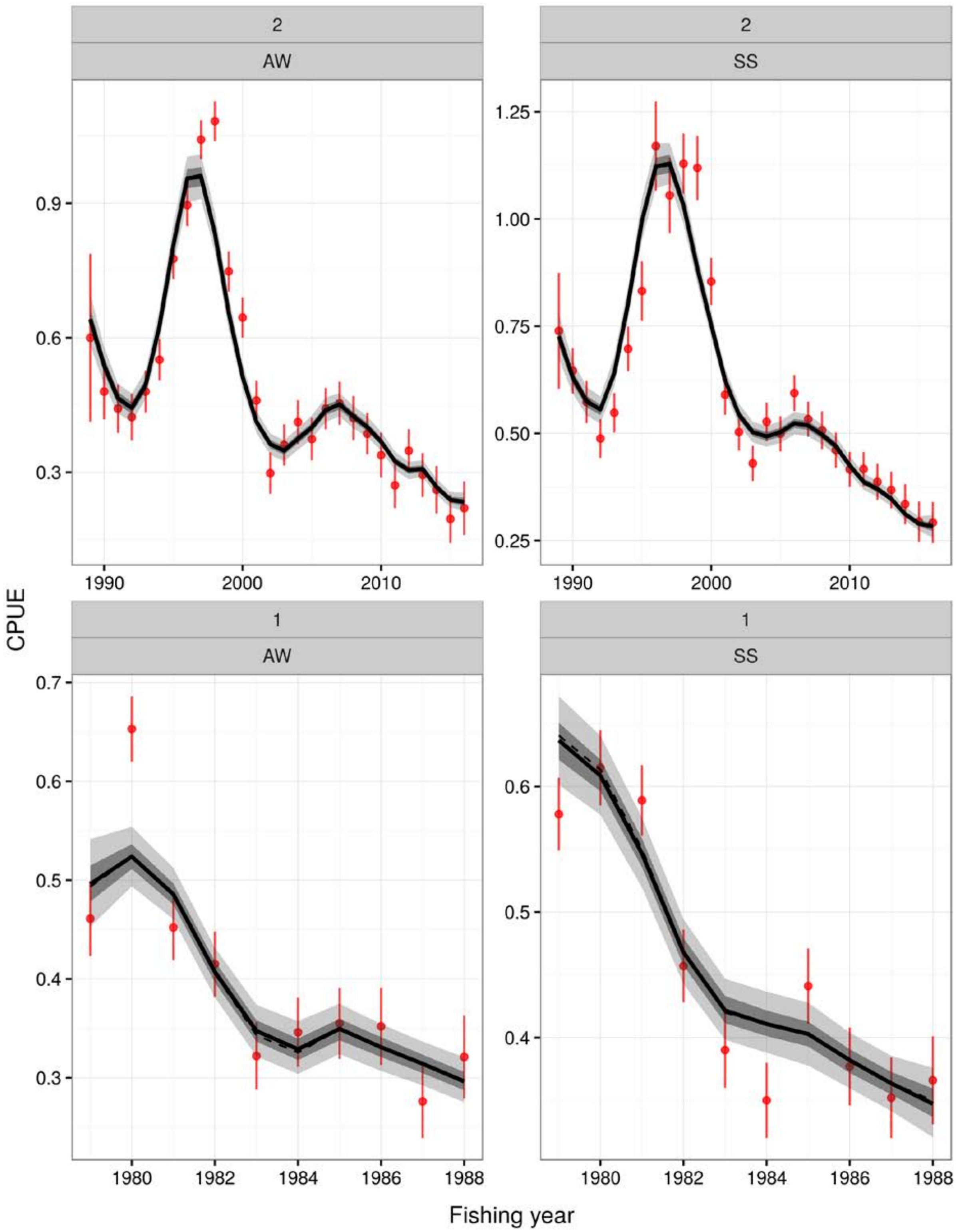


Figure 29: CRA 2 base case MCMC: posterior of the fit to CPUE. Shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior, the heavy solid line is the median of the posterior distribution, the dashed line is the MAP, error bars on the CPUE values are one standard deviation.

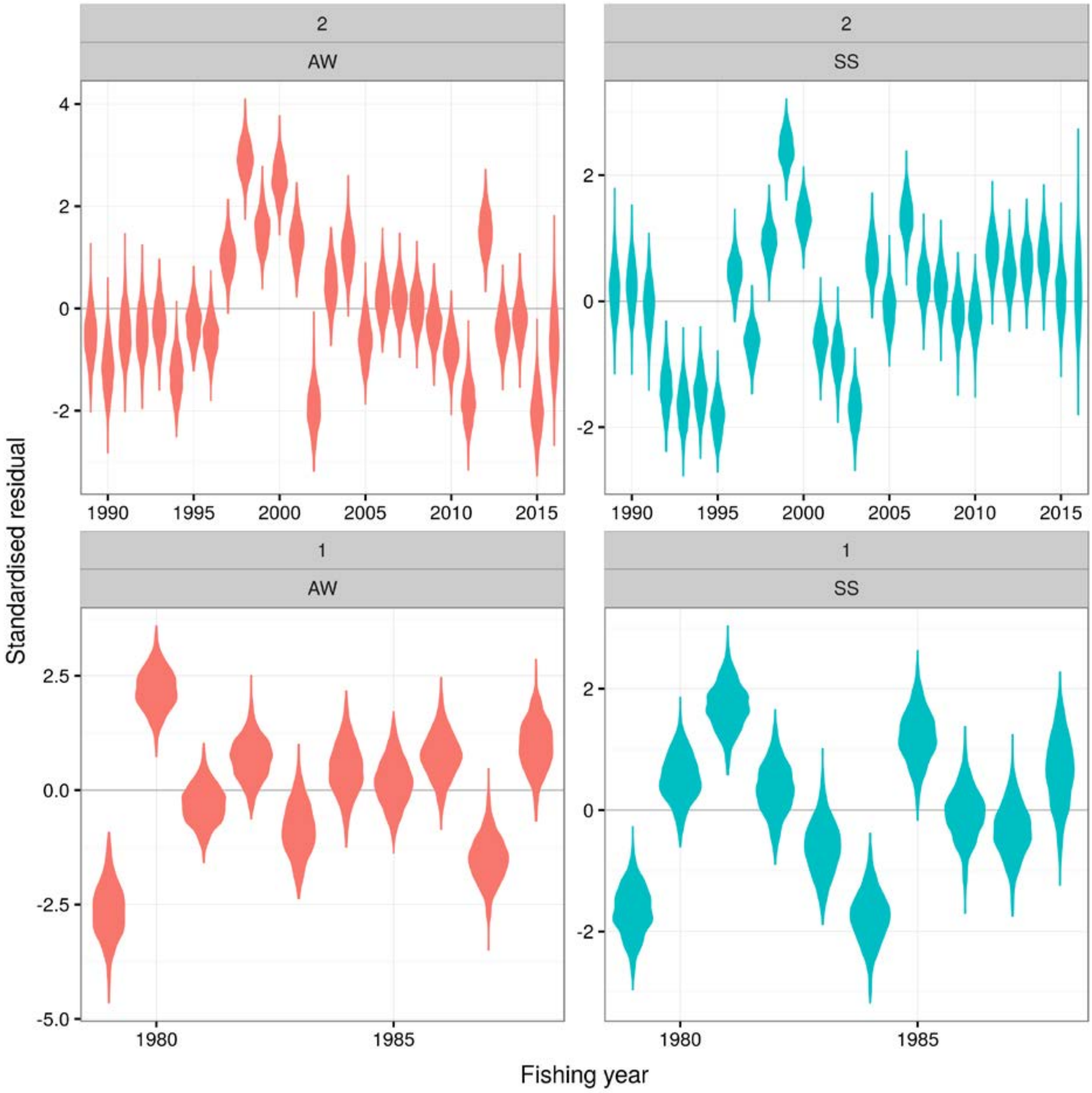


Figure 30: CRA 2 base case MCMC: CPUE residuals during autumn-winter (AW, left panels) and spring-summer (SS, right panels) for 1979–1988 (bottom panels) and 1989–2016 (top panels).

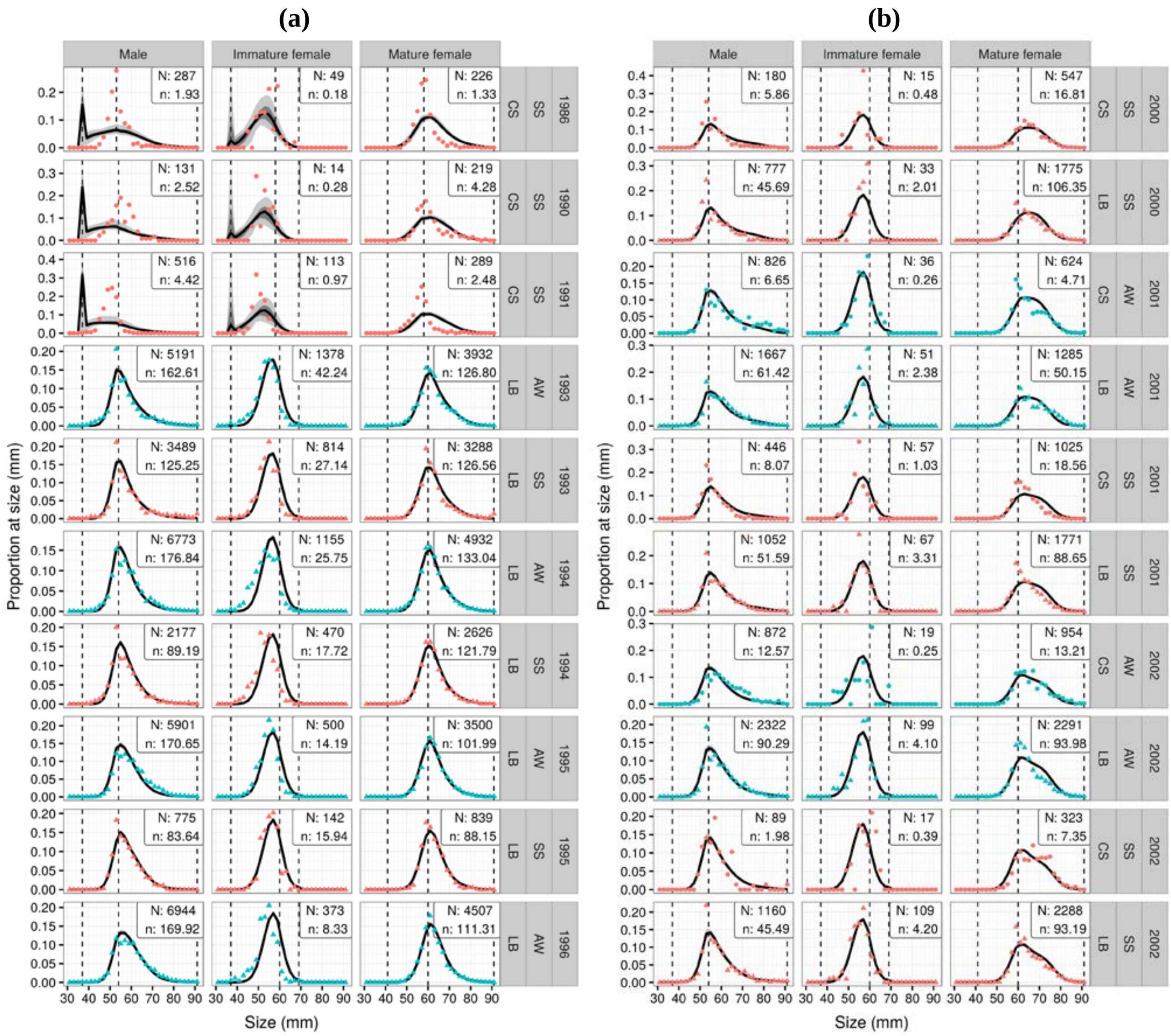


Figure 31: CRA 2 base case MCMC: model fits to LFs for each sex category from (a) 1986 SS LB – 1996 AW LB; (b) 2000 SS CS – 2002 SS LB. For each panel "N" is the number of individuals measured and "n" is the effective sample size used in the stock assessment model.

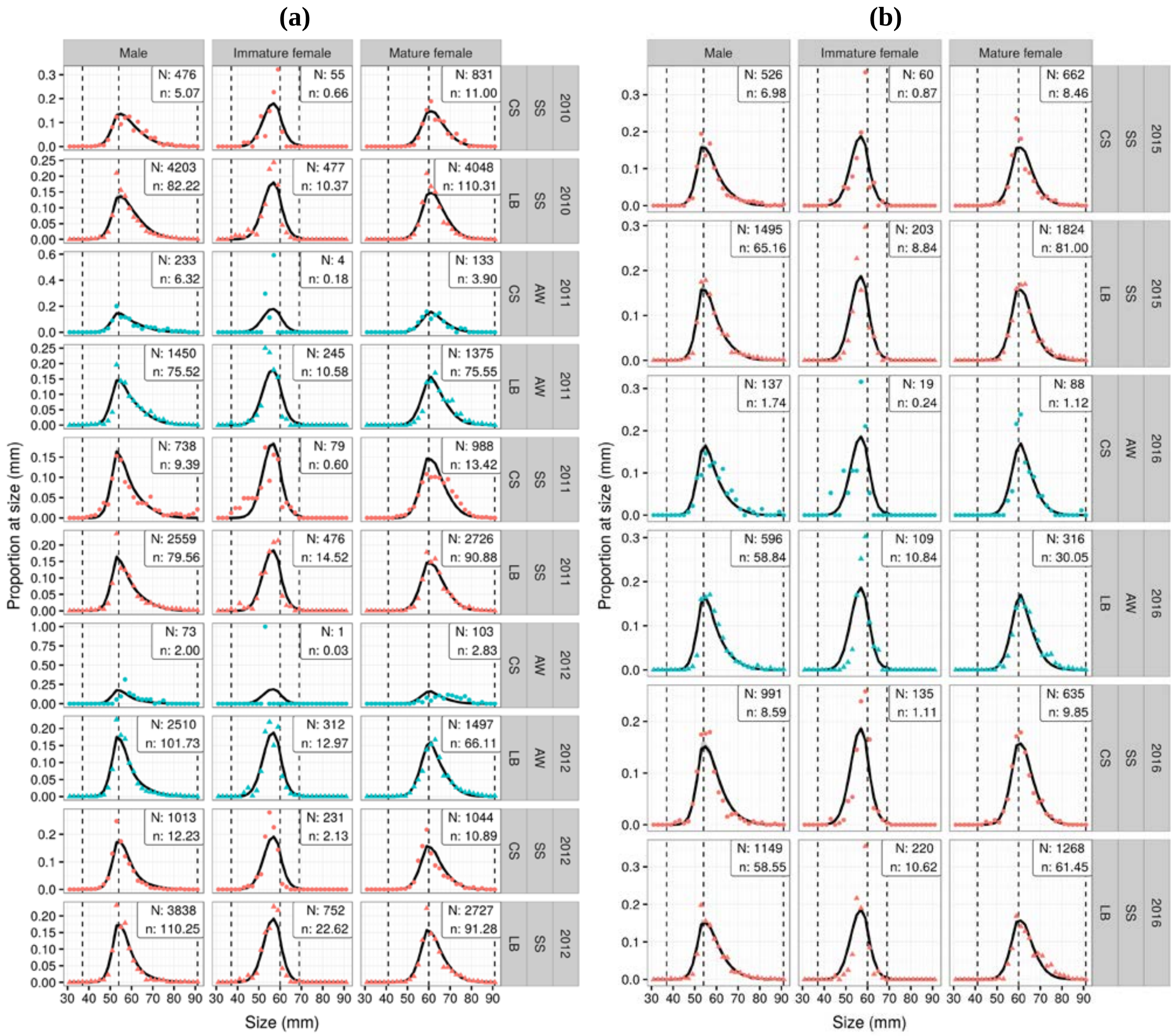


Figure 32: CRA 2 base case MCMC: Model fits to LFs from (a) 2010 SS CS – 2012 SS LB; (b) 2015 SS CS – 2016 SS LB.

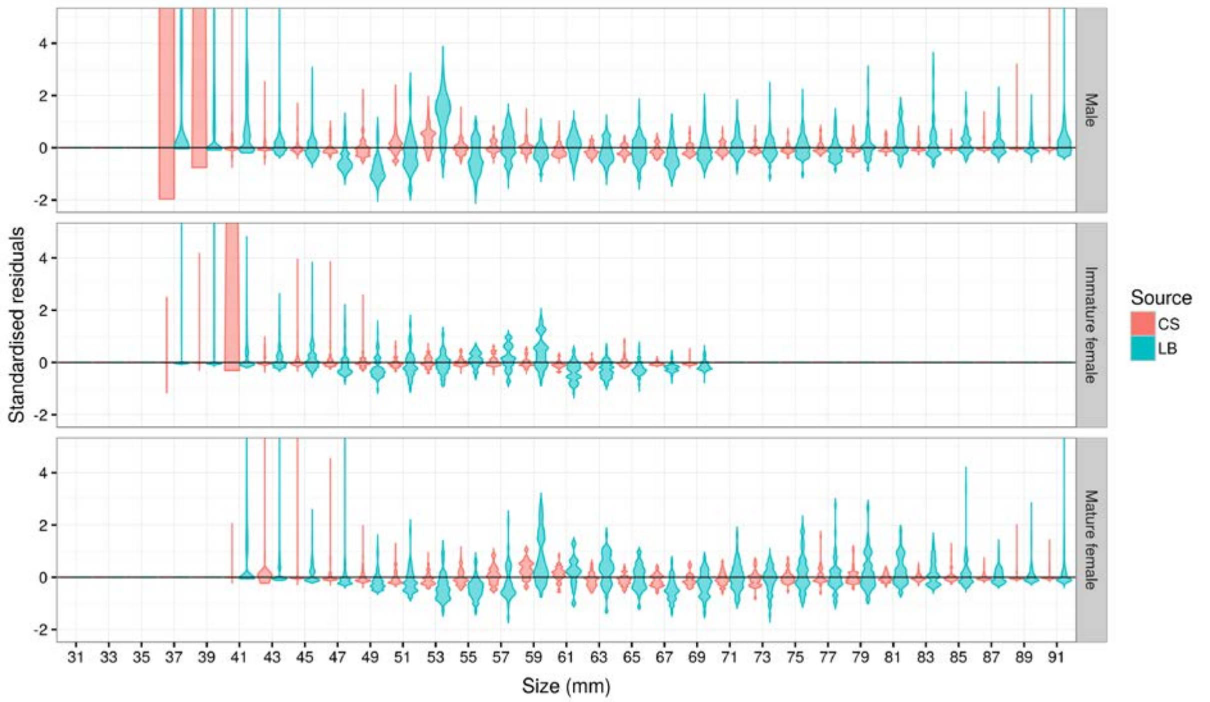


Figure 33: CRA 2 base case: MCMC residuals from fit to the LF data, showing residuals by sex, 2 mm size bin, and sampling source.

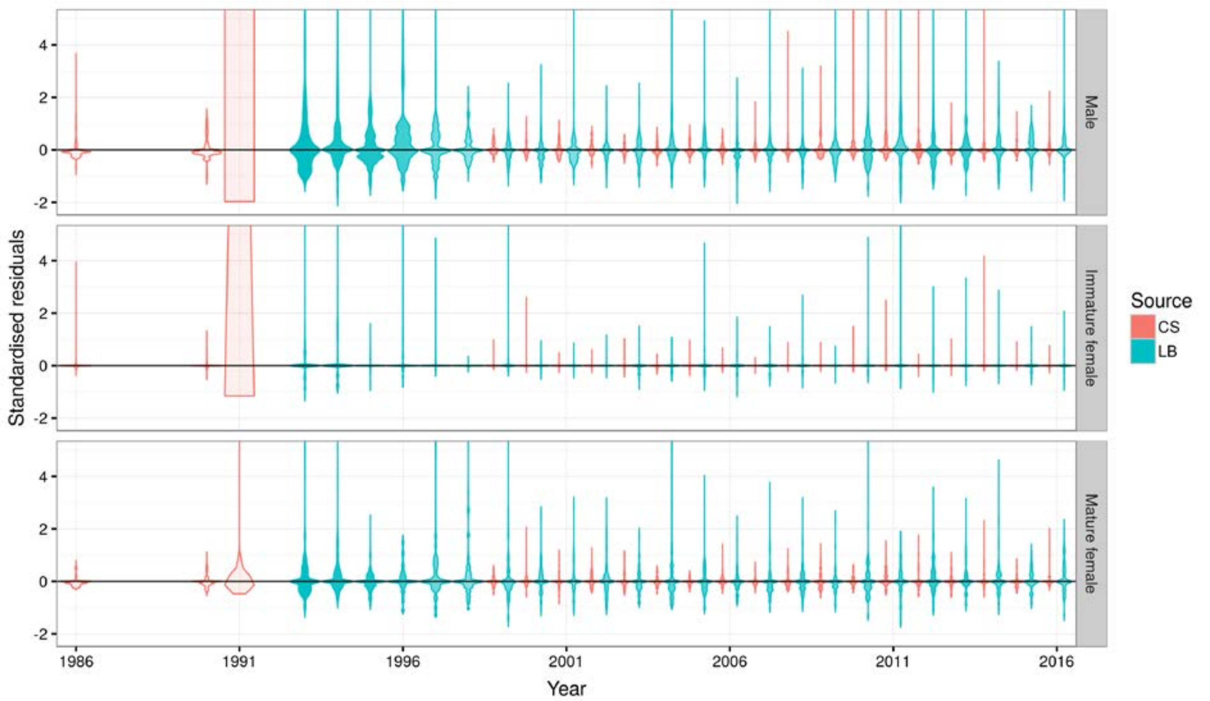


Figure 34: CRA 2 base case: MCMC residuals from fit to the LF data, showing residuals by sex, year, and sampling source.

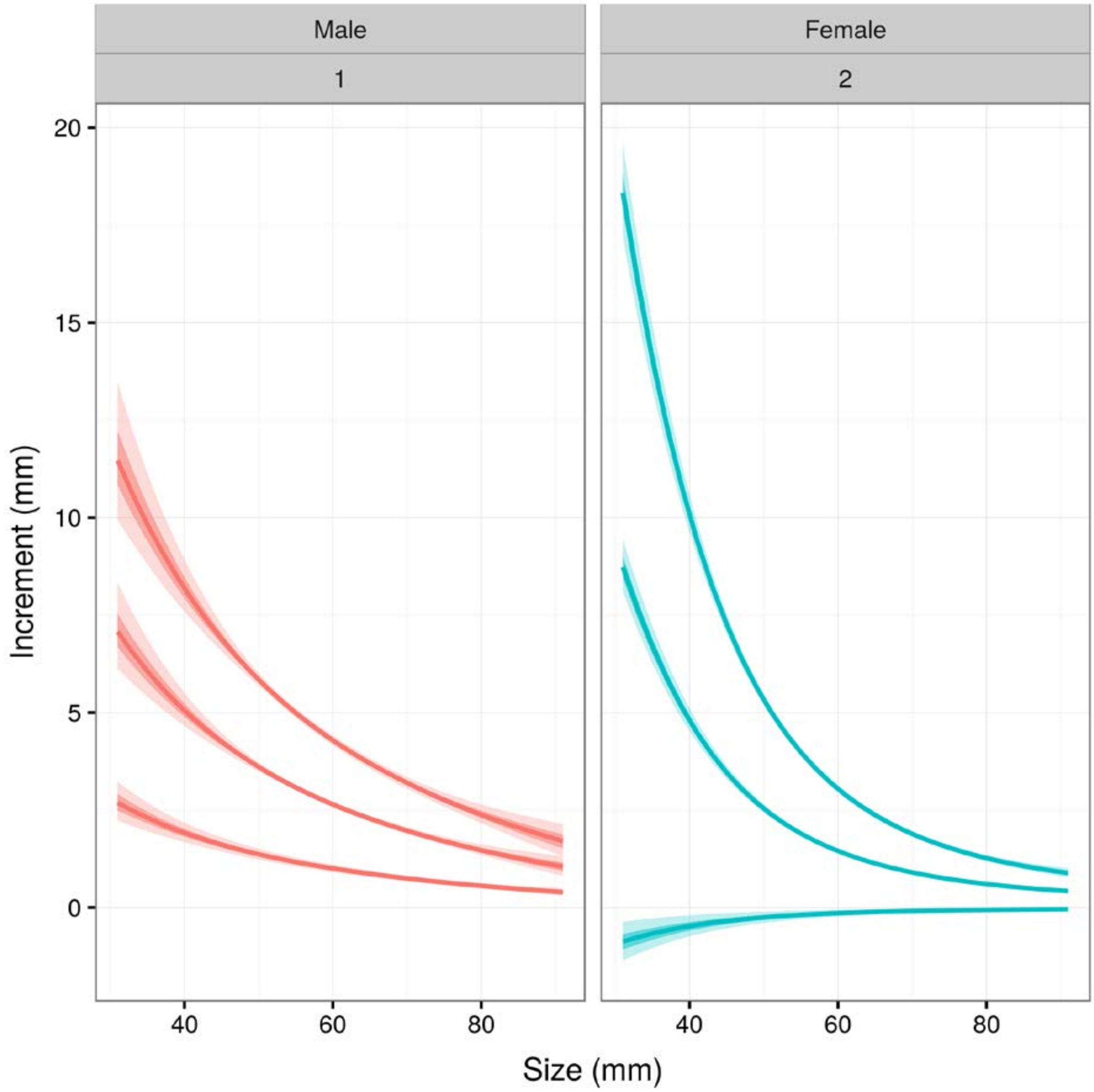


Figure 35: CRA 2 base case MCMC: predicted increments-at-length and their standard deviations.

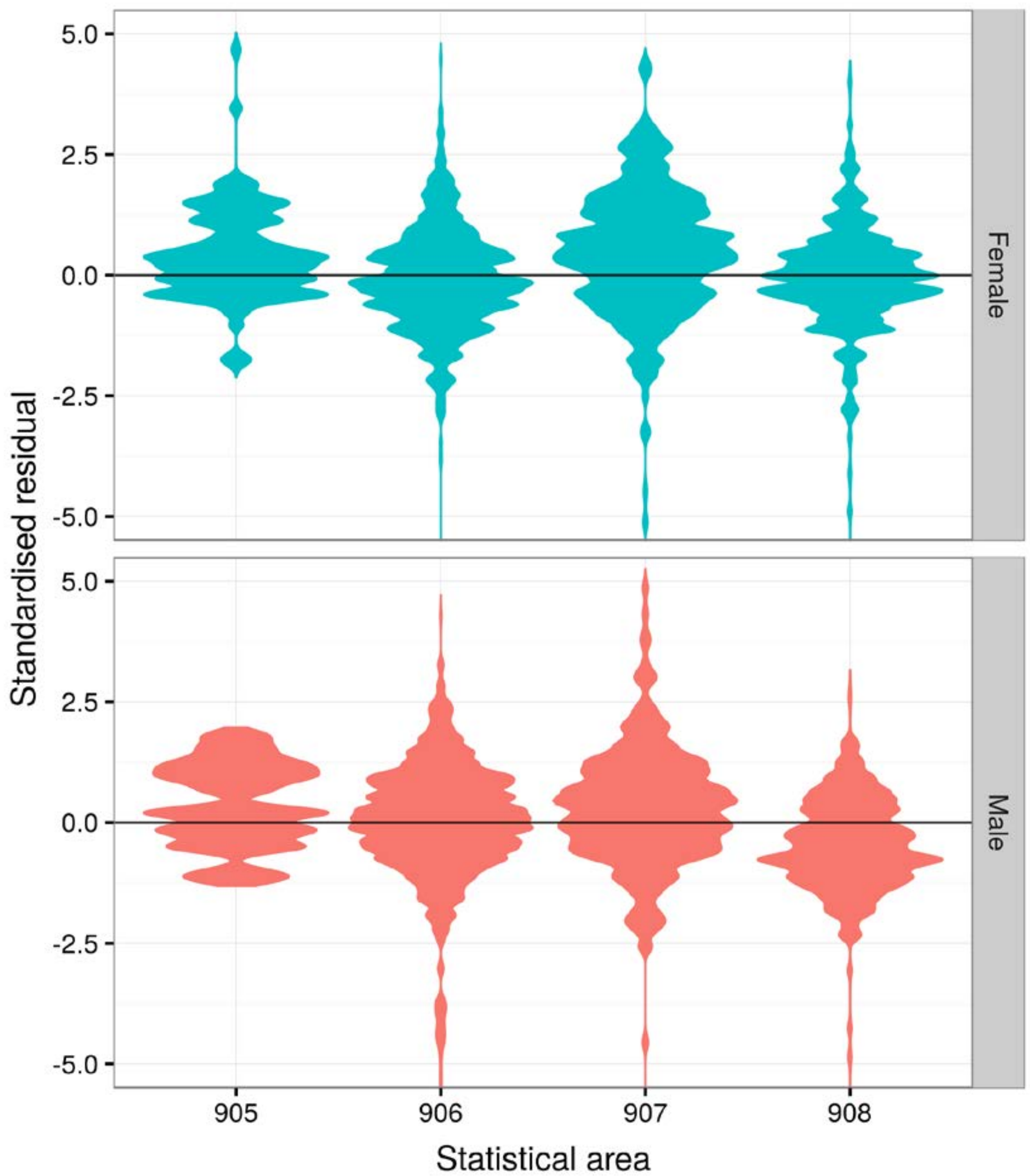


Figure 36: CRA 2 base case MCMC: distribution of standardised residuals from the fit to tag data by sex and statistical area of release.

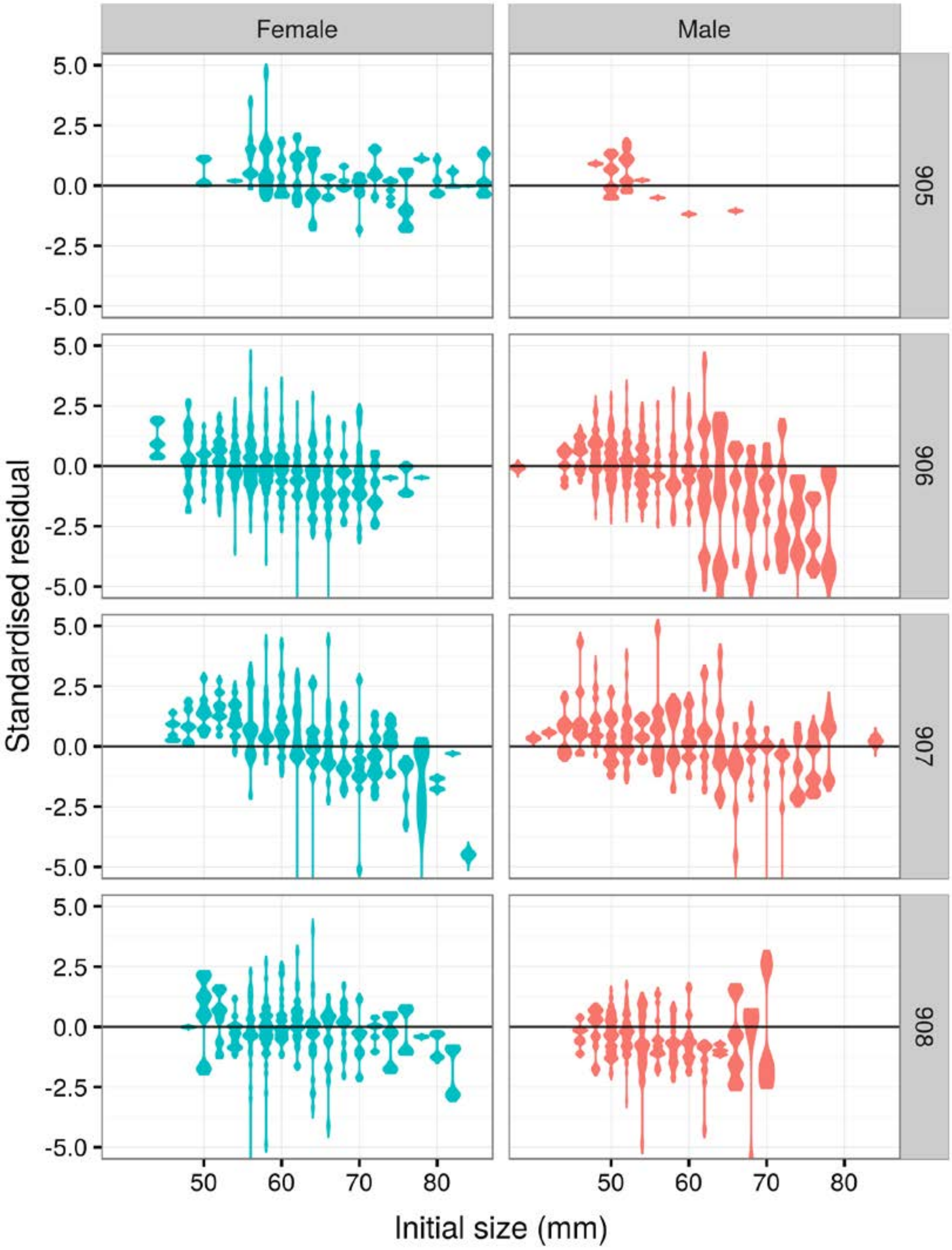


Figure 37: CRA 2 base case MCMC: distribution of standardised residuals from the fit to tags by sex, size class, and statistical area of release.

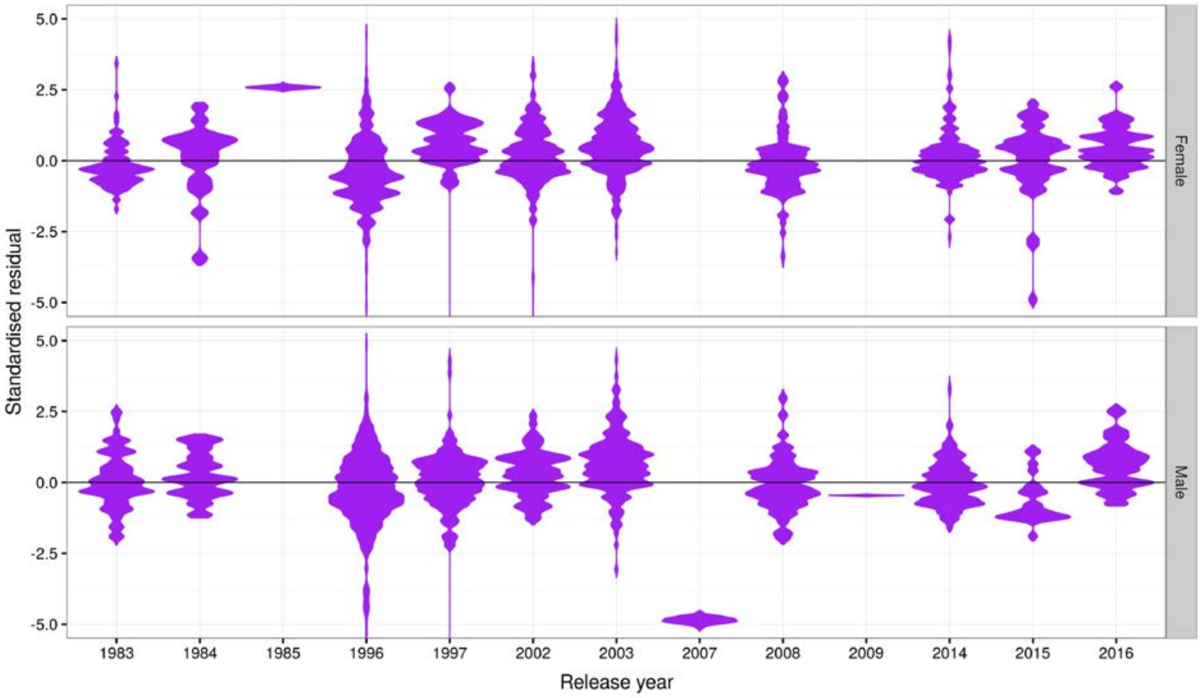


Figure 38: CRA 2 base case MCMC: distribution of standardised residuals from the fit to tags by sex and release year.

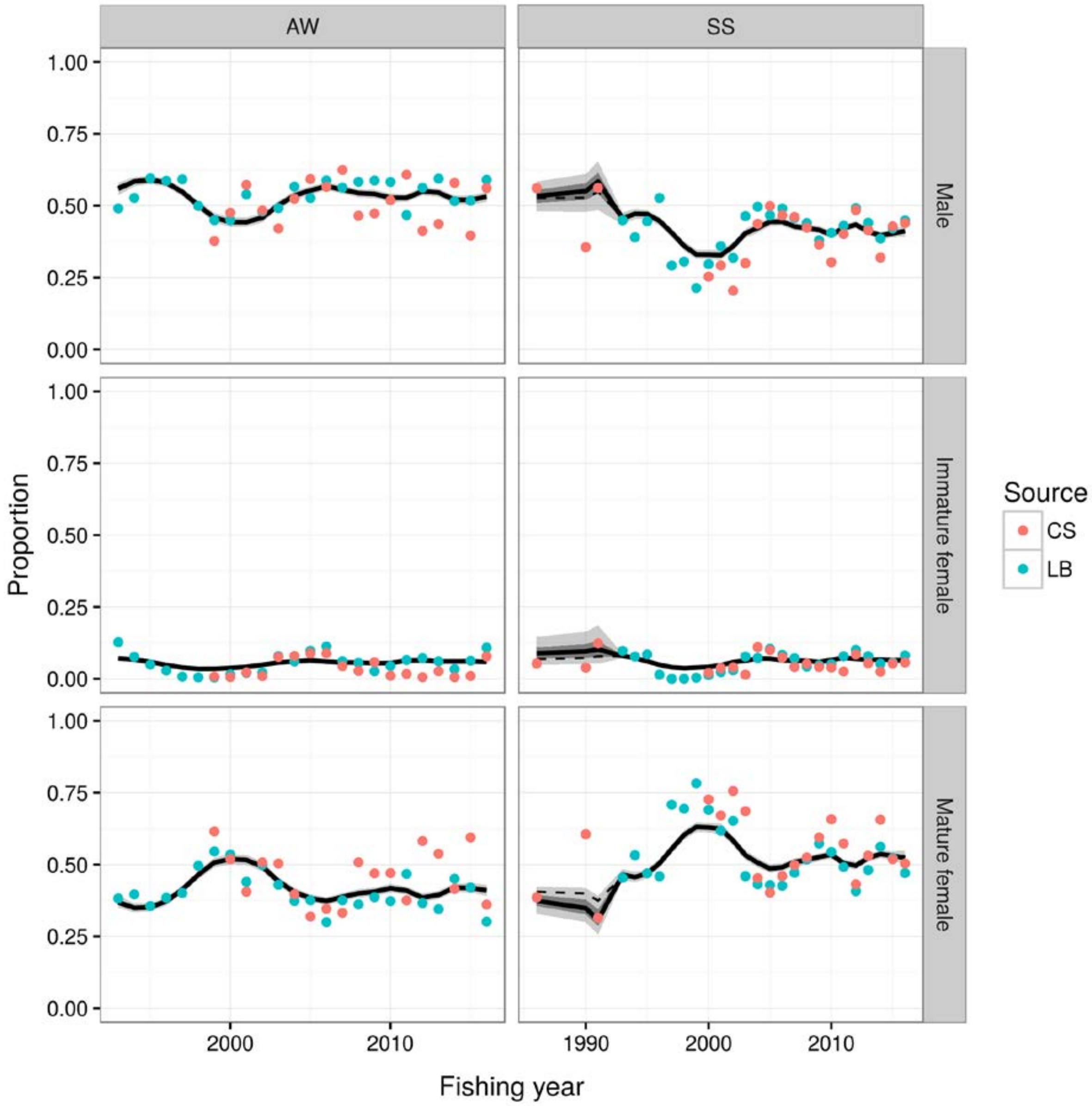


Figure 39: CRA 2 base case MCMC: posterior of the fit to the proportions-at-sex in the LF data by season, sex, and data source; shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior and the heavy solid line is the median of the posterior distribution.

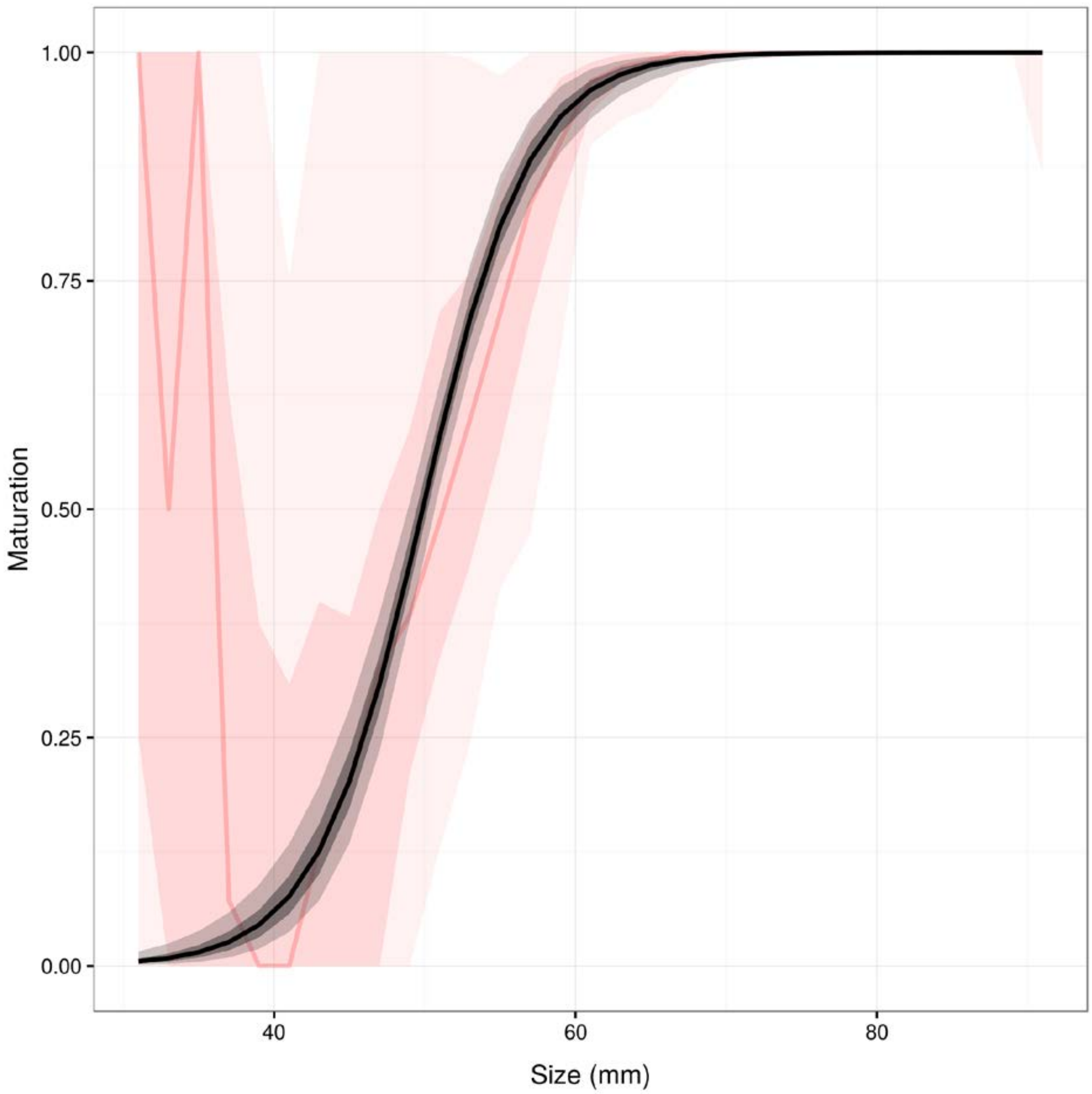


Figure 40: From the base case MCMC, the posterior distribution of maturation-at-size. There are very few observations below 40 mm.

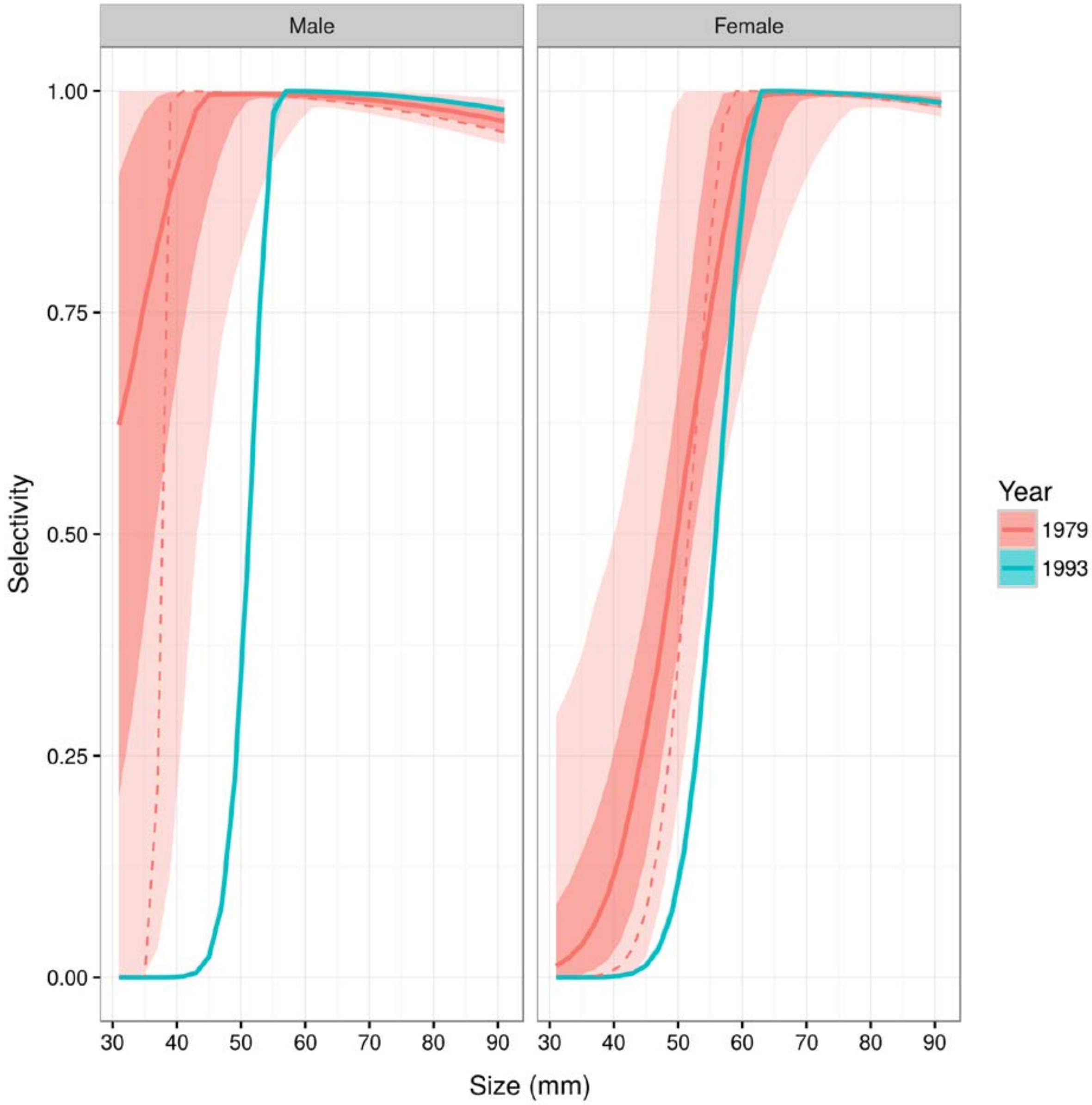


Figure 41: From the base case MCMC, the posterior distribution of selectivity by sex and period.

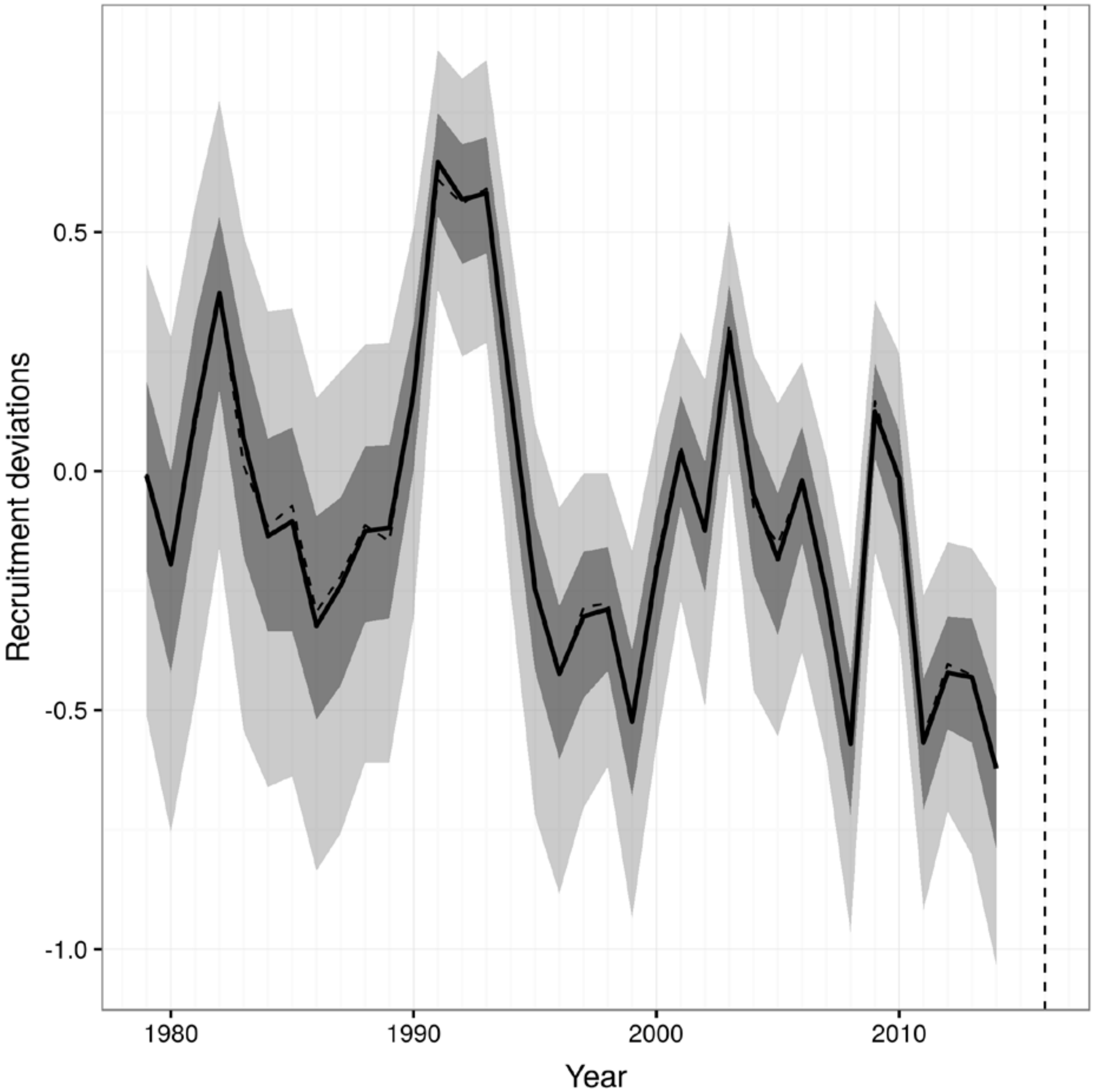


Figure 42: Posterior trajectory of recruitment deviations to the model, 1979–2016 from the base case MCMC; shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior; the heavy solid line is the median of the posterior distribution; the vertical line shows 2016, the final fishing year of the model reconstruction.

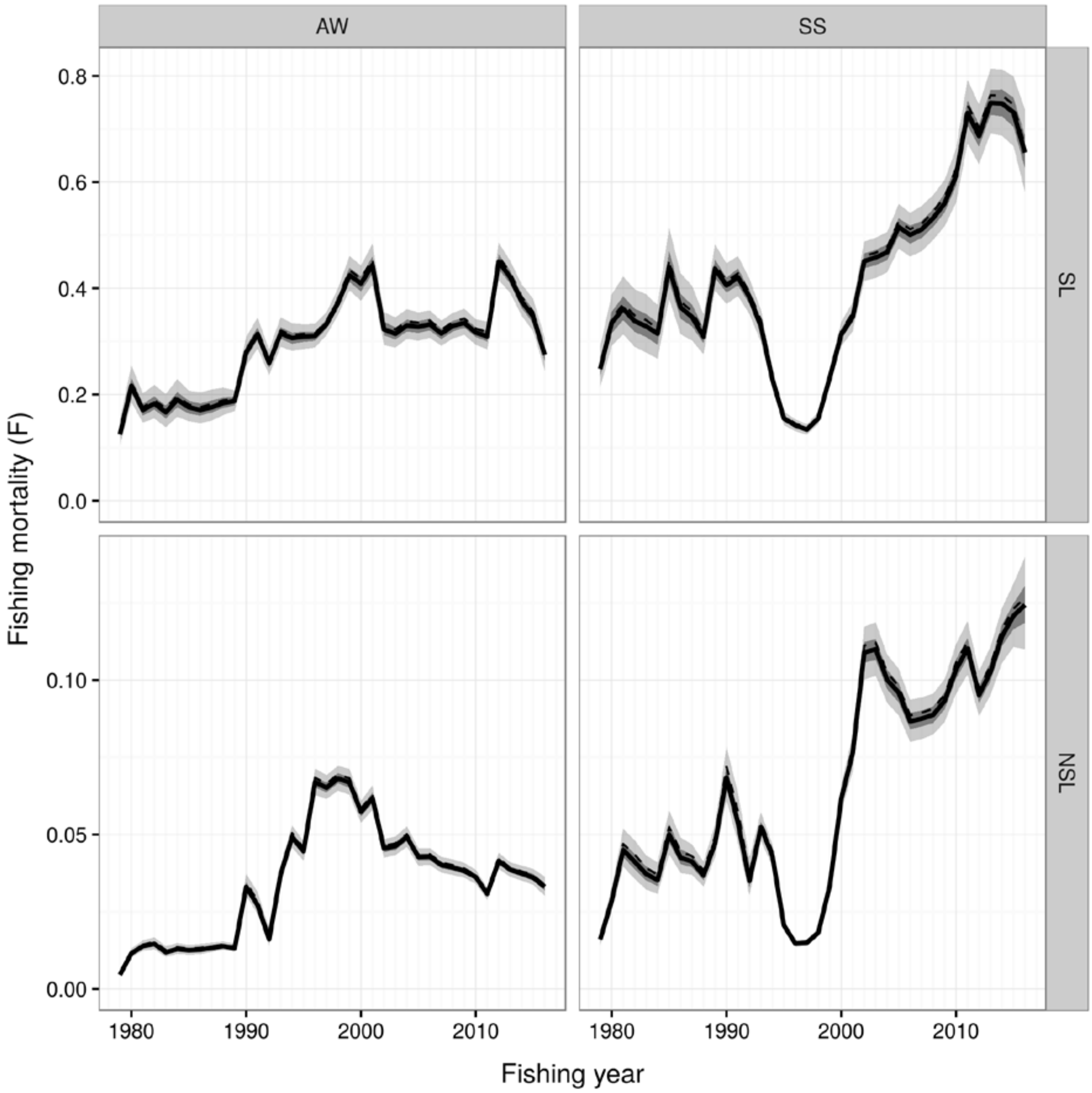


Figure 43: Posterior trajectory of SL and NSL fishing mortality, 1979–2016 from the base case MCMC; shaded areas show the 5%, 25%, 75% and 95% quantiles of the posterior; the heavy solid line is the median of the posterior distribution.

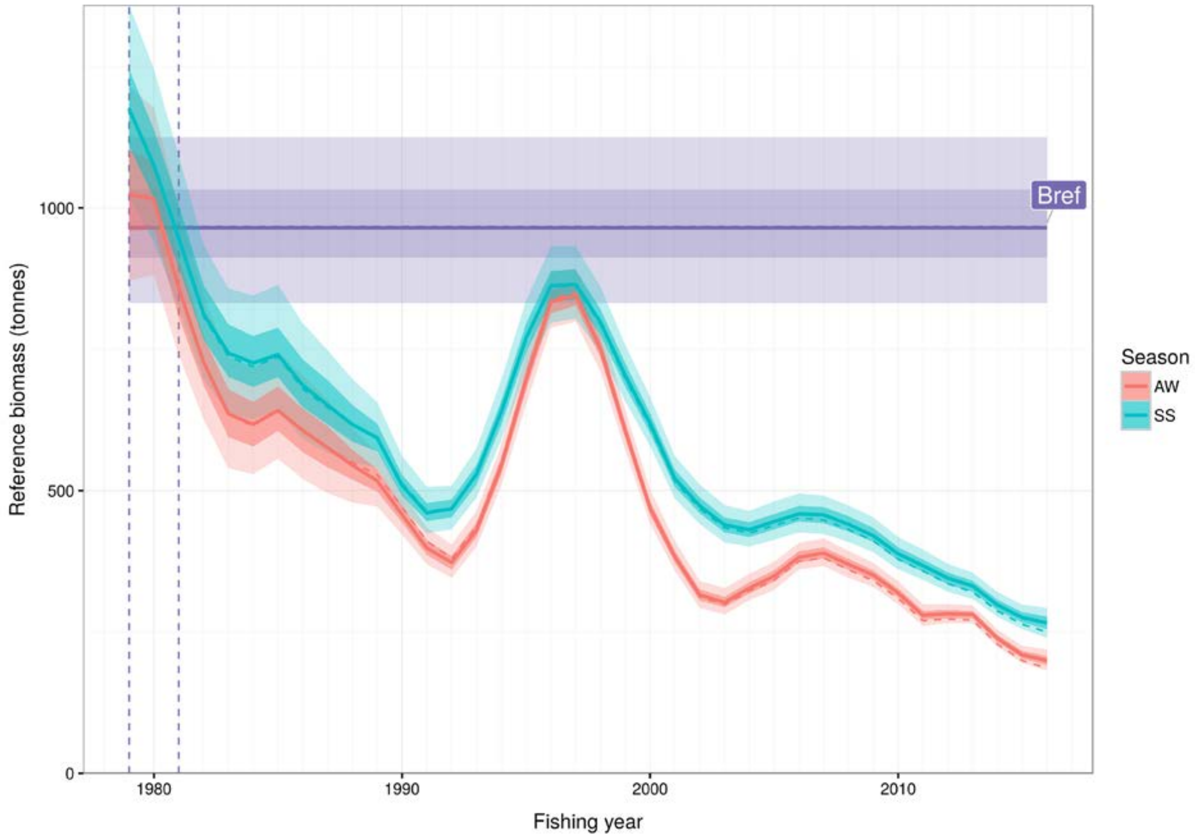


Figure 44: From the base case MCMC, vulnerable biomass from 1979–2016 by season from the base case MCMC; shaded areas show the 90% credibility intervals; the heavy solid line is the median of the posterior distributions; the vertical line shows 2016, the final fishing year of the model reconstruction. *B_{REF}* is plotted in purple, showing the median, the 75% and 90% credibility intervals.

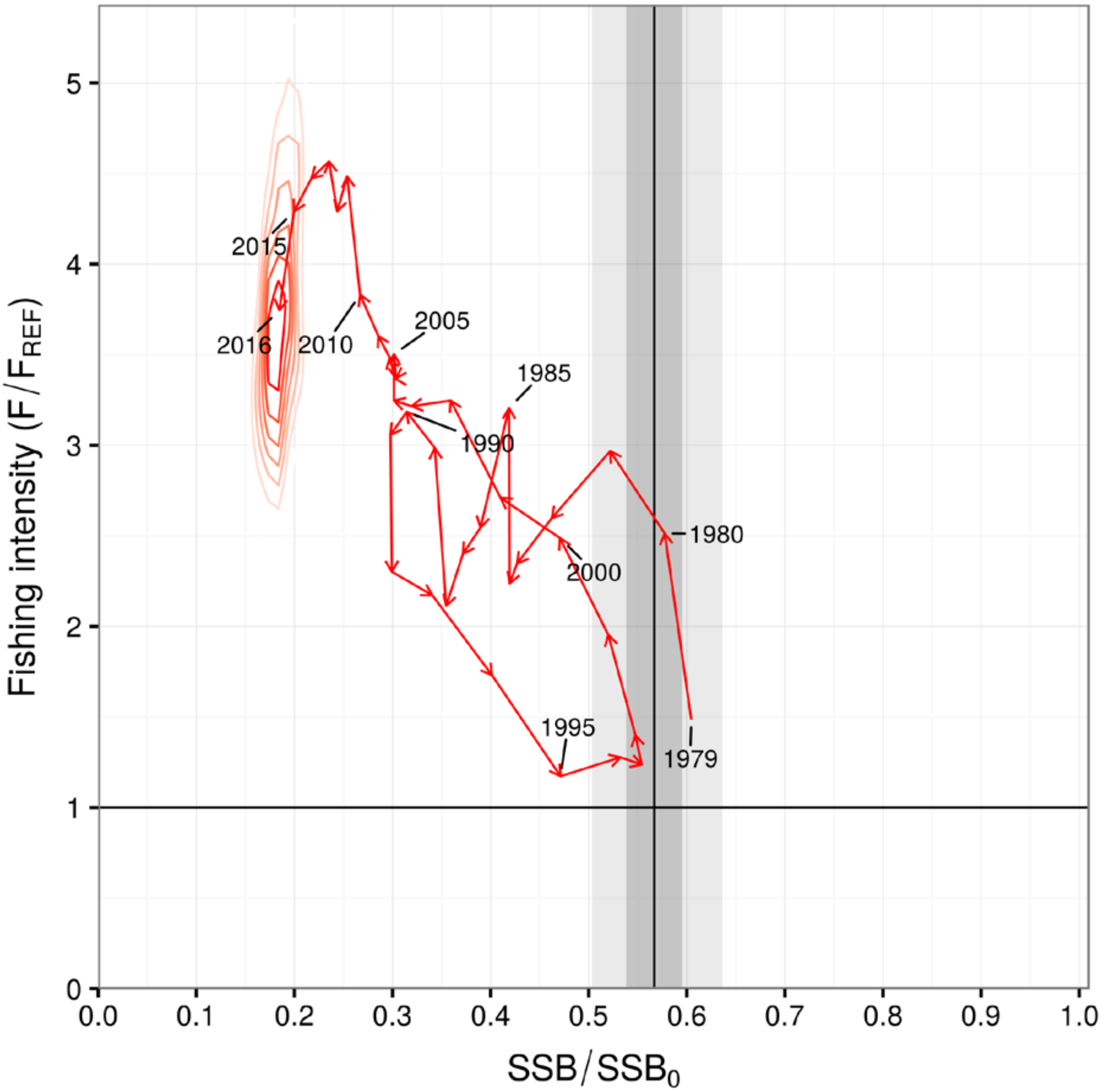


Figure 45: Phase plot summarising the *SSB* history of the CRA 2 stock. The x-axis is the AW spawning stock biomass *SSB* in each year as a proportion of the unfished spawning stock biomass (SSB_0). The y-axis is fishing intensity in each year as a proportion of the fishing intensity (F_{REF}) that gives SSB_{REF} under the fishing patterns in that year. Each point on the figure shows the median of the posterior distributions of biomass ratio and fishing intensity ratio for one year. The vertical line in the figure is the median (line), 70%, and 90% interval (shading) of the posterior distribution of SSB_{REF}. This ratio was calculated using the fishing pattern in 2016. The horizontal line in the figure is drawn at 1, the fishing intensity associated with F_{REF}. The contour density for the final year of the plot (2016) shows the posterior distributions of the two ratios.

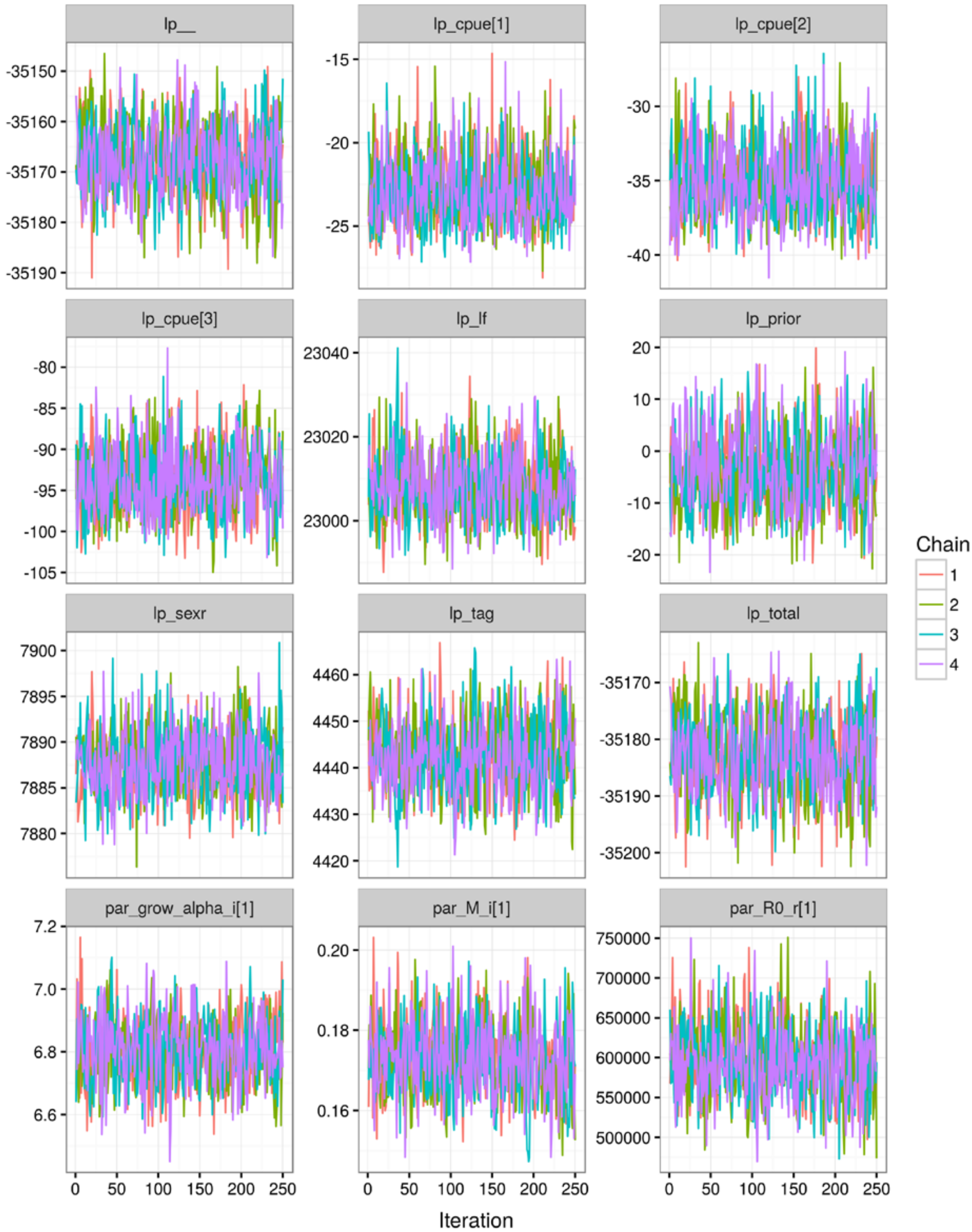


Figure 46: Traces from the start 1945 MCMC sensitivity trial.

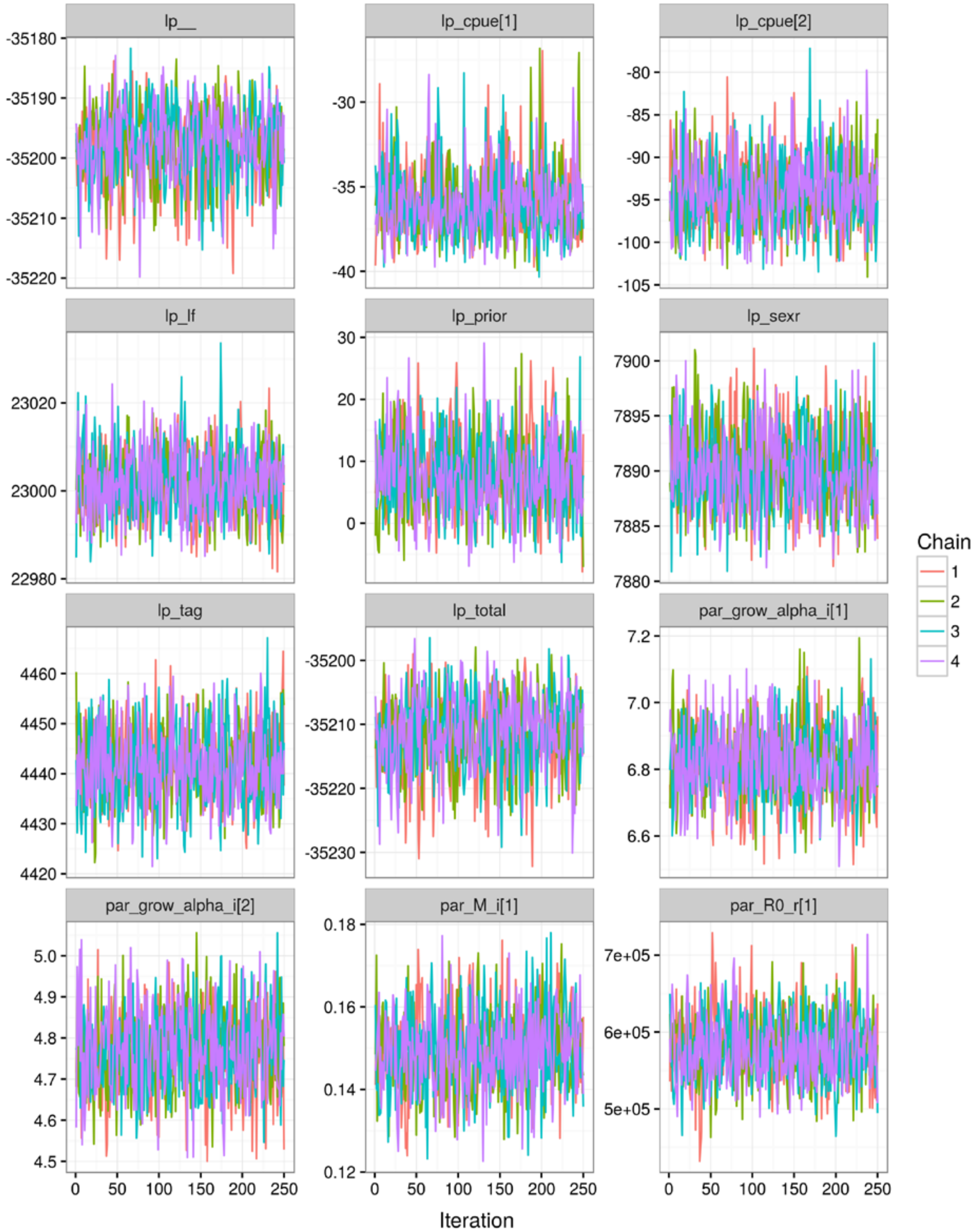


Figure 47: Traces from the 2 × recreational catch MCMC sensitivity trial.

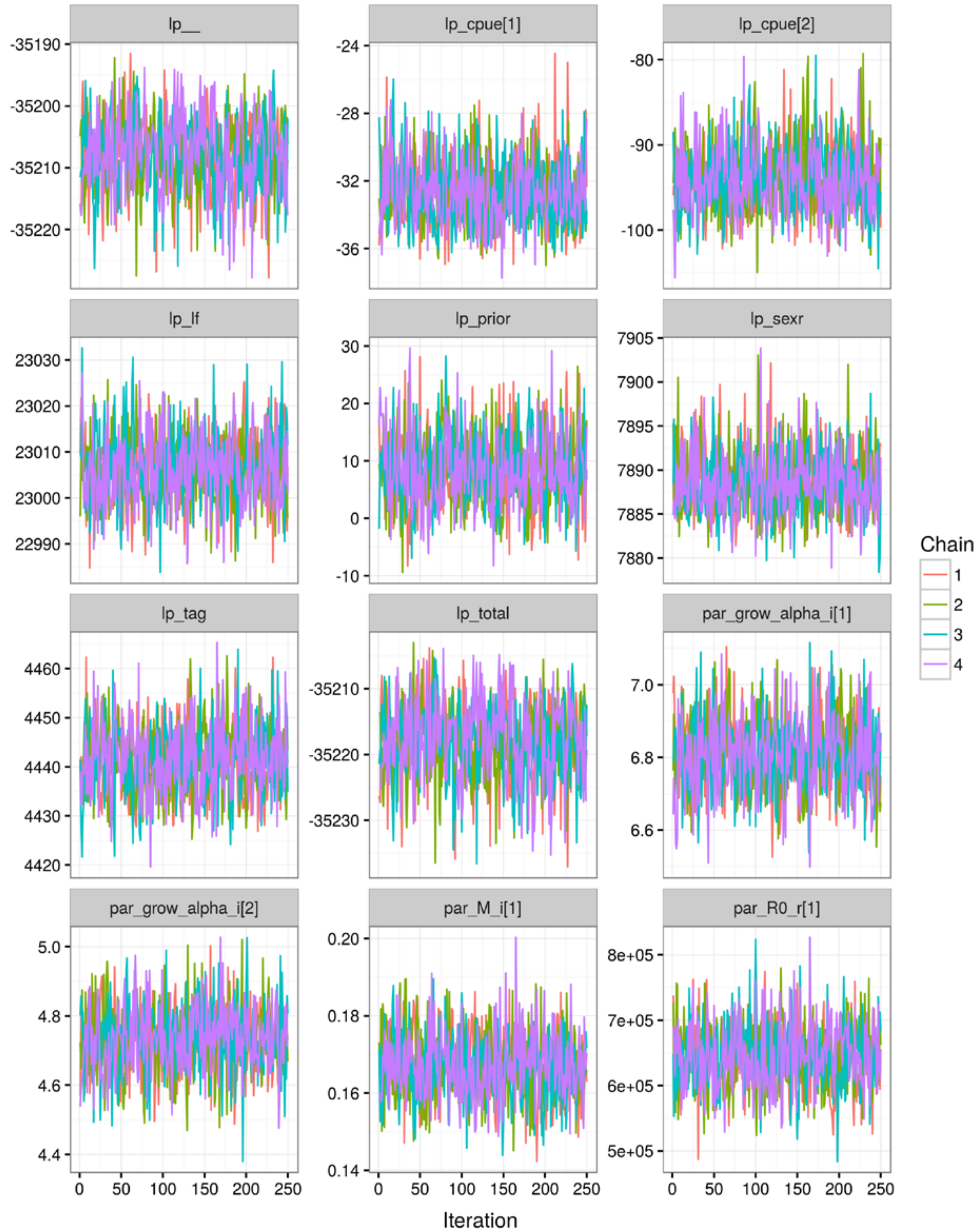


Figure 48: Traces from the *q*-drift MCMC sensitivity trial.

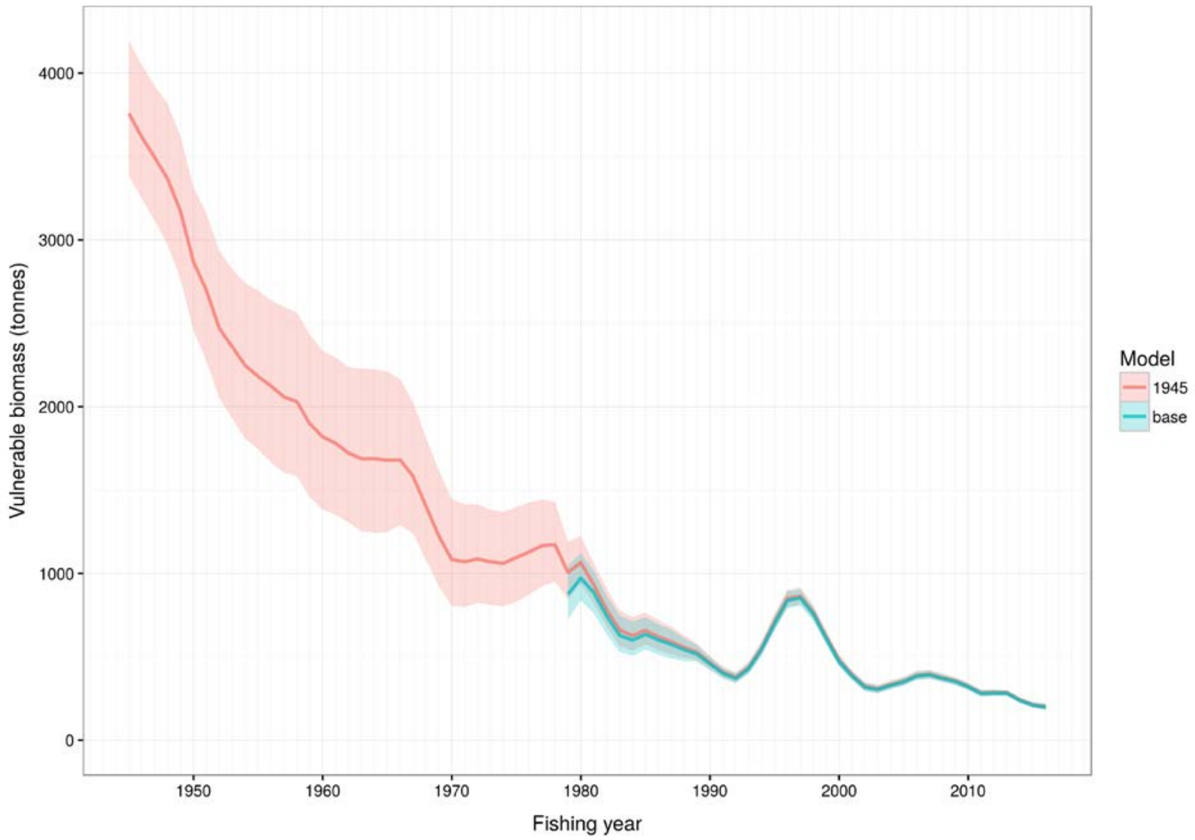


Figure 49: Vulnerable biomass trajectories from the base case MCMC and the start 1945 MCMC sensitivity trial.

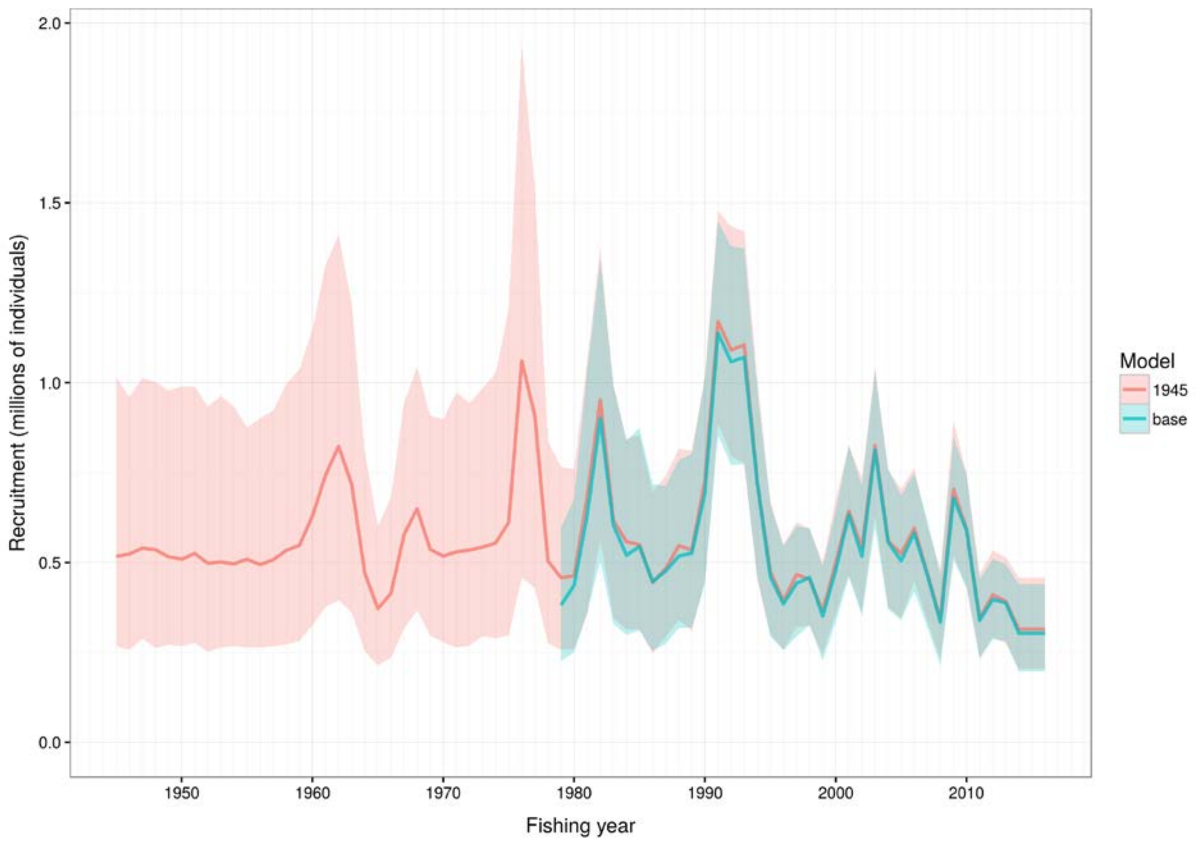


Figure 50: Recruitment in the base case MCMC and the start 1945 MCMC sensitivity trial.

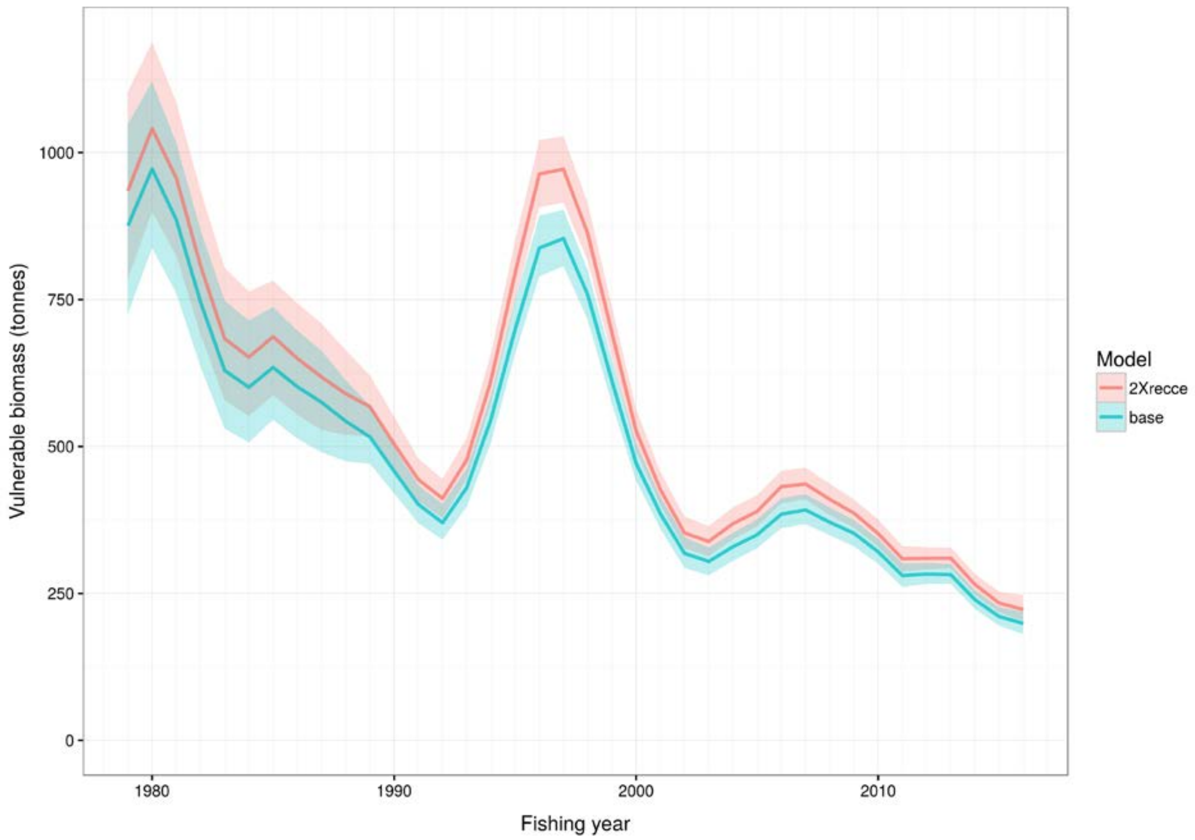


Figure 51: Vulnerable biomass trajectories from the base case MCMC and the 2 × recreational catch MCMC sensitivity trial.

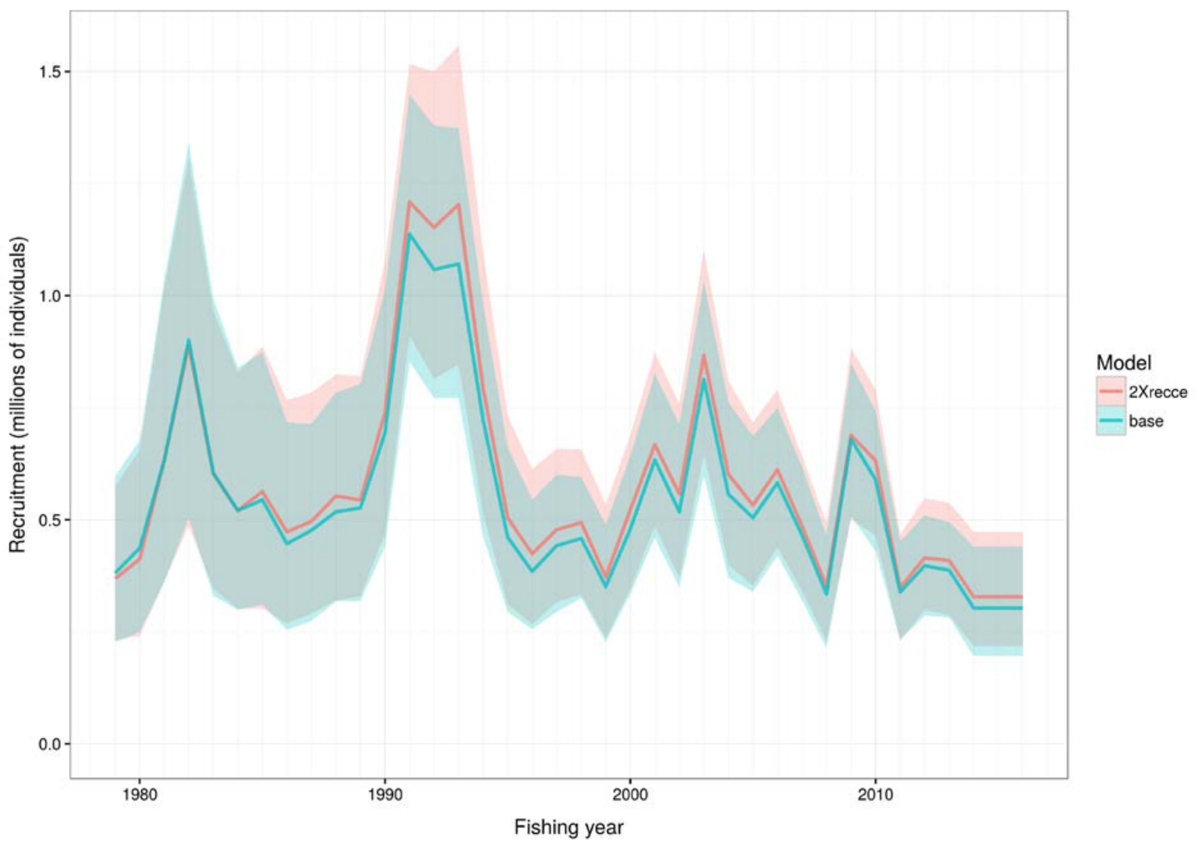


Figure 52: Recruitment in the base case MCMC and the 2 × recreational catch MCMC sensitivity trial.

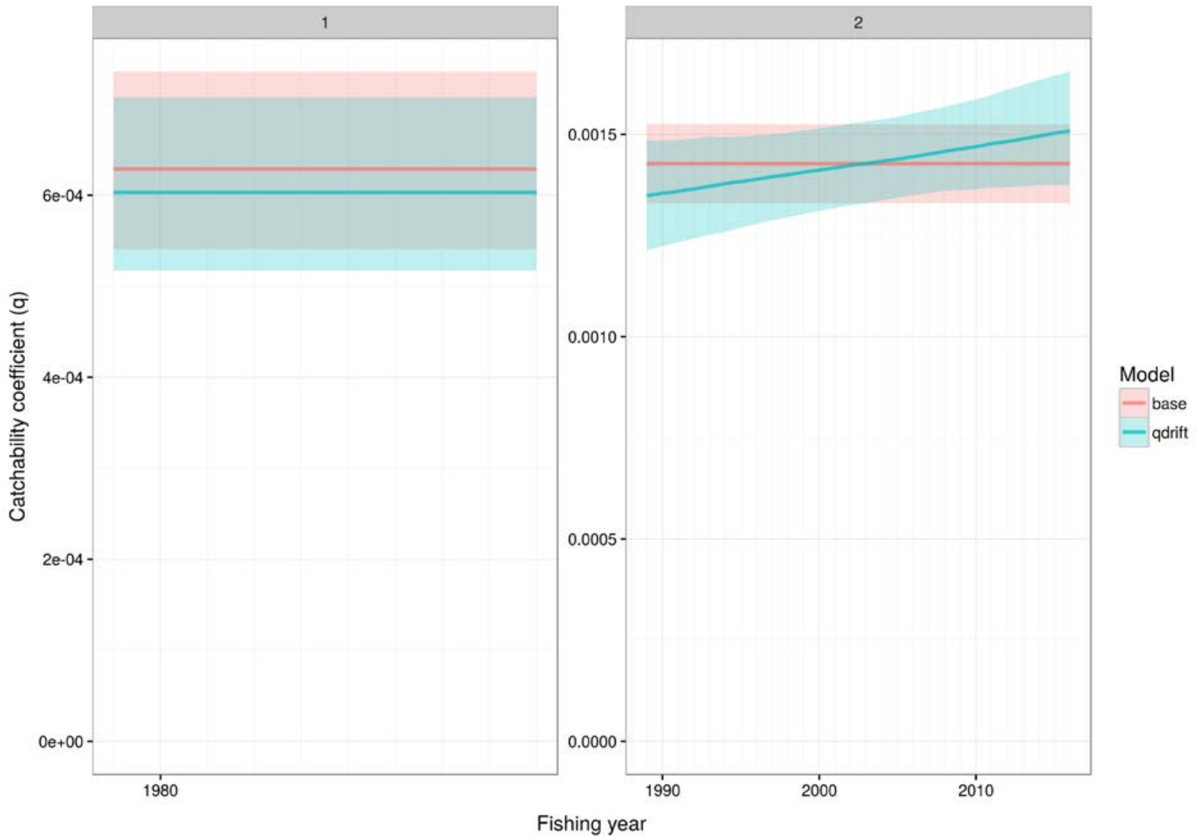


Figure 53: Catchability (q) each year in the base case MCMC and the q-drift MCMC sensitivity trial.

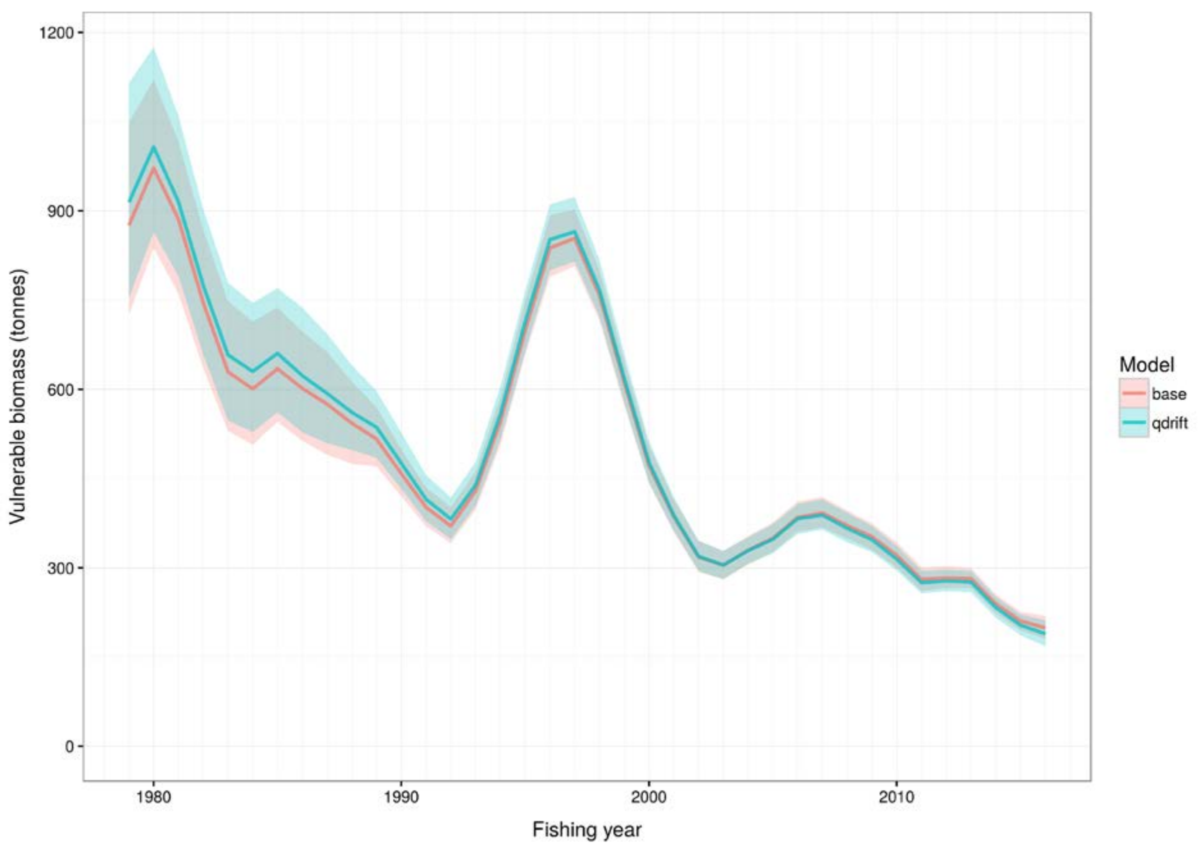


Figure 54: Vulnerable biomass trajectories from the base case MCMC and the q-drift MCMC sensitivity trial.

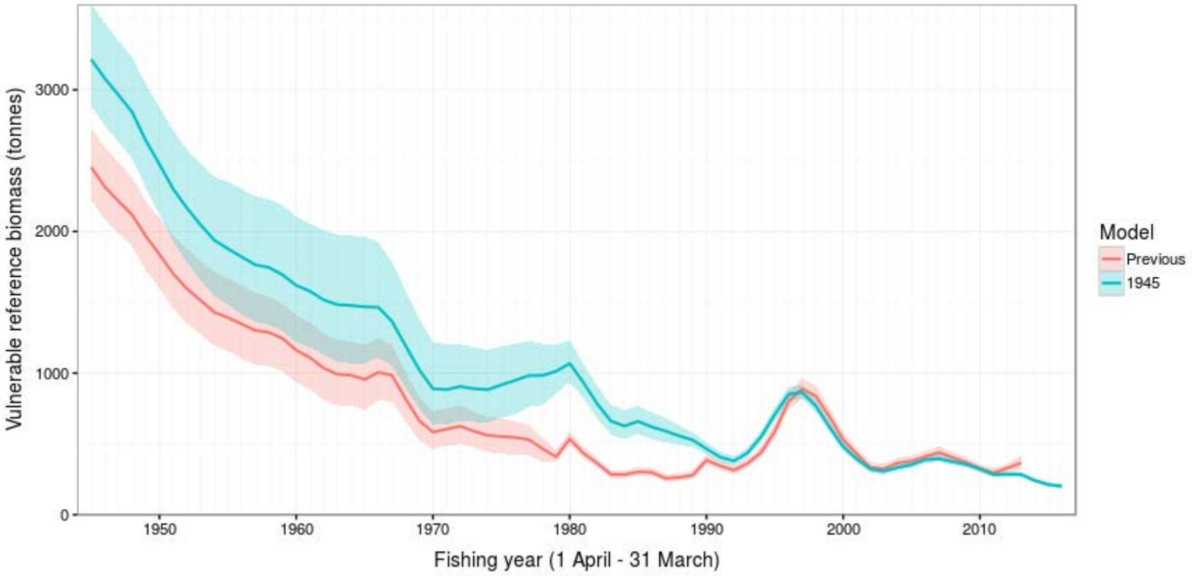


Figure 55: Comparison of vulnerable reference biomass trajectories from the start 1945 MCMC sensitivity and the previous CRA 2 stock assessment base case MCMC.

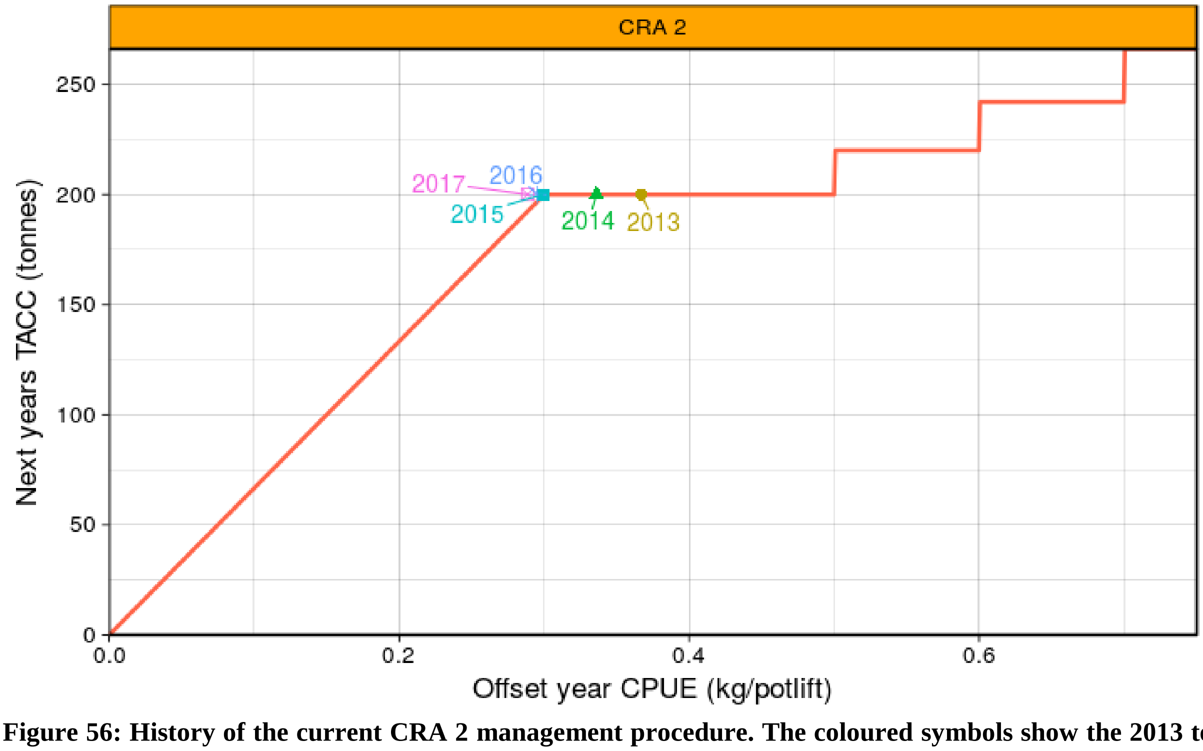


Figure 56: History of the current CRA 2 management procedure. The coloured symbols show the 2013 to 2017 offset-year CPUE and the resulting TACCs. Note that the functional TACCs for 2014 was 175 tonnes after voluntary shelving and for 2016 and 2017 were 151 tonnes after voluntary shelving.

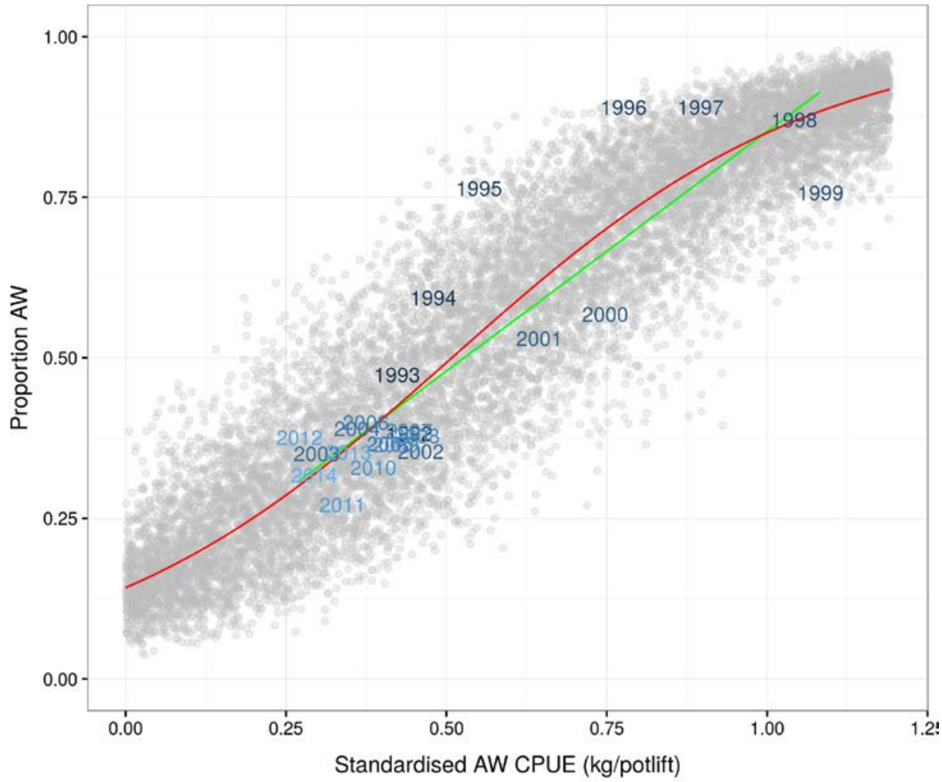


Figure 57: Observed proportion of catch taken in AW vs. the standardised AW CPUE. The red line shows a predictive logistic regression ($R^2 = 0.74$), the grey points are simulations from the logistic regression, and the green line shows a predictive linear regression.

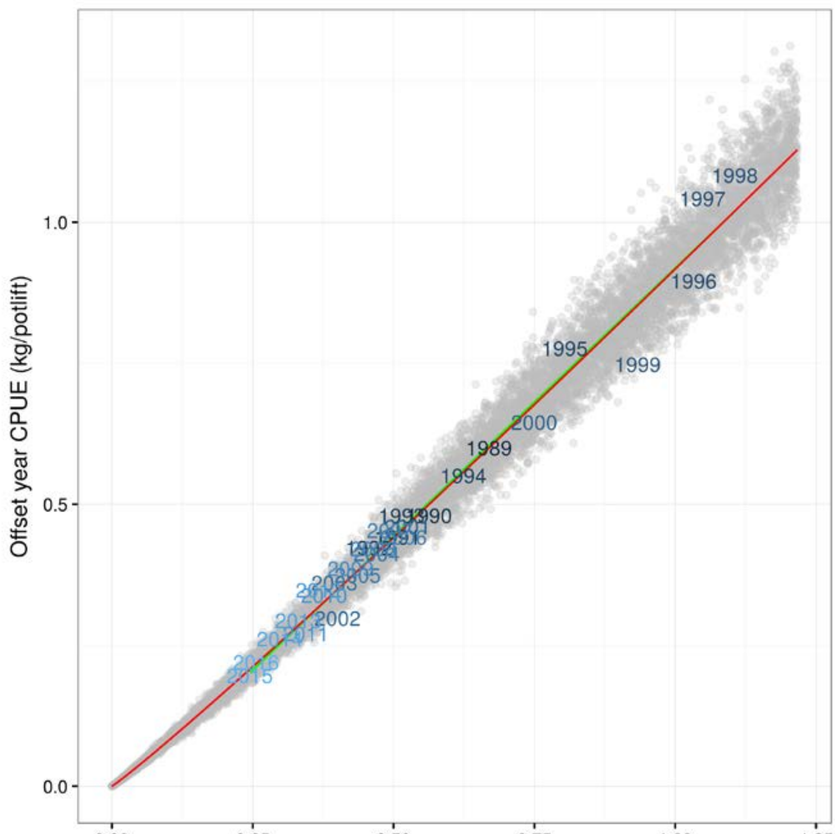


Figure 58: Observed standardised offset-year CPUE vs. the average of AW CPUE in the same year and SS CPUE from the previous year. The red line shows a predictive log-log regression ($R^2 = 0.98$), the grey points are simulations from the log-log regression, and the green line shows a predictive linear regression.

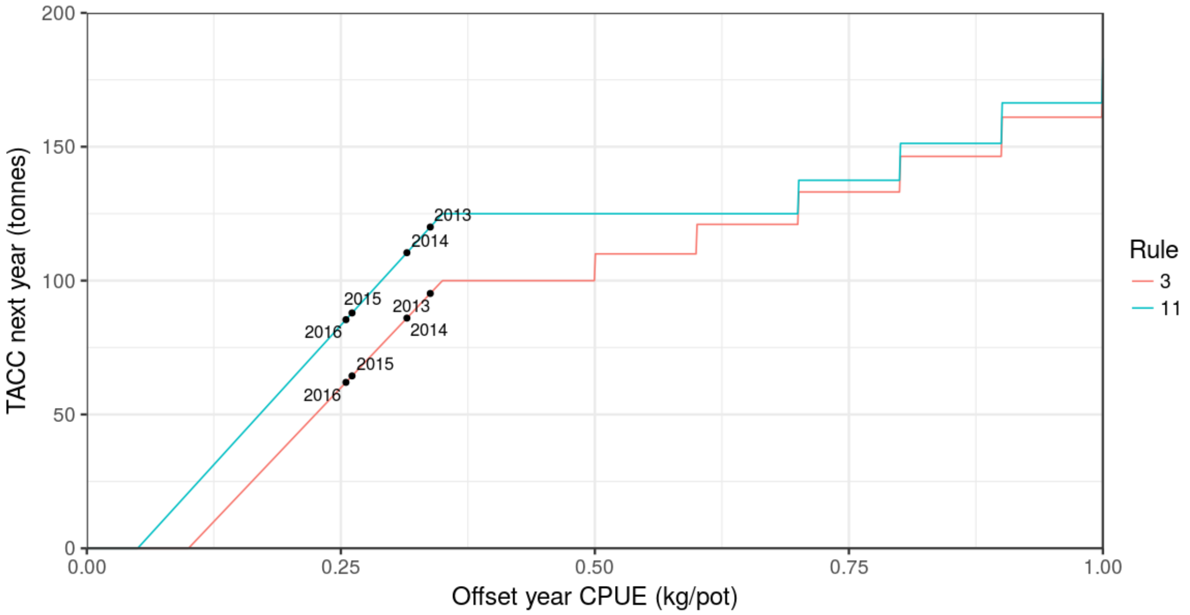


Figure 59: The plateau step rules 3 and 11, used in the initial 2018 MP exploration.

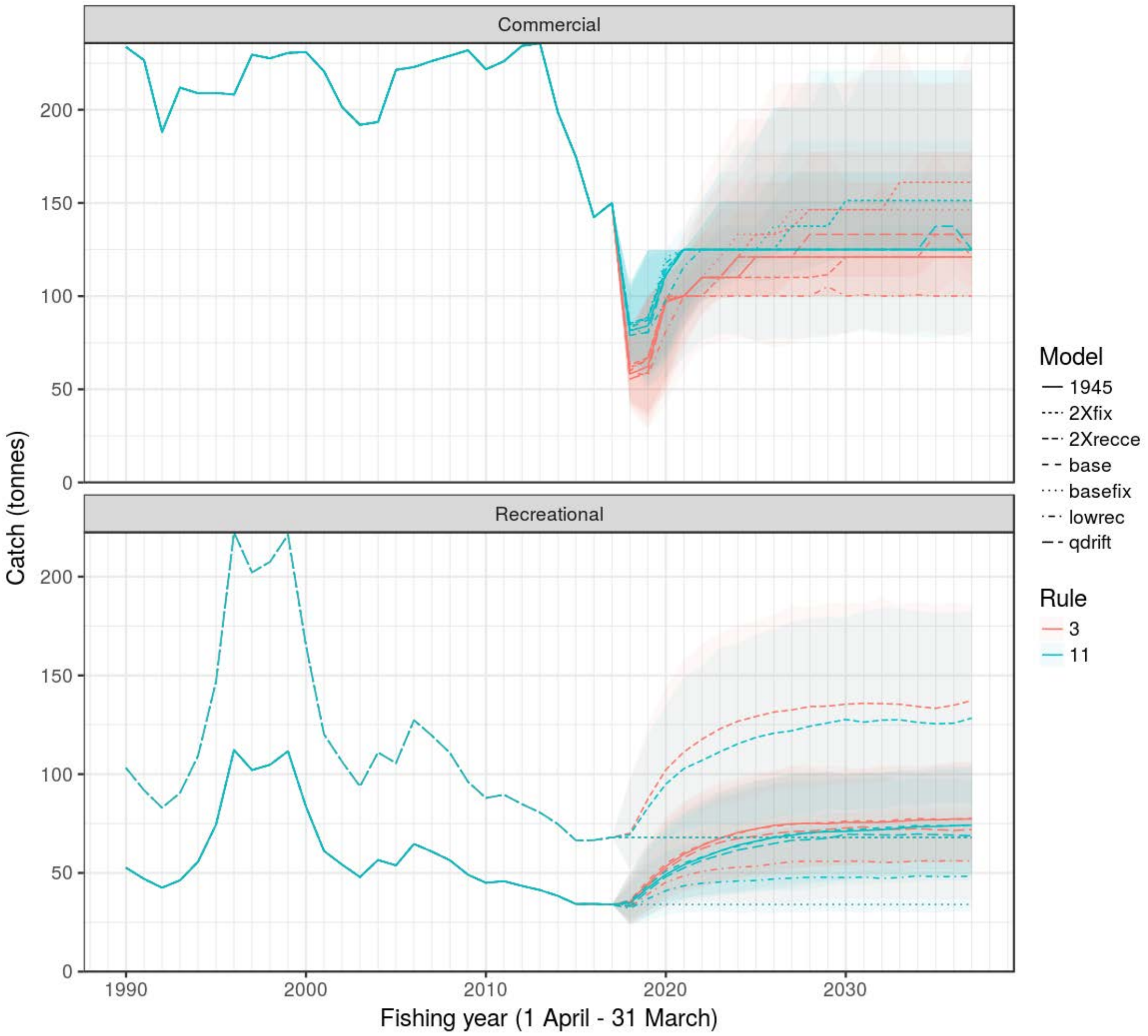


Figure 60: The commercial and recreational catch in each year for all 2018 MP model scenarios using the plateau-step rules 3 and 11 (see Figure 59).

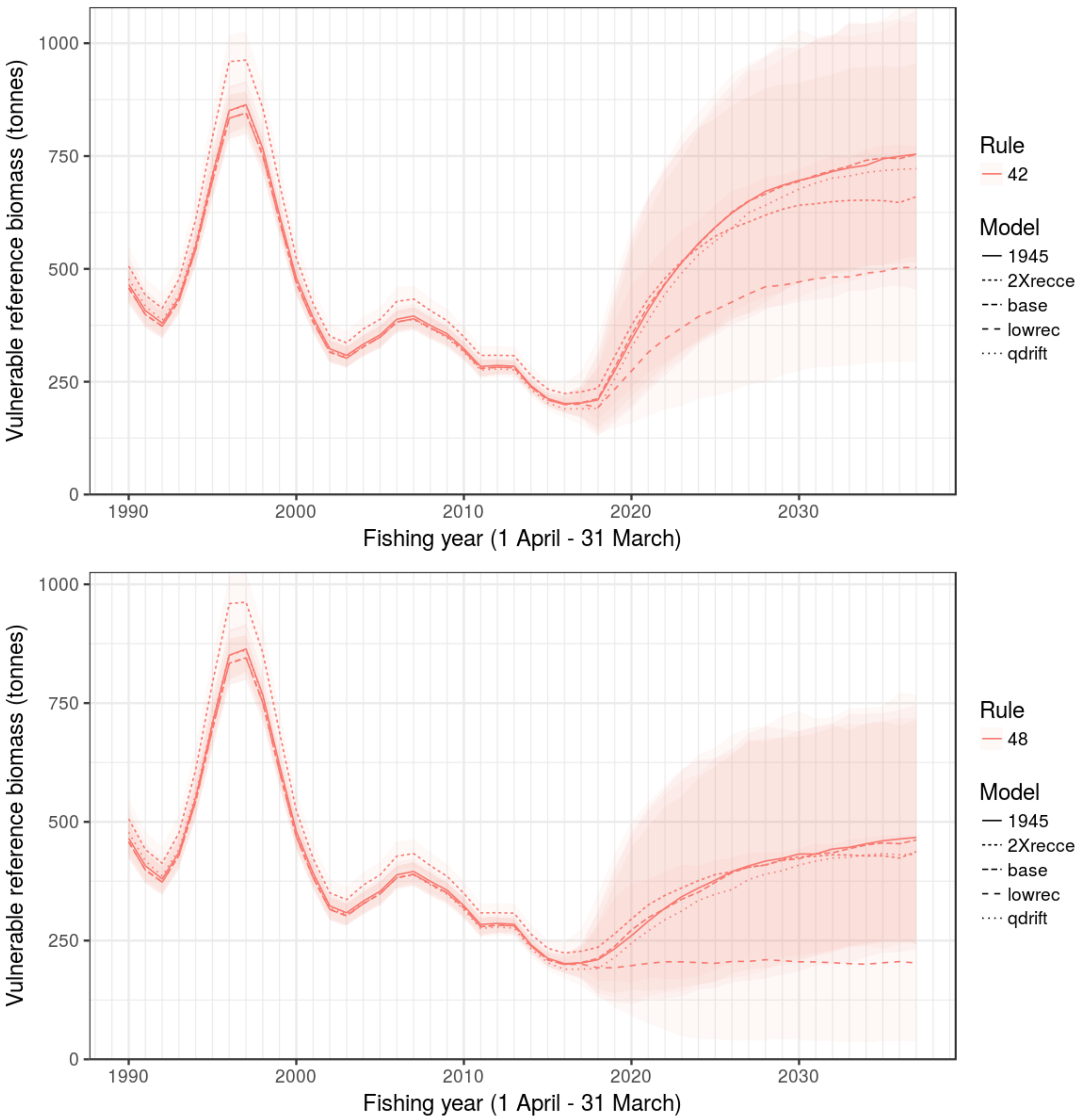


Figure 61: Vulnerable reference biomass for the 80 tonne constant catch rule (rule 42, top) and 140 tonne constant catch rule (rule 48, bottom) for the base case, sensitivities, and the low recruitment robustness trial.

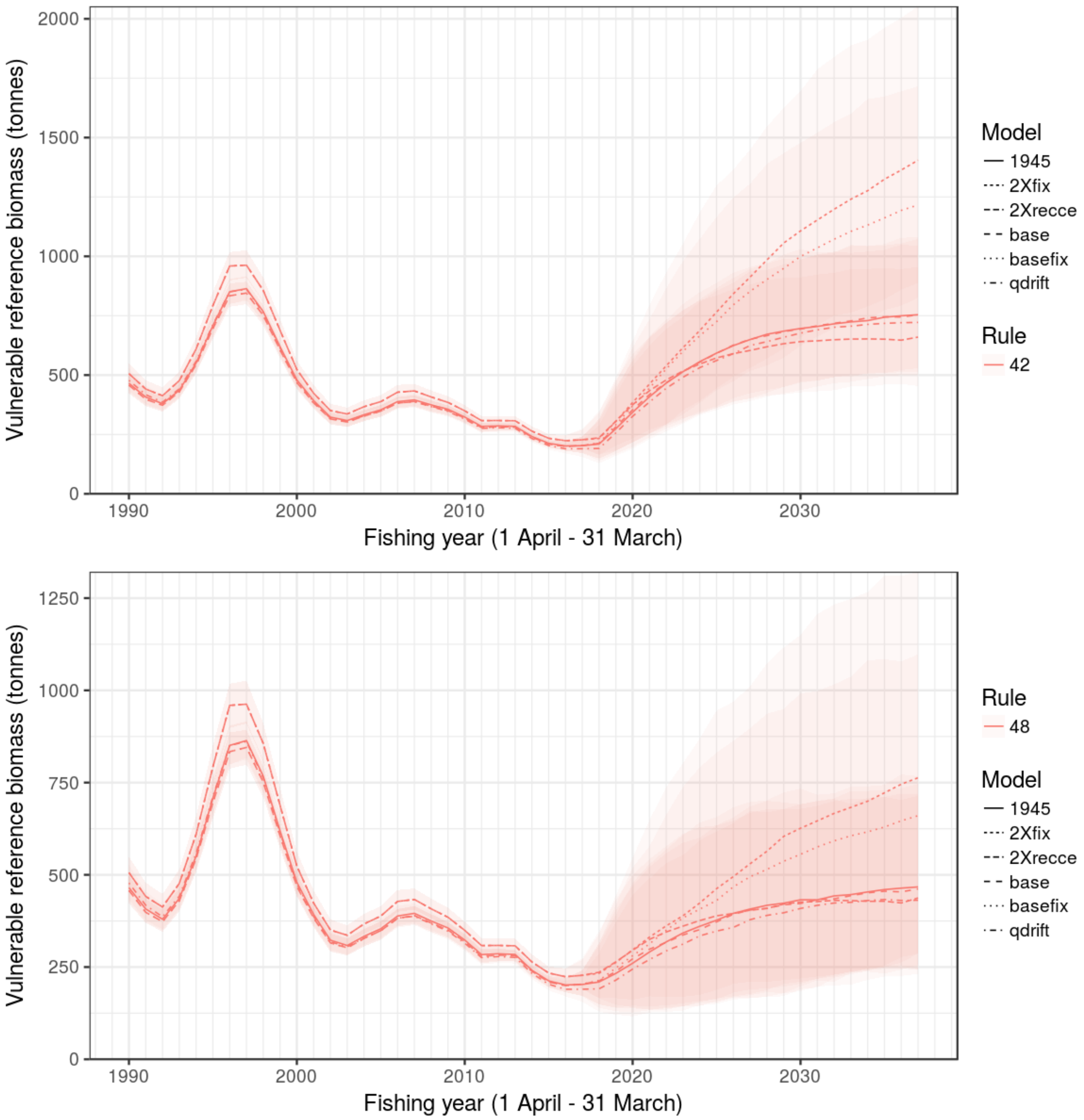
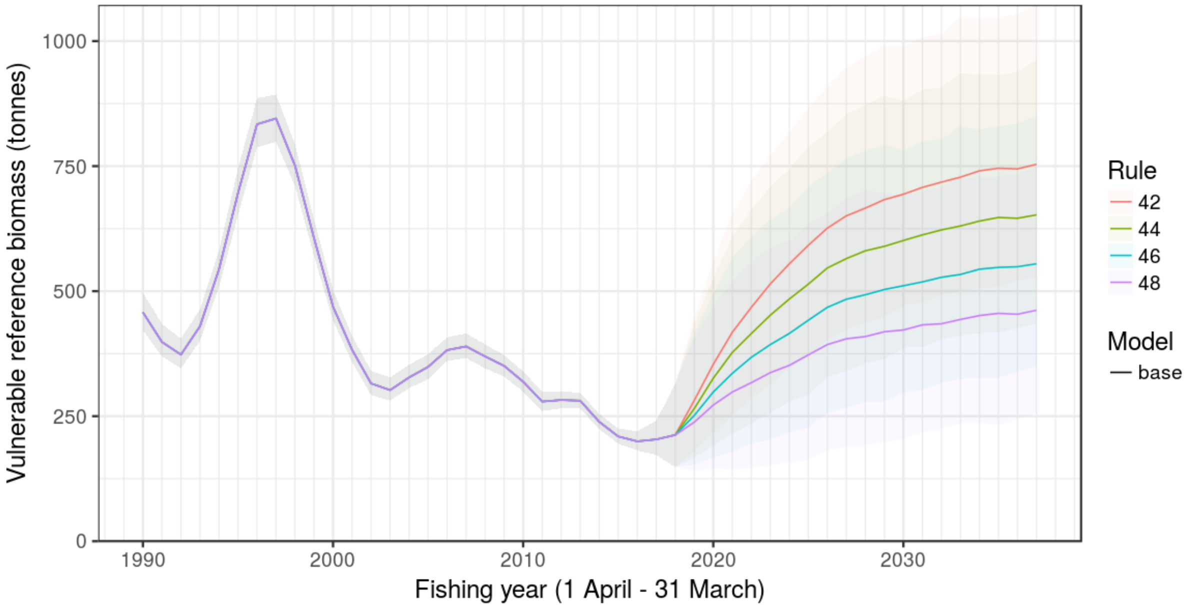


Figure 62: Vulnerable reference biomass for the 80 tonne constant catch rule (rule 42, top) and 140 tonne constant catch rule (rule 48, bottom) for the base case, sensitivities, and the two fixed recreational catch robustness trials.



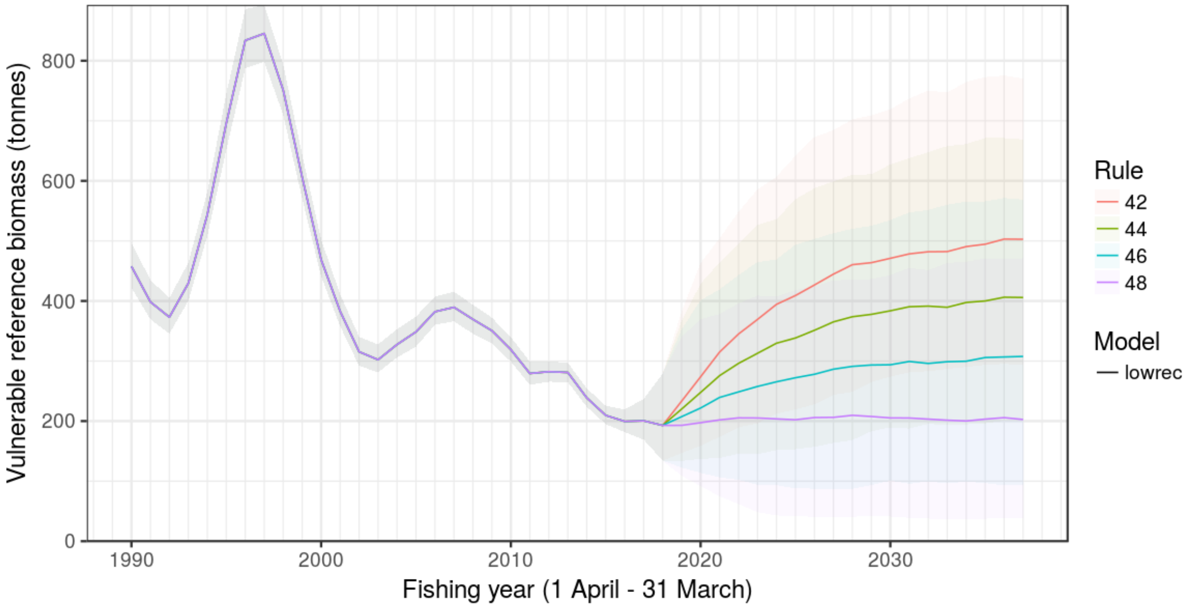


Figure 63: Vulnerable reference biomass for the base case (top) and low recruitment robustness trial (bottom) for the constant catch rules setting projected commercial catch to 80, 100, 120, 140 tonnes (rules 42, 44, 46, and 48).

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 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).

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.

B_0: the expected biomass that would be attained if there were no fishing and recruitment were constant at its average level.

Bayesian stock assessment: an inferential method that allows prior information or expert judgement to be used formally in addition to the data. Often uncertainty is estimated using Markov chain Monte Carlo simulations (MCMC) which samples the posterior distribution of estimated and derived parameters.

$B_{current}$: the model 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.

B_{MIN}: the minimum of estimated vulnerable biomass in the years for which the model estimates biomass.

B_{MSY}: 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.

B_{PROJ}: vulnerable biomass in the last projection year, determined by running the model dynamics forward with specified catches and simulated recruitment.

B_{VULN}: 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, to biomass, or that relates the puerulus settlement index to numbers; usually has the symbol *q*.

catch sampling: see logbooks and observer catch sampling.

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

CPUE: catch per unit of effort; usually has the units kg of catch per potlift; assumed to be an abundance index such that CPUE = catchability ×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: a 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 (R_0) 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 non-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 F_{MSY}.

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.

***F_{MSY}*:** 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.

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.

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.

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

***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. MCMC simulations explore the combinations of parameters in the region near the "best" set of parameters, and from this set, 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*.

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; previous version of the stock assessment model (Haist et al. 2009).

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; the model 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: non size limited 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.

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.

R_0: the base recruitment value in numbers of fish.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SL catch: the size limited 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 $SSB_{current}$, the estimated *SSB* in the last year with data; SSB_0, the *SSB* in the first model year; SSB_{MSY}, the *SSB* at equilibrium B_{MSY}.

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"); this 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: Total Allowable Catch limit set by the Minister for Primary Industries for a stock.

TACC: Total Allowable Commercial Catch limit 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; $Z = F + M$.