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Tini a Tangaroa

The 2019 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 1

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
1. INTRODUCTION.....	2
2. STOCK ASSESSMENT	3
2.1 Data.....	4
2.2 Model	4
2.3 Parameters and priors.....	5
2.4 Assessment indicators.....	6
2.5 Maximum <i>a posteriori</i> (MAP) inference	6
2.5.1 MAP base case	6
2.5.2 MAP sensitivity trials.....	8
2.6 Bayesian inference using Markov chain Monte Carlo (MCMC).....	9
2.6.1 MCMC base case.....	10
2.6.2 MCMC sensitivity trials	11
2.7 Projections	11
3. DISCUSSION.....	12
3.1 Future research.....	12
4. ACKNOWLEDGMENTS.....	13
5. REFERENCES.....	13
6. TABLES.....	14
7. FIGURES.....	23

EXECUTIVE SUMMARY

Rudd, M.B.; Roberts, J.; Large, K.; Webber, D.N.; Starr, P.J. (2021). The 2019 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 1.

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This document describes the 2019 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 1. The stock assessment used the lobster stock dynamics model. Data inputs and all technical decisions were discussed and agreed upon by the Rock Lobster Fishery Assessment Working Group (RLFAWG), who oversaw this work.

The model was fitted to standardised catch-per-unit-effort (CPUE) indices, size frequency data, sex ratio data, and tag-recapture data. This document describes the procedure used to find an acceptable base case model and shows the model fits. Several sensitivity trials were done to test assumptions in the base case model.

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

The stock assessment estimated increasing fishing mortality from 1945 through the late 1960s, resulting in a decline in rock lobster biomass in CRA 1. Since the 1990s, size-limited catch has remained relatively stable whereas non-size-limited catch has increased over time. The stock assessment estimated that the spawning stock biomass has generally remained above the soft limit of 20% SSB_0 . Although CPUE has been increasing, projections predict that continued harvest at constant current catch levels would likely lead to a decline in the vulnerable and spawning stock biomass.

1. INTRODUCTION

This work addresses Objective 4 of the Fisheries New Zealand contract CRA2018-01. This one-year contract, which began in April 2019, was awarded to the New Zealand Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contracted Objective 4 to the New Zealand rock lobster stock assessment team.

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

The National Rock Lobster Management Group (NRLMG) decided that CRA 1 and CRA 3 should be assessed in 2019. Data were compiled for both stocks by a team comprising Paul Starr (Starrfish), D'Arcy Webber (Quantifish), Merrill Rudd (Scaleability), Kath Large (NIWA), and Jim Roberts (independent consultant). CRA 1 (Figure 1) was then assessed by Merrill Rudd and Kath Large, and CRA 3 was assessed by D'Arcy Webber and Jim Roberts, with Paul Starr supporting both teams. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).

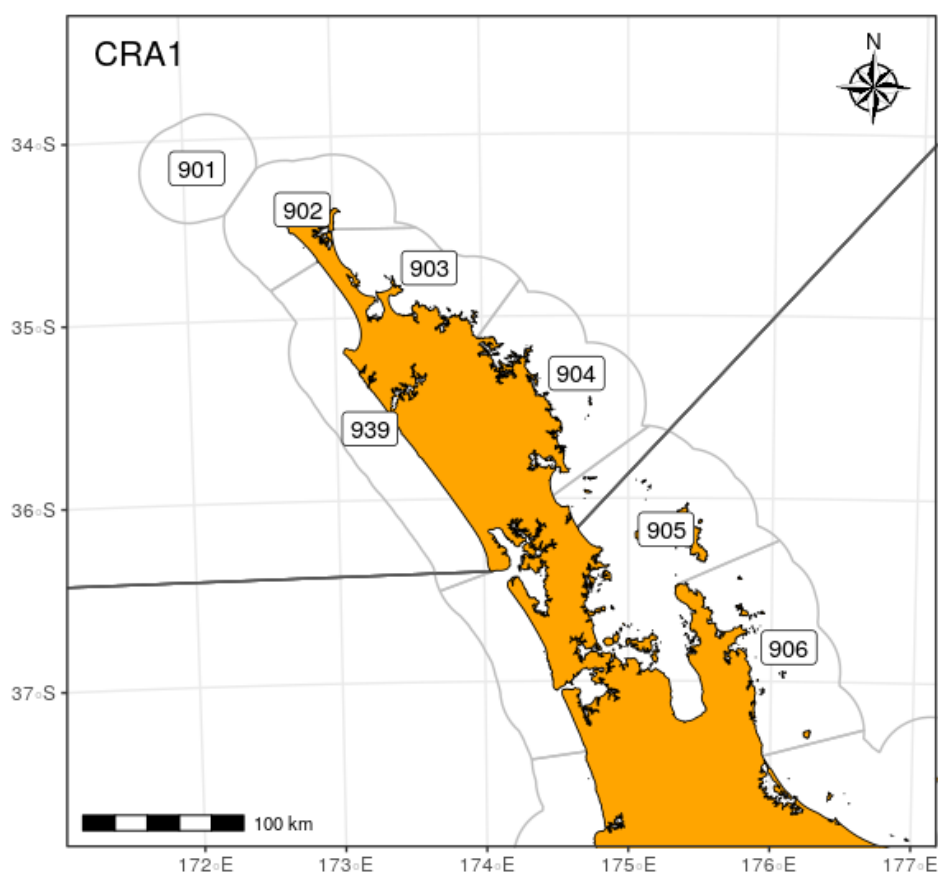


Figure 1: The CRA 1 stock area on the northern coasts of the North Island, and its statistical areas. The QMA boundaries are defined by black lines and the statistical area boundaries by grey lines. Statistical Areas 905 and 906 in CRA 2 are also shown because tag-recapture data from these areas were included in this assessment to supplement the CRA 1 tagging data.

This document describes a new stock assessment for CRA 1. All the tables referred to in this document can be found in Section 6 and all the figures except for Figure 1 are in Section 7. Data used in this stock assessment are documented by Starr et al. (2020). CRA 1 was assessed assuming a single homogeneous stock across the five statistical areas (901, 902, 903, 904, and 939), using the lobster stock dynamics (LSD) model (Webber et al. 2018a).

The CRA 1 commercial fishery is primarily a trap or pot fishery, fished by small boats on day trips in relatively shallow waters. Multi-day trips with larger vessels are used to fish Statistical Area 901 (Three Kings Islands), a major catching area. From 2015 to 2018, the CRA 1 total allowable commercial catch (TACC) was set using a management procedure (MP) based on the offset-year catch per unit effort (CPUE). The stock assessment that was scheduled for 2019 has been completed and is presented in this report. However, MP rules were not run in 2019. Because of changes to the collection of catch and effort data (see below), this form of management has been temporarily discontinued. Allowances are added by the Minister for the non-commercial fisheries to produce a total allowable catch (TAC). Other management measures include protection of ovigerous (berried) females, a minimum legal size (MLS) for each sex, and escape gaps in pots.

CRA 1 extends from Kaipara Harbour on the west coast to the Waipu River, south of Bream Bay and Whangarei on the east coast (Figure 1). This QMA includes the Three Kings Islands, designated by a separate statistical area (901). Commercial fishing occurs on both sides of the North Cape of the North Island, as well as at the Three Kings Islands. The first TAC for CRA 1 was set at 273.062 t for the 2015–16 fishing year as a result of the 2014 stock assessment, with the CRA 1 TACC remaining unchanged at 131.062 t. This TAC is comprised of a customary allowance of 20 t, a 50 t recreational allowance, and a 72 t allowance for “other mortalities”. This stock assessment uses estimates of customary, recreational, and “other mortalities” provided by Fisheries New Zealand or generated by agreement of the RLFAWG (see Starr et al. 2020) that are less than the TAC allowances. Commercial landings have remained at or near the 131 t TACC since the early 1990s. In the 2017–18 fishing year, there were 12 vessels operating in CRA 1, a total that has remained relatively unchanged since the early 2000s (Starr 2019). There is significant iwi involvement in quota share ownership and fishing, and rock lobsters have great cultural significance to local Māori. The commercial harvest has an approximate landed value of \$11.1 million based on an average port price of \$84,500/tonne (Daryl Sykes, NZRLIC, pers. comm.). CRA 1 landings are shipped to Leigh and to Auckland for processing and export.

The stock assessment was completed in a workshop held in Wellington during September and October 2019 and was presented to the Fisheries New Zealand mid-year Plenary during November 2019 (Fisheries New Zealand 2019).

2. STOCK ASSESSMENT

The 2019 CRA 1 stock assessment used the lobster stock dynamics model (LSD, Webber et al. 2018a). This model is coded in Stan (Stan Development Team 2016, 2017). The transition from the multi-stock length-based model (MSLM, Haist et al. 2009) to the new LSD model is considered complete, having been tested alongside the MSLM model for the CRA 4 stock assessment in 2016. LSD was used as the main assessment model for CRA 2 in 2017 after ascertaining that LSD and MLSM in that year provided equivalent results, and as the main assessment model for CRA 6 in 2018.

Maximum *a posteriori* (MAP) estimation and Markov chain Monte Carlo (MCMC) were used to make inferences about the CRA 1 stock. A series of MAP sensitivity trials were explored. Three models, including the base case and two sensitivity trials, were extended to a full Bayesian implementation using MCMC.

The uncertainty associated with the change in commercial catch and effort data collection from paper forms to electronic monitoring, prevented the development of a new MP based on the outcome of this stock assessment, resulting in the loss of MPs for setting the TACC over the next few years. Multiple options for setting interim catch levels without an MP were explored, including projections based on current catch levels and identifying the fixed level of catch that maintains current vulnerable biomass. Existing management targets are based on female spawning stock biomass and vulnerable biomass, which are defined by unfished spawning stock biomass (SSB_0), spawning stock biomass associated with MSY (SSB_{MSY}), and unfished vulnerable biomass (B_0).

2.1 Data

Data used in this stock assessment are documented by Starr et al. (2020) and the temporal extent of these data is illustrated in Figure 2. Following the example of the 2018 CRA 2 and the 2019 CRA 6 stock assessments (Webber et al 2018b, Rudd et al. 2019), a vessel explanatory variable was included in the CPUE standardisation procedure (see Starr et al. 2020) and CPUE was split into three series:

- o The catch rate (CR) series is a non-seasonal un-standardised daily catch rate from 1963 to 1973. Catchability (q) is assumed constant over this period.
- o The Fisheries Statistics Unit (FSU) series is a seasonal standardised index from 1979 to 1988. The standardisation model includes year, month, and statistical area explanatory variables but no vessel effect. Catchability (q) is assumed constant over this period.
- o The Catch Effort Landing Return (CELR) series is a seasonal standardised series from 1989 to 2018 with a vessel explanatory variable (vessels required to have fished CRA 1 for at least five years). Catchability (q) is assumed to improve over time at a constant rate, with the rate of change estimated in the model by the *qdrift* parameter.

Due to the limited number of tag recaptures, this assessment combined tag data from CRA 1 (tags released in Statistical Areas 901–904 and 939) and tags released in the two western CRA 2 areas (Statistical Areas 905 and 906). Initial model exploration suggested that individuals recaptured multiple times tended to have slower growth rates, resulting in a decision to only fit to the first tag recapture event. Although there was extensive discussion on the possibility of a moulting bias associated with the timing of tagging and recapture (Webber et al. 2020), preliminary model runs determined limited impact of including or excluding the tags at liberty less than one year. Therefore, to include as much data as possible, all tags at first recovery were included, regardless of their time at liberty.

Starr et al. (2020) examined the available CPUE and length frequency data for differences among two trial sub-regions of CRA 1: 1) Statistical Areas 903 and 904, comprising the east coast of Northland; and 2) the three remaining Statistical Areas 901, 902, and 939, comprising the west coast of Northland, North Cape, and the Three Kings Islands. There was concern that these two sub-regions were not homogenous and required separate stock assessments. However, the visual examination did not find strong differences among the available data and it was decided to assess CRA 1 as a single region (Appendix C of Starr et al. 2020).

From 1945 to 1949, there was no MLS for rock lobster in New Zealand. MLS restrictions were initially implemented for New Zealand rock lobster as measurements of tail length in inches. This measurement standard was subject to some abuse because tails could be stretched but was accepted because a significant fraction of the catch came from Fiordland where it was permissible to tail lobsters at sea. MLS was changed to a width measurement (in mm) across the spines of the second abdominal segment (called tail width or TW) in 1988 for all of New Zealand red rock lobster, requiring the conversion of the pre-1988 regulations into equivalent TW measurements for use in the stock assessment model. The TW values used for the MLS in the model are given in Table 1.

2.2 Model

This stock assessment treated CRA 1 as a single homogeneous area. The first fishing year in the model was set to 1945, because this was the first year of the commercial fishery. The last year was 2018, because this was the last complete fishing year with data. Fishing years extend from 1 April to 31 March. The model delineates two six-month seasons within a fishing year: autumn-winter (AW, April through September) and spring-summer (SS, October through March). The model tracks the numbers of immature females, mature females, and males in 36 2-mm TW bins (i.e., {[30, 32), [32, 34), ..., [100, ∞)}). The maximum bin size was extended to 100 mm from the 90-mm maximum bin size used in 2014, based on the number of lobsters observed greater than 90 mm TW.

In summary, the base case model dimensions and structural choices included:

- Fishing years: 1945–2018 (i.e., ending with the 2018–19 fishing year)
 - Sensitivity test explored starting the model in 1979, the first year of the FSU CPUE series
- Two seasons: AW and SS during each fishing year
- Three sex categories: immature females, mature females, males
- Tail width bins: 36 2-mm wide bins from 30 mm to 100 mm tail width (last bin is a “plus group” or accumulator bin)
- Size at recruitment: mean 32 mm with standard deviation 2 mm
- Likelihoods:
 - Lognormal for three CPUE series (CR, FSU, and CELR)
 - Robust normal for tags
 - Multinomial for length frequencies (LFs), fitted to proportions for males, immature females, and mature females, with each sex category normalised separately
 - Multinomial for sex ratios
- Data weighting: determined iteratively. No re-weighting of tag data because they are self-weighting through estimation of an observation error parameter
- Fishing mortality dynamics: instantaneous using the Newton-Raphson algorithm to iteratively solve the Baranov catch equation
- Growth model: Schnute-Francis
- Recruitment deviations (*Rdevs*) estimated: 1945–2016 (final two years are set to the 2016 estimate, given no real information in data for these recruitments and lack of puerulus settlement data for the assessment area)
- Selectivity: ‘double-normal’ with right-hand limb parameter fixed at 250
 - Sensitivity test explored estimating the right-hand limb parameter
- Handling mortality: two periods 1945–1989 fixed at 0.1 and 1990–2018 fixed at 0.05
- Stock-recruitment: off
- Density-dependent growth: off
 - Sensitivity test explored estimating density-dependent growth
- Three CPUE series, each with separate *q* parameter
- *qdrift* parameter: estimated annual proportional increase of the CPUE *q* for CELR series
 - Sensitivity test explored fixing *qdrift* = 0.
- Catch from 1945 to 2018, with illegal catch from 1981 to the present set at 20% of the commercial catch based on the pattern of CPUE
 - Sensitivity test explored the illegal catch from 1981 to present set at 10% of the commercial catch based on the pattern of CPUE.

2.3 Parameters and priors

Estimated model parameters are listed in Table 2 and Table 3. Priors and parameter bounds for these parameters are provided in Table 3. Fixed values for some parameters and model settings are available in Table 4.

Wide uniform priors were specified for average recruitment (R_0) and the catchability coefficients (q) for each CPUE series. Beta distributions with both shape parameters set to 1 were used for all priors bounded between 0 and 1, including *Gdiff* (Table 3), all vulnerability parameters, and, when applicable, the initial exploitation rate and density-dependent growth parameter. An informative lognormal prior was specified for natural mortality (M) and an informative normal prior based on an unpublished meta-analysis was specified for the growth parameters *Gshape* and *GCV* (Table 3). Uninformative normal prior distributions were specified for all other model parameters. These uninformative normal priors are basically flat across sensible ranges for each of these parameters and therefore do not influence the outcome of the stock assessment, though they do help the model software (Stan) with MCMC mixing.

The vulnerability of immature females and mature females during the SS season was assumed to be the same. The four vulnerability parameters (i.e., one for each sex and season) were estimated relative to the vulnerability of males during the AW season (which is fixed to 1), because males during AW have the highest fishing mortality among the six available sex/season combinations (Table 5).

Handling mortality was assumed to be 10% for all lobsters returned to sea before 1990 and 5% from 1990 to present. This reduction in handling mortality was agreed by the RLFAWG to coincide with the start of the live export market. Handling mortality was applied to undersized lobsters of each sex taken in either season by the size-limited (SL) fishery as well as to mature females taken in the AW SL fishery. It was assumed that there were no discards in the non-size-limited (NSL) fishery. H_{2018} is the model estimate of the amount of handling mortality (in tonnes) in the final (2018) fishing year.

2.4 Assessment indicators

No additional indicators beyond those included in the 2018 CRA 6 stock assessment (Rudd et al. 2019) were included in this stock assessment. The main indicators were related to the relative estimates of vulnerable biomass, vulnerable reference biomass, spawning stock biomass, and total biomass, including the probabilities of each of the biomass indicators falling below current levels after projecting the current catch for five years.

Vulnerable biomass was defined as 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 final model year to all previous years, including those years where alternative regulations were applied.

The probability of the spawning stock biomass being below the soft and hard limits was also calculated. Spawning stock biomass (SSB) is defined as the biomass of all mature females at the start of AW. SSB_0 was the spawning stock biomass at unfished equilibrium with R_0 . The soft and hard limits are set at the default 20% SSB_0 and 10% SSB_0 , respectively.

The derived values of assessment indicators are summarised in Table 6. Probabilities were calculated from MCMC posterior distribution samples.

2.5 Maximum *a posteriori* (MAP) inference

Maximum *a posteriori* inference was used for exploring potential model options without committing the computing time required for Bayesian inference. A base case was developed, and sensitivities were used to test the base case assumptions described in Section 2.5.2.

2.5.1 MAP base case

2.5.1.1 Matching previous MLSM model to current LSD model

Because the previous CRA 1 stock assessment in 2014 used the MLSM program, building the 2019 base case model involved first matching the results from the LSD model to the 2014 base case assessment. This process included data up to and including the 2013 fishing year (Model 1_base2014, see Table 7). Following the initial emulation of the previous base case, data updates implemented for the 2019 assessment and changes to the model assumptions were iteratively added until the model held the desired attributes of a new base case but was still based on data that were current up to the end of 2013. This iterative procedure is recommended for all future assessments using the LSD model.

For CRA 1, this procedure used ten steps, sequentially described in Table 7. The data were re-weighted in a standardised process for each run, aiming for a standard deviation of the normalised residual (SDNR) of 1.0 for all CPUE series and the sex ratio (Breen et al. 2003, Francis 2011). Note that the tag data are self-weighting and the LF weight comes from the Francis approach (Francis 2011). Table 7

presents the sequential models, where each subsequent model accumulates the modifications from the previous models. The outcomes are shown in Figures 4–6 and Figures 8–12, and Figure 7 shows the change in maximum length bin from 90 mm to 100 mm. All 10 cumulative iterative steps have been superimposed in Figure 13.

2.5.1.2 Searching for a 2019 base case

At the end of the procedure described in Table 7 (and plotted in Figure 13), the final model included all data to the end of the 2018 fishing year. In addition to the Table 7 changes from the base model in 2014, model fits and outputs from several additional preliminary models were compared. These models included:

- 1) Excluding tags at liberty less than one year
- 2) *Galpha* estimated at 30 mm instead of 50 mm with a wide, normal prior centred at 5-mm growth increment with standard deviation 10-mm growth increment
- 3) Forcing fits to the sex ratio data by up- and down-weighting data.
- 4) *qdrift* parameter accounting for improvements in technology in the fishery during the CELR series
- 5) Starting the model in 1963 (start of CR series) and 1979 (start of FSU series) instead of 1945 by estimating an initial exploitation rate parameter
- 6) Estimating right-limb selectivity (as opposed to fixed at a high value to represent a logistic function)
- 7) Estimating season-specific selectivity (instead of assuming a single selectivity curve across seasons)
- 8) Illegal catch set at 10% of commercial catch from 1981 onwards scaled to the CPUE (instead of 20%)
- 9) Five Newton-Raphson iterations (instead of three)

The WG reviewed these model explorations and made specific recommendations that the base case be formulated as follows:

- Start the model in 1945, assuming an unfished population
- Separate *q* parameters for CR (1963–1978), FSU CPUE (1979–1988), and CELR CPUE (1989–2018)
 - *q* is constant for the CR and FSU CPUE series (no drift parameter)
 - *q* is assumed to improve over time at a constant rate for the CELR CPUE, with the rate of change estimated in the model by the *qdrift* parameter
- Sex-specific double-normal selectivity, with the right-hand limb selectivity fixed at 250 to preclude a descending limb
- Selectivity constant through time
- Illegal catch set at 20% of commercial catch from 1981 onwards based on the pattern of CPUE
- All initial tag recaptures from CRA 1 and CRA 2 Statistical Areas 905 and 906 included
- *Galpha* parameter estimated at 30 mm and with a normal prior (with a mean of 5 mm TW and standard deviation of 10 mm TW)
- Three Newton-Raphson iterations

Based on an investigation into the timing of moulting and the impact of growth increment estimates, the removal of the tag recaptures that were at liberty less than one year was explored (see CRA3 assessment, Webber et al. 2020). All tags (initial recaptures only) were included, regardless of time at liberty, to maximise the amount of growth information from the tagging data in this stock assessment.

The 2019 CRA 3 assessment estimated juvenile growth from dive survey length-frequency sampling at Gisborne Wharf (Webber et al. 2020). This analysis fitted a linear growth model to mean carapace length (CL) estimates of juvenile rock lobster cohorts measured by a dive survey series in the late 1970s, by assuming that progressive modal peaks represented annual growth between dive survey years. This

procedure estimated an annual growth rate of 15.9 mm CL up to 30 mm TW, which approximates to an annual growth rate of 8 mm TW. Based on this analysis, the *Galpha* parameter was shifted to estimate the first inflexion point of the growth curve at 30 mm TW (previously 50 mm TW), and included a wide, normal prior on *Galpha* with a mean of 5 mm TW and standard deviation of 10 mm TW. A very wide prior was used to account for uncertainty in the growth increment in juveniles, as well as potential growth rate differences between CRA 1 and CRA 3.

Because of poor fits to the SS mature female sex ratios in the 2014 assessment and similar poor fits in preliminary runs in 2019 it was necessary to force the fits to the sex ratio data, to determine if the inference about the population would change. These fits indicated that although the estimated population biomass trajectories did not change excessively under this scenario, the steps taken to force the fit to the sex ratio data were not acceptable, e.g., upweighting the sex ratio data, removing logbook data, season-specific selectivity, and assuming immature and mature females have separate vulnerability parameters in the SS season. Therefore, the assessment progressed with good fits to the sex ratio data from logbooks, and poor fits to the SS sex ratios from catch sampling (see Figure 24).

The WG decided to include the *qdrift* parameter in the base case model due to significant improvements in the likelihood when this was included, and the plausible parameter estimates obtained. The base case model without the *qdrift* parameter was included as a sensitivity using MCMC inference.

Because the *base* and *no_qdrift* models used the same data but a different number of estimated parameters, they were compared using the leave-one-out information criterion (LOOIC, Vehtari et al. 2016). LOOIC is a method for estimating pointwise out-of-sample prediction accuracy from a Bayesian model, and is generally more robust than other information criterion for Bayesian inference with weak priors or influential observations (Vehtari et al. 2016). LOOIC estimates the expected log predictive density (ELPD) by dataset and the standard error in predictive accuracy. The *base* model had a larger ELPD (smallest LOOIC) compared with the *no_qdrift* model for both the CPUE and sex ratio datasets, confirming that the *base* model fitted the data better than when excluding the *qdrift* parameter (see Table 14).

Preliminary model runs found that the estimates for unfished biomass were sensitive to the choice of model start year. The WG decided to remove the model run starting in 1963, but to keep the model run starting in 1979 as a sensitivity using MCMC inference.

All other preliminary model runs made little difference to the estimated population trajectories, i.e., estimating the right-limb of the selectivity curve, season-specific selectivity, illegal catch at 10% of commercial catch, five Newton-Raphson iterations, and excluding tags at liberty less than one year.

Diagnostic plots for the base case are presented from Figure 14 to Figure 30, consisting of model predictions relative to observed data, or the standardised residuals of the model fits to the data. Annual plots of key generated quantities for the base case are shown in Figure 31 (recruitment), Figure 32 (fishing mortality), Figure 33 (recruited biomass by season), and Figure 34 (vulnerable biomass by season). Parameter estimates, likelihoods, and indicators for the base case and sensitivity tests are given in the tables (Table 9 [likelihoods], Table 10 [parameters], Table 11 [reference points]).

2.5.2 MAP sensitivity trials

The WG decided on eight sensitivity trials (see Table 8) as single variants relative to the base case. These included sensitivities relating to the catch data, catchability, tag data, density dependent growth, and data set weighting. Although the results of the sensitivity tests span a range of relative spawning stock biomass and recruitment, most of these runs did not have large impacts on the vulnerable reference biomass or the general stock trajectories, including current stock status. A comparison of the vulnerable biomass estimates for all eight runs is shown in Figure 35 (upper panel) and as relative spawning biomass (lower panel, Figure 35). Figure 36 compares the values of SSB_{2018}/SSB_0 for all eight sensitivity runs with the equivalent base case value. Figure 37 compares the recruitment trends for all eight

sensitivity runs with the base case recruitment trend. Figure 38 compares the male and female selectivity curves for all eight sensitivity runs with the base case selectivity curve. Individual or smaller groups of sensitivities are compared with the base model in Figure 39 to Figure 57.

A summary of sensitivity tests is provided below.

- *no_qdrift*: Assume constant catchability (q) for the CELR CPUE series, i.e., q drift parameter not estimated
 - Relative spawning stock biomass and relative vulnerable reference biomass were estimated approximately equivalent to the base case during the time series but were higher than the base case in recent years.
- *restrict_liberty*: Remove tag recaptures at liberty less than one year
 - Results were very similar to the base case. The estimated spawning stock biomass was scaled slightly higher than the base case, but because the scale was consistent the relative spawning biomass was very similar.
- *start_1979*: Start model in 1979 and estimate equilibrium harvest rate in 1979 (U_0)
 - Very similar relative vulnerable reference biomass to the base case and very similar recruitment. The relative spawning biomass was estimated to be lower than the base case, and the SSB_0 was estimated much higher than the base case.
- *illegal10*: Illegal catch set at 10% of commercial catch from 1981 onwards based on the pattern of CPUE
 - Relative vulnerable reference biomass and relative spawning stock biomass were only slightly less than the base case; these two runs were very similar.
- *dd_growth*: Assume density dependent growth
 - Almost equivalent to the base case, because the density dependent growth parameter was estimated to be very low.
- *downwtCPUE*: Down-weighting CPUE
 - This sensitivity had the highest impact. The relative spawning stock biomass and estimated spawning stock biomass trajectory were much higher than the base case, but relative vulnerable reference biomass and relative spawning stock biomass were lower in recent years. Recruitment deviations were less pronounced. Selectivity for females was at the asymptote for even the smallest individuals. The estimated change in catchability ($qdrift$) for the CPUE series was also much higher than other model runs, and the catchability parameter estimate for the CR series was much higher than other models.
- *downwtSexRatio*: Down-weighting sex ratio
 - Down-weighting the sex ratio led to much lower estimates of spawning biomass in the early years of the fishery, but relatively higher relative spawning stock biomass in recent years.
- *downwtLF*: Down-weighting length frequency
 - Down-weighting the length frequency data did not have much impact on the relative vulnerable reference biomass, and only led to slightly higher relative spawning stock biomass in recent years.

2.6 Bayesian inference using Markov chain Monte Carlo (MCMC)

Bayesian inference was used to characterise parameter uncertainty. LSD uses Stan software to run MCMC simulations using the Hamiltonian Monte Carlo (HMC) algorithm. The MAP values in Table 9 and Table 10 were used as starting values. For the base case and two selected sensitivity tests (Table 12), the posterior distributions were explored with a total of approximately 1000 samples across four chains, each with a warm-up phase of 500 iterations and length of 500 samples, retaining every second sample. The *no_qdrift* model had only 750 samples across three chains due to one of the chains stalling during the warm-up phase. Despite that setback, enough samples from the posterior were obtained for the base case and all sensitivities.

2.6.1 MCMC base case

MCMC was used to obtain samples from the posterior distribution for the base case model described in Section 2.5.1. Diagnostic traces are shown for estimated parameters in Figure 58, Figure 59, and Figure 60. Density plots of the posterior distributions of estimated parameters and important derived quantities are shown in Figure 61, Figure 62, and Figure 63. Cumulative density diagnostic plots are shown in Figure 64, Figure 65, and Figure 66. Posterior distributions of parameter estimates and derived quantities are summarised in Table 13.

Trace and cumulative density plots indicate that MCMC chains were well-mixed. Traces for the key estimated biological parameters, such as M and R_0 , showed an acceptable level of stability, with most MCMC chains staying away from parameter bounds. MCMC chains for the *Galpa* parameters came away from the centre of the wide, normal prior distributions, occasionally reaching the upper bound of 20 mm TW (at 30 mm TW). This run was used because this bound was based on a literature review of juvenile growth information (Webber et al. 2020). Trace and cumulative density plots indicate that MCMC chains were well-mixed.

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 of model fits to the data, are shown in Figure 67 to Figure 79. These are comparable with those provided for the base case MAP results (Figure 14 to Figure 30).

The model fitted the CPUE time series well, with acceptable residual patterns (Figure 67 and Figure 68). These CPUE fits were similar to the equivalent MAP fits (Figure 14 and Figure 15). Model fits to the data were also generally acceptable (Figure 70 to Figure 73). Model fits to the logbook data were generally better than fits to the catch sampling data. In some years, the catch sampling LFs were skewed to the right compared with most other years, indicating the sampling obtained much larger individuals in those years and seasons. It is not known whether the fishing dynamics changed in those years/seasons (e.g., fishing at the Three Kings Islands) or if the sampling was unrepresentative of the fishery in that year. Either hypothesis is tenable, because scheduling catch sampling in CRA 1 is often difficult, particularly obtaining representative samples from the long Three Kings Islands trips. The model fitted to the logbook sex ratio data very well but had poor fits to the catch sampling sex ratio data, particularly in the SS season (Figure 77). Maturation was estimated to be below the female MLS (Figure 79), with 50% of females near 50 mm TW.

Fits to the tagging data were acceptable, with no strong patterns to the residuals (see Figure 80 to Figure 84), even among the added CRA 2 statistical areas. The main exception to this was an increasing pattern of negative residuals for large males in Statistical Area 906 (Figure 82, left panel), which may indicate that growth is faster in CRA 1 than in the western CRA 2 statistical areas. The estimated annual growth increment at 30 mm TW was high for both females (18.5 mm) and males (16.3 mm) (Table 13, Figure 85).

One strong recruitment event was estimated in the early 1990s, with lesser recruitment peaks in the late 1970s and mid 2000s (Figure 86). Recruitment was estimated to be low in the 1980s. Recent mean (2009–2016) recruitment is estimated to be slightly above R_0 , but dips below R_0 in 2016 (Figure 86).

Fishing mortality was estimated to be high in the late 1960s to the 1970s, when annual catches were at their highest. Catch was lowest in 1974, then remained high through the 1980s before stabilising in the early 1990s. Estimates of population biomass (vulnerable, spawning, recruited, and total) decreased rapidly in the early years of the fishery through to the mid-1970s. Population biomass increased from 1973 to 1983, and then decreased through the 1980s, a period when fishing mortality in the AW period was much lower than in the SS period. From the 1990s onwards, population biomass has remained relatively constant, with AW and SS catches and fishing mortality at similar levels. Size-limited catch has remained relatively constant whereas the NSL catch and associated fishing mortality increased

slightly due to the assumption that the illegal catch matched the pattern of the CPUE time series, which has been increasing since 2011 (Figure 87).

Current vulnerable reference biomass was predicted to be at 15.5% of B_0 ($B_{2019}/B_0 = 0.155$ [90% credible interval (CI) = 0.117 – 0.210]) and was projected to decrease to 13.5% of B_0 by 2023, at current catch ($SSB_{2023}/SSB_0 = 0.135$ [90% CI = 0.071 – 0.231]; Figure 88). Current spawning stock biomass was predicted to be at 37.0% of SSB_0 ($SSB_{2019}/SSB_0 = 0.370$ [90% CI = 0.312 – 0.443]) and was projected to remain relatively constant at current levels of catch ($SSB_{2023}/SSB_0 = 0.369$ [90% CI = 0.267 – 0.498]; Figure 89). There was a negligible probability of being below the soft limit (20% SSB_0) and a probability of 0.813 of being above B_{MIN} . At current catch levels, there was a probability of 0.254 that the vulnerable biomass in 2023 will be greater than in 2019 and probability of 0.401 that the 2023 spawning biomass will be greater than in 2019.

2.6.2 MCMC sensitivity trials

Two sensitivity trials (see Table 12) were chosen to be analysed with MCMC: *start_1979* and *no_qdrift*. These runs represented plausible alternative hypotheses that differed in the parameter space investigated (i.e., biomass trajectories) relative to the base case. Both sensitivities had acceptable MCMC diagnostics for the completed chains (Table 12). Comparisons of these sensitivity trials to the base case are shown in Figure 90 to Figure 98.

The *no_qdrift* scenario had identical settings to the base case but did not estimate a *qdrift* parameter for the CELR time series. This produced a very similar population biomass (spawning stock and vulnerable reference biomass) until approximately 1974. From 1974 the population biomass for the *no_qdrift* scenario was lower than the base case, slowly becoming more similar to the base case until 2005, when the trajectories intersect and the *no_qdrift* biomass becomes larger than the base case. By 2019 the median relative vulnerable reference biomass was estimated to be 1.34 times higher than the median relative vulnerable reference biomass for the base case ($B_{2019}/B_0 = 0.208$ [90% CI = 0.155 – 0.273]) (Table 13). The median relative spawning biomass in 2019 under the *no_qdrift* scenario was estimated to be 1.18 times higher than the equivalent median base case ratio ($SSB_{2019}/SSB_0 = 0.437$ [90% CI = 0.373 – 0.513]) (Table 13).

The *start_1979* scenario estimated a lower vulnerable reference biomass than the base case from approximately 1979 to 2001. After 2001, the base case and *start_1979* model estimated approximately equal vulnerable reference biomass levels. The *start_1979* model estimated slightly higher unfished vulnerable reference biomass than the base case model, resulting in a 2019 median relative vulnerable reference biomass that was 81% of the median base case ratio ($B_{2019}/B_0 = 0.125$ [90% CI = 0.090 – 0.184]) (Table 13). The *start_1979* model estimated spawning biomass to generally be higher than the base case, but, because unfished spawning biomass was also estimated higher than the base case, the relative spawning biomass was estimated to be equal to or lower than the base case throughout the time series. These differences resulted in a 2019 median relative spawning biomass at 91% of the median base case estimate ($SSB_{2019}/SSB_0 = 0.336$ [90% CI = 0.273 – 0.416]) (Table 13).

2.7 Projections

For each of the models analysed with MCMC, the 2018 catch was projected forward from 2019–2023 (Figure 99, Figure 100, Figure 101). The relative vulnerable reference biomass was expected to decline by 2023 at current levels of catch, whereas relative spawning biomass was expected to only slightly decrease (*base* and *start_1979*) or slightly increase (*no_qdrift*), on average.

The RLEAWG explored various options for an interim vulnerable biomass target while a more formal target reference point is developed. Because the current TACC was predicted to cause the biomass to decline over the next five years with a high probability (Table 13), Fisheries New Zealand instructed the WG to explore alternative options that would result in maintaining or improving the current stock status. The WG considered whether the vulnerable biomass associated with the midpoint of the plateau of the 2014 MP rule could be used as an interim reference vulnerable biomass, but this option was

discarded because the biomass estimates from the two models had diverged too much. The WG also considered the use of a target reference biomass, based on long-term projections of fixed catch or MPs. These options were also discarded because they were too conservative (fixed catch) or required too many subjective assumptions that could not be thoroughly explored given time constraints (MPs). Consequently, the catch advice was restricted to the level of catch required to maintain the vulnerable biomass at current levels (i.e., equal probability of increase/decrease) until a more formal target reference point is developed.

3. DISCUSSION

This assessment describes a stock that was initially heavily fished, resulting in a rapid decline in stock size in the early 1970s, followed by a slowly declining population during the 1980s. After fishing pressure was decreased and catches were stabilised, the rock lobster population in CRA 1 appeared to increase in the 1990s. The stock has experienced a relatively stable population size since 2000, along with relatively stable catches. However, projections show that the population is predicted to decrease over the next five years under current catch levels (Table 13). This could be due to the inability to sustain the current SL catches or recent poor recruitment.

The LSD model fitted the CRA 1 data reasonably well, with the exception of the sex ratio data from SS catch sampling. The fit to the sex ratio from logbook data was relatively good, and it may be that the SS catch sampling is either not representative of the fishery or of variations in fleet dynamics. For example, length frequency distributions from catch sampling appear to be highly skewed to the right in some years, indicating that the sampled catch may have come from an area with large lobsters in those years.

This assessment considered juvenile growth estimated from dive survey length-frequency sampling at Gisborne Wharf (Webber et al. 2020). This analysis led to the change in location of the first inflexion point of the growth curve from 50 mm to 30 mm. CRA 1 is further north in latitude, therefore faster growth would be expected in CRA 1 than was observed at Gisborne Wharf. This difference was accounted for by including a wider prior on the estimated growth increment at 30 mm TW. The *Galpa* parameters for both males and females, representing the annual growth increment at 30 mm TW, were estimated close to the upper bound of 20 mm TW. These estimates of *Galpa* are reasonable given the study at Gisborne Wharf and considering that CRA 1 growth rates may be higher than in CRA 3. However, it is unreasonable to increase the upper bound on *Galpa* beyond 20 mm. The tendency towards higher juvenile growth will be worth exploring in future stock assessments.

3.1 Future research

Based on the better fits to the logbook LF data compared with the observer sampling LF data, future sampling effort in CRA 1 should consider expanding the logbook programme and reducing the reliance on catch sampling. There is concern that CRA 1 would be better represented by two sub-regions: the two east Northland Statistical Areas 903 and 904; and the remaining Statistical Areas 901, 902, and 939. The available length frequency data and estimated CPUE trajectories do not presently provide sufficient information to distinguish between these two sub-regions. However, expanded participation in the logbook programme throughout CRA 1 should lead to improved information on the spatial heterogeneity and dynamics in CRA 1. Deployment of more tags, particularly in Statistical Areas 903 and 904, would reduce the need to use tag data from CRA 2. Direct ageing and further exploration of juvenile growth rates would also be useful to potentially update the prior distributions on growth rates and better understand the age structure across areas in CRA 1.

Fisheries New Zealand has now switched from the old paper forms to electronic forms for the collection of commercial catch and effort data. The RLFAWG concluded that the new data collection system would not be comparable to the previous system and thus would break the continuity of the CELR CPUE series estimated using paper forms. Previous New Zealand experience with changes to the collection of catch/effort data has demonstrated that it is not possible to assume that data will be comparable across

the two data collection systems. As a result, it will not be possible to use the CELR CPUE to develop a new MP. In the meantime, the WG agreed to estimate the constant catch that maintains vulnerable reference biomass at current levels over a five-year period. This may be useful for management of CRA1 in the absence of a new MP.

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6. TABLES

Table 1: Minimum legal size (MLS) limits for males and females over time.

Period	MLS (tail width, mm)	
	Males	Females
1945–1949	None	None
1950–1951	47	49
1952–1958	51	53
1959–1987	53	58
1988–1991	54	58
1992–2018	54	60

Table 2: Definitions of parameters and derived quantities discussed in the text.

Parameters	Definition
R_0	initial numbers recruiting
M	instantaneous rate of natural mortality
$Rdevs$	annual recruitment deviations
σR	standard deviation of $Rdevs$
qCR	catchability coefficient (relationship between B and CR series)
$qFSU$	catchability coefficient (relationship between B and FSU CPUE series)
$qCELR$	catchability coefficient (relationship between B and CELR CPUE series)
$Mat50$	size where 50% of immature females become mature
$Mat95$	difference between $Mat50$ and $Mat95$
$Galpha$	annual growth increment at 30 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)
$SelM$	size at maximum selectivity
$vuln$	relative vulnerability by sex and season
$qdrift$	Additive change in catchability coefficient each year
U_0	initial exploitation rate (first year is in equilibrium using this estimate)
Gdd	density-dependent growth parameter
$Gbeta$	annual growth increment at 80 mm TW

Table 3: Specifications for estimated parameters in the CRA 1 models including the upper and lower bounds, prior type, and prior parameters (par 1 and par 2).

Season	Sex	Par	Lower bound	Upper bound	Prior type	par 1	par 2
		R_0	exp(1)	exp(25)	uniform		
		M	0.01	0.35	lognormal	0.12	0.4
		$Rdevs$	-2.3	2.3	uniform		
		qCR	exp(-25)	exp(0)	uniform		
		$qFSU$	exp(-25)	exp(0)	uniform		
		$qCELR$	exp(-25)	exp(0)	uniform		
		$Mat50$	10	80	normal	50	50
		$Mat95$	1	60	normal	10	10
	male	$Galpha$	1	20	normal	5	10
	male	$Gdiff$	0.001	0.99	beta	1	1
	male	$Gshape$	0.1	15	normal	4.81	5
	male	GCV	0.01	2	normal	0.59	5
	female	$Galpha$	1	20	normal	5	10
	female	$Gdiff$	0.001	0.99	beta	1	1
	female	$Gshape$	0.1	15	normal	4.51	5
	female	GCV	0.01	2	normal	0.82	5
		$Gobs$	0.0001	10	normal	1.48	1
	male	$SelLH$	1	50	normal	20	100
	female	$SelLH$	1	50	normal	20	100
	male	$SelM$	30	90	normal	50	50
	female	$SelM$	30	90	normal	50	50
SS	male	$vuln1$	0.01	1	beta	1	1
AW	immafem	$vuln2$	0.01	1	beta	1	1
SS	imma & matfem	$vuln3$	0.01	1	beta	1	1
AW	matfem	$vuln4$	0.01	1	beta	1	1
		$qdrift$	-0.08	0.08	normal	0	1
		U_0	0.00	0.99	beta	1	1
		Gdd	0.00	1.00	beta	1	1

Table 4: Fixed quantities used in the CRA 1 models.

Quantity	Value	Quantity	Value
data set weights		fixed parameters	
Tags	1	σR	0.4
CELR CPUE	2.8	male length-weight a	4.16e-6
FSU CPUE	0.85	male length-weight b	2.935
CR CPUE	0.93	female length-weight a	1.3e-5
sex ratio	38	female length-weight b	2.545
LFs	7.62	recruitment	
catch and handling		last year of estimated $Rdevs$	2016
handling mortality, 1945–1989	0.10	years for estimating $Rdevs$ for projections	2007–2016
handling mortality, 1990–2018	0.05	years for estimating autocorrelation	1945–2016
projected SL commercial catch	130.56 t	recruitment size mean	32 mm
projected SL recreational catch	31.48 t	recruitment size SD	2 mm
Projected NSL illegal catch	37.68 t	recruitment autocorrelation (derived)	0.20
Projected NSL customary catch	10.0 t	other	
growth		Newton-Raphson iterations	3
length at $Galpha$	30	Tail compression: male bins	4 to 36
length at $Gbeta$	80	Tail compression: female immature bins	4 to 22
Minimum increment $Gmin$	0.5	Tail compression: female mature bins	4 to 36

Table 5: CRA 1 base case: map of vulnerability (*vuln*) parameters. Note that the vulnerability for males in AW is fixed at 1 and all other *vuln* parameters are estimated relative to the vulnerability of males during AW.

Sex	Season	<i>vuln</i>
male	AW	1
male	SS	<i>vuln1</i>
immature female	AW	<i>vuln2</i>
immature female	SS	<i>vuln3</i>
mature female	AW	<i>vuln4</i>
mature female	SS	<i>vuln3</i>

Table 6: Reference points, performance indicators, and stock status probabilities for the CRA 1 stock assessment.

Type	Description
Reference Points	
B_0	beginning of season AW vulnerable biomass before fishing (1945)
SSB_0	female AW spawning stock biomass before fishing began (1945)
$B_{0\text{ NOW}}$	equilibrium vulnerable biomass using mean 2007–2016 recruitment
$SSB_{0\text{ NOW}}$	equilibrium female spawning biomass using mean 2007–2016 recruitment
$B_{0\text{TOT}}$	equilibrium total biomass
B_{MIN}	the lowest beginning AW vulnerable biomass in the series
B_{2019}	beginning of season AW vulnerable biomass for 2019
B_{2023}	beginning of season AW vulnerable biomass for 2023
SSB_{2019}	female spawning stock biomass at beginning of 2019 AW season
SSB_{2023}	female spawning stock biomass at beginning of 2023 AW season
$B_{2019\text{TOT}}$	beginning of season AW total biomass for 2019
$CPUE_{2019}$	AW CPUE at beginning of 2019 (in kg/potlift)
$CPUE_{2023}$	AW CPUE at beginning of 2023 (in kg/potlift)
H_{2018}	total handling mortality for 2018 (tonnes)
H_{2022}	total handling mortality for 2022 (tonnes)
Performance indicators	
B_{2019} / B_0	ratio of B_{2019} to B_0
B_{2023} / B_0	ratio of B_{2023} to B_0
B_{2023} / B_{2019}	ratio of B_{2023} to B_{2019}
SSB_{2019}/SSB_0	ratio of SSB_{2019} to SSB_0
SSB_{2023}/SSB_0	ratio of SSB_{2023} to SSB_0
SSB_{2023}/SSB_{2019}	ratio of SSB_{2023} to SSB_{2019}
$B_{2019\text{TOT}} / B_{0\text{TOT}}$	ratio of $B_{2019\text{TOT}}$ to $B_{0\text{TOT}}$
$B_{2023\text{TOT}} / B_{0\text{TOT}}$	ratio of $B_{2023\text{TOT}}$ to $B_{0\text{TOT}}$
$B_{2023\text{TOT}} / B_{2019\text{TOT}}$	ratio of $B_{2023\text{TOT}}$ to $B_{2019\text{TOT}}$
Probabilities	
$P(B_{2019} > B_{\text{MIN}})$	probability B_{2019} is greater than B_{MIN}
$P(SSB_{2019} < 20\%SSB_0)$	probability SSB_{2019} is less than 20% SSB_0
$P(SSB_{2019} < 10\%SSB_0)$	probability SSB_{2019} is less than 10% SSB_0

Table 7: List of model runs used to iteratively update the base case used in the 2014 assessment of CRA 1.

Model name	Model description	Outcome
<i>1_base2014</i>	Mimics the 2014 assessment model: - Catch and CPUE used in 2014 assessment (up to and including the 2013 fishing year) - LF from the new data extract (due to formatting differences from the MLSM model in 2014), only including years used in the 2014 assessment, with maximum bin size at 90mm - Tag data used in 2014 assessment - FSU and CELR CPUE series linked with single catchability parameter (q).	MAP estimates of vulnerable reference biomass match very well (Figure 3).
<i>2_CR</i>	Included CR CPUE series and estimated a separate catchability (q) parameter, along with the single catchability parameter estimated for the combined FSU and CELR series.	Similar vulnerable reference biomass to base2014 (Figure 4). Maturity is also similar: $1_base2014 = 0.107$, $2_CR = 0.112$.
<i>3_handling</i>	Changed the handling mortality from 10% to 5% from 1990 onwards.	Very similar vulnerable reference biomass to the Model <i>2_CR</i> (Figure 5).
<i>4_maxbin100</i>	Increased the maximum bin size from 90 mm to 100 mm (Figure 7).	Very similar vulnerable reference biomass pre-1980 to Model <i>1_base2014</i> , with post-1980 similar to Model <i>2_CR</i> (Figure 6).
<i>5_splitCPUE</i>	Split the FSU and CELR CPUE series and therefore estimated separate catchability parameters for each of the 3 series (CR, FSU, CELR).	Similar vulnerable reference biomass to Model <i>2_CR</i> , and virtually an exact match from 1990 (Figure 8).
<i>6_1selex</i>	Used one selectivity period due to the limited length frequency data prior to 1994 (two selectivity periods used previously from 1945 and 1993).	Vulnerable reference biomass almost the same as Model <i>5_splitCPUE</i> (Figure 8). Results in similar selectivity to previous models for the latter period, which include all the data (Figure 9).
<i>7_newCC2014_20</i>	Catch and CPUE formulated for the 2019 assessment through to the 2013 fishing year, including illegal catch as 20% of commercial catch from 1981 onwards based on the pattern of CPUE.	Vulnerable reference biomass remains relatively constant from 1990 onwards compared with the increasing trend for the same period from the Model <i>5_splitCPUE</i> (Figure 10).
<i>8_newCC2014_10</i>	Same as Model <i>7_newCC2014_20</i>, but with illegal catch set at 10% of commercial catch from 1981 onwards based on the pattern of CPUE.	Similar result to Model <i>7_newCC2014_20</i> (Figure 10).
<i>9_newtag2014</i>	Included data from the 2019 updated tagging dataset, up to and including the 2013 fishing year.	Vulnerable reference biomass similar to Model <i>7_newCC2014_20</i> (Figure 11).
<i>10_LF1976</i>	Included data from the 2019 updated LF dataset through to and including the 2013 fishing year, which also included additional LF data from 1976.	Vulnerable reference biomass similar to Model <i>9_newtag2014</i> , and almost the same from 1980 (Figure 12).

Table 8: List of CRA 1 Maximum *a posteriori* (MAP) sensitivity runs.

Type	Model name	Model description
Base	<i>base</i>	as defined in Section 2.5.1*
Catchability	<i>no_qdrift</i>	CELR CPUE series assumed to have constant catchability
Catch	<i>start_1979</i>	Start the model in 1979
	<i>illegal10</i>	Reduce illegal catch from 20% to 10% of commercial catch
Tags	<i>restrict_liberty</i>	Remove tags that have been at liberty less than 1 year
Density dependence	<i>dd_growth</i>	Assume density dependent growth
Weighting	<i>downwtCPUE</i>	Down-weight all CPUE series, by multiplying the weights by 0.1
	<i>downwtSexRatio</i>	Down-weight the sex ratio information by multiplying the weights by 0.1
	<i>downwtLF</i>	Down-weight length frequency data information by multiplying the weights by 0.1

Table 9: CRA 1 stock assessment: MAP reference base case and sensitivity trial results for *likelihoods*, *standardised normalised residuals (SDNR)*, *median of absolute residuals (MAR)*, and *weightings*. Growth increment values in mm TW, biomass values in tonnes and R_0 in numbers.

	<i>base</i>	<i>no_qdrift</i>	<i>start_1979</i>	<i>restrict_liberty</i>	<i>dd_growth</i>	<i>illegal10</i>	<i>downwt</i> <i>CPUE</i>	<i>downwt</i> <i>SexRatio</i>	<i>downwt</i> <i>LF</i>
Likelihoods									
Total	11 283	11 235	10 916	8 661	11 283	11 282	11 521	9 542	7 552
Prior	-23	-22	7	-23	-23	-23	-24	-24	-23
tag	5 413	5 413	4 809	2 790	5 413	5 413	5 414	5 413	5 409
sexr	1 928	1 878	2 008	1 928	1 928	1 927	1 967	196	1 924
LF	4 138	4 140	4 251	4 139	4 138	4 138	4 171	4 133	418
CR	-8	-7	–	-8	-8	-8	13	-8	-8
FSU	-44	-43	-38	-44	-44	-44	-6	-44	-43
CELR	-121	-123	-121	-122	-121	-121	-13	-124	-124
SDNR									
Tag	1.55	1.55	1.50	1.17	1.55	1.55	1.51	1.55	1.55
Sexr	1.03	1.02	1.00	1.03	1.03	1.02	1.25	0.40	1.01
LF	0.35	0.36	0.36	0.36	0.35	0.35	0.35	0.35	0.51
CR	0.99	1.02	–	0.99	0.99	1.02	0.09	0.99	0.99
FSU	1.01	1.02	1.03	1.01	1.01	1.00	0.28	1.00	1.02
CELR	1.01	1.01	1.02	1.00	1.01	1.01	0.24	0.96	0.96
MAR									
tag	0.70	0.70	0.70	0.71	0.70	0.70	0.71	0.70	0.70
Sexr	0.68	0.69	0.69	0.67	0.68	0.68	0.87	0.30	0.63
LF	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.03
CR	0.50	0.50	–	0.51	0.50	0.53	0.35	0.51	0.51
FSU	0.60	0.62	0.55	0.61	0.60	0.61	0.17	0.69	0.60
CELR	0.82	0.78	0.75	0.80	0.81	0.80	0.13	0.74	0.81
Weightings									
sexr	38	37	40	38	38	38	38	0.38	38
LF	7.62	7.86	8.13	7.86	7.86	7.86	7.86	7.86	0.786
CR	0.93	0.95	–	0.96	0.96	0.96	0.096	0.96	0.96
FSU	0.85	0.85	0.67	0.85	0.85	0.85	0.085	0.85	0.85
CELR	2.8	2.9	2.8	2.8	2.8	2.8	0.280	2.8	2.8

Table 10: CRA 1 stock assessment: MAP reference base case and sensitivity trial results, parameters. Growth increment values in mm TW, biomass values in tonnes and R_0 in numbers.

Parameters	base	no_qdrift	start_1979restrict_liberty	dd_growth	illegal10	downwt CPUE	downwt SexRatio	downwt LF
R_0	229 821	233 924	217 940	224 936	229 610	221 929	194 907	246 725
M	0.10	0.10	0.08	0.10	0.10	0.10	0.08	0.11
qdrift	0.0147	–	0.0134	0.0152	0.0146	0.0124	0.0364	0.0109
qCPUE	0.0017	0.0022	0.0018	0.0018	0.0017	0.0019	0.0015	0.0019
qFSU	0.0012	0.0014	0.0012	0.0012	0.0012	0.0013	0.0011	0.0013
qCR	0.0377	0.0406	–	0.0378	0.0377	0.0405	0.9971	0.0404
U_0	–	–	0.15	–	–	–	–	–
mat50	50.63	50.64	50.20	50.21	50.61	50.64	52.46	54.41
mat95	11.45	11.21	10.03	11.83	11.58	11.56	10.99	11.29
Galpha males	16.14	16.11	17.62	15.72	16.15	16.16	16.22	16.30
Gbeta males	2.66	2.69	2.50	2.74	2.66	2.67	2.61	2.69
Gshape males	2.96	2.96	3.45	2.82	2.96	2.97	2.97	3.01
GCV males	0.40	0.40	0.40	0.42	0.40	0.40	0.40	0.40
Galpha females	18.65	19.18	18.51	19.94	18.65	18.62	19.94	18.91
Gbeta females	1.22	1.23	1.15	1.18	1.22	1.21	1.11	1.20
Gshape females	5.54	5.77	5.49	5.98	5.54	5.54	5.97	5.64
GCV females	0.77	0.76	0.80	0.70	0.77	0.77	0.72	0.77
GObs	0.55	0.55	0.67	1.56	0.55	0.55	0.68	0.56
Gdd	–	–	–	–	0.0010	–	–	–
vuln1	0.75	0.74	0.72	0.75	0.75	0.74	0.85	0.81
vuln2	0.51	0.48	0.53	0.45	0.51	0.50	0.16	0.29
vuln3	0.56	0.56	0.53	0.51	0.56	0.54	0.53	0.45
vuln4	0.42	0.43	0.39	0.38	0.42	0.41	0.35	0.44
SelL males	10.07	9.94	10.34	10.06	10.06	10.08	9.87	10.06
SelM males	62.51	62.23	62.30	62.72	62.49	62.51	61.26	62.21
SelL females	14.87	14.56	14.09	14.12	14.90	14.66	49.92	14.01
SelM females	67.73	66.66	66.17	65.20	67.74	67.25	30.03	62.41

Table 11: CRA 1 stock assessment: MAP reference base case and sensitivity trial results, Reference points. Growth increment values in mm TW, biomass values in tonnes and R_0 in numbers.

Reference points	base	no_qdrift	start_1979restrict_liberty	dd_growth	illegal10	downwt CPUE	downwt SexRatio	downwt LF
Vulnerable reference biomass								
B_0	3 502	3 441	4 361	3 566	3 502	3 368	4 371	3 212
B_{0_NOW}	3 336	3 484	4 055	3 423	3 339	3 129	4 301	2 963
B_{MIN}	395	331	375	382	395	357	417	397
B_{2019}	467	591	472	448	468	456	406	506
B_{2019}/B_0	0.13	0.17	0.11	0.13	0.13	0.14	0.09	0.16
Spawning biomass								
SSB_0	1 602	1 596	1 886	1 637	1 602	1 536	1 969	1 468
SSB_{0_NOW}	1 480	1 569	1 754	1 503	1 481	1 382	1 848	1 308
SSB_{2019}	564	645	600	581	565	558	622	628
SSB_{2019}/SSB_0	0.35	0.40	0.32	0.35	0.35	0.36	0.32	0.43

Table 12: List of CRA 1 Markov chain Monte Carlo (MCMC) models.

Model name	Model description	Number of usable chains	Number of MCMC samples
<i>base</i>	as defined in Section 2.5.1	4	1000
<i>no_qdrift</i>	CELR CPUE series assumed to have constant catchability	3	750
<i>start_1979</i>	Start the model in 1979	4	1000

Table 13: CRA 1 base case sensitivity runs and combined model (see Table 12 for run descriptions) MCMC outputs, reporting the 5th, 50th (median; highlighted in yellow), and 95th quantiles of the posterior distributions. Growth increment values in mm TW, biomass values in tonnes and R_0 in numbers. Handling mortality (H) in tonnes and CPUE in kg/potlift. ‘-’: not applicable. (Continued on next page)

	base			no_qdrift			start_1979		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods									
Total	11320	11330	11340	11270	11280	11300	10940	10950	10960
Prior	-4.358	3.489	12.990	-4.161	3.534	12.710	12.410	17.450	23.560
Tag	5413	5416	5421	5414	5417	5422	4809	4812	4817
Sex ratio	1925	1929	1934	1876	1880	1885	2006	2010	2015
LFs	4140	4146	4152	4143	4148	4154	4253	4259	4265
CPUE[CR]	-8.60	-7.58	-5.39	-8.487	-7.161	-4.544	-	-	-
CPUE[FSU]	-43.25	-41.40	-38.08	-43.24	-40.97	-37.47	-39.080	-36.690	-33.110
CPUE[CELR]	-119.40	-115.00	-109.30	-121.30	-116.80	-111.20	-119.50	-114.70	-109.00
Standard deviation normalised residuals (SDNR)									
Tag	1.475	1.563	1.711	1.477	1.564	1.719	1.428	1.497	1.591
Sex ratio	0.998	1.042	1.102	0.992	1.040	1.098	0.975	1.018	1.076
LFs	0.330	0.360	0.425	0.337	0.367	0.423	0.336	0.368	0.447
CPUE[CR]	0.894	0.978	1.132	0.894	1.008	1.188	-	-	-
CPUE[FSU]	1.008	1.099	1.232	1.013	1.113	1.256	0.982	1.090	1.235
CPUE[CELR]	1.028	1.103	1.189	1.036	1.106	1.191	1.025	1.105	1.191
Mean absolute residual (MAR)									
Tag	0.683	0.699	0.714	0.681	0.697	0.716	0.682	0.699	0.717
Sex ratio	0.630	0.708	0.779	0.627	0.714	0.798	0.637	0.703	0.767
LFs	0.100	0.106	0.112	0.101	0.106	0.112	0.100	0.106	0.112
CPUE[CR]	0.486	0.634	0.921	0.468	0.634	0.959	-	-	-
CPUE[FSU]	0.472	0.651	0.858	0.464	0.657	0.891	0.451	0.622	0.829
CPUE[CELR]	0.688	0.834	0.982	0.669	0.816	0.948	0.691	0.823	0.961
Parameters									
R_0	198600	230100	272400	202100	237000	284600	190500	218900	253800
M	0.093	0.108	0.125	0.094	0.111	0.131	0.074	0.090	0.109
$qdrift$	0.006	0.016	0.026	-	-	-	0.004	0.014	0.023
$qCPUE$	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002	0.002
$qFSU$	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001
qCR	0.029	0.038	0.049	0.031	0.040	0.053	-	-	-
$mat50$	46.820	50.170	52.310	47.010	50.230	52.390	46.170	49.720	51.910
$mat95$	8.175	12.700	20.530	8.338	12.490	20.490	6.403	10.790	18.120
$Galpha$ male	14.790	16.310	17.700	14.840	16.290	17.860	16.220	17.920	19.400
$Gbeta$ male	2.412	2.625	2.835	2.443	2.645	2.880	2.268	2.467	2.703
$Gshape$ male	2.546	3.019	3.493	2.569	3.028	3.561	3.007	3.570	4.111
GCV male	0.388	0.405	0.422	0.389	0.405	0.424	0.387	0.406	0.425
$Galpha$ female	17.100	18.530	19.690	17.750	19.060	19.850	17.180	18.580	19.680
$Gbeta$ female	1.152	1.232	1.321	1.160	1.253	1.355	1.094	1.165	1.247
$Gshape$ female	5.017	5.526	5.999	5.249	5.757	6.110	5.046	5.524	5.987
GCV female	0.734	0.773	0.811	0.734	0.773	0.811	0.756	0.796	0.838
$StdObs$	0.363	0.532	0.672	0.347	0.526	0.664	0.526	0.663	0.797
$vuln1$	0.724	0.757	0.789	0.714	0.743	0.776	0.690	0.728	0.767
$vuln2$	0.413	0.603	0.868	0.393	0.578	0.834	0.412	0.593	0.849
$vuln3$	0.525	0.641	0.814	0.517	0.629	0.816	0.481	0.596	0.728
$vuln4$	0.382	0.472	0.603	0.391	0.488	0.628	0.352	0.434	0.532
$SelL$ male	8.466	10.110	12.160	8.437	9.975	11.900	8.696	10.350	12.290
$SelM$ male	59.450	62.160	65.200	59.360	61.940	64.920	59.170	62.030	64.800
$SelL$ female	12.640	15.850	20.380	12.590	15.880	20.320	12.060	14.660	18.250
$SelM$ female	64.100	69.780	78.390	63.540	69.180	77.530	62.570	67.210	73.190
U_0	-	-	-	-	-	-	0.092	0.133	0.182
Derived parameters: vulnerable biomass									
B_0	2810	3216	3642	2720	3169	3724	3168	4000	5009
B_{0_NOW}	2664	3145	3694	2791	3322	3961	3100	3789	4757
B_{MIN}	356	430	513	304	362	430	331	403	498
B_{2019}	398	498	646	539	654	795	401	504	652
B_{2023}	237	433	714	415	643	885	267	459	745
B_{2019} / B_0	0.117	0.155	0.210	0.155	0.208	0.273	0.090	0.125	0.184
B_{2023} / B_0	0.071	0.135	0.231	0.128	0.202	0.297	0.064	0.115	0.201
B_{2023} / B_{2019}	0.524	0.849	1.248	0.692	0.965	1.275	0.602	0.888	1.262

	base			no_qdrift			start_1979		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
Derived parameters: spawning biomass (females only)									
SSB_0	1327	1481	1653	1304	1482	1674	1422	1750	2146
SSB_{0_NOW}	1232	1412	1621	1320	1515	1745	1398	1665	2037
SSB_{2019}	469	548	643	569	647	738	510	588	685
SSB_{2023}	400	545	724	533	684	847	452	595	773
SSB_{2019}/SSB_0	0.312	0.370	0.443	0.373	0.437	0.513	0.273	0.336	0.416
SSB_{2023}/SSB_0	0.267	0.369	0.498	0.354	0.456	0.579	0.249	0.338	0.456
SSB_{2023}/SSB_{2018}	0.787	0.969	1.175	0.867	1.025	1.190	0.818	0.988	1.195
Derived parameters: total biomass									
B_{0tot}	4362	4916	5502	4248	4864	5603	4819	5969	7398
B^{tot}_{2019}	1048	1255	1532	1311	1533	1792	1093	1282	1550
B^{tot}_{2023}	847	1200	1663	1121	1534	1997	897	1242	1728
B^{tot}_{2019}/B_0	0.206	0.256	0.326	0.253	0.316	0.394	0.164	0.213	0.290
B^{tot}_{2023}/B_0	0.168	0.242	0.351	0.226	0.314	0.423	0.144	0.208	0.309
B^{tot}_{2023}/B_{2019}	0.759	0.942	1.195	0.831	0.995	1.193	0.778	0.966	1.201
Other derived parameters									
$CPUE_{2018}$	1.073	1.166	1.264	1.109	1.190	1.278	1.089	1.180	1.276
$CPUE_{2023}$	0.640	1.025	1.533	0.776	1.131	1.494	0.700	1.077	1.617
H_{2018}	2.124	2.367	2.645	2.003	2.206	2.445	2.122	2.386	2.652
H_{2023}	2.319	3.244	4.528	2.016	2.854	3.772	2.269	3.198	4.434
B_{male} / B_{female}	0.855	0.989	1.127	0.919	1.059	1.200	0.791	0.921	1.069
Probabilities									
$P(B_{2019} > B_{MIN})$		0.813			1.000			0.910	
$P(SSB_{2019} < 20\%SSB_0)$		0.000			0.000			0.000	
$P(SSB_{2019} < 10\%SSB_0)$		0.000			0.000			0.000	
$P(B_{2023} > B_{2019})$		0.254			0.408			0.298	
$P(SSB_{2023} > SSB_{2019})$		0.401			0.604			0.464	
$P(B^{tot}_{2023} > B^{tot}_{2019})$		0.329			0.477			0.389	

Table 14: LOOIC calculations by model and dataset. Models with the same number of data points can be compared.

Model	Dataset	ELPD diff	SE diff	LOOIC	SE LOOIC
base	CPUE	0.00	0.00	342.14	14.01
no_qdrift	CPUE	-1.29	1.14	344.73	14.53
base	Sex ratio	0.00	0.00	-3853.57	415.12
no_qdrift	Sex ratio	-49.44	5.43	-3754.69	404.37

7. FIGURES

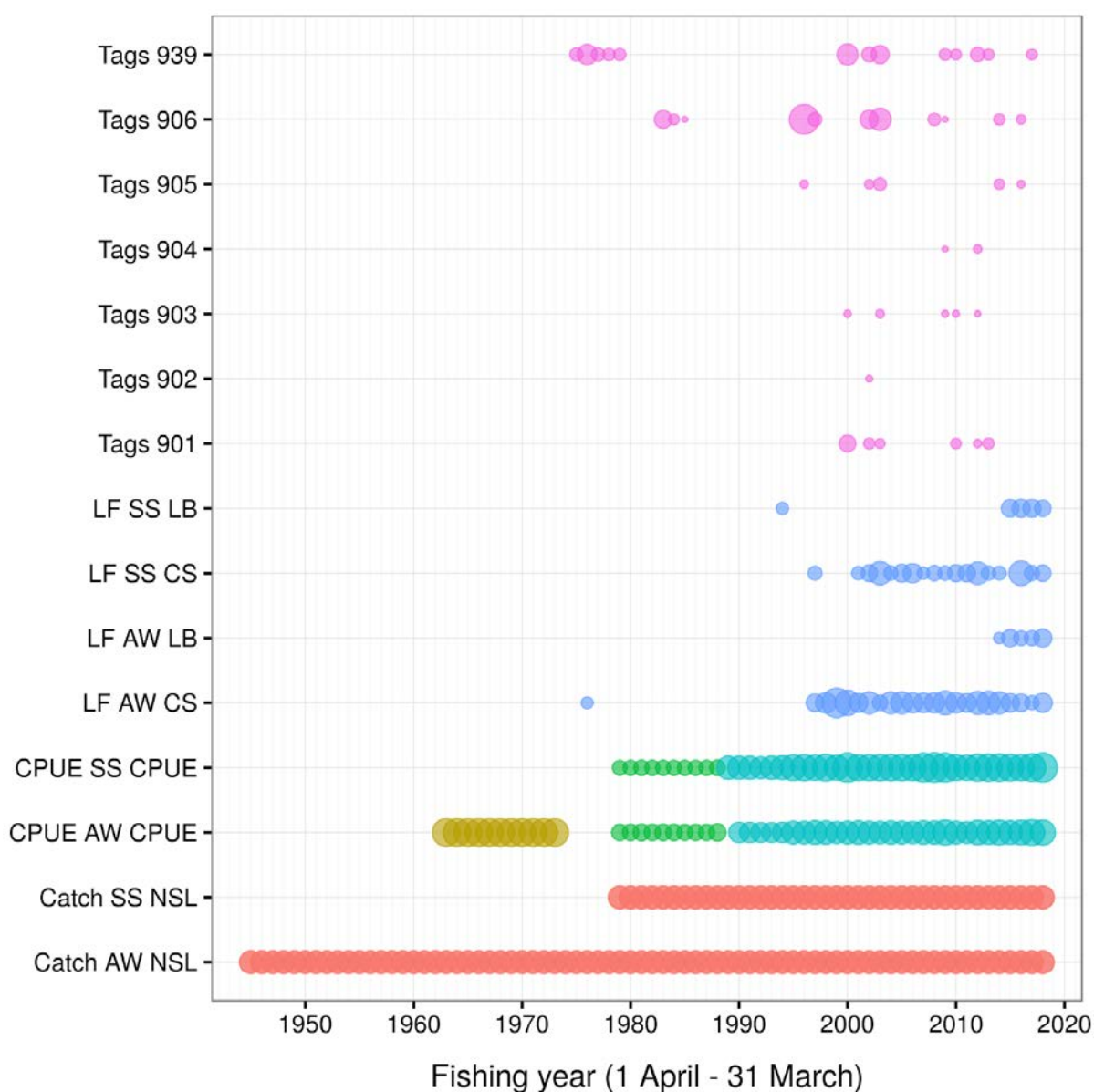


Figure 2: Temporal extent of data for each fishing year used in the CRA 1 stock assessment. The sizes of the bubbles respectively represent the relative number of recaptured tags, the effective sample size for length frequency distributions, the standard deviation for CPUE series, and a fixed size for catch. The different bubble colours represent different data sets (e.g., for CPUE, the CR, FSU, and CELR series).

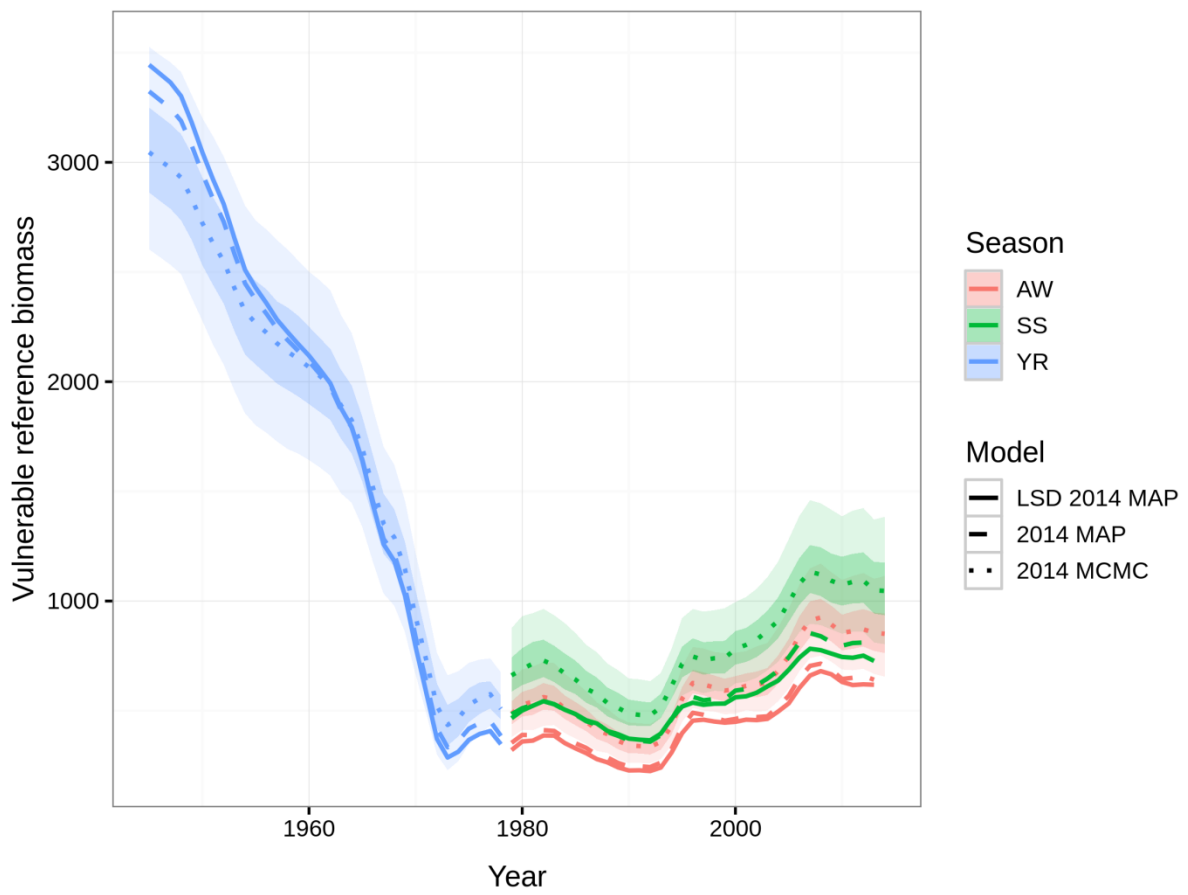


Figure 3: CRA 1 trajectory of vulnerable reference biomass by season. Comparison with the 2014 assessment: thick solid line is the MAP for the 2019 model mimic of the 2014 model using LSD. The dashed line is the previous model's MAP using MLSM in 2014. Note: the dotted lines and shaded areas are the from the 2014 model's MCMC.

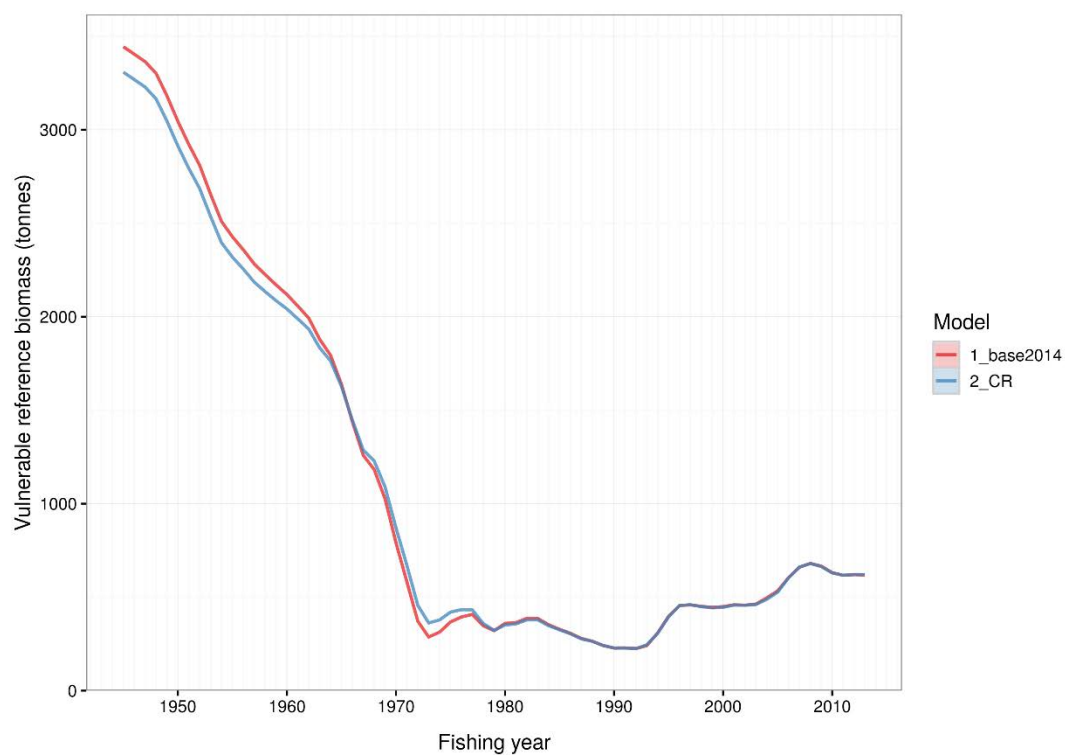


Figure 4: CRA 1 trajectory of vulnerable reference biomass. Comparison of mimicked 2014 assessment Model 1_base2014 with iterative update: model 2_CR.

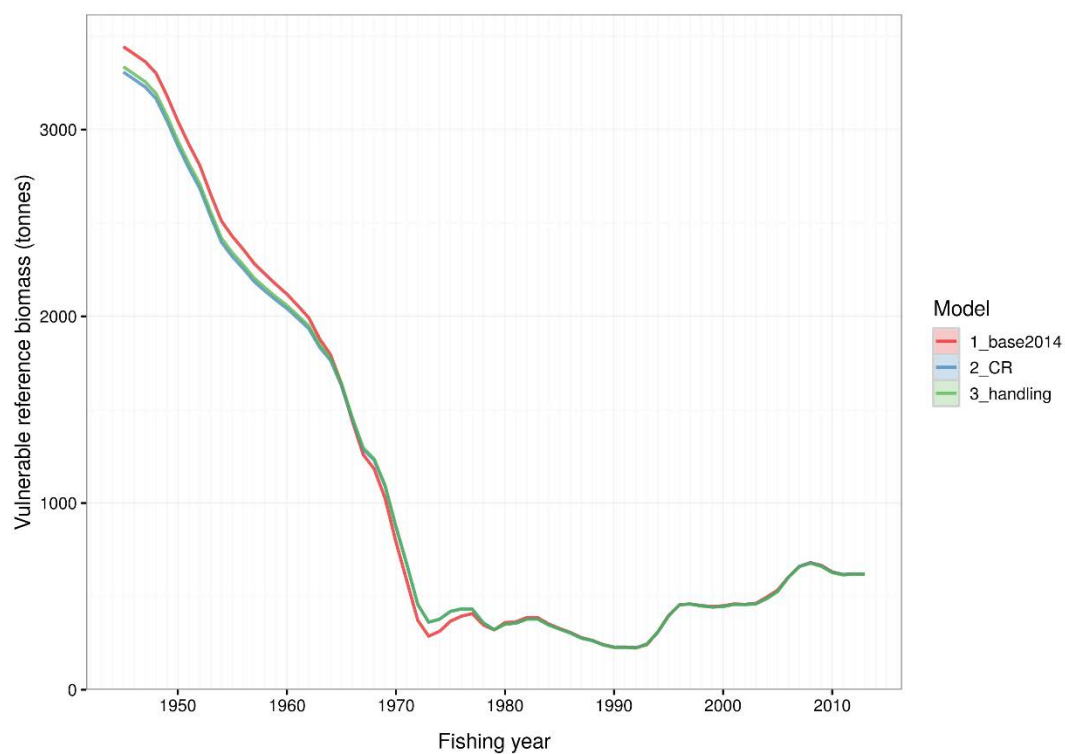


Figure 5: CRA 1 trajectory of vulnerable reference biomass. Comparison of mimicked 2014 assessment Model 1_base2014 with iterative updates: Model 2_CR and Model 3_handling.

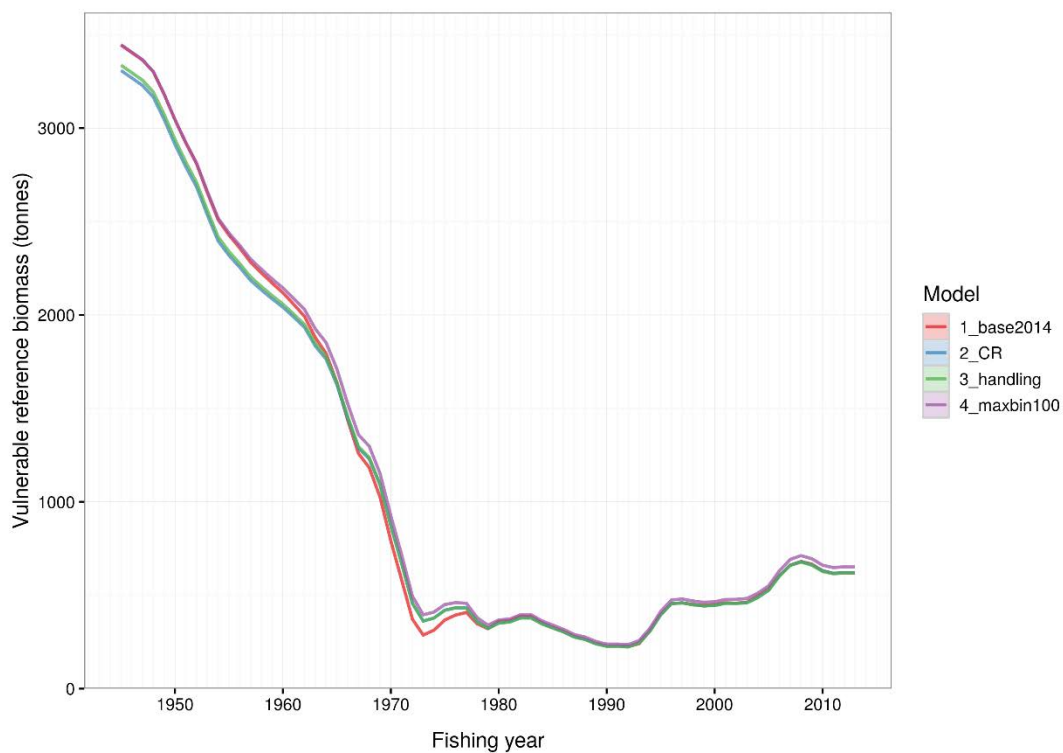


Figure 6: CRA 1 MAP trajectory of vulnerable reference biomass. Comparison of mimicked 2014 assessment Model *1_base2014* with iterative updates: Model *2_CR*, Model *3_handling* and Model *4_maxbin100*.

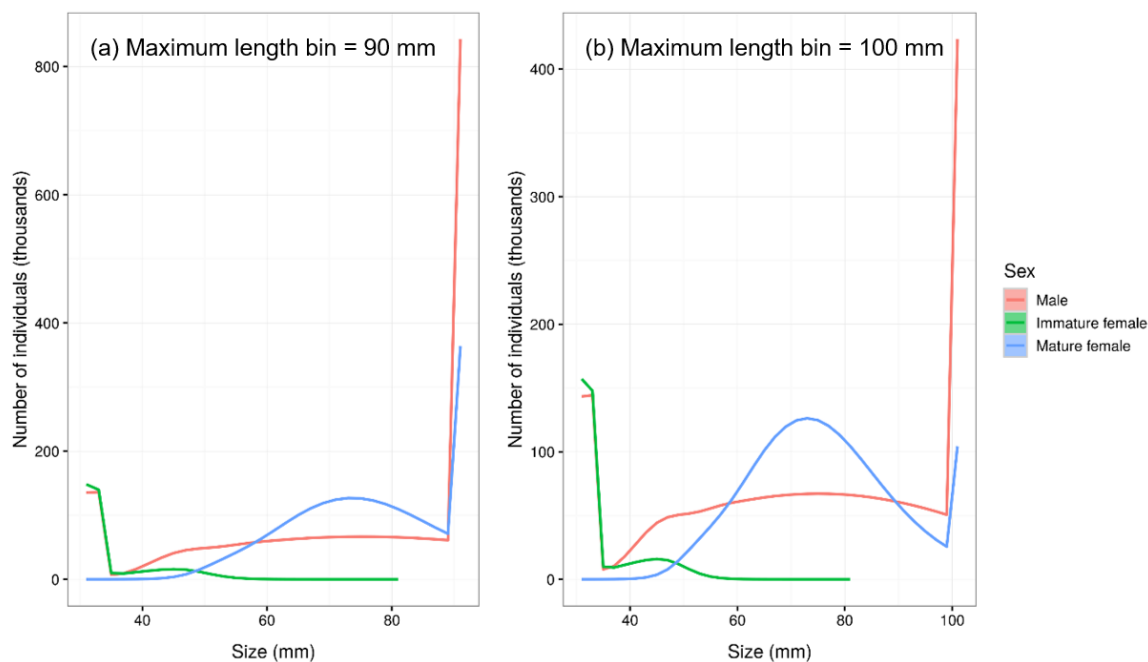


Figure 7: CRA1 MAP initial number of individuals by sex category for (a) Model *1_base2014* with maximum length bin at 90mm, and (b) Model *4_maxbin100* with maximum length bin at 100 mm.

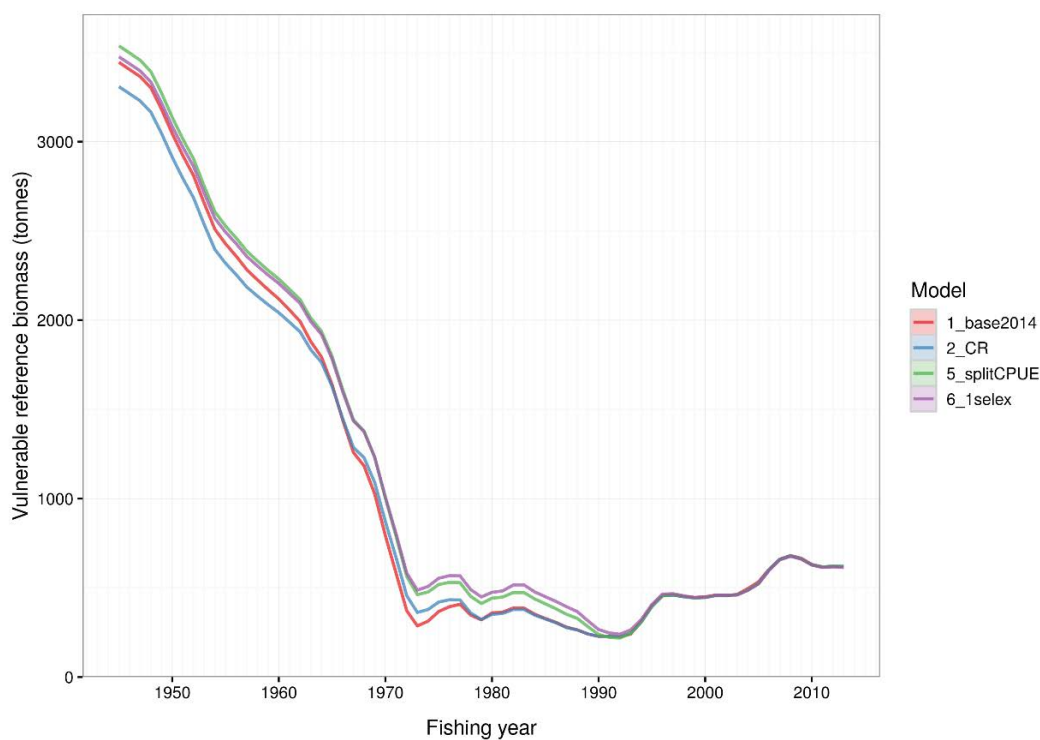


Figure 8: CRA 1 MPA trajectory of vulnerable reference biomass. Comparison of mimicked 2014 assessment Model 1_base2014 with iterative updates: Model 2_CR, Model 5_splitCPUE and Model 6_selex.

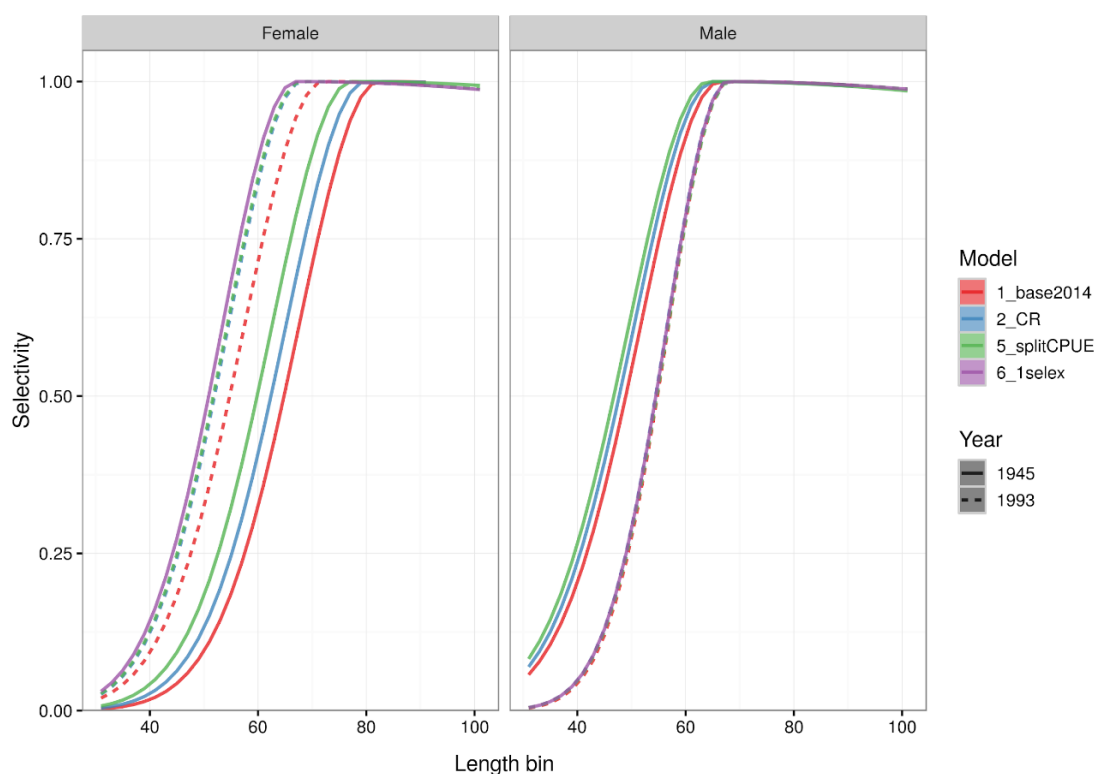


Figure 9: CRA1 MAP: Changes in selectivity: two selectivity epochs are estimated in Model 1_base2014, Model 2_CR, and Model 5_splitCPUE; one selectivity epoch is estimated in Model 6_1selex3. There was a slight shift from selecting smaller to larger males from 1993 onwards in the selectivity for males, and this shift was reversed for females.

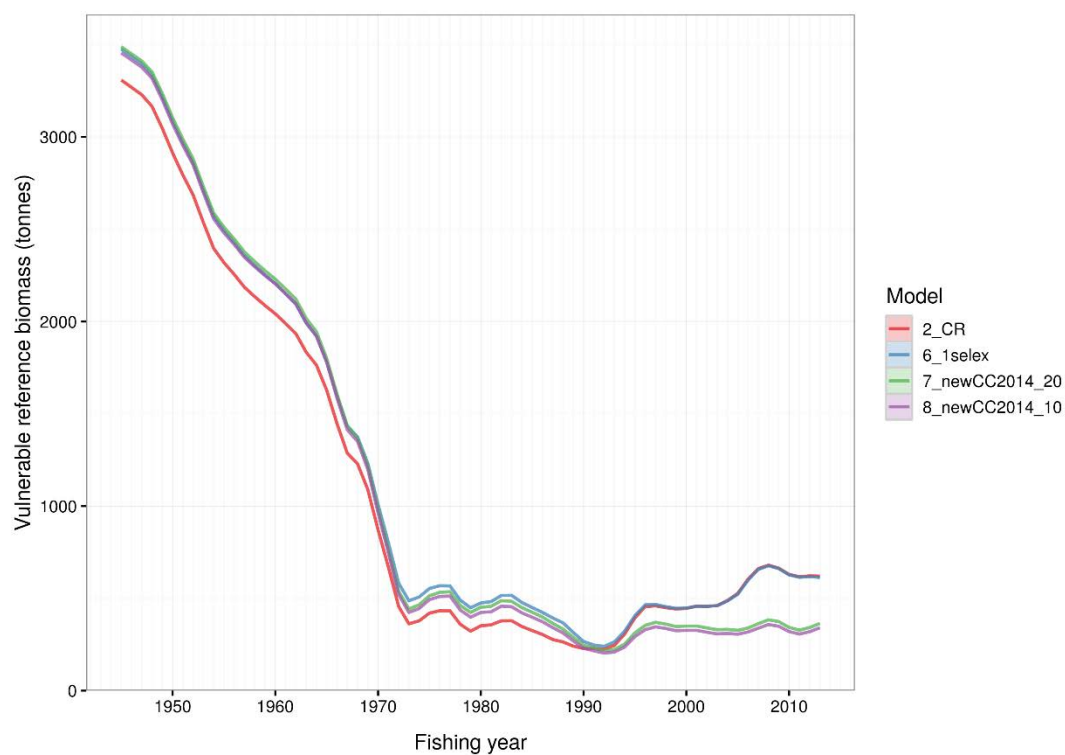


Figure 10: CRA 1 trajectory of vulnerable reference biomass. Comparison of Model 2_CR with iterative updates: Model 6_1selex, Model 7_newCC2014_20, and Model 8_newCC2014_10.

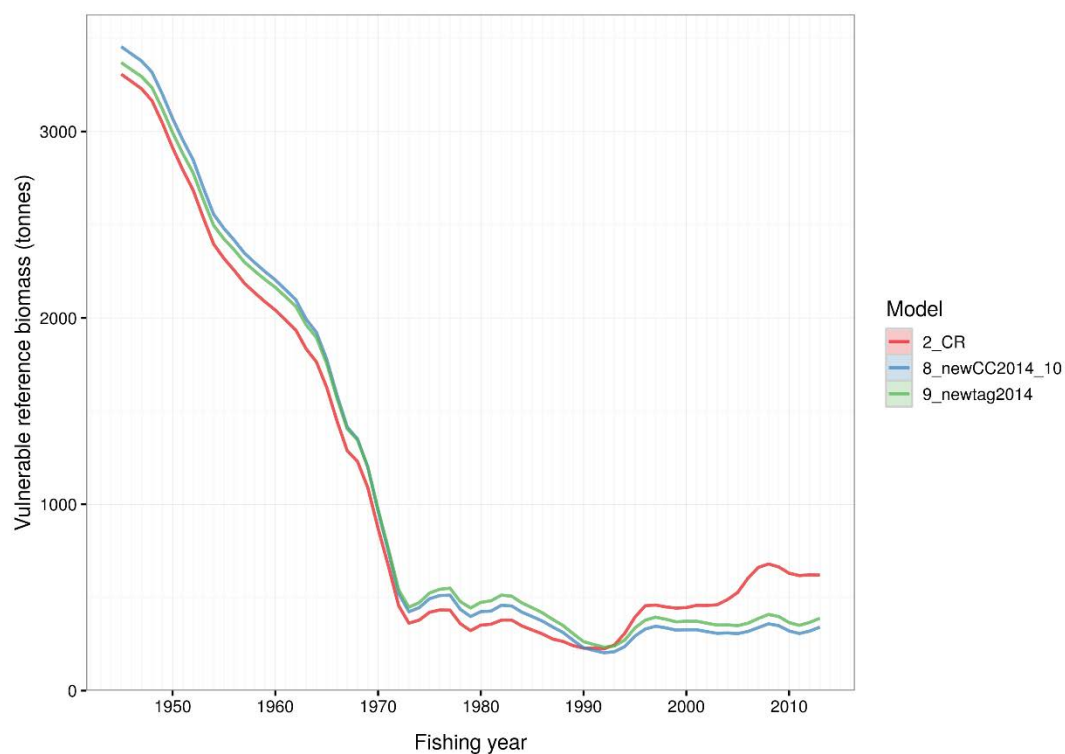


Figure 11: CRA 1 trajectory of vulnerable reference biomass. Comparison of Model 2_CR with iterative updates: Model 8_newCC2014_10, and Model 9_newtag2014.

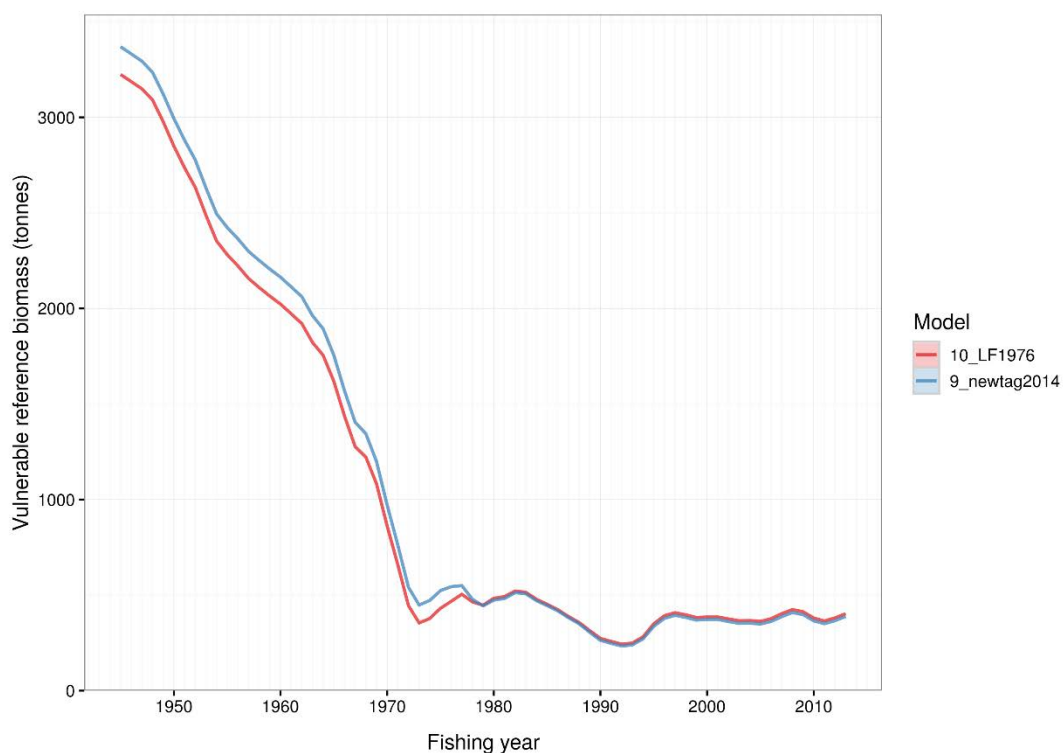


Figure 12: CRA 1 trajectory of vulnerable reference biomass. Comparison of Model 9_newtag2014 with iterative update: Model 10_LF1976.

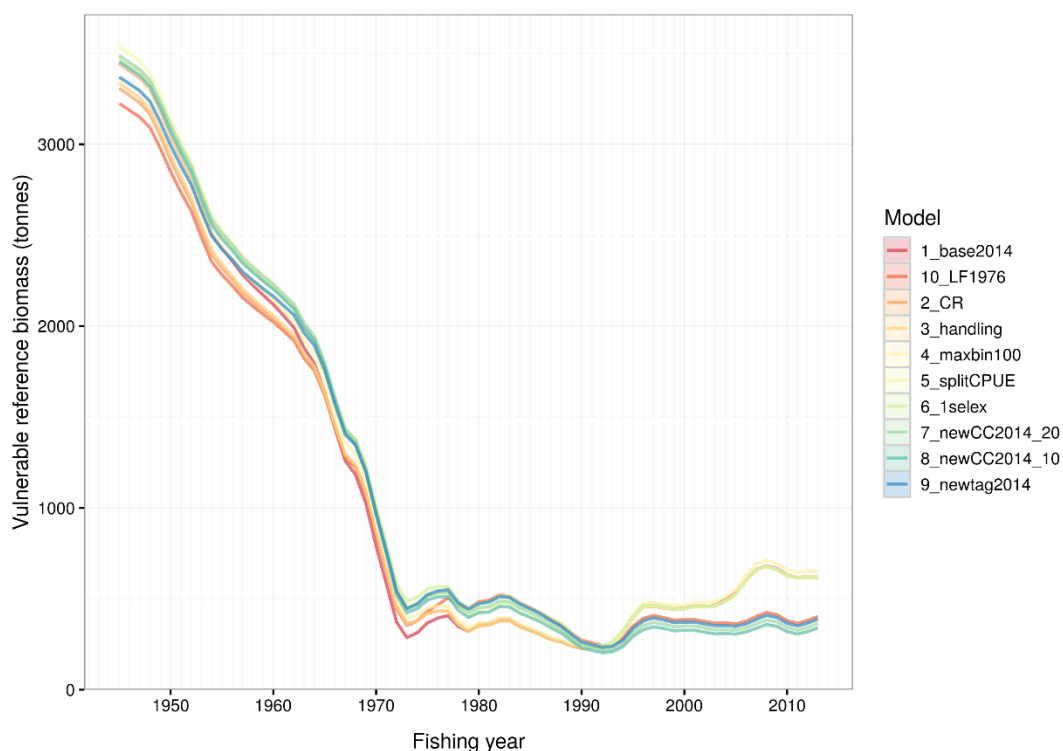


Figure 13: CRA 1 trajectory of vulnerable reference biomass. Comparison of mimicked 2014 assessment Model 1_base2014 with all nine iterative updates. Models 5-10 that include the post-FSU/CELR split and the estimation of 3 catchability parameters show a flattened vulnerable biomass trend from 1993 compared to the previous 4 models where the CPUE series are not split. Notes: Model 10 is shown below Model 1 in the figure legend.

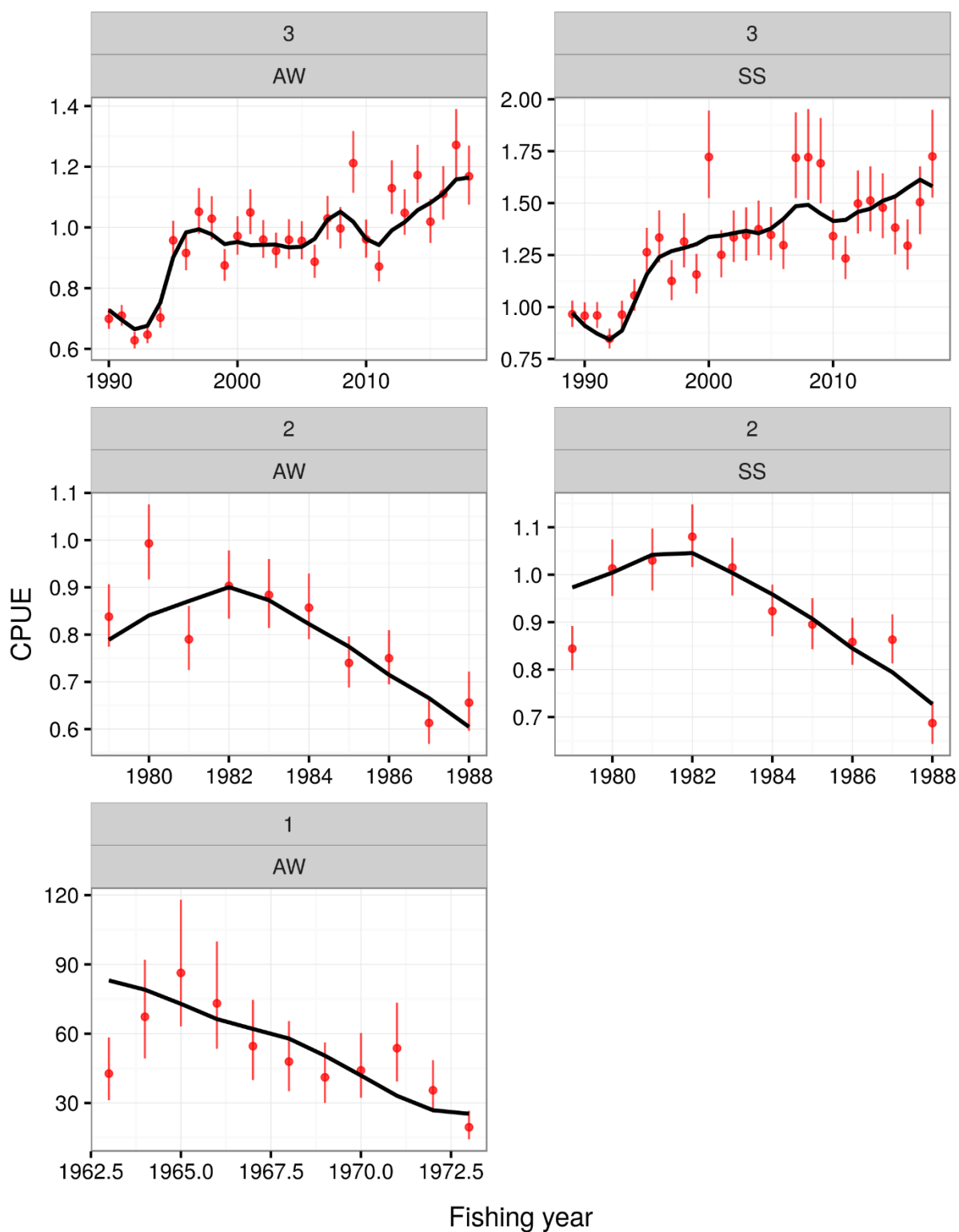


Figure 14: CRA 1 base case: MAP model fit to CPUE. Upper panels=CELR fit; middle panels=FSU fit; lower panels=CR fit.

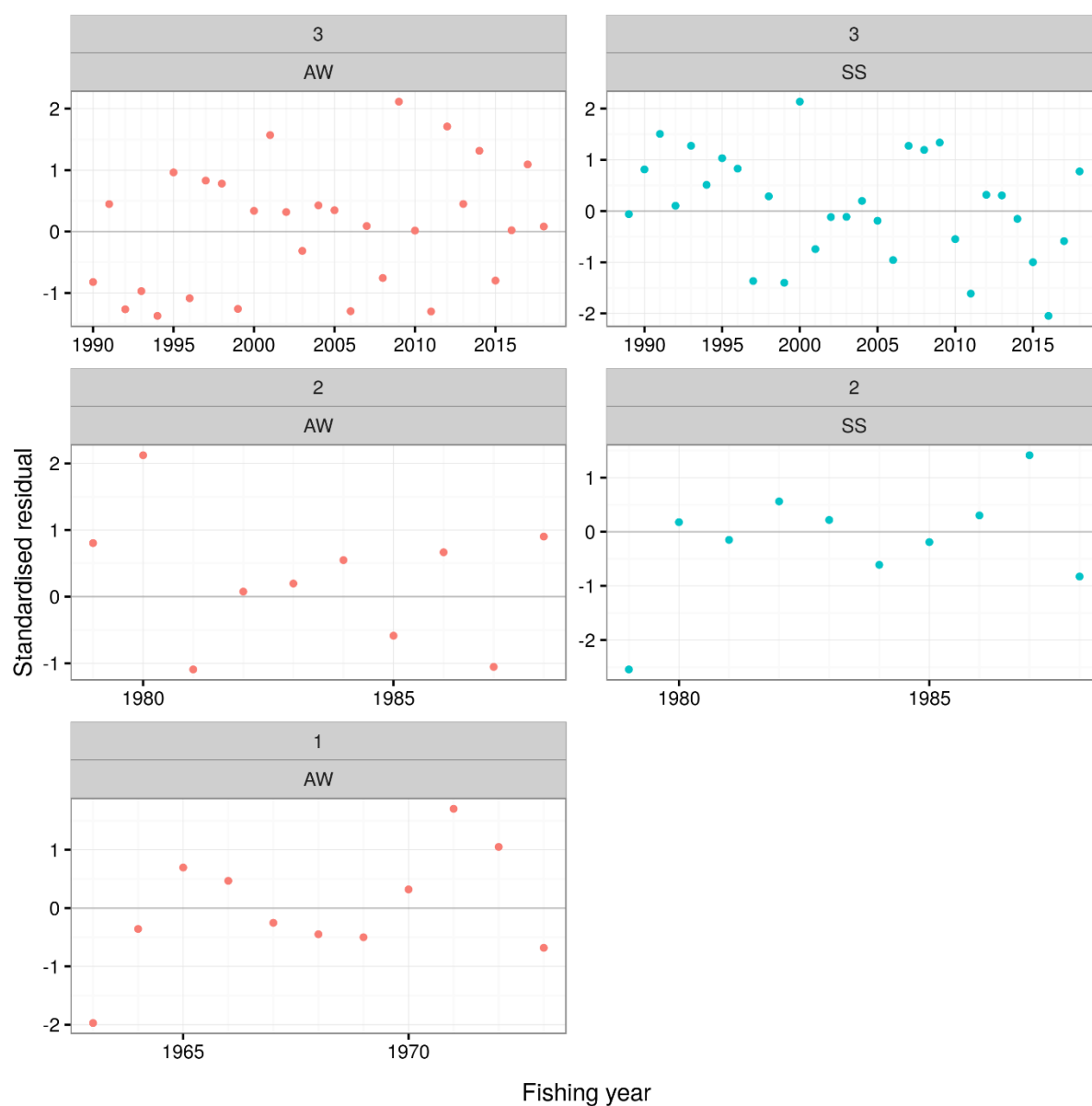


Figure 15: CRA 1 base case: MAP residuals from fit to CPUE. Upper panels=CELR fit; middle panels=FSU fit; lower panels=CR fit.

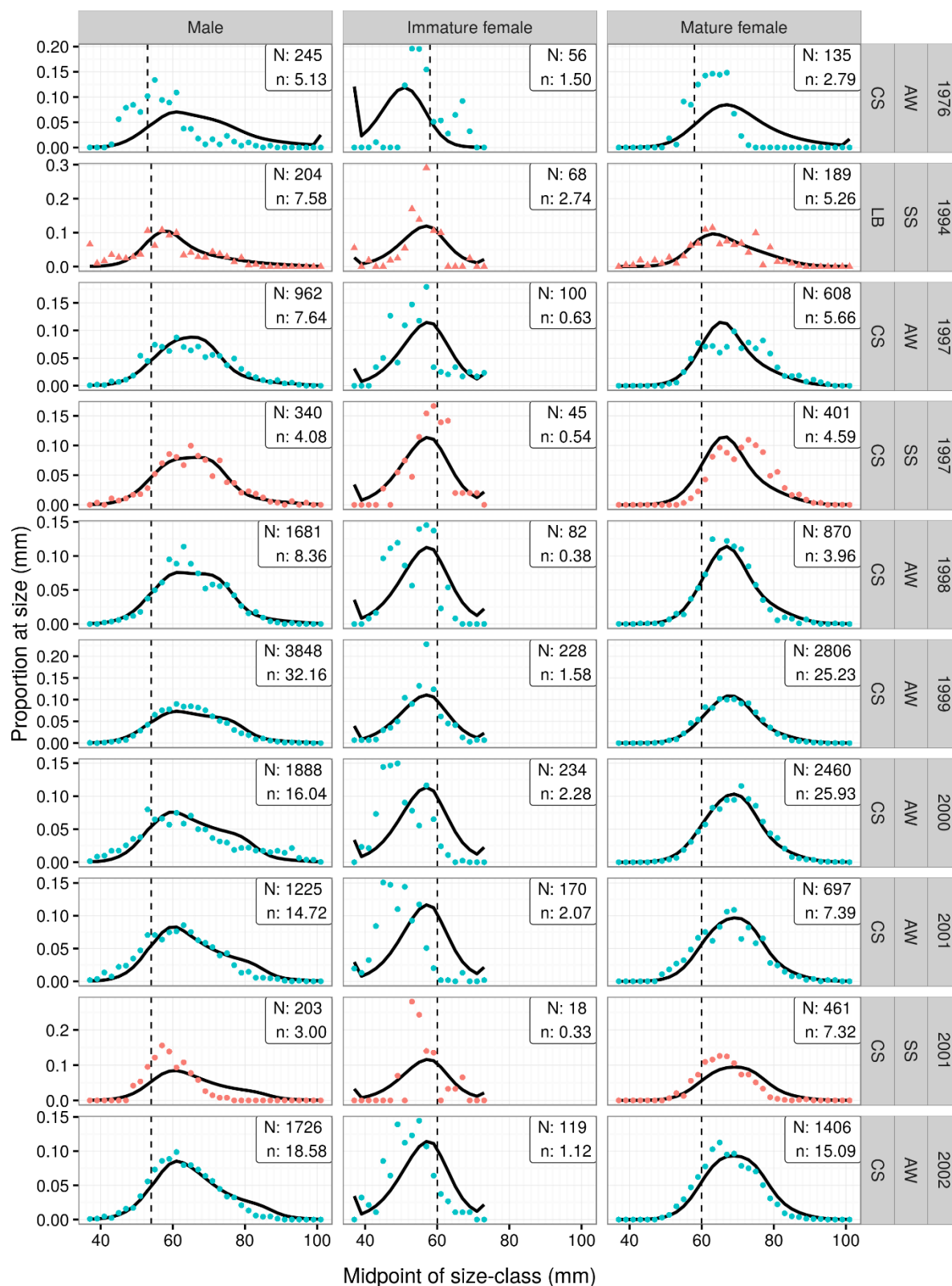


Figure 16: CRA 1 base case MAP: Model fits to LFs from 1976 AW CS – 2002 AW CS by sex, fishing year, season, and data source (AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling).

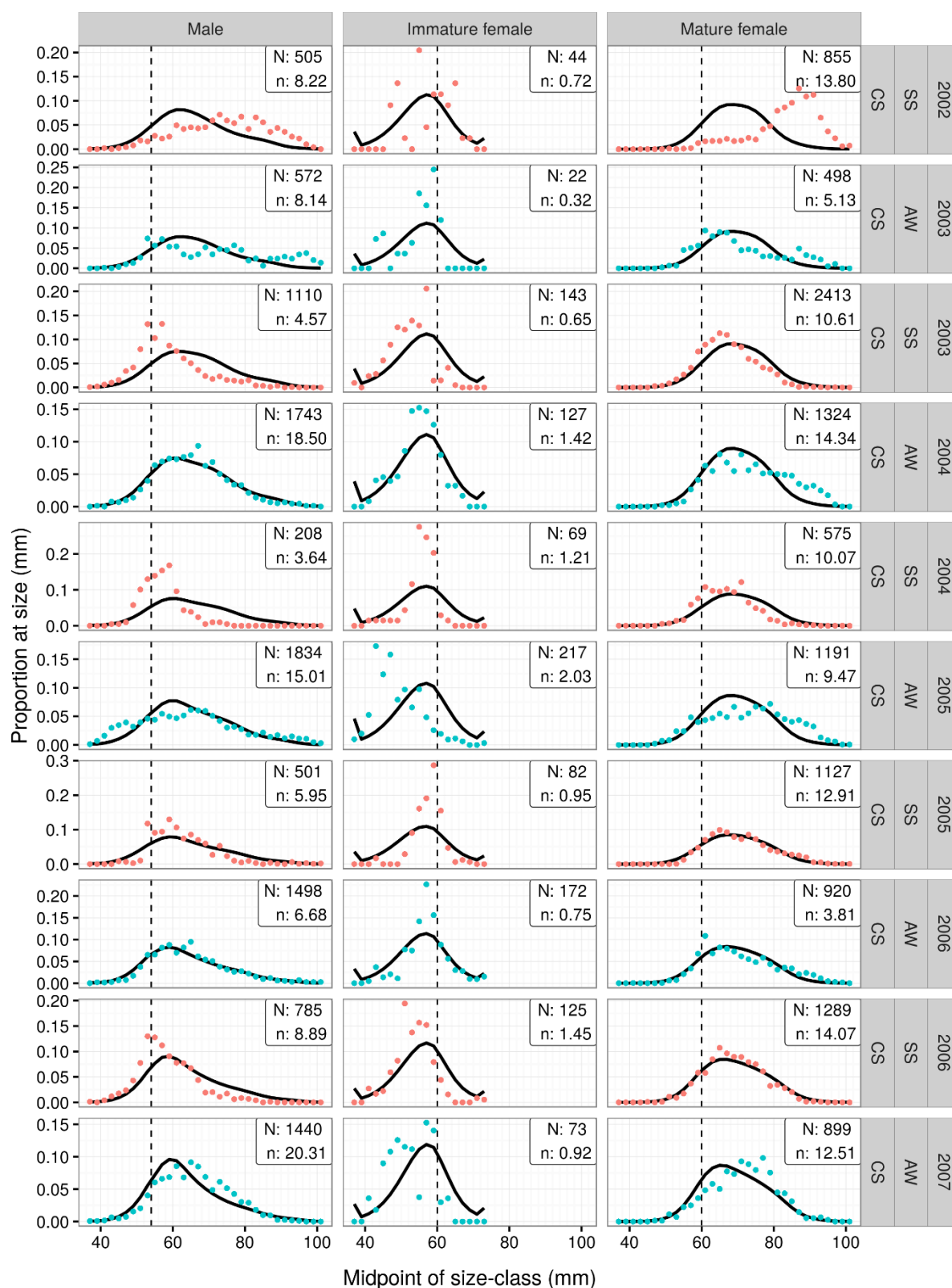


Figure 17: CRA 1 base case MAP: Model fits to LFs from 2002 SS CS – 2007 AW CS by sex, fishing year, season, and data source (AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling).

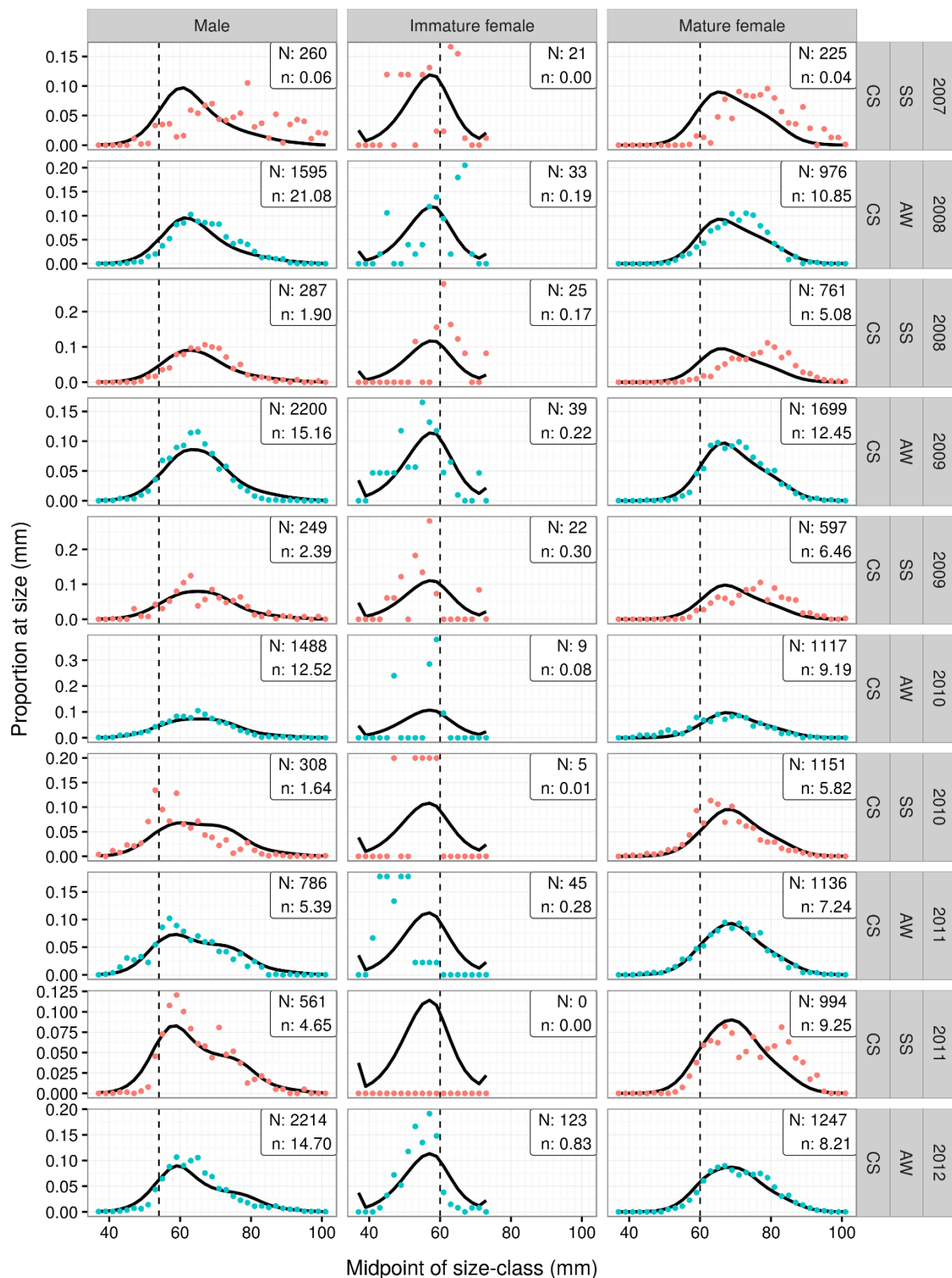


Figure 18: CRA 1 base case MAP: Model fits to LFs from 2007 SS CS – 2012 AW CS by sex, fishing year, season and data source (AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling).

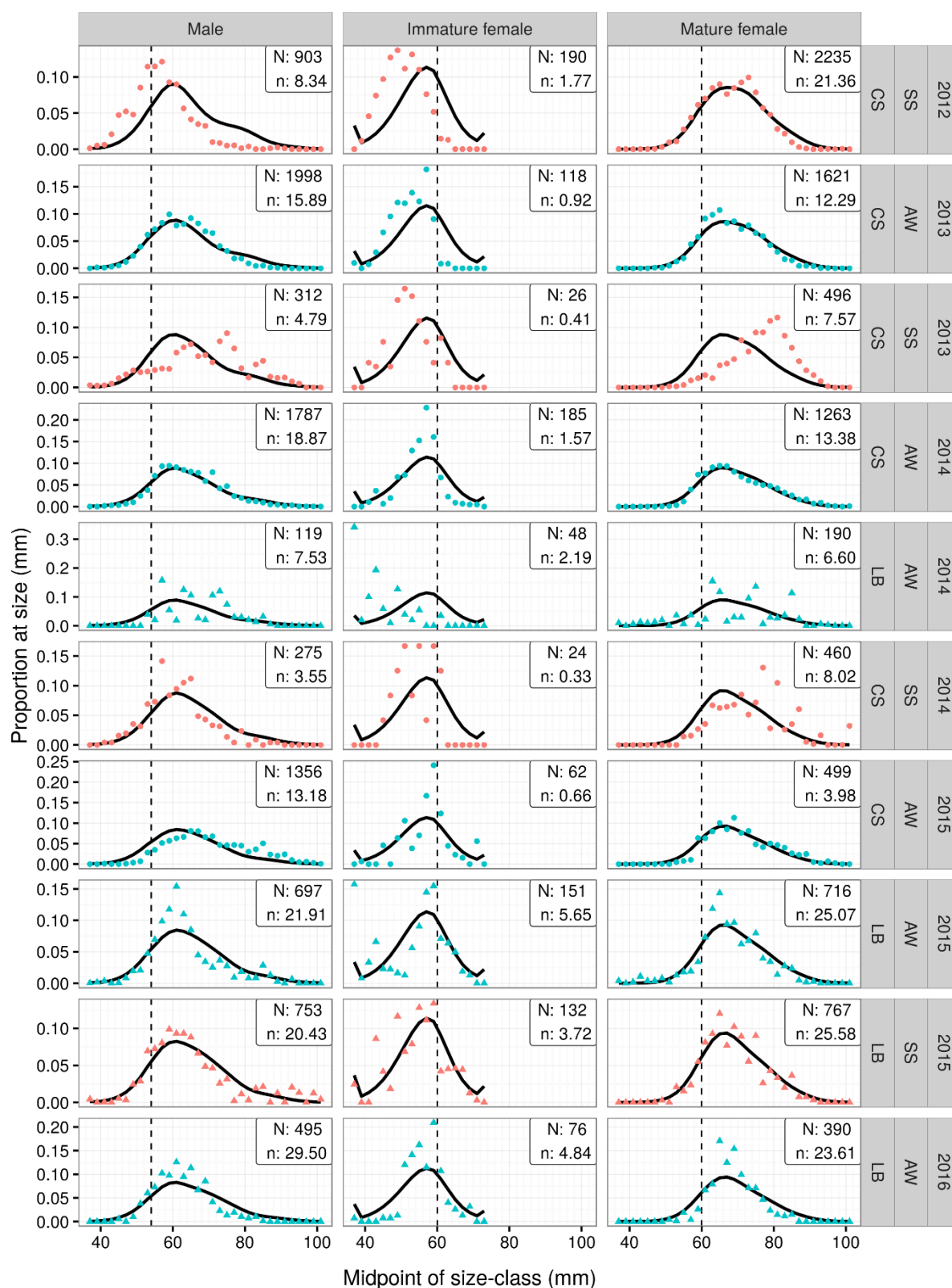


Figure 19: CRA 1 base case MAP: Model fits to LFs from 2012 SS CS – 2016 AW LB by sex, fishing year, season, and data source (AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling).

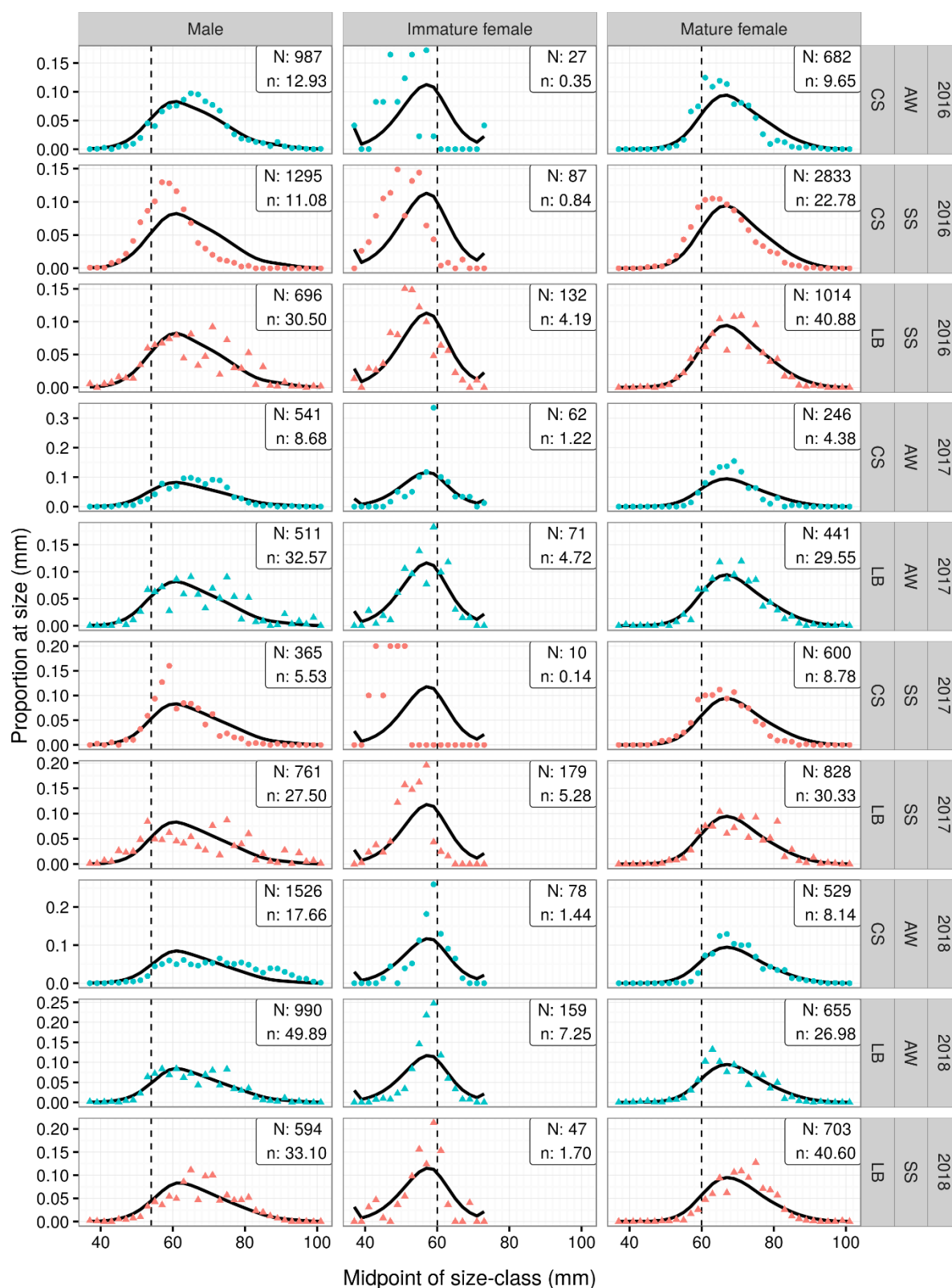


Figure 20: CRA 1 base case MAP: Model fits to LFs from 2016 AW CS – 2018 SS LB by sex, fishing year, season, and data source (AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling).

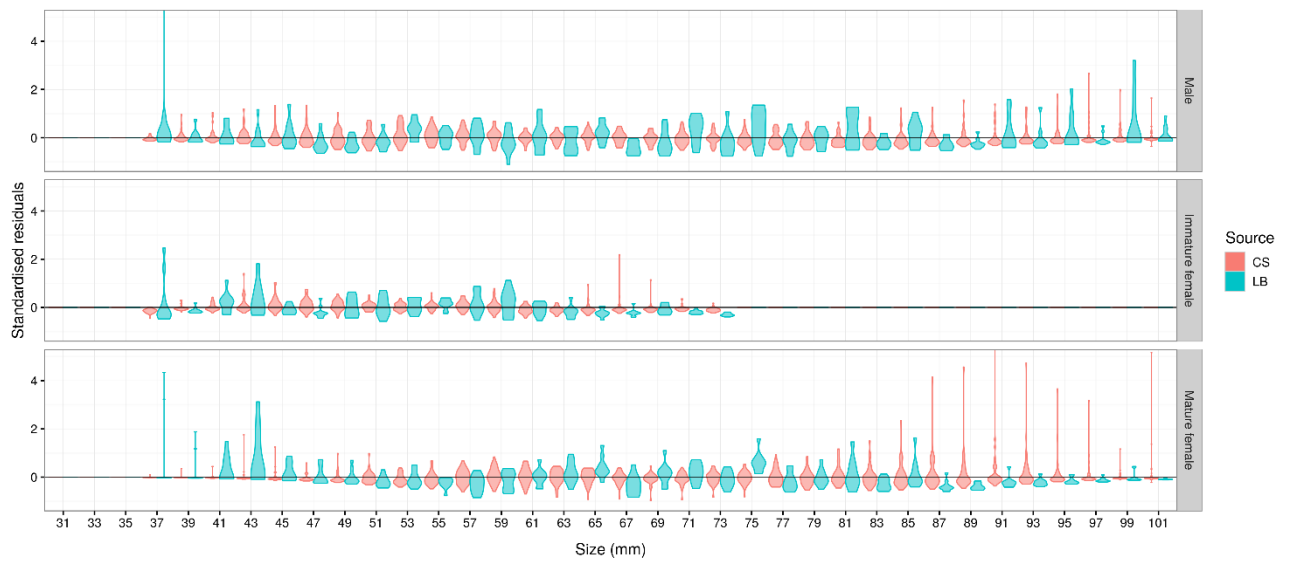


Figure 21: CRA 1 base case: MAP residuals from fit to the LF data, showing residuals by sex, 2 mm TW bin, and sampling source.

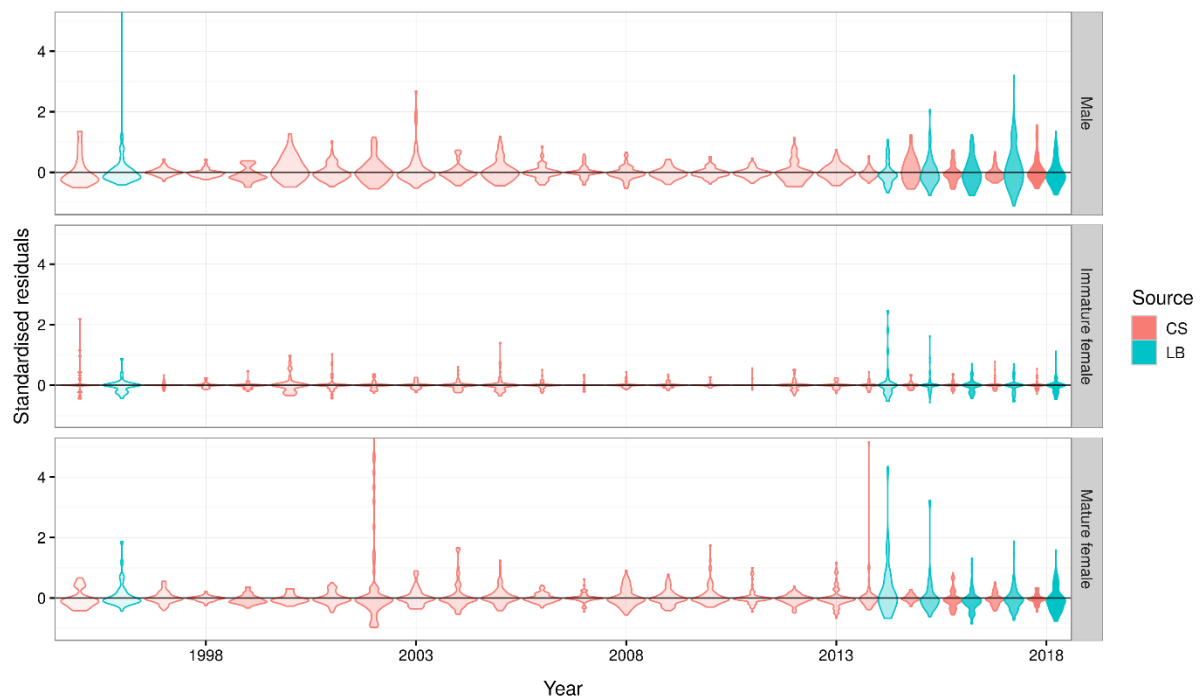


Figure 22: CRA 1 base case: MAP residuals from fit to the LF data, showing residuals by sex, year, and sampling source.

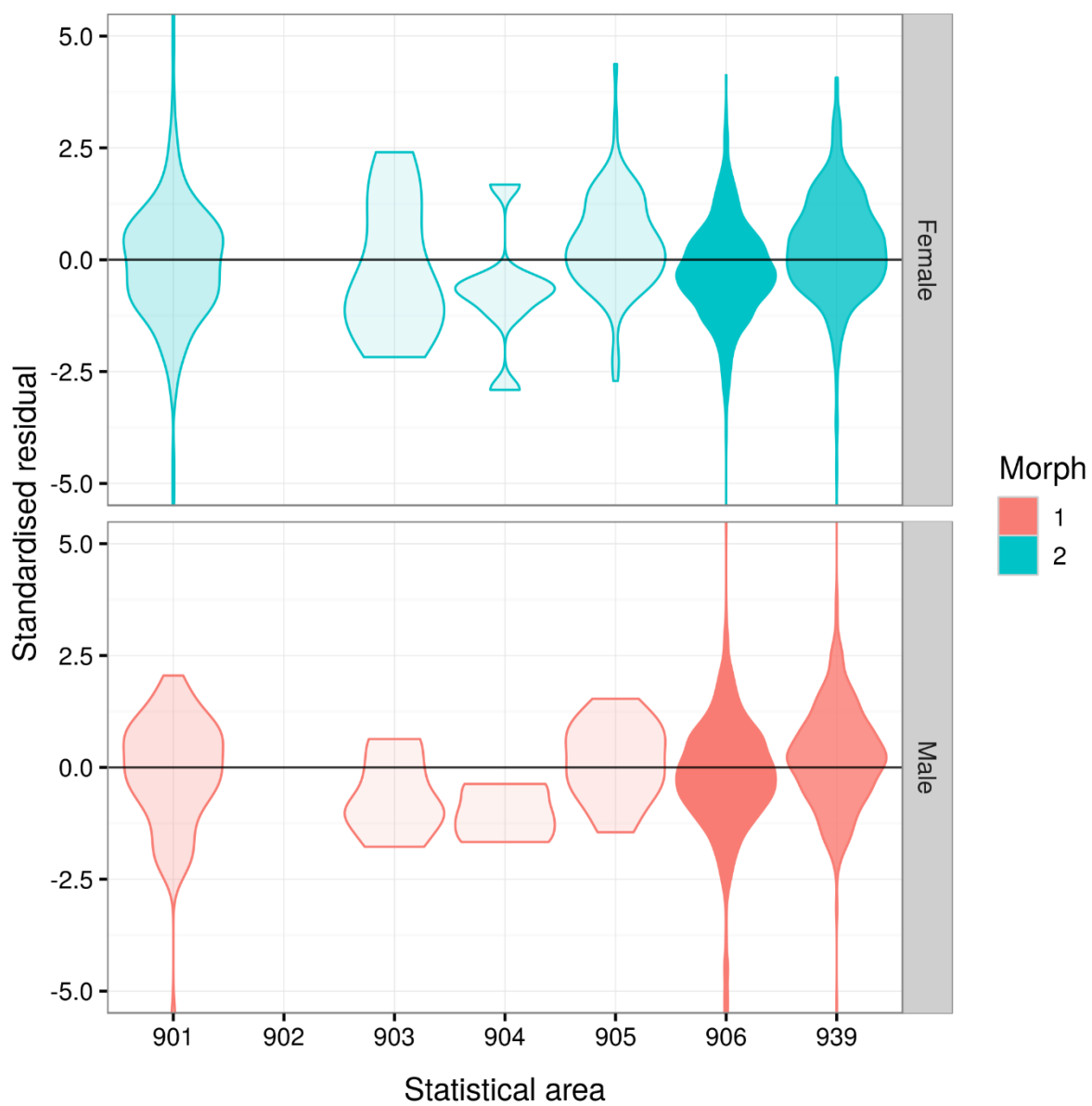


Figure 23: CRA 1 base case MAP: tag residuals by statistical area of release. Darker shading represents a higher number of tags by area.

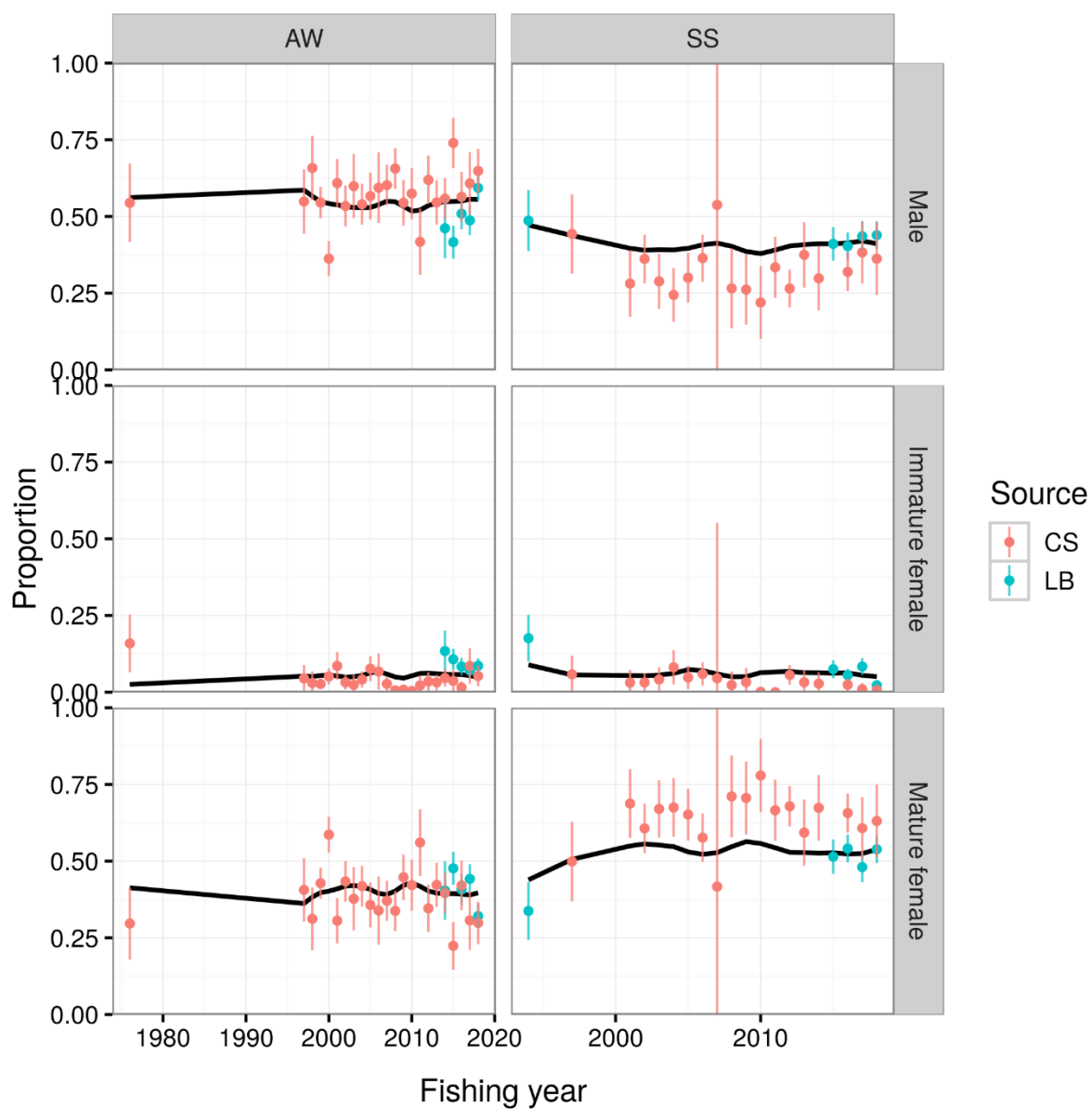


Figure 24: CRA 1 base case MAP: model fit to sex ratios, by year and LF data source.

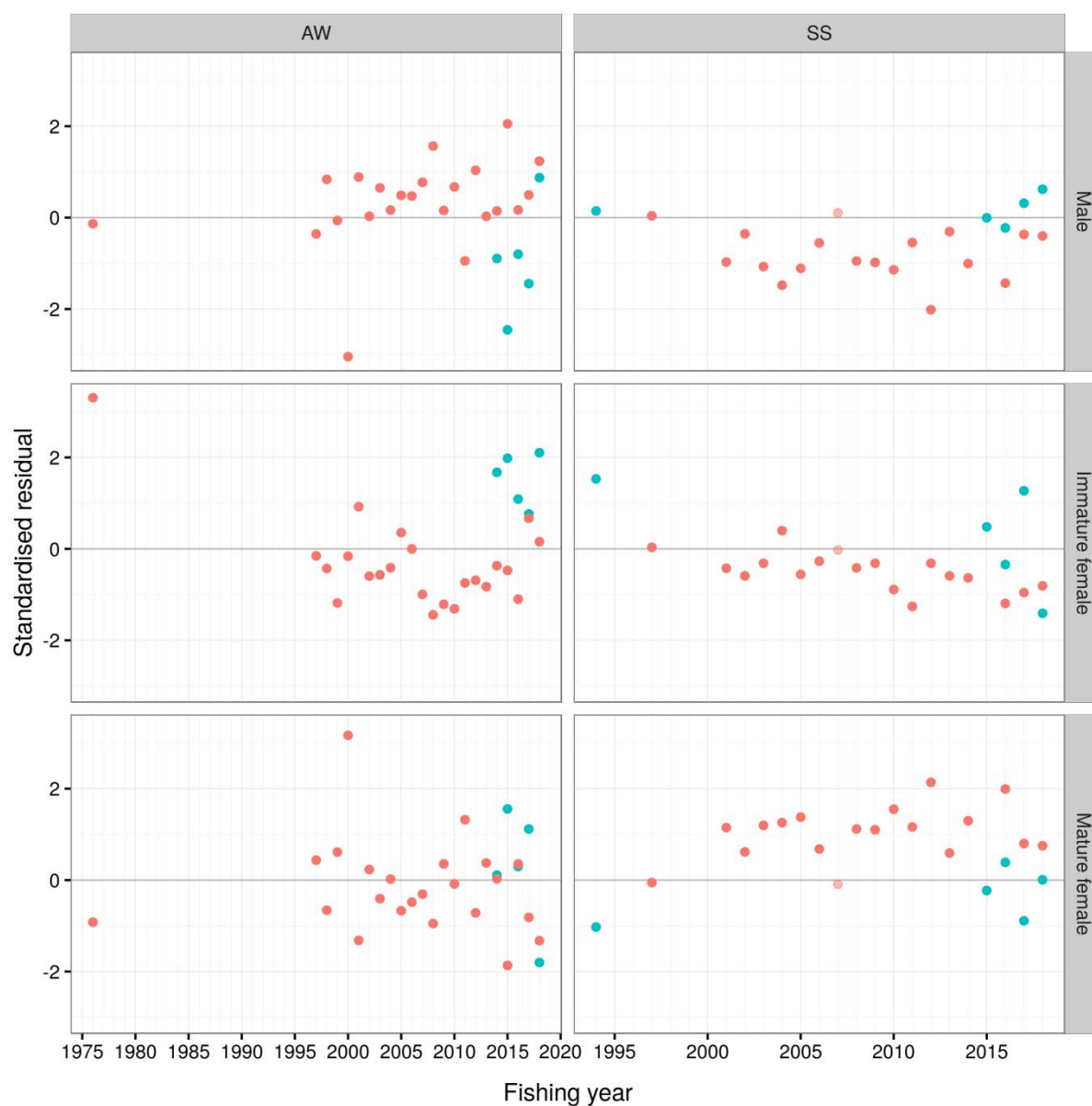


Figure 25: CRA 1 base case MAP: sex ratio residuals, by year and LF data source (red = catch sampling, blue = logbook).

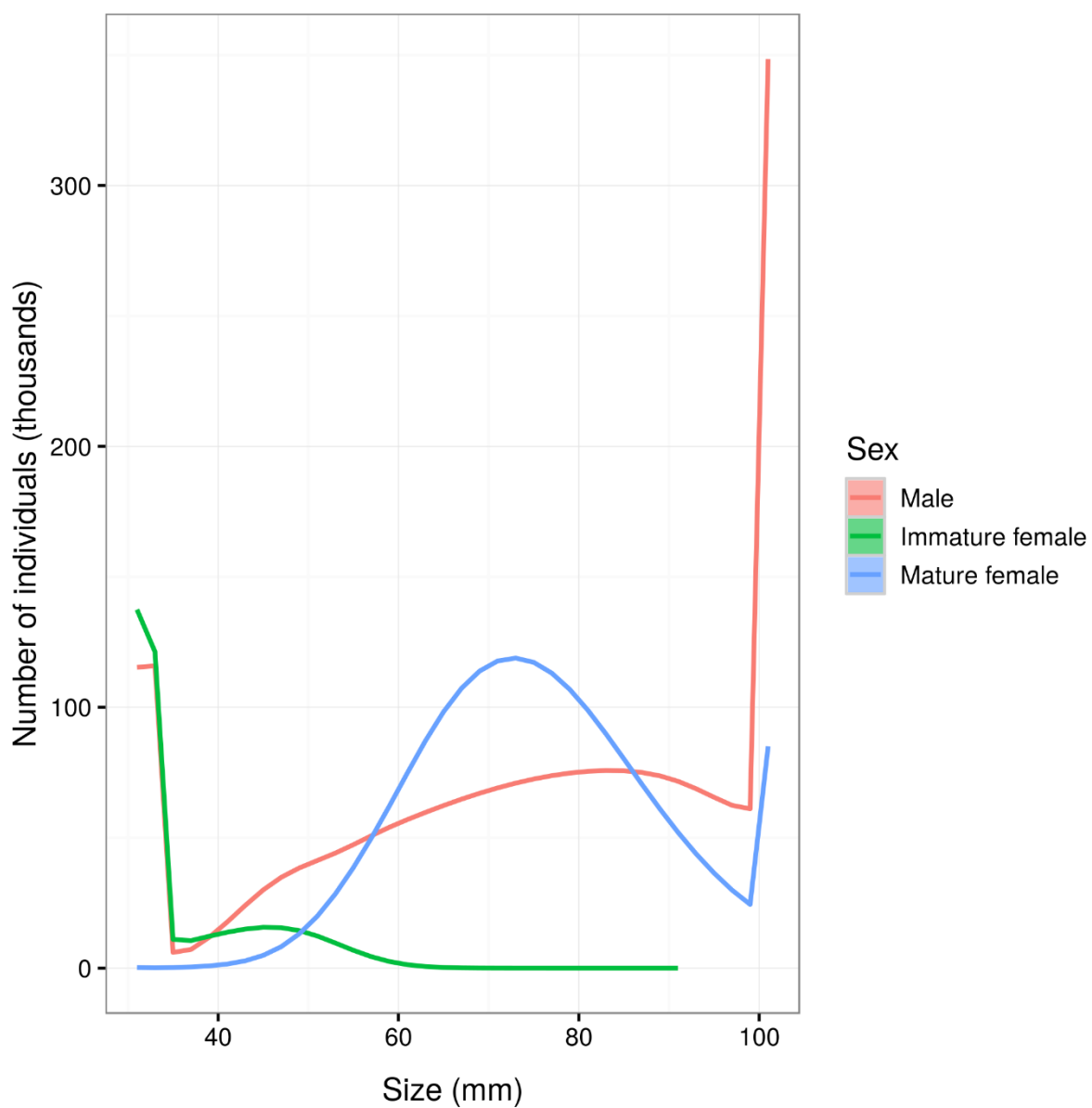


Figure 26: CRA 1 base case MAP: Initial number of individuals by sex category.

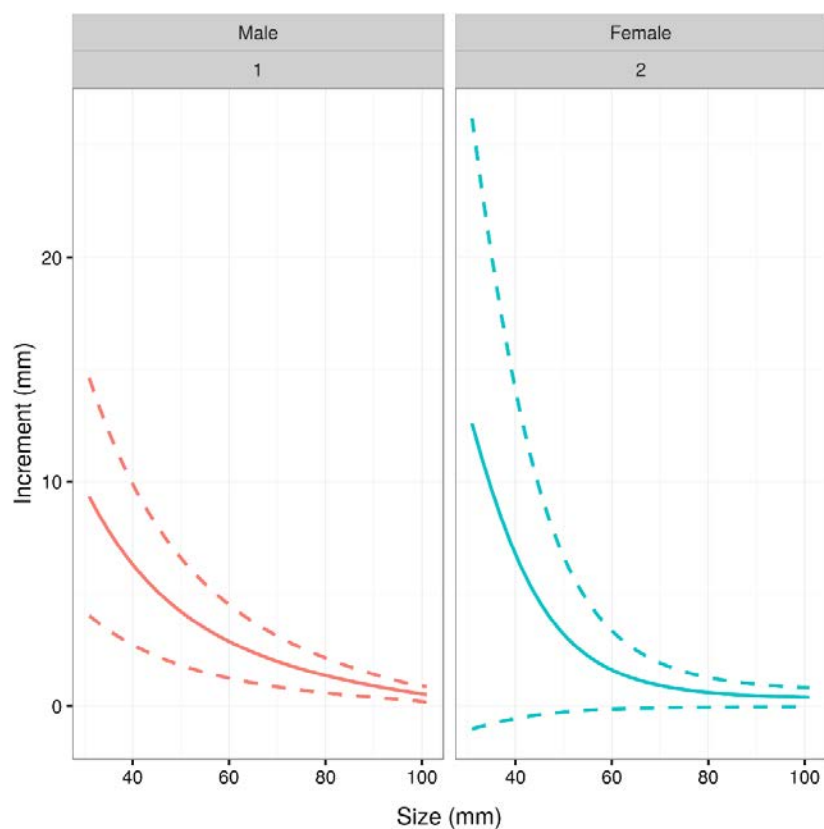


Figure 27: CRA 1 base case MAP: Predicted six-month increments-at-length and ± 1 standard deviation.

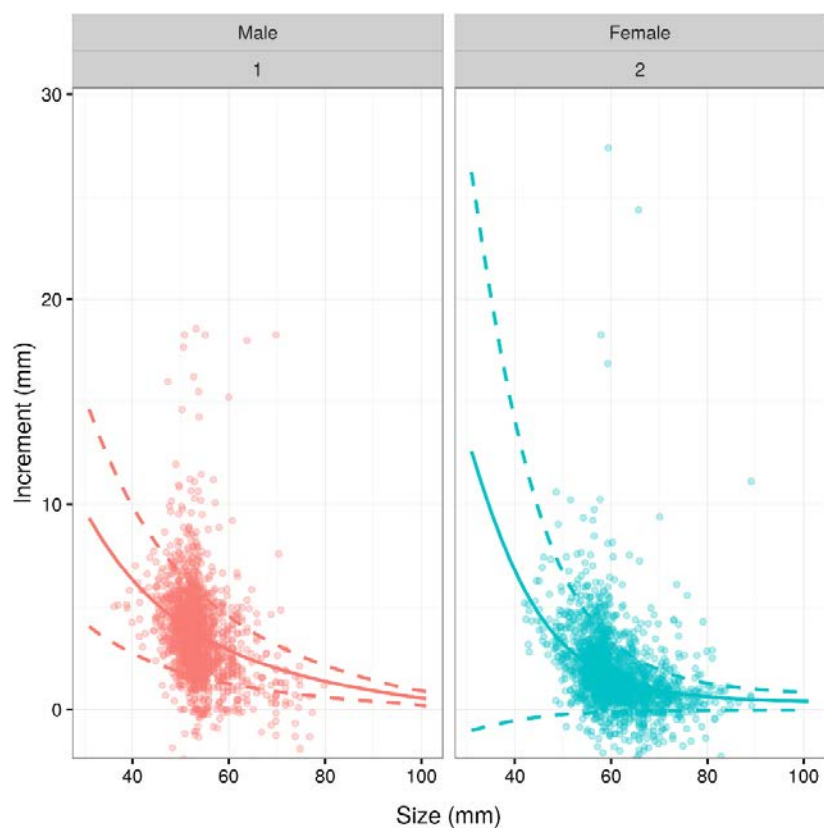


Figure 28: CRA 1 base case MAP: Predicted six-month increments-at-length and ± 1 standard deviation, with observed increments-at-length (points).

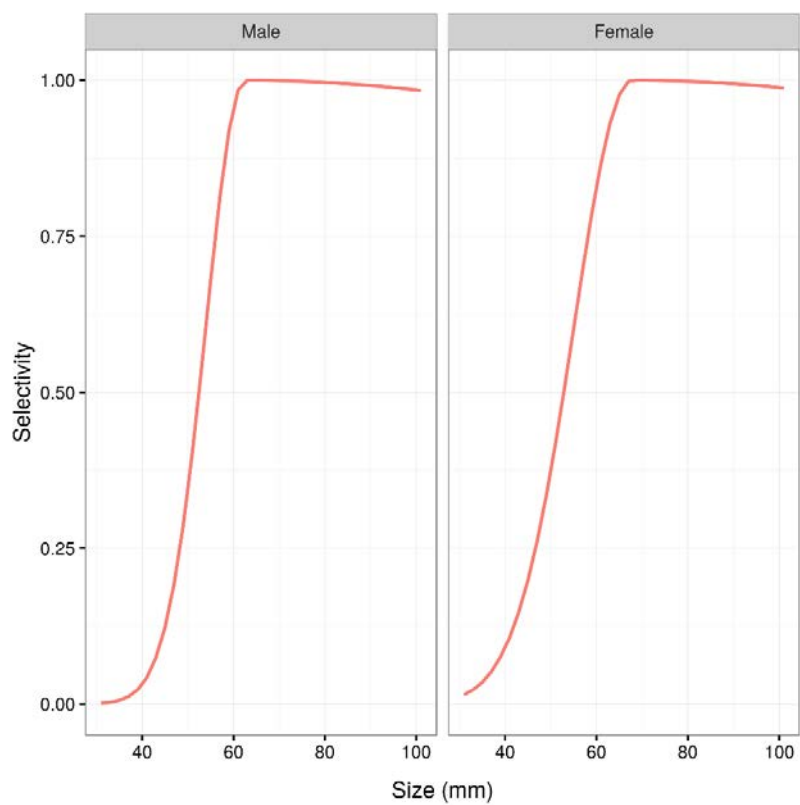


Figure 29: CRA 1 base case MAP: selectivity by sex.

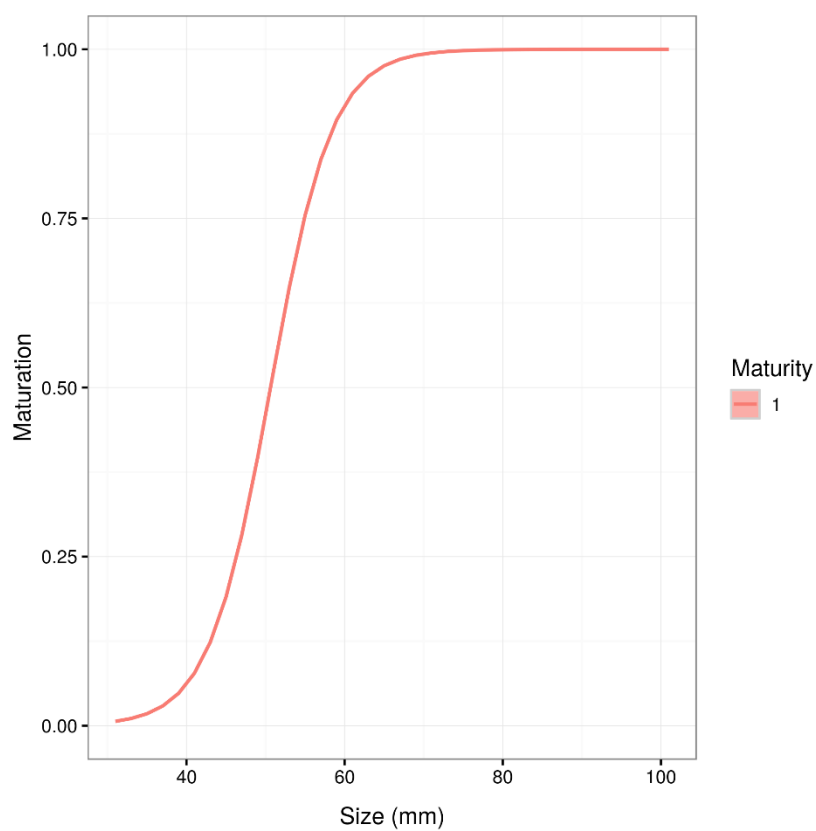


Figure 30: CRA 1 base case MAP: female maturation curve.

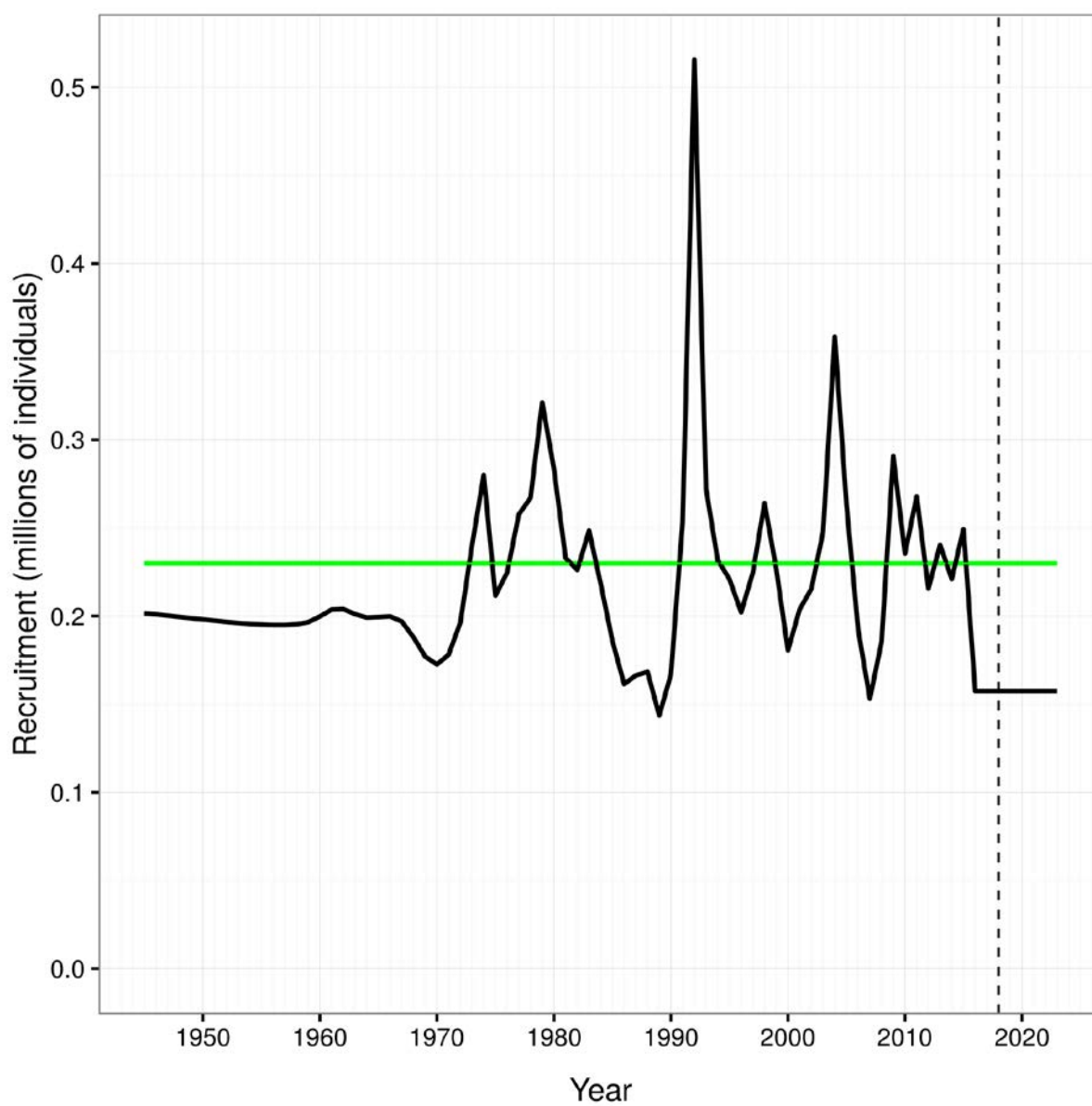


Figure 31: CRA 1 base case MAP: recruitment in 000 000s. Horizontal green line is R_0 and vertical dashed line is the final year of the reconstruction period.

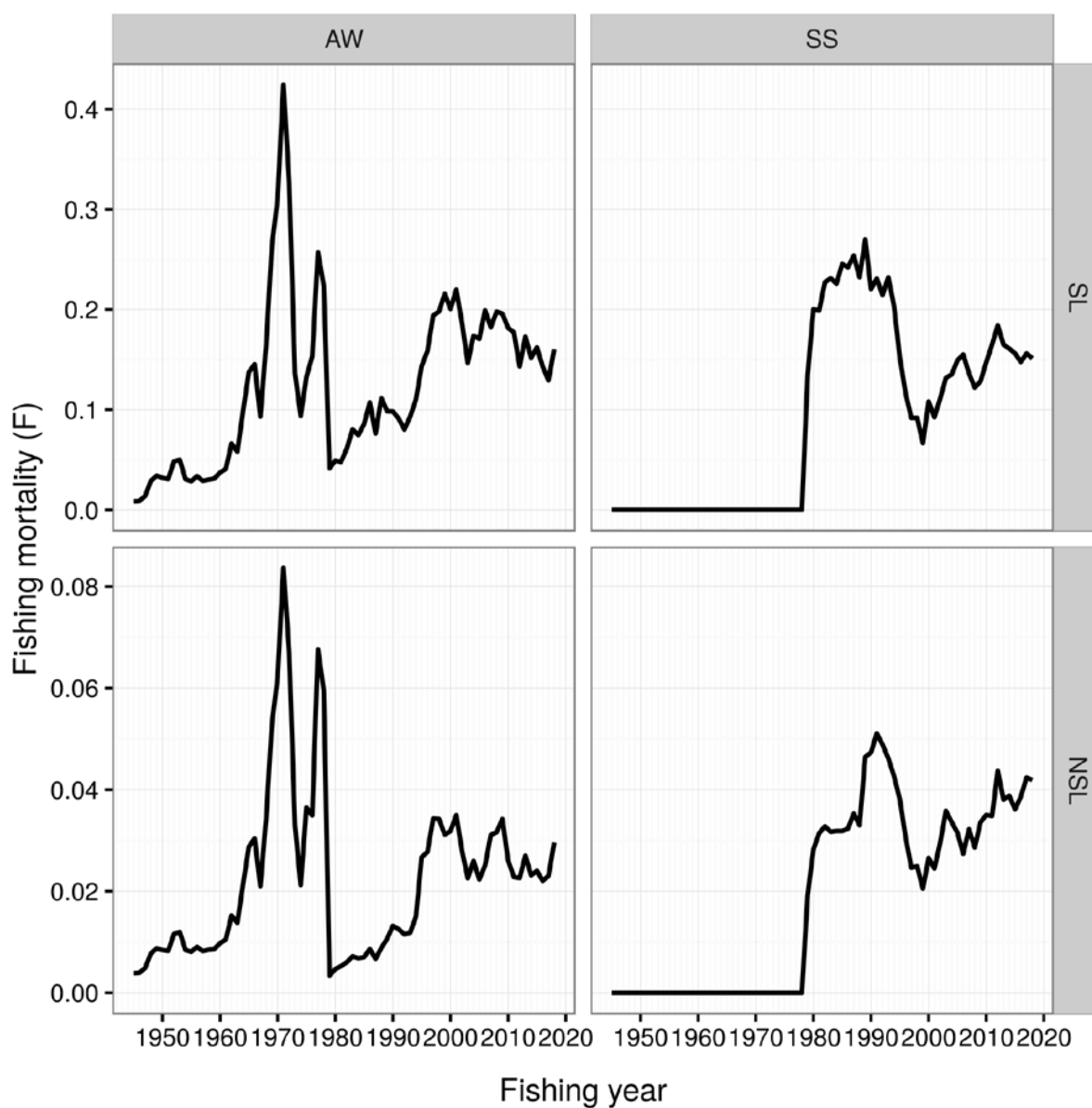


Figure 32: CRA 1 base case MAP: fishing mortality by year, season, and catch category.

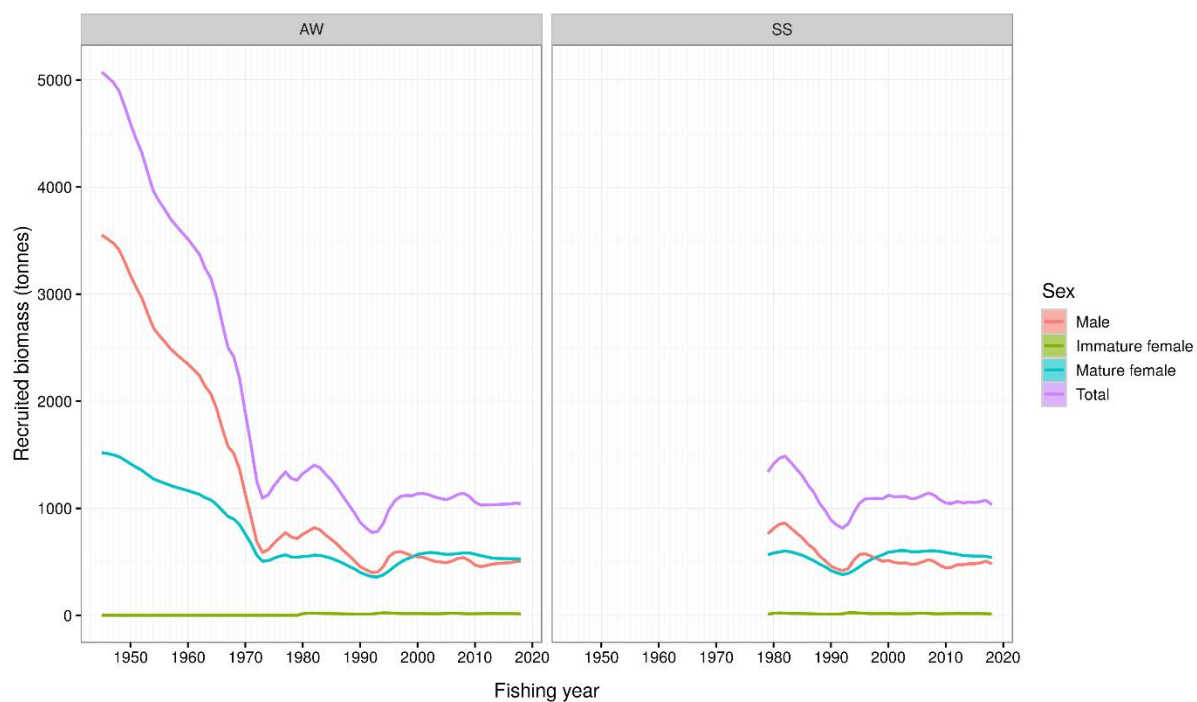


Figure 33: CRA 1 base case MAP: trajectory of recruited biomass by sex category and season. The total biomass across all three sex categories is shown as a purple line.

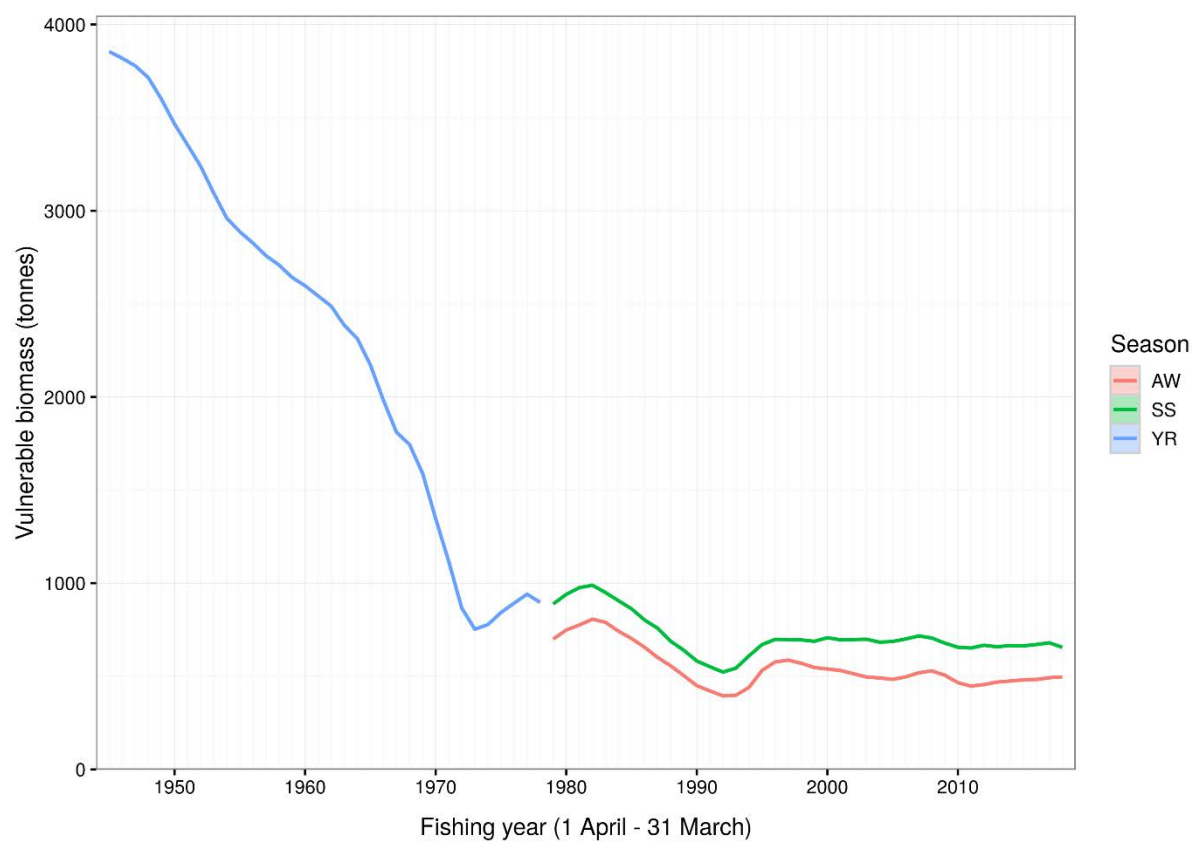


Figure 34: CRA 1 base case MAP: trajectory of vulnerable biomass (tonnes) by season (AW = autumn-winter, SS = spring-summer, YR = single time step).

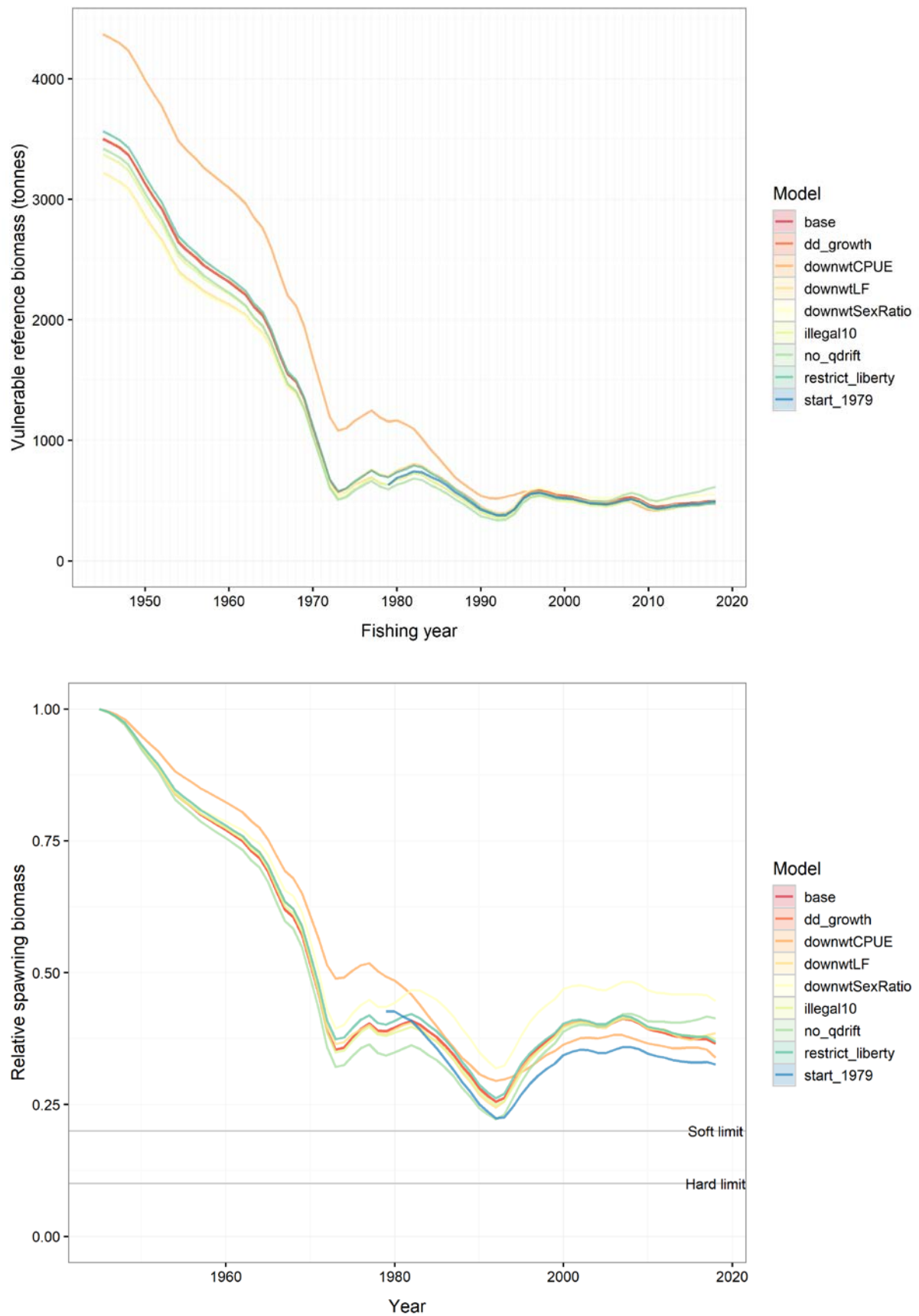


Figure 35: CRA 1 MAP comparisons showing all sensitivities with the base case for vulnerable reference biomass [top panel] and relative spawning biomass [bottom panel].

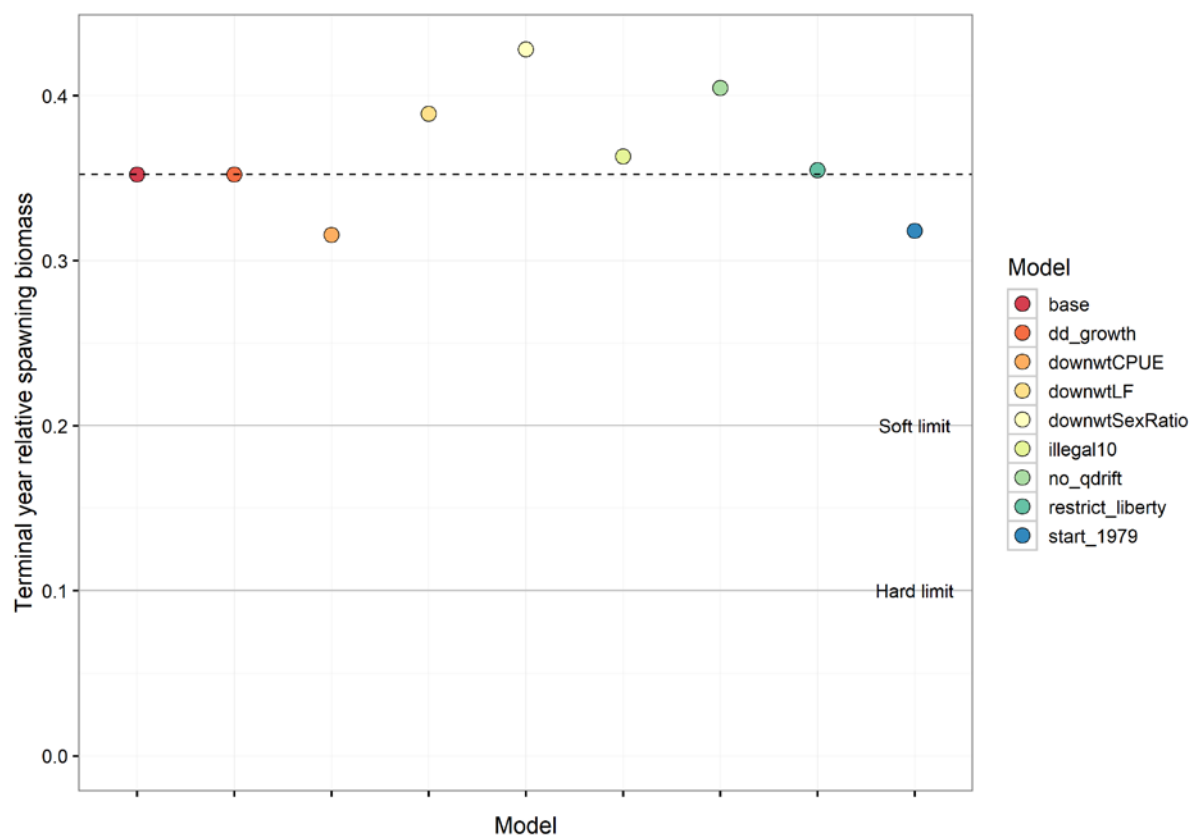


Figure 36: CRA 1 MAP comparisons of SSB_{2019}/SSB_0 for all sensitivity runs with the base case for the terminal reconstruction year of the 2018-2019 fishing year. Dashed line shows the base case value for SSB_{2019}/SSB_0 .

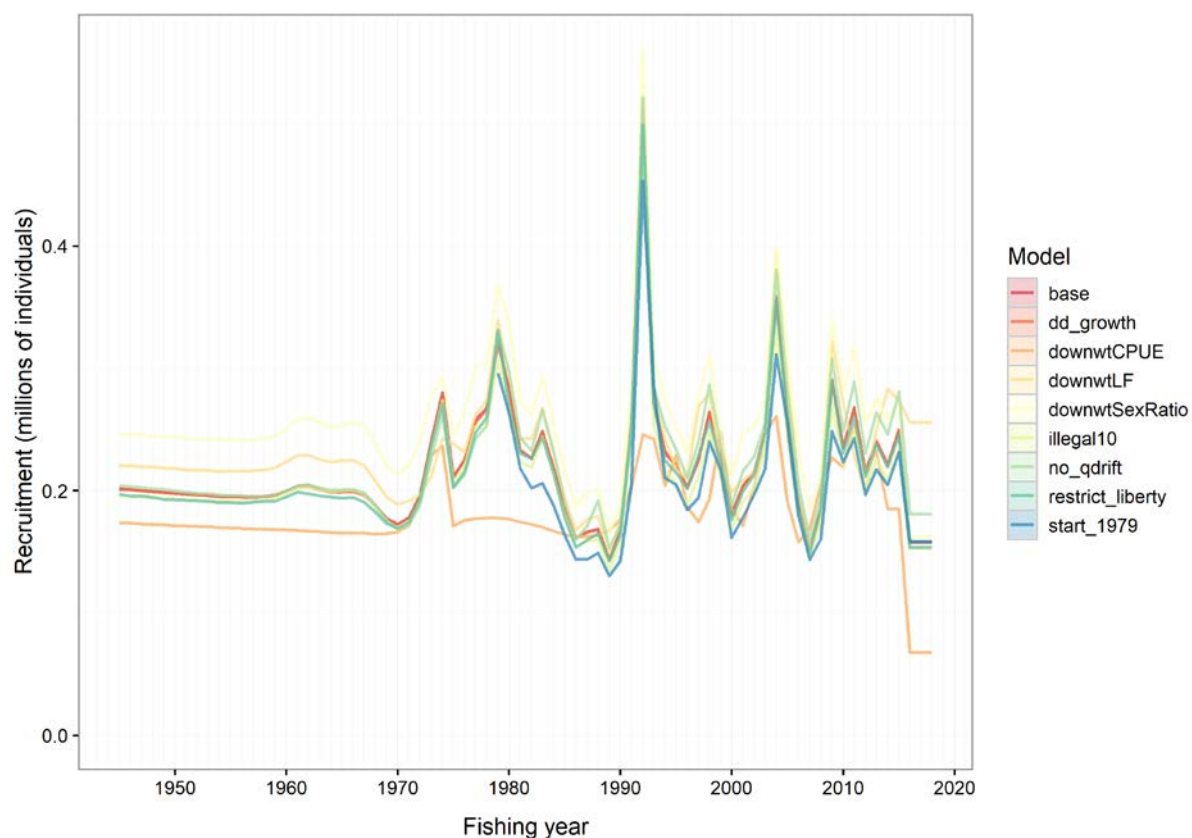


Figure 37: CRA 1 MAP comparisons of recruitment showing all sensitivities with the base case.

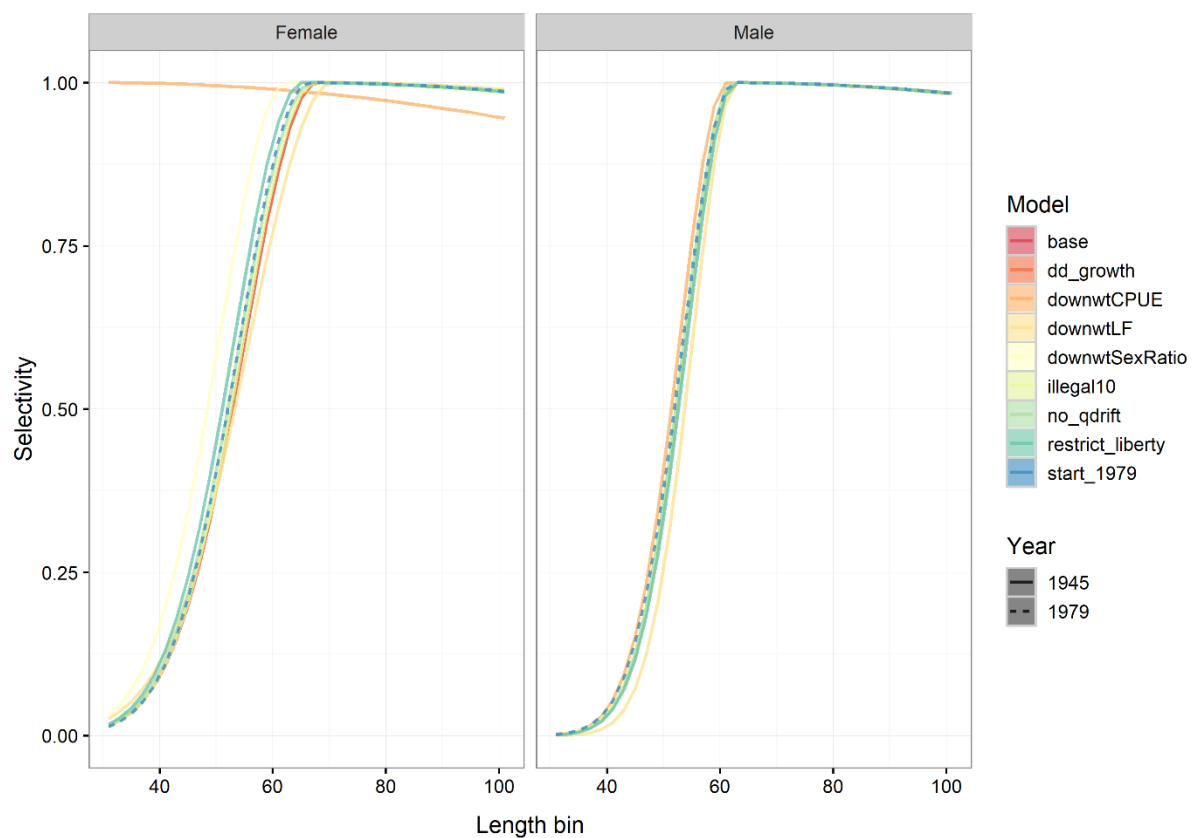


Figure 38: CRA 1 MAP comparisons of selectivity curves showing all sensitivities with the base case.

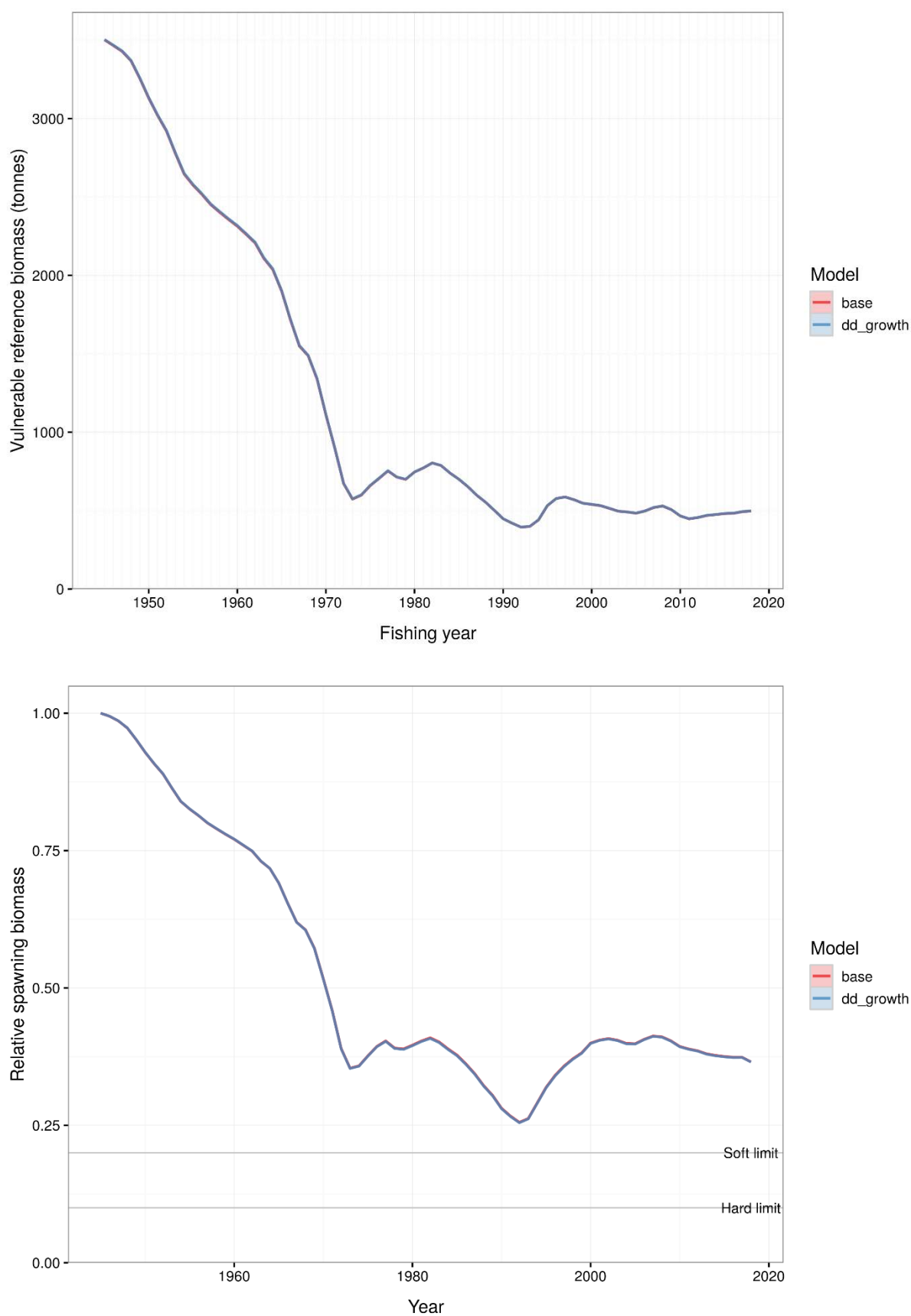


Figure 39: CRA 1 MAP comparisons of the base case with the version assuming density dependence: [top panel]: absolute vulnerable biomass; [bottom panel] relative spawning stock biomass. The base case is not visible because it is identical to *dd_growth*.

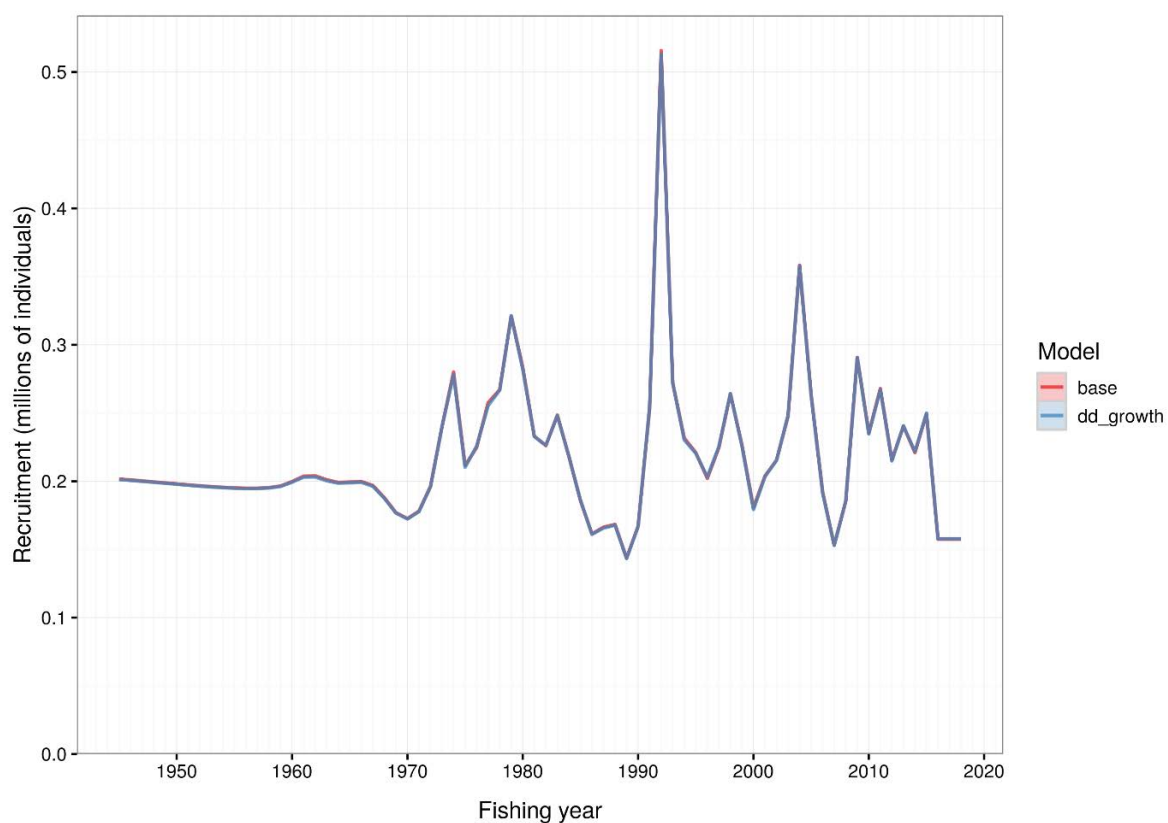


Figure 40: CRA 1 MAP comparisons of the base case with the version assuming density dependence: recruitment trajectories. The base case is not visible because it is identical to *dd_growth*.

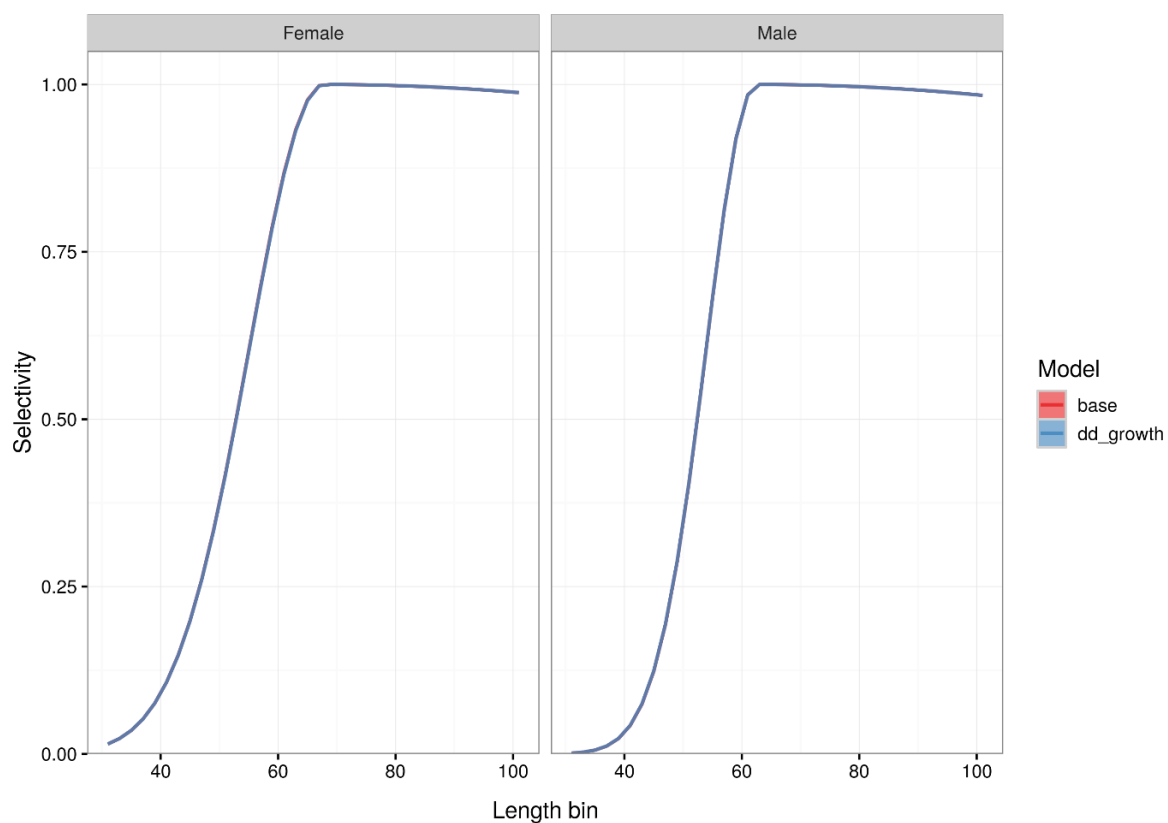


Figure 41: CRA 1 MAP comparisons of the base case with the version assuming density dependence: selectivity curves. The base case is not visible because it is identical to *dd_growth*.

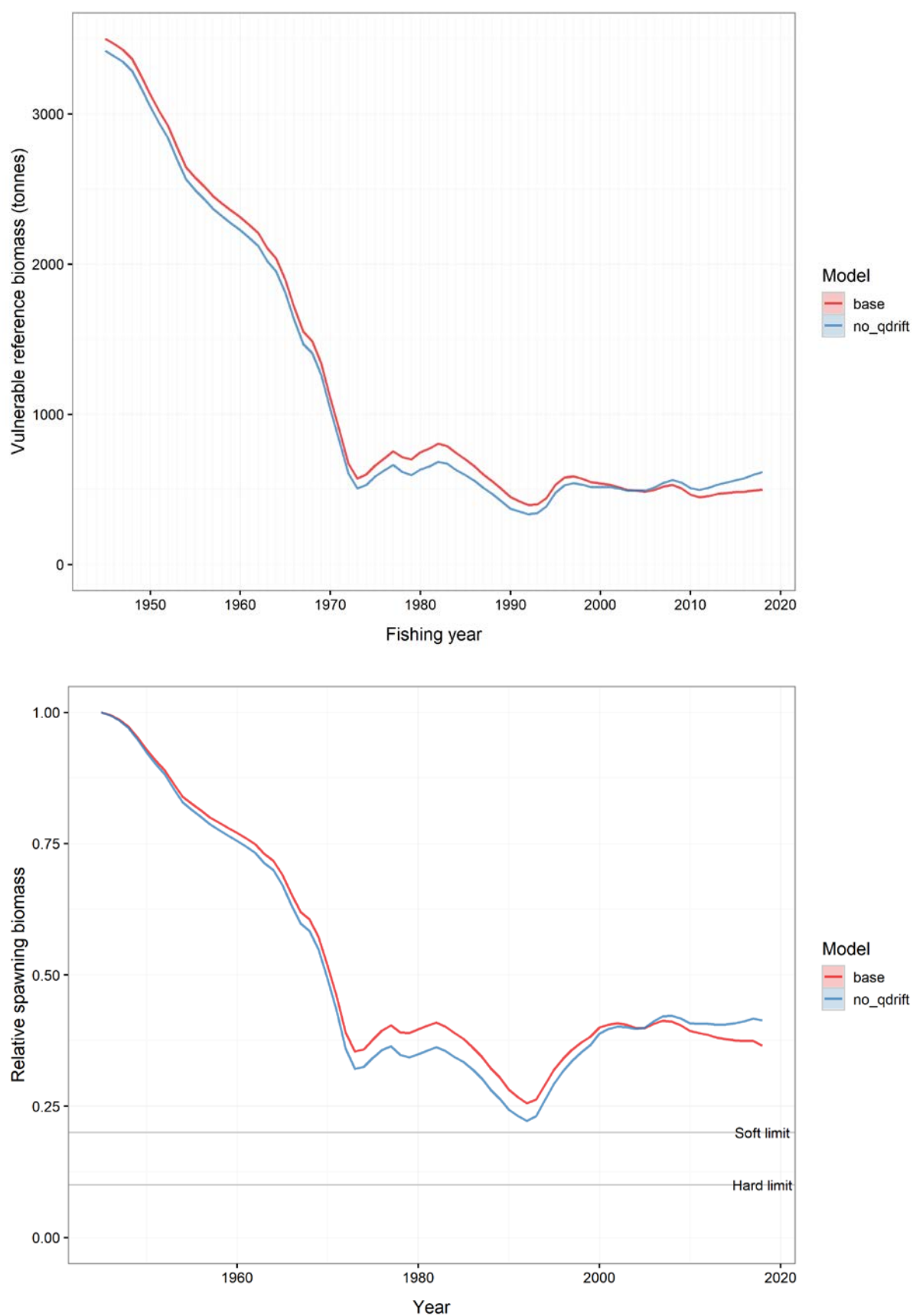


Figure 42: CRA 1 MAP comparisons of base case with the version assuming constant catchability for the CELR CPUE series (*qdrift* parameter not estimated): [top panel] vulnerable reference biomass; [bottom panel] relative spawning biomass.

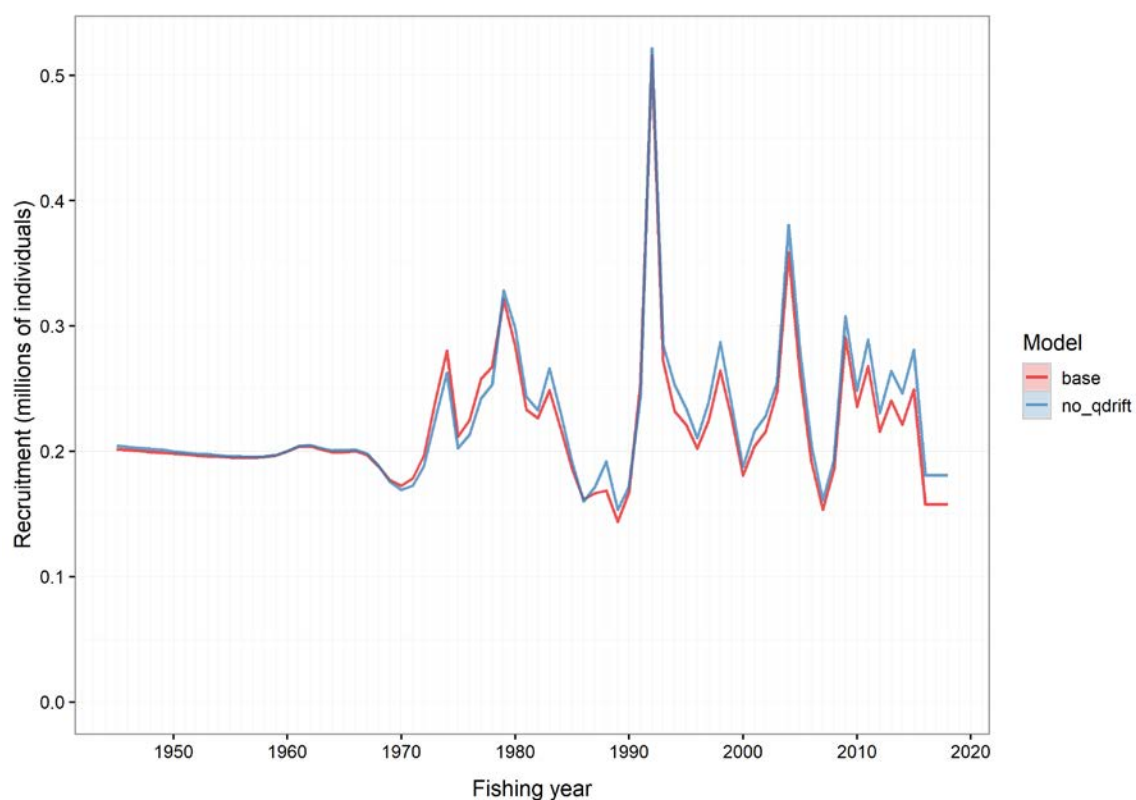


Figure 43: CRA 1 MAP comparisons of base case with the version assuming constant catchability for the CELR CPUE series (*qdrift* parameter not estimated): recruitment trajectories.

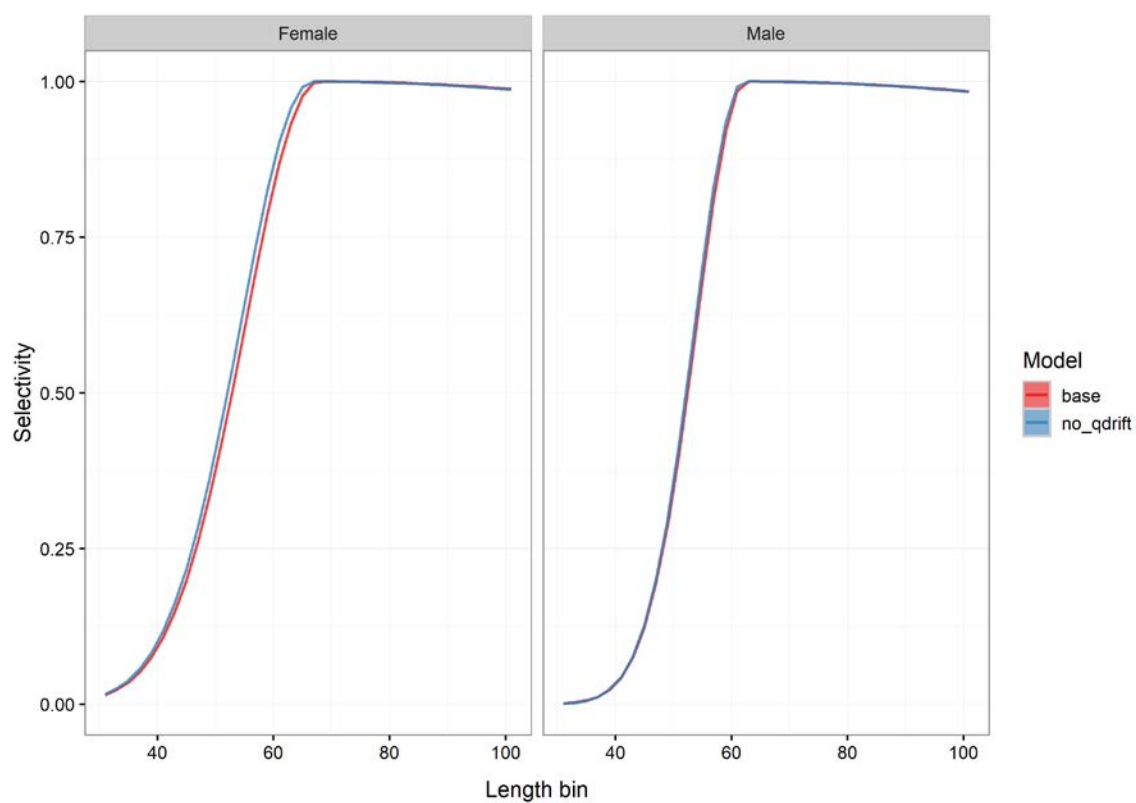


Figure 44: CRA 1 MAP comparisons of base case with the version assuming constant catchability for the CELR CPUE series (*qdrift* parameter not estimated): selectivity curves.

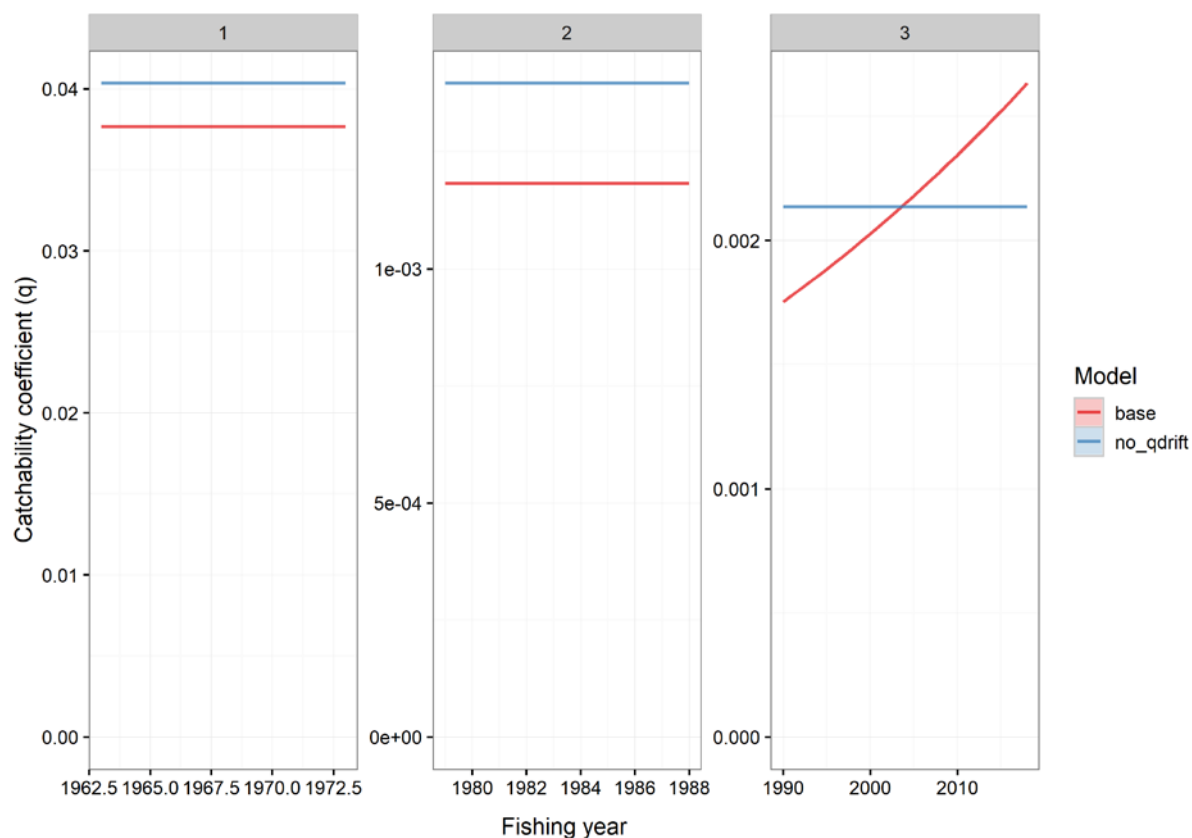


Figure 45: CRA 1 MAP comparisons of base case with the version assuming constant catchability for the CELR CPUE series ($qdrift$ parameter not estimated): catchability coefficient (q) estimate by fishing year. Left panel=CR; middle panel=FSU; right panel=CELR.

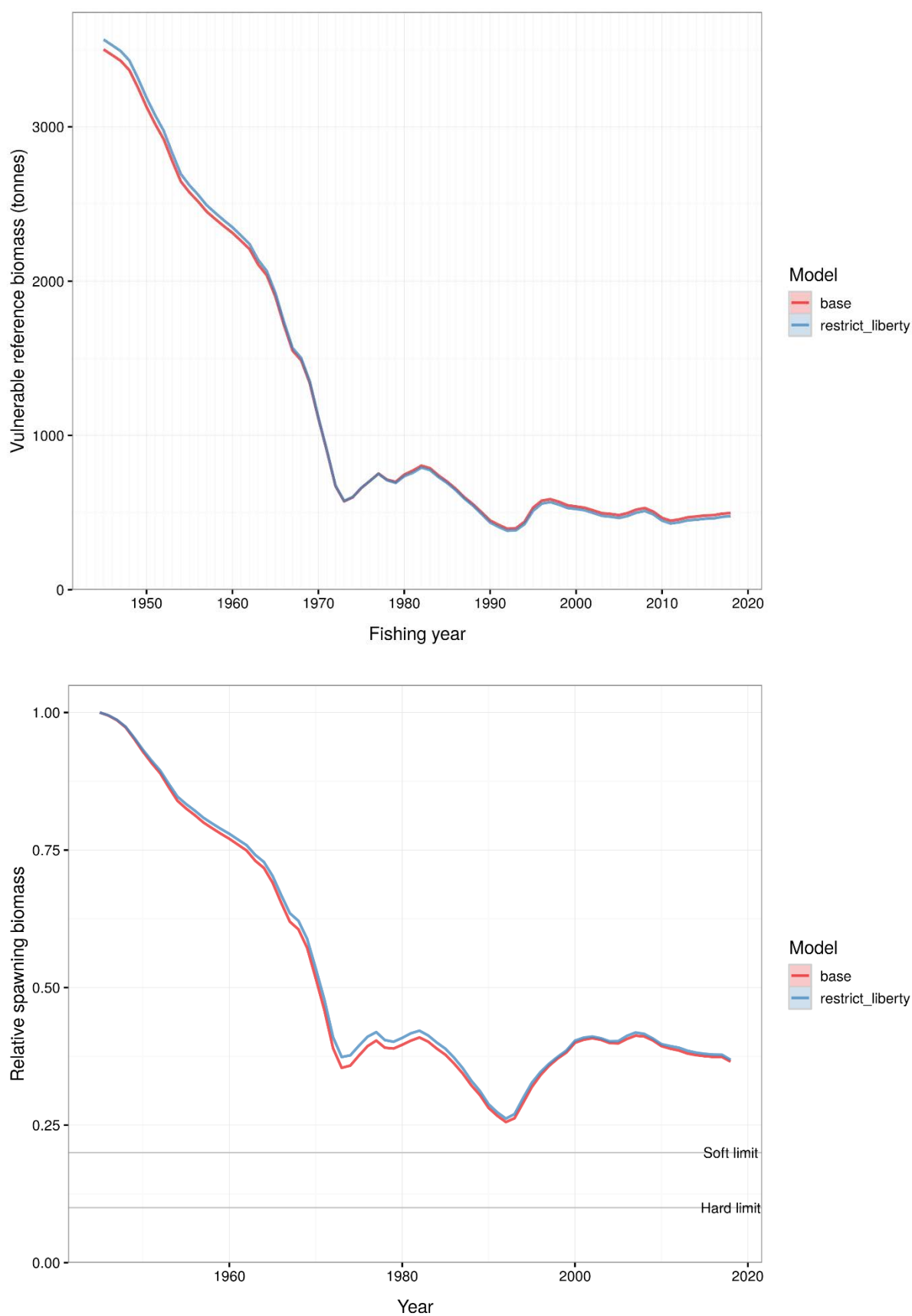


Figure 46: CRA 1 MAP comparisons of the restricted at-liberty sensitivity run with the base case: [top panel] vulnerable reference biomass; [bottom panel] relative spawning stock biomass.

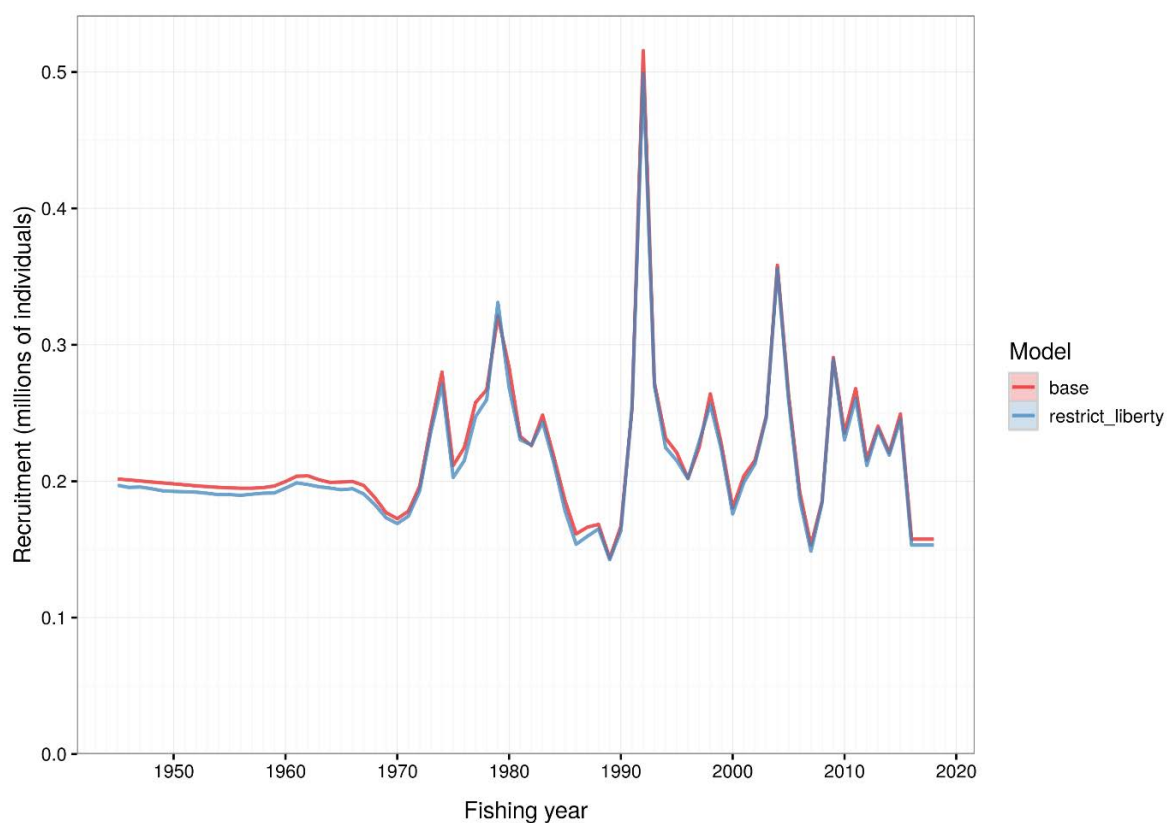


Figure 47: CRA 1 MAP comparisons of the restricted at-liberty sensitivity run with the base case: recruitment trajectories.

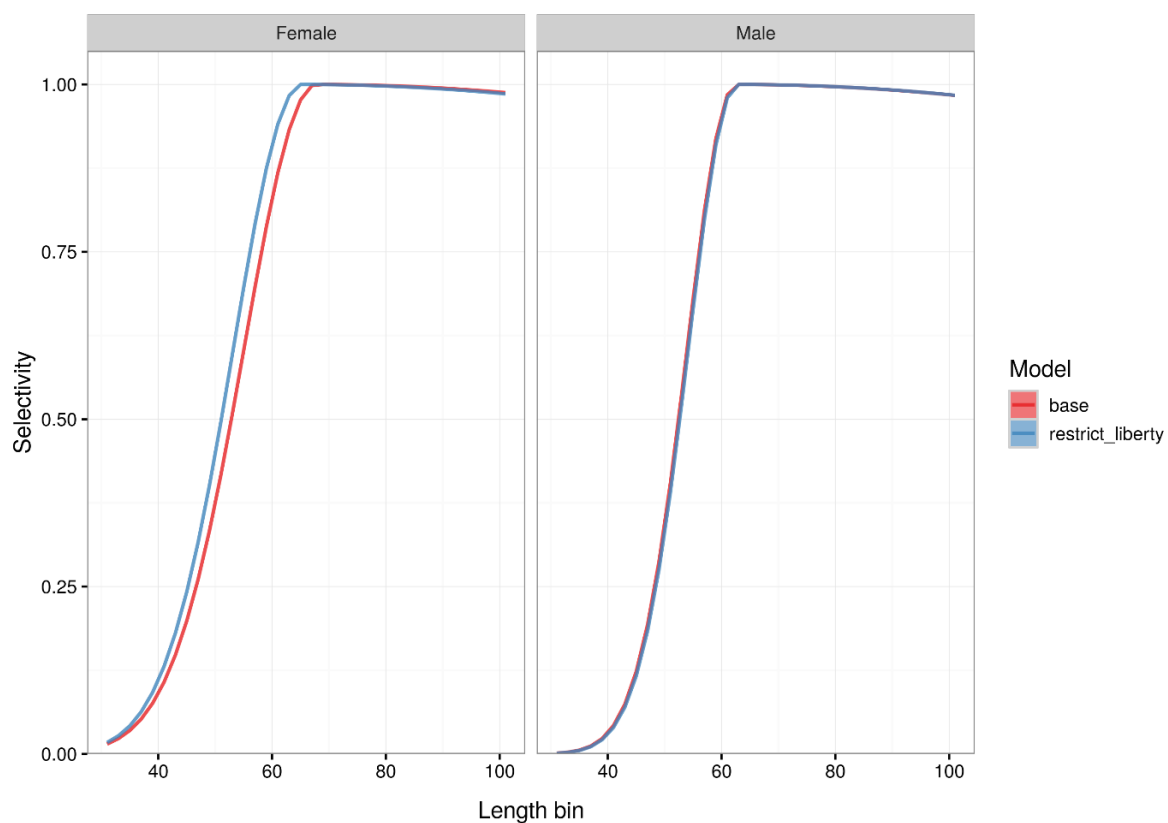


Figure 48: CRA 1 MAP comparisons of the restricted at-liberty sensitivity run with the base case: selectivity curves.

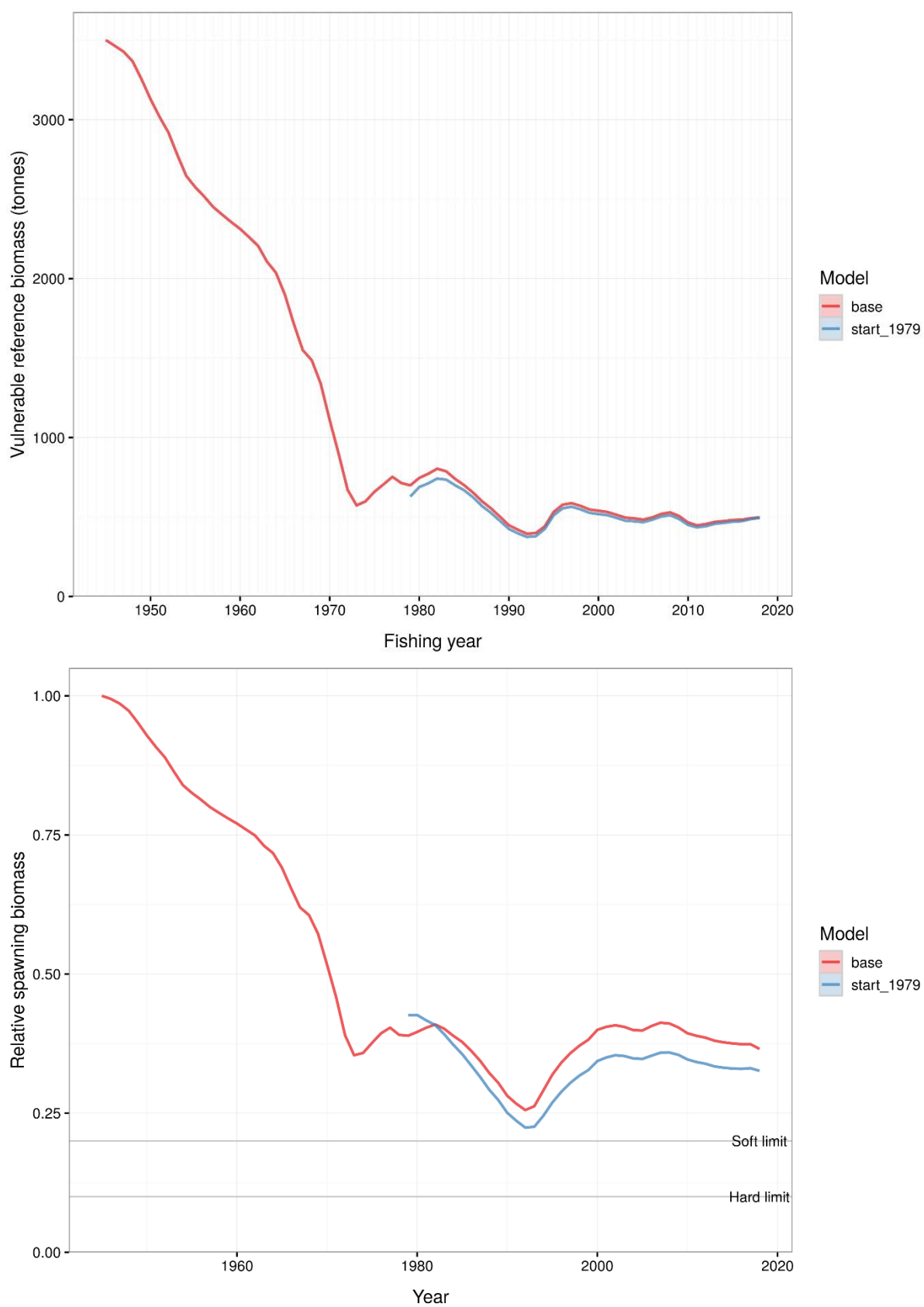


Figure 49: MAP comparisons of the sensitivity run starting the model and 1979 with the base case: [top panel] vulnerable reference biomass; [bottom panel] relative spawning biomass.

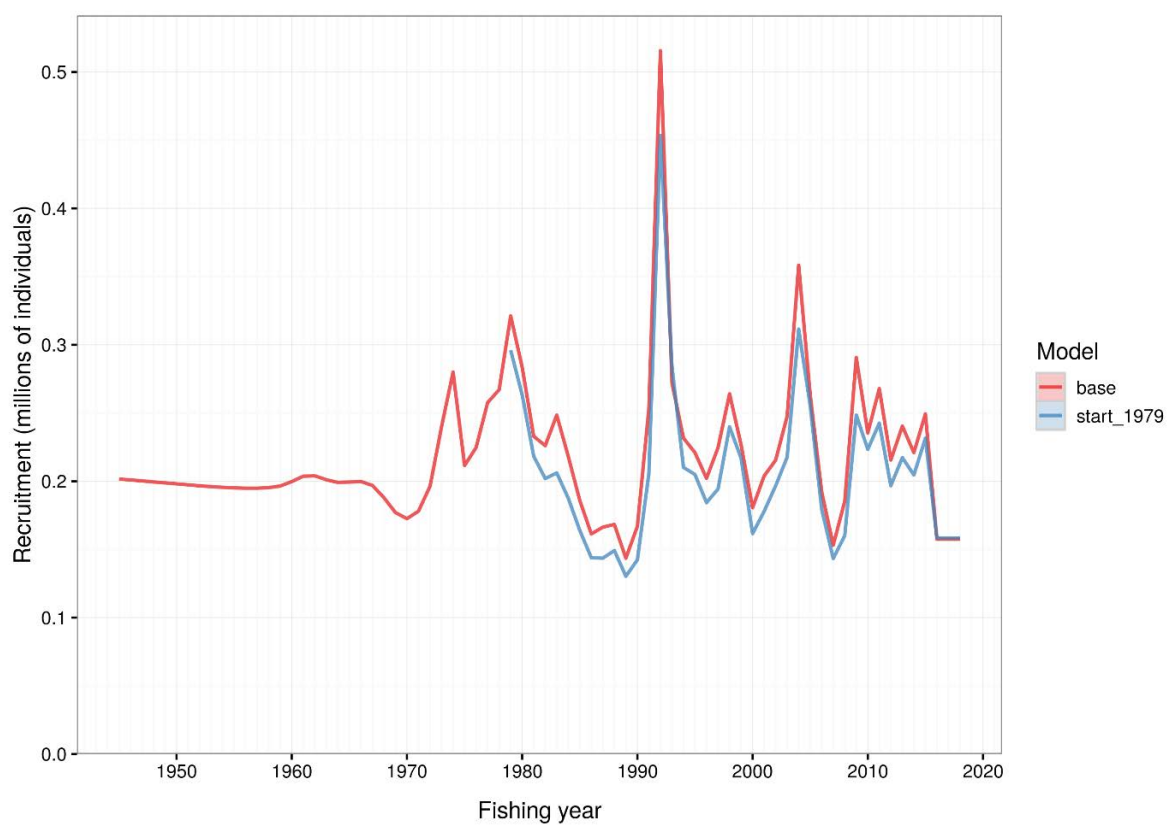


Figure 50: MAP comparisons of the sensitivity run starting the model and 1979 with the base case recruitment trajectories.

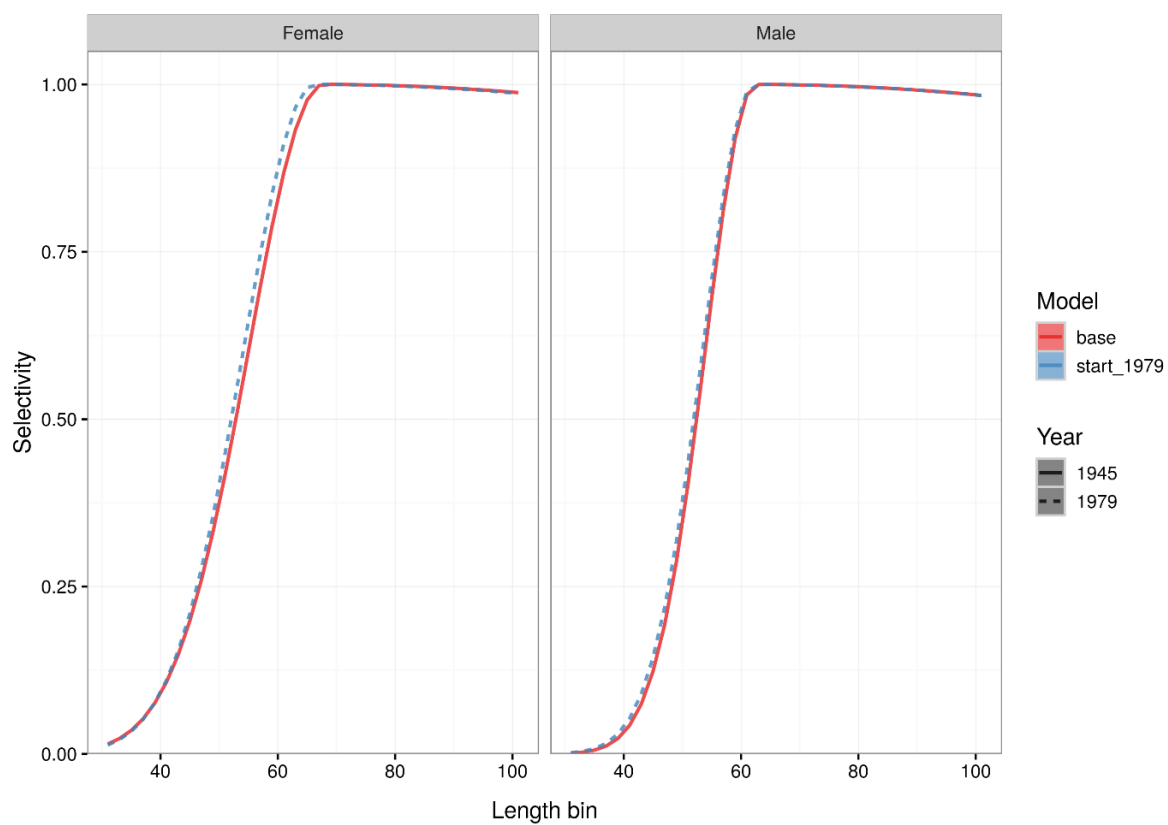


Figure 51: MAP comparisons of the sensitivity run starting the model and 1979 with the base case selectivity curves.

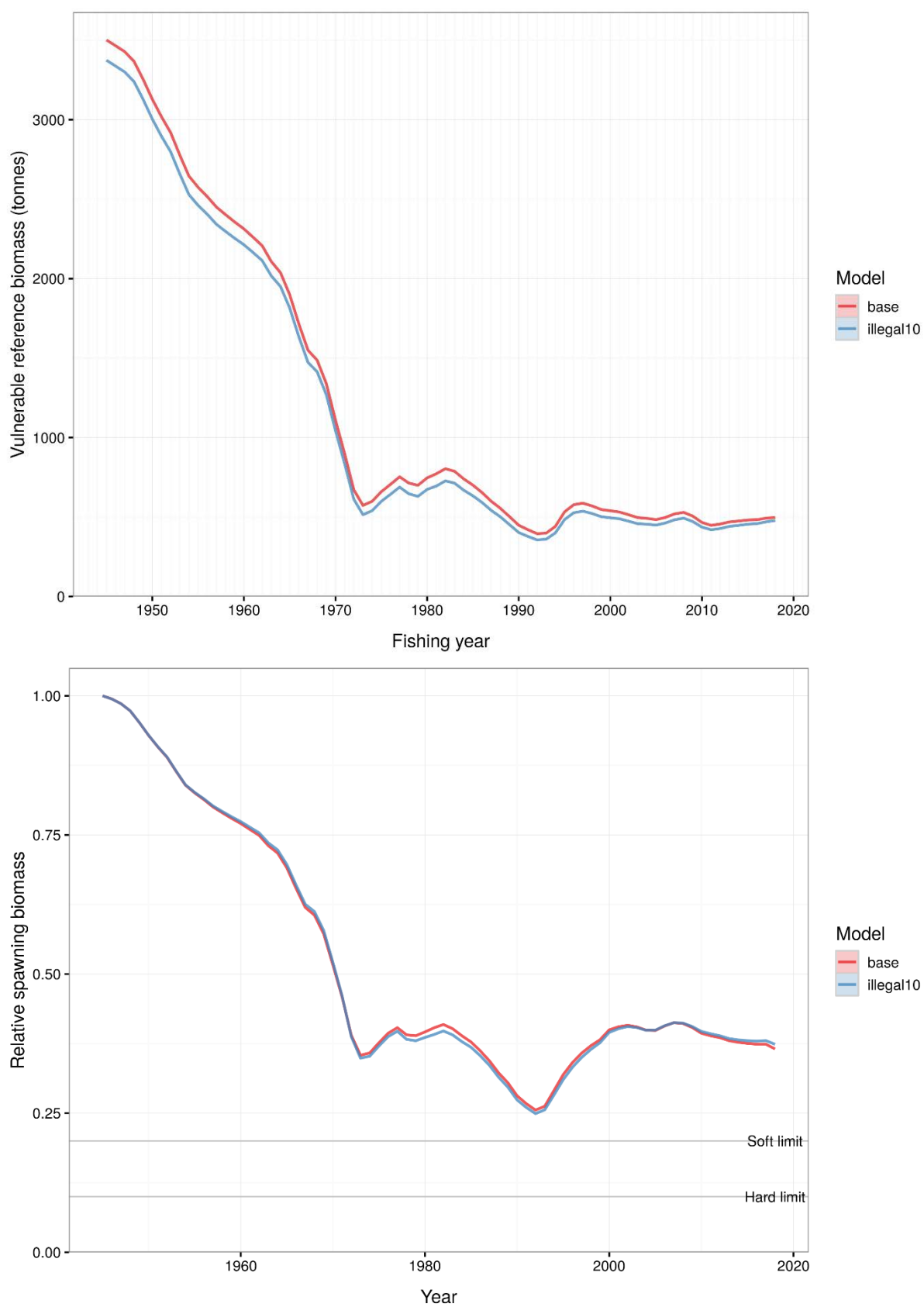


Figure 52: CRA 1 MAP comparisons of illegal catch set at 10% of the commercial catch sensitivity run with the base case: [top panel] vulnerable reference biomass; [bottom panel] relative spawning biomass.

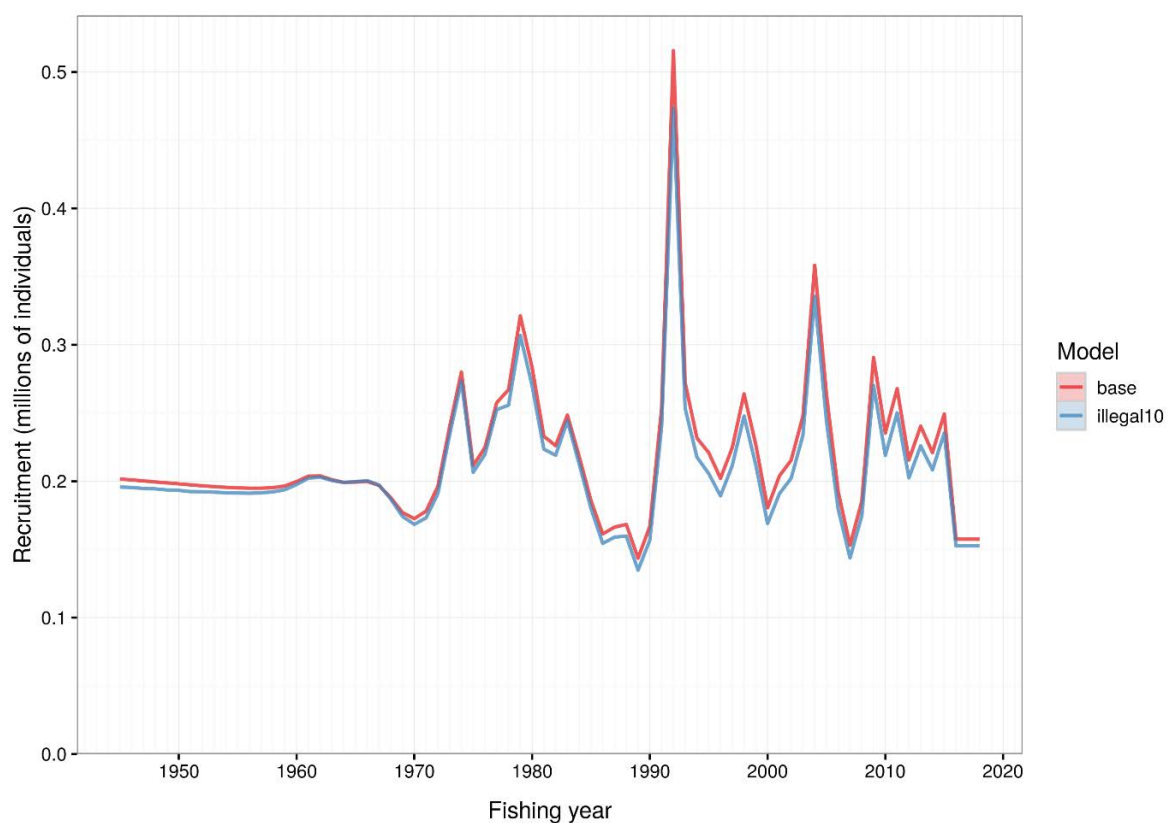


Figure 53: CRA 1 MAP comparisons of illegal catch set at 10% of the commercial catch sensitivity run with the base case: recruitment trajectories.

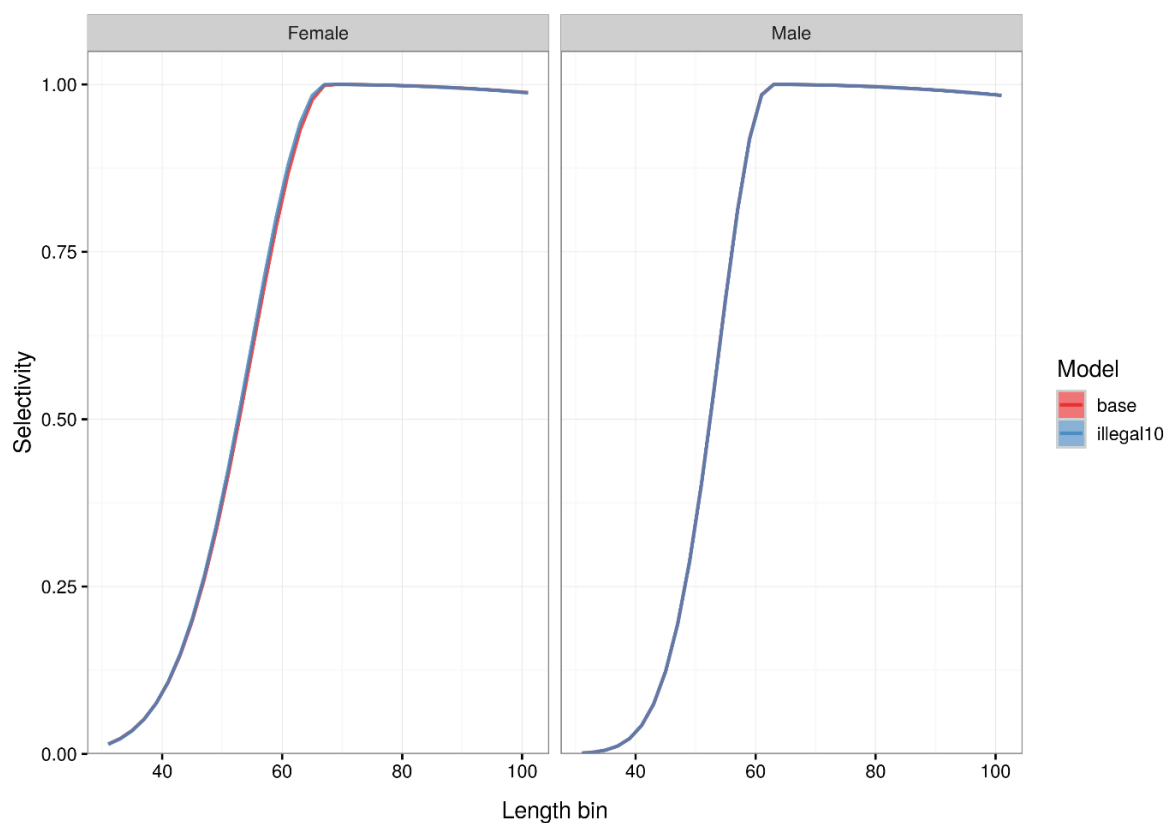


Figure 54: CRA 1 MAP comparisons of illegal catch set at 10% of the commercial catch sensitivity run with the base case: selectivity curves.

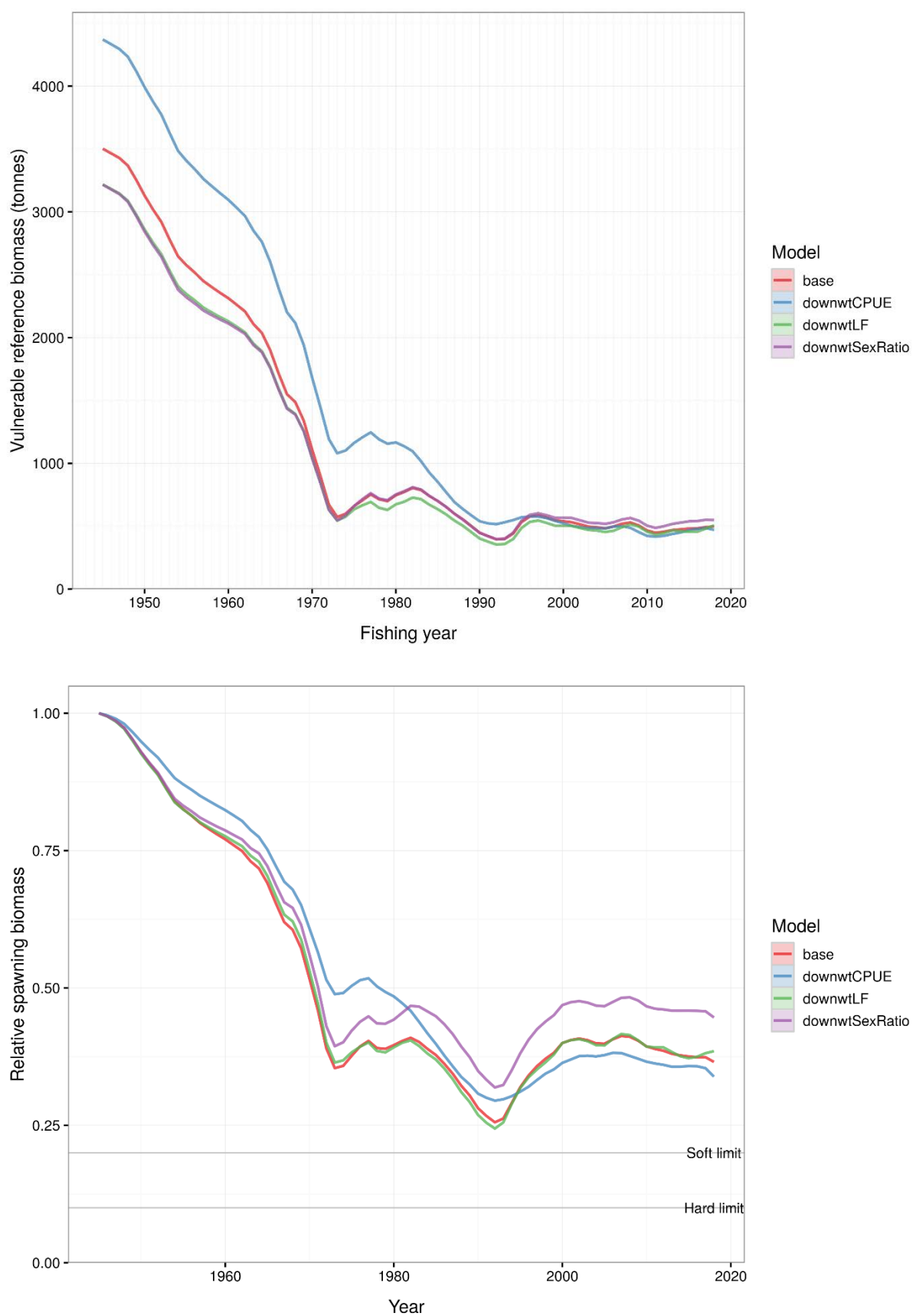


Figure 55: CRA 1 MAP comparisons of the data weighting sensitivity runs with the base case: [top panel] vulnerable reference biomass; [bottom panel] relative spawning stock biomass.

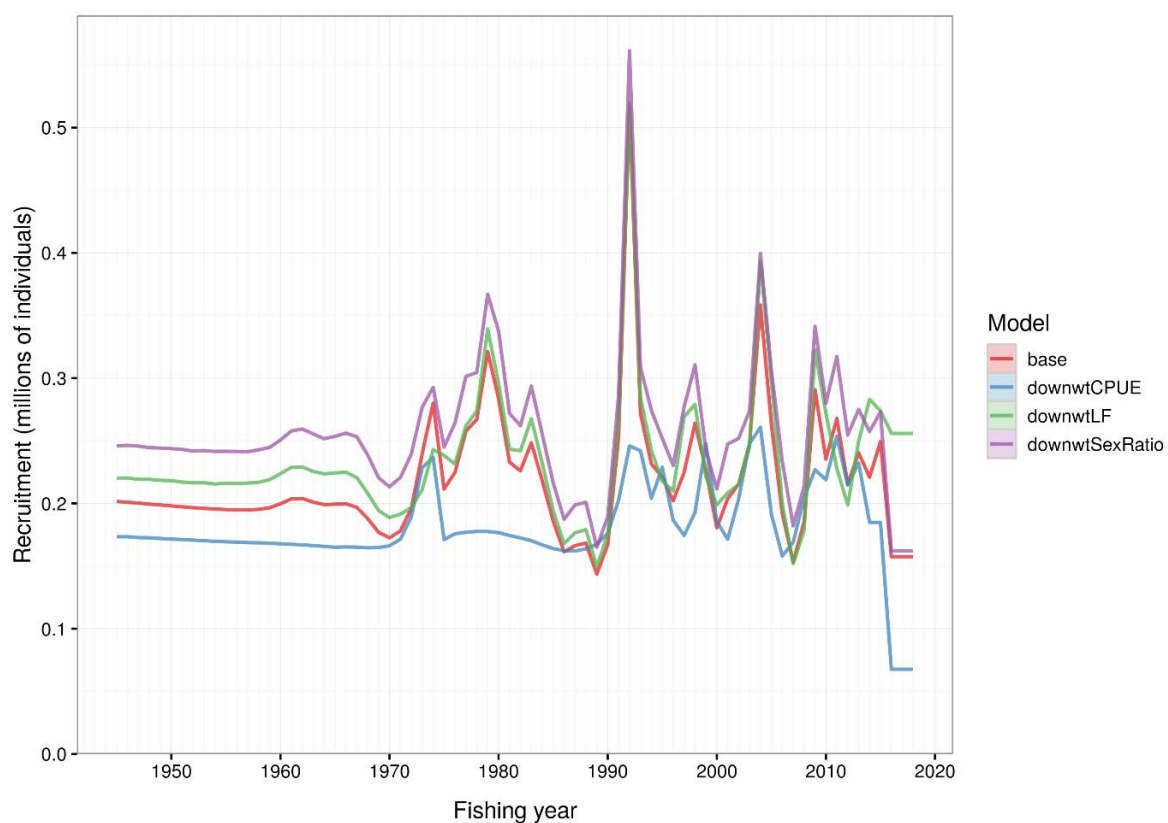


Figure 56: CRA 1 MAP comparisons of the data weighting sensitivity runs with the base case: recruitment trajectories.

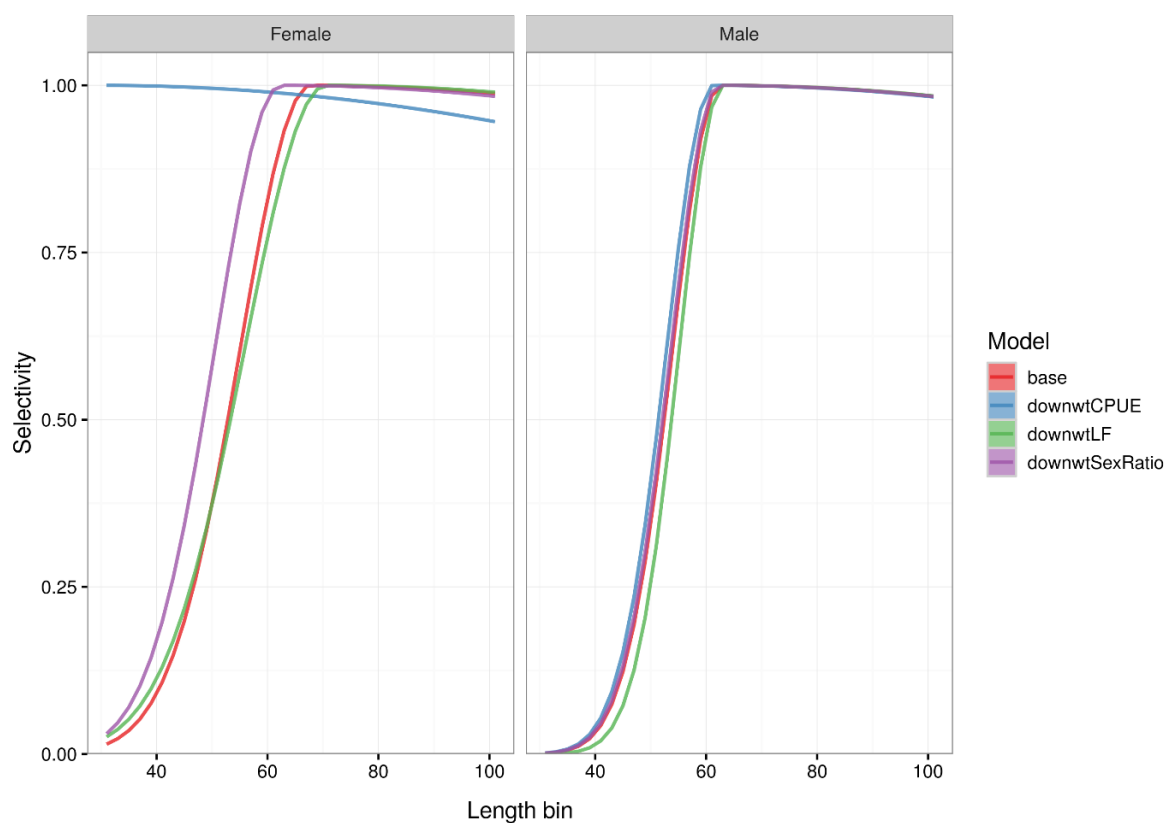


Figure 57: CRA 1 MAP comparisons of the data weighting sensitivity runs with the base case: selectivity curves.

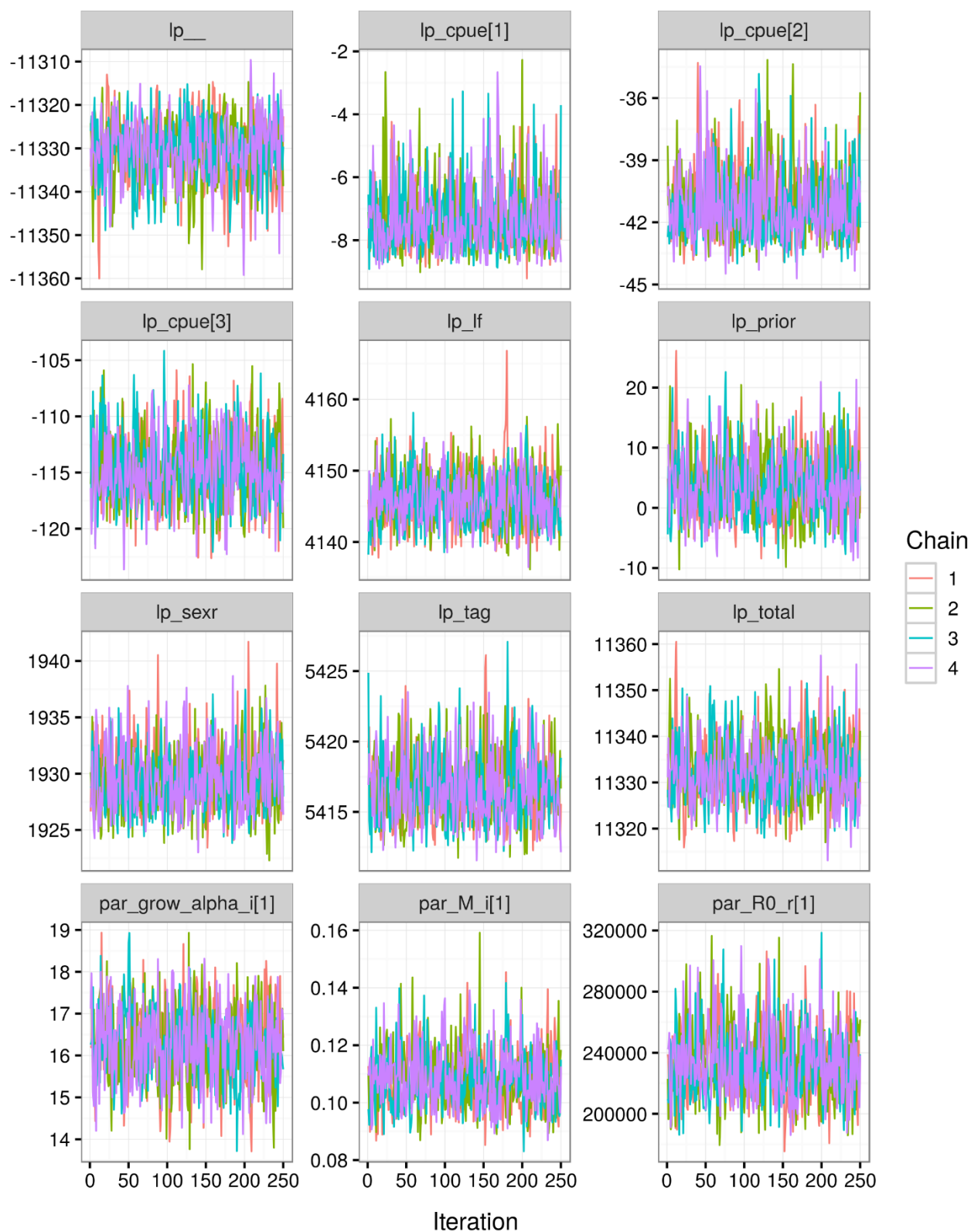


Figure 58: CRA 1 base case: MCMC trace plots by independent chain for likelihood components and estimated growth, natural mortality (M), and R_0 parameters.

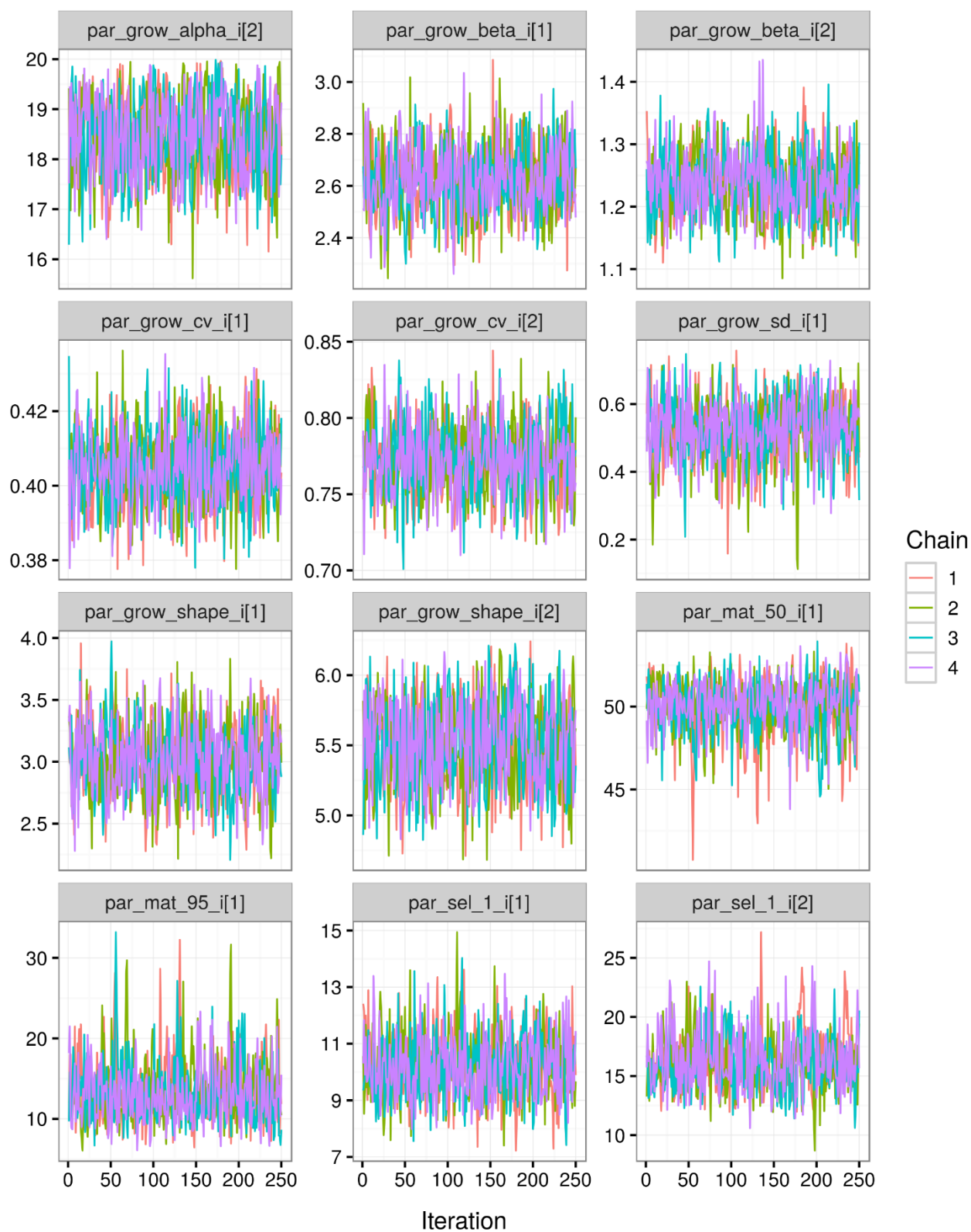


Figure 59: CRA 1 base case: MCMC trace plots by independent chain for estimated growth, maturity, and selectivity parameters.

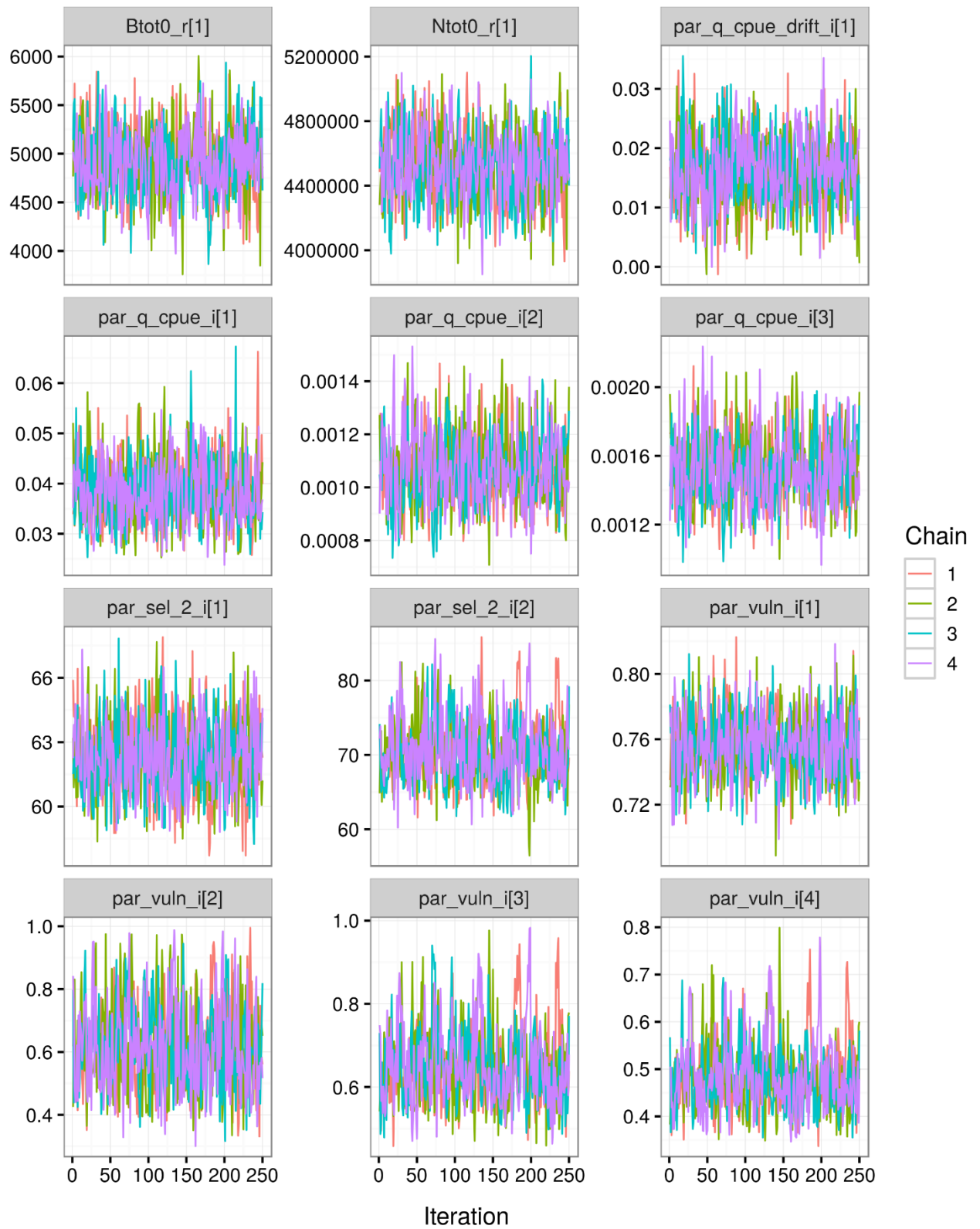


Figure 60: CRA 1 base case: MCMC trace plots by independent chain for estimated total biomass and numbers, catchability (q), selectivity, and vulnerability parameters.

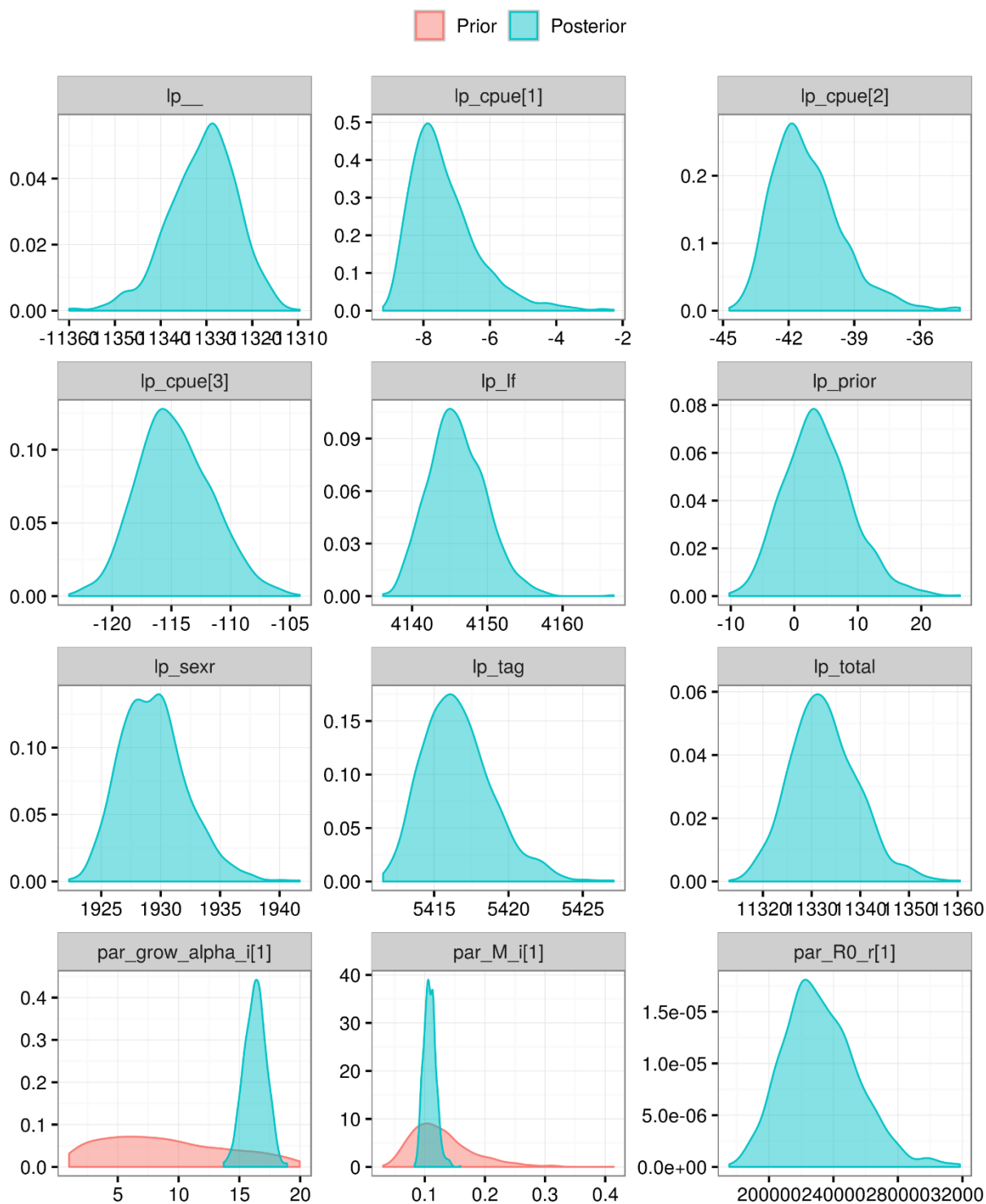


Figure 61: CRA 1 base case: density plots showing prior (red) and posterior distributions (blue) for likelihood components, growth, natural mortality (M), and R_0 parameters.

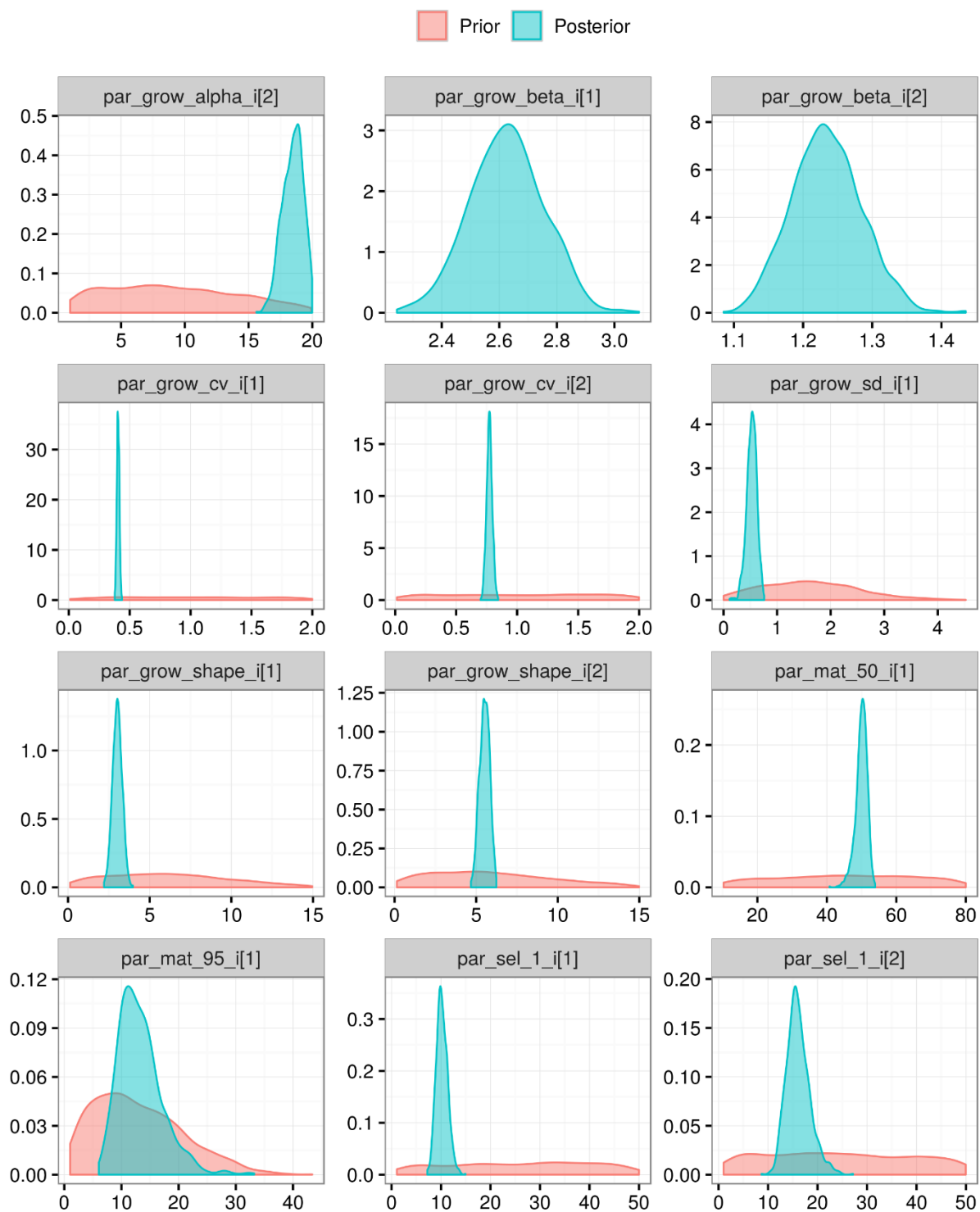


Figure 62: CRA 1 base case: density plots showing prior (red) and posterior distributions (blue) for growth, maturity, and selectivity parameters.

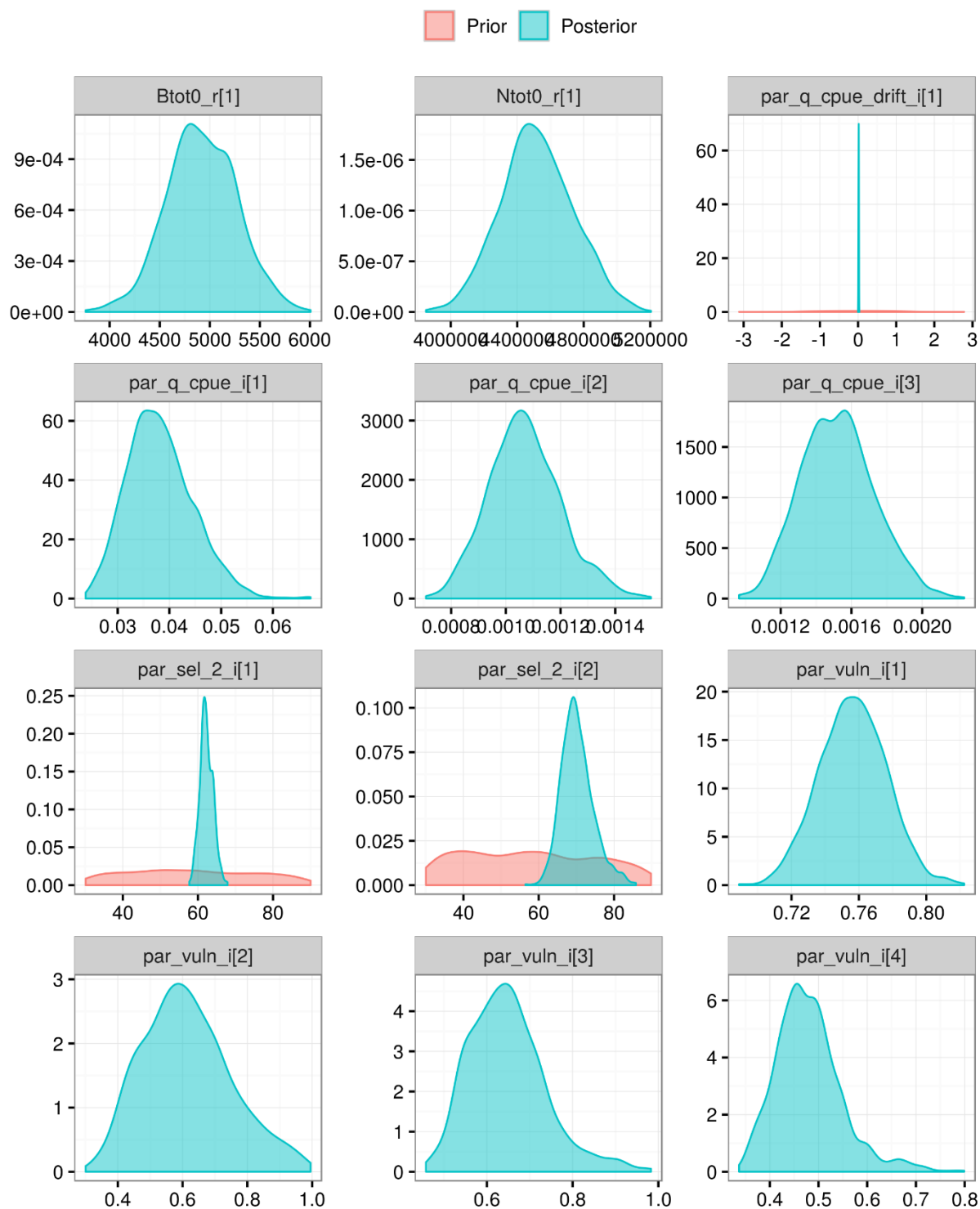


Figure 63: CRA 1 base case: density plots showing prior (red) and posterior distributions (blue) for total biomass and numbers, catchability (q), selectivity, and vulnerability parameters.

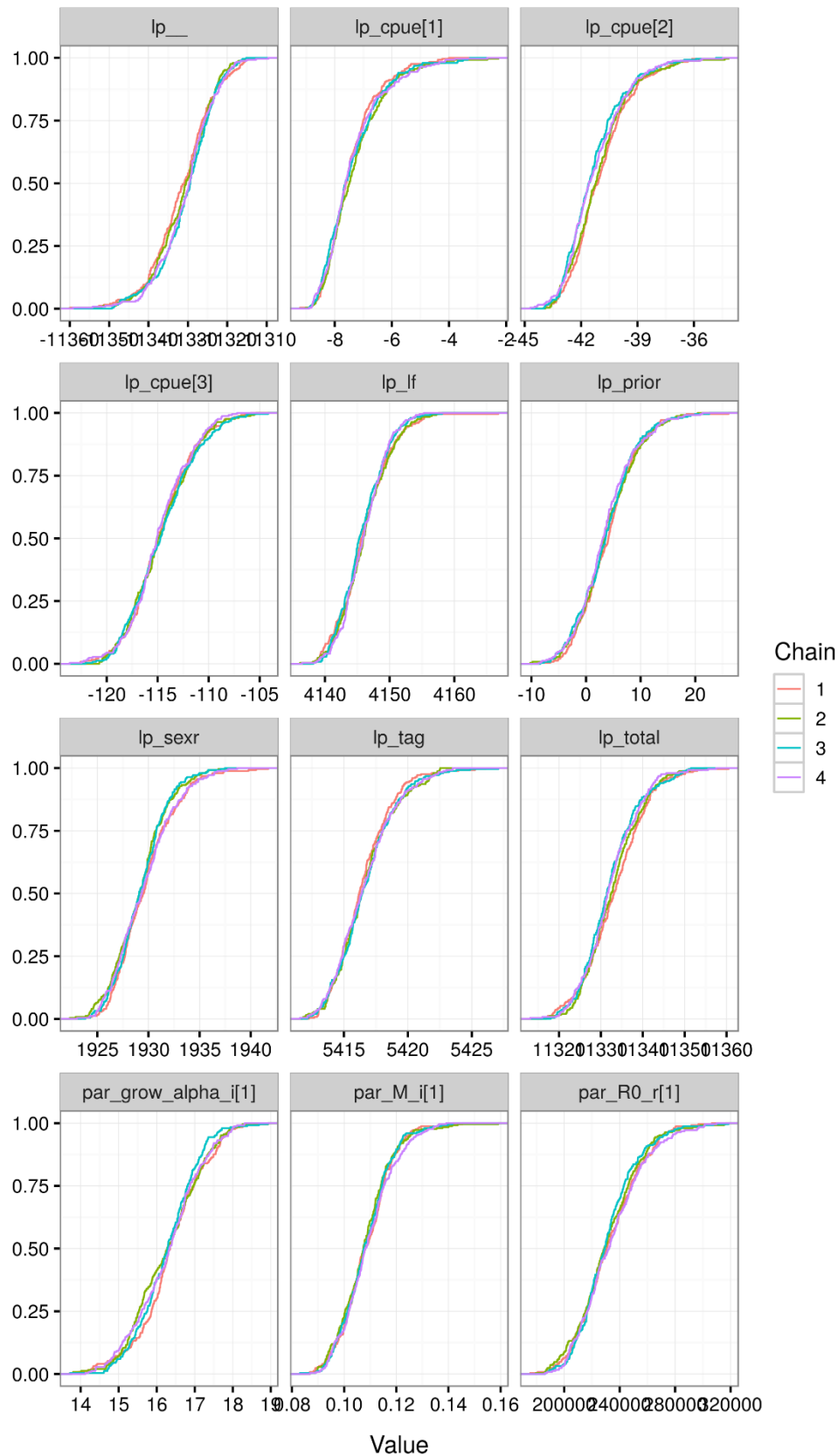


Figure 64: CRA 1 base case: empirical cumulative proportional distributions for each independent MCMC chain for likelihood components and growth, natural mortality (M), and R_0 parameters.

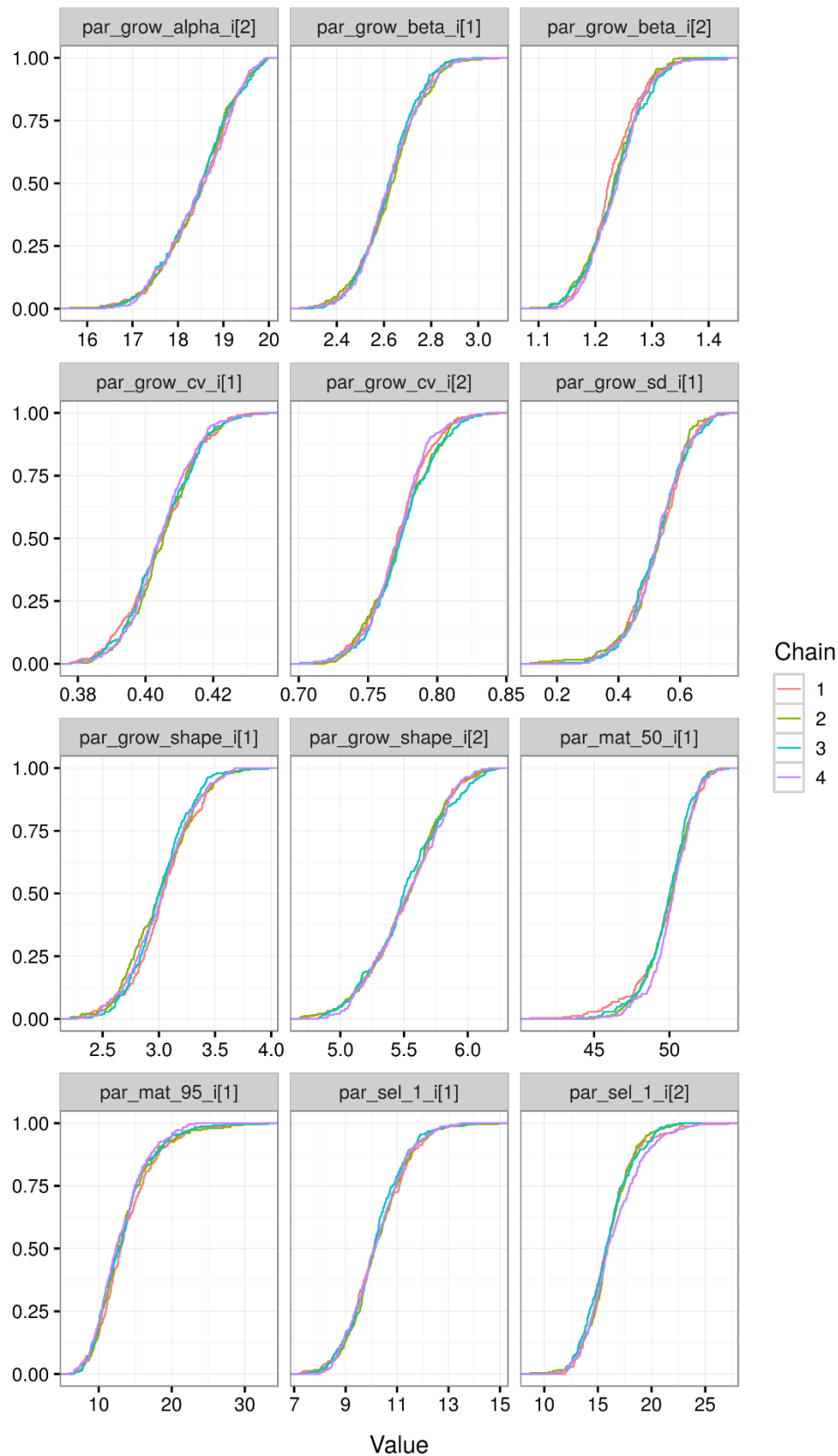


Figure 65: CRA 1 base case: empirical cumulative proportional distributions for each independent MCMC chain for growth, maturity, and selectivity parameters.

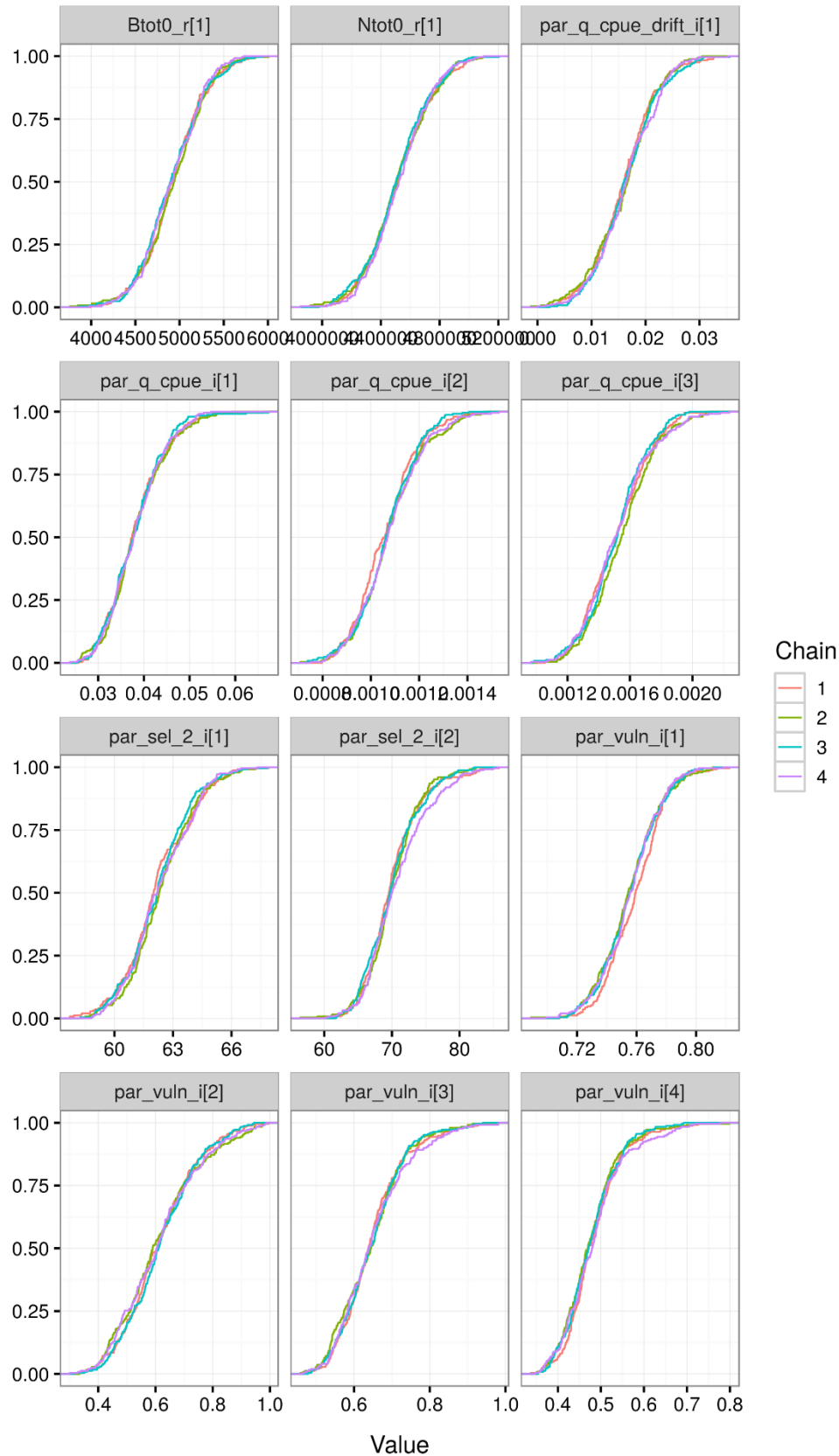


Figure 66: CRA 1 base case: empirical cumulative proportional distributions for each independent MCMC chain for total numbers and biomass, catchability (q), selectivity, and vulnerability parameters.

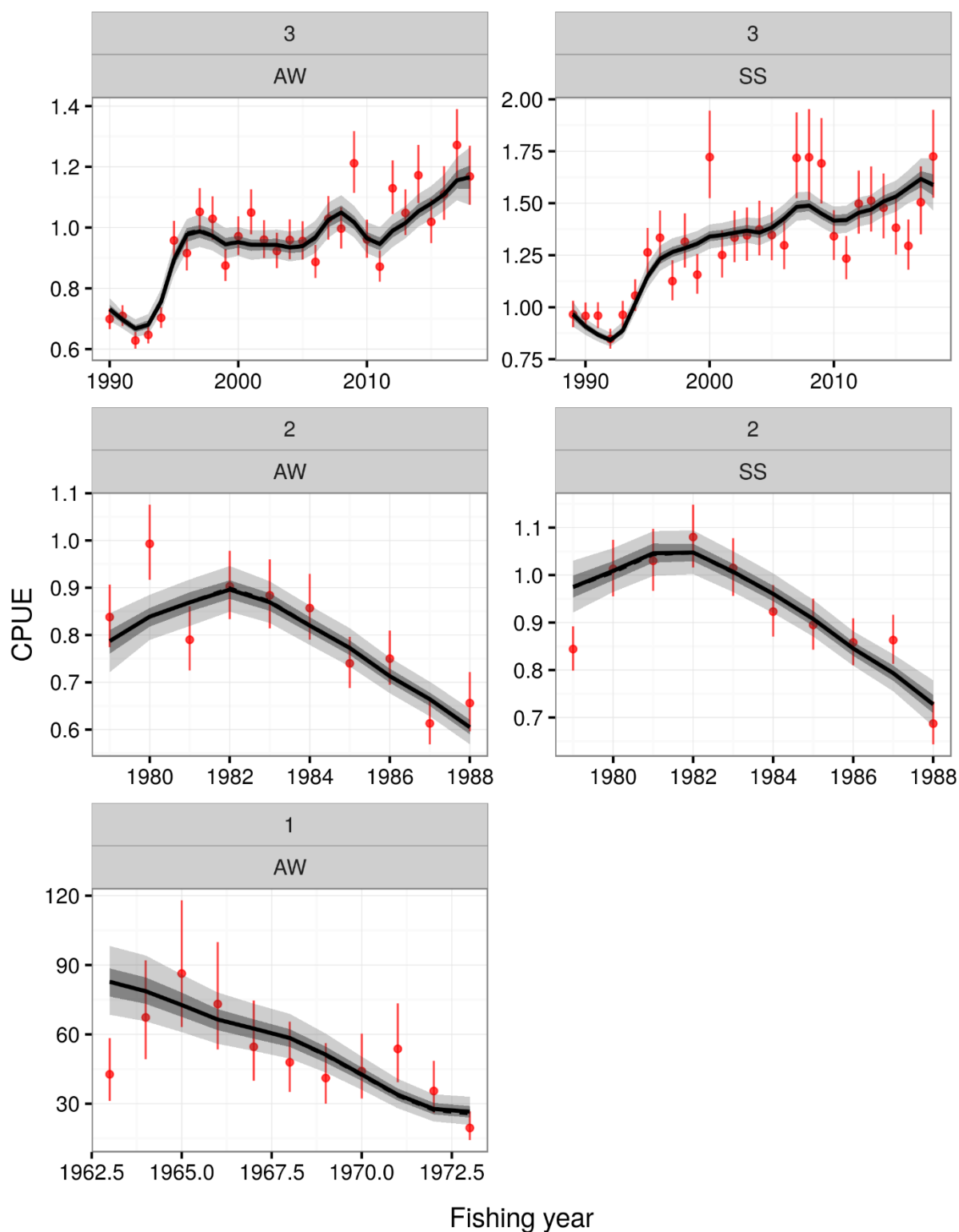


Figure 67: CRA 1 base case: posterior of predicted CPUE by season: upper panels=CELRFit; middle panels=FSU fit; lower panels=CR fit. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. A dashed line (often not visible as it is covered by the median line) indicates the corresponding MAP estimates.

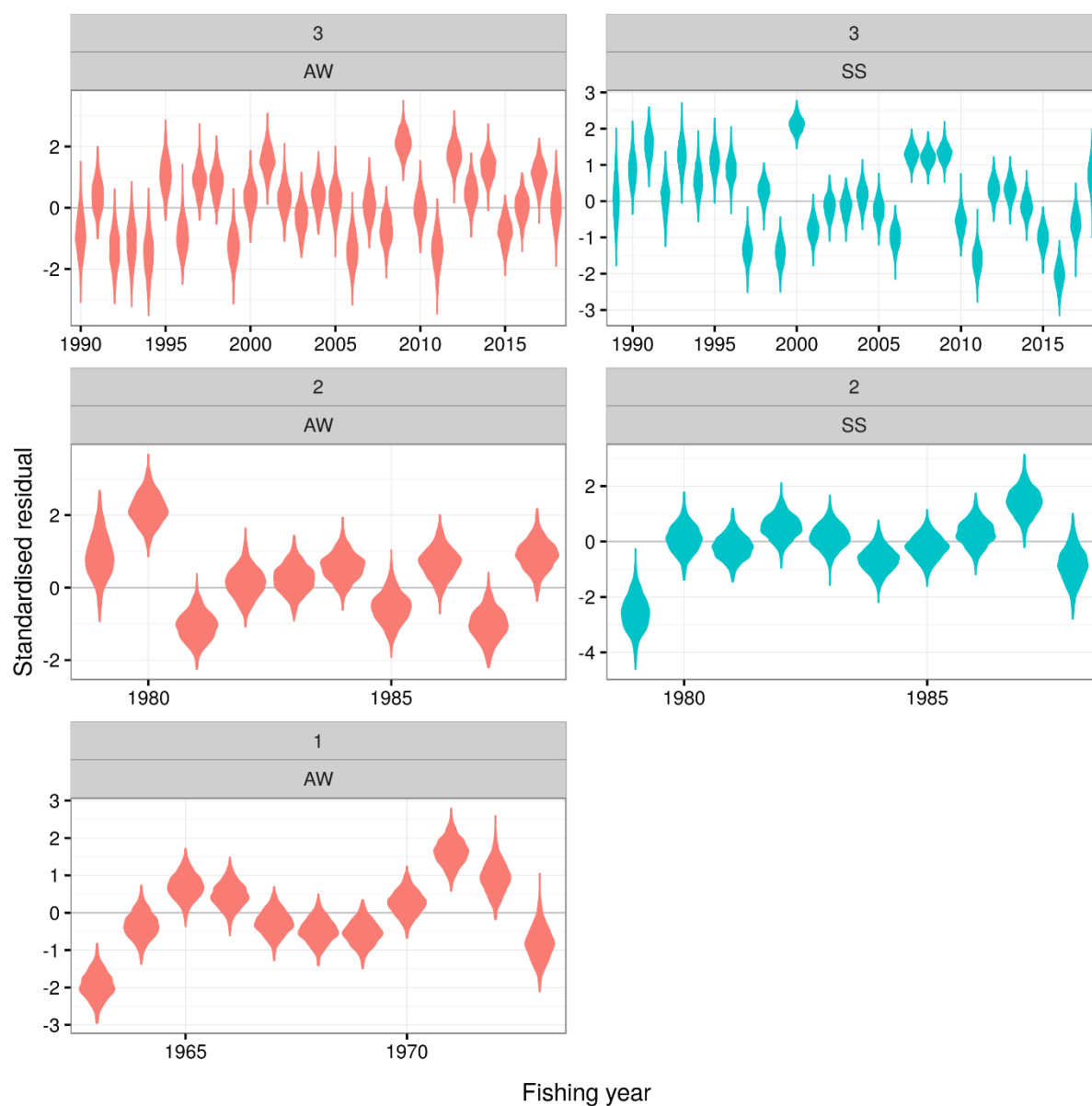


Figure 68: CRA 1 base case: distribution of standardised residuals between the predicted CPUE and observed CPUE by season for each sample from the posterior distribution. Upper panels=CELR fit; middle panels=FSU fit; lower panels=CR fit.

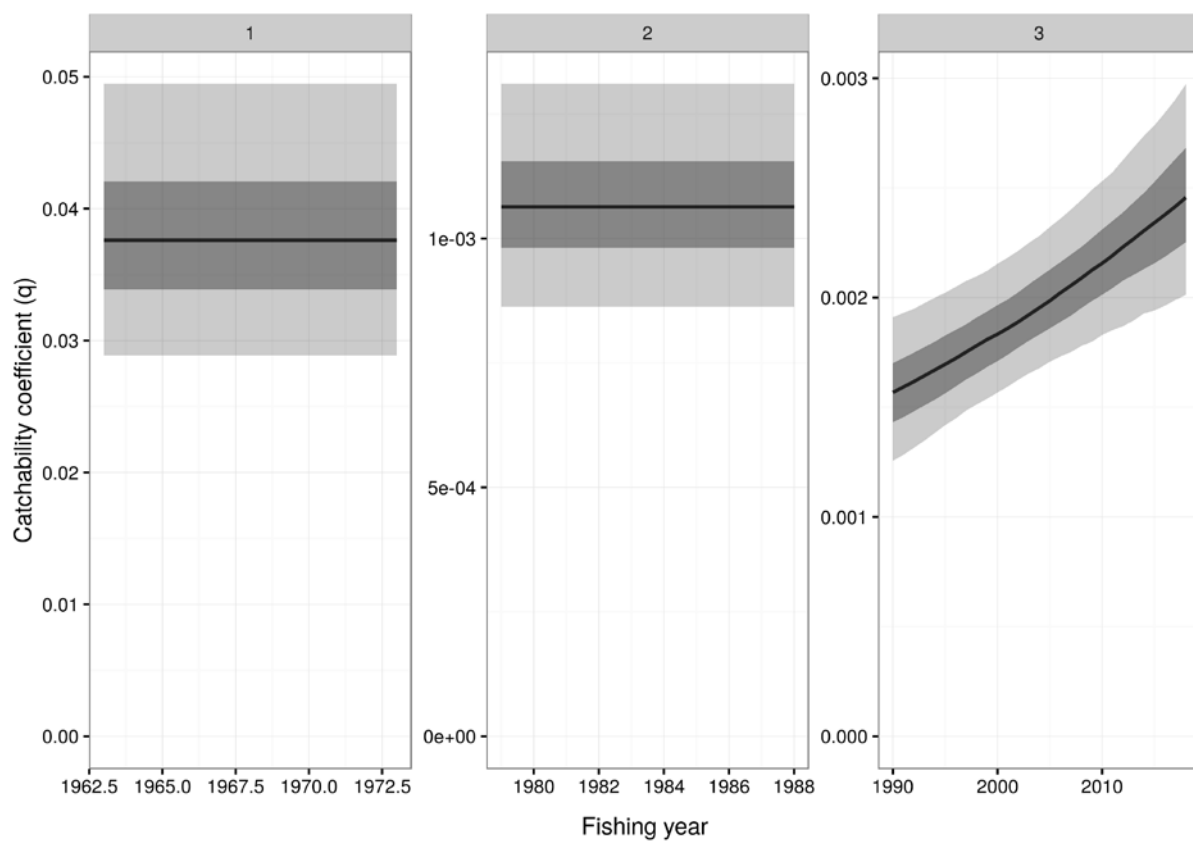


Figure 69: CRA 1 base case catchability coefficient (q) selectivity by fishing year, with the solid line indicating the posterior median and the variable intensity grey shaded bands showing the 50% and 90% credible intervals. Left panel=CR fit; middle panel=FSU fit; right panels=CELR fit.

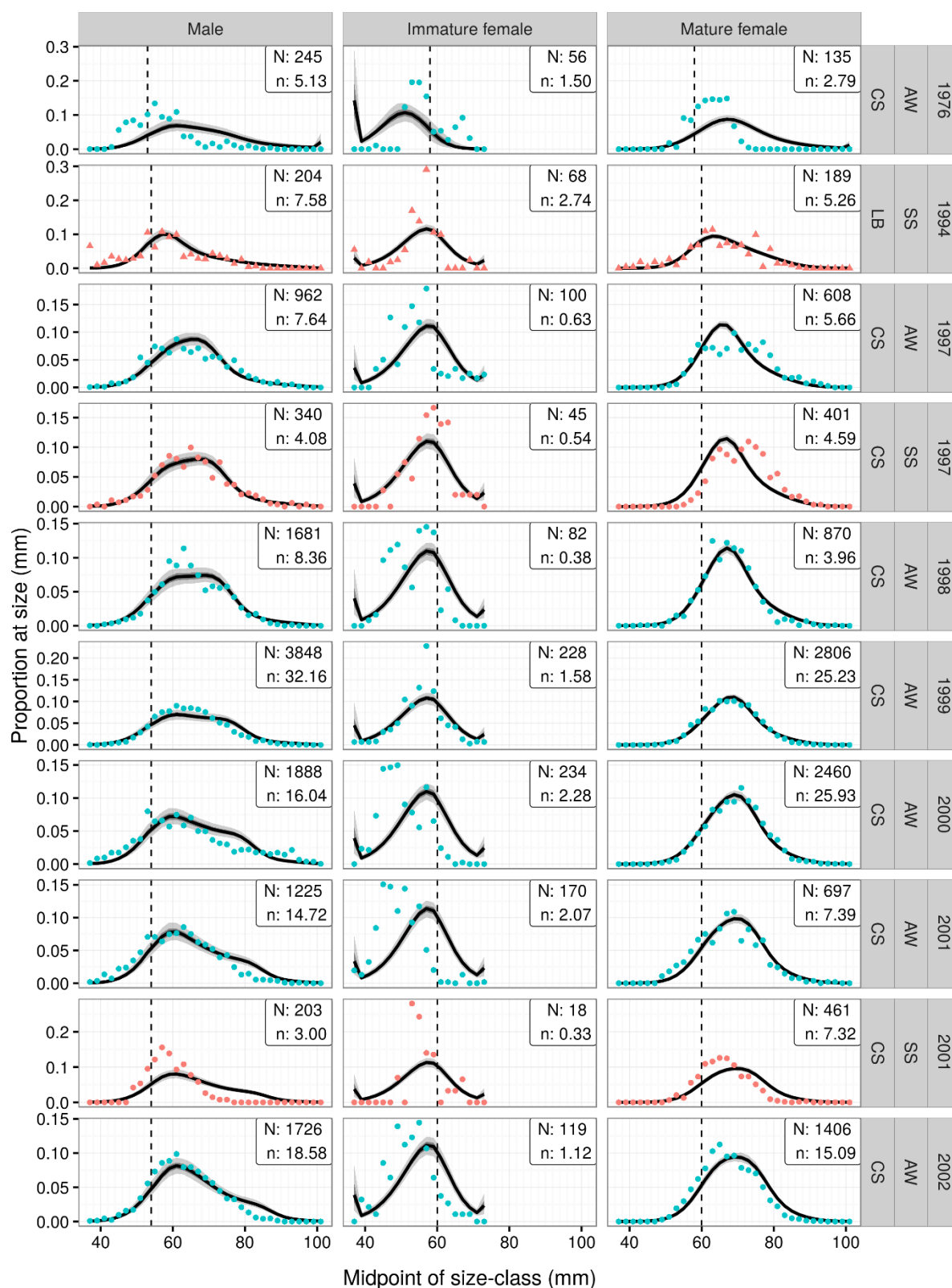


Figure 70: CRA 1 base case posterior vs. observed LFs from 1916 AW CS – 2002 AW CS. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals.

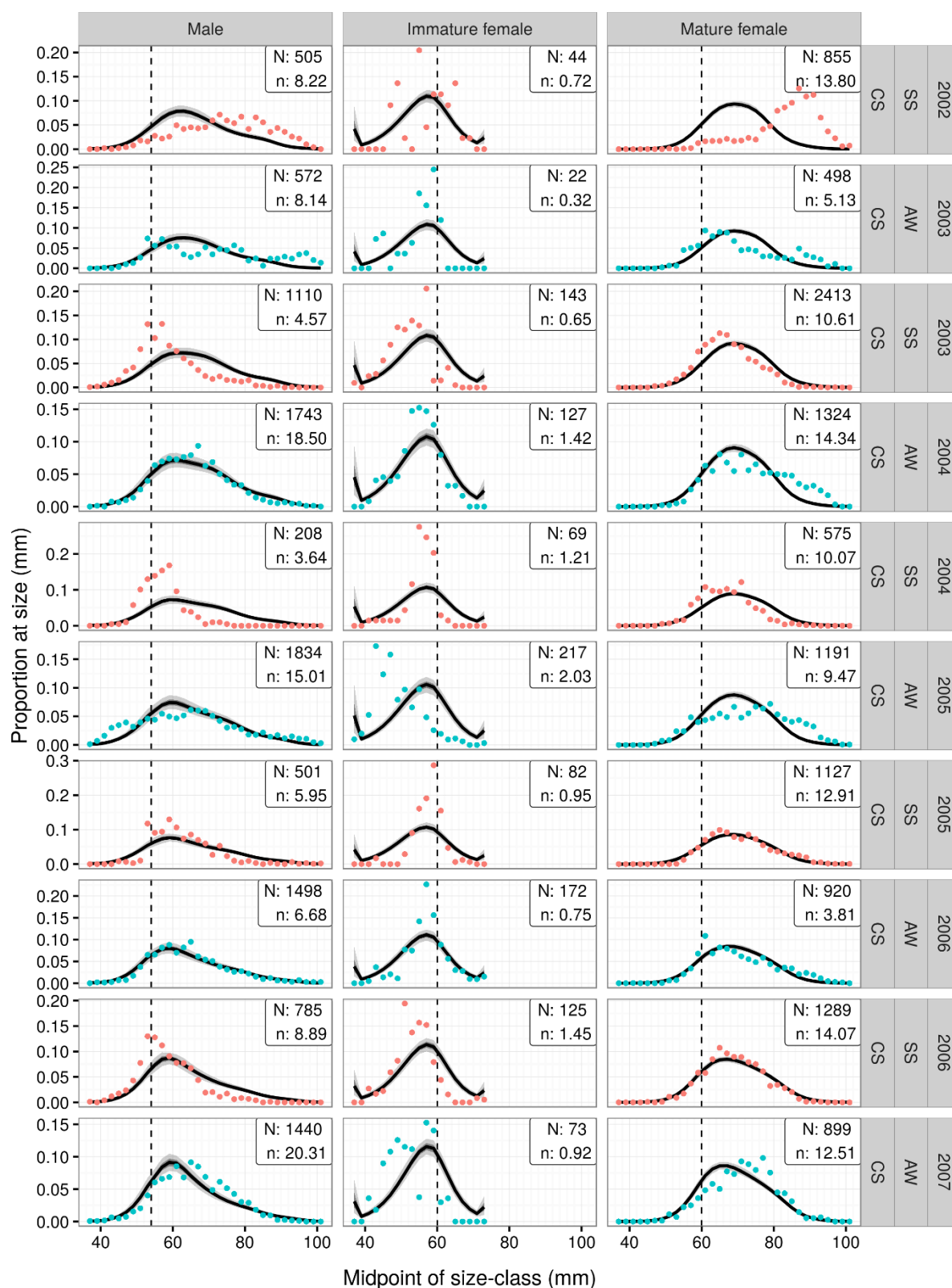


Figure 71: CRA 1 base case posterior vs. observed LFs from 2002 SS CS – 2007 AW CS. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals.

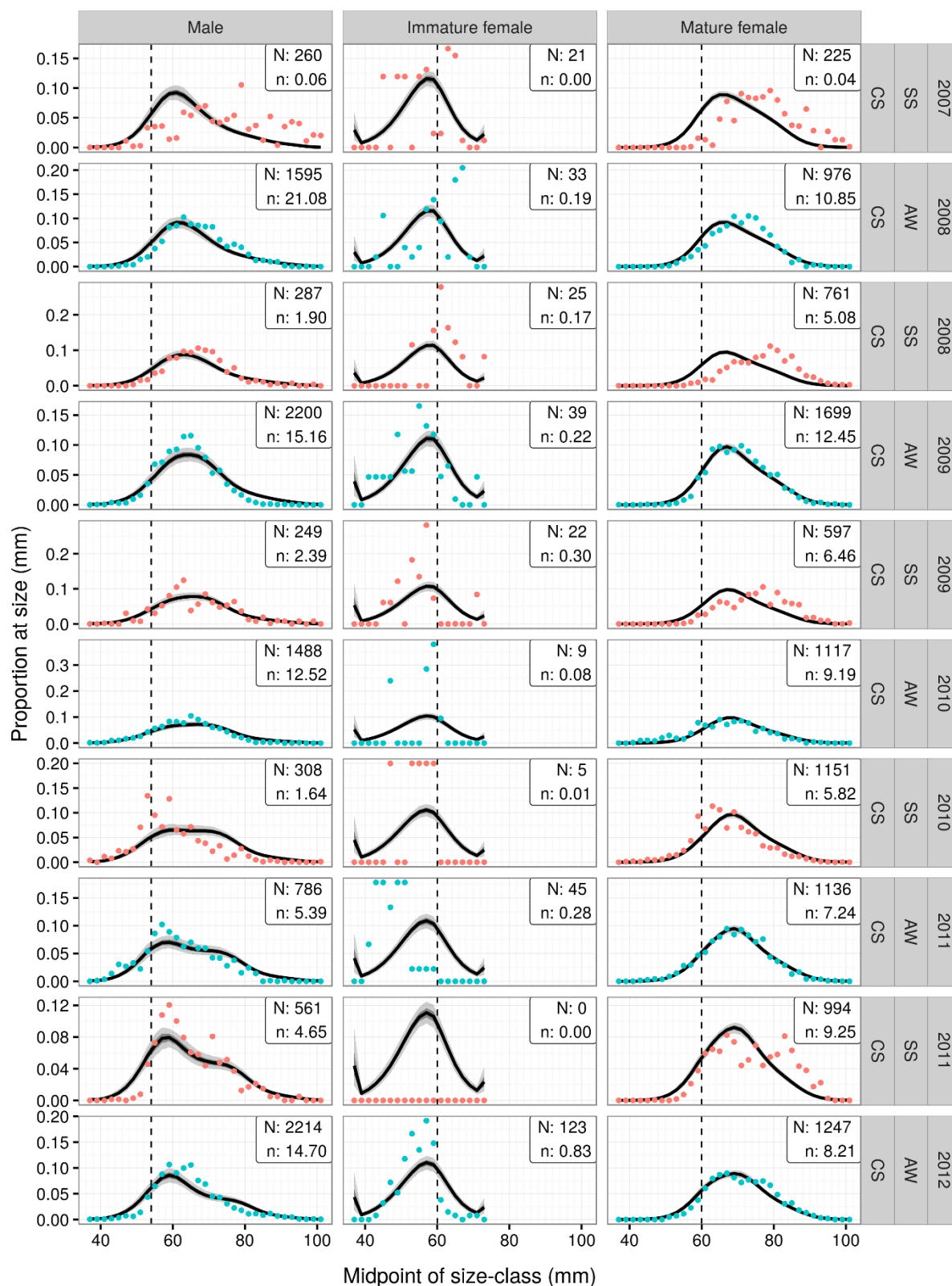


Figure 72: CRA 1 base case posterior vs. observed LFs from 2007 SS CS – 2012 AW CS. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals.

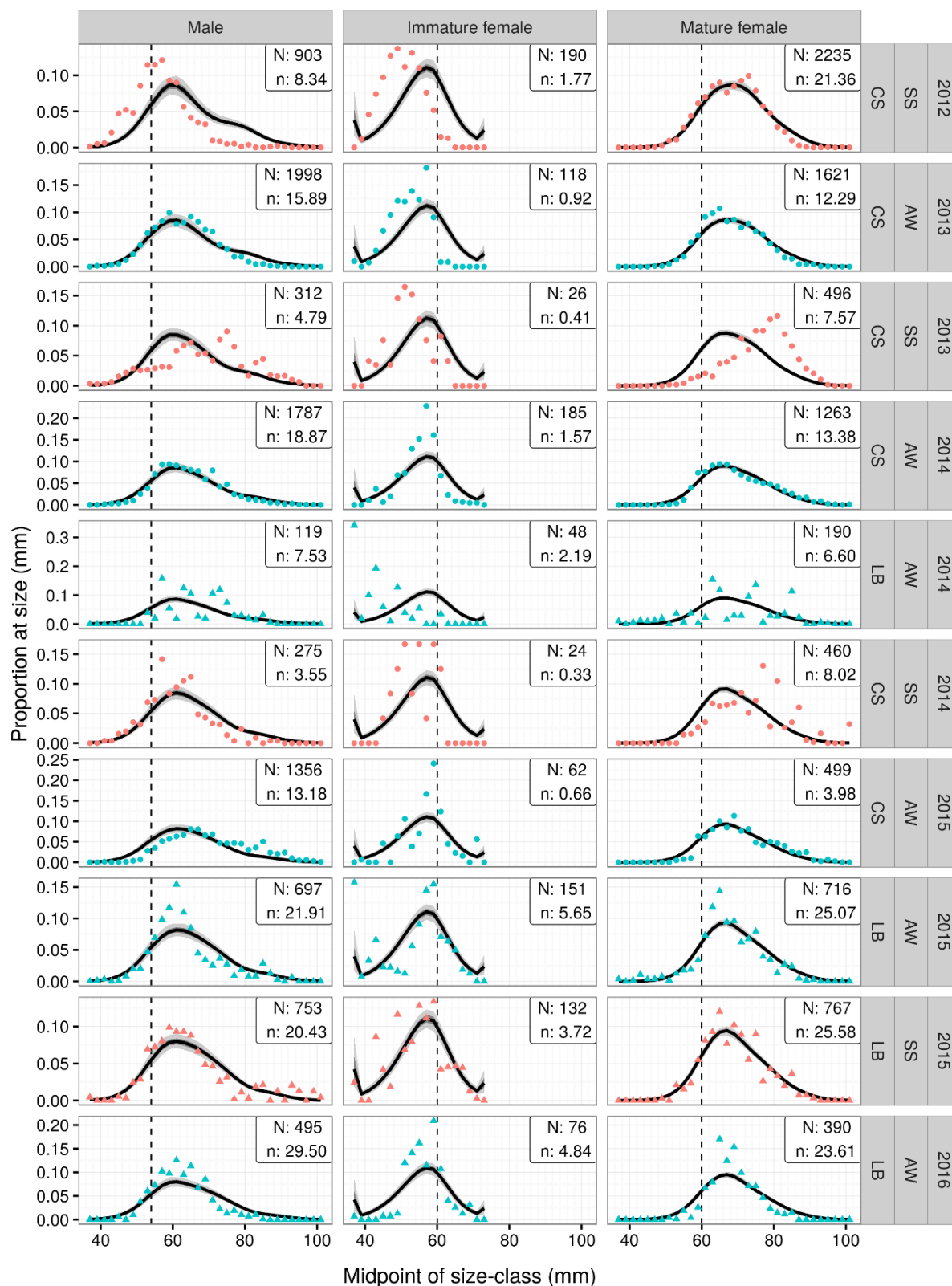


Figure 73: CRA 1 base case posterior vs. observed LFs from 2012 SS CS – 2016 AW LB. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals.

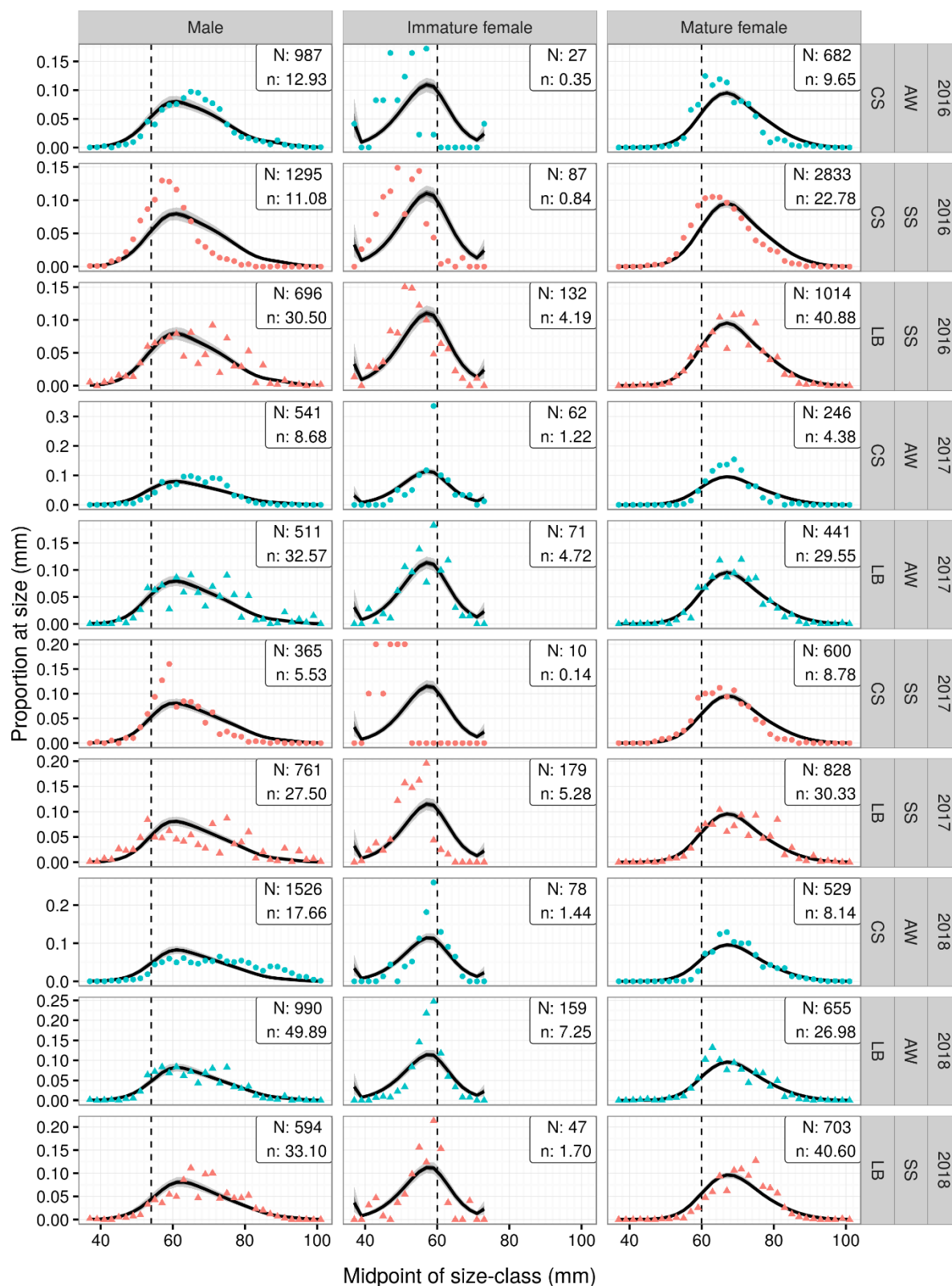


Figure 74: CRA 1 base case posterior vs. observed LFs from 2016 AW CS – 2018 SS LB. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals.

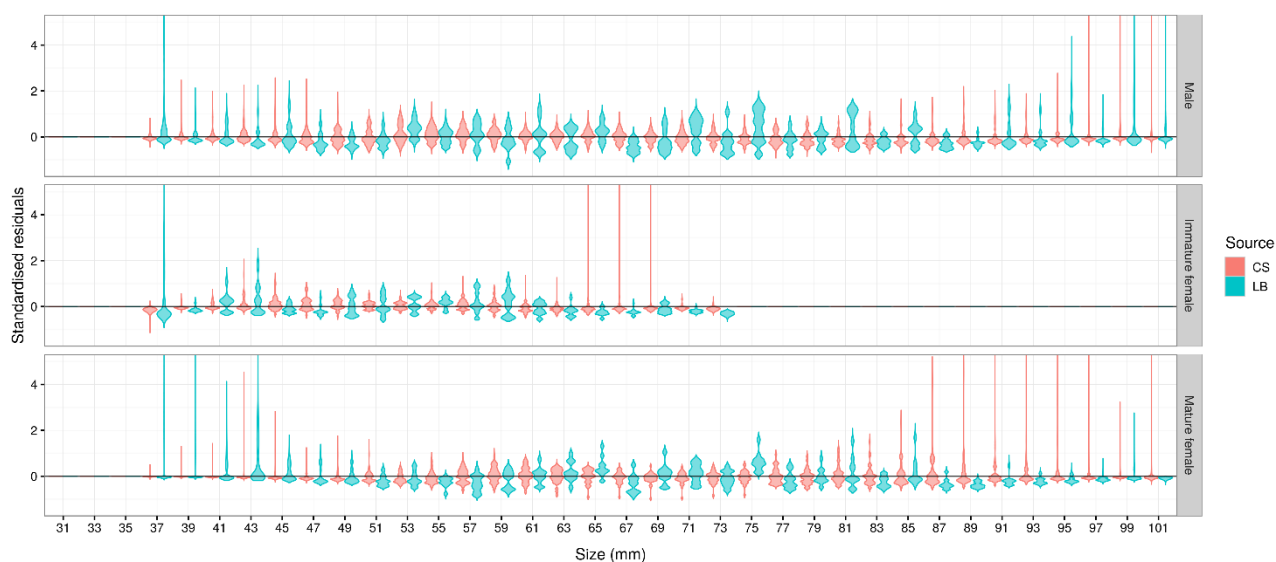


Figure 75: CRA 1 base case: distribution of standardised residuals between the predicted LF distributions and LF data for each sample from the posterior distribution, showing residuals by sex, 2-mm size bin, and sampling source. Shading intensity varies with number of observations.

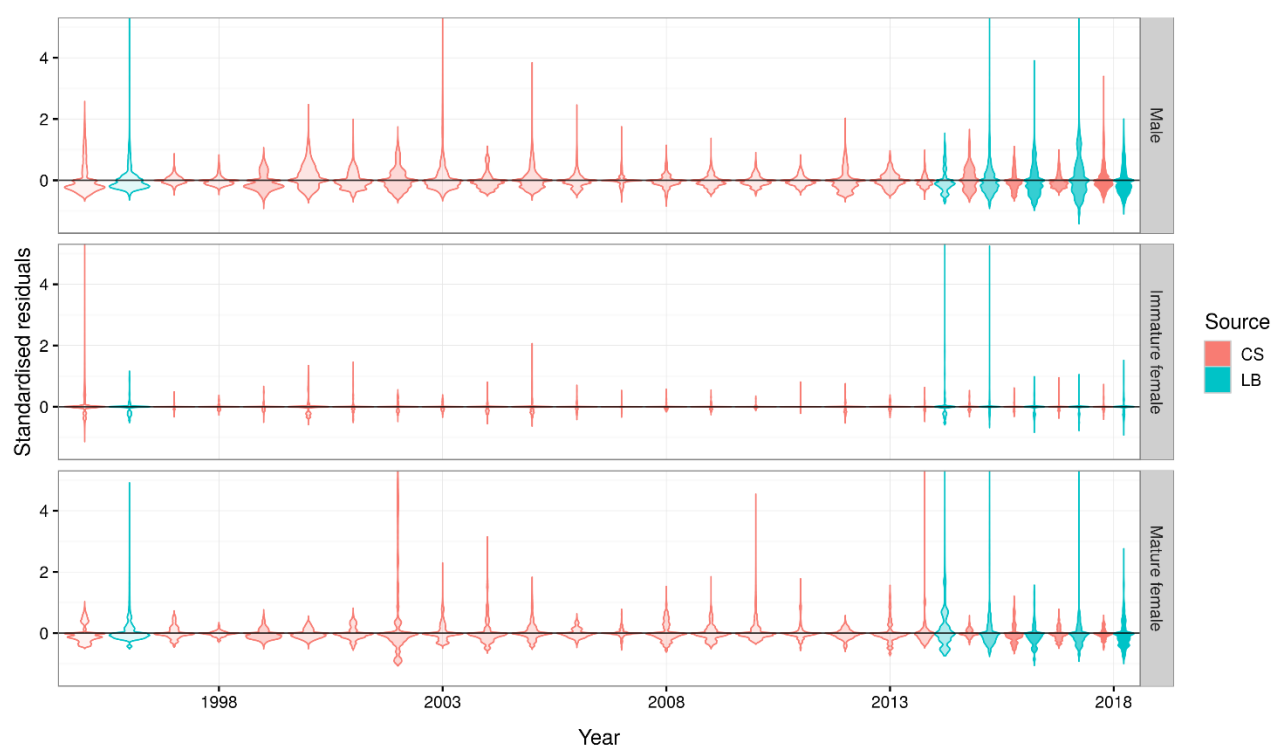


Figure 76: CRA 1 base case: distribution of standardised residuals between the predicted LF distributions and LF data for each sample from the posterior distribution, showing residuals by sex, year, and sampling source. Shading intensity varies with number of observations.

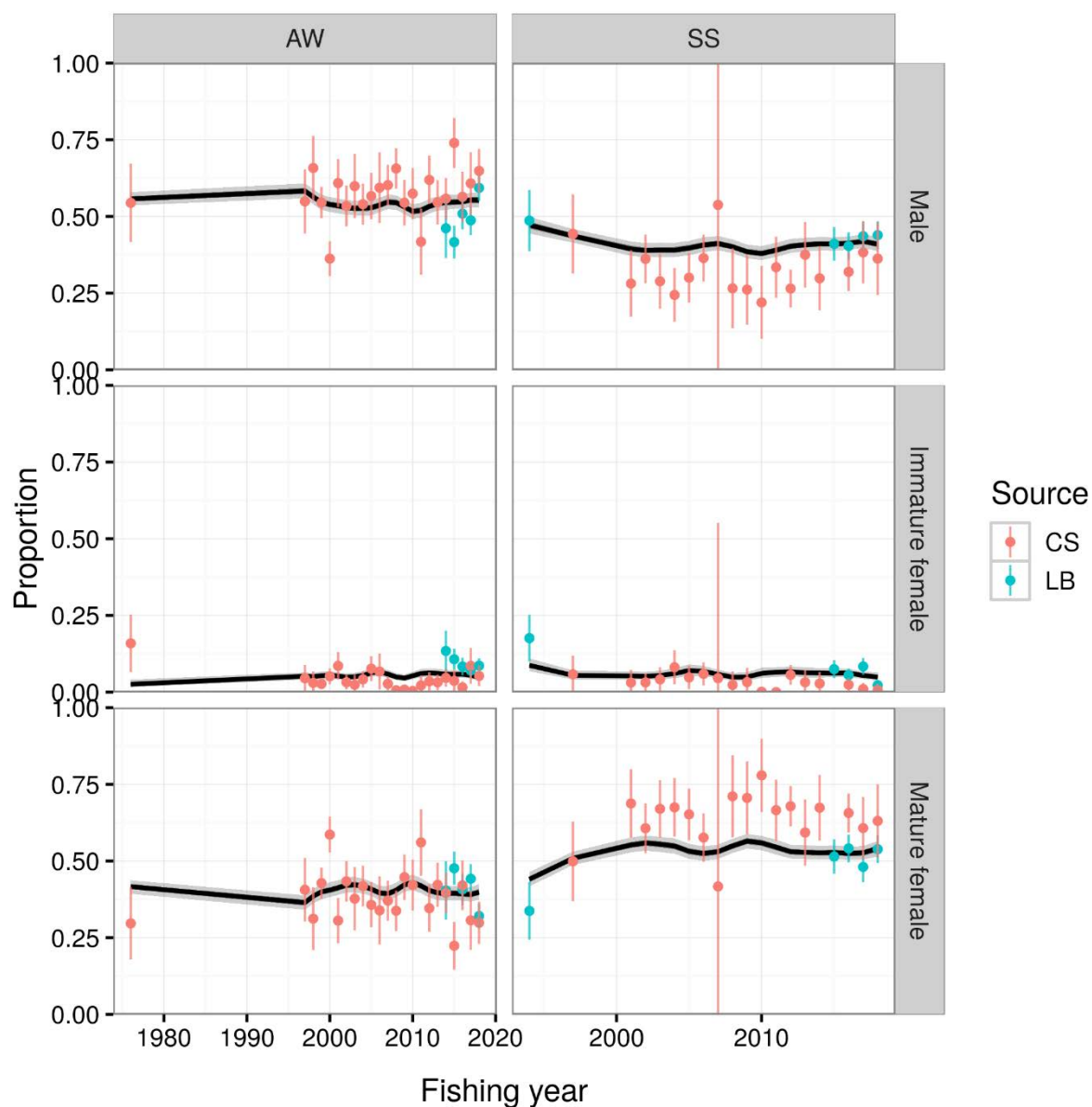


Figure 77: CRA 1 base case: model fit to sex ratios by year and LF data source. The solid line indicates the posterior median and grey shading with variable intensity indicates the 90% credible intervals. A dashed line (not visible) indicates the corresponding MAP estimates.

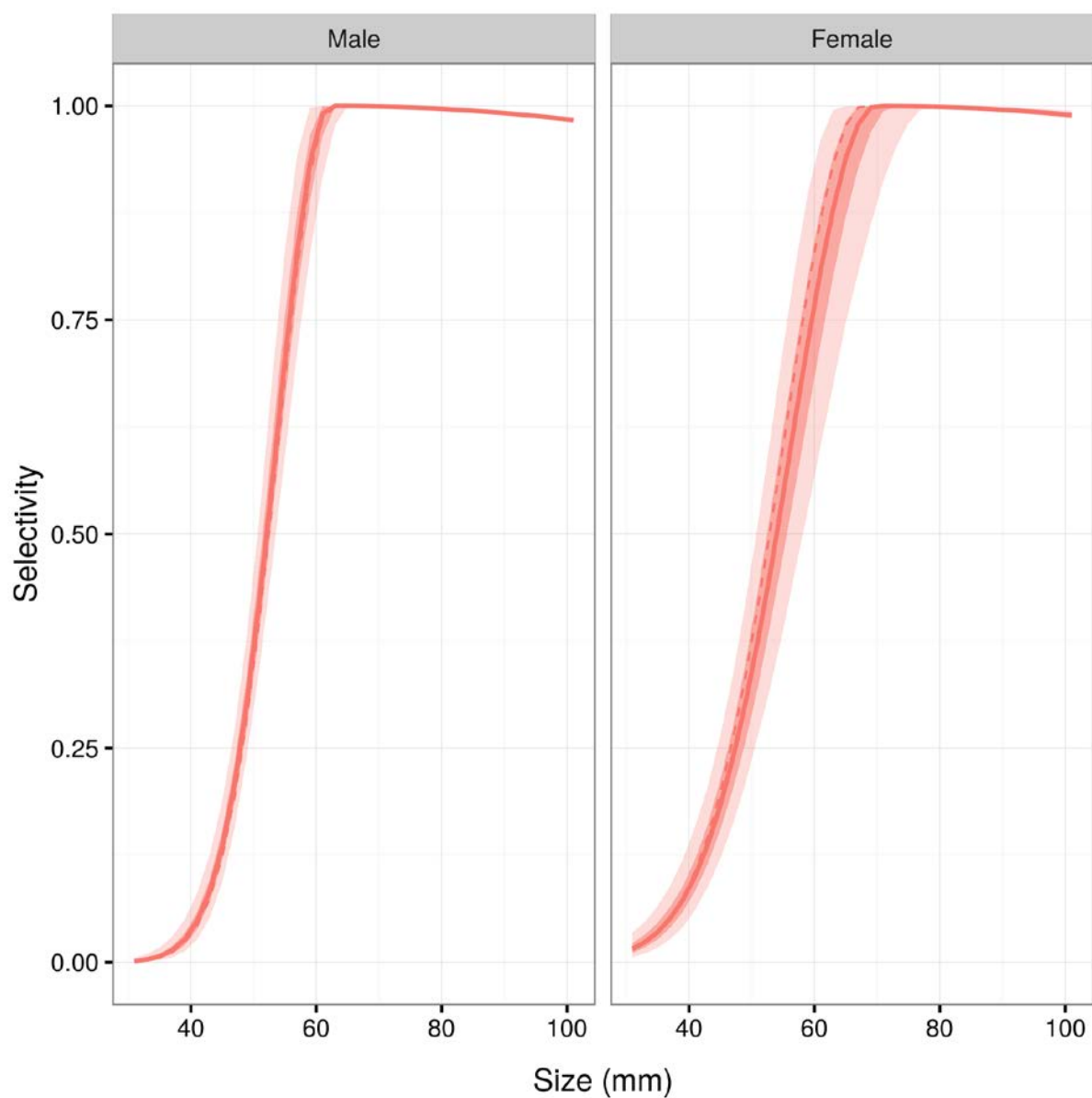


Figure 78: CRA 1 base case selectivity by sex, with the solid line indicating the posterior median and the variable intensity coloured bands showing the 50% and 90% credible intervals. Dashed lines indicate the corresponding MAP estimates.

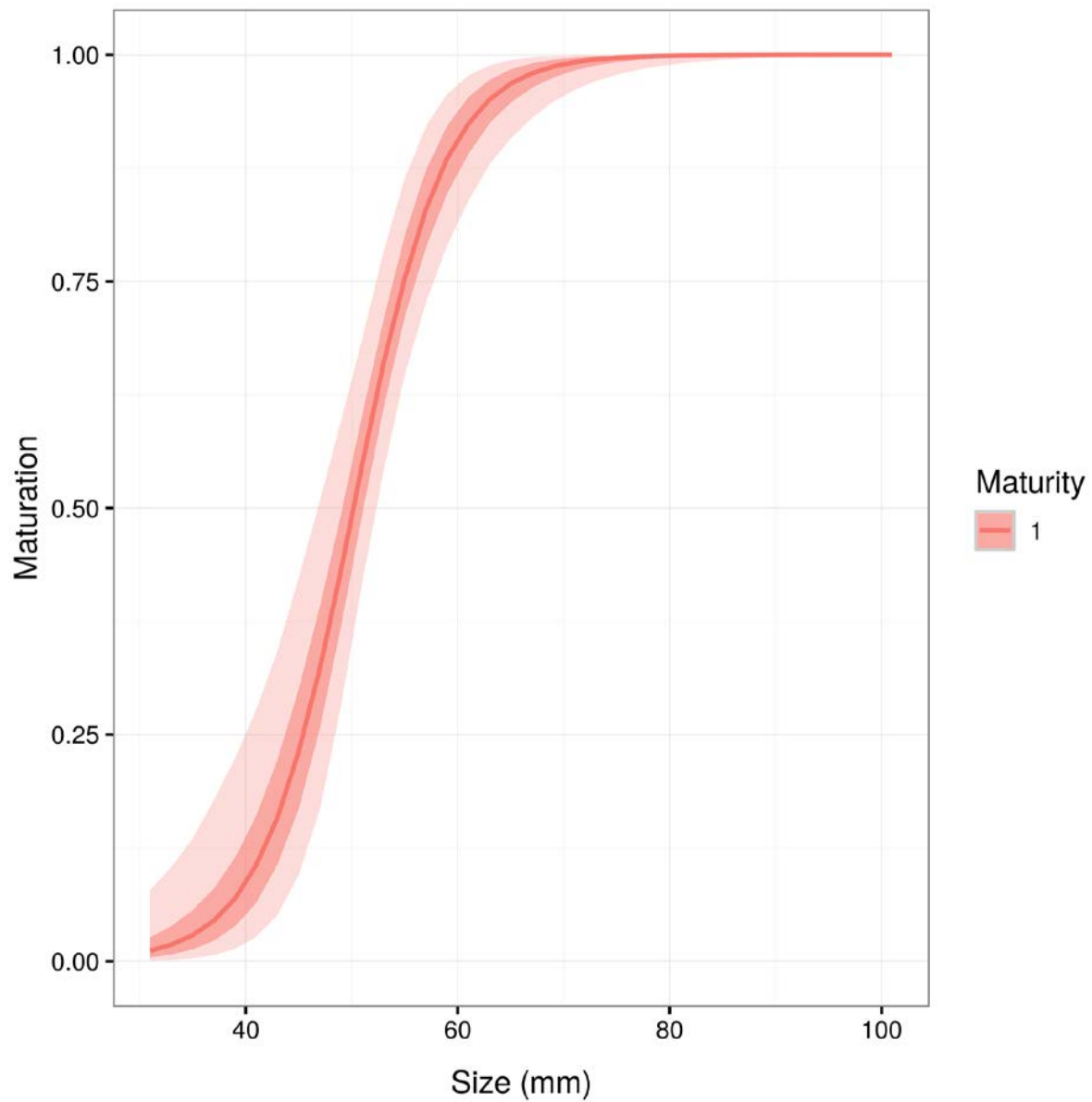


Figure 79: CRA 1 base case female maturity, where the solid line indicates the posterior median and shading with variable intensity indicates the 50% and 90% credible intervals. A dashed line (not visible) indicates the corresponding MAP estimates.

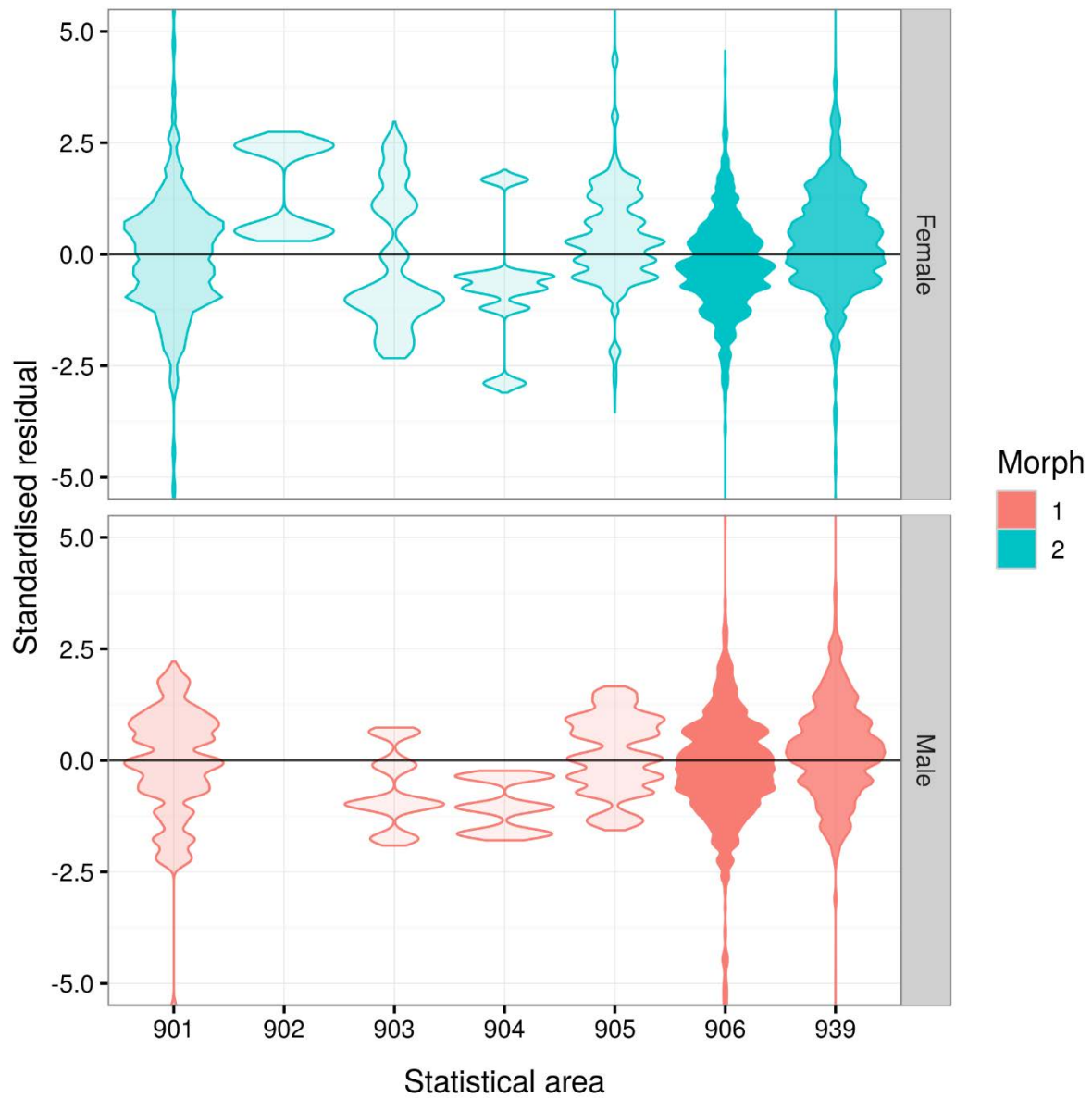


Figure 80: CRA 1 base case: distribution of tag residuals by statistical area of release for each sample from the posterior distribution. Shading intensity varies with number of observations.

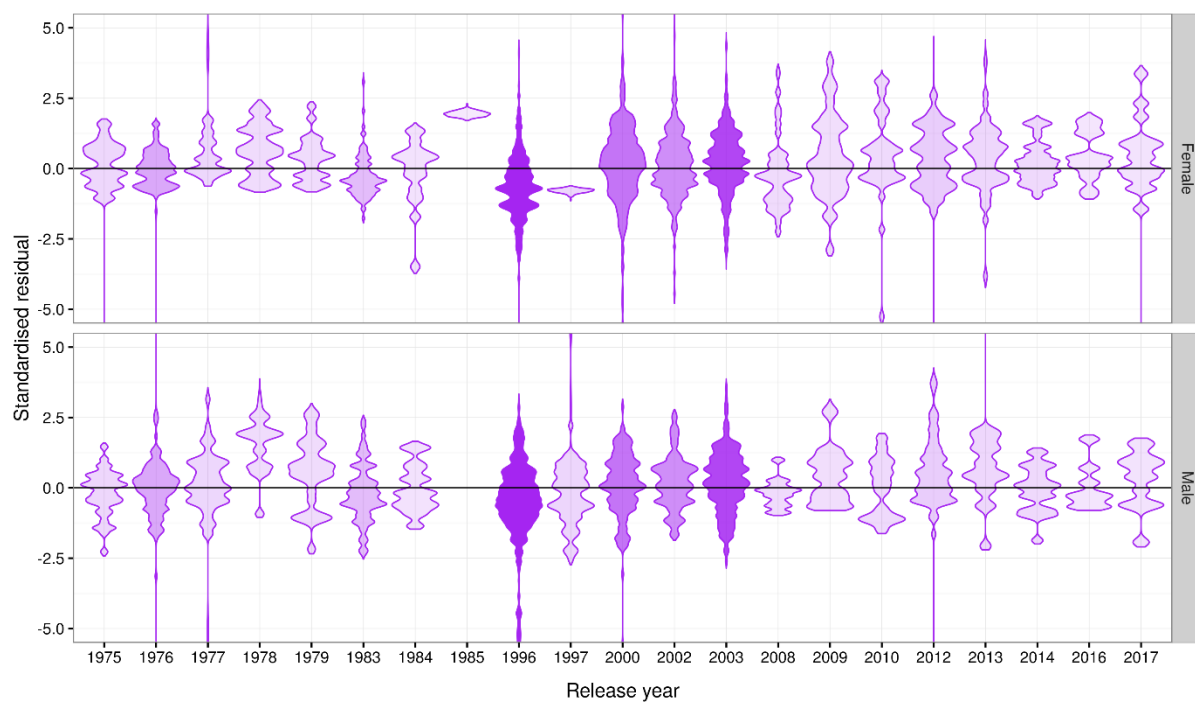


Figure 81: CRA 1 base case: distribution of tag residuals by year of release for each sample from the posterior distribution. Shading intensity varies with number of observations.

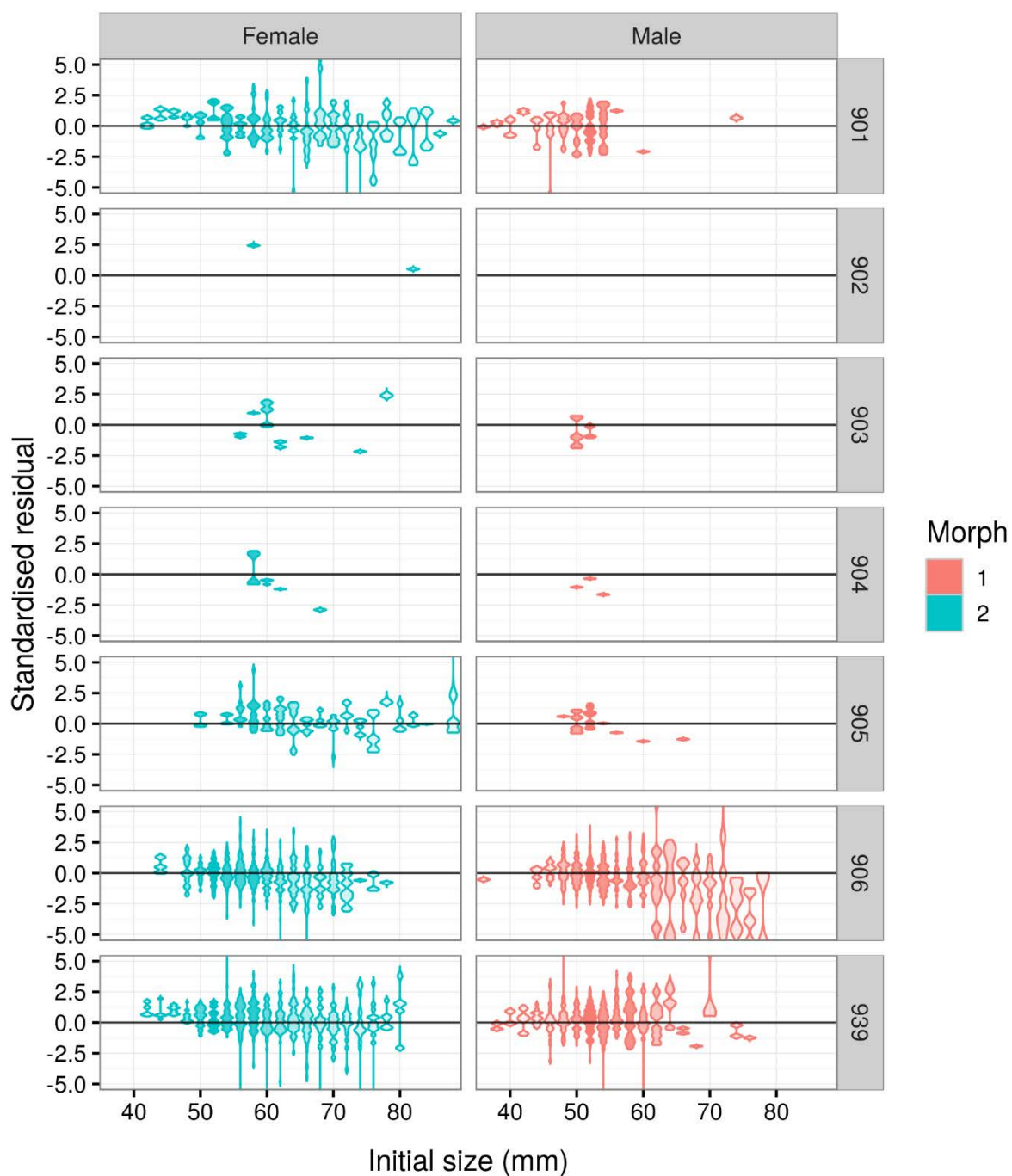


Figure 82: CRA 1 base case: distribution of tag residuals by statistical area of release and by TW bin for each sample from the posterior distribution. Shading intensity varies with number of observations.

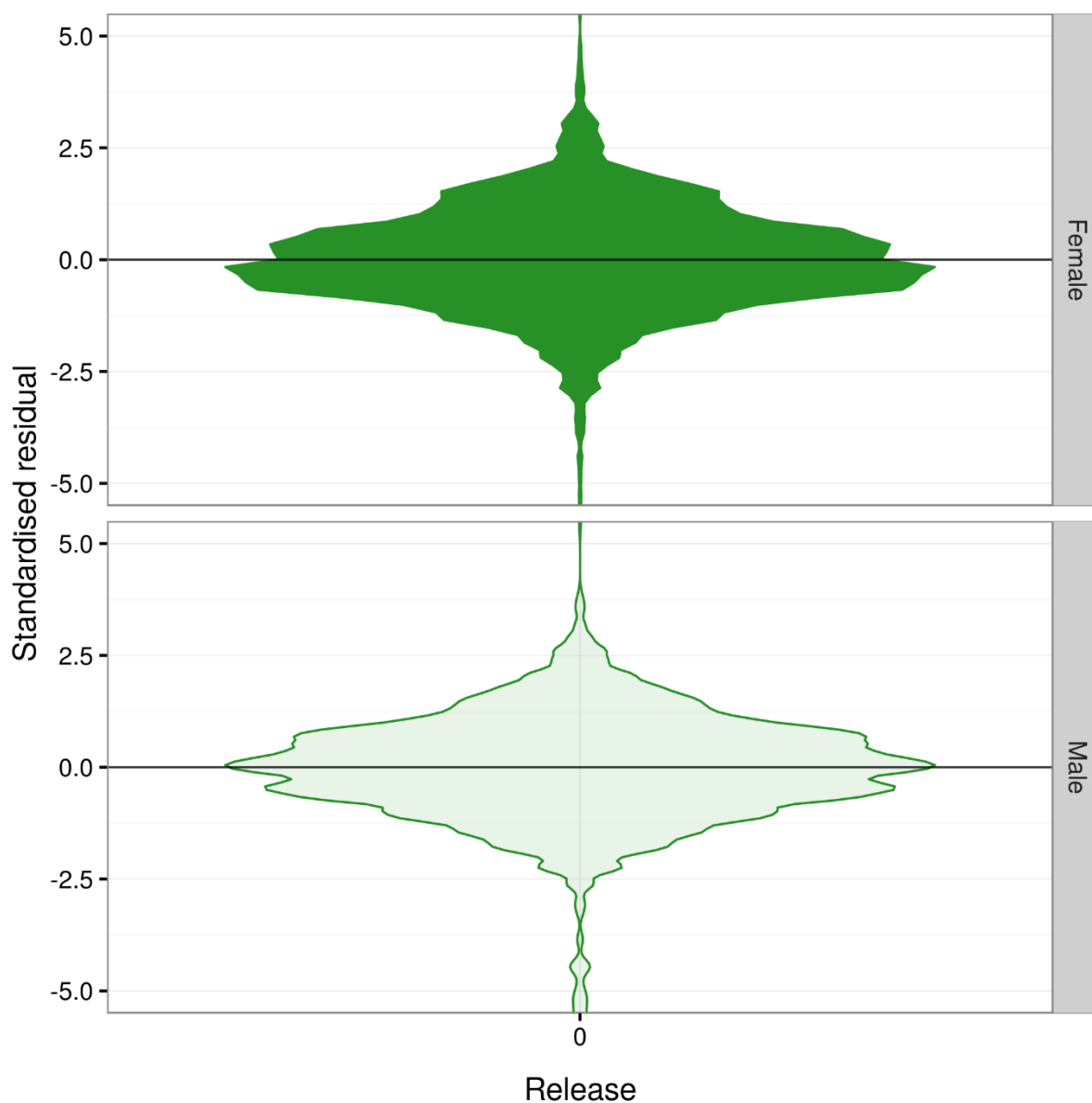


Figure 83: CRA 1 base case: distribution of tag residuals by sex at release for each sample from the posterior distribution. Shading intensity varies with number of observations.

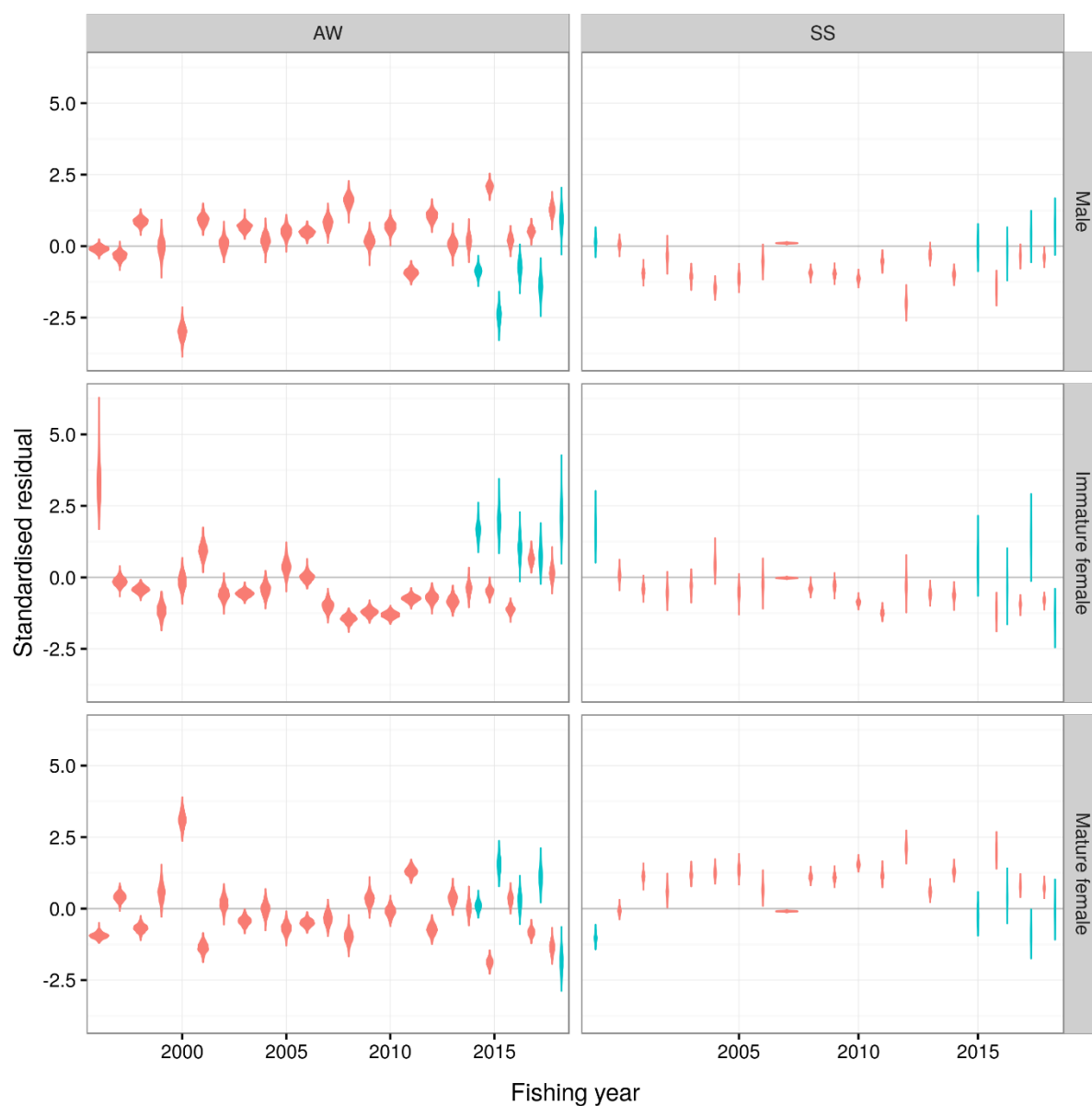


Figure 84: CRA 1 base case: distribution of tag residuals by year of release and sex category for each sample from the posterior distribution. Shading intensity varies with number of observations.

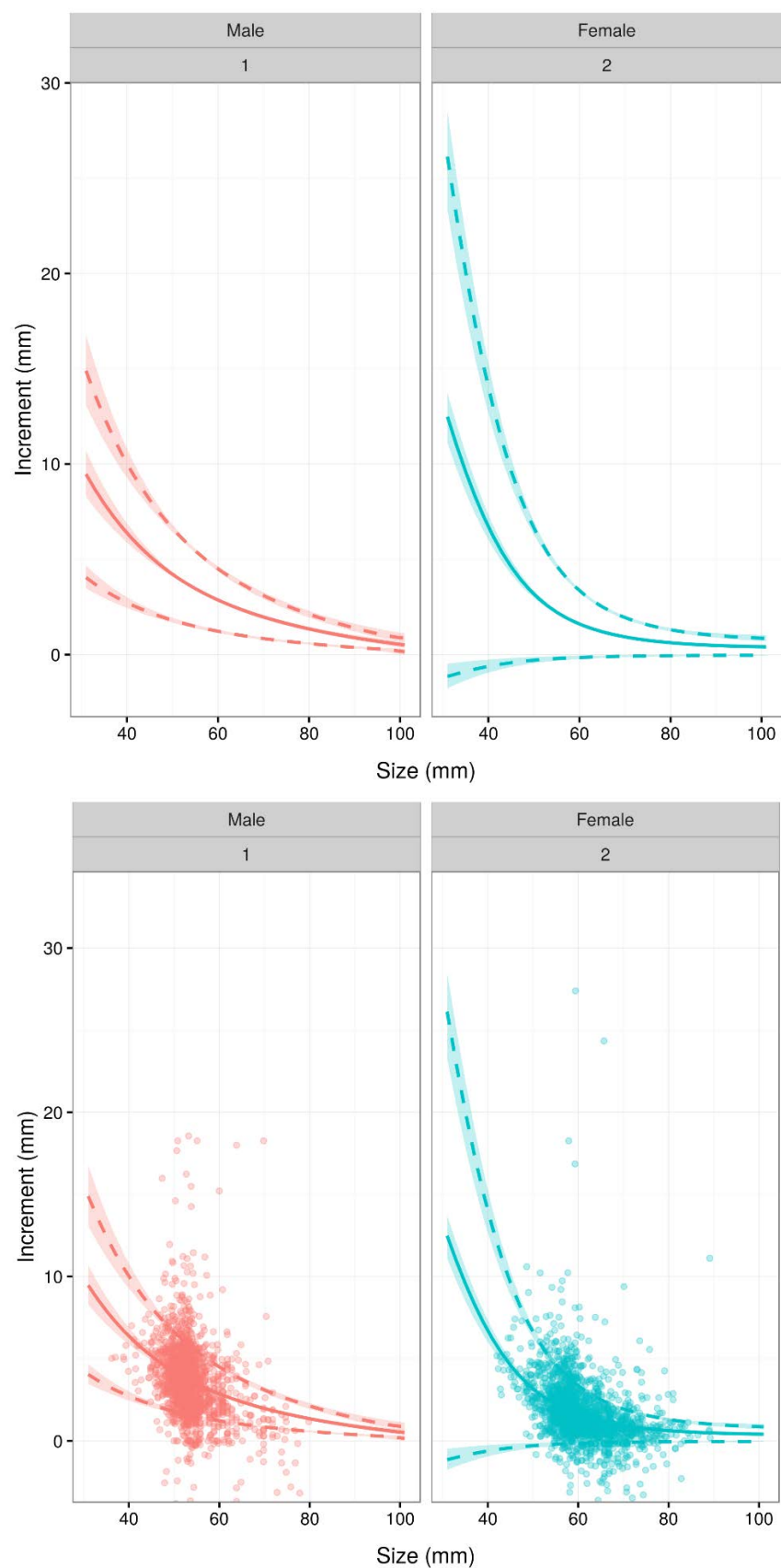


Figure 85: CRA 1 base case: Predicted increments-at-length (showing and not showing the observed recoveries) and ± 1 standard deviation (dashed coloured lines), with the solid line indicating the posterior median and the shaded bands showing the 90% credible intervals. A dashed line (not visible underneath the posterior median) indicates the corresponding MAP estimates.

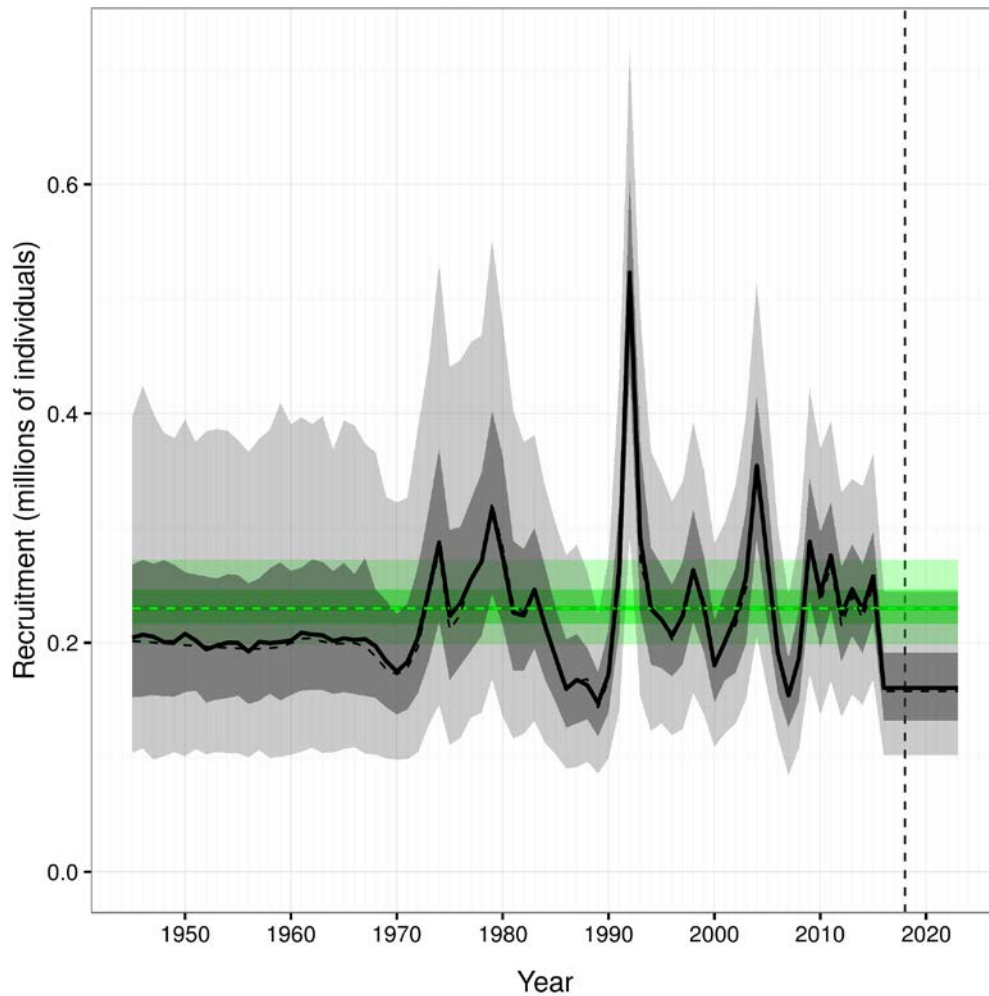


Figure 86: CRA 1 base case recruitment in 000 000s, where the dashed black line indicates the MAP, the solid black line indicates the median of the posterior and variable shading intensity indicates the 50% and 90% credible intervals. The horizontal solid green line is the median of the posterior for R_0 with green shading indicating the 50% and 90% credible intervals for R_0 . The vertical dashed line is the final year of the reconstruction period and the dashed green line is the MAP for R_0 . Projection recruitments (plotted to the right of the vertical dashed line) are based on the mean and standard deviation of the 2007–2016 recruitment and the 1945–2016 estimated autocorrelation.

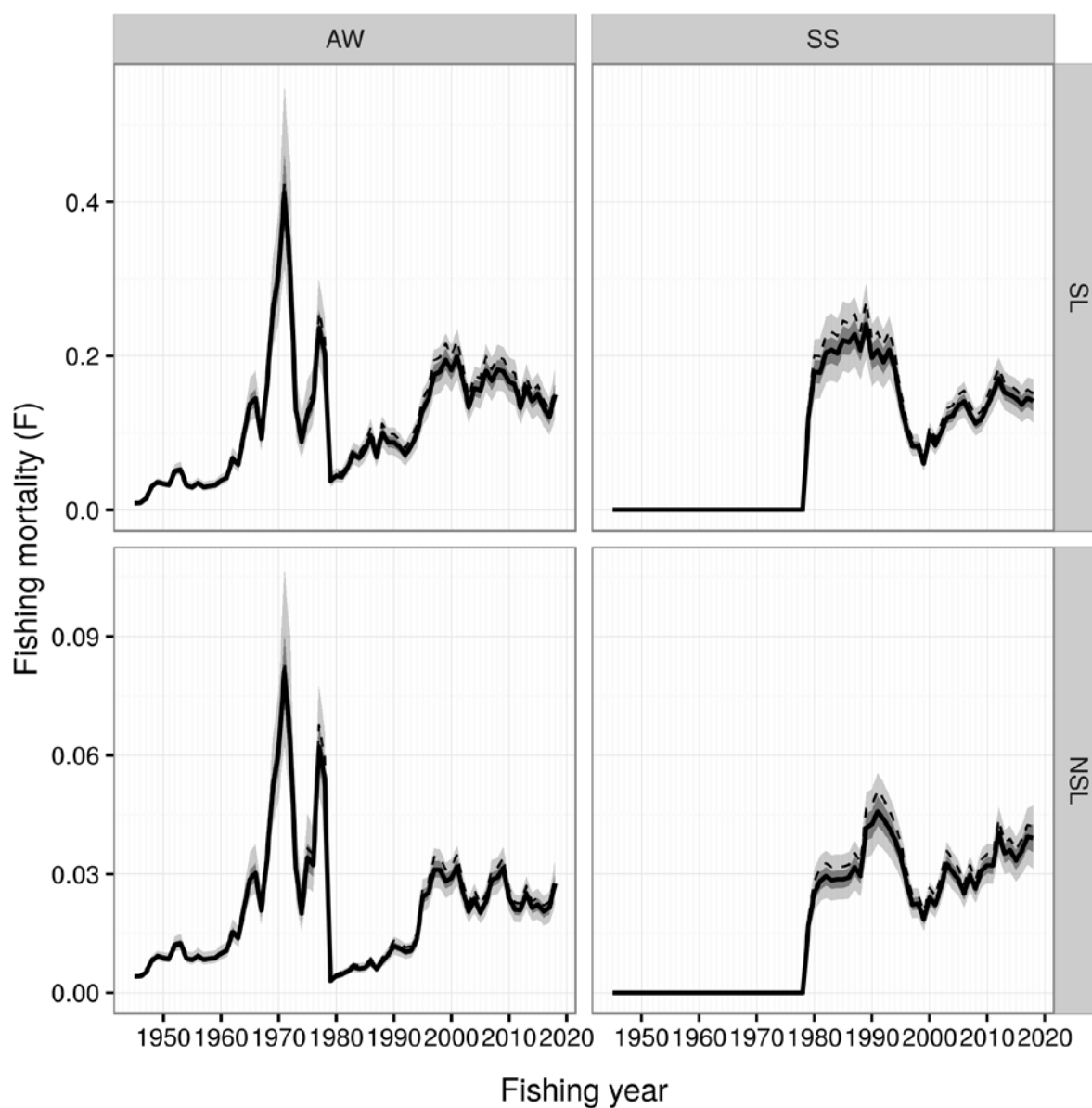


Figure 87: CRA 1 base case fishing mortality by year, season, and fishery (SL = size limited; NSL = non size limited), with the dashed black line (not always visible) indicating the MAP, the solid black line indicating the median of the posterior and variable shading intensity indicating the 50% and 90% credible intervals.

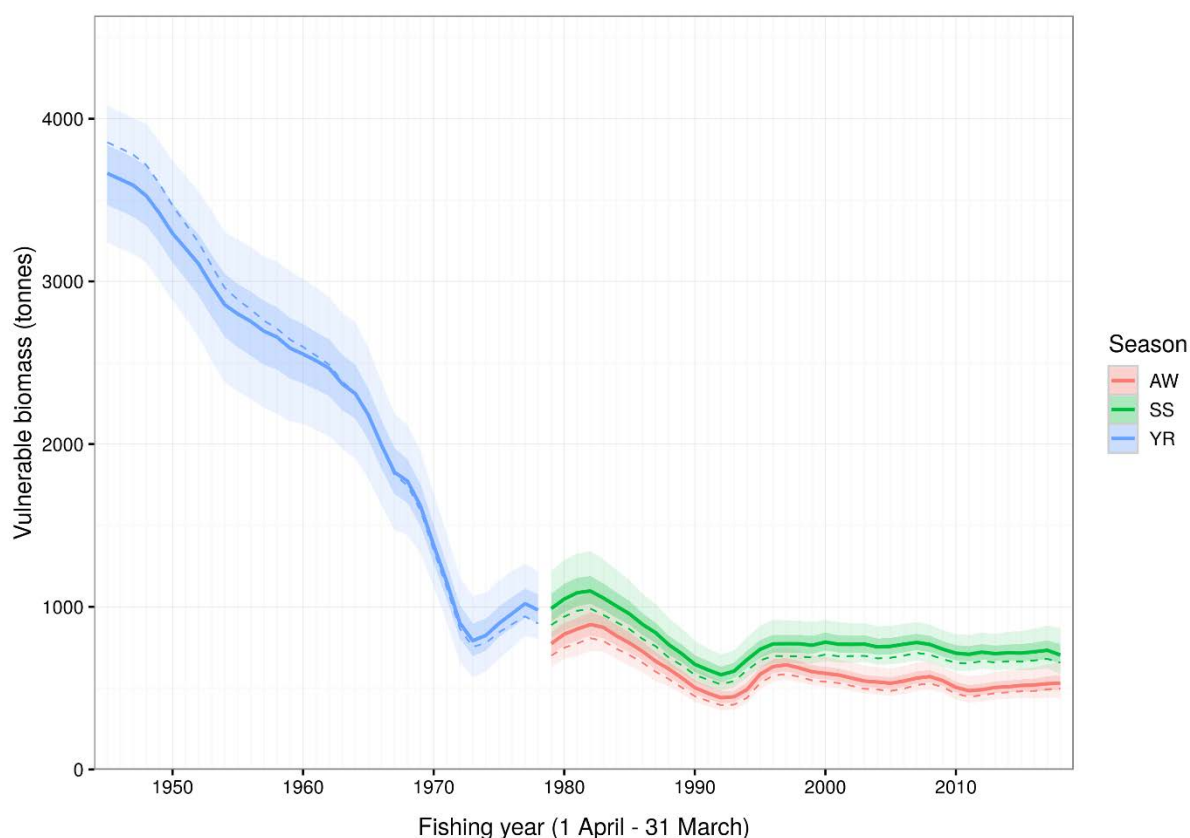


Figure 88: Posterior distribution of the CRA 1 base case vulnerable reference biomass by season, with dashed lines indicating the equivalent MAP estimates. Variable shading intensity indicates the 50% and 90% credible intervals.

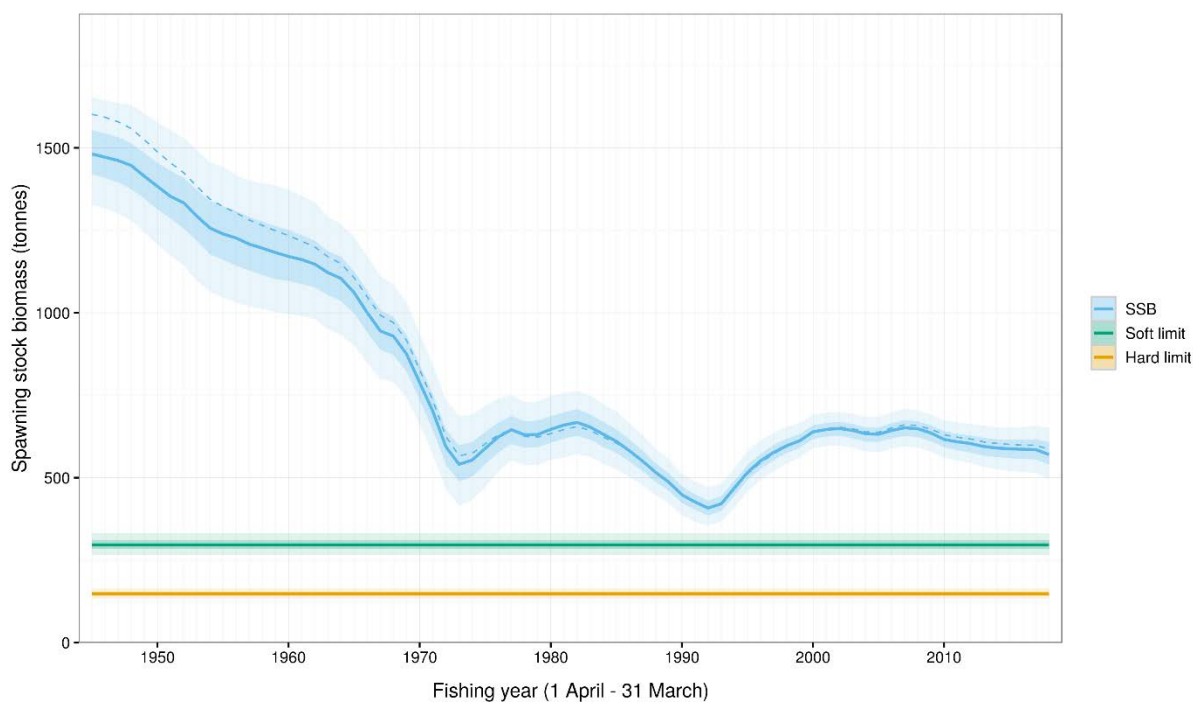


Figure 89: Posterior distribution of the CRA 1 base case spawning biomass, with dashed lines indicating the equivalent MAP estimates. Variable shading intensity indicates the 50% and 90% credible intervals.

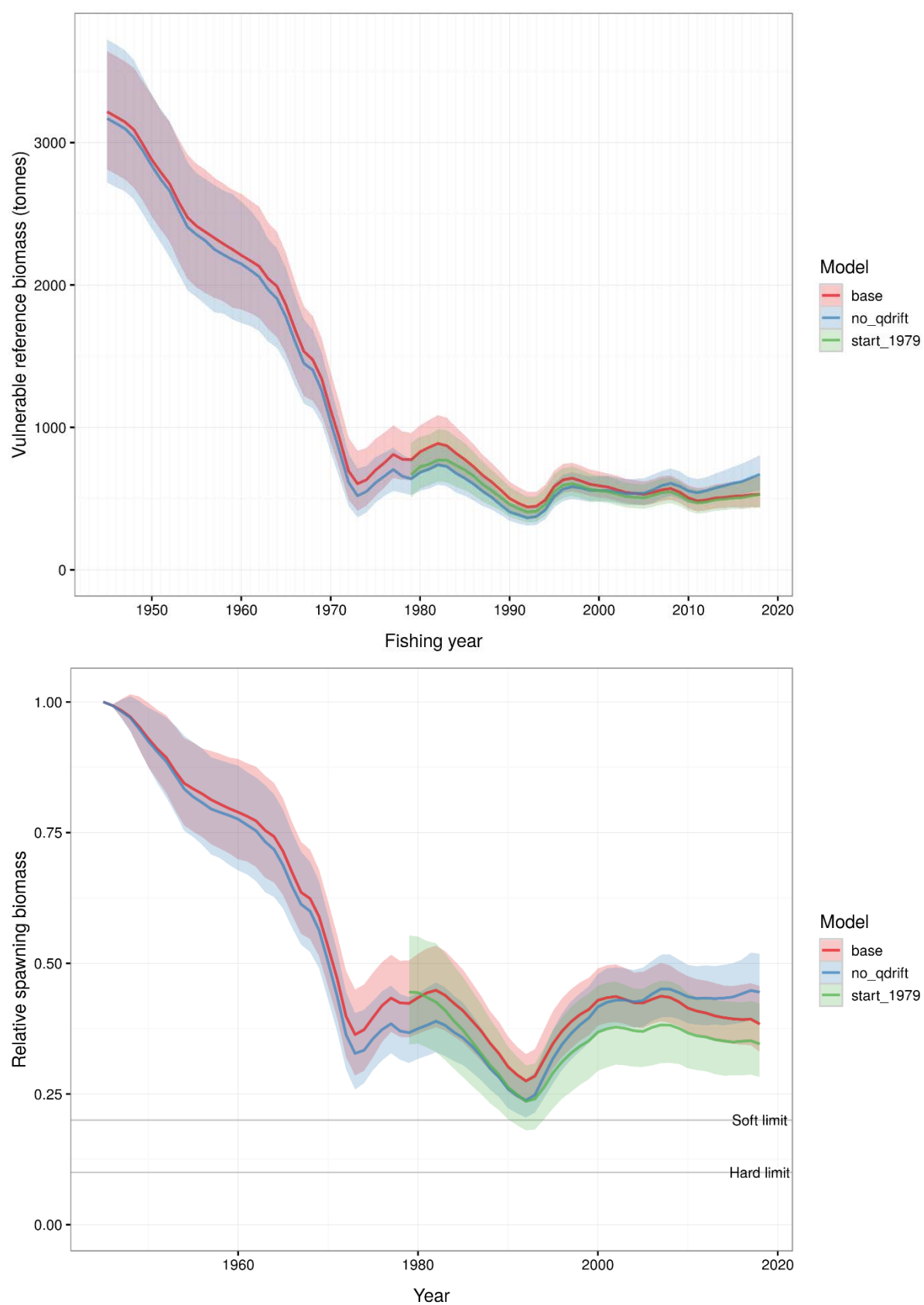


Figure 90: Comparison of the vulnerable reference biomass [upper panel] and relative spawning stock biomass [lower panel] trajectories between the base run and the two sensitivity runs (Table 12).

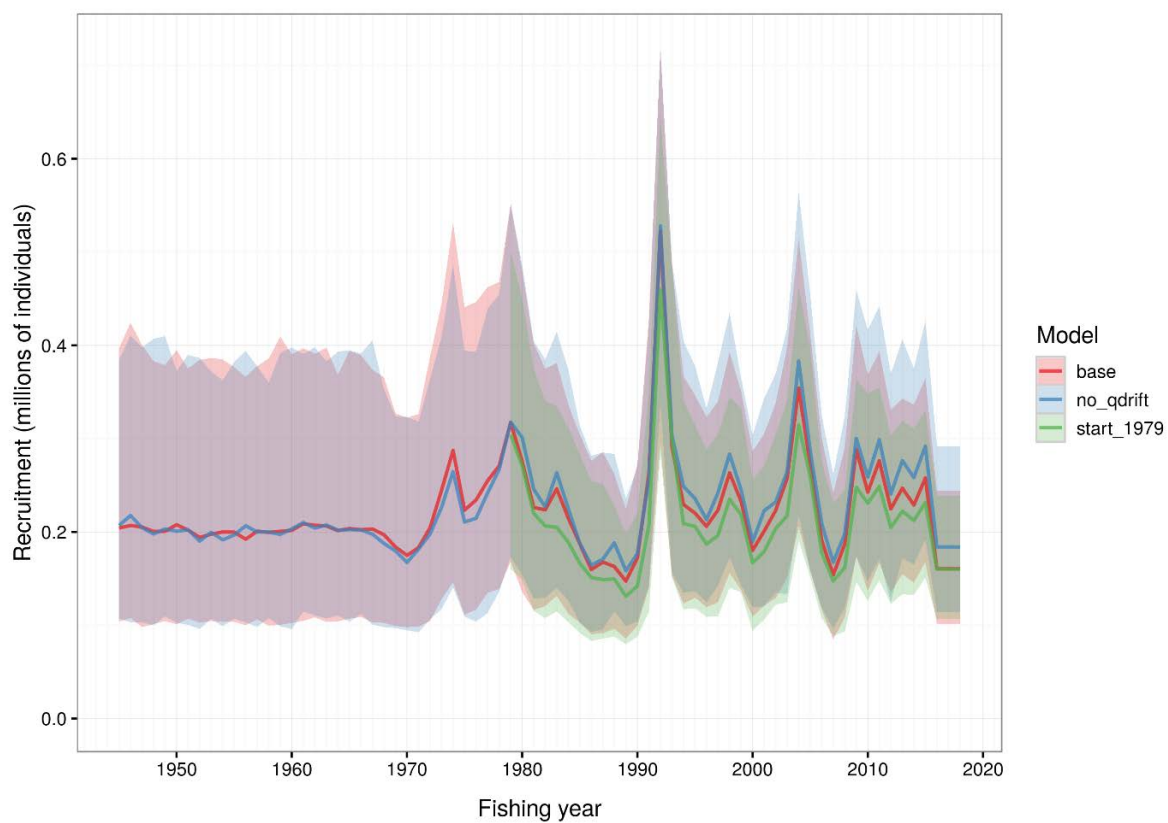


Figure 91: CRA 1 MCMC Comparison of recruitment trajectories between the base run and the MCMC sensitivities.

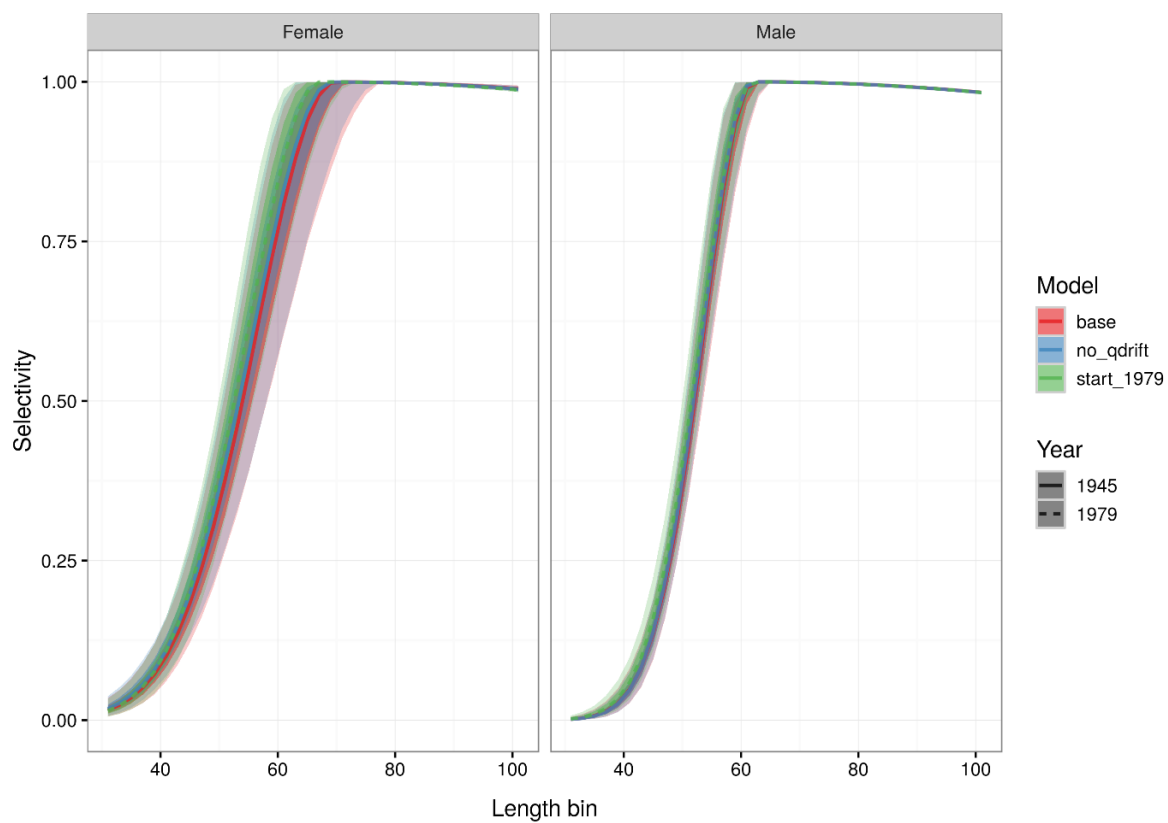


Figure 92: CRA 1 Comparison of selectivity curves between the MCMC runs.

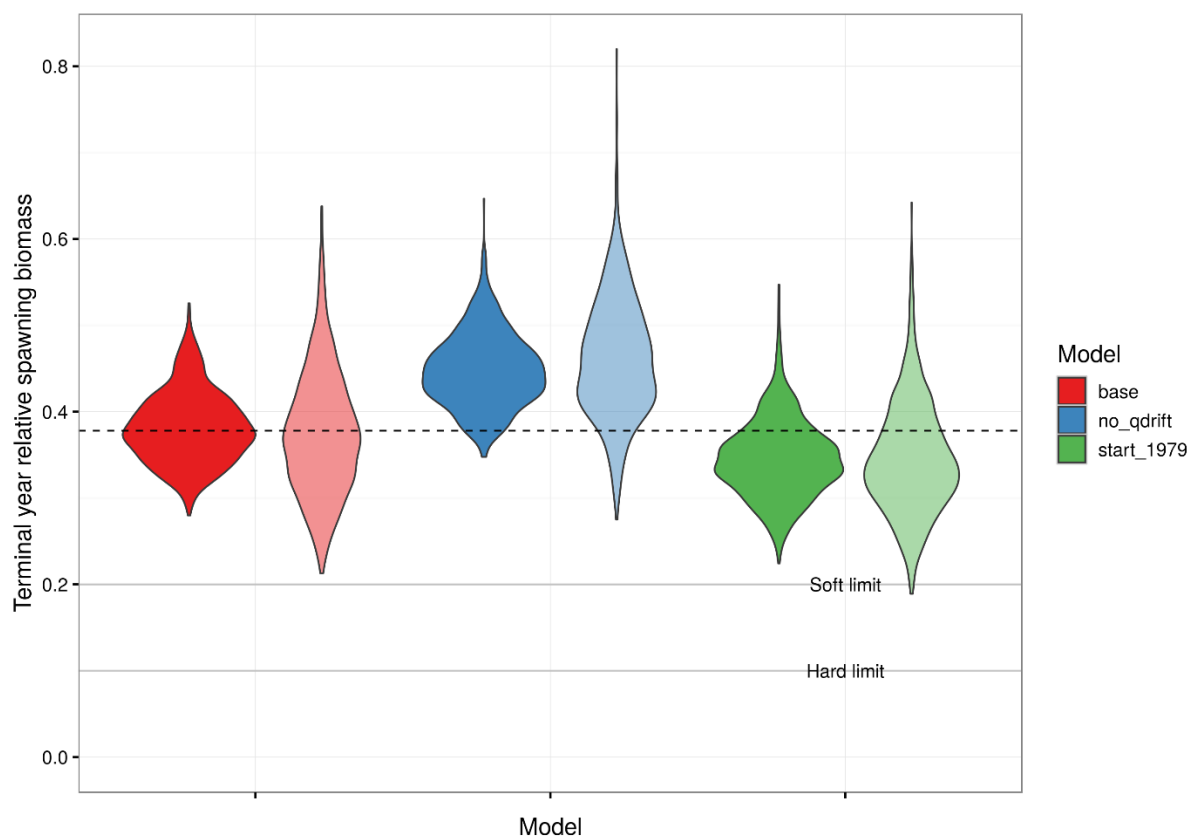


Figure 93: Comparison of the relative spawning stock biomass as a proportion of SSB_0 in the terminal reconstruction year (dark shading, 2019) and the terminal projection year (light shading, 2023) between the *no_qdrift* and *start_1979* runs with the *base* model. The horizontal dashed line shows the mean SSB_y / SSB_0 for the base case.

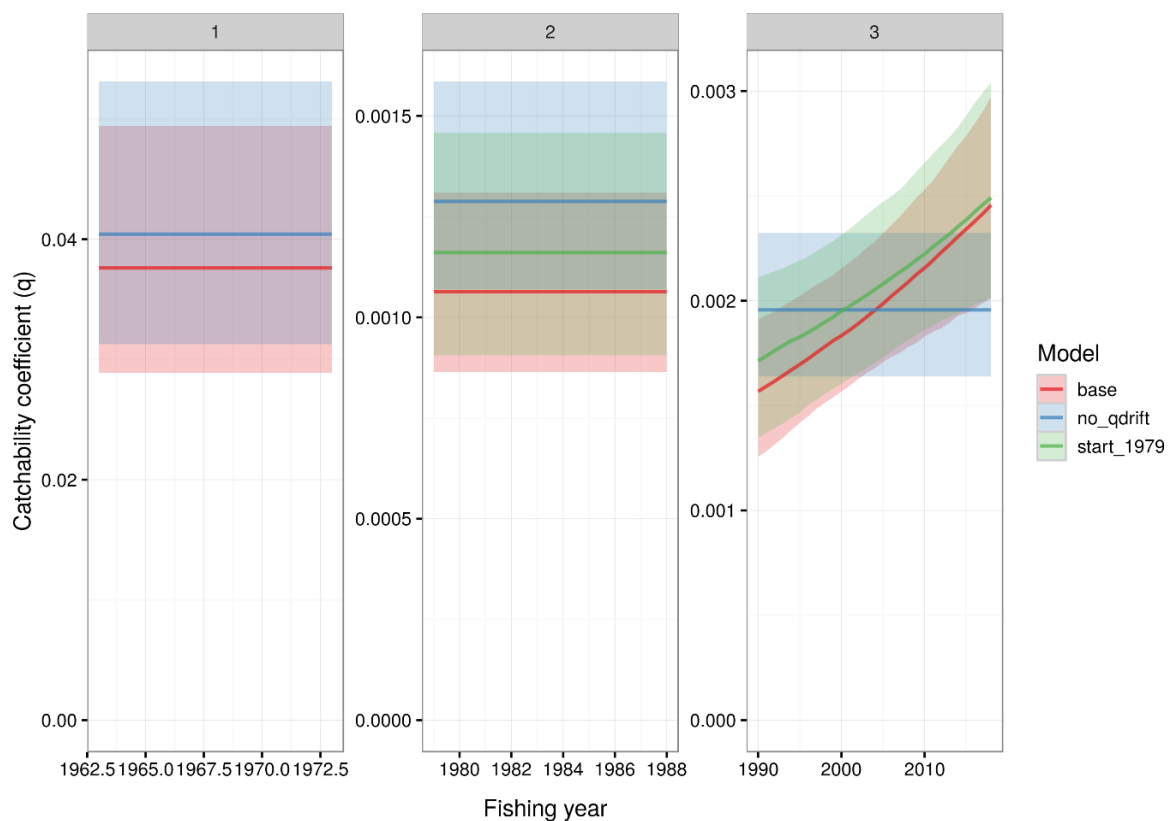


Figure 94: CRA 1 Comparison of q estimates between the base run and the MCMC sensitivity runs (Table 12): 1=CR CPUE q ; 2=FSU CPUE q ; 3=CELR CPUE q .

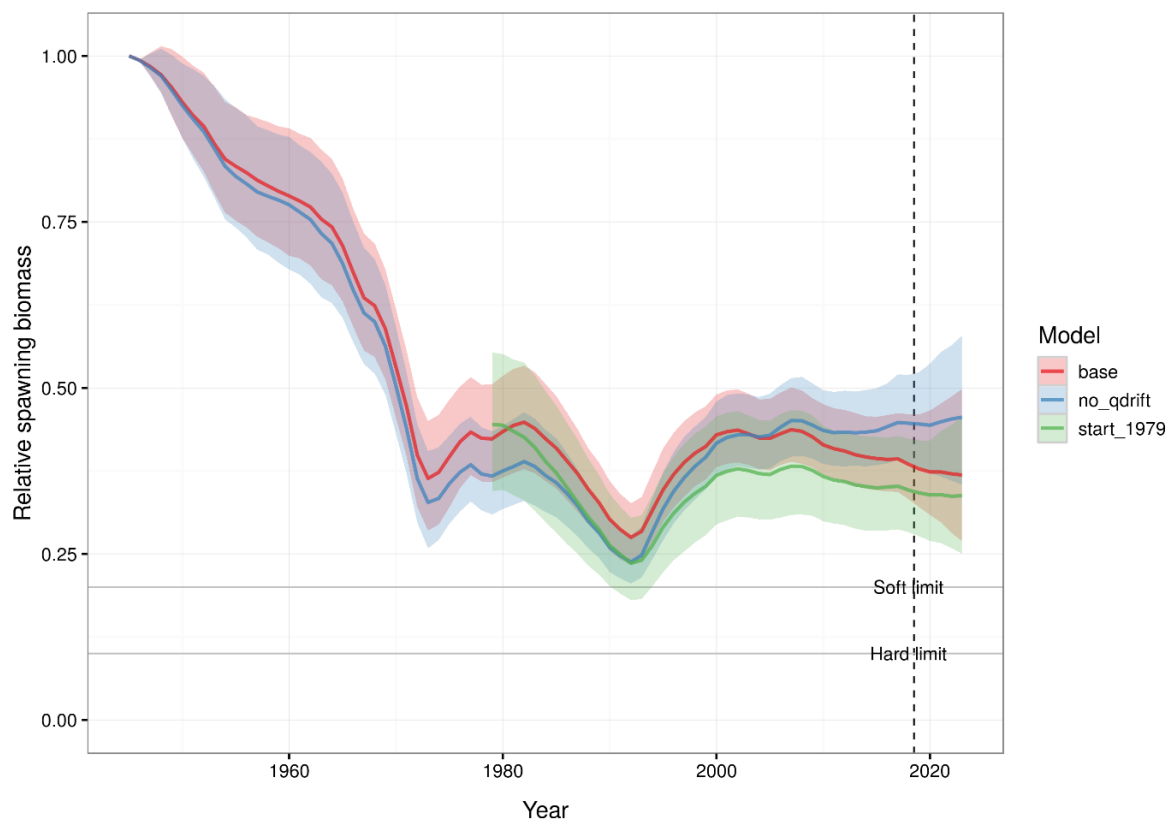


Figure 95: Spawning biomass trajectory expressed as proportion SSB_0 for three CRA 1 runs.

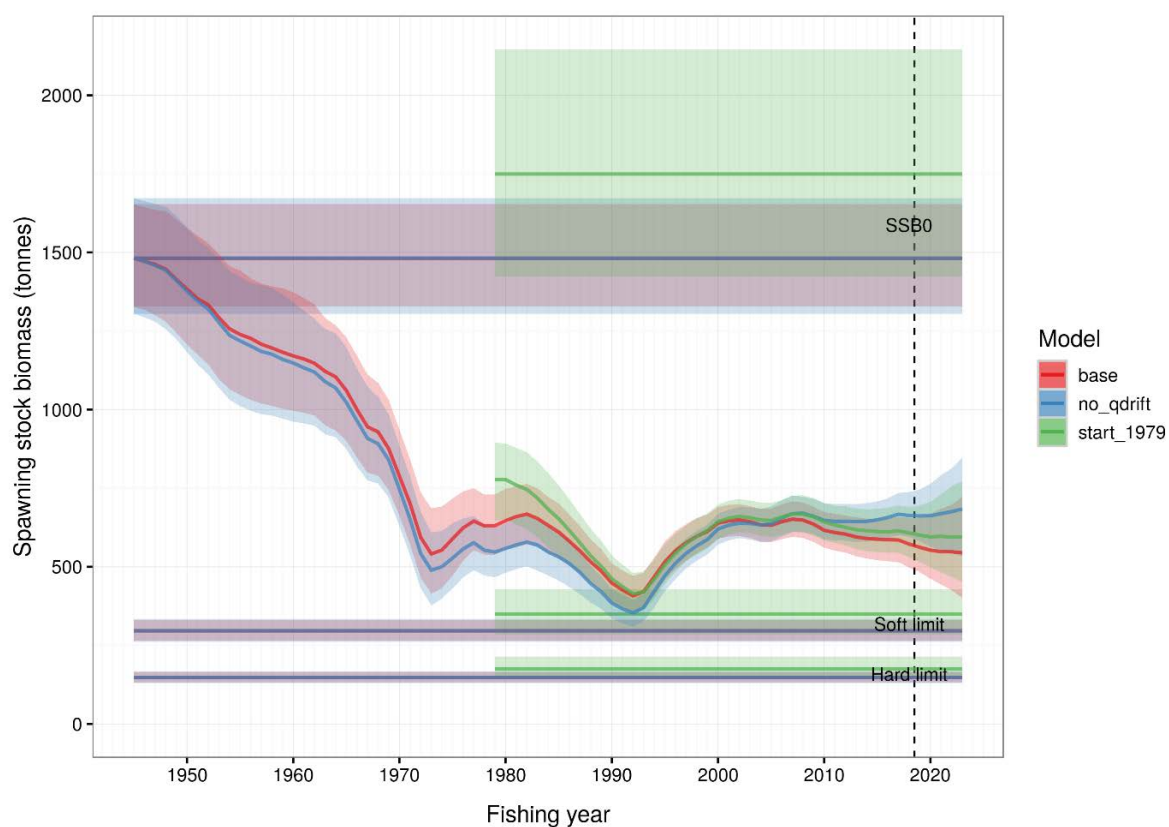


Figure 96: Spawning stock biomass, with unfished spawning biomass and the associated soft limits (20% SSB_0) and hard limits (10% SSB_0) for three CRA 1 runs.

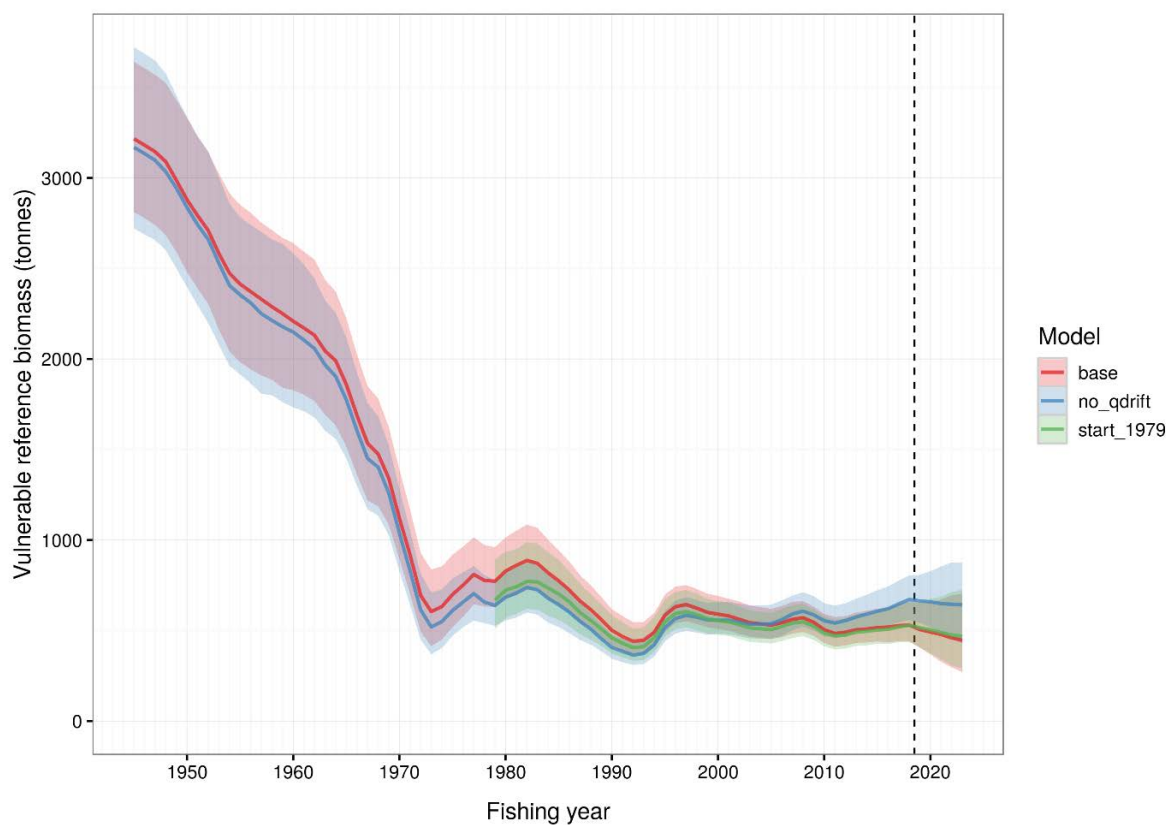


Figure 97: Vulnerable reference biomass for three CRA 1 runs.

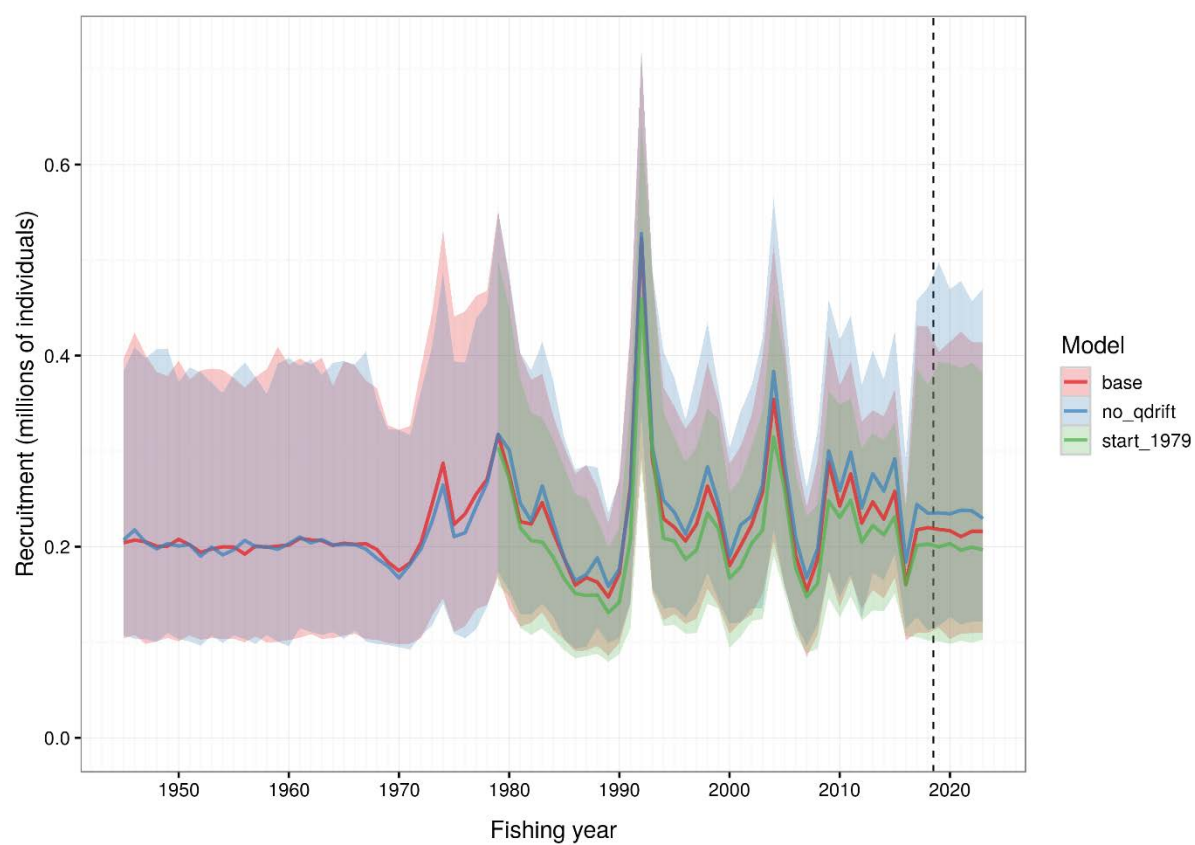


Figure 98: Recruitments for three CRA 1 runs.

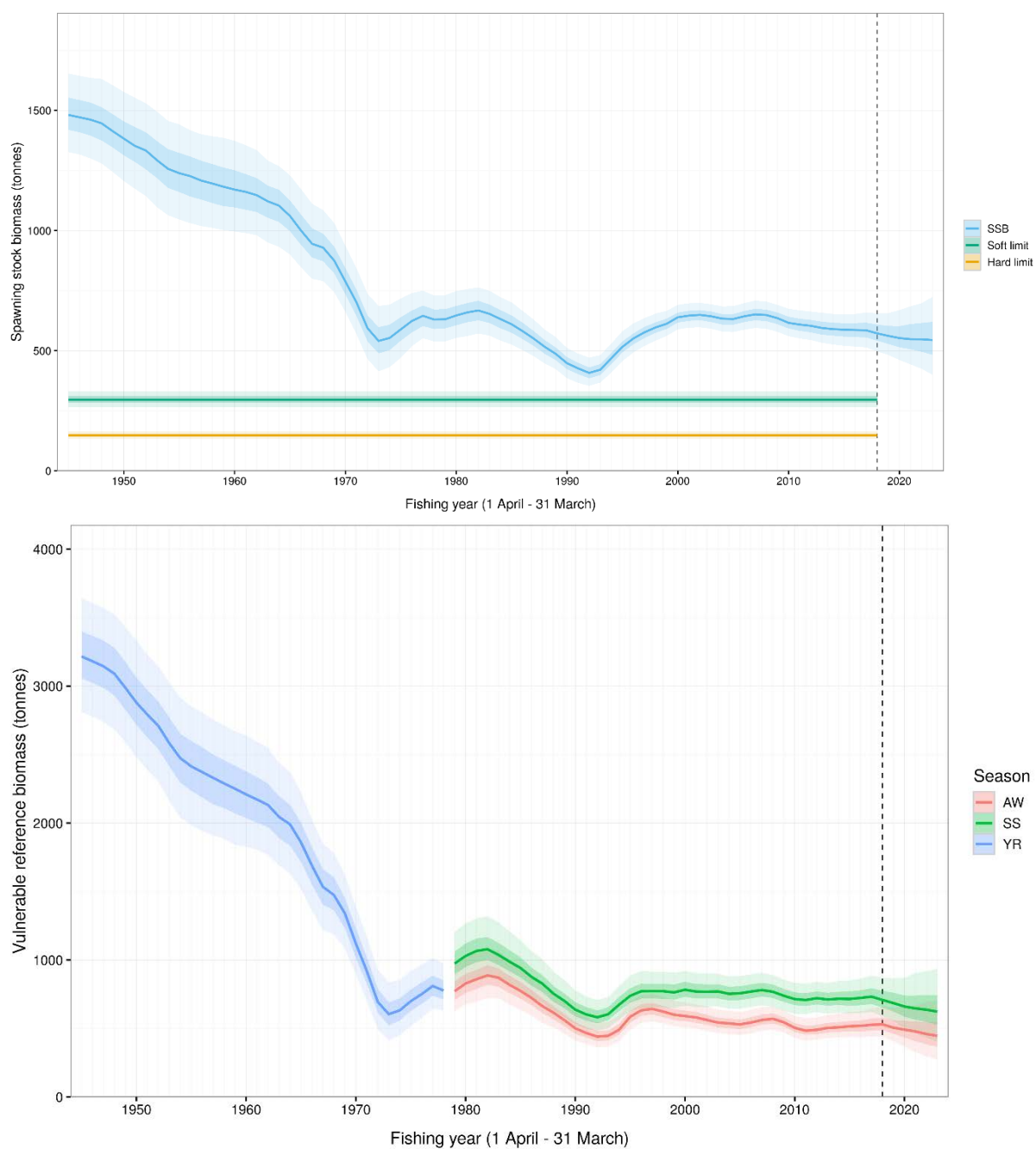


Figure 99: Base case current catch projection.

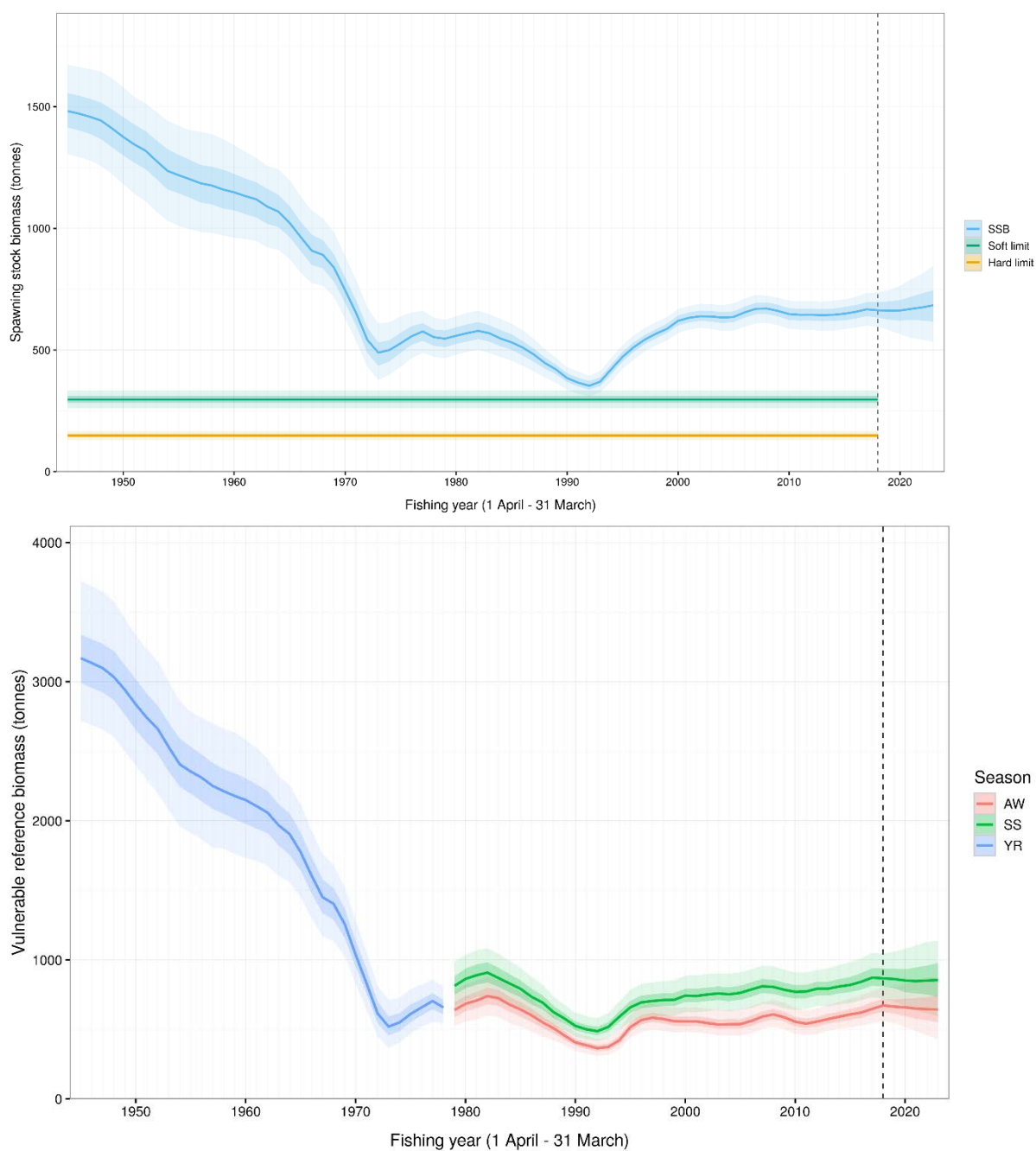


Figure 100: *No_qdrift* current catch projection.

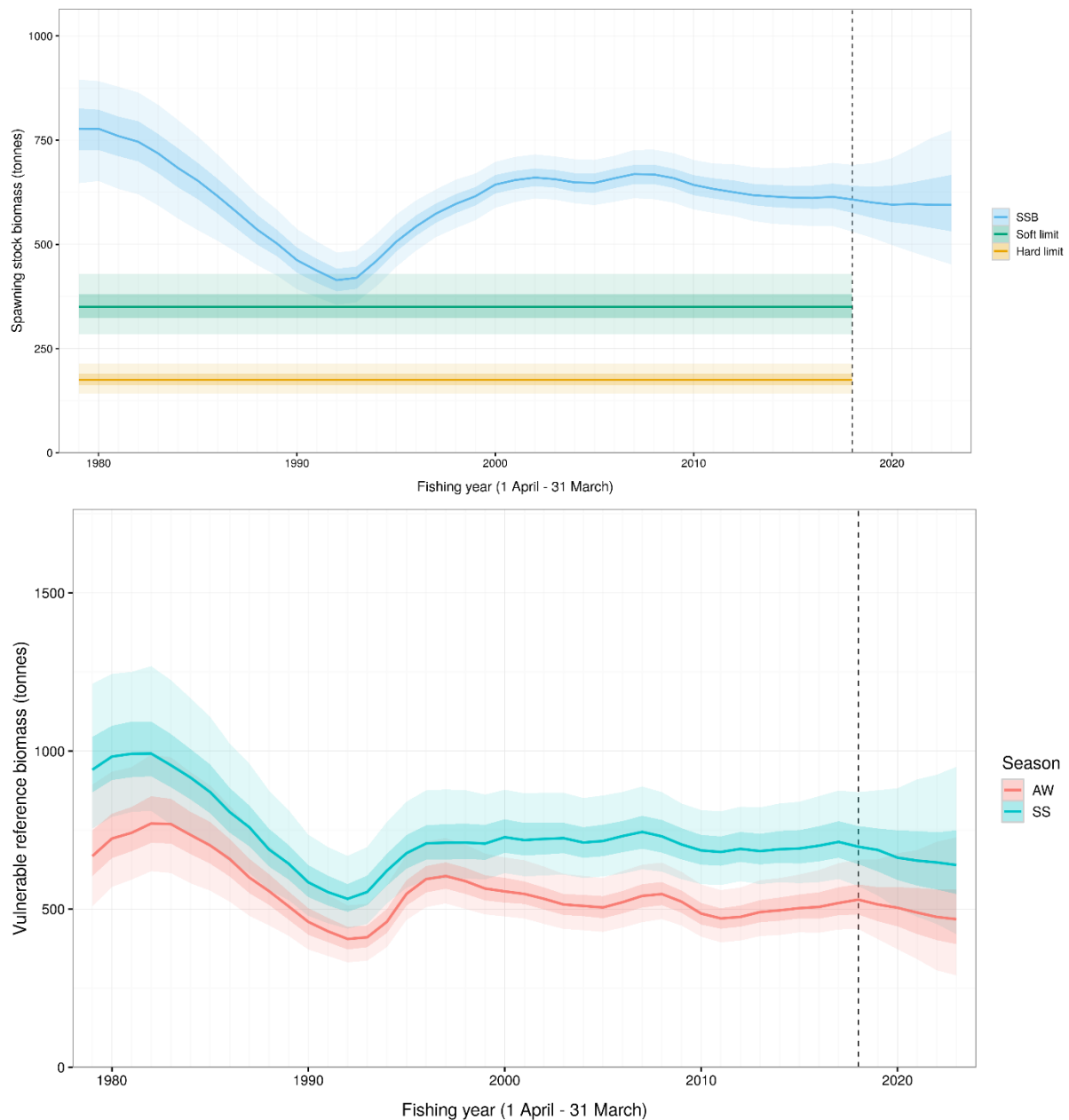


Figure 101: start_1979 current catch projection.