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Tini a Tangaroa

The 2022 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2

New Zealand Fisheries Assessment Report 2023/43

M.B. Rudd, M. Pons, D.N. Webber, P.J. Starr,
J. Roberts, Z.D. Goeden

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Fisheries Science Editor
Fisheries New Zealand
Ministry for Primary Industries
PO Box 2526
Wellington 6140
NEW ZEALAND

Email: Fisheries-Science.Editor@mpi.govt.nz
Telephone: 0800 00 83 33

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
1. INTRODUCTION.....	2
2. STOCK ASSESSMENT	3
2.1 Data	3
2.2 Covariates.....	4
2.3 Model	5
2.4 Parameters and priors	6
2.5 Assessment indicators	6
2.6 Maximum <i>a posteriori</i> (MAP) inference	7
2.7 Bayesian inference using Markov chain Monte Carlo (MCMC)	12
2.8 Reference level.....	14
2.9 Projections.....	15
3. DISCUSSION	16
4. POTENTIAL RESEARCH.....	17
5. FULFILLMENT OF BROADER OUTCOMES	17
6. ACKNOWLEDGEMENTS	18
7. REFERENCES.....	18
8. TABLES.....	20
9. FIGURES.....	36
APPENDIX A. GLOSSARY	95
APPENDIX B. MCMC LENGTH FREQUENCY FITS.....	103

EXECUTIVE SUMMARY

Rudd, M.B.¹; Pons, M.²; Webber, D.N.³; Starr, P.J.⁴; Roberts, J.⁵; Goeden Z.D.⁶ (2023). The 2022 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2.

New Zealand Fisheries Assessment Report 2023/43. 108 p.

This document describes the 2022 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2. The stock assessment used the lobster stock dynamics (LSD) model. Data inputs and technical decisions were discussed and agreed upon by the Rock Lobster Working Group (RLWG), who oversaw this work.

The model was fitted to length frequency data, sex ratio data, tag-recapture growth increment data, and standardised catch-per-unit-effort (CPUE) indices. 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 stock assessment assumed a single-region model that combined all CRA 2 statistical areas. This model choice was informed by a regional characterisation of the fishery data, where catch-per-unit-effort and length frequency distributions did not vary enough spatially to warrant a multi-region approach to modelling the stock. The reconstruction of the base model began in 1979, as was done in the 2017 assessment, due to uncertain commercial catches in the early years of the fishery and negligible differences in the stock trajectory in sensitivity analyses.

This stock assessment estimated generally increasing exploitation rates throughout the stock's history leading to a continuous decline in vulnerable biomass except for a period in the late 1990s where there was an increase in stock biomass, likely due to a recruitment pulse. The 2017 stock assessment estimated that the stock was below the soft limit, requiring a rebuilding plan. Catch cuts in the late 2010s and a period of improved recruitment around 2015 have helped the stock rebuild since the 2017 stock assessment. This stock assessment also estimated a reference level for CRA 2 and the stock was estimated to be above the reference level.

¹ Scaleability LLC, Seattle, USA.

² Independent consultant, Montevideo, Uruguay.

³ Quantifish Ltd, Tauranga, New Zealand.

⁴ Independent consultant, Wellington, New Zealand.

⁵ Anemone Consulting Ltd, Wellington, New Zealand.

⁶ Independent consultant, Wellington, New Zealand.

1. INTRODUCTION

The National Rock Lobster Management Group (NRLMG) decided that a stock assessment for red rock lobsters (*Jasus edwardsii*) in CRA 2 should be done in 2022. This stock assessment was completed in a workshop during September and October 2022. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Working Group (RLWG). The stock assessment was presented to and approved by the Fisheries New Zealand mid-year Plenary in November 2022 (Fisheries New Zealand 2022).

The CRA 2 Quota Management Area (QMA) extends from Te Arai Point, south of Whangarei, to East Cape at the easternmost end of the Bay of Plenty (Figure 1). This QMA includes: the Hauraki Gulf, the Coromandel Peninsula, the Great and Little Barrier Islands, and the Bay of Plenty.

Beginning with the 2014–15 fishing year and extending to the 2019–20 fishing year, the CRA 2 Total Allowable Commercial Catch (TACC) was set using an evaluated management procedure (MP). The MP was suspended after 2020 because the introduction of electronic reporting changed the reporting process of the rock lobster catch and effort data, resulting in a lack of comparability with data collected previously on paper forms. The current CRA 2 TACC is 80 tonnes. The CRA 2 non-commercial allowances set by the Minister of Fisheries were 16.5 tonnes for customary catch, 34 tonnes for recreational catch, and 42.5 tonnes for illegal removals, for a Total Allowable Catch (TAC) of 173 tonnes. Each component of the fishery is meant to stay within its allowance, but only the commercial catch is actively constrained to stay within the TACC via the application of the controls implemented through the Quota Management System (QMS). Additional management tools include output controls including: minimum legal sizes (MLS), which, in CRA 2, is 54 mm tail width (TW) for males and 60 mm TW for females for both the commercial and recreational fisheries; and a general prohibition of the take of berried females and soft-shelled individuals. The recreational fishery is constrained by a bag (possession) limit of three lobsters for a fisher in a day.

Potting and hand-gathering are the preferred methods for recreational fishers in CRA 2 (see table 4 of Roberts et al. 2023). Most of the recreational catch is taken during the summer months, consistent with other red rock lobster stocks. The region also sustains a dive charter industry catering to recreational fishing during summer. The customary allowance allows lobsters to be taken under permit.

The previous (2017) CRA 2 stock assessment estimated that the spawning stock biomass (*SSB*) was below the 20% B_0 soft limit in 2016–17 (Webber et al. 2018). This outcome triggered management actions in the form of significant catch cuts to all sectors of the fishery, which were implemented in April 2018 (see Fisheries New Zealand 2022). Rapid updates in 2020 and 2021 indicated that there had been improvements in the CRA 2 stock status after the implementation of these catch reductions (Webber et al. 2021a, Rudd et al. 2022).

This document presents a new stock assessment for CRA 2, which includes updates to the catch-per-unit-effort (CPUE) standardisation procedure and other inputs up to the end of the 2021⁷ fishing year. All tables referred to in this document can be found in Section 8 and all figures are in Section 9. A glossary of terms can be found in Appendix A.

⁷ The 2021–22 fishing year is referred to in this document with the first year (2021) of the pair of years.

2. STOCK ASSESSMENT

The previous stock assessment of CRA 2 (Webber et al. 2018) used the lobster stock dynamics (LSD) model (Webber et al. 2023). The LSD model was coded in Stan (Stan Development Team 2016, 2017) and has now been used as the main assessment software for all assessed rock lobster stocks in New Zealand, including CRA 2 (2017, 2022, Webber et al. 2018), CRA 6 (2018, 2023, Rudd et al. 2019), CRA 1 (2019, Rudd et al. 2021a), CRA 3 (2019, Webber et al. 2020), CRA 4 (2020, Rudd et al. 2021b), CRA 5 (2020, Webber et al. 2021b), and CRA 7&8 (2021, Webber et al. 2022).

Maximum *a posteriori* (MAP) estimation and Markov chain Monte Carlo (MCMC) simulation were used to make inference about the CRA 2 stock. MAP runs were used to develop a base case model and then a series of MAP model runs were used to explore the sensitivity of model outputs to changes in model structure and inputs. Full Bayesian inference using MCMC was completed for the base case model run and a subset of the sensitivity model runs. The posterior distribution of the base case model run was used to derive the CRA 2 reference level (Rudd et al. 2021c). Finally, the posterior distributions from the base case and a subset of sensitivity model runs were used to project forward five years for providing management advice.

The data and covariates used in this stock assessment were documented by Roberts et al. (2023) and are summarised briefly in Section 2.1 and Section 2.2 below. The stock assessment model settings are described in Section 2.3 and model parameters and priors are defined in Section 2.4. Finally, the stock assessment outputs including stock status indicators are defined in Section 2.5.

2.1 Data

The data sets used in this stock assessment included CPUE time series, length frequencies (LFs) of the commercial catch, sex ratios (SRs) of the commercial catch, and tag-recapture data collected by commercial and recreational fishers. Puerulus settlement indices were not available in CRA 2. The temporal extent of the input data and covariates are illustrated in Figure 2.

Four separate CPUE series were available for use in this stock assessment including:

- The catch rate (CR) series, which is an annual arithmetic daily catch rate from 1963 to 1973.
- The Fisheries Statistics Unit (FSU) series, which is a seasonal standardised index from April-September (autumn/winter or AW) 1979 to AW 1989. The standardisation model included year, month, statistical area, and vessel explanatory variables. The FSU CPUE standardisation included all vessels.
- The Catch Effort Landing Return (CELR) series, which is a seasonal standardised series from October-March (spring-summer or SS) 1989 to AW 2019. The standardisation model included year, month, statistical area, and vessel explanatory variables. The CELR CPUE standardisation data set only included vessels that had fished for at least five years in CRA 2.
- The logbook series, which is a seasonal standardised series from AW 1993 to SS 2022. The standardisation model included year, month, statistical area, and vessel explanatory variables. The logbook CPUE standardisation included all vessels that reported logbook data.

The apparent change in reporting behaviour associated with the change in commercial catch and effort data collection from paper forms to electronic monitoring prevented the extension of the CELR CPUE abundance series beyond the autumn/winter of the 2019 fishing year (see appendix B in Starr 2022 for the evidence supporting this decision).

Biological sampling in CRA 2 has been done by observer catch sampling from 1986 to 2021. The CRA 2 fishing industry made a commitment to the voluntary logbook programme when it was first introduced in 1993, implementing this sampling methodology as the primary source of stock monitoring

information from 1993 to 2021. Both sets of data were used in the 2022 stock assessment to derive standardised LFs and SRs of the commercial catch and CPUE.

This assessment used paired individual tag-recapture observations from initial tags releases in all four CRA 2 statistical areas (905, 906, 907, and 908) (Figure 1). Tag-recapture data were used to inform growth within the stock assessment model and were also useful to inform the degree of movement within CRA 2 and among other QMAs. Consistent with the base case model of the 2017 assessment (Webber et al. 2018), which identified a negative bias in the growth residuals after the first recapture event, only growth information from the initial release-recapture event was used (i.e., excluding subsequent recaptures after re-release). Including re-releases in the assessment was previously found to have very little effect on the model prediction of stock status (Webber et al. 2018).

2.2 Covariates

The covariates used in this stock assessment included the catch, assumed handling mortality rates associated with the commercial and recreational catch, the MLS, estimates of the proportion of mature females in berry (i.e., egg bearing), and other fixed quantities provided in Table 1.

The commercial catch time series came from a range of sources from 1945 up to the present, described by Roberts et al. (2023). Similarly, the development of the non-commercial catches was also described by Roberts et al. (2023). Catches in the model were implemented annually up to 1978, after which catches were divided into the AW and SS seasons. The commercial and recreational catches were combined within the model to form the size-limited (SL) catch, being the component that conformed to the MLS and the non-retention of berried females, while the customary and illegal catches were combined to form the non-size-limited (NSL) catch, whereby the full range of captured lobsters were kept without discarding undersized or berried lobsters.

Handling mortality was assumed to be 10% for all lobsters returned to sea before 1990 and 5% from 1990 onwards. This step-reduction in handling mortality was agreed by the RLWG to coincide with the start of the live export market and the introduction of rock lobsters into the QMS, under the assumption that fishers would take more care in the handling of lobsters once they became quota owners, to maintain a high-quality product for live export. Handling mortality was applied to undersized lobsters of each sex taken in either season by the SL fishery as well as to mature berried females taken by both the AW and SS SL fisheries. It was assumed that there were no discards in the NSL fishery. Unlike other New Zealand rock lobster fisheries, discarding of large lobsters is rare in CRA 2, so discard mortality for this category was not modelled in this stock assessment. The value H_{2021} is the model estimate of the amount of handling mortality (in tonnes) in the final fishing year (2021).

From 1945 to 1949, there was no MLS for red rock lobster in New Zealand. MLS restrictions were initially implemented for New Zealand red rock lobster as measurements of tail length in inches. This measurement standard was subject to some abuse because tails could be stretched, but it was required because a significant fraction of the catch came from Fiordland where it was permissible to tail lobsters at sea. The MLS was changed to a width measurement (in mm) across the spines of the second abdominal segment (called the tail width or TW) in 1988 for all New Zealand red rock lobsters, requiring the conversion of the pre-1988 regulations into equivalent TW measurements for use in the stock assessment model (Breen et al. 1988). The TW values used for the MLS in the model are provided in Table 2.

The proportion of mature females in berry is a covariate that excludes berried females from the catch in the SL fishery (legal commercial and recreational catch). Previous New Zealand rock lobster stock assessments treated this process as binary, assuming all females were in berry during the AW season and none in the SS season. This assessment used logbook data to derive unstandardised proportions of berried females for AW and SS for all of CRA 2, that were averaged over all years. The stock assessment model was modified to allow the mature females in berry by season to be a proportion (rather than binary) by year, season, and region. Based on logbook data, the average proportion of berried females was 0.825 in AW and 0.178 in SS.

2.3 Model

The lobster stock dynamics (LSD) model was described by Webber et al. (2023). The model tracks numbers of individual lobsters in three sex categories (immature females, mature females, and males) for each of 31 two-mm TW bins, by year, and season.

Like the previous CRA 2 stock assessment model, the first model year was set to 1979 and an equilibrium population structure with an initial exploitation rate (U_0) was estimated. This was done because there is uncertainty in the quality of all catch estimates before the FSU system began in 1979, but there is confidence in the quality of the commercial catch estimates from the FSU and QMS systems. The last year in the reconstruction of the stock was 2021, but this was extended to 2026 for the projections. All catches in the base case model were split into the AW and SS seasons, but for the sensitivity run starting in 1945, a calendar year model time step from 1945 to 1978 was adopted, with the January–March 1979 catches added to 1978 to ensure no catch was lost when changing from calendar year to fishing year. Fishing years in the model started in 1979–80 (denoted as 1979) and extended from 1 April to 31 March. The model used two six-month seasons within a model year: AW (April to September) and SS (October to March).

The 2022 stock assessment treated CRA 2 as a single homogenous area, as was done in the previous two assessments for this stock in 2017 (Webber et al. 2018) and 2013 (Starr et al. 2014). This choice was informed by a lack of regional variation in CPUE, length frequency distribution, and growth rate from the available tag-recapture data, as well as in the regional distribution of catch through time.

A logistic selectivity ogive was assumed to define the size composition of the fishery catch (i.e., the commercial and recreational catch), which was assumed to be size class and sex-specific and the same for both immature and mature females. Selectivity was assumed to be the same during the AW and SS seasons. This is an update from the 2017 assessment (Webber et al. 2018) which assumed a double normal ogive, although with the right-hand limb fixed to a shape approximating logistic selectivity (i.e., nearly fully selected at large size).

Vulnerability parameters defined the relative scaling (i.e., the height) of the selectivity curves by sex and season. The LSD model allows up to six vulnerabilities to be specified, with one per sex category and season. These parameters were estimated relative to the sex/season category with the greatest assumed vulnerability (i.e., most often males in AW are assumed to have the highest vulnerability, so that parameter would be fixed to one) and the remaining vulnerability parameters estimated to be between zero and one relative to the maximum selectivity.

To account for retention and discarding, retention was defined as the probability of retaining an individual lobster by year, season, sex, and size class. For CRA 2, this included legal status rules (MLS and the proportion of mature females in berry) but did not include any other forms of retention, such as high-grading.

New for the 2022 CRA 2 stock assessment, the LSD model removed catch from the population and used discrete exploitation rates instead of instantaneous fishing mortality rates as was done in previous rock lobster stock assessments. The combination of selectivity, vulnerability, and retention was used to define exploitation rates (U) for the SL fishery, while only selectivity and vulnerability were needed to define exploitation rates for the NSL fishery.

Also new for the 2022 CRA 2 stock assessment, a model-based method was introduced for fitting to sea surface temperature (SST) indices or other covariates that may influence recruitment. SST indices were fitted to in the same way as puerulus indices were in previous rock lobster stock assessments (Webber et al. 2023).

2.4 Parameters and priors

Estimated model parameters included productivity parameters (i.e., average recruitment, natural mortality, and growth), maturation parameters, and fishery parameters (i.e., catchability, selectivity, and vulnerability). All model parameters are listed in Table 3.

Four vulnerability parameters (i.e., *vuln1*, *vuln2*, *vuln3*, and *vuln4*) were estimated for: SS males, AW immature females, SS immature and mature females shared, and AW mature females (Table 4).

Uninformative priors with wide parameter bounds were specified for most model parameters (Table 5). Wide uniform priors were specified for the catchability coefficient (q) for each of the CPUE series and recruitment deviates (Table 5). Beta distributions, with both shape parameters set to one, were used for priors for all parameters bounded between zero and one including *Gdiff* and all vulnerability parameters (Table 5). An informative lognormal prior was specified for natural mortality (M); and informative normal priors were specified for the growth parameters *Gshape*, *GCV*, and *Gobs*, based on an unpublished meta-analysis (Table 5). Uninformative normal prior distributions were specified for all other model parameters (Table 5). These uninformative normal priors were essentially flat across sensible ranges for each of these parameters and, therefore, did not influence the outcome of the stock assessment, although they helped the model software (Stan) during the warm-up phase of the MCMC algorithm.

2.5 Assessment indicators

Work has been completed to develop model-based reference levels for red rock lobster stocks. To calculate the reference level, a wide range of fixed catch and fixed U rules were projected forward 30 years, and the performance of each rule was assessed over the final 20 years of the projection period. Recruitment deviates in the projection were based on estimated recruitment deviates starting in the first year with a reasonable amount of length data and ending three years before the final model year. For CRA 2, this included 26 years from 1993 to 2018. Stock assessments for other QMAs typically estimated recruitment deviates up to two years before the final model year. This was adjusted for the 2022 CRA 2 stock assessment due to an estimated recruitment spike in 2019, when that recruitment deviate was allowed to be estimated. While this could be caused by an observation of small individuals recruited in recent years or model weighting to fit increasing CPUE, the RLWG and the Plenary were uncomfortable with including this recruitment spike and wanted to wait until further years of data were available to inform it. Evaluated performance indicators included the average annual catch, the coefficient of variation (CV) of catch over time, and the probability of falling below the soft limit (20% SSB_0). The rule that maximised catch while maintaining less than 5% chance of falling below the soft limit was identified for each rule type (fixed catch or fixed U). Fixed catch rules were further constrained by requiring 99% of the fixed catch amount to be able to be taken for more than 95% of years and simulation replicates. The reference level (B_R) was defined as the average adjusted vulnerable biomass between the maximum constrained fixed catch and fixed U rules. The methods used to estimate the reference levels are more thoroughly discussed by Rudd et al. (2021c).

This assessment used the same indicators that were used in the 2021 CRA 7&8 assessment (Table 6, Table 7, Webber et al. 2022), but it used a discrete exploitation rate in place of the instantaneous fishing mortality rate that was used in previous rock lobster stock assessments. The exploitation rate associated with the reference level was updated to be defined as the fixed exploitation rate associated with a median vulnerable biomass equal to B_R at equilibrium (U_R). The main indicators were related to the relative estimates of adjusted vulnerable biomass⁸, spawning stock biomass (SSB), and total biomass, including the probabilities that each of the biomass indicators would fall below current levels after projecting the current catch forward for five years. Probabilities were calculated over all samples of the posterior distribution.

⁸ In past stock assessments, this quantity was called 'vulnerable reference biomass' rather than 'adjusted vulnerable biomass'. This change was made to distinguish clearly between rock lobster reference points and this biomass definition.

In the past, vulnerable biomass was defined as start-of-season AW biomass, which did not include any mature females because they were all assumed to be in berry in this season and, therefore, not harvestable. However, in this assessment, a small proportion of mature females (the proportion not in berry—see AW proportion in berry estimate given in Table 1) were included in the AW vulnerable biomass. Vulnerable biomass accounts for the MLS, selectivity, and sex/seasonal vulnerability and was the estimated biomass available to be caught by the fishery at the beginning of the AW season. Adjusted vulnerable biomass was calculated by applying the MLS and selectivity from the final model year to all previous years, including those years where earlier regulations were active.

The probability of the *SSB* being below the soft and hard limits was also calculated. *SSB* was defined as the biomass of all mature females at the start of AW. SSB_0 was the *SSB* at unfished equilibrium with R_0 . The soft and hard limits were set to the default values from the Harvest Strategy Standard (Ministry of Fisheries 2011), i.e., 20% SSB_0 and 10% SSB_0 , respectively.

2.6 Maximum *a posteriori* (MAP) inference

MAP inference involves identifying the set of parameter values that represent the mode of the density specified by the model. This set of parameter values may be used as parameter estimates or as the basis of approximations to a Bayesian posterior. MAP inference was used for exploring alternative modelling choices without committing the computing time required for Bayesian inference. A base case was developed (Section 2.6.1) and sensitivities (Section 2.6.2) were used to test some of the base case assumptions.

2.6.1 MAP base case

2.6.1.1 Matching the previous assessment model

The 2017 CRA 2 stock assessment model used an earlier version of the LSD model. There have been several updates to the LSD code since then, so the first step in the 2022 assessment involved matching the results from the 2022 model to the 2017 base case assessment. Key updates for the 2022 assessment included:

1. Updated the assumed statistical areas for tag data: using more accurate assignment of statistical area from latitude and longitude than was previously used (see appendix F of Roberts et al. 2023; the main differences being that some tags were moved from statistical area 905 to 906 and from statistical area 908 to CRA 3).
2. Assumptions about recreational catch: the WG decided to exclude the 1994 and 1996 Otago surveys as they were not considered to be reliable and are no longer used to inform stock assessments for other species/fish stocks. Recreational catch was based on SS seasonal CPUE series (FSU/CELR 1979–1992, logbook 1993–2018) fitted to 2010 and 2011 Holdsworth surveys (Holdsworth 2016) and National Panel Surveys in 2011–12 and 2017–18 (Wynne-Jones et al. 2014, 2019) and assumed recreational catch for 2019, 2020, and 2021 was equal to the model maximum likelihood estimate from Hartill et al. 2022 – see section 2.2 of Roberts et al. 2023).
3. Assumptions about illegal catch: the RLWG agreed to discontinue the use of the export discrepancy approach for early years, as has been done for recent assessments of other QMAs. Illegal catch was assumed to be 20% of commercial catch from 1945 to 1989 and 10% of commercial catch from 1990 to present. Illegal catch for 1979–present was scaled by annual CPUE approximated by the average of seasonal CPUE for each year (FSU/CELR 1979–1992, logbook 1993–2021), with a constant average for years prior to 1979.
4. Inclusion of logbook CPUE series: updated model code to include newly developed logbook CPUE series for 1993–2021, in terms of numbers, with FSU (1979–1989) and overlapping CELR (1990–2019 AW) also included, in terms of kg/potlift.
5. Standardised length frequency and sex ratios: previous approach kept catch sampling and logbook data separate using ad-hoc weightings; the 2022 updated approach standardised the LFs and SRs

based on various attributes including source, resulting in a single series for each year, season, and sex category—weighted by the catch and sample size.

6. Calculation of discrete exploitation rates instead of instantaneous fishing mortality rates: this resulted in negligible changes to model estimates and no longer required running iterations of the Newton-Raphson algorithm to calculate fishing mortality rates, which improves speed of model runs.
7. Changed from double-normal to logistic selectivity: the previous assessment fixed the right-limb selectivity to be approximately logistic, but choosing logistic selectivity simplified the model structure and resulted in negligible changes to model estimates.
8. Used average proportion of mature females in berry covariate derived from the logbook data to update the assumption of 100% berried in AW and 0% berried in SS based on logbook data from fishing year, season, and month. The 2022 stock assessment used an average over years by season. This resulted in minor changes to model results but is expected to model the *SSB* and vulnerable biomass more accurately.
9. Estimated recruitment deviates to 2018 (three years prior to final model year) rather than 2019 (other rock lobster stock assessments have typically used two years prior to final model year). This was to avoid including an estimated 2019 recruitment spike in the model projections until more information is available to inform it, i.e., in future assessments.

2.6.1.2 Searching for a 2022 base case

Exploratory model runs were done to develop a new base case stock assessment model. The following is an abbreviated sequence of steps that led to the CRA 2 base case as model changes were implemented.

1. Including all input data up to the end of 2021.
2. Single selectivity epoch due to lack of early length frequency data.
3. Standardised length frequency data and sex ratios.
4. Discrete exploitation rate (U) in place of instantaneous fishing mortality rate (F).
5. Changed selectivity from double-normal with the right-hand limb fixed at a high value (i.e., essentially logistic) to logistic.
6. Set proportion of berried females to 0.178/0.825 for SS/AW.

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

- Model years: 1979 to 2021⁹, assuming a population at equilibrium fished at a constant rate (U_0) prior to 1979.
- Two six-month seasons: AW (April-September) and SS (October-March), during each fishing year.
- A single model region: for statistical areas 905, 906, 907, and 908.
- Three sex categories: males, immature females, and mature females.
- Tail width bins: 31 two-mm wide bins from 30 mm to 90 mm tail width (last bin was a ‘plus group’ or accumulator bin).
- Recruitment deviations ($Rdevs$): estimated from 1979 to 2018. The final three model years were set to the 2018 estimate, given no real information in data for these recruitments and no puerulus settlement index. No stock recruitment relationship was assumed.
- Size at recruitment specified with a mean of 32 mm and standard deviation 2 mm, based on recent studies of juvenile growth (Figure 3, Roberts & Webber 2022).
- Sex-specific growth using the Schnute-Francis growth model. No density-dependent growth.
- Selectivity: logistic and sex specific.
- Female only maturation ogive.
- Four estimated vulnerability parameters: one per sex per season (see Table 4).
- a single natural mortality shared between sexes.

⁹ April-March fishing years from 1979–80 (1979) to 2021–22 (2021).

- Discrete exploitation rates.
- Handling mortality, two periods: 1979 to 1989 fixed at 0.1, and 1990 to 2026 fixed at 0.05.
- Three CPUE series (FSU, CELR, and logbook), each with a separate catchability coefficient (q).
- Catch from 1979 to 2021 using updated assumptions on illegal and recreational catch (see sections 2.2, 2.3, and 2.4 of Roberts et al. 2023).
- Fixed increasing trend in catchability coefficient ($qdrift$) at 1% per year for both the CELR and logbook series. No $qdrift$ assumed for the FSU series (Figure 4).
- Only fit to the first tag-recapture event, discarding all subsequent recovery events following re-releases of the same lobster.
- Likelihoods:
 - Lognormal for all CPUE series (CR, FSU, and CELR);
 - Robust normal for tags;
 - Multinomial for LFs, fitted to standardised proportions at length for males, immature females, and mature females, with each sex category normalised separately; and
 - Multinomial for SRs.
- Data weighting: determined iteratively and simultaneously for all data types. The LFs were weighted following the TA1.8 weighting method of Francis (2011) and the other data types were weighted aiming for a standard deviation of the normalised residual (SDNR) of one. No re-weighting of tag data because they are self-weighting through the estimation of an observation error parameter.

The *base* case model fit to the FSU CPUE series (from 1979 to 1988) was adequate (Figure 5), with the exception of one year during the AW (i.e., the standardised residual was outside of the ± 2 range during AW 1979, Figure 6). The fit to the CELR CPUE series (since 1990) was also adequate (Figure 5), with the exception of one year during the AW and two years during the SS (i.e., the standardised residuals were outside of the ± 2 range during AW 1998, SS 1999, and SS 2017; Figure 6). The fit to the logbook CPUE series (since 1993) was also adequate (Figure 5), with the exception of two years during the AW and one year during the SS (i.e., the standardised residuals were outside of the ± 2 range during AW 2009, AW 2018, and SS 1999; Figure 6).

The *base* case model fit to the sex ratio data was reasonably good (Figure 7), with the exception of only a few points, and there was no pronounced residual pattern with respect to year (Figure 8).

Model fits to the LF data were generally acceptable (Appendix B), and only a few size classes of standardised residuals were outside the ± 2 range (Figure 9) and during very few years (Figure 10). This is a vast difference to standardised residuals for LF fits in previous stock assessments and is likely attributable to the new standardisation procedure for the LF data.

The most notable feature of the tagging data used to estimate growth is the extreme variability in the observed individual growth increments, through which the model finds an average (Figure 11). This variation could be attributed to measurement error, individual variability in growth, spatial-temporal variability, or the short time period many lobsters spend at liberty. However, it is important to note that this model is using a continuous growth function to model growth, while lobster growth is a discrete process (i.e., growth can only occur after moulting). Attempts were made in the early 2000s to model growth more realistically, but these were unsuccessful because there is no reliable indicator that can be used to determine whether a lobster has recently moulted. However, while the residuals in this growth model are large, there is little evidence for a systematic bias by sex in terms of statistical area of release (Figure 12).

The size distribution of the unfished population (Figure 13) suggests there were many large males (in terms of TW) as indicated by the large number in the plus group.

The selectivity functions by sex (Figure 14) are simplified from previous assessments that included an early epoch that was dropped by this stock assessment (the previous assessment assumed different

selectivity pre-1993 and from 1993 onwards because it used small amounts of observer sampling data that were omitted from this assessment).

Fifty percent of female maturation was estimated to occur near to the 50 mm TW bin in CRA 2 (Figure 15), indicating that the fishery probably takes few sub-mature females, because the MLS is 60 mm TW.

The MAP estimate of the initial exploitation rate (U_0) was low at 0.069. The SL exploitation rate generally followed an increasing trend throughout the mid-2010s, with the exception of a sharp decline in the SS season in the mid-1990s, because of a shift of catches to the AW season in response to high abundance in that period (Figure 16). The exploitation rate was estimated to have decreased dramatically since the mid-2010s in response to declining SL catches. The NSL exploitation rate was estimated to have remained relatively constant, with the exception of declines in SS in the mid-1990s and late-2010s translating to increased exploitation rate at the same time in the AW season (Figure 16). However, the NSL exploitation rates were estimated to be low compared with the SL exploitation rates.

CRA 2 appeared to have experienced a relatively strong recruitment pulse in the years around 1993 (Figure 17). Otherwise, recruitment has remained below average since the mid-1990s, with three spikes above the estimated R_0 in 2004, 2010, and 2015 (Figure 17).

Plots of the adjusted vulnerable biomass showed a strong declining trend from 1979 to the mid-1990s. The large recruitment pulse around 1993 and sharp decrease in the estimated exploitation rate contributed to a boost in vulnerable biomass in the mid-1990s. Vulnerable biomass then declined until catches were cut in the late 2010s (Figure 18).

All parameter estimates, likelihoods for all data components, indicators, and other derived parameters are presented for the *base* case in the first column of Table 9.

2.6.2 MAP sensitivity trials

The RLWG decided on sixteen sensitivity trials as single variants relative to the *base* case (Table 8). These included sensitivities testing assumptions relating to key *base* model assumptions and updates from 2017 (Group 1: *base_F*, *berry_01*, *no_qdrift*, and *start1945*), exploring the relationship between M and selectivity (Group 2: *fixM*, *selRH*, and *selRH_fixM*), time-varying selectivity and vulnerabilities (Group 3: *sel1_vuln3*, *sel3_vuln1*, and *sel3_vuln3*), SST covariates (Group 4: *rec_sst_1yr*, *rec_sst_3yr*, and *rec_sst_3yr_1945*) (see appendix C of Roberts et al. 2023 for a description of how the SST indices were produced), and successively down-weighting the CPUE, sex ratio, or LF data sets (Group 5: *downCPUE*, *downSR*, *downLF*). The runs which down-weighted the primary data components were instructive as diagnostics, but cannot be used as credible runs.

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the sixteen sensitivity trials are presented in Table 9. The estimated *base* case selectivities, recruitment, and vulnerable biomass were compared with the sensitivity runs, grouped in five blocks of related runs (as indicated above), as well as a comparison with the previous 2017 CRA 2 stock assessment and the 2021 CRA 2 rapid update (Rudd et al. 2022) (Figure 19–Figure 36).

The Group 1 sensitivities (*base_F*, *berry_01*, *no_qdrift*, and *start1945*) had negligible impact on predicted vulnerable biomass (Figure 32). Setting *qdrift* to 0 resulted in slightly higher adjusted vulnerable biomass in 2019, 2020, and 2021 compared with the other model runs (Figure 32). The Group 2 and Group 3 models, that either fixed M to 0.12, estimated right-limb selectivity, or included time-varying selectivity and vulnerabilities shifted, predicted lower levels of vulnerable biomass across the full time series when compared with the *base* model. Model run *sel3_vuln3*, which included three blocks of time varying vulnerabilities and selectivities, estimated the greatest downward shift in vulnerable biomass relative to the *base* model (Figure 33 and Figure 34).

The MAP fits of model runs *rec_sst_1yr*, *rec_sst_3yr*, and *rec_sst_3yr_1945* to the respective SST indices are shown in Figure 37 and Figure 38. These were reasonably good given that other processes might also affect interannual recruitment strength experienced by the fishery, with relatively high recruitment in the coldest years in the time series, around 1993. Including SST covariates on recruitment resulted in lower estimated vulnerable biomass in recent years (Figure 35). While recruitment generally followed the same patterns as the *base* model throughout the time series, an increase in recruitment estimated by the *base* model for 2018 did not occur for the models that included the SST covariate (Figure 29).

A summary of the sensitivity runs is provided below (also see Table 8).

- ***base_F***: fishing mortality rates instead of exploitation rate, with the initial 1979 biomass estimated to be larger than the *base* but ending at the same absolute level. MCMC was done for this model run.
- ***berry_01***: set to old proportion in berry, with the initial 1979 biomass estimated to be larger than the *base* but ending at the same absolute level. MCMC was done for this model run.
- ***no_qdrift***: set *qdrift* to 0. Setting *qdrift* to 0 resulted in slightly higher adjusted vulnerable biomass in 2019, 2020, and 2021 compared with other model runs. MCMC was done for this model run.
- ***start1945***: start model in 1945. This run matches the *base* run from 1979 onwards. MCMC was done for this model run.
- ***fixM***: fix *M* to 0.12. Predicted vulnerable biomass shifted downward across the time series when compared with the *base* model. MCMC was done for this model run.
- ***selRH***: estimate dome-shaped right-limb selectivity (*M* estimated). Predicted vulnerable biomass shifted downward across the time series when compared with the *base* model, but less than the *fixM* run during the biomass peak in the late 1990s. MCMC was done for this model run.
- ***selRH_fixM***: estimate dome-shaped right-limb selectivity (*M* fixed to 0.12). Predicted vulnerable biomass shifted downward across the time series when compared with the *base* model and with either *fixM* or *selRH* on their own. MCMC was done for this model run.
- ***sel1_vuln3***: one block of selectivity and three blocks of vulnerabilities (see Table 8 for vulnerability block definitions for this and the following two runs) with *M* fixed at 0.12, estimate right-limb selectivity. Vulnerabilities varied by sex and season in the same manner as the *base* model (Table 4) but were time-varying in three blocks (1945–2001, 2002–2017, 2018–2021). Predicted vulnerable biomass shifted downward across the time series when compared with the *base* model, but was negligibly different from other model runs with time-varying selectivity and vulnerabilities.
- ***sel3_vuln1***: three blocks of selectivity and one block of vulnerabilities, with *M* fixed at 0.12, estimate right-limb selectivity. Selectivity varied by sex and was estimated for each of three time blocks (1945–1999, 2000–2009, 2010–2021). Predicted vulnerable biomass shifted downward across the time series when compared with the *base* model, but was negligibly different from other model runs with time-varying selectivity and vulnerabilities.
- ***sel3_vuln3***: three blocks of selectivity and three blocks of vulnerabilities, with *M* fixed at 0.12, estimate right-limb selectivity. Selectivity varied by sex but was estimated in three time blocks (1945–1999, 2000–2009, 2010–2021). Vulnerabilities varied by sex and season in the same manner as the *base* model (Table 4), but were time-varying in three blocks (1945–2001, 2002–2017, 2018–2021). Predicted vulnerable biomass shifted downward across the time series when compared with the *base* model, but was negligibly different from other model runs with time-varying selectivity and vulnerabilities. MCMC was done for this model run.
- ***rec_sst_1yr***: SST covariate of recruitment deviations. almost indistinguishable from the *base* run except that 2020 and 2021 vulnerable biomass estimates are lower than the *base* run.

- **rec_sst_3yr:** SST covariate of recruitment deviations with three-year running mean, almost indistinguishable from the *base* run except that 2020 and 2021 vulnerable biomass estimates are lower than the *base* run.
- **rec_sst_3yr_1945:** SST covariate of recruitment deviations with three-year running mean starting in 1945; matches the *base* run around 1991, then the same as the *base* run except that 2020 and 2021 vulnerable biomass estimates are lower than the *base* run.
- **downCPUE:** down weight the likelihood for all CPUE series to 10%. This run had the greatest impact on predicted vulnerable biomass prior to 1990.
- **downLF:** down weight the likelihood for the LF data to 10%, resulted in some differences in estimated selectivity, growth parameters, and the timing of recruitment spikes relative to the *base* run and some improvement in fit to the CPUE indices, although little change from the biomass trend of the *base* run.
- **downSR:** down weight the likelihood for SRs to 10%, almost indistinguishable from the *base* run.

2.7 Bayesian inference using Markov chain Monte Carlo (MCMC)

Bayesian inference was used to characterise parameter uncertainty. LSD uses the Stan software to run MCMC simulations using the Hamiltonian Monte Carlo (HMC) algorithm. The MAP values (Table 9) were used as starting values. For the *base* case and four selected sensitivity tests (*berry_01*, *fixM*, *no_qdrift*, and *start1945*), the posterior distributions were explored with a total of 1000 samples across four chains, each with a warm-up phase of 500 iterations and length of 500 samples, retaining every second sample.

2.7.1 MCMC base case

MCMC was used to obtain samples from the posterior distribution of the *base* case model described in Section 2.6.1. MCMC trace plots indicated that MCMC chains were well-mixed (Figure 39, Figure 40, and Figure 41). The traces for the key estimated biological parameters, such as M and R_0 , showed an acceptable level of stability, with MCMC chains staying away from parameter bounds. The posterior distributions for most model parameters updated the prior (Figure 42, Figure 43, and Figure 44). However, the posterior distribution of the *Gobs* parameter (labelled as *par_grow_sd[1]* in Figure 43) was beyond the traction of its prior. This is concerning because this parameter defines the observation error associated with the tagging data and, if less error is attributed to observation error, then, by definition, more error is attributed to process error. This process error was used in defining the growth transition matrix, where a higher process error smeared individuals over a wider range of size classes when the transition matrix was applied. These priors were derived from an unpublished meta-analysis based on the tag release-recovery data available in 2015 and should probably be revisited.

Table 10 provides likelihoods, SDNRs, MARs, and parameter estimates, and Table 11 provides derived parameter and probabilities, including projections, for the *base* run. Figures are presented for the MCMC outputs of the *base* case model only. These outputs are comparable with those provided for the *base* case MAP results.

Fits to the FSU CPUE series, the CELR CPUE series, and the logbook CPUE series were acceptable (Figure 45, Figure 46). The fits to the CELR CPUE were similar to the logbook CPUE fits and mirrored the MAP fits to each series (Figure 5, Figure 6). In general, the fits to the AW CPUE index values were better than the SS indices, particularly on the descending limb in the late 1990s, as the stock size was declining after the estimated peak in vulnerable abundance was reached in 1997.

The fits to the sex ratio data (Figure 47, Figure 48) mirrored the MAP fits, with the model able to track the shifting estimates of the sex ratio over time without too much patterning in the residuals.

The fits to the LF data (all MCMC LF fits are presented in Appendix B) and the associated residuals (Figure 49, Figure 50) showed similar properties to those described for the equivalent MAP fits, with some poor fits to the male and mature female lengths at the lower and upper ends of the distributions, but generally the fits to the LFs in the centre of the distributions were acceptable with some bias at the MLS for either sex category.

The plot of growth increments showed surprisingly tight credible intervals despite the large amount of variability shown in the equivalent MAP plot (compare Figure 11 with Figure 51). Tag residual plots by statistical area (Figure 52) confirmed the conclusions reached from the MAP fits: growth was reasonably consistent across the four CRA 2 statistical areas, across recaptures, and by sex. Two further plots show tag residuals by year of release (Figure 53) and by the size at release for each statistical area (Figure 54). The year of release appeared to have little or no bias in the residuals with growth consistent across the nearly 40 years spanning the tag release data (Figure 53). For both sexes, there appears to be some negative bias in model estimates of growth at small sizes relative to the tag-based growth information, and a positive bias at large sizes, except possibly for males in statistical areas 907 and 908 (Figure 54).

The selectivity posterior plots (Figure 55) for the *base* model showed little uncertainty in these parameters, indicating that selectivity was well defined by the data (see the posterior density plots for selectivity in Figure 43 and Figure 44).

The posterior distribution of the maturation curve was only slightly more uncertain than the uncertainty around the selectivity curve, with most females mature below the 60 mm TW MLS (Figure 56). The median estimate for *mat50* (at 50.6 mm) was the same as the MAP estimate (at 50.6 mm).

As noted for the MAP plot, the exploitation rate was high in both the AW and the SS, rising to greater than 0.5 in the SS between 2010 and 2016, before catches were reduced through shelving followed by a TAC cut (Figure 57). It is apparent that the model had no difficulty in accommodating the catches shown in Figure 58.

As for most of these *base* case posteriors, the recruitment posteriors resemble the equivalent MAP plots, with a long period of below average recruitment following the surge in recruitment in the early 1990s, responsible for the low stock status estimated by the 2017 stock assessment (Figure 59).

As seen in the equivalent MAP plot, the plot of adjusted vulnerable biomass showed a decline in biomass from the beginning of the reconstruction in 1979 to the early 1990s, when the decline reversed in response to a period of above average recruitment (Figure 60). This was followed by a strong increase in estimated biomass to a peak in 1997. The estimated vulnerable biomass then dropped steadily until around 2018, after which there began an increasing trend that was projected to continue to 2026 (Figure 60). The *SSB* plot shows a similar trend, with a period of decline followed by an abundance peak in the late 1990s, a decline to 2018, and a subsequent reversal (Figure 61). Total biomass shows the same pattern in both season and for each sex category (Figure 62).

2.7.2 MCMC sensitivity trials

The RLWG chose four of the MAP sensitivity trials to be explored using MCMC, three from Group 1 and one from Group 2 (Table 8): *berry_01*, *fixM*, *no_qdrift*, and *start1945*. The *berry_01*, *no_qdrift*, and *start1945* represent assumptions typically made in previous assessments of CRA 2 (*berry_01*) or in other QMAs (*no_qdrift* and *start1945*) that are key uncertainties. The *fixM* run was included because there was concern that the *M* parameter was not well informed when estimated and recruitment estimates were sensitive to that value. All sensitivity runs had acceptable MCMC diagnostics (not presented).

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the *base* case and these four MCMC sensitivity trials are presented in Table 12 and Table 13. Probabilities associated with model indicators are shown in Table 14 for the four sensitivity runs and the *base* run. Comparisons of these sensitivity trials to the *base* case are shown for fits to the CELR

CPUE indices (Figure 63), the logbook CPUE indices (Figure 64), selectivity (Figure 55), recruitment (Figure 65), and adjusted vulnerable biomass (Figure 66).

The only sensitivity run which differed markedly from the *base* case run was the *fixM* run. This run estimated a substantially lower R_0 and much higher B_0 compared with the *base* run (median R_0 : *base* = 536 000; *fixM* = 393 000, Table 12; median B_0 : *base* = 2826; *fixM* = 4166, Table 13). This translated to a much lower productivity for this run, as well as a lower level of stock status (median B_{2022}/B_0 : *base* = 0.20; *fixM* = 0.13; median SSB_{2022}/SSB_0 : *base* = 0.40; *fixM* = 0.29, Table 13). The lower productivity can be seen in the adjusted vulnerable biomass trajectories, with the *fixM* run lying well below the *base* run and the other three sensitivity runs (Figure 66).

Two of the chosen sensitivity runs differed little from the *base* case run. These were *berry_01* and *no_qdrift*, which did not deviate much from the *base* run in terms of overall stock size, although both runs were slightly more optimistic with regard to stock status (median B_{2022}/B_0 : *base* = 0.20; *berry_01* = 0.22; *no_qdrift* = 0.23; median SSB_{2022}/SSB_0 : *base* = 0.40; *berry_01* = 0.43; *no_qdrift* = 0.43, Table 13).

The sensitivity run which began the stock reconstruction in 1945, consistent with the 2013 CRA 2 stock assessment (Starr et al. 2014), also returned parameter estimates that were similar to the *base* run (Table 12). This is an excellent result because it means that the estimates of the initial exploitation rate in the *base* run are consistent with CRA 2 reconstructed catch history. Estimates of stock size and stock status from this sensitivity run are also consistent with the *base* run (B_0 : *base* = 2826; *start1945* = 2705; SSB_0 : *base* = 1276; *start1945* = 1291; median B_{2022}/B_0 : *base* = 0.20; *start1945* = 0.21; median SSB_{2022}/SSB_0 : *base* = 0.40; *start1945* = 0.39; Table 13).

All four sensitivity runs were evaluated to be above the 20% SSB_0 ‘soft limit’ in 2022 with a probability of 1.0 (Table 14).

2.8 Reference level

An updated reference level (B_R) was calculated based on the CRA 2 *base* model posterior distribution following methods detailed by Rudd et al. (2021c). Samples from the *base* model posterior distribution were used to project the population 30 years into the future across a suite of fixed catch and fixed U harvest control rules. Recruitment deviates were drawn from a lognormal distribution based on the mean, standard deviation, and autocorrelation of estimated recruitment deviates from the years with length data directly from catch sampling and logbook programmes (the ‘data’ period, 1993–2018). Fixed catch and fixed U rules that maximised catch while meeting risk and catch constraints in the latter 20 years of the projection were identified (called ‘maximum constrained’ rules for each control rule type). B_R was then defined as the average of the AW adjusted vulnerable biomass associated with the maximum constrained fixed catch and fixed U rules.

Previous reference level projections assessed the performance of fixed catch and fixed F control rules. Because the stock assessment used discrete U instead of instantaneous F to quantify mortality from fishing, the first step in the reference level calculation was to compare results of fixed F and fixed U rules. Once it was verified that results were the same, reference level calculation moved forward using fixed U rules instead of fixed F . In both fixed catch and fixed U projections, customary and illegal catch were assumed equal to 2021. Fixed catch was split between seasons based on the commercial catch split in 2021.

Fixed SL catch rules ranged from 80 to 300 tonnes. Fixed U rules ranged from 0.05 to 0.95. The same U value was applied to both seasons.

Catch was maximised and risk constraints were met with a fixed SL catch of 205 tonnes per year and a fixed U of 0.5 per season per year. This resulted in an average annual catch of 237 tonnes with a fixed catch rule and 257 tonnes with a fixed U rule and median AW adjusted vulnerable biomass of 492 tonnes

with fixed catch and 185 tonnes with fixed U . Averaging the distributions of AW adjusted vulnerable biomass between the fixed catch and fixed U rules resulted in a B_R of 339 tonnes, or 12% of unfished equilibrium vulnerable biomass.

The exploitation rate associated with the reference level (U_R) was defined in this assessment to be the fixed U associated with a median vulnerable biomass equal to B_R at equilibrium. Previous assessments defined U_R as the ratio of AW catch to AW vulnerable biomass at the reference level. However, with the use of U in the stock assessment, this definition could be improved to more appropriately represent the equilibrium U associated with the reference level. In practice, U_R was identified by finding the fixed U associated with B_R over the latter 20 years of the 30-year projection. An annual estimate of U_R was calculated by weighting seasonal U based on vulnerable biomass per season. The 2022 CRA 2 stock assessment found that a fixed U of 0.30 (0.27 SL) led to a median AW vulnerable biomass of 335 tonnes, maintaining the reference level on average over 30 years (Table 11).

B_R calculated for the 2022 assessment is lower than that from the 2017 assessment, likely due to changes in estimates of equilibrium, unfished biomass resulting from lower historical illegal and recreational catch. The reference level relative to equilibrium, unfished vulnerable biomass (B_R/B_0) is about the same or slightly higher than the 2017 results.

The CRA 2 stock is predicted to be very likely above B_R and below U_R (not overfished and not undergoing overfishing) (see Figure 70).

2.9 Projections

Five-year projection of the status quo TACC (80 tonnes) examined vulnerable biomass in relation to the proposed reference level, based on methods described by Rudd et al. (2021c). This five-year projection, for the fishing years 2022 to 2026, was done for the *base* case model only. This projection was repeated for each sample from the posterior distribution.

The recreational and NSL catches were assumed to be the same as the final model year (2021) and were set to be constant when projecting forward (Table 15). The projected commercial catch in 2021 was set to the CRA 2 TACC of 80 tonnes, split into the two seasons. The projected commercial and illegal catches were allocated to each season based on the 2021 commercial catch, and the recreational and customary catches were split into seasons by assuming that 10% of these catches were taken in the AW and the remainder in the SS (Table 15).

Projected recruitment deviates were simulated from a normal distribution with mean calculated from the mean of the 2009–2018 recruitment deviates, the standard deviation set to σ_R (Table 1), and recruitment autocorrelation derived from the 1993–2018 recruitment deviates. Projected recruitment deviates replaced the 2019, 2020, and 2021 deviates because recruitment was not estimated in the reconstruction model for these years (Figure 59).

The base case and all four sensitivity runs predicted a rapid increase in the adjusted vulnerable biomass and SSB over the next five years (Figure 66, Figure 68). In the *base* case model run, the median 2022 adjusted vulnerable biomass was predicted to be 20% of B_0 ($B_{2022}/B_0 = 0.199$ [90% credible interval (CI) = 0.160–0.247]) and was projected to increase to a median value of 30% of B_0 by 2026, at current catch ($B_{2026}/B_0 = 0.298$ [90% CI = 0.210–0.426]) (Table 13). In the *base* case model run, the median 2022 SSB was predicted to be 40% of SSB_0 ($SSB_{2022}/SSB_0 = 0.397$ [90% CI = 0.332–0.496]) and was projected to increase to a median value of 49% of SSB_0 ($SSB_{2025}/SSB_0 = 0.486$ [90% CI = 0.379–0.629]; Table 13, Figure 69) by 2026.

The projection for the base case predicted that the CRA 2 stock will increase from 68% greater than B_R ($B_{2022}/B_R = 1.68$ [90% CI = 1.44–1.98]) to 154% greater than B_R ($B_{2026}/B_R = 2.54$ [90% CI = 1.78–3.52]) by the beginning of 2026 (Table 13).

Projections for the four sensitivity runs were consistent with the base run (Figure 66, Figure 68). All four sensitivity runs were projected to remain above the 20% SSB_0 ‘soft limit’ with a probability of 1.0 (Table 14).

3. DISCUSSION

The 2022 assessment made several improvements over the previous assessment of CRA 2 (Webber et al. 2018), including: fitting to a new logbook CPUE index of relative abundance from 1993 to 2021; fitting to standardised length frequencies and sex ratios, with more defensible data weightings for these observation types and with improvements in model fits to these data; improved assumptions about the magnitude of historical recreational and illegal catches; and using observed rather than assumed values for the average proportion of mature females in berry by season. These improvements resulted in only minor changes to model outputs, although with probable improvements in the accuracy of model estimates of SSB and vulnerable biomass. In addition, the change to calculating discrete exploitation rates, instead of instantaneous fishing mortality rates (as was done for previous assessments), resulted in much faster model runs with negligible changes to the model outputs.

The *base* case model fitted the CRA 2 data well. An exception to this was the fit to the CELR CPUE series in some years (Figure 45), which may have arisen from the assumption of invariant selectivity for all years and among all statistical areas. Future stock assessments could allow for different selectivities to be estimated for different portions of the catch (without the need to move to a multi-region model), so that the different dynamics within CRA 2 statistical areas can be captured (as long as there are sufficient data to support varying selectivities). In addition, there was an apparent bias in the fits to the tag-based growth information with respect to size at release (Figure 54). This was noted from changes to model estimated growth parameters, particularly of females, when the LF data were down-weighted (*downLF* run) (Table 9). This observation would be consistent with conflicting growth information from the tag data and the LF data. An alternative source of growth information, such as from direct ageing from gastric ossicles (e.g., Gnanalingam et al. 2018), may be useful to determine growth more accurately. Despite these issues, the model was considered to have done a reasonable job at representing the CRA 2 stock.

This assessment describes a stock that was initially fished at a relatively low level ($U < 0.1$) in the late 1970s, which then experienced a rising level of exploitation up to the late 2010s in the SS, but which levelled out in the AW in the mid-1990s (Figure 57). This pattern in exploitation rates resulted in a declining trend in vulnerable biomass up to the end of the 2010s, which was interrupted by a biomass increase in the mid-1990s that was fished down by the high exploitation rates (compare Figure 57 and Figure 60), resulting in a stock abundance that was well below the reference level (B_R) between 2010 and 2018 (Figure 67). The decline in stock abundance was exacerbated by a period of low recruitment after the above average recruitment estimated for the early 1990s (Figure 59). This generated a strong management response beginning in the mid-2010s and then accelerating in 2018, resulting in a rapid restoration of stock abundance to a level above the reference level (Figure 67) and which also appears to have benefitted from at least one year of above average recruitment (Figure 59).

The base case run vulnerable biomass was estimated to be above the reference level (B_R) at the beginning of 2022 and was expected to continue to increase, remaining above B_R in 2026 (Table 13). At the status quo future catch levels specified in the projections, the *base* model predicted that the stock will increase over the next five years (Figure 67). A similar pattern was observed for the SSB (Figure 61).

The models exploring the use of an SST covariate of annual recruitment strength gave some support for there being a negative correlation between SST and recruitment in CRA 2. There was a better fit to the three-year running mean SST index than the one-year index, consistent with temperature in the years around recruitment being influential, and not just the year of recruitment. The years of strongest estimated recruitment strength (around 1993) were also the coldest years during the time series, and there was a general decreasing trend in recruitment compared with the general increasing trend in SST

(also see appendix C of Roberts et al. 2023). However, there were some years that did not fit the overall pattern well, such that, if the relationship is real, then other factors are also likely to influence the temporal pattern of estimated recruitment strength (e.g., annual variation in puerulus settlement rates). This initial exploration is encouraging from a modelling perspective, suggesting that an SST-based covariate may have utility for predicting recruitment strength and would benefit from further exploration.

4. POTENTIAL RESEARCH

Potential research considerations relating directly to the stock assessment model include:

- allow different fisheries within the same region (i.e., the ‘areas as fisheries’ concept using different selectivities; this would enable different selectivities for each of the statistical areas with CRA 2);
- investigate the influence of growth priors where the posteriors are substantially different from the prior (e.g., *Gobs* and perhaps also *Gshape* for males) to determine whether these priors are appropriate and influential, and/or whether the growth meta-analysis needs to be redone;
- further explore the growth function, including separation by season;
- look into estimating the growth transition matrix directly (i.e., rather than estimating a continuous growth function and then translating this into a growth matrix);
- explore alternative selectivity functions; and
- start estimating recruitment deviates from the year when length frequencies are available (and fix them to R_0 prior to this).

Future research considerations relating to the development of stock assessment inputs include:

- develop an alternative CPUE index based on electronic reporting data as soon as possible;
- investigate alternative handling mortality assumptions;
- develop a model standardised estimate of the proportion of mature females in the catch that are in berry in each season;
- further investigate the development of climate covariates, including SST indices, for predicting temporal recruitment variability, as experienced by the fishery; and
- investigate fishery-independent methods for the collection of growth information across the vulnerable size range, such as direct ageing.

5. FULFILLMENT OF BROADER OUTCOMES

Whakapapa links all people back to the land, sea, and sky, and our obligations to respect the physical world. This research aims to ensure the long-term sustainability of red rock lobster stocks, for the good of the wider community (including stakeholders and the public) and the marine ecosystems that lobsters inhabit. This project supports both Māori and regional businesses and our research is inextricably linked to the moana from the work it carries out and the tangata whenua it supports.

To support the wider fisheries science community and enable more value to be extracted from the limited resources (time and money) available for fisheries research we make as much code as possible open source (i.e., publicly available). Furthermore, this project has built capacity and capability in fisheries science and stock assessment by employing researchers with a range of experience so that those with a long history of working in fisheries science can pass on their knowledge. This approach has meant that rock lobster stock assessments have consisted of a team with some members that have been involved for many years and some newer team members. This approach further mitigates risk associated with team members not being able to participate any longer.

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7. REFERENCES

- Breen, P.A.; Booth, J.D.; Tyson, P.J. (1988). Feasibility of a minimum size limit based on tail width for the New Zealand rock lobster *Jasus edwardsii*. *New Zealand Fisheries Technical Report No. 6*. 16 p.
- Fisheries New Zealand (2022). Fisheries Assessment Plenary, November 2022: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand, Wellington, New Zealand. 684 p.
- Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* 68(6): 1124–1138.
- Gnanalingam, G.; Butler, M.J., IV; Matthews, T.R.; Hutchinson, E.; Kilada, R. (2018). Directly ageing the Caribbean spiny lobster, *Panulirus argus*, with validated band counts from gastric mill ossicles. *ICES Journal of Marine Science* 76: 442–451.
- Hartill, B.; Evans, O.; Taylor, R.; Armiger, H.; Marsh, C. (2022). Creel survey monitoring of trends in recreational landings from CRA 2 – update for 2021–22. (Unpublished Research Progress Report produced for Fisheries New Zealand.) 26 p.
- Holdsworth, J.C. (2016). Amateur harvest estimates from an access point survey of marine fishers in the western Bay of Plenty, New Zealand in 2010–11 and 2011–12. *New Zealand Fisheries Assessment Report 2016/30*. 46 p.
- Ministry of Fisheries. (2011). Operational Guidelines for New Zealand’s Harvest Strategy Standard. Ministry of Fisheries, New Zealand. 80 p. (<https://www.mpi.govt.nz/dmsdocument/19706-OPERATIONAL-GUIDELINES-FOR-NEW-ZEALANDS-HARVEST-STRATEGY-STANDARD>.)
- Roberts, J.; Webber, D.N. (2022). Growth of juvenile red rock lobster (*Jasus edwardsii*) in New Zealand and implications for stock assessment. *New Zealand Fisheries Assessment Report 2022/45*. 59 p.
- Roberts, J.; Webber, D.N.; Starr, P.J.; Rudd, M.B.; Pons, M.; Goeden, Z. (2023). Data for the 2022 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2. *New Zealand Fisheries Assessment Report 2023/42*. 91 p.
- Rudd, M.B.; Haist, V.; Large, K.; Webber, D.N.; Starr, P.J. (2019). The 2018 Chatham Islands (CRA 6) rock lobster (*Jasus edwardsii*) stock assessment. *New Zealand Fisheries Assessment Report 2019/47*. 90 p.
- Rudd, M.B.; Pons, M.; Roberts, J.; Webber, D.N.; Starr, P.J. (2021b). The 2020 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4. *New Zealand Fisheries Assessment Report 2021/80*. 112 p.
- Rudd, M.B.; Roberts, J.; Large, K.; Webber, D.N.; Starr, P.J. (2021a). The 2019 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 1. *New Zealand Fisheries Assessment Report 2021/04*. 105 p.
- Rudd, M.B.; Webber, D.N.; Starr, P.J. (2021c). Model-based reference points for New Zealand red rock lobster (*Jasus edwardsii*). *New Zealand Fisheries Assessment Report 2021/81*. 42 p.
- Rudd, M.B.; Webber, D.N.; Starr, P.J. (2022). Rapid updates for New Zealand rock lobster (*Jasus edwardsii*) stocks in 2021. *New Zealand Fisheries Assessment Report 2022/36*. 60 p.
- Stan Development Team (2016). *CmdStan: User’s Guide*. Version 2.16.0

- Stan Development Team (2017). *Stan Modelling Language: User's Guide and Reference Manual*. Version 2.16.0.
- Starr, P.J. (2022). Rock lobster catch and effort data: 1979–80 to 2021–22. *New Zealand Fisheries Assessment Report 2022/42*. 151 p.
- Starr, P.J.; Haist, V.; Breen, P.A.; Edwards, C.T.T.E. (2014). The 2013 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2 and development of management procedures. *New Zealand Fisheries Assessment Report 2014/19*. 76 p.
- Starr, P.J.; Webber, D.N.; Rudd, M.B.; Pons, M.; Roberts, J. (2022). Data for the 2021 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7&8. *New Zealand Fisheries Assessment Report 2022/16*. 140 p.
- Webber, D.N.; Rudd, M.B.; Starr, P.J. (2021a). Rapid updates for New Zealand rock lobster (*Jasus edwardsii*) stocks in 2020. *New Zealand Fisheries Assessment Report 2021/61*. 34 p.
- Webber, D.N.; Rudd, M.B.; Starr, P.J.; Roberts, J.; Pons, M. (2023). The lobster stock dynamics (LSD) model. *New Zealand Fisheries Assessment Report 2023/11*. 28 p.
- Webber, D.N.; Starr, P.J.; Haist, V.; Rudd, M.B.; Edwards, C.T.T. (2018). The 2017 stock assessment and management procedure evaluation for rock lobsters (*Jasus edwardsii*) in CRA 2. *New Zealand Fisheries Assessment Report 2018/17*. 87 p.
- Webber, D.N.; Starr, P.J.; Roberts, J.; Rudd, M.B.; Pons, M. (2021b). The 2020 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 5. *New Zealand Fisheries Assessment Report 2021/62*. 91 p.
- Webber, D.N.; Starr, P.J.; Rudd, M.B.; Large, K.; Roberts, J. (2020). The 2019 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 3. *New Zealand Fisheries Assessment Report 2020/42*. 93 p.
- Webber, D.N.; Starr, P.J.; Rudd, M.B.; Roberts, J.; Pons, M. (2022). The 2021 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8. *New Zealand Fisheries Assessment Report 2022/17*. 113 p.
- Wynne-Jones, J.; Gray, A.; Hill, L.; Heinemann, A. (2014). National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 p.
- Wynne-Jones, J.; Gray, A.; Heinemann, A.; Hill, L.; Walton, L. (2019). National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

8. TABLES

Table 1: Fixed quantities used in the CRA 2 stock assessment models.

Quantity	Value	Quantity	Value
Relative data set weights		Length-weight parameters	
Tags	1.000	male length-weight <i>a</i>	4.16e-6
FSU CPUE	0.850	male length-weight <i>b</i>	2.9354
CELR CPUE	1.350	female length-weight <i>a</i>	1.300e-5
LB CPUE	1.300	female length-weight <i>b</i>	2.5450
Sex ratio	0.950	Recruitment	
LFs	0.747	<i>sigmaR</i>	0.4
Catch and handling mortality		last year of estimated <i>Rdevs</i>	2018
Handling mortality, 1945–1989	0.10	years for estimating <i>Rdevs</i> for projections	2009–2018
Handling mortality, 1990–2025	0.05	years for estimating autocorrelation	1993–2018
Growth		recruitment size mean	32 mm
length at <i>Galpha</i>	50 mm	recruitment size SD	2 mm
length at <i>Gbeta</i>	80 mm	Other	
<i>Gmin</i>	0.0001 mm	Tail compression: male bins	4 to 31
Catch per unit effort		Tail compression: immature female bins	4 to 20
<i>qdrift</i>	0.01	Tail compression: mature female bins	6 to 31
		Proportion of mature females in berry	
		AW	0.825
		SS	0.178

Table 2: The tail width (mm) minimum legal size (MLS) limits for males and females over time in CRA 2. Note that MLS before 1987 were expressed in terms of tail length and have been converted to tail width using the procedure described by Breen et al. (1988).

Period	Males	Females
1945–1949	None	None
1950–1951	47	49
1952–1958	51	53
1959–1987	53	58
1988–1991	54	58
1992–2022	54	60

Table 3: Definitions of parameters and derived quantities discussed in the text.

Parameter	Definition
R_0	initial numbers recruiting
$Rdevs$	annual recruitment deviations
σR	standard deviation of $Rdevs$
U_0	initial exploitation rate (the first model year is in equilibrium using this estimate)
M	instantaneous rate of natural mortality
qCR	catchability coefficient (relationship between the vulnerable biomass and CR series)
$qFSU$	catchability coefficient (relationship between the vulnerable biomass and FSU CPUE series)
$qCELR$	catchability coefficient (relationship between the vulnerable biomass and CELR CPUE series)
qLB	catchability coefficient (relationship between the number of lobsters above the MLS including berried females and LB CPUE series)
$qdrift$	additive change in catchability coefficient each year
$mat50$	TW at which 50% of immature females become mature
$mat95$	difference between $Mat50$ and the TW at which 95% of immature females become mature
$Galpha$	annual growth increment at 50 mm TW
$Gbeta$	annual growth increment at 80 mm TW
$Gdiff$	the ratio of $Gbeta$ to $Galpha$ ($Gbeta = Gdiff \times Galpha$)
$Gshape$	parameter for shape of growth curve: 1 implies von Bertalanffy straight line; >1 implies a concave upwards curve
GCV	standard deviation of growth-at-size divided by growth-at-size
$Gobs$	standard deviation of observation error for tag-recaptures
Gdd	density-dependent growth parameter
$selL$	shape of the left-hand limb of the selectivity curve (as if it were a standard deviation)
$selM$	size at maximum selectivity
$selRH$	shape of the right-hand limb of the selectivity curve (as if it were a standard deviation)
$vuln$	relative vulnerability by sex and season

Table 4: Mapping of vulnerability ($vuln$) parameters by season and sex. Note that the vulnerability for males during the AW is fixed at 1 and all other $vuln$ parameters are estimated relative to the vulnerability of males during the AW in each region.

Sex	Season	
	Autumn/winter (AW)	Spring/summer (SS)
male	1	$vuln1$
immature female	$vuln2$	$vuln3$
mature female	$vuln4$	$vuln3$

Table 5: Specifications for estimated parameters in the CRA 2 models including the upper and lower bounds, prior type, and prior parameters.

Sex	Parameters	Bounds		Type	Prior	
		Lower	Upper		Parameter 1	Parameter 2
	R_0	exp(1)	exp(25)	uniform		
	$Rdevs$	-2.3	2.3	uniform		
	M	0.01	0.35	lognormal	0.12	0.4
	qCR	exp(-25)	1	uniform		
	$qFSU$	exp(-25)	1	uniform		
	$qCELR$	exp(-25)	1	uniform		
	qLB	exp(-25)	1	uniform		
	$mat50$	30	80	normal	50	15
	$mat95$	1	60	normal	10	10
	$Galpha$	1	20	normal	2	30
	$Gdiff$	0.001	0.99	beta	1	1
M	$Gshape$	0.1	15	normal	4.81	1
F	$Gshape$	0.1	15	normal	4.51	1
M	GCV	0.01	2	normal	0.59	0.3
F	GCV	0.01	2	normal	0.82	0.3
	$Gobs$	0.00001	10	normal	1.48	0.074
	$selL$	1	50	normal	10	30
	$selM$	30	90	normal	50	30
	$selR$	1	2000	normal	30	500
	$vuln$	0.01	1	beta	1	1

Table 6: Reference points for the CRA 2 stock assessment.

Type	Description
B_0	equilibrium AW adjusted vulnerable biomass before fishing
SSB_0	equilibrium female spawning stock biomass
T_0	equilibrium total biomass
B_{0now}	equilibrium adjusted vulnerable biomass using mean of 2009–2018 recruitment
SSB_{0now}	equilibrium female spawning stock biomass using mean 2009–2018 recruitment
T_{0now}	equilibrium total biomass using mean of 2009–2018 recruitment
B_{MIN}	the lowest beginning AW adjusted vulnerable biomass in the series
B_{2022}	beginning of season AW adjusted vulnerable biomass for 2021
B_{2026}	beginning of season AW adjusted vulnerable biomass for 2026
SSB_{2022}	female spawning stock biomass at beginning of 2022 AW season
SSB_{2026}	female spawning stock biomass at beginning of 2026 AW season
T_{2022}	beginning of season AW total biomass for 2022
T_{2026}	beginning of season AW total biomass for 2026
H_{2021}	total handling mortality for 2021 (tonnes)
H_{2025}	total handling mortality for 2025 (tonnes)
B_R	average AW vulnerable biomass between projected fixed catch and fixed U rules that maximise catch while meeting constraints
U_R	fixed exploitation rate required to reach B_R at equilibrium
U_{2022}	annual exploitation rate in 2022 weighted by seasonal catch
U_{2026}	annual exploitation rate in 2026 weighted by assumed seasonal catch

Table 7: Performance indicators and stock status probabilities for the CRA 2 stock assessment.

Type	Description
Performance indicators	
B_{2022} / B_0	Ratio of B_{2022} to B_0
B_{2026} / B_0	Ratio of B_{2026} to B_0
B_{2022} / B_{0now}	Ratio of B_{2022} to B_{0now}
B_{2026} / B_{0now}	Ratio of B_{2026} to B_{0now}
B_{2026} / B_{2022}	Ratio of B_{2026} to B_{2022}
SSB_{2022} / SSB_0	Ratio of SSB_{2022} to SSB_0
SSB_{2026} / SSB_0	Ratio of SSB_{2026} to SSB_0
SSB_{2022} / SSB_{0now}	Ratio of SSB_{2022} to SSB_{0now}
SSB_{2026} / SSB_{0now}	Ratio of SSB_{2026} to SSB_{0now}
SSB_{2026} / SSB_{2022}	Ratio of SSB_{2026} to SSB_{2022}
T_{2022} / T_0	Ratio of T_{2022} to T_0
T_{2022} / T_{0NOW}	Ratio of T_{2022} to T_{0NOW}
T_{2026} / T_0	Ratio of T_{2026} to T_0
T_{2026} / T_{0NOW}	Ratio of T_{2026} to T_{0NOW}
T_{2026} / T_{2022}	Ratio of T_{2026} to T_{2022}
B_{2022} / B_R	Ratio of B_{2022} to B_R
B_{2026} / B_R	Ratio of B_{2026} to B_R
U_{2022} / U_R	Ratio of U_{2022} to U_R
U_{2026} / U_R	Ratio of U_{2026} to U_R
U_{2026} / U_{2022}	Ratio of U_{2026} to U_{2022}
Probabilities	
$P(B_{2022} > B_{MIN})$	Probability B_{2022} is greater than B_{MIN}
$P(SSB_{2022} < 20\%SSB_0)$	Probability SSB_{2022} is less than 20% SSB_0
$P(SSB_{2022} < 10\%SSB_0)$	Probability SSB_{2022} is less than 10% SSB_0
$P(SSB_{2022} < 20\%SSB_{0now})$	Probability SSB_{2022} is less than 20% SSB_{0now}
$P(SSB_{2022} < 10\%SSB_{0now})$	Probability SSB_{2022} is less than 10% SSB_{0now}
$P(SSB_{2026} < 20\%SSB_0)$	Probability SSB_{2026} is less than 20% SSB_0
$P(SSB_{2026} < 10\%SSB_0)$	Probability SSB_{2026} is less than 10% SSB_0
$P(SSB_{2026} < 20\%SSB_{0now})$	Probability SSB_{2026} is less than 20% SSB_{0now}
$P(SSB_{2026} < 10\%SSB_{0now})$	Probability SSB_{2026} is less than 10% SSB_{0now}
$P(B_{2026} > B_{2022})$	Probability B_{2026} is greater than B_{2022}
$P(SSB_{2026} > SSB_{2022})$	Probability SSB_{2026} is greater than SSB_{2022}
$P(T_{2026} > T_{2022})$	Probability T_{2026} is greater than T_{2022}
$P(U_{2026} > U_{2022})$	Probability U_{2026} is greater than U_{2022}
$P(B_{2022} > B_R)$	Probability B_{2022} is greater than B_R
$P(B_{2026} > B_R)$	Probability B_{2026} is greater than B_R
$P(U_{2022} > U_R)$	Probability U_{2022} is greater than U_R
$P(U_{2026} > U_R)$	Probability U_{2026} is greater than U_R

Table 8: List of maximum *a posteriori* (MAP) sensitivity runs. Each model run below the *base* model run implements a single change to the *base* model run.

Group	Model name	Model description	MCMC
0	<i>base</i>	1979–2021, estimate recruitment deviates through 2018, fix <i>qdrift</i> parameter on CELR and logbook CPUE series to 1%	Yes
1	<i>base_F</i>	Revert back to using fishing mortality rates instead of exploitation rates	Yes
1	<i>berry_01</i>	Set to old proportion in berry	Yes
1	<i>no_qdrift</i>	Set <i>qdrift</i> to 0	Yes
1	<i>start1945</i>	Start model in 1945	Yes
2	<i>fixM</i>	Fix <i>M</i> at 0.12	Yes
2	<i>selRH</i>	Estimate dome-shaped right-limb selectivity (<i>M</i> estimated)	Yes
2	<i>selRH_fixM</i>	Estimate dome-shaped right-limb selectivity (<i>M</i> fixed at 0.12)	Yes
3	<i>sel1_vuln3</i>	1 block of selectivity and 3 blocks of vulnerabilities (1945–2001, 2002–2017, 2018–2021) with <i>M</i> fixed at 0.12, estimate right-limb selectivity	No
3	<i>sel3_vuln1</i>	3 blocks of selectivity (1945–1999, 2000–2009, 2010–2021) and 1 block of vulnerabilities with <i>M</i> fixed at 0.12, estimate right-limb selectivity	No
3	<i>sel3_vuln3</i>	3 blocks of selectivity (1945–1999, 2000–2009, 2010–2021) and 3 blocks of vulnerabilities (1945–2001, 2002–2017, 2018–2021) with <i>M</i> fixed at 0.12, estimate right-limb selectivity	Yes
4	<i>rec_sst_1yr</i>	SST covariate of recruitment deviations	No
4	<i>rec_sst_3yr</i>	SST covariate of recruitment deviations: 3-year running mean	No
4	<i>rec_sst_3yr_1945</i>	SST covariate of recruitment deviations: 3-year running mean, starting in 1945	No
5	<i>downCPUE</i>	Downweight CPUE	No
5	<i>downLF</i>	Downweight LF	No
5	<i>downSR</i>	Downweight sex ratios	No

Table 9: CRA 2 MAP outputs showing likelihoods, standard deviation of normalised residuals (SDNRs), median absolute residuals (MARs), likelihood weights, and parameter estimates. Parameter estimates for time-varying selectivities and vulnerabilities shown for blocks [1] (1979–1999), [2] (2000–2009), and [3] (2010–2021, and applied to any projection years). Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. ‘–’: not applicable. Fixed values are indicated in grey. SDNRs or MARs for tags and LF’s are not included because the tag likelihood is self-weighting and the LF’s were iteratively reweighted using the Francis method (Francis 2011). (Continued on next 2 pages)

	Group 1					Group 2			Group 3			Group 4			Group 5		
	<i>base</i>	<i>base_F</i>	<i>berry_01</i>	<i>no_qdrift</i>	<i>start 1945</i>	<i>fixM</i>	<i>selRH</i>	<i>selRH_fixM</i>	<i>sel1_vuln3</i>	<i>sel3_vuln1</i>	<i>sel3_vuln3</i>	<i>rec_sst_1yr</i>	<i>rec_sst_3yr</i>	<i>rec_sst_3yr_1945</i>	<i>down CPUE</i>	<i>down LF</i>	<i>down SR</i>
Likelihoods																	
Total	27 074	27 049	27 086	27 071	27 335	25 404	27 740	26 724	28 426	34 355	35 205	26 727	27 572	27 300	27 173	12 068	21 883
Prior	30.282	29.257	31.135	29.477	21.968	29.427	31.864	31.294	22.006	49.977	58.783	20.578	18.305	-6.200	13.211	16.746	20.537
tag	4 807	4 805	4 807	4 808	4 807	4 805	4 792	4 789	4 788	4 791	4 795	4 803	4 804	4 805	4 802	4 772	4 803
Sex ratio	5 730	5 729	5 730	5 729	5 911	4 655	5 731	4 836	5 129	4 535	5 196	5 639	5 670	5 912	5 733	5 717	575
LF	16 598	16 577	16 601	16 596	16 672	16 001	17 274	17 150	18 586	25 064	25 241	16 361	17 178	16 668	16 571	1 678	16 582
CR	–	–	–	–	18.914	–	–	–	–	–	–	–	–	17.714	–	–	–
FSU	-13.350	-13.312	-12.885	-13.539	-18.230	-14.898	-13.965	-14.935	-16.909	-16.940	-15.039	-14.946	-15.030	-18.392	8.362	-15.650	-15.573
CELR	-44.420	-44.445	-42.628	-44.285	-45.292	-40.906	-41.070	-36.402	-40.356	-34.425	-34.632	-46.403	-44.511	-44.605	24.929	-58.516	-47.027
Logbook CPUE	-34.210	-34.624	-28.570	-34.574	-34.252	-30.699	-35.328	-32.310	-41.338	-33.692	-37.992	-31.825	-28.655	-28.770	21.163	-41.433	-35.186
Standard deviation of normalised residual (SDNR)																	
Sex ratio	1.016	1.008	1.025	1.001	1.032	1.018	1.020	1.023	0.990	1.004	1.013	1.035	1.043	1.063	1.039	0.952	0.374
CR	–	–	–	–	0.998	–	–	–	–	–	–	–	–	1.122	–	–	–
FSU	0.996	1.003	1.022	0.990	0.662	0.993	1.028	1.015	1.006	1.004	1.015	1.010	1.006	1.056	0.194	0.987	0.991
CELR	0.987	0.993	1.022	0.988	1.035	1.015	1.023	1.031	1.004	1.020	1.014	1.004	1.036	1.152	0.168	0.785	1.008
Logbook CPUE	0.996	0.994	1.094	0.992	0.974	1.021	1.013	1.022	1.003	1.027	1.019	0.995	1.009	1.049	0.123	0.899	1.016
Median of absolute residual (MAR)																	
Sex ratio	0.653	0.632	0.705	0.646	0.670	0.732	0.665	0.722	0.722	0.694	0.719	0.628	0.638	0.668	0.647	0.608	0.230
CR	–	–	–	–	0.574	–	–	–	–	–	–	–	–	0.575	–	–	–
FSU	0.620	0.609	0.623	0.622	0.569	0.594	0.593	0.542	0.588	0.533	0.580	0.548	0.648	0.425	1.784	0.609	0.578
CELR	0.611	0.630	0.644	0.686	0.626	0.630	0.668	0.695	0.720	0.681	0.738	0.645	0.622	0.716	1.655	0.555	0.662
Logbook CPUE	0.575	0.586	0.583	0.515	0.644	0.611	0.583	0.551	0.712	0.555	0.699	0.561	0.554	0.576	1.934	0.591	0.617
Likelihood weights																	
Sex ratio	0.950	0.950	0.950	0.950	0.980	0.770	0.950	0.800	0.850	0.750	0.860	0.935	0.940	0.980	0.950	0.950	0.095
LF	0.747	0.747	0.747	0.747	0.751	0.720	0.777	0.772	0.837	1.131	1.139	0.737	0.774	0.751	0.747	0.075	0.747
CR	–	–	–	–	1.300	–	–	–	–	–	–	–	–	1.300	–	–	–
FSU	0.850	0.850	0.850	0.850	0.250	0.900	0.900	0.930	0.920	0.920	0.930	0.840	0.840	0.250	0.085	0.850	0.850
CELR	1.350	1.350	1.350	1.350	1.150	1.300	1.300	1.210	1.200	1.100	1.150	1.330	1.330	1.150	0.135	1.350	1.350
Logbook CPUE	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Parameters																	
R_0	535 974	539 126	595 224	524 961	550 496	392 686	483 800	380 441	387 035	393 621	386 451	536 412	537 616	538 544	476 341	479 851	548 839
M	0.181	0.175	0.201	0.173	0.187	0.12	0.165	0.12	0.12	0.12	0.12	0.181	0.181	0.184	0.170	0.180	0.182
$mat50$	50.602	50.404	50.418	50.625	50.502	50.978	50.381	50.744	50.709	50.979	50.873	50.649	50.661	50.572	50.761	48.599	49.244
$mat95add$	11.419	11.495	11.294	11.529	11.306	12.167	11.684	12.206	11.993	11.954	12.133	11.187	11.233	11.212	11.511	10.173	11.303
$Galpha$ [male]	6.854	6.903	6.827	6.857	6.865	6.946	7.095	7.192	7.214	7.175	7.091	6.920	6.934	7.029	6.895	7.283	6.942
$Gbeta$ [male]	2.723	2.724	2.703	2.765	2.722	2.772	2.203	2.104	2.067	2.079	2.140	2.725	2.748	2.806	2.661	2.290	2.719
$Gshape$ [male]	2.338	2.494	2.256	2.415	2.292	2.685	2.405	2.581	2.476	2.355	2.330	2.394	2.444	2.618	2.537	3.379	2.445
GCV [male]	0.439	0.436	0.438	0.438	0.436	0.436	0.427	0.424	0.416	0.418	0.428	0.430	0.428	0.422	0.429	0.410	0.429
$Galpha$ [female]	4.902	4.918	4.912	4.878	4.922	4.748	5.068	4.963	4.993	4.921	4.896	4.933	4.932	4.963	4.890	5.603	4.869
$Gbeta$ [female]	1.183	1.182	1.186	1.192	1.193	1.122	1.109	1.054	1.073	1.075	1.109	1.182	1.190	1.211	1.151	0.846	1.168
$Gshape$ [female]	4.173	4.182	4.211	4.152	4.181	4.088	4.328	4.299	4.304	4.203	4.187	4.223	4.223	4.269	4.137	4.875	4.070

	Group 1					Group 2			Group 3			Group 4			Group 5		
	base	base_F	berry_01	no_qdrift	start 1945	fixM	selRH	selRH_fixM	sell_vuln3	sel3_vuln1	sel3_vuln3	rec_sst_1yr	rec_sst_3yr	rec_sst_3yr_1945	down_CPUE	down_LF	down_SR
GCV [female]	0.748	0.750	0.748	0.752	0.745	0.773	0.730	0.744	0.736	0.739	0.742	0.744	0.741	0.738	0.743	0.716	0.750
Gobs	0.999	0.998	0.995	0.995	1.001	0.993	1.029	1.031	1.045	1.042	1.028	1.008	1.011	1.015	1.019	1.074	1.004
U ₀	0.065	0.070	0.053	0.079	-	0.101	0.044	0.087	0.088	0.094	0.086	0.075	0.077	-	0.014	0.073	0.069
qCR	-	-	-	-	5.474E-2	-	-	-	-	-	-	-	-	6.270E-2	-	-	-
qFSU	1.172E-3	1.164E-3	1.167E-3	1.253E-03	1.285E-3	1.322E-3	1.311E-3	1.503E-3	1.417E-3	1.501E-3	1.386E-3	1.276E-3	1.290E-3	1.753E-3	2.100E-4	1.276E-3	1.189E-3
qCELR	1.289E-6	1.321E-6	1.306E-6	1.465E-6	2.396E-3	1.397E-6	1.320E-6	1.436E-6	1.464E-6	1.437E-6	1.436E-6	1.330E-6	1.334E-6	2.533E-3	2.427E-7	1.282E-6	1.327E-6
qLogbook	1.172E-3	1.164E-3	1.167E-3	1.253E-3	1.298E-6	1.322E-3	1.311E-3	1.503E-3	1.417E-3	1.501E-3	1.386E-3	1.276E-3	1.290E-3	1.381E-6	2.100E-4	1.276E-3	1.189E-3
qSST	-	-	-	-	-	-	-	-	-	-	-	1.708E-6	1.832E-6	1.789E-6	-	-	-
vuln1 SS M [1]	0.903	0.911	0.823	0.900	0.894	0.849	0.897	0.852	0.866	0.851	0.868	0.903	0.903	0.886	0.868	0.890	0.907
vuln2 AW IF [1]	0.642	0.625	0.630	0.652	0.633	0.670	0.563	0.569	0.491	0.572	0.467	0.617	0.620	0.606	0.656	0.591	0.987
vuln3 SS IF/MF [1]	0.755	0.724	0.668	0.757	0.736	0.739	0.697	0.681	0.781	0.689	0.801	0.734	0.735	0.709	0.731	0.737	0.723
vuln4 AW MF [1]	0.582	0.529	0.568	0.587	0.576	0.565	0.536	0.519	0.626	0.523	0.643	0.567	0.569	0.559	0.599	0.567	0.529
vuln1 SS M [2]	-	-	-	-	-	-	-	-	0.819	-	0.823	-	-	-	-	-	-
vuln2 AW IF [2]	-	-	-	-	-	-	-	-	0.590	-	0.671	-	-	-	-	-	-
vuln3 SS IF/MF [2]	-	-	-	-	-	-	-	-	0.609	-	0.637	-	-	-	-	-	-
vuln4 AW MF [2]	-	-	-	-	-	-	-	-	0.440	-	0.460	-	-	-	-	-	-
vuln1 SS M [3]	-	-	-	-	-	-	-	-	0.996	-	0.966	-	-	-	-	-	-
vuln2 AW IF [3]	-	-	-	-	-	-	-	-	0.444	-	0.511	-	-	-	-	-	-
vuln3 SS IF/MF [3]	-	-	-	-	-	-	-	-	0.608	-	0.642	-	-	-	-	-	-
vuln4 AW MF [3]	-	-	-	-	-	-	-	-	0.495	-	0.526	-	-	-	-	-	-
selL male [1]	4.861	5.048	4.841	4.846	4.848	4.877	4.884	4.867	4.864	6.098	6.106	4.854	4.862	4.902	4.812	4.682	4.862
selM male [1]	50.816	51.216	50.912	50.779	50.850	50.508	55.489	55.245	55.328	56.664	56.613	50.778	50.775	50.791	50.657	49.921	50.802
selL female [1]	7.602	7.733	7.527	7.583	7.569	7.610	7.398	7.375	7.343	9.505	9.793	7.571	7.571	7.569	7.542	8.092	7.328
selM female [1]	55.509	55.871	55.450	55.507	55.491	55.402	62.275	62.137	62.027	63.695	64.490	55.355	55.373	55.312	55.441	54.146	55.745
selL male [2]	-	-	-	-	-	-	-	-	-	4.027	4.054	-	-	-	-	-	-
selM male [2]	-	-	-	-	-	-	-	-	-	54.553	54.609	-	-	-	-	-	-
selL female [2]	-	-	-	-	-	-	-	-	-	5.975	6.067	-	-	-	-	-	-
selM female [2]	-	-	-	-	-	-	-	-	-	60.724	60.959	-	-	-	-	-	-
selL male [3]	-	-	-	-	-	-	-	-	-	4.916	4.939	-	-	-	-	-	-
selM male [3]	-	-	-	-	-	-	-	-	-	55.461	55.496	-	-	-	-	-	-
selL female [3]	-	-	-	-	-	-	-	-	-	7.206	7.060	-	-	-	-	-	-
selM female [3]	-	-	-	-	-	-	-	-	-	62.638	62.331	-	-	-	-	-	-
selR	-	-	-	-	-	-	25.025	25.061	25.137	23.340	25.417	-	-	-	-	-	-
Derived parameters: adjusted vulnerable biomass																	
B ₀	2 826	3 012	2 447	2 971	2 704	4 165	1 633	1 918	1 967	1 834	1 974	2 837	2 846	2 823	2 827	2 711	2 864
B _{0now}	2 266	2 398	1 942	2 511	2 170	3 535	1 330	1 653	1 638	1 534	1 684	2 089	2 063	2 045	2 487	2 159	2 235
B _{MIN}	164	169	161	181	164	147	160	146	146	151	153	163	165	162	205	150	162
B ₂₀₂₂	561	558	544	674	559	548	493	468	456	496	457	412	401	403	649	538	581
B ₂₀₂₂ / B ₀	0.198	0.184	0.221	0.228	0.206	0.131	0.302	0.244	0.232	0.271	0.230	0.145	0.141	0.143	0.229	0.198	0.203
Derived parameters: spawning stock biomass (females only)																	
SSB ₀	1 276	1 350	1 183	1 324	1 291	1 753	1 348	1 718	1 756	1 767	1 743	1 273	1 272	1 311	1 240	1 245	1 282
SSB _{0now}	1 022	1 074	936	1 116	987	1 483	1 101	1 472	1 463	1 478	1 480	937	922	907	1 091	992	1 000
SSB ₂₀₂₂	508	512	508	567	503	501	518	509	542	536	530	407	401	400	560	476	540
SSB ₂₀₂₂ / SSB ₀	0.398	0.378	0.430	0.430	0.390	0.287	0.383	0.297	0.309	0.303	0.303	0.320	0.315	0.305	0.452	0.382	0.421
Derived parameters: total biomass																	
T ₀	4 481	4 740	4 155	4 651	4 340	6 142	4 601	5 859	5 933	6 003	5 898	4 480	4 488	4 461	4 385	4 202	4 516
T _{0now}	3 587	3 775	3 284	3 930	3 467	5 199	3 767	5 010	4 943	5 023	5 024	3 299	3 253	3 215	3 858	3 346	3 523
T ₂₀₂₂	1 422	1 422	1 462	1 604	1 423	1 343	1 410	1 322	1 369	1 476	1 340	1 064	1 053	1 049	1 664	1 218	1 548

	<i>Group 1</i>					<i>Group 2</i>			<i>Group 3</i>			<i>Group 4</i>			<i>Group 5</i>		
	<i>base</i>	<i>base_F</i>	<i>berry_01</i>	<i>no_qdrift</i>	<i>start 1945</i>	<i>fixM</i>	<i>selRH</i>	<i>selRH_ fixM</i>	<i>sel1_ vuln3</i>	<i>sel3_ vuln1</i>	<i>sel3_ vuln3</i>	<i>rec_ sst_1yr</i>	<i>rec_ sst_3yr</i>	<i>rec_sst_ 3yr_1945</i>	<i>down CPUE</i>	<i>down LF</i>	<i>down SR</i>
Other derived parameters																	
<i>H</i> ₂₀₂₁	2.243	2.162	2.196	2.101	2.228	2.256	2.380	2.415	2.484	2.522	2.426	2.198	2.265	2.231	2.365	2.071	2.302
<i>B</i> _{male} / <i>B</i> _{female}	1.112	1.101	1.147	1.152	1.114	1.052	1.100	1.042	0.967	1.061	0.991	1.037	1.030	1.030	1.134	1.107	1.111

Table 10: CRA 2 summary of the posterior distribution for the model likelihoods, data set weighting diagnostics, and parameter estimates for the *base* case model. The mean, standard deviation (SD) of the mean, median, 90% credible interval (i.e., 5% and 95%), effective number of samples, and rhat statistic are reported. Growth increment values in mm TW, biomass values in t, and R_0 in numbers. ‘–’: not applicable.

	Mean	SD	5%	Median	95%	Effective N	Rhat
Likelihoods							
Total	4 807	7.455	4 795	4 807	4 820	975	0.999
Prior	27 070	5.904	27 060	27 070	27 080	847	1.001
Tags	30.340	6.401	20.320	30.300	41.150	925	0.999
Sex ratio	5 730	2.431	5 726	5 730	5 734	862	0.999
LFs	16 600	7.398	16 590	16 600	16 610	1 018	0.999
CPUE [FSU]	-13.230	1.614	-15.640	-13.350	-10.430	974	1.002
CPUE [CELR]	-44.240	3.818	-50.260	-44.420	-37.870	1 069	0.999
CPUE [LB]	-34.020	2.602	-37.960	-34.210	-29.500	912	1.001
SDNR							
Tag	1.399	0.025	1.359	1.398	1.440	979	0.999
Sex ratio	1.040	0.024	1.005	1.039	1.083	835	1.000
LFs	0.412	0.011	0.395	0.411	0.433	935	0.999
CPUE [FSU]	1.077	0.067	0.969	1.077	1.190	973	1.002
CPUE [CELR]	1.044	0.061	0.944	1.043	1.149	1 057	1.000
CPUE [LB]	1.026	0.043	0.959	1.025	1.098	909	1.000
MAR							
Tag	0.683	0.010	0.665	0.683	0.700	1 125	0.999
Sex ratio	0.666	0.033	0.613	0.665	0.722	939	0.999
LFs	0.157	0.005	0.150	0.157	0.165	942	0.999
CPUE [FSU]	0.715	0.144	0.483	0.712	0.950	1 001	0.999
CPUE [CELR]	0.667	0.094	0.516	0.668	0.823	1 128	1.000
CPUE [LB]	0.610	0.059	0.517	0.605	0.715	876	1.001
Parameters							
R_0	538 338	49 263	460 917	535 990	624 415	944	1.000
M	0.181	0.011	0.162	0.181	0.200	1 090	0.999
U_0	0.066	0.020	0.035	0.065	0.100	796	1.001
qCR	0.001	0.000	0.001	0.001	0.001	900	0.999
$qFSU$	0.002	0.000	0.002	0.002	0.003	1 051	1.000
$qCELR$	0.000	0.000	0.000	0.000	0.000	982	1.001
qLB	0.001	0.000	0.001	0.001	0.001	900	0.999
$mat50$	50.580	0.568	49.610	50.600	51.460	841	0.999
$mat95$	11.510	1.590	9.131	11.420	14.200	949	0.999
$Galpha$ [M]	6.852	0.105	6.671	6.854	7.023	925	0.999
$Galpha$ [F]	4.900	0.100	4.739	4.902	5.064	988	1.000
$Gbeta$ [M]	2.727	0.160	2.472	2.723	2.985	1 165	0.999
$Gbeta$ [F]	1.186	0.048	1.114	1.183	1.267	1 038	1.000
$Gshape$ [M]	2.349	0.340	1.810	2.338	2.926	1 026	0.999
$Gshape$ [F]	4.172	0.172	3.886	4.174	4.445	930	0.999
$IGCV$ [M]	0.439	0.014	0.417	0.439	0.463	821	1.000
GCV [F]	0.750	0.024	0.713	0.748	0.791	919	0.999
$Gobs$	0.999	0.060	0.899	0.999	1.099	898	0.999
$vuln SS$ [M]	0.904	0.023	0.867	0.903	0.943	832	0.999
$vuln AW$ [IF]	0.647	0.075	0.533	0.642	0.776	911	0.999
$vuln SS$ [IF+MF]	0.755	0.038	0.693	0.755	0.817	835	0.999
$vuln AW$ [MF]	0.584	0.033	0.530	0.582	0.637	813	0.999
$sell$ [M]	4.863	0.233	4.490	4.861	5.239	710	0.999
$sell$ [F]	7.600	0.290	7.117	7.602	8.072	849	0.999
$selM$ [M]	50.810	0.188	50.490	50.820	51.100	1 086	0.999
$selM$ [F]	55.500	0.288	55.020	55.510	55.980	903	0.999

Table 11: CRA 2 summary of the posterior distribution for the derived quantities for the *base* case model. The mean, standard deviation (SD) of the mean, median, and 90% credible interval (i.e., 5% and 95%) are reported. Biomass values and handling mortality (*H*) are reported in tonnes. (Continued next page)

	Mean	SD	5%	50%	95%
Vulnerable biomass					
B_0	2 834.000	245.800	2 445.000	2 826.000	3 253.000
B_{0now}	2 275.000	168.400	2 018.000	2 266.000	2 579.000
B_{MIN}	164.600	8.480	151.000	164.500	178.200
B_R	335.100	0.000	335.100	335.100	335.100
B_{2022}	564.900	57.870	481.100	561.500	664.600
B_{2026}	864.100	175.300	595.400	851.300	1 178.000
B_R / B_0	0.119	0.010	0.103	0.119	0.137
B_R / B_{0now}	0.148	0.011	0.130	0.148	0.166
B_{2022} / B_0	0.201	0.027	0.160	0.199	0.247
B_{2026} / B_0	0.307	0.065	0.210	0.298	0.426
B_{2022} / B_{0now}	0.249	0.030	0.206	0.248	0.300
B_{2026} / B_{0now}	0.381	0.078	0.267	0.374	0.524
B_{2026} / B_{2022}	1.529	0.264	1.121	1.513	1.992
B_{2022} / B_R	1.686	0.173	1.436	1.676	1.983
B_{2026} / B_R	2.579	0.523	1.777	2.541	3.515
Exploitation					
U_R	—	—	0.296	0.296	0.296
U_{2022}	0.106	0.011	0.089	0.106	0.125
U_{2026}	0.078	0.015	0.056	0.077	0.105
U_{2022} / U_R	0.359	0.038	0.300	0.358	0.423
U_{2026} / U_R	0.265	0.050	0.190	0.260	0.356
Spawning stock biomass					
SSB_0	1 276.000	98.910	1 116.000	1 276.000	1 439.000
SSB_{0now}	1 024.000	60.070	931.500	1 023.000	1 132.000
SSB_{2022}	507.100	40.610	442.300	505.300	578.600
SSB_{2026}	626.200	87.020	491.200	620.300	780.800
SSB_{2022} / SSB_0	0.400	0.044	0.332	0.397	0.476
SSB_{2026} / SSB_0	0.493	0.075	0.379	0.486	0.629
SSB_{2022} / SSB_{0now}	0.497	0.045	0.429	0.493	0.573
SSB_{2026} / SSB_{0now}	0.613	0.086	0.486	0.606	0.770
SSB_{2026} / SSB_{2022}	1.234	0.131	1.038	1.222	1.462
Total biomass					
T_0	4 483.000	347.400	3 926.000	4 482.000	5 057.000
T_{0now}	3 596.000	213.400	3 268.000	3 588.000	3 972.000
T_{2022}	1 432.000	159.300	1 195.000	1 417.000	1 718.000
T_{2026}	1 783.000	279.200	1 359.000	1 759.000	2 272.000
T_{2022} / T_0	0.322	0.044	0.255	0.317	0.399
T_{2026} / T_0	0.400	0.068	0.299	0.394	0.525
T_{2022} / T_{0now}	0.400	0.050	0.328	0.395	0.487
T_{2026} / T_{0now}	0.497	0.080	0.378	0.489	0.637
T_{2026} / T_{2022}	1.245	0.140	1.038	1.229	1.496
T_{male} / T_{female}	1.112	0.029	1.066	1.111	1.156
Other quantities					
R_{mean}	43 1400.000	25 130.000	392 500.000	430 200.000	474 600.000
R_{rho}	0.000	0.017	-0.029	0.002	0.024
H_{2020}	2.258	0.162	2.036	2.240	2.558
H_{2026}	1.698	0.185	1.428	1.678	2.045
Probabilities					
$P(B_{2022} > B_{MIN})$	1.000	—	—	—	—
$P(B_{2022} > B_R)$	1.000	—	—	—	—
$P(B_{2026} > B_R)$	1.000	—	—	—	—
$P(B_{2026} > B_{2022})$	0.989	—	—	—	—
$P(SSB_{2022} < 20\% SSB_0)$	0.000	—	—	—	—
$P(SSB_{2022} < 10\% SSB_0)$	0.000	—	—	—	—

	Mean	SD	5%	50%	95%
$P(SSB_{2026} < 20\% SSB_0)$	0.000	—	—	—	—
$P(SSB_{2026} < 10\% SSB_0)$	0.000	—	—	—	—
$P(SSB_{2022} < 20\% SSB_{0now})$	0.000	—	—	—	—
$P(SSB_{2022} < 10\% SSB_{0now})$	0.000	—	—	—	—
$P(SSB_{2026} < 20\% SSB_{0now})$	0.000	—	—	—	—
$P(SSB_{2026} < 10\% SSB_{0now})$	0.000	—	—	—	—
$P(SSB_{2026} > SSB_{2022})$	0.980	—	—	—	—
$P(T_{2026} > T_{2022})$	0.975	—	—	—	—
$P(U_{2022} > U_R)$	0.000	—	—	—	—
$P(U_{2026} > U_R)$	0.000	—	—	—	—
$P(U_{2026} > U_{2022})$	0.013	—	—	—	—

Table 12: CRA 2 MCMC outputs, reporting the 5%, 50% (median), and 95% quantiles of the posterior distribution, showing likelihoods, standard deviation of normalised residuals (SDNRs), median absolute residuals (MARs), and parameter estimates. These values are for the base case and four sensitivity runs. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. Fixed values are indicated in grey. ‘–’: not applicable. (Continued next page)

	<i>base</i>			<i>berry 01</i>			<i>fixM</i>			<i>no qdrift</i>			<i>start1945</i>		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods															
Total	27 060	27 070	27 080	27 080	27 090	27 100	25 400	25 400	25 410	27 060	27 070	27 080	27 320	27 330	27 350
Prior	20.32	30.30	41.15	21.70	31.14	41.22	18.74	29.43	39.87	20.27	29.48	39.88	9.966	21.98	34.16
Tag	4 795	4 807	4 820	4 796	4 807	4 819	4 793	4 805	4 817	4 796	4 808	4 820	4 796	4 807	4 820
Sex ratio	5 726	5 730	5 734	5 726	5 730	5 735	4 651	4 655	4 660	5 726	5 729	5 734	5 907	5 910	5 915
LFs	16 590	16 600	16 610	16 590	16 600	16 610	15 990	16 000	16 010	16 580	16 600	16 610	16 660	16 670	16 690
CPUE [CR]	–	–	–	–	–	–	–	–	–	–	–	–	15.44	18.92	23.36
CPUE [FSU]	-15.64	-13.35	-10.43	-15.08	-12.88	-9.582	-16.89	-14.9	-11.74	-15.68	-13.54	-10.3	-21.19	-18.23	-14.31
CPUE [CELR]	-50.26	-44.42	-37.87	-48.95	-42.62	-34.41	-46.92	-40.9	-34.77	-50.36	-44.28	-37.04	-50.89	-45.28	-38.93
CPUE [LB]	-37.96	-34.21	-29.5	-33.81	-28.56	-23.1	-34.76	-30.7	-26.14	-38.38	-34.57	-30.22	-38.19	-34.24	-29.84
Standard deviation normalised residuals (SDNR)															
Tag	1.359	1.398	1.440	1.355	1.400	1.444	1.359	1.401	1.448	1.358	1.398	1.441	1.357	1.398	1.444
Sex ratio	1.005	1.039	1.083	1.005	1.042	1.094	0.997	1.041	1.093	0.991	1.026	1.071	1.019	1.054	1.096
LFs	0.395	0.411	0.433	0.397	0.412	0.432	0.393	0.408	0.431	0.393	0.407	0.427	0.397	0.413	0.433
CPUE [CR]	–	–	–	–	–	–	–	–	–	–	–	–	0.7551	1.124	1.464
CPUE [FSU]	0.969	1.077	1.190	1.001	1.097	1.216	0.970	1.061	1.173	0.969	1.066	1.195	1.012	1.137	1.294
CPUE [CELR]	0.944	1.043	1.149	0.967	1.074	1.194	0.963	1.065	1.161	0.943	1.044	1.159	0.933	1.028	1.129
CPUE [LB]	0.959	1.025	1.098	1.034	1.117	1.200	0.978	1.047	1.117	0.947	1.017	1.085	0.955	1.025	1.095
Mean absolute residual (MAR)															
Tag	0.665	0.683	0.700	0.664	0.684	0.702	0.658	0.675	0.693	0.665	0.683	0.698	0.668	0.684	0.701
Sex ratio	0.613	0.665	0.722	0.628	0.685	0.750	0.678	0.744	0.815	0.612	0.664	0.722	0.622	0.669	0.725
LFs	0.150	0.157	0.165	0.151	0.157	0.164	0.149	0.156	0.163	0.149	0.157	0.165	0.151	0.158	0.166
CPUE [CR]	–	–	–	–	–	–	–	–	–	–	–	–	0.387	0.734	1.174
CPUE [FSU]	0.483	0.712	0.950	0.481	0.718	0.992	0.497	0.700	0.959	0.480	0.716	0.984	0.506	0.725	0.988
CPUE [CELR]	0.516	0.668	0.823	0.590	0.734	0.901	0.535	0.675	0.829	0.546	0.714	0.872	0.504	0.649	0.796
CPUE [LB]	0.517	0.605	0.715	0.539	0.632	0.730	0.550	0.633	0.736	0.508	0.604	0.705	0.500	0.595	0.693
Parameters															
R_0	460 900	536 000	624 400	517 100	595 300	680 300	352 500	392 700	436 500	459 300	525 000	599 400	484 100	550 500	625 100
M	0.162	0.181	0.200	0.185	0.201	0.219	0.120	0.120	0.120	0.157	0.173	0.192	0.171	0.187	0.206
$qdrift$	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.000	0.000	0.000	0.010	0.010	0.010
$q[CR]$	–	–	–	–	–	–	–	–	–	–	–	–	0.0390	0.0547	0.0847
$q[FSU]$	0.0010	0.0012	0.0014	0.0010	0.0012	0.0014	0.0011	0.0013	0.0016	0.0011	0.0013	0.0015	0.0011	0.0013	0.0015
$q[CELR]$	0.0022	0.0024	0.0026	0.0022	0.0024	0.0026	0.0025	0.0027	0.0028	0.0026	0.0028	0.0030	0.0022	0.0024	0.0026
$q[LB]$	1.21e-6	1.29e-6	1.37e-6	1.22e-6	1.31e-6	1.40e-6	1.32e-6	1.40e-6	1.49e-6	1.37e-6	1.47e-6	1.57e-6	1.21e-6	1.30e-6	1.39e-6

	<i>base</i>			<i>berry 01</i>			<i>fixM</i>			<i>no qdrift</i>			<i>start1945</i>		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
<i>mat50</i>	49.610	50.600	51.460	49.450	50.420	51.380	49.930	50.980	51.980	49.650	50.630	51.490	49.590	50.500	51.410
<i>mat95</i>	9.131	11.420	14.200	9.110	11.290	13.790	9.884	12.170	15.160	9.181	11.530	14.570	8.914	11.310	14.250
<i>Galpha male</i>	6.671	6.854	7.023	6.661	6.827	6.995	6.777	6.946	7.132	6.692	6.857	7.034	6.695	6.865	7.032
<i>Gbeta male</i>	2.472	2.723	2.985	2.472	2.703	2.979	2.499	2.773	3.085	2.523	2.765	3.048	2.486	2.722	2.993
<i>Gshape male</i>	1.810	2.338	2.926	1.767	2.257	2.781	2.155	2.685	3.292	1.926	2.415	2.973	1.833	2.293	2.820
<i>GCV male</i>	0.417	0.439	0.463	0.418	0.439	0.461	0.413	0.436	0.457	0.415	0.438	0.461	0.415	0.437	0.457
<i>Galpha female</i>	4.739	4.902	5.064	4.752	4.912	5.075	4.585	4.748	4.928	4.709	4.878	5.041	4.750	4.923	5.078
<i>Gbeta female</i>	1.114	1.183	1.267	1.120	1.186	1.266	1.059	1.122	1.200	1.117	1.192	1.267	1.125	1.193	1.278
<i>Gshape female</i>	3.886	4.174	4.445	3.939	4.211	4.493	3.815	4.088	4.355	3.874	4.152	4.420	3.921	4.182	4.456
<i>GCV female</i>	0.713	0.748	0.791	0.709	0.748	0.790	0.734	0.773	0.814	0.713	0.752	0.792	0.705	0.745	0.787
<i>Gobs</i>	0.899	0.999	1.099	0.903	0.995	1.104	0.898	0.993	1.095	0.898	0.995	1.096	0.898	1.001	1.110
<i>vuln SS Male</i>	0.867	0.903	0.943	0.787	0.823	0.857	0.812	0.849	0.883	0.863	0.900	0.940	0.859	0.894	0.934
<i>vuln AW Imm. Female</i>	0.533	0.642	0.776	0.517	0.630	0.764	0.544	0.670	0.825	0.540	0.652	0.786	0.524	0.633	0.760
<i>vuln SS Imm. & Mat. Female</i>	0.693	0.755	0.817	0.608	0.668	0.729	0.677	0.739	0.805	0.694	0.757	0.828	0.675	0.736	0.810
<i>vuln AW Mat. Female</i>	0.530	0.582	0.637	0.514	0.568	0.626	0.511	0.565	0.621	0.532	0.587	0.647	0.523	0.576	0.635
<i>selL male</i>	4.490	4.861	5.239	4.5000	4.841	5.257	4.474	4.877	5.271	4.466	4.846	5.253	4.468	4.848	5.260
<i>selL female</i>	7.117	7.602	8.072	7.075	7.527	7.993	7.124	7.611	8.097	7.098	7.583	8.067	7.109	7.570	8.045
<i>selM male</i>	50.49	50.82	51.10	50.60	50.91	51.21	50.19	50.51	50.81	50.47	50.78	51.05	50.53	50.85	51.16
<i>selM female</i>	55.02	55.51	55.98	54.95	55.45	55.89	54.90	55.40	55.89	55.02	55.51	55.98	55.02	55.49	55.97
<i>U₀</i>	0.035	0.065	0.100	0.024	0.053	0.086	0.074	0.101	0.136	0.050	0.079	0.113	0.000	0.000	0.000

Table 13: CRA 2 base case and sensitivity run MCMC derived quantities, reporting the 5%, 50% (median), and 95% quantiles of the posterior distributions. Biomass values in tonnes, H (handling mortality) in tonnes, U is an exploitation rate bounded between 0 and 1. ‘–’: not applicable. (Continued next page)

Variable	<u>base</u>			<u>berry 01</u>			<u>fixM</u>			<u>no_qdrift</u>			<u>start1945</u>		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
AW adjusted vulnerable biomass															
B_0	2 445	2 826	3 253	2 157	2 448	2 790	3 743	4 166	4 648	2 608	2 971	3 408	2 423	2 705	3 026
B_{0now}	2 018	2 266	2 579	1 743	1 942	2 149	3 370	3 535	3 703	2 248	2 512	2 835	1 941	2 170	2 423
B_{min}	151.0	164.5	178.2	147.1	161.0	177.5	136.0	147.3	159.7	165.6	180.9	198.2	151.1	164.0	180.3
B_R	335.1	335.1	335.1	–	–	–	–	–	–	–	–	–	–	–	–
B_{2022}	481.1	561.5	664.6	464.4	543.2	641.0	462.5	545.7	661.4	583.4	679.0	796.5	480.6	561.6	656.5
B_{2026}	595.4	851.3	1 178.0	552.0	778.1	1 081.0	681.4	948.6	1 307.0	747.5	1 008.0	1 386.0	590.4	841.1	1 150.0
B_{2022}/B_0	0.160	0.199	0.247	0.182	0.222	0.273	0.107	0.131	0.163	0.185	0.228	0.280	0.168	0.207	0.252
B_{2026}/B_0	0.210	0.298	0.426	0.221	0.318	0.456	0.161	0.227	0.325	0.242	0.338	0.474	0.215	0.309	0.435
B_{2022}/B_{0now}	0.206	0.248	0.300	0.239	0.280	0.333	0.134	0.154	0.182	0.228	0.269	0.324	0.215	0.257	0.310
B_{2026}/B_{0now}	0.267	0.374	0.524	0.283	0.400	0.564	0.196	0.269	0.367	0.295	0.402	0.551	0.270	0.385	0.529
B_{2026}/B_{2022}	1.121	1.513	1.992	1.053	1.423	1.910	1.333	1.725	2.248	1.159	1.483	1.928	1.130	1.495	1.975
B_{2022}/B_R	1.436	1.676	1.983	–	–	–	–	–	–	–	–	–	–	–	–
B_{2026}/B_R	1.777	2.541	3.515	–	–	–	–	–	–	–	–	–	–	–	–
Exploitation rate, weighted across seasons by vulnerable biomass															
U_{2022}	0.089	0.106	0.125	0.092	0.110	0.129	0.091	0.110	0.130	0.074	0.089	0.104	0.090	0.107	0.126
U_{2026}	0.056	0.077	0.105	0.061	0.082	0.112	0.053	0.072	0.096	0.049	0.065	0.086	0.058	0.078	0.107
U_{2022}/U_R	0.300	0.358	0.423	–	–	–	–	–	–	–	–	–	–	–	–
U_{2026}/U_R	0.190	0.260	0.356	–	–	–	–	–	–	–	–	–	–	–	–
Spawning biomass (females only)															
SSB_0	1 116	1 276	1 439	1 051	1 183	1 327	1 567	1 753	1 955	1 169	1 324	1 494	1 175	1 291	1 413
SSB_{0now}	931.5	1 023.0	1 132.0	864.9	936.4	1 016.0	1 417.0	1 483.0	1 558.0	1 018.0	1 116.0	1 233.0	911.1	987.0	1 074.0
SSB_{2022}	442	505	579	451	508	591	446	500	570	506	569	656	445	507	580
SSB_{2026}	491	620	781	490	612	777	543	669	836	565	698	877	486	618	773
SSB_{2022}/SSB_0	0.332	0.397	0.476	0.368	0.431	0.512	0.245	0.286	0.338	0.367	0.431	0.515	0.336	0.391	0.460
SSB_{2026}/SSB_0	0.379	0.486	0.629	0.406	0.516	0.671	0.301	0.382	0.492	0.413	0.526	0.680	0.371	0.476	0.612
SSB_{2022}/SSB_{0now}	0.429	0.493	0.573	0.486	0.542	0.631	0.308	0.337	0.377	0.447	0.510	0.594	0.449	0.510	0.593
SSB_{2026}/SSB_{0now}	0.486	0.606	0.770	0.525	0.652	0.825	0.370	0.450	0.557	0.507	0.626	0.791	0.494	0.624	0.785
SSB_{2026}/SSB_{2022}	1.038	1.222	1.462	1.005	1.194	1.431	1.147	1.330	1.564	1.056	1.217	1.435	1.037	1.214	1.441

Variable	<u>base</u>			<u>berry 01</u>			<u>fixM</u>			<u>no qdrift</u>			<u>start1945</u>		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Total biomass															
T_0	3 926	4 482	5 057	3 701	4 155	4 673	5 499	6 143	6 857	4 146	4 652	5 266	3 942	4 341	4 766
T_{0now}	3 268	3 588	3 972	3 030	3 284	3 571	4 983	5 199	5 451	3 586	3 931	4 342	3 184	3 467	3 797
T_{2022}/T_0	0.255	0.317	0.399	0.289	0.353	0.443	0.180	0.216	0.270	0.283	0.345	0.437	0.267	0.328	0.409
T_{2026}/T_0	0.299	0.394	0.525	0.324	0.424	0.566	0.225	0.296	0.393	0.328	0.428	0.564	0.308	0.404	0.534
T_{2022}/T_{0now}	0.328	0.395	0.487	0.376	0.443	0.546	0.222	0.256	0.304	0.342	0.410	0.508	0.340	0.412	0.505
T_{2026}/T_{0now}	0.378	0.489	0.637	0.413	0.538	0.703	0.273	0.348	0.444	0.399	0.509	0.664	0.389	0.508	0.655
T_{2026}/T_{2022}	1.038	1.229	1.496	1.013	1.194	1.452	1.165	1.353	1.606	1.065	1.232	1.477	1.036	1.219	1.474
Other derived parameters															
H_{2021}	2.036	2.240	2.558	1.981	2.196	2.509	2.050	2.259	2.527	1.921	2.101	2.392	2.020	2.244	2.569
H_{2025}	1.428	1.678	2.045	1.414	1.695	2.066	1.346	1.578	1.865	1.348	1.563	1.828	1.419	1.664	2.021
B_{male}/B_{female}	1.066	1.111	1.156	1.100	1.147	1.189	1.001	1.051	1.105	1.111	1.152	1.199	1.070	1.114	1.158

Table 14: Probabilities calculated from the MCMC posteriors for the indicated derived parameters.

Variable	<i>base</i>	<i>berry_01</i>	<i>fixM</i>	<i>no_qdrift</i>	<i>start1945</i>
$P(B_{2022} > B_{MIN})$	1.000	1.000	1.000	1.000	1.000
$P(B_{2022} > B_R)$	1.000	—	—	—	—
$P(B_{2026} > B_R)$	1.000	—	—	—	—
$P(B_{2026} > B_{2022})$	0.989	0.975	1.000	0.996	0.987
$P(SSB_{2022} < 20\% SSB_0)$	0.000	0.000	0.000	0.000	0.000
$P(SSB_{2022} < 10\% SSB_0)$	0.000	0.000	0.000	0.000	0.000
$P(SSB_{2026} < 20\% SSB_{0now})$	0.000	0.000	0.000	0.000	0.000
$P(SSB_{2026} < 10\% SSB_{0now})$	0.000	0.000	0.000	0.000	0.000
$P(SSB_{2026} > SSB_{2022})$	0.980	0.958	1.000	0.988	0.973
$P(T_{2026} > T_{2022})$	0.975	0.964	1.000	0.989	0.973
$P(U_{2022} > U_R)$	0.000	—	—	—	—
$P(U_{2026} > U_R)$	0.000	—	—	—	—
$P(U_{2026} > U_{2022})$	0.013	0.034	0.000	0.006	0.017

Table 15: Catch (tonnes) in the final model year and the projection years by season and fishing sector.

Fishing year	Commercial		Recreational		Customary		Illegal	
	AW	SS	AW	SS	AW	SS	AW	SS
2022–23	47.496	32.504	3.311	29.795	0.5	4.5	16.244	11.117
2023–24	47.496	32.504	3.311	29.795	0.5	4.5	16.244	11.117
2024–25	47.496	32.504	3.311	29.795	0.5	4.5	16.244	11.117
2025–26	47.496	32.504	3.311	29.795	0.5	4.5	16.244	11.117
2026–27	47.496	32.504	3.311	29.795	0.5	4.5	16.244	11.117

9. FIGURES

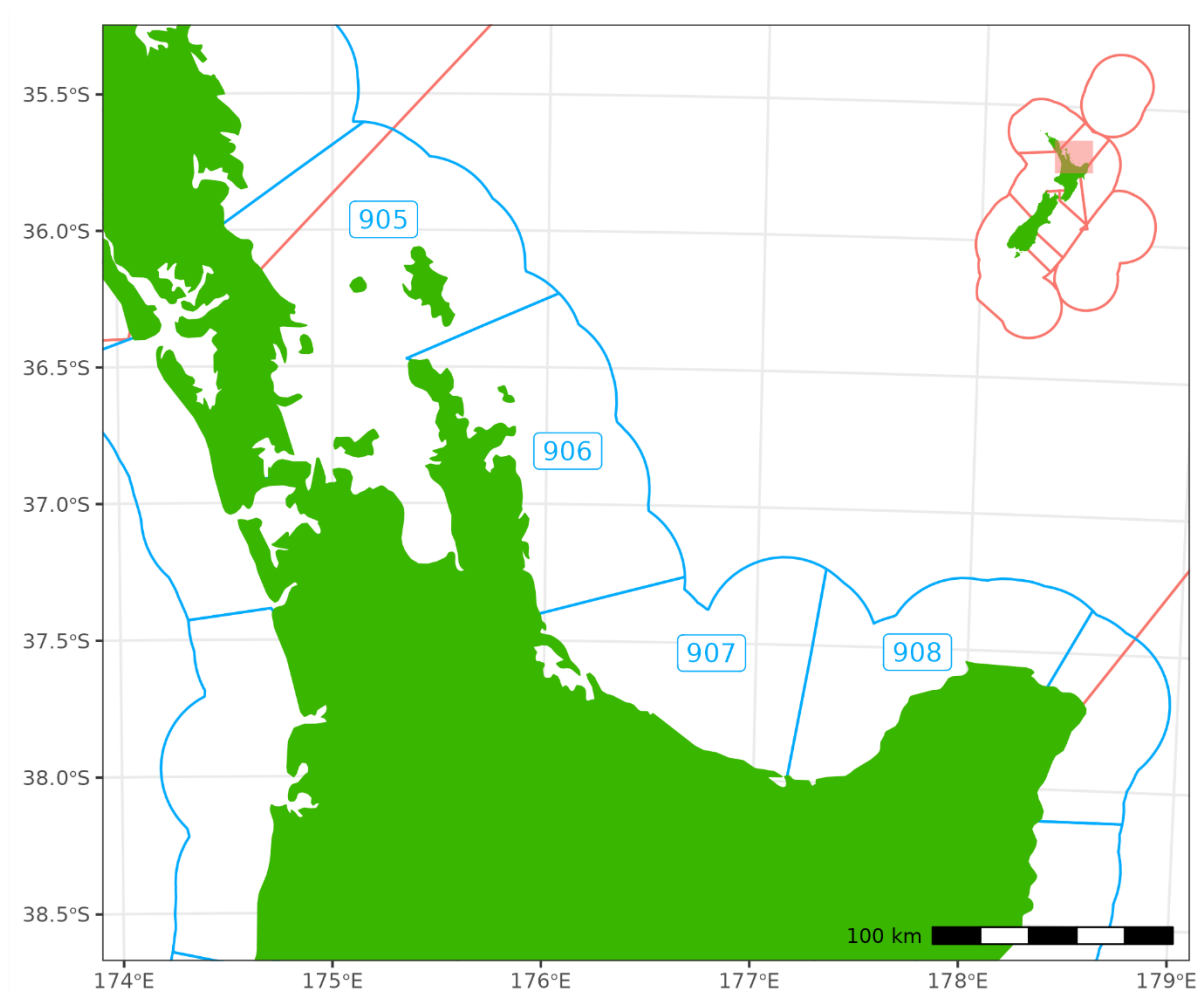


Figure 1: The CRA 2 Quota Management Area (QMA) boundaries (solid red lines) and statistical area boundaries (solid blue lines).

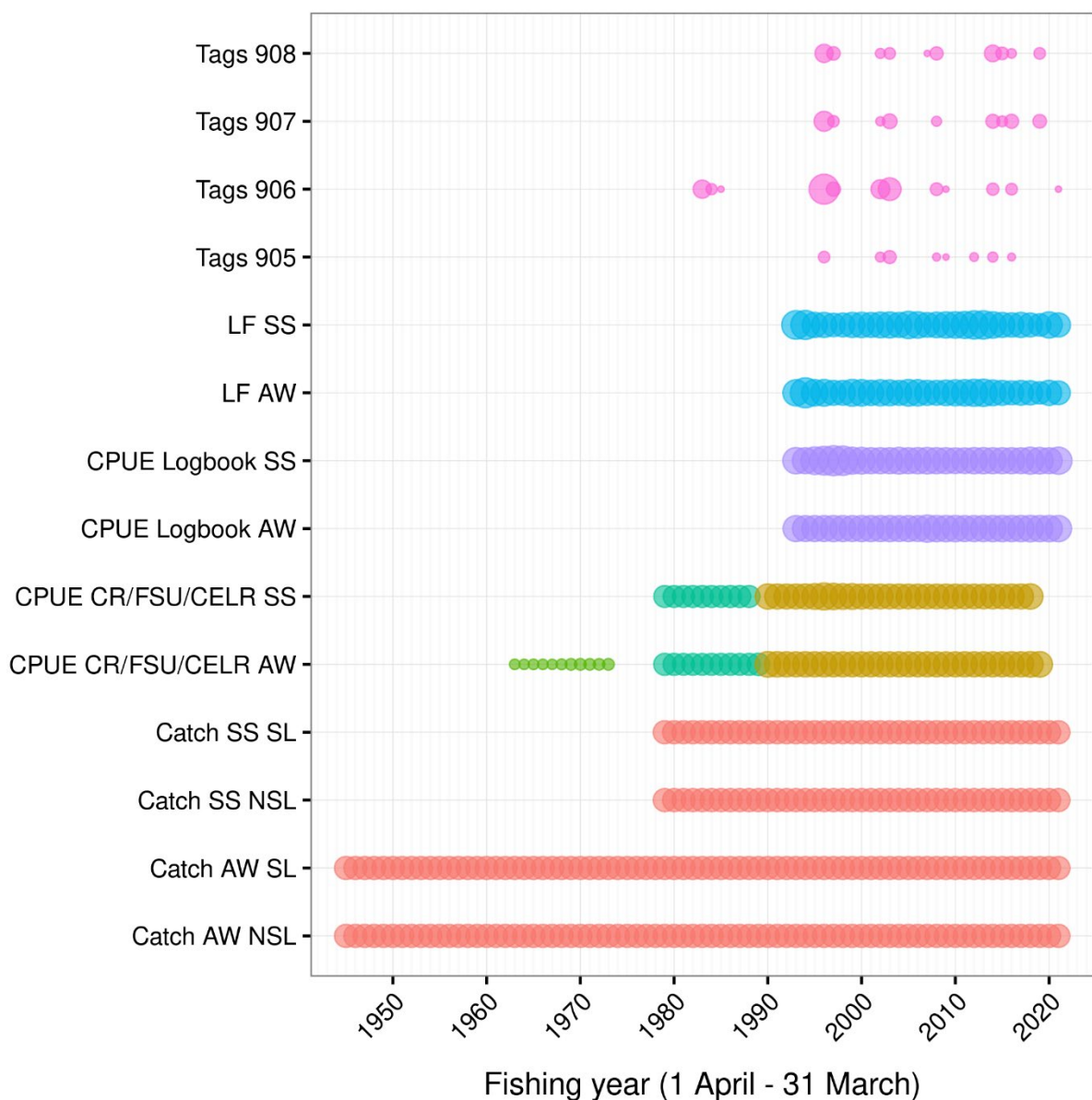


Figure 2: Data extent by fishing year used in the CRA 2 stock assessment. The size of the bubbles represents the relative number of recaptured tags, the effective sample size for length frequency distributions, the standard deviation for CPUE, or a fixed size for catch. Bubble colours vary for the different data sets (CPUE colours: CR = green, FSU = teal, and CELR = gold). See Starr et al. (2022) for a detailed description of these data. Note the base model excludes all data prior to 1979.

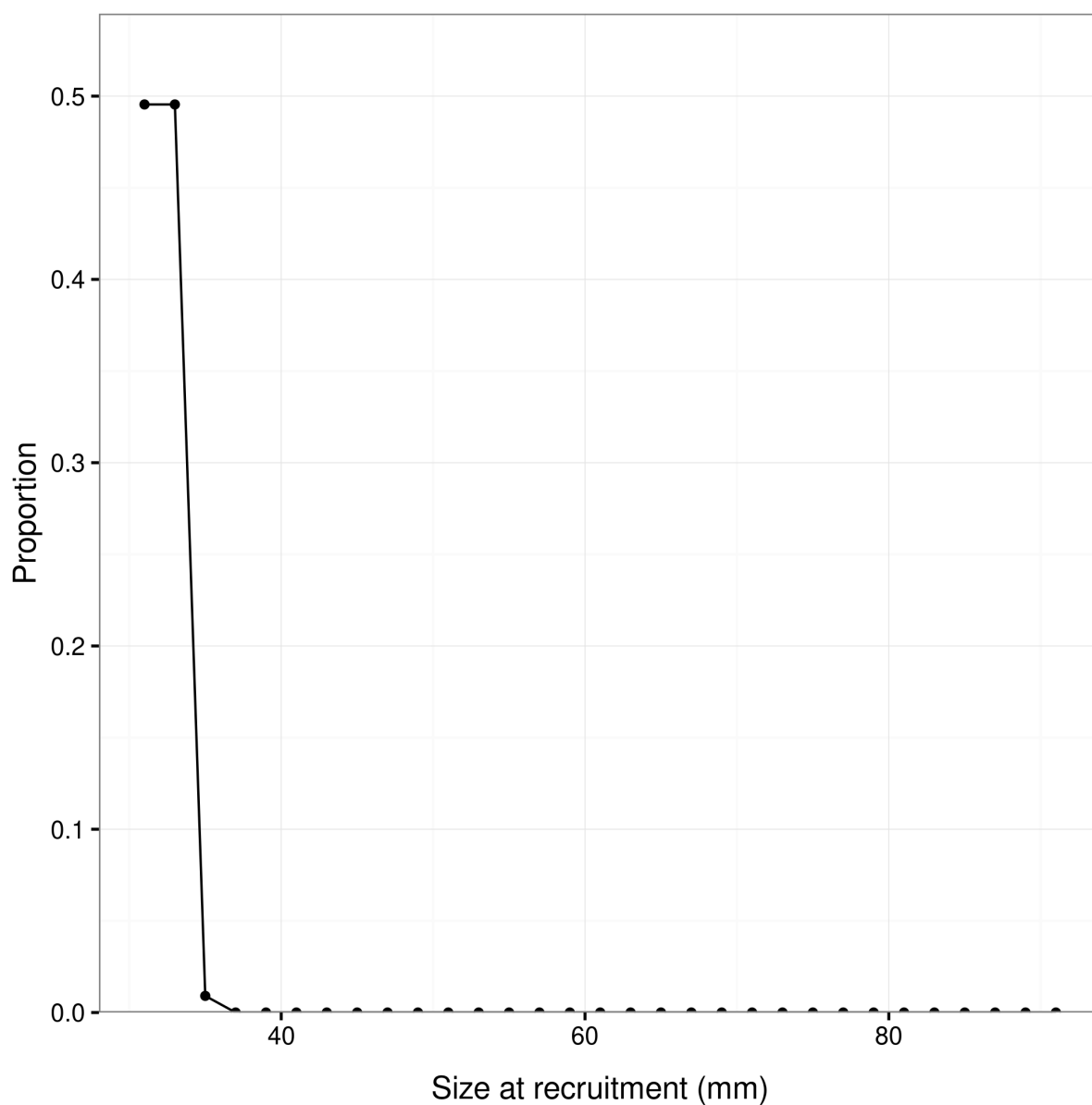


Figure 3: Distribution of size at recruitment size (mm) assumed in the CRA 2 stock assessment.

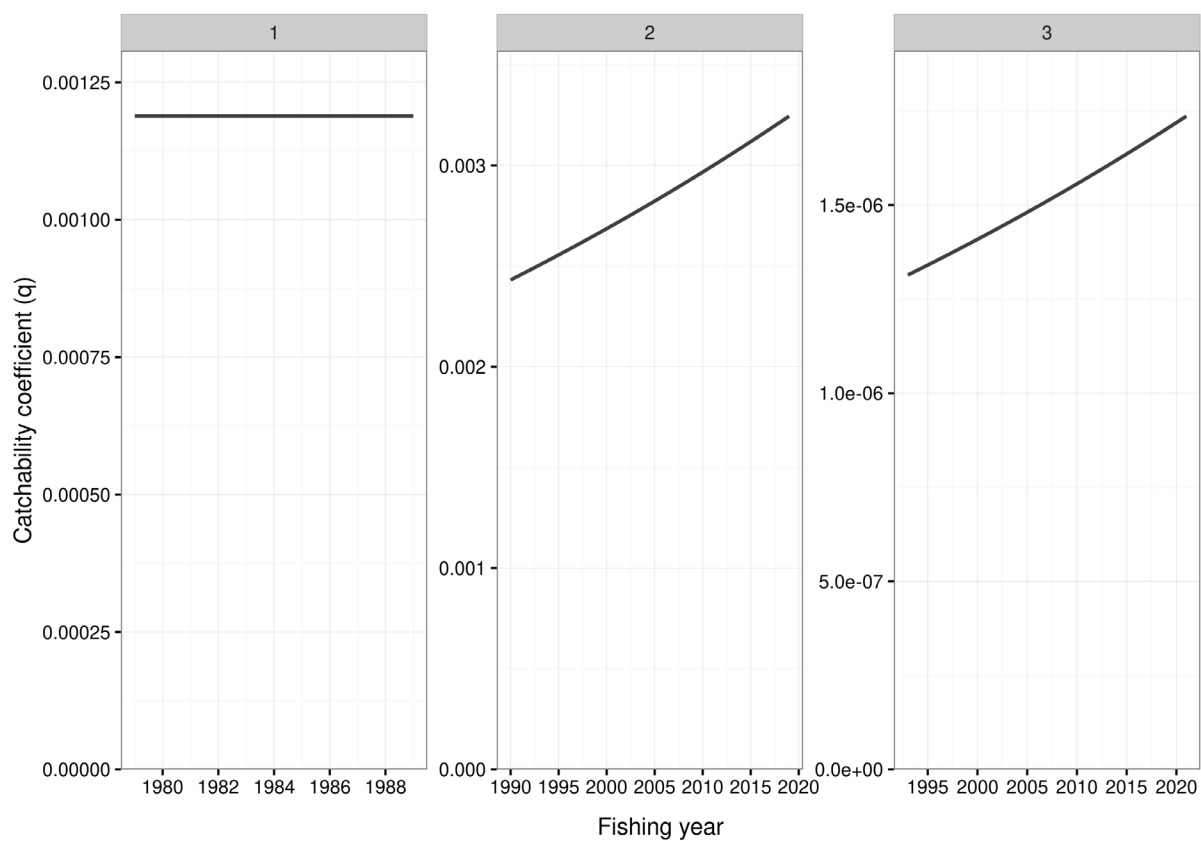


Figure 4: MAP catchability coefficient (q) for the FSU, CELR, and logbook CPUE indices by fishing year in the base case model run.

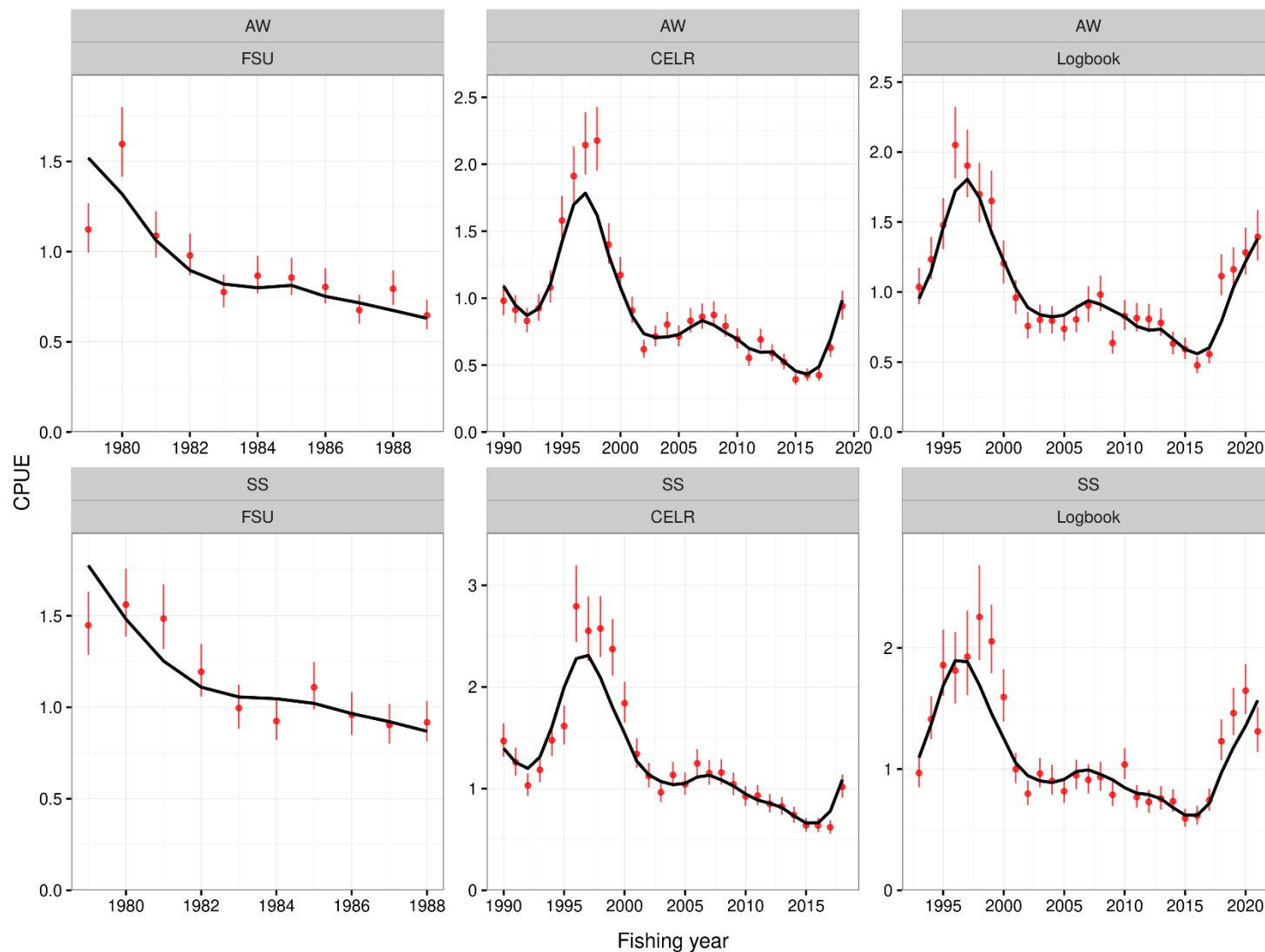


Figure 5: MAP model fit to the FSU, CELR, and logbook CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) in the base case model run. Error bars are $\pm$ one standard deviation.

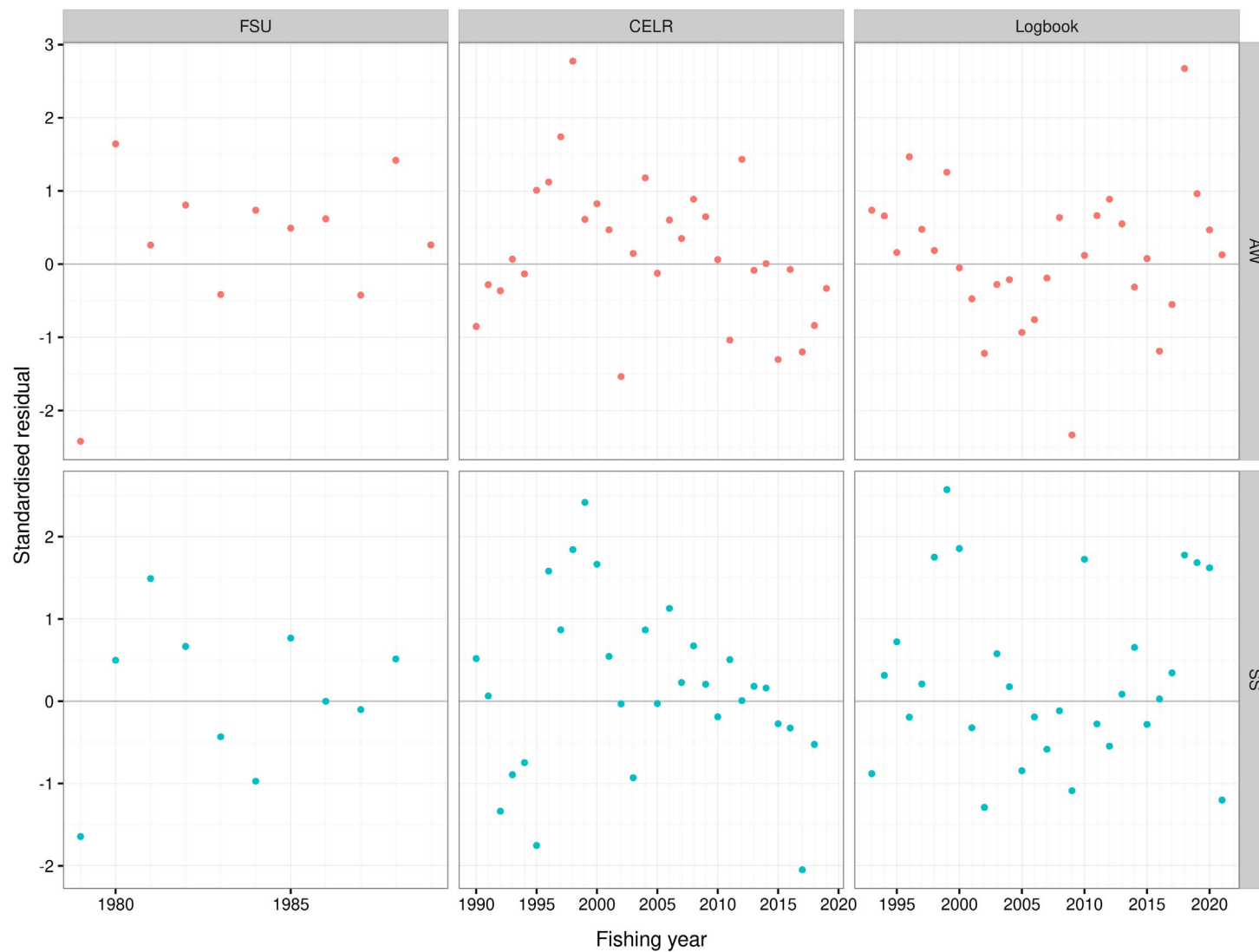


Figure 6: MAP standardised residuals from model fit to the FSU, CELR, and logbook CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) in the base case model run.

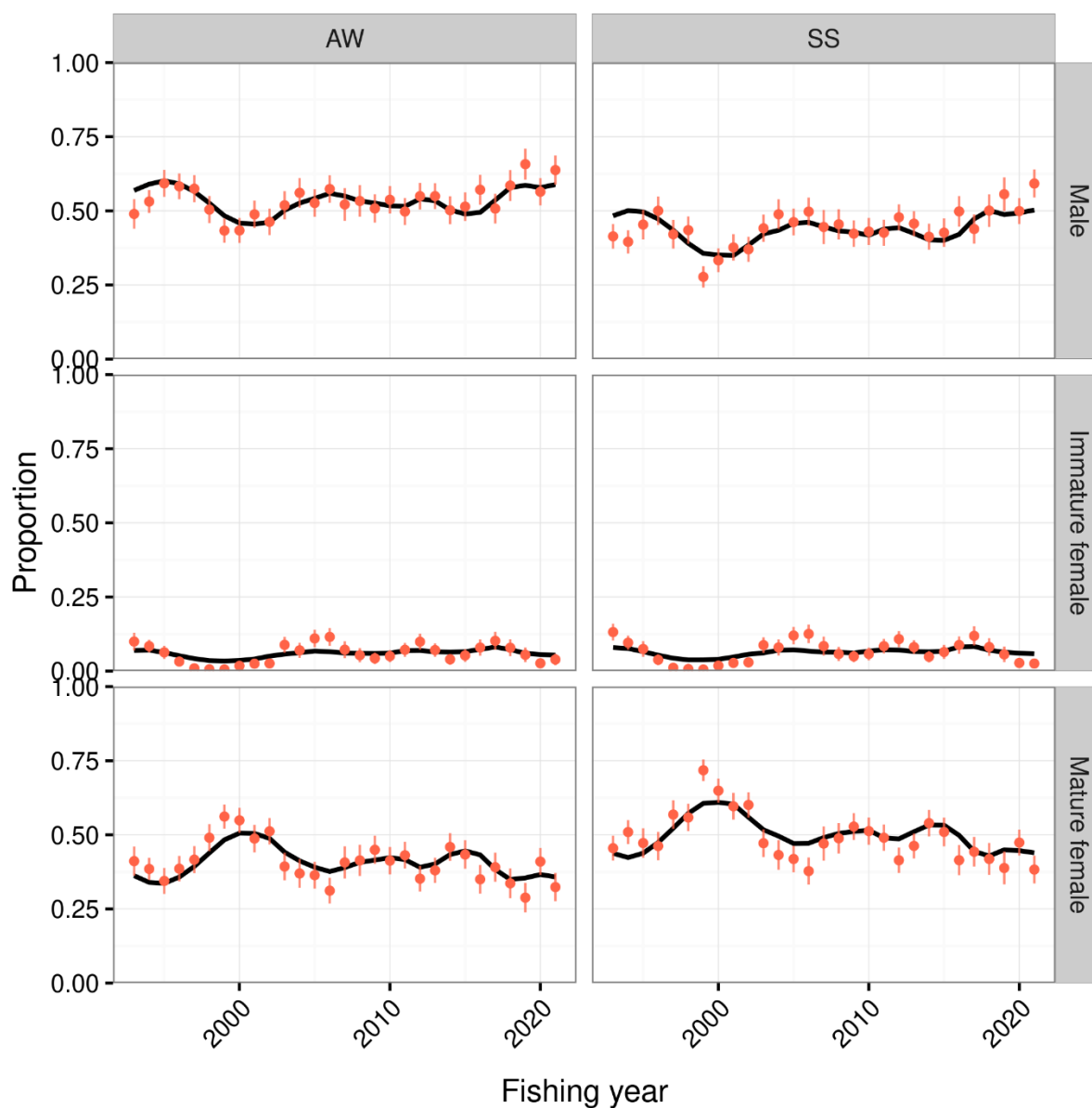


Figure 7: MAP model fit to the sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex in the base case model run. Error bars are +/- one standard deviation.

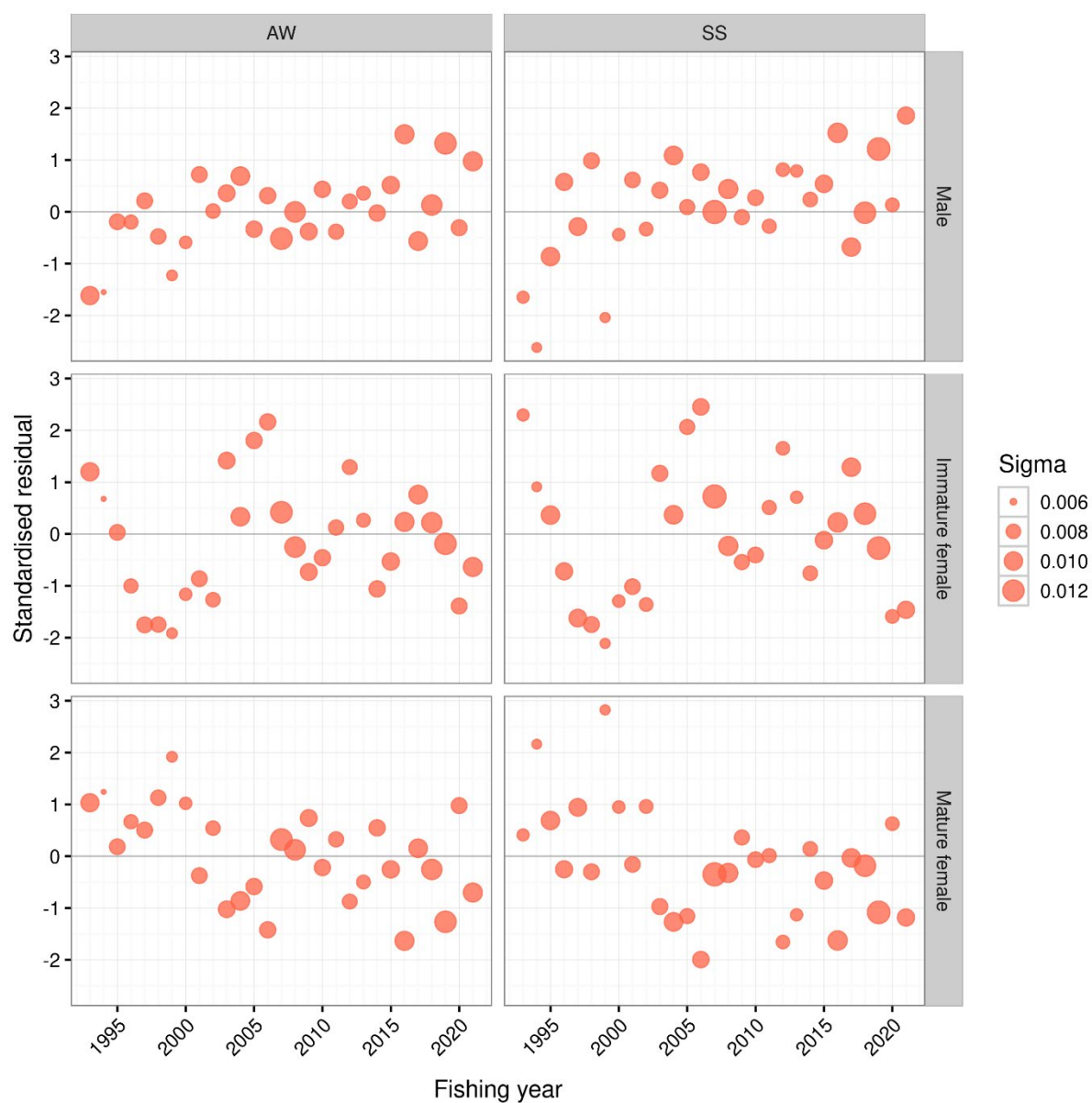


Figure 8: MAP standardised residuals for the model fit to the sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex in the base case model run.

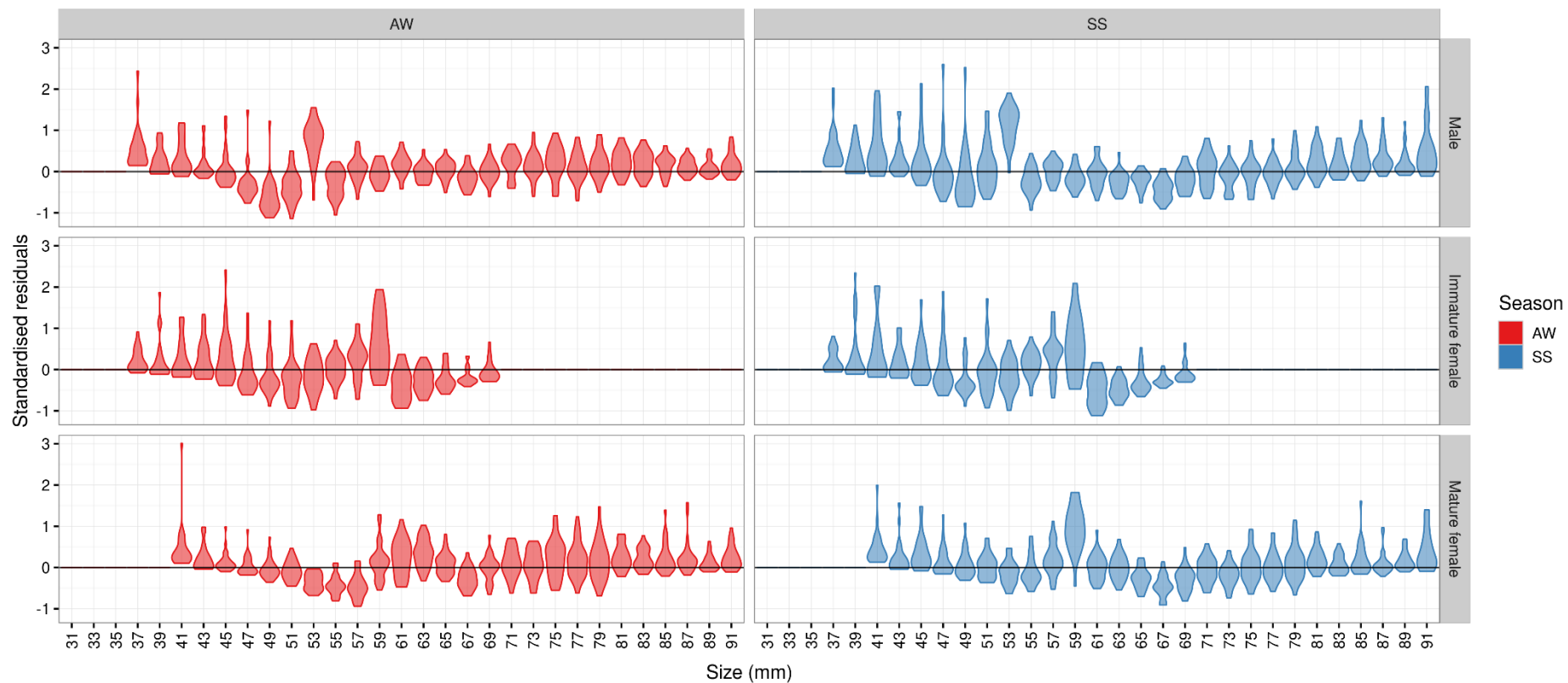


Figure 9: MAP standardised residuals from fits to the LF data by sex, season (AW = autumn/winter, SS = spring/summer), and 2 mm TW bin.

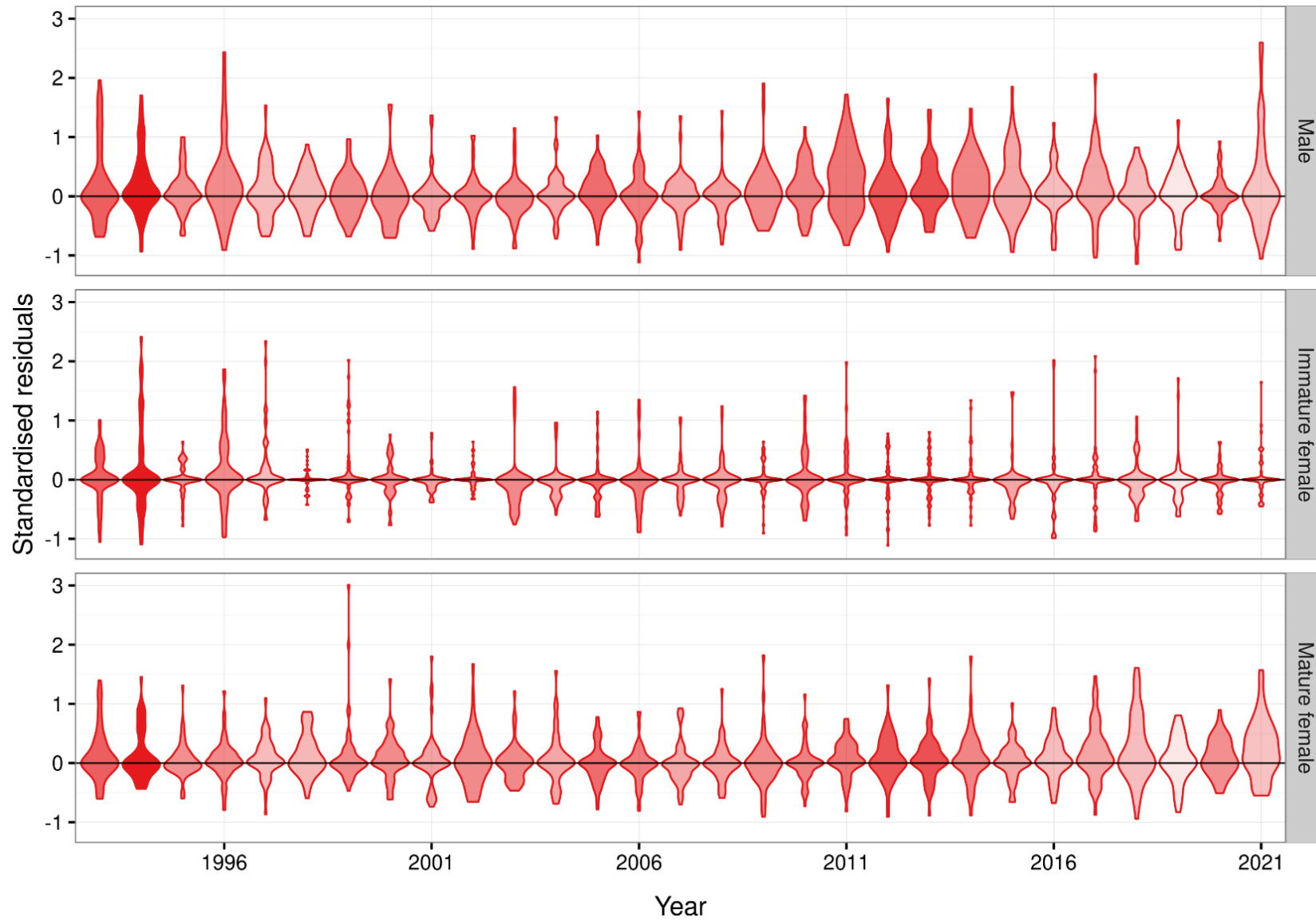


Figure 10: MAP standardised residuals from fits to the LF data by sex and fishing year.

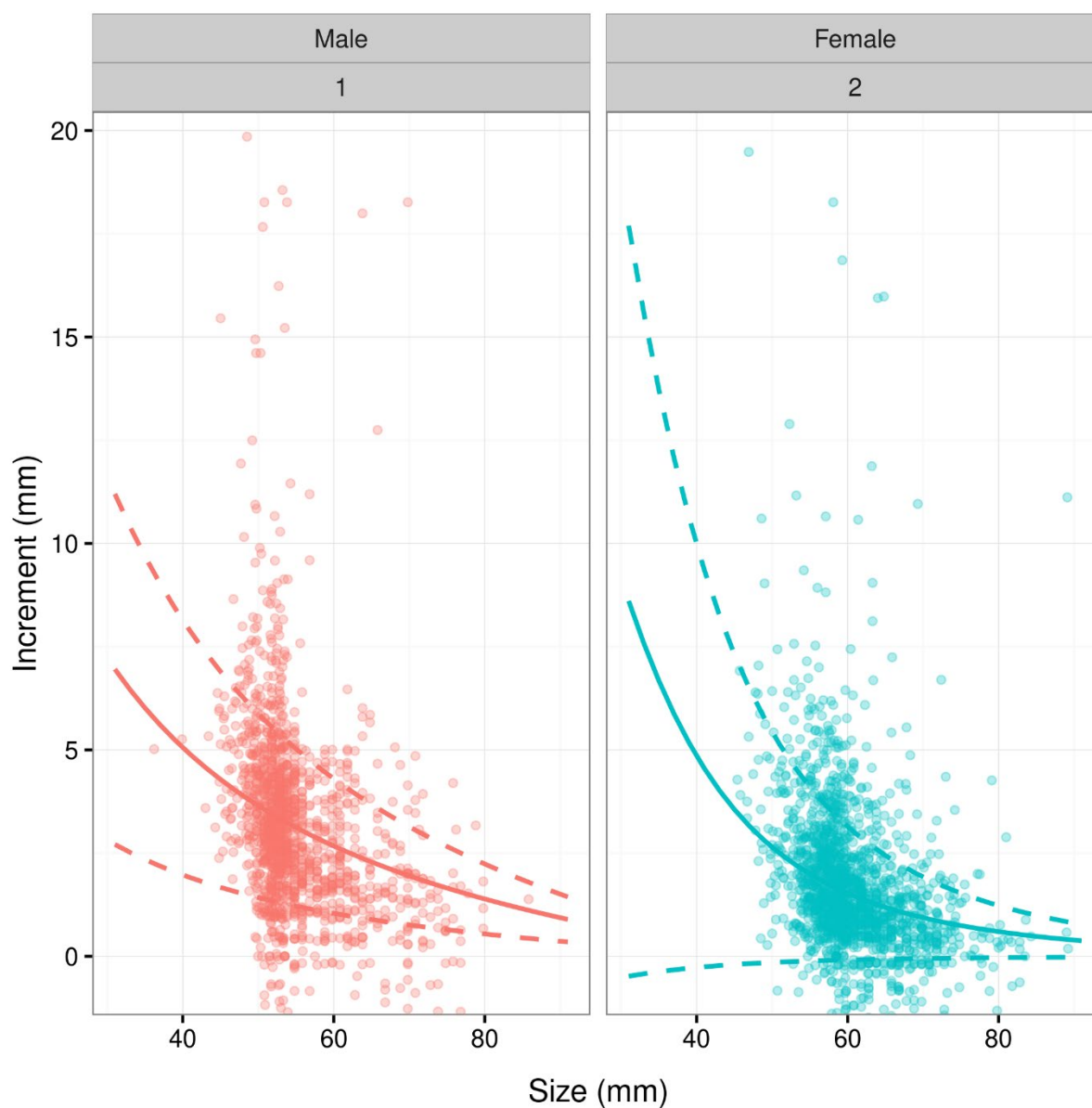


Figure 11: MAP predicted 6 monthly growth increment by size and sex in the base case model run showing the mean (solid line), ± 1 standard deviation (dashed line), and observed growth increments divided by time-at-liberty (points).

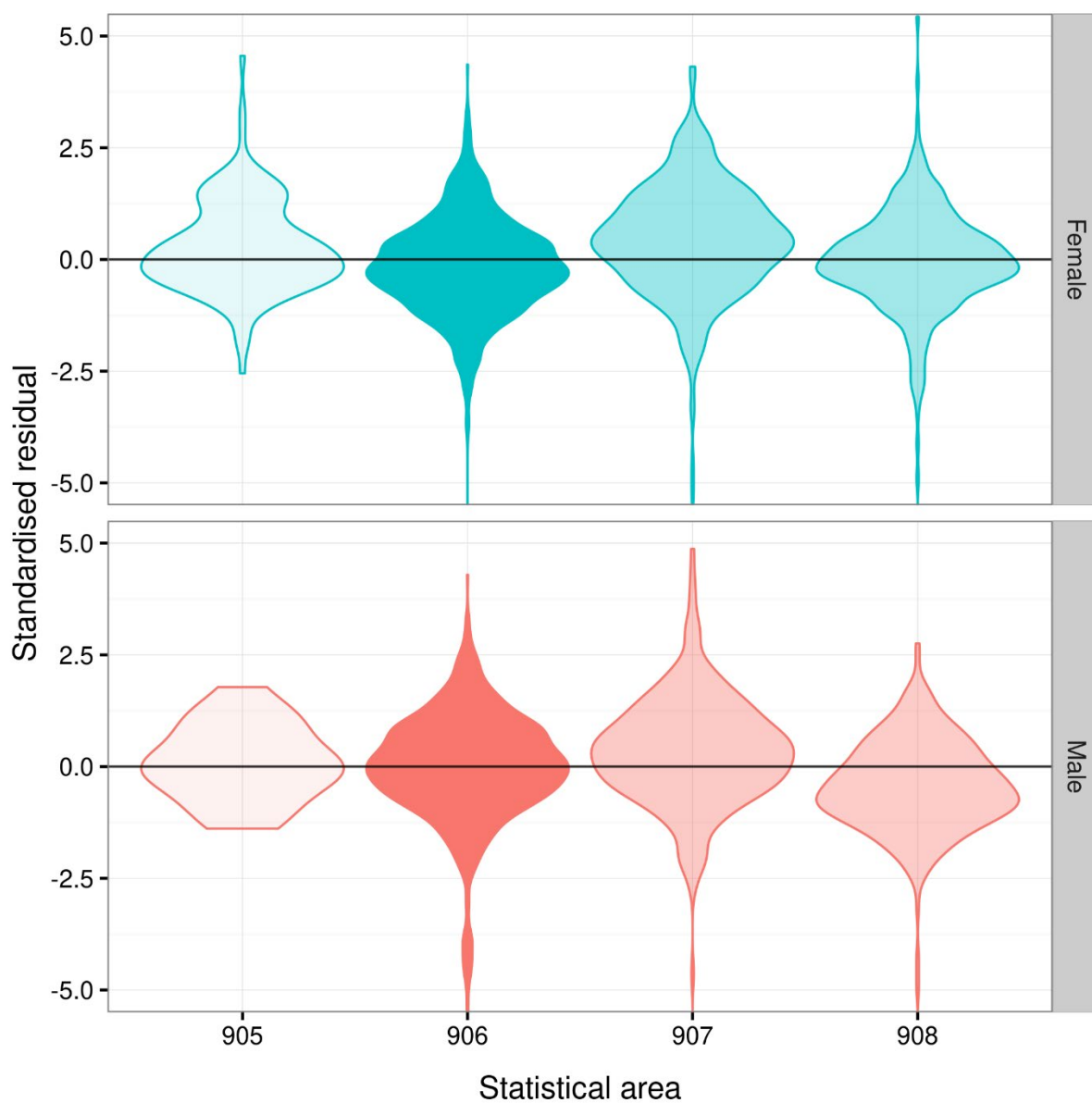


Figure 12: MAP standardised residuals of fits to tag-recapture data by statistical area of release and sex in the base case model run. Darker shading represents a higher number of tags.

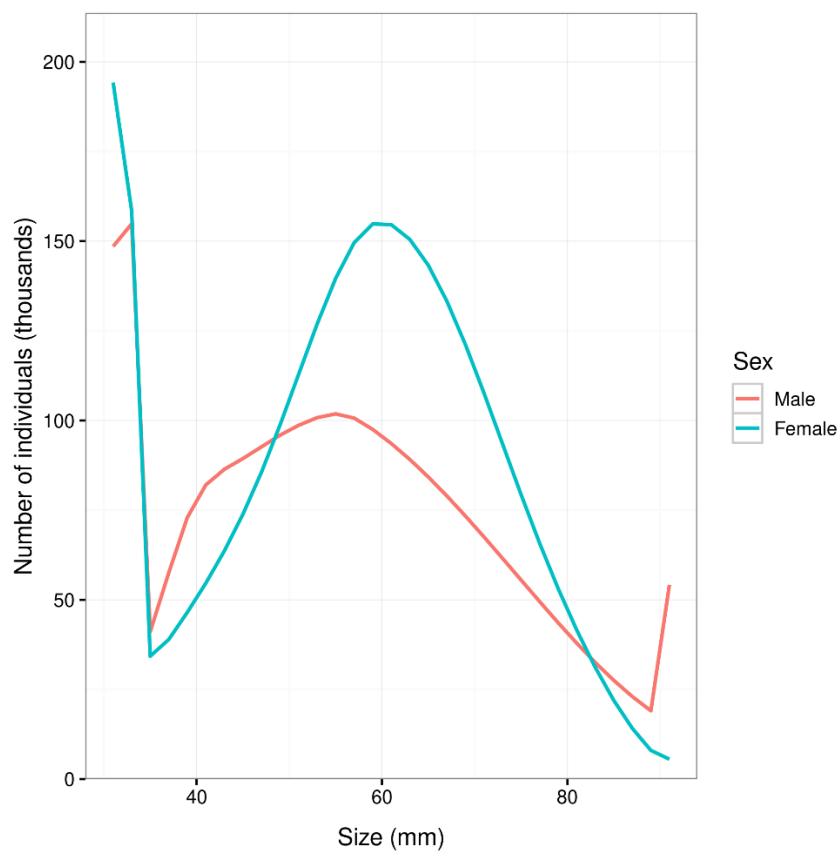
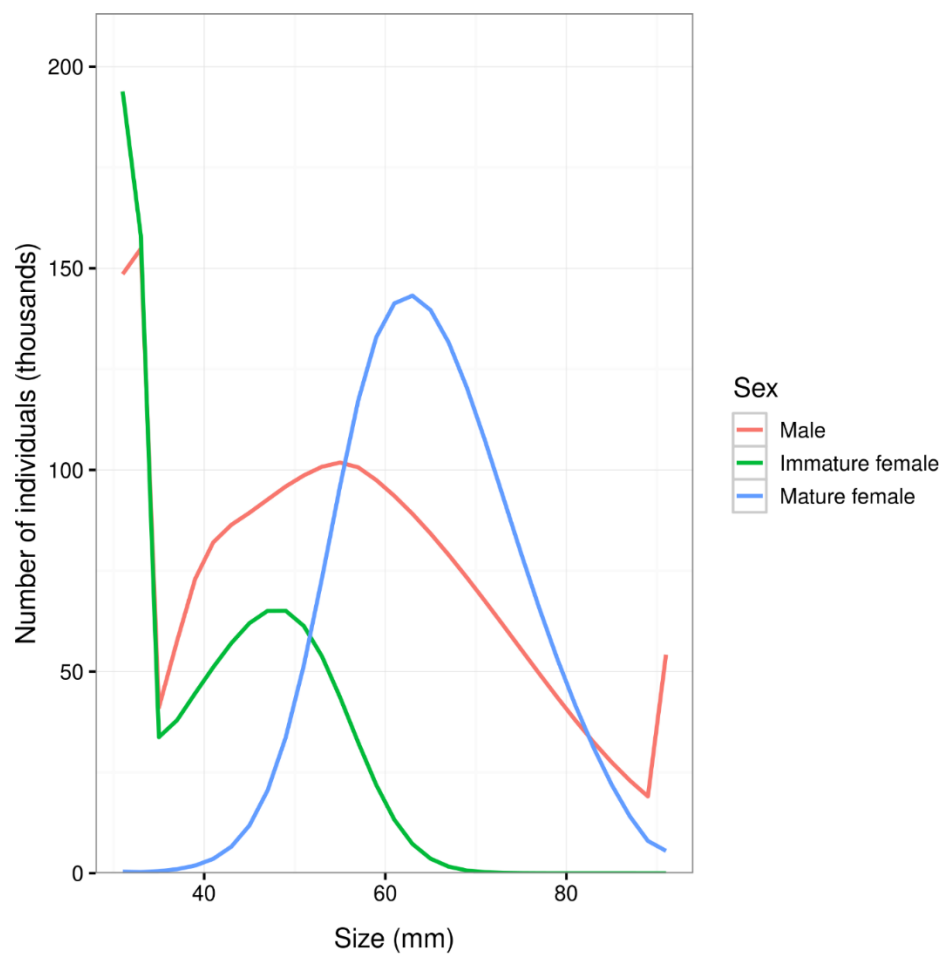


Figure 13: MAP initial number of individuals by size and sex category in the base case model run.

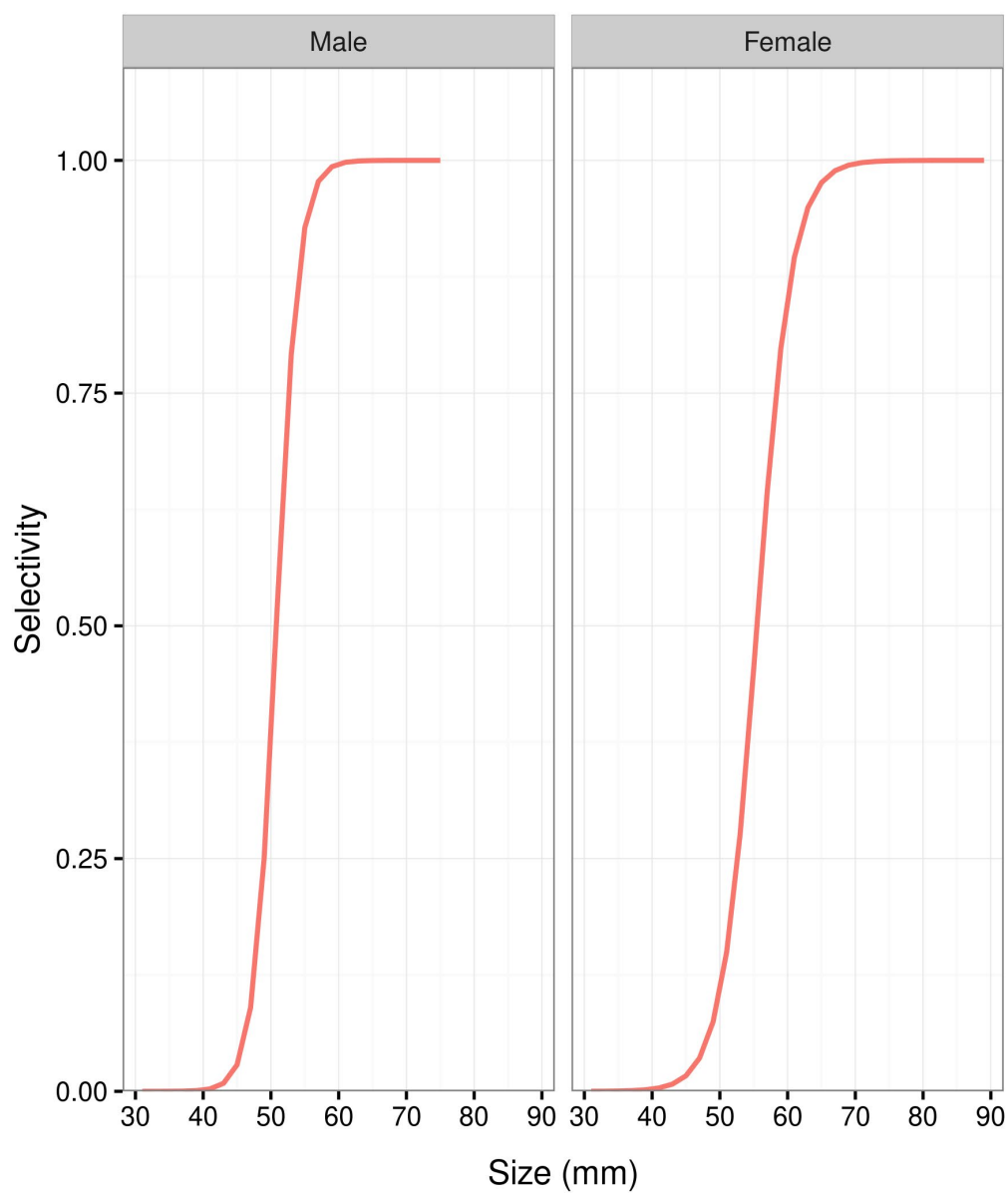


Figure 14: MAP of selectivity by sex and size in the base case model run.

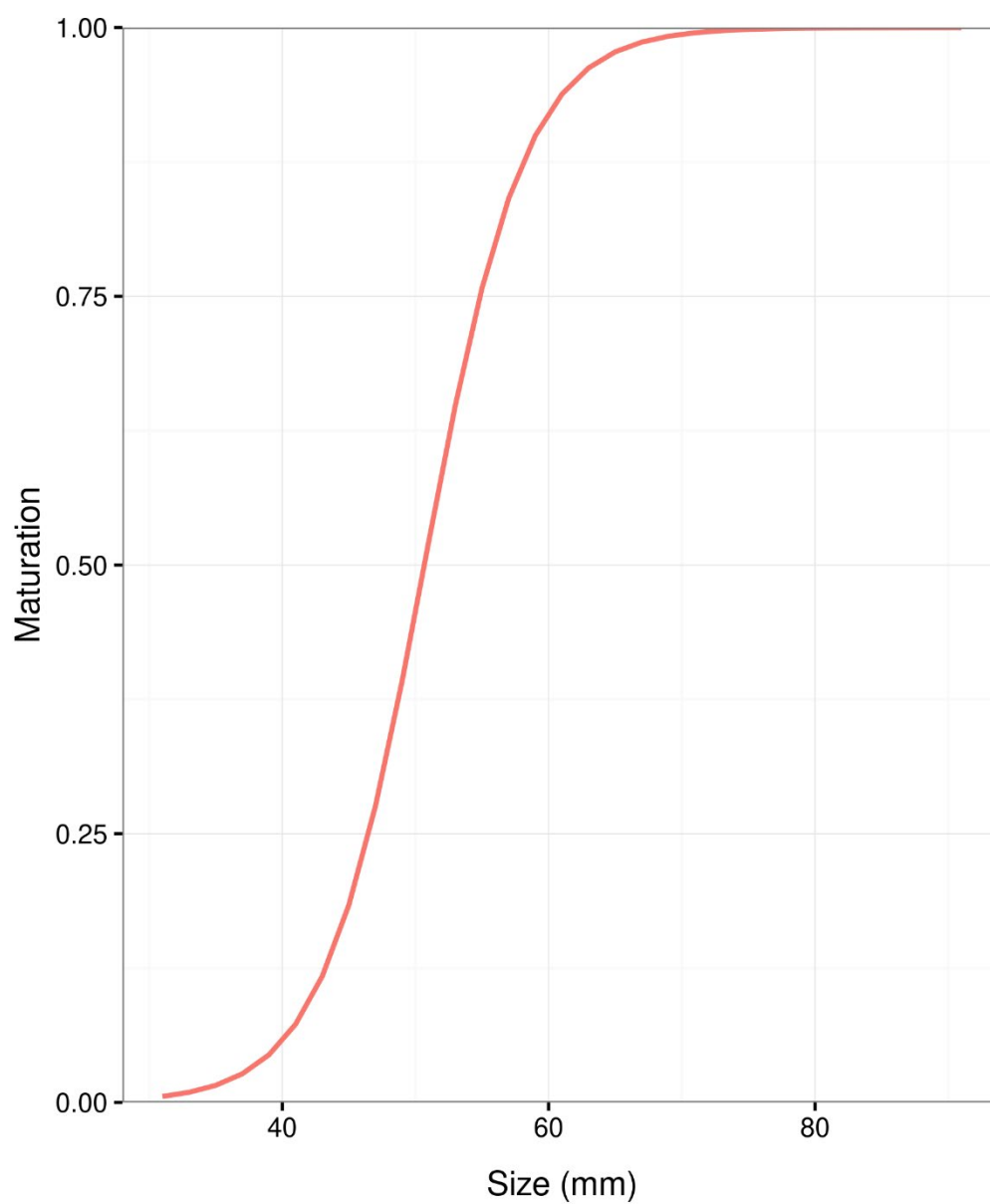


Figure 15: MAP of female maturation curve by size in the base case model run.

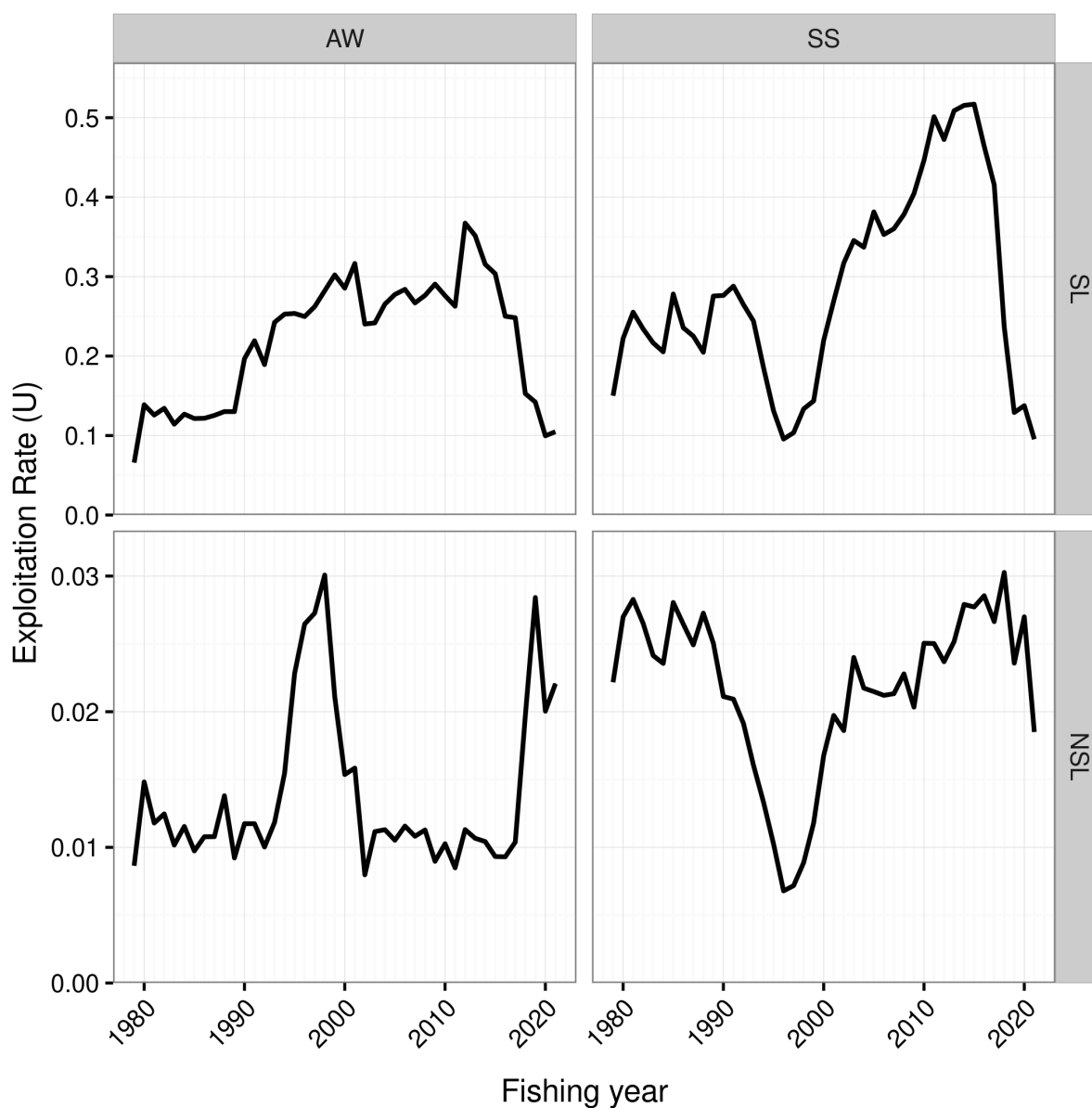


Figure 16: MAP of exploitation rate by fishing year and season (AW = autumn/winter, SS = spring/summer) for the size limited (SL) and non-size limited (NSL) fisheries in the base case model run. Note that the AW exploitation rates before 1979 are annual rather than seasonal.

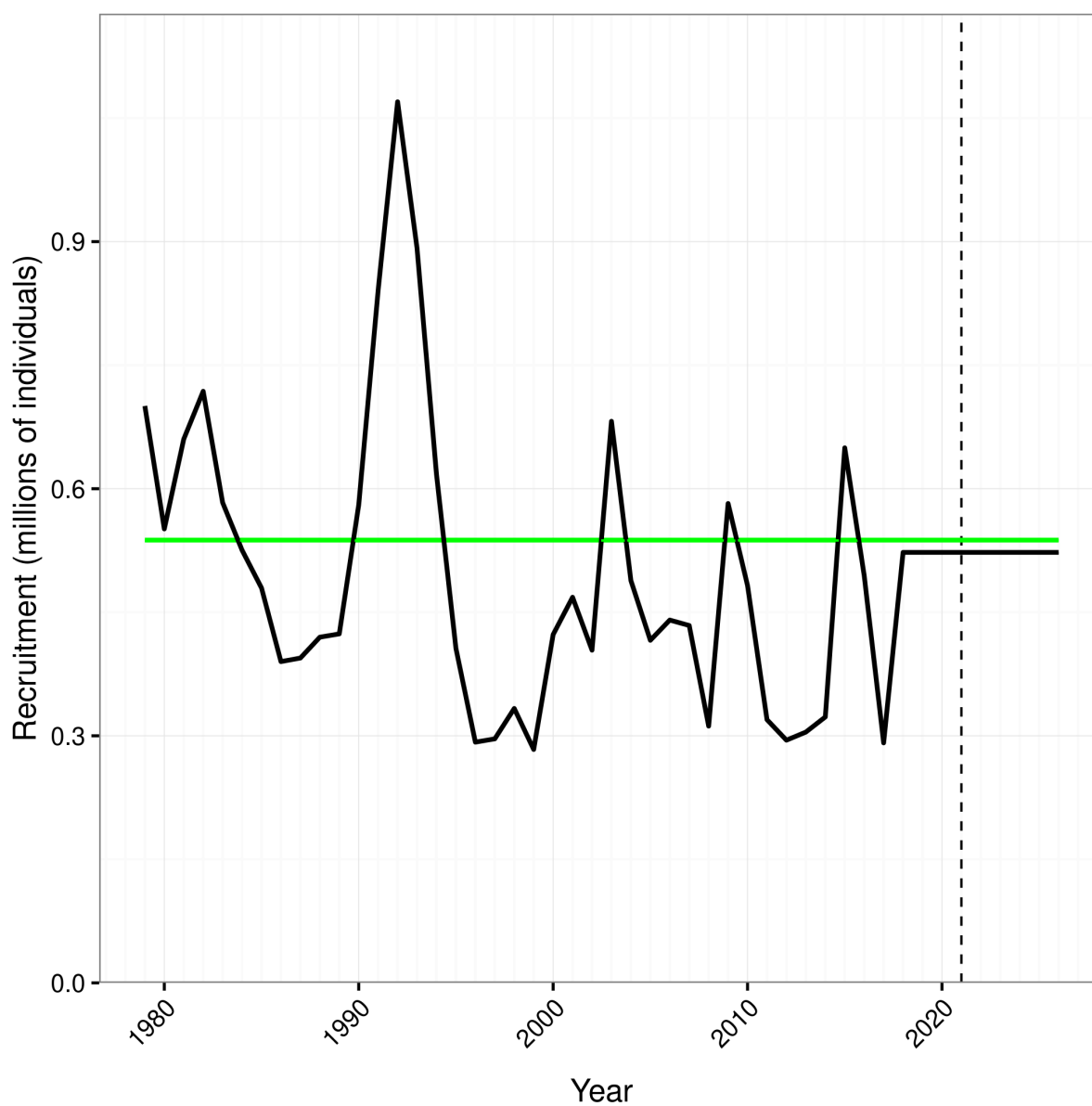


Figure 17: MAP of recruitment for the base case model run. Horizontal green line is R_0 and vertical dashed line is the final year of the reconstruction period.

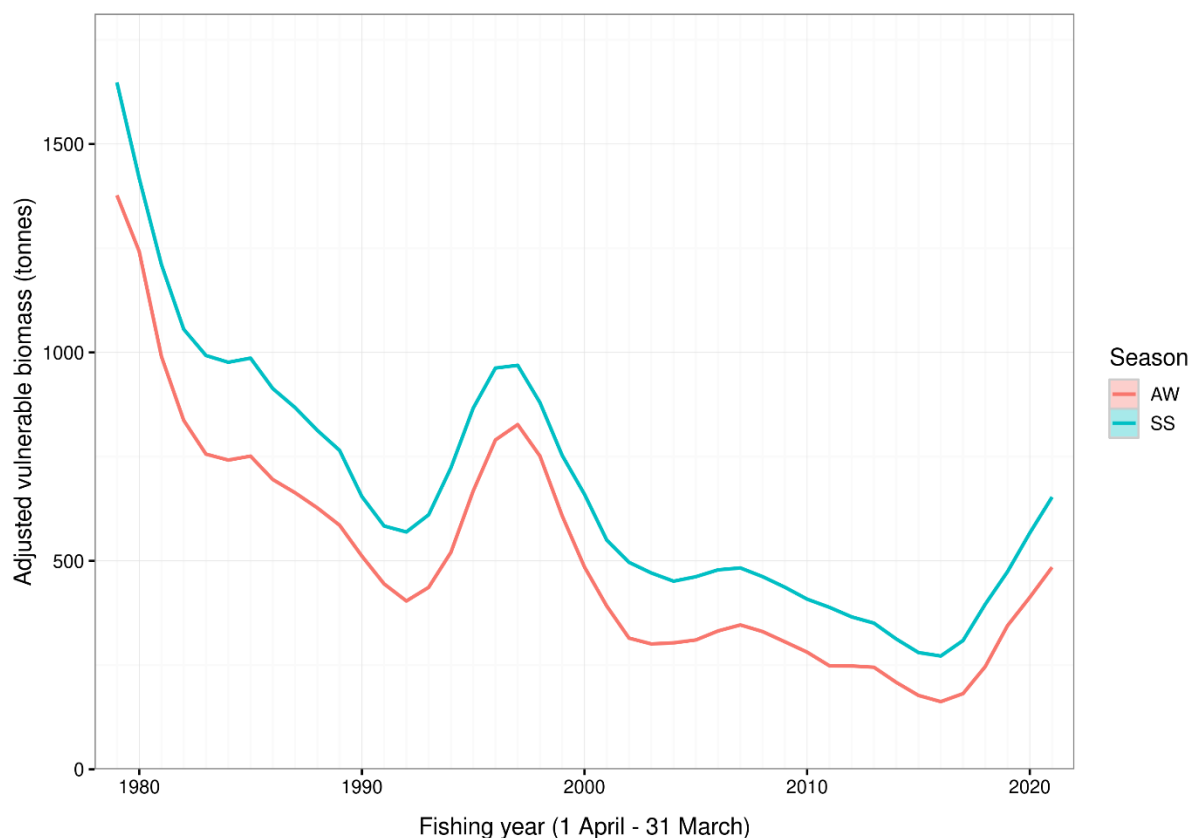


Figure 18: MAP of adjusted vulnerable biomass (tonnes) by season (AW = autumn/winter, SS = spring/summer) and fishing year in the base case model run.

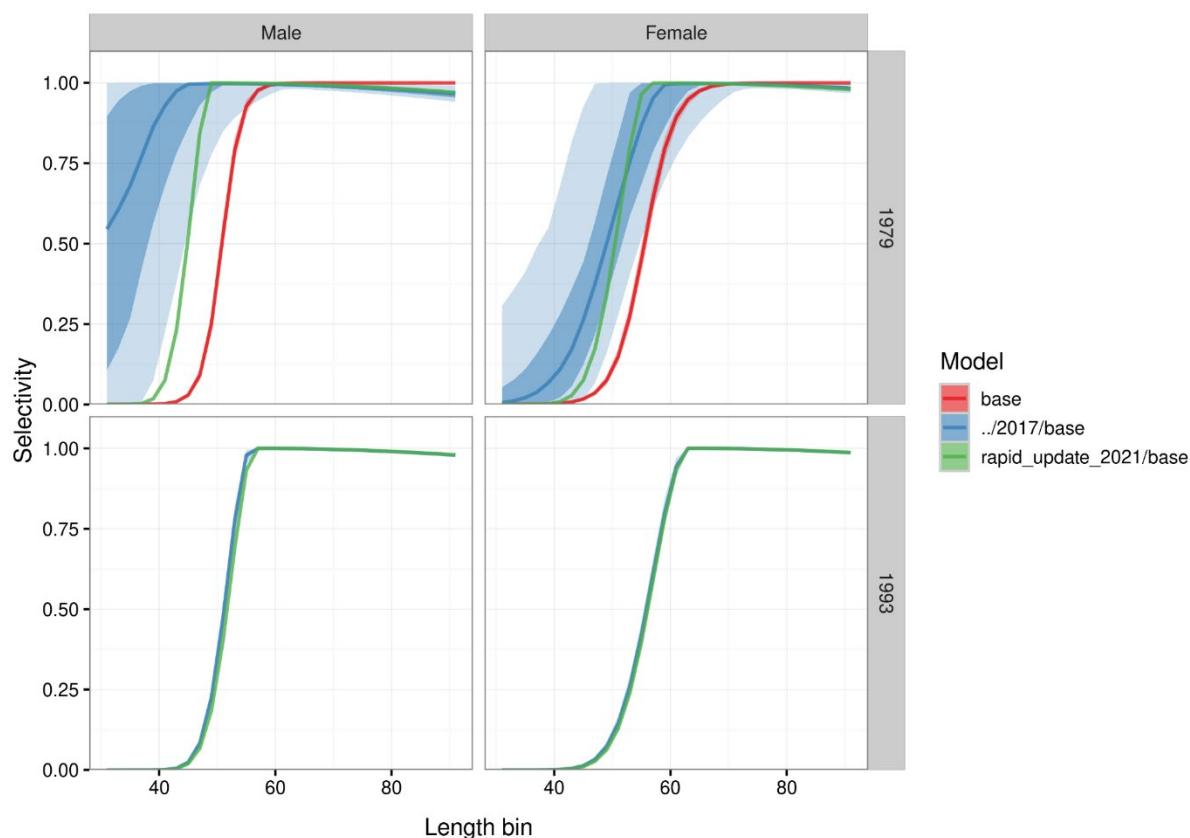


Figure 19: MAP selectivity curves by sex and time period for *base*, the 2017 assessment and most recent (2021) rapid update. The row label year shows the start of the time period.

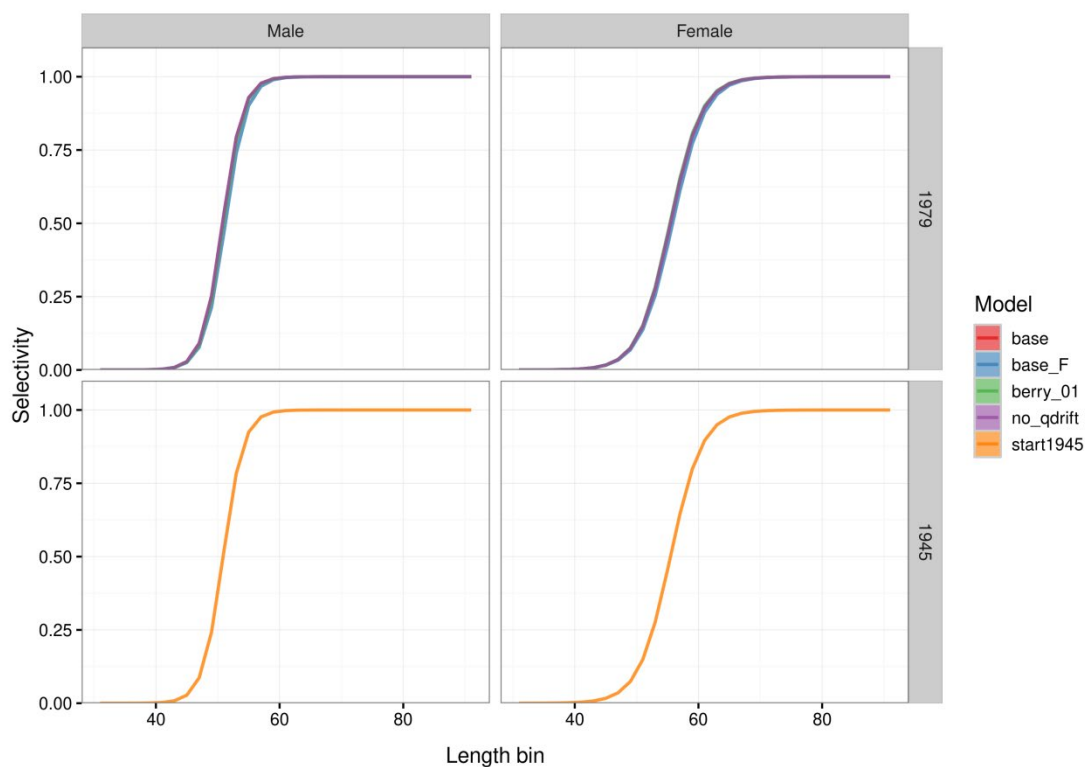


Figure 20: MAP selectivity curves by sex and time period for *base* and sensitivity runs using previous model settings: *base_F*, *berry_01*, *no_qdrift*, and *start1945*. The row label year shows the start of the time period.

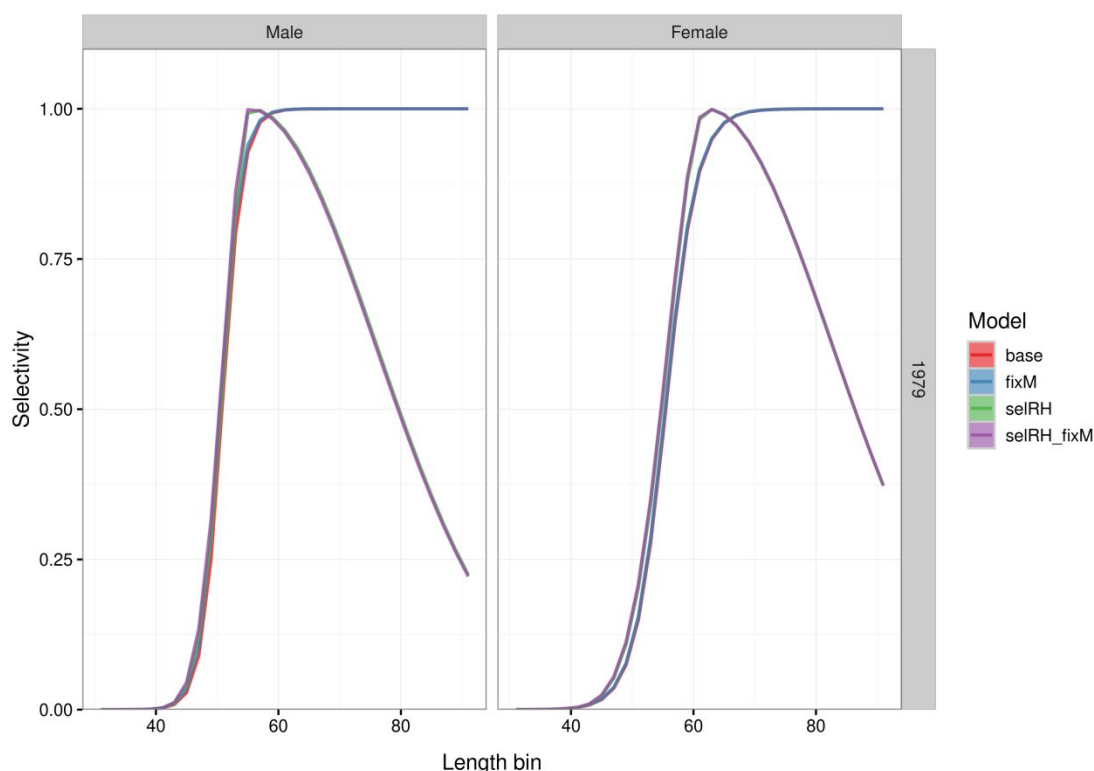


Figure 21: MAP selectivity curves by sex for *base* and sensitivity runs fixing *M* and estimating right-limb selectivity: *fixM*, *selRH*, and *selRH_fixM*.

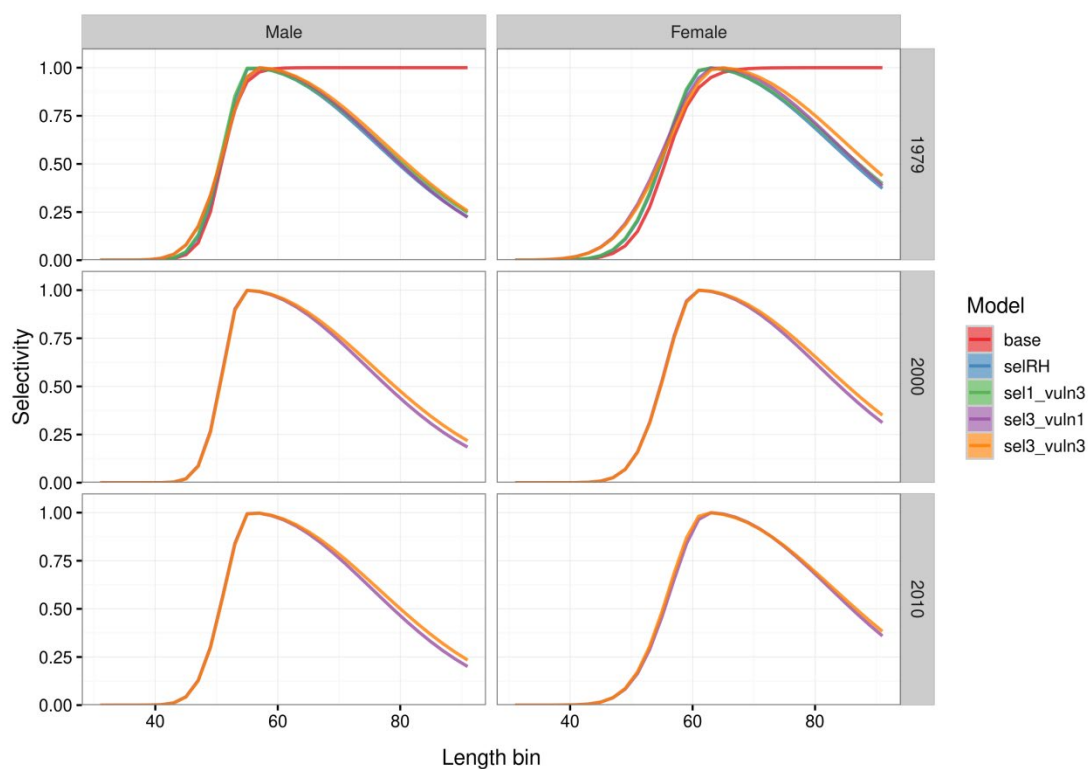


Figure 22: MAP selectivity curves by sex and time period for *base* and sensitivity runs exploring selectivity and vulnerability blocks: *selRH*, *sel1_vuln3*, *sel3_vuln1*, and *sel3_vuln3*. The row label year shows the start of the time period.

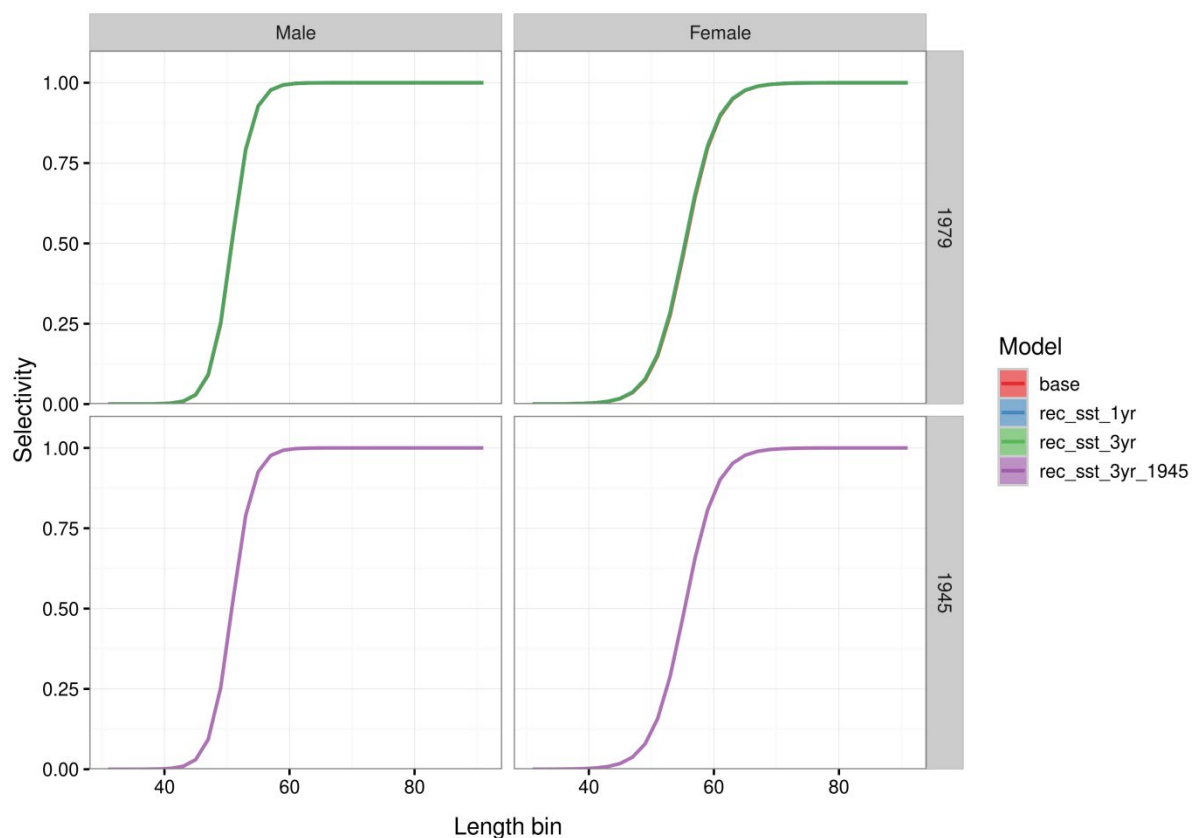


Figure 23: MAP selectivity curves by sex and time period for *base* and sensitivity runs using SST as a covariate on recruitment deviates: *rec_sst_1yr*, *rec_sst_3yr*, and *rec_sst_3yr_1945*. The row label year shows the start of the time period.

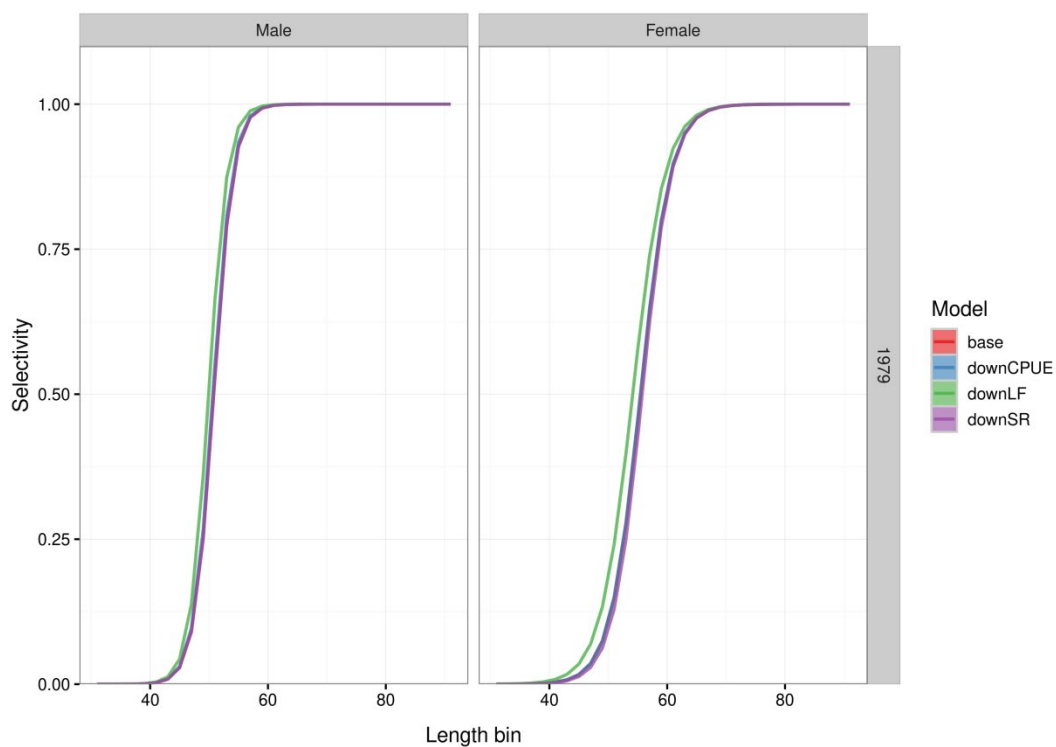


Figure 24: MAP selectivity curves by sex for *base* and sensitivity runs *downCPUE*, *downLF*, and *downSR*.

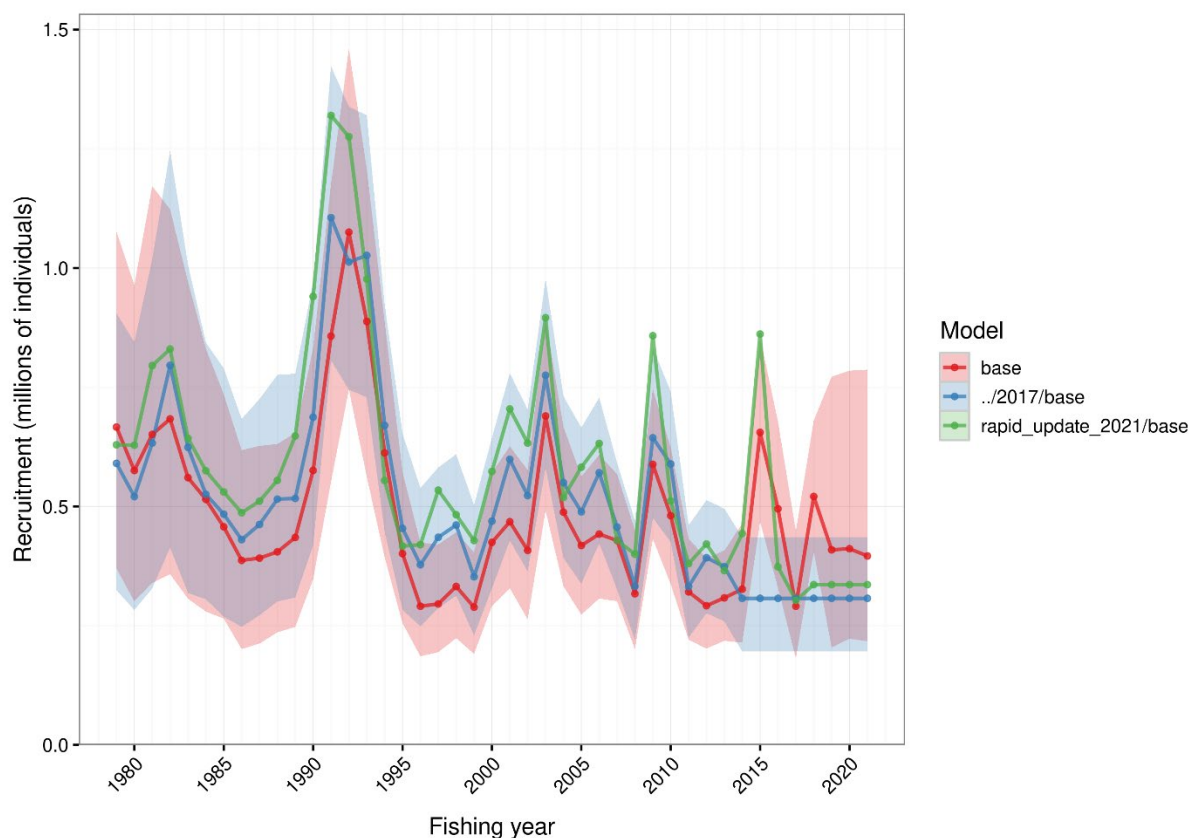


Figure 25: MAP recruitments for *base*, the 2017 assessment and most recent (2021) rapid update.

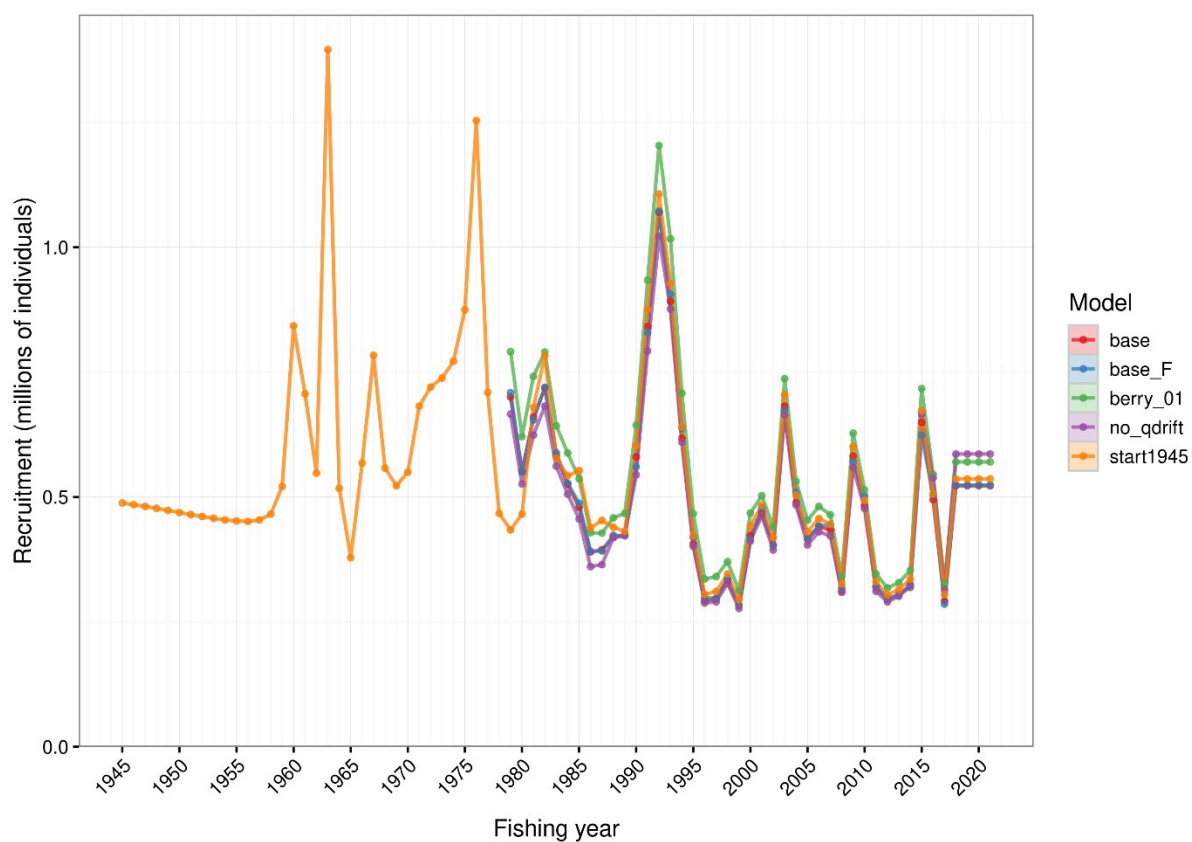


Figure 26: MAP recruitments for *base* and sensitivity runs *base* and sensitivity runs using previous model settings: *base_F*, *berry_01*, *no_qdrift*, and *start1945*.

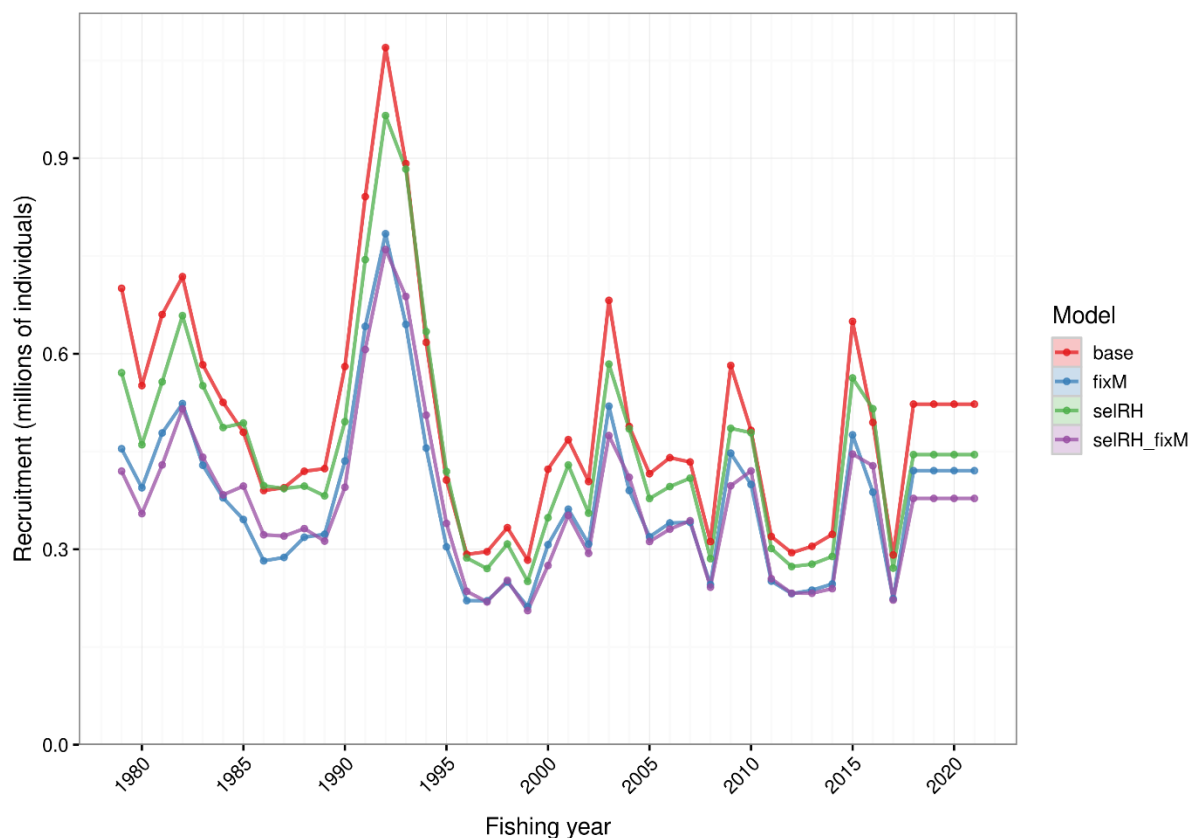


Figure 27: MAP recruitments for *base* and sensitivity runs fixing M and estimating right-limb selectivity: *fixM*, *selRH*, and *selRH_fixM*.

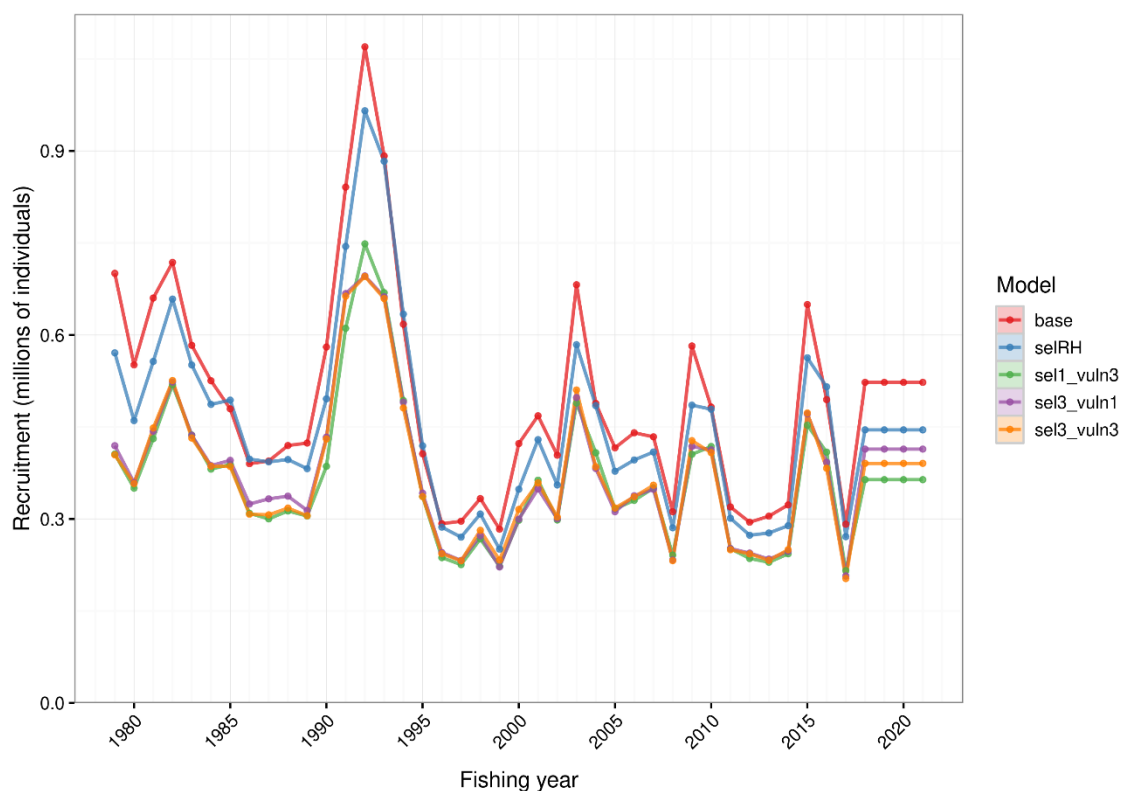


Figure 28: MAP recruitments for *base* and sensitivity runs exploring selectivity and vulnerability blocks: *selRH*, *sel1_vuln3*, *sel3_vuln1*, and *sel3_vuln3*.

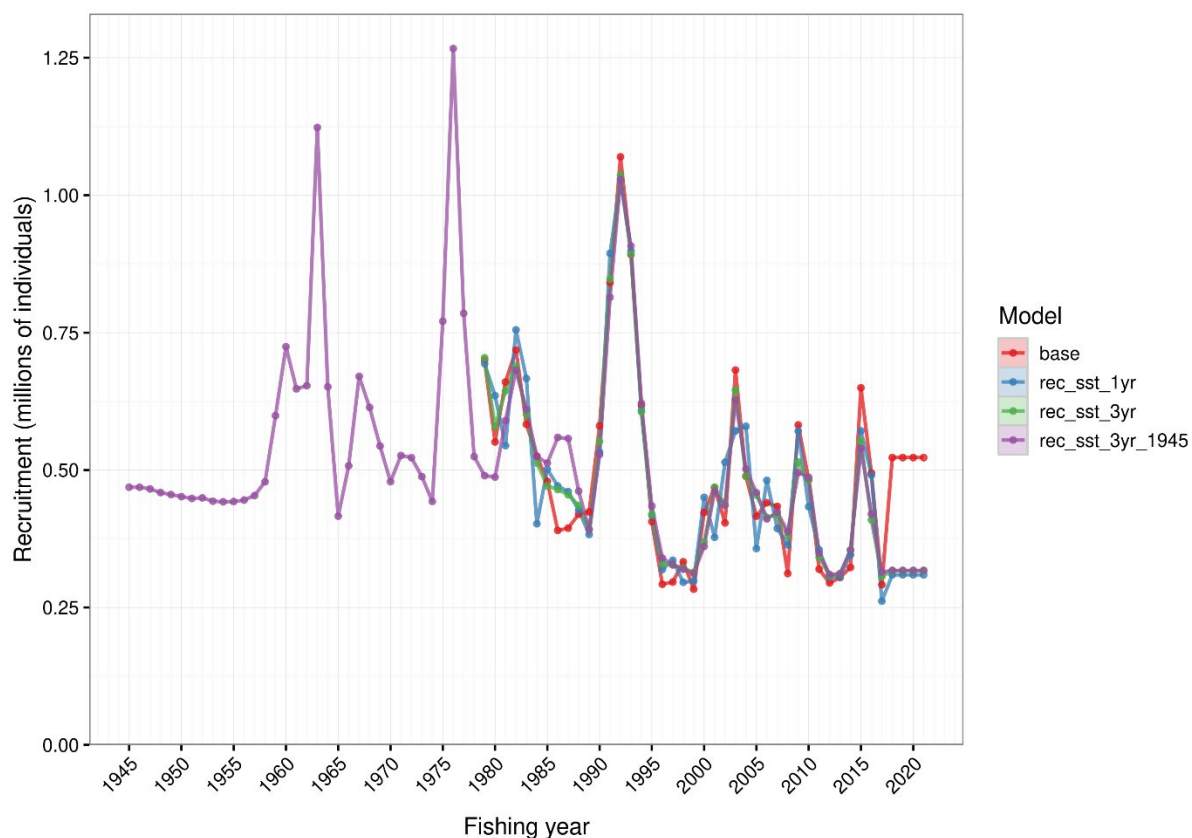


Figure 29: MAP recruitments for *base* and sensitivity runs using SST as a covariate on recruitment deviates: *rec_sst_1yr*, *rec_sst_3yr*, and *rec_sst_3yr_1945*.

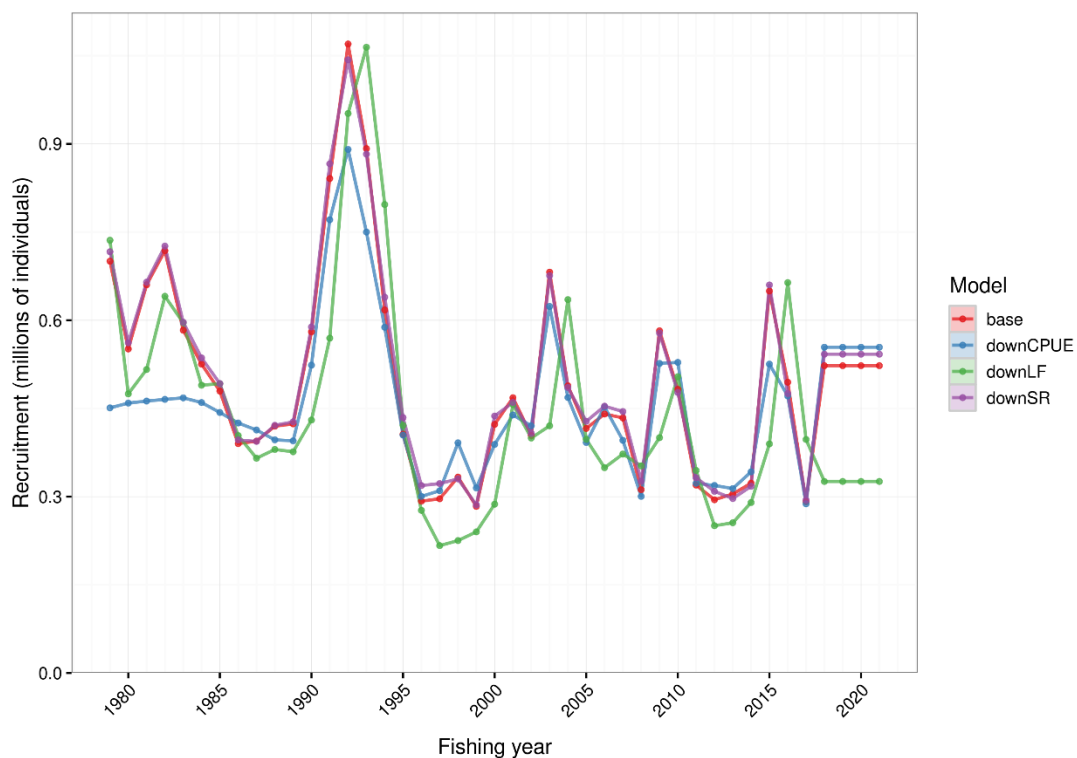


Figure 30: MAP recruitments for *base* and sensitivity runs *downCPUE*, *downLF*, and *downSR*.

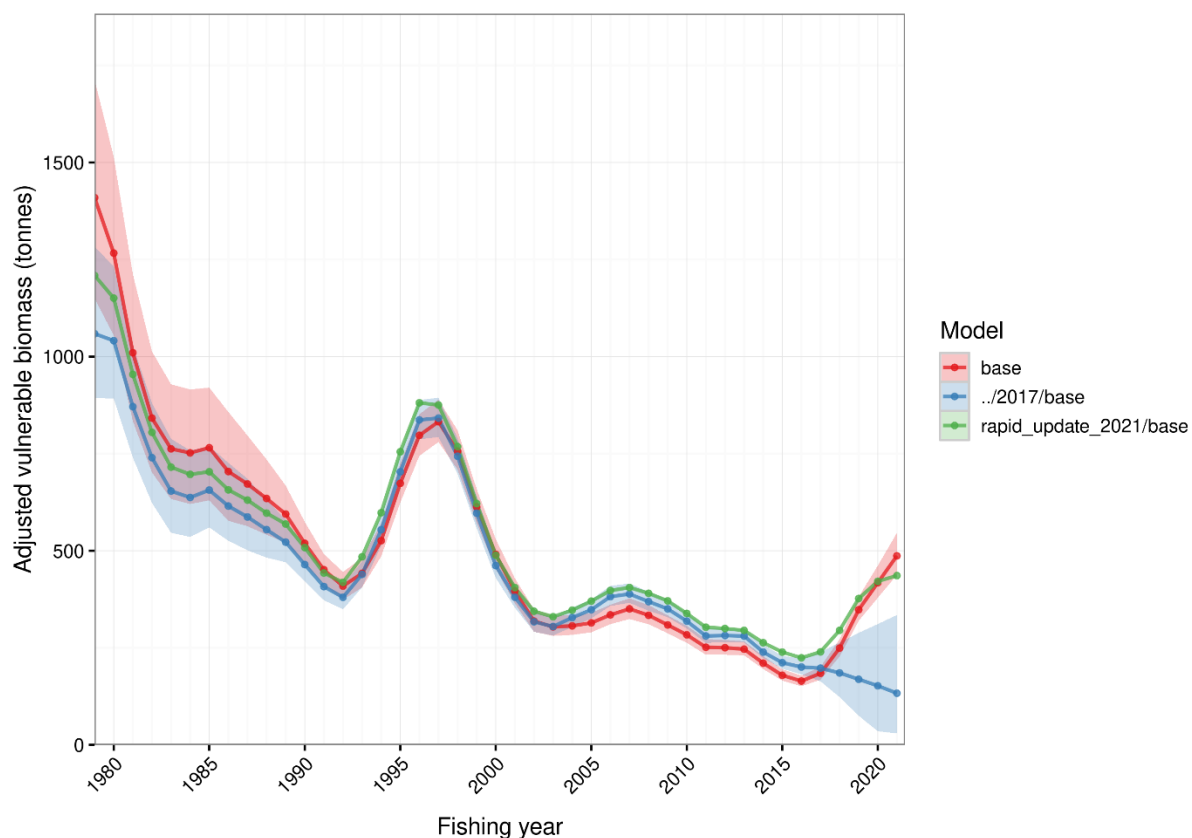


Figure 31: and MAP adjusted vulnerable biomass for *base*, the 2017 assessment and most recent (2021) rapid update. Note that the 2017 base run vulnerable biomass has been projected to 2021.

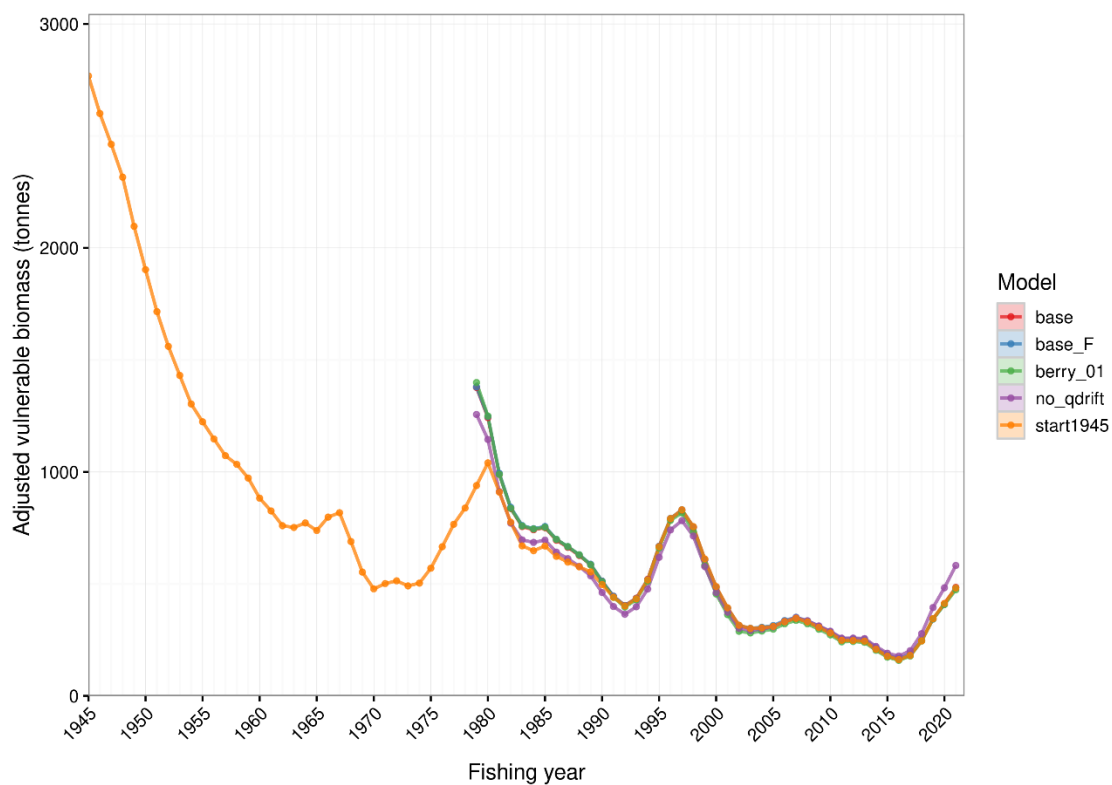


Figure 32: MAP adjusted vulnerable biomass for *base* and sensitivity runs using previous model settings: *base_F*, *berry_01*, *no_qdrift*, and *start1945*.

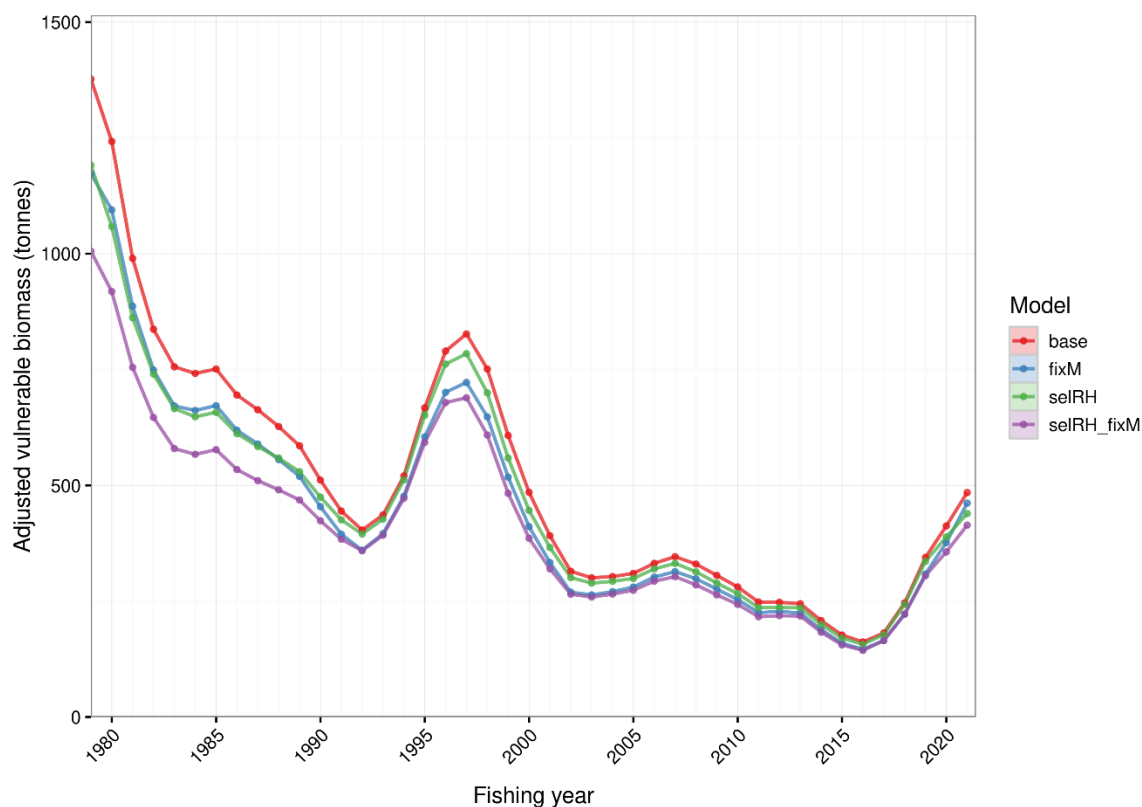


Figure 33: MAP adjusted vulnerable biomass for *base* and sensitivity runs fixing *M* and estimating right-limb selectivity: *fixM*, *selRH*, and *selRH_fixM*.

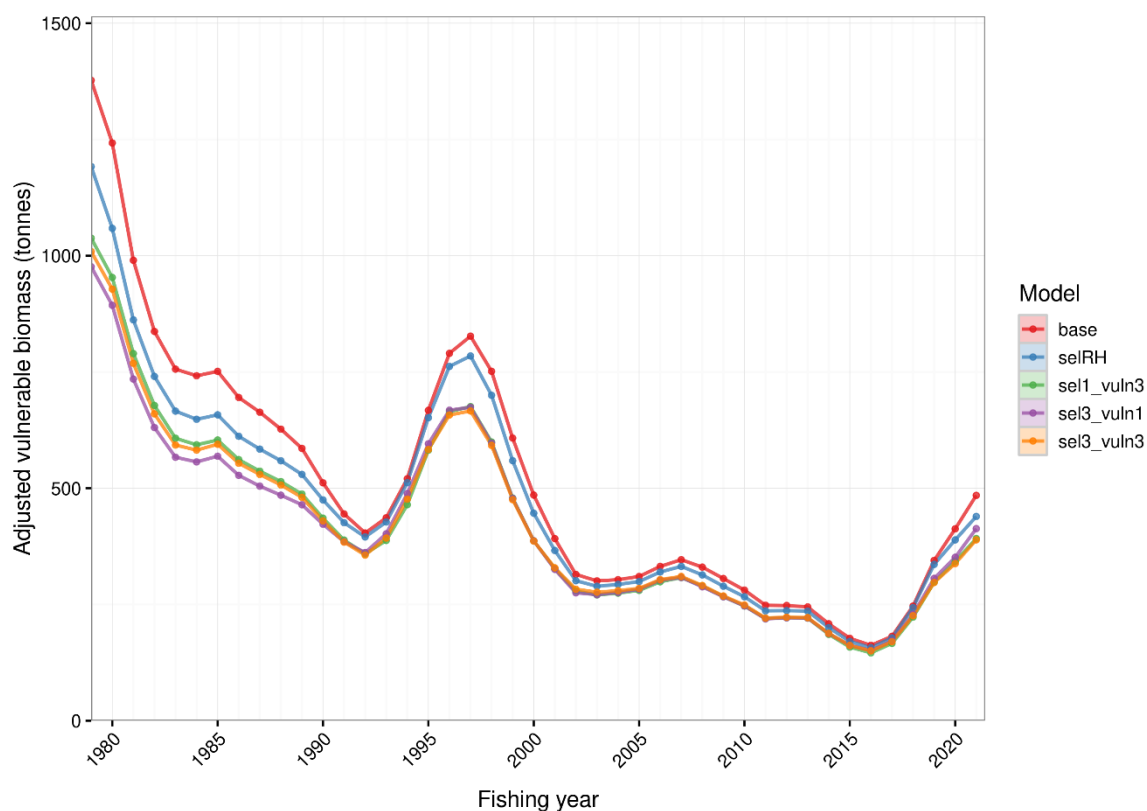


Figure 34: MAP adjusted vulnerable biomass for *base* and sensitivity runs exploring selectivity and vulnerability blocks: *selRH*, *sel1_vuln3*, *sel3_vuln1*, and *sel3_vuln3*.

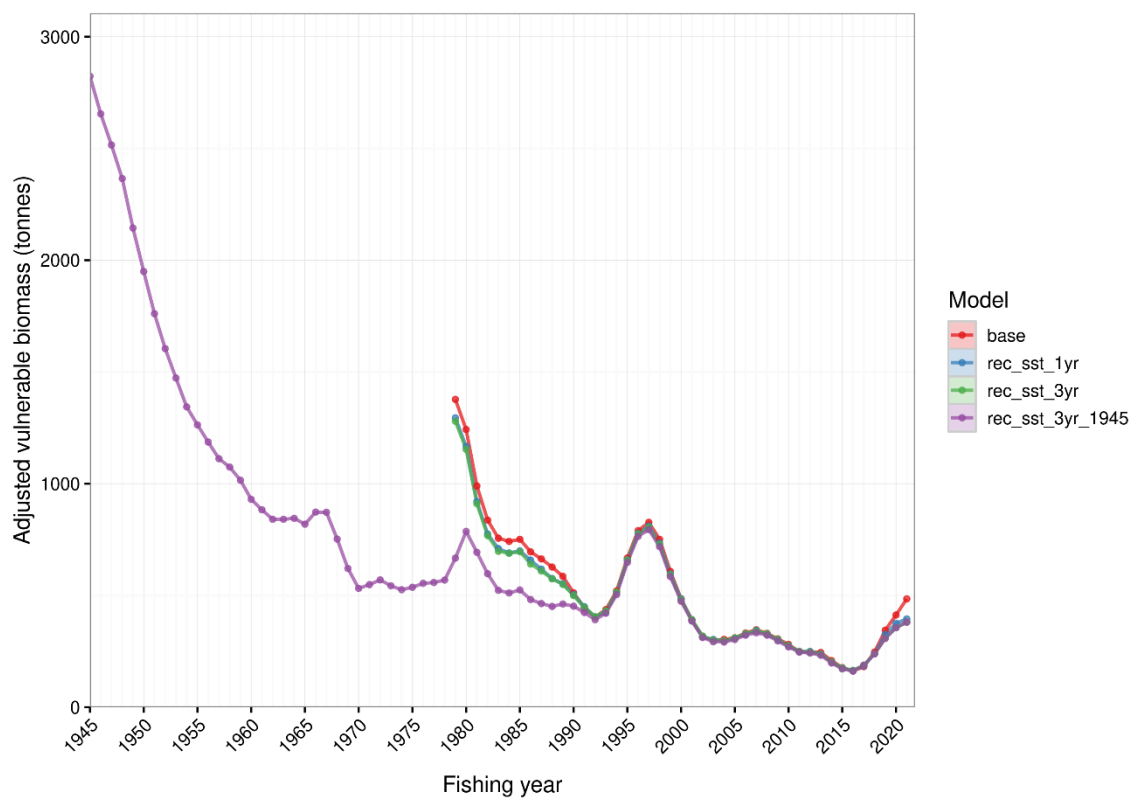


Figure 35: MAP adjusted vulnerable biomass for *base* and sensitivity runs using SST as a covariate on recruitment deviates: *rec_sst_1yr*, *rec_sst_3yr*, and *rec_sst_3yr_1945*.

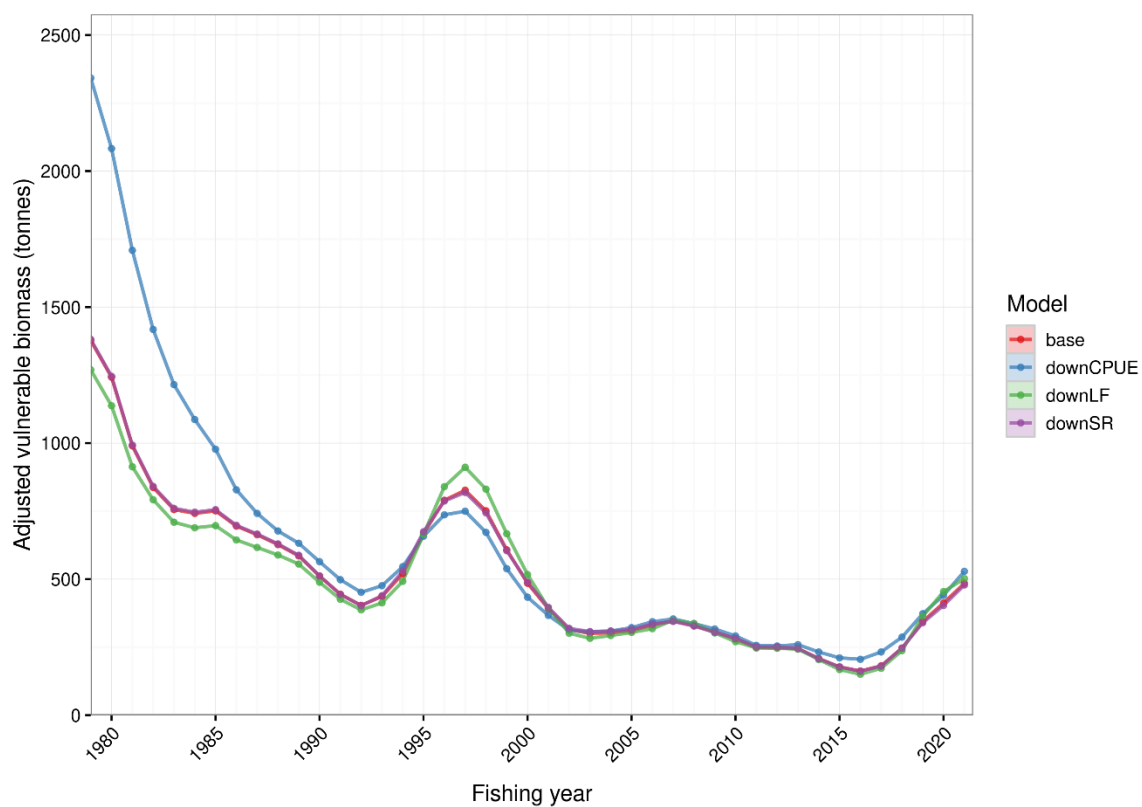


Figure 36: MAP adjusted vulnerable biomass for *base* and sensitivity runs *downCPUE*, *downLF*, and *downSR*.

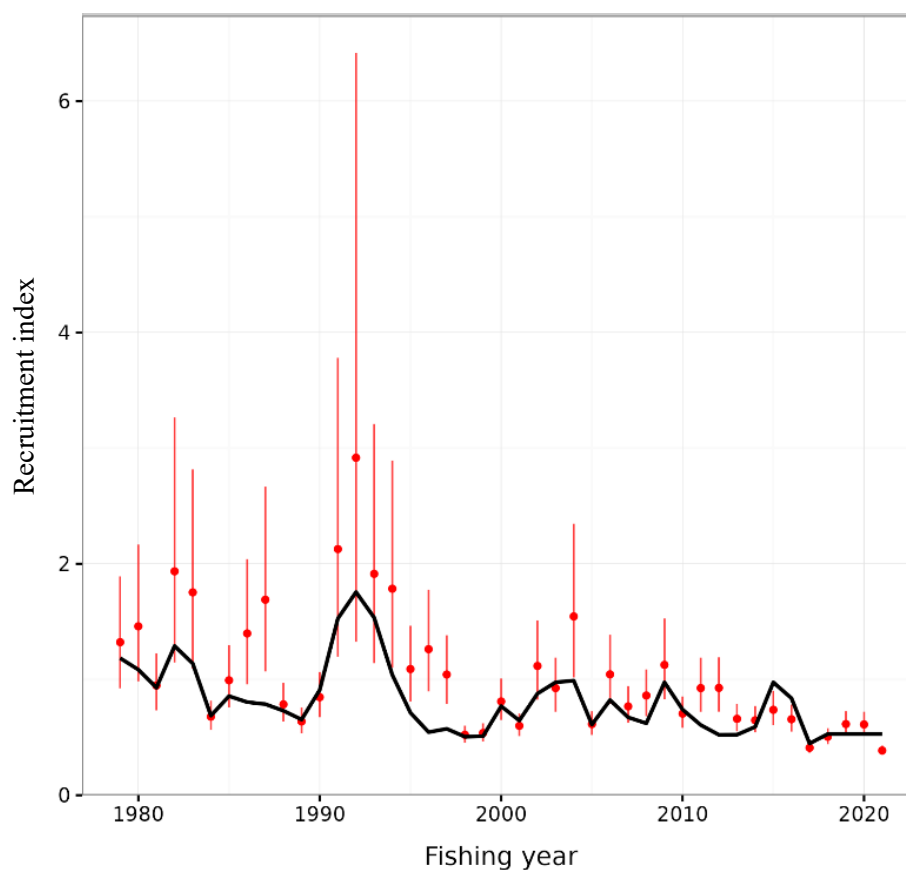


Figure 37: MAP fit (black line) to SST indices for the *rec_sst_1yr* model run (red points represent the mean of the SST index and the red bars represent the range of the 20% coefficient of variation of this index). Note that the SST values were inverted for the purposes of model fitting, so that warmer years appear near the bottom of the y-axis and colder years near the top.

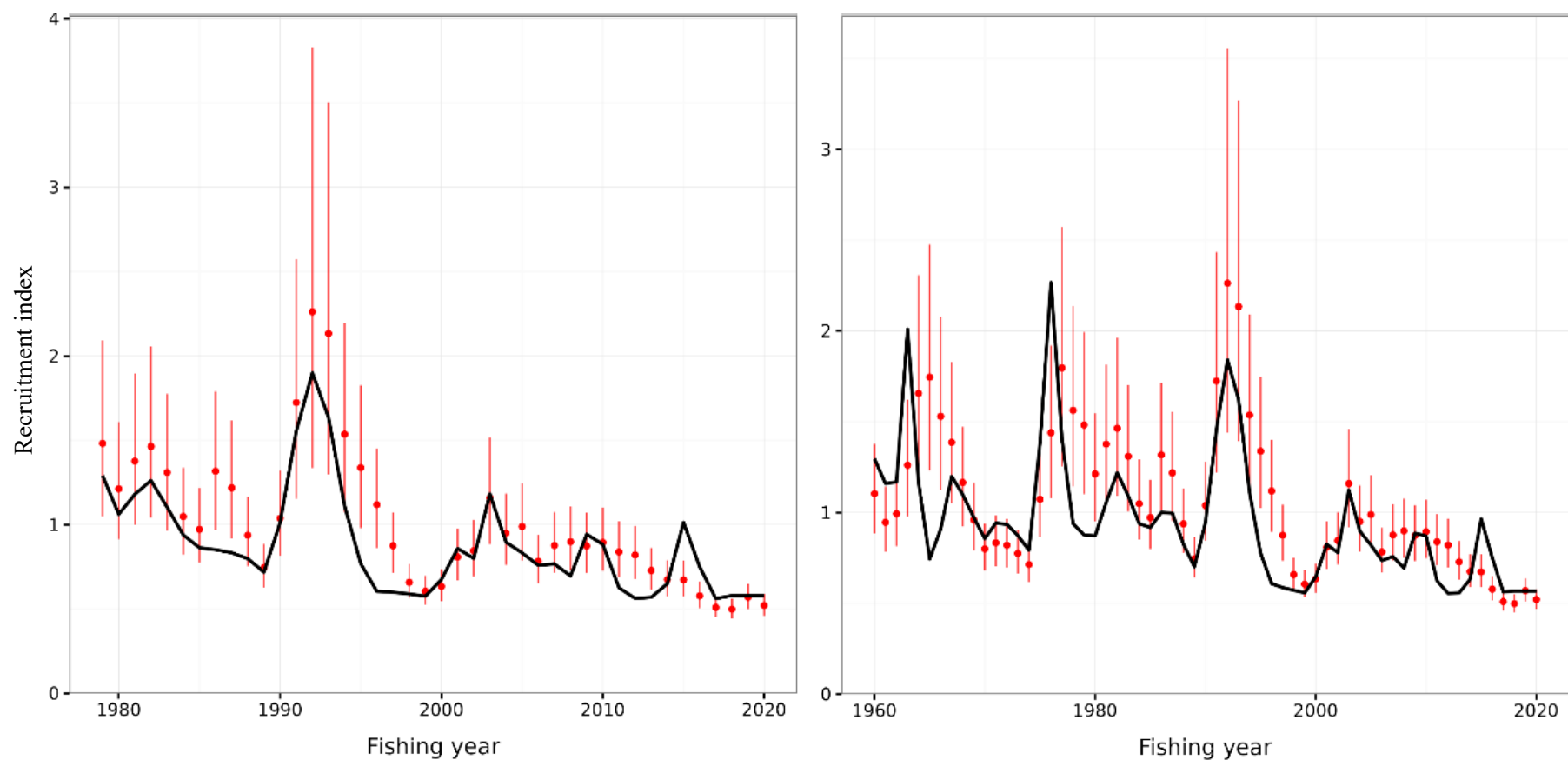


Figure 38: MAP fit (black line) to SST indices for the *rec_sst_3yr* and *rec_sst_3yr_1945* model runs (red points represent the mean of the SST index and the red bars represent the range of the 20% coefficient of variation of this index). Note that the SST values were inverted for the purposes of model fitting, so that warmer years appear near the bottom of the y-axis and colder years near the top.

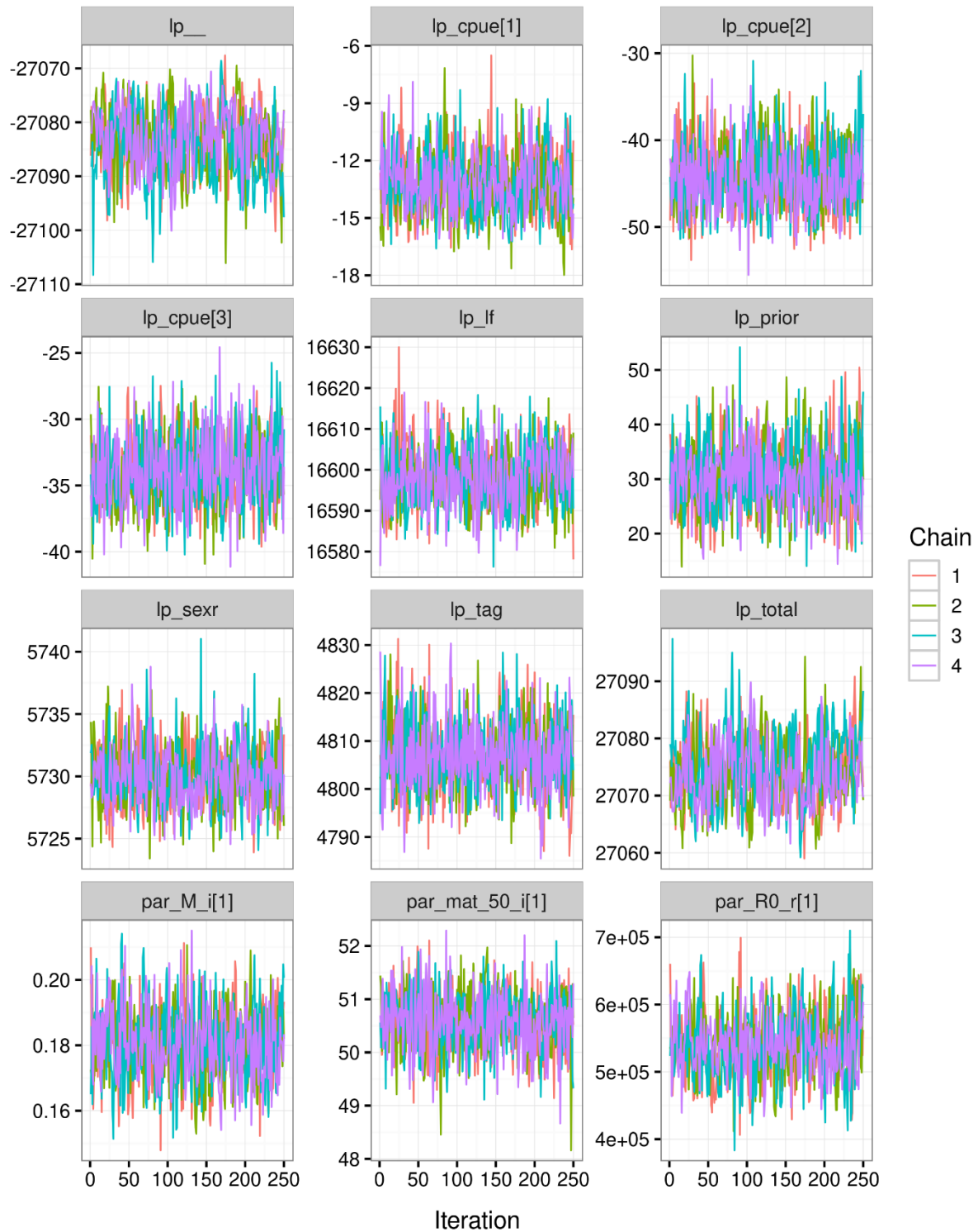


Figure 39: MCMC trace plots by independent chain for likelihood components, natural mortality (M), one of the maturation parameters, and the R_0 parameter for the base case model run.

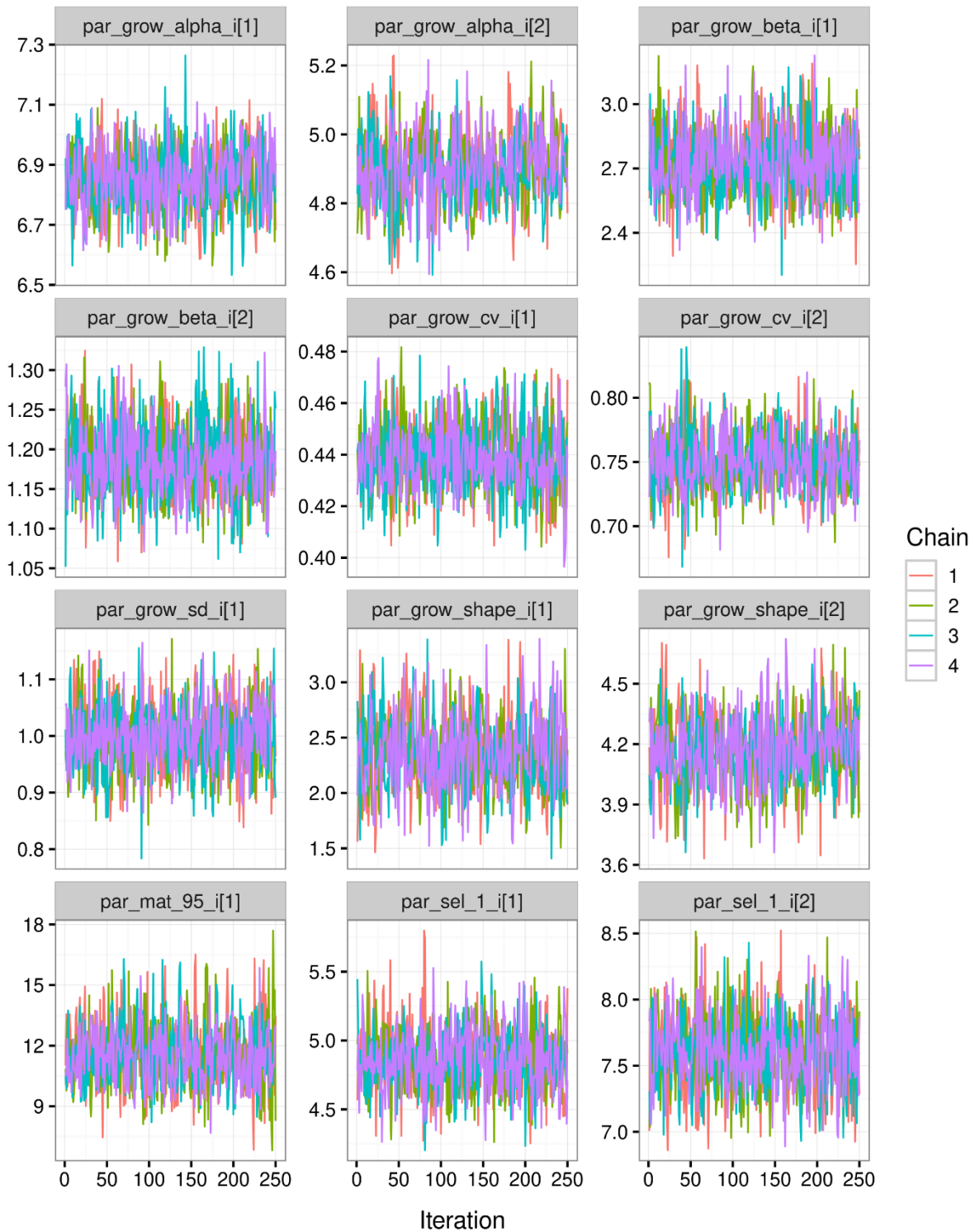


Figure 40: MCMC trace plots by independent chain for growth parameters, one of the maturation parameters, and two selectivity parameters for the base case model run.

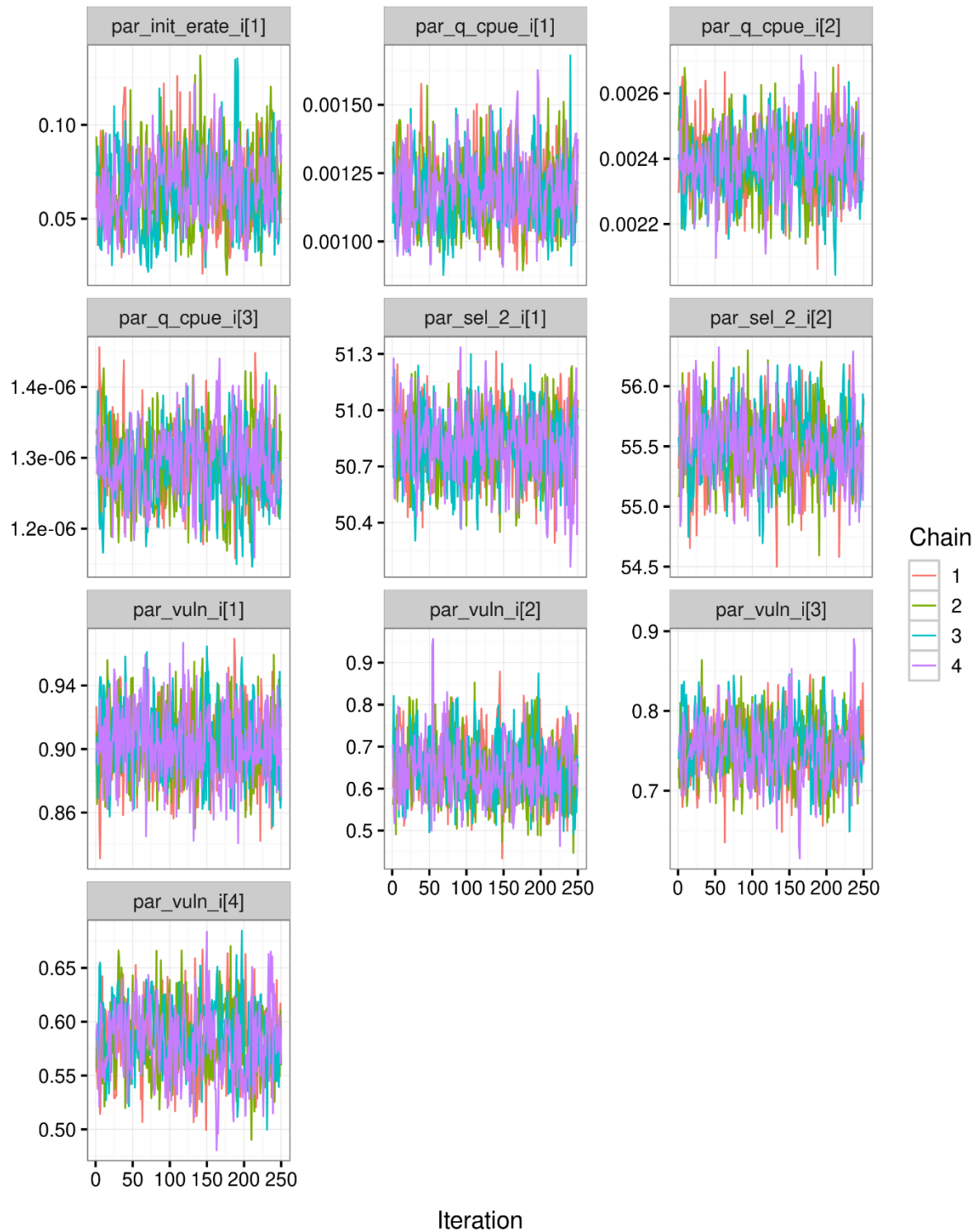


Figure 41: MCMC trace plots by independent chain for the initial exploitation rate (U_0), the remaining selectivity parameters, the vulnerability parameters, and catchability coefficients (q) for the base case model run.

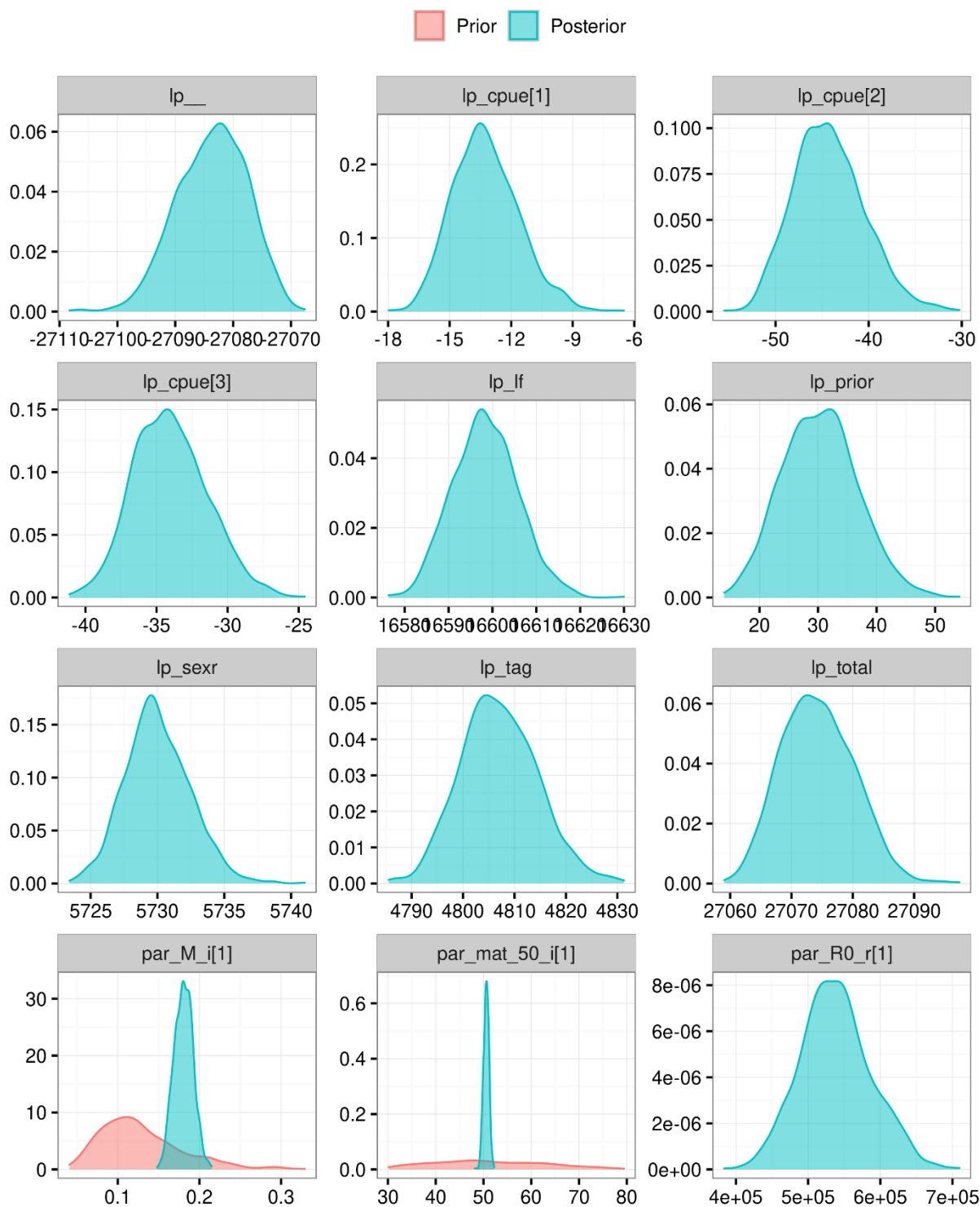


Figure 42: Density plots showing prior (red) and posterior distributions (blue) for natural mortality (M), one of the maturation parameters, and the R_0 parameter for the base case model run.

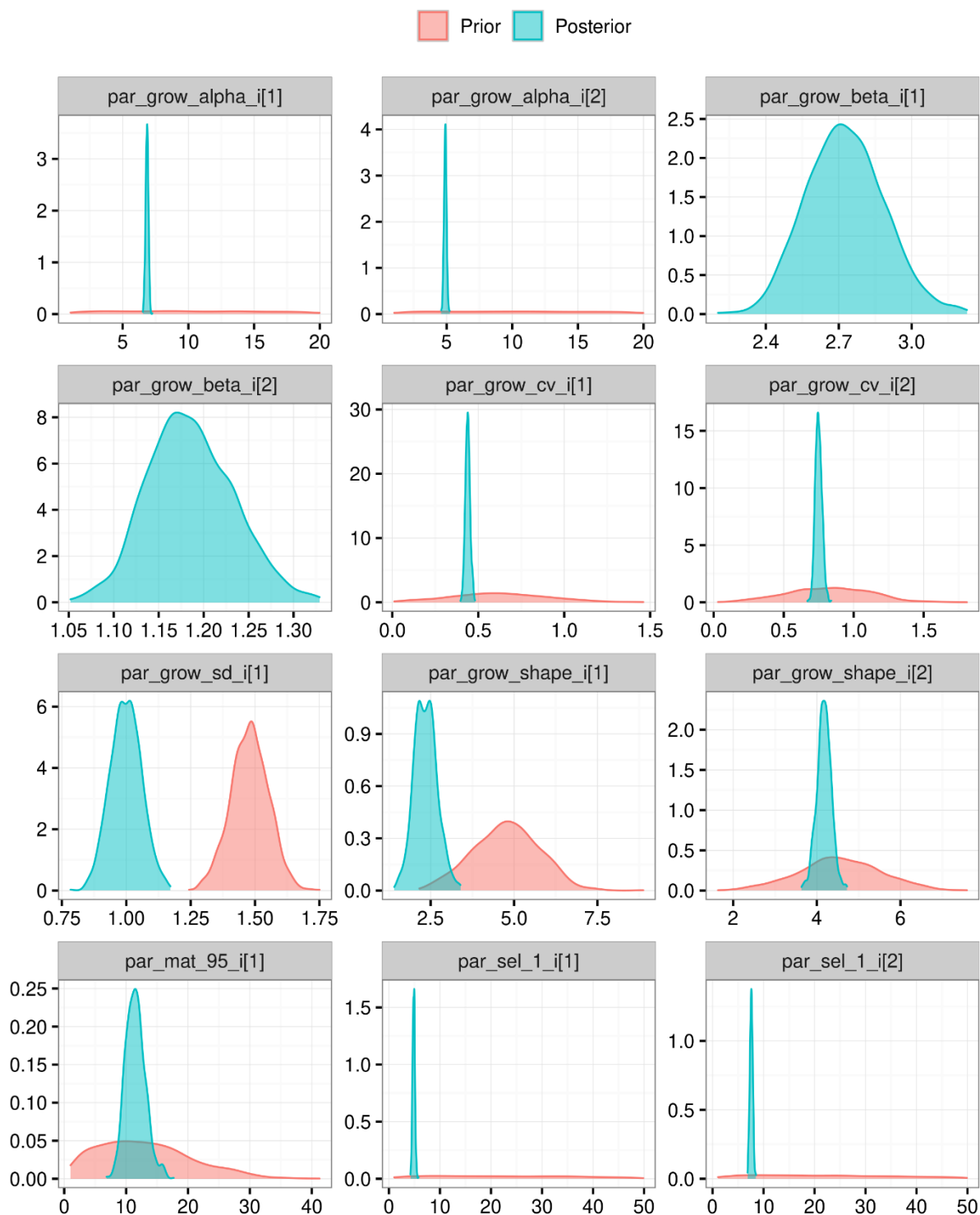


Figure 43: Density plots showing prior (red) and posterior distributions (blue) for growth, two of the selectivity parameters, and one maturation parameter for the base case model run.

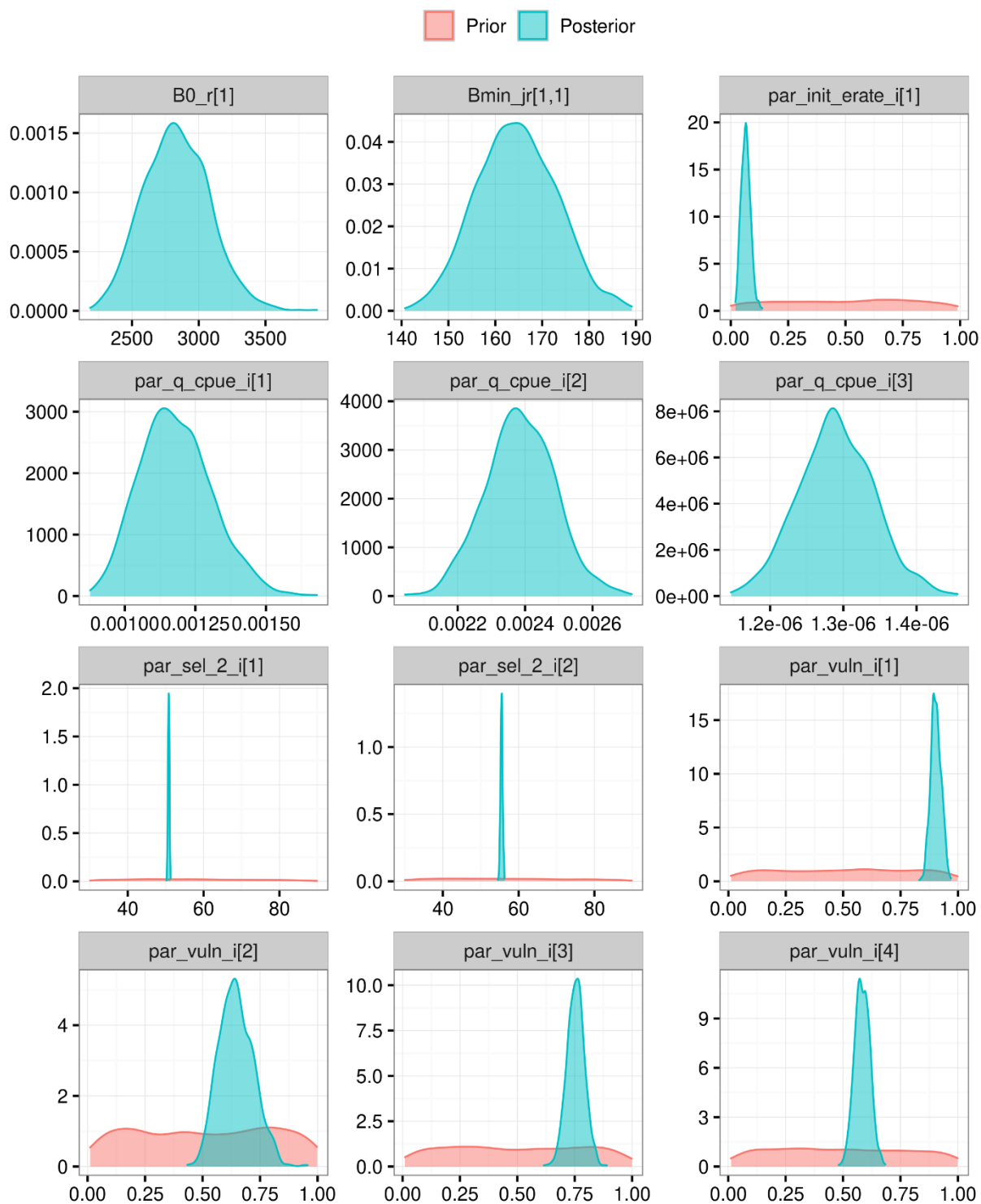


Figure 44: Density plots showing prior (red) and posterior distributions (blue) for the initial exploitation rate (U_0), catchability coefficients, and vulnerability parameters for the base case model run.

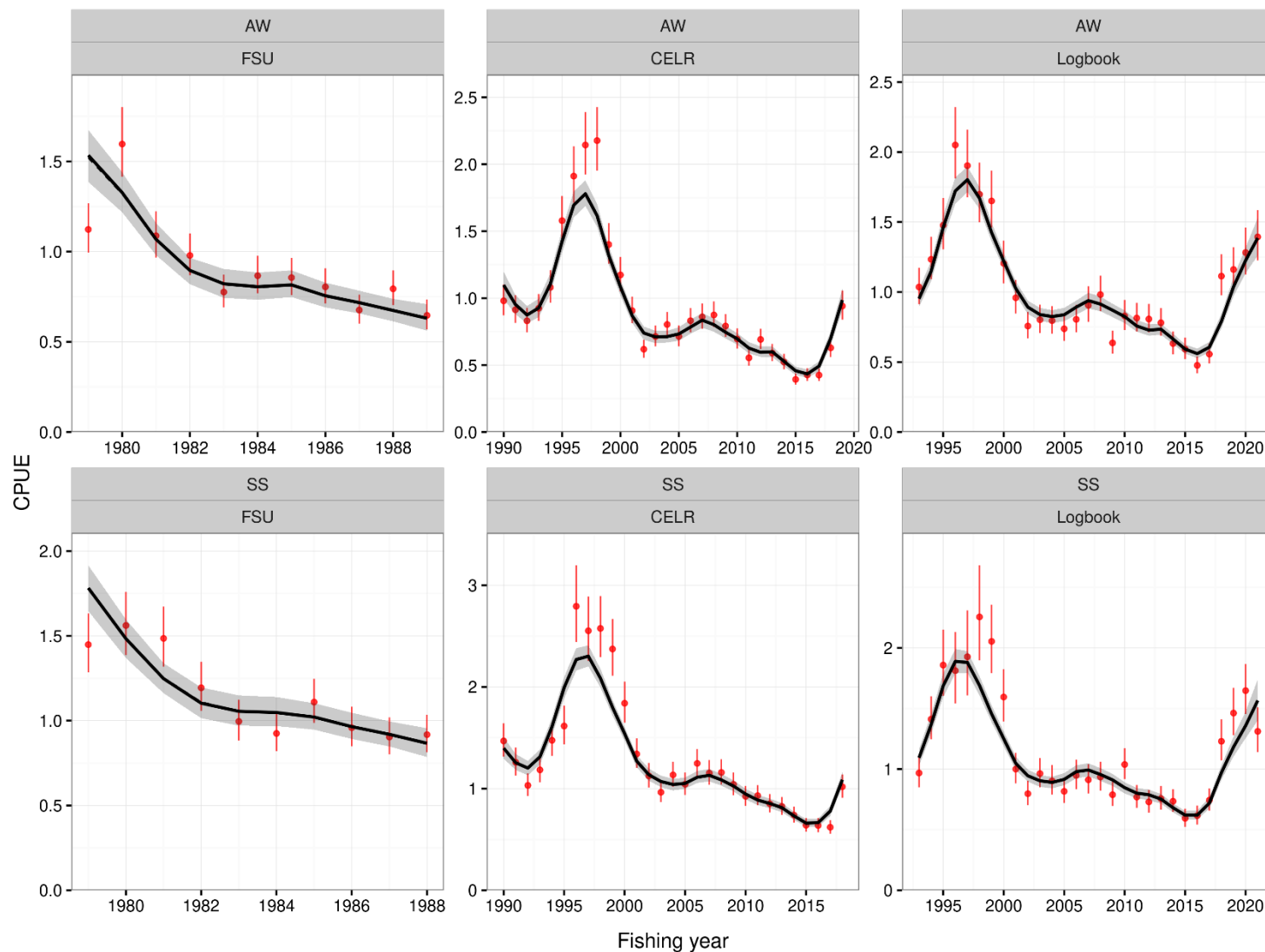


Figure 45: Posterior predicted CPUE for the FSU, CELR, and logbook series by fishing year in the base case model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. A dashed line (often not visible as it is covered by the median line) indicates the corresponding MAP estimates. Error bars are +/- one standard deviation.

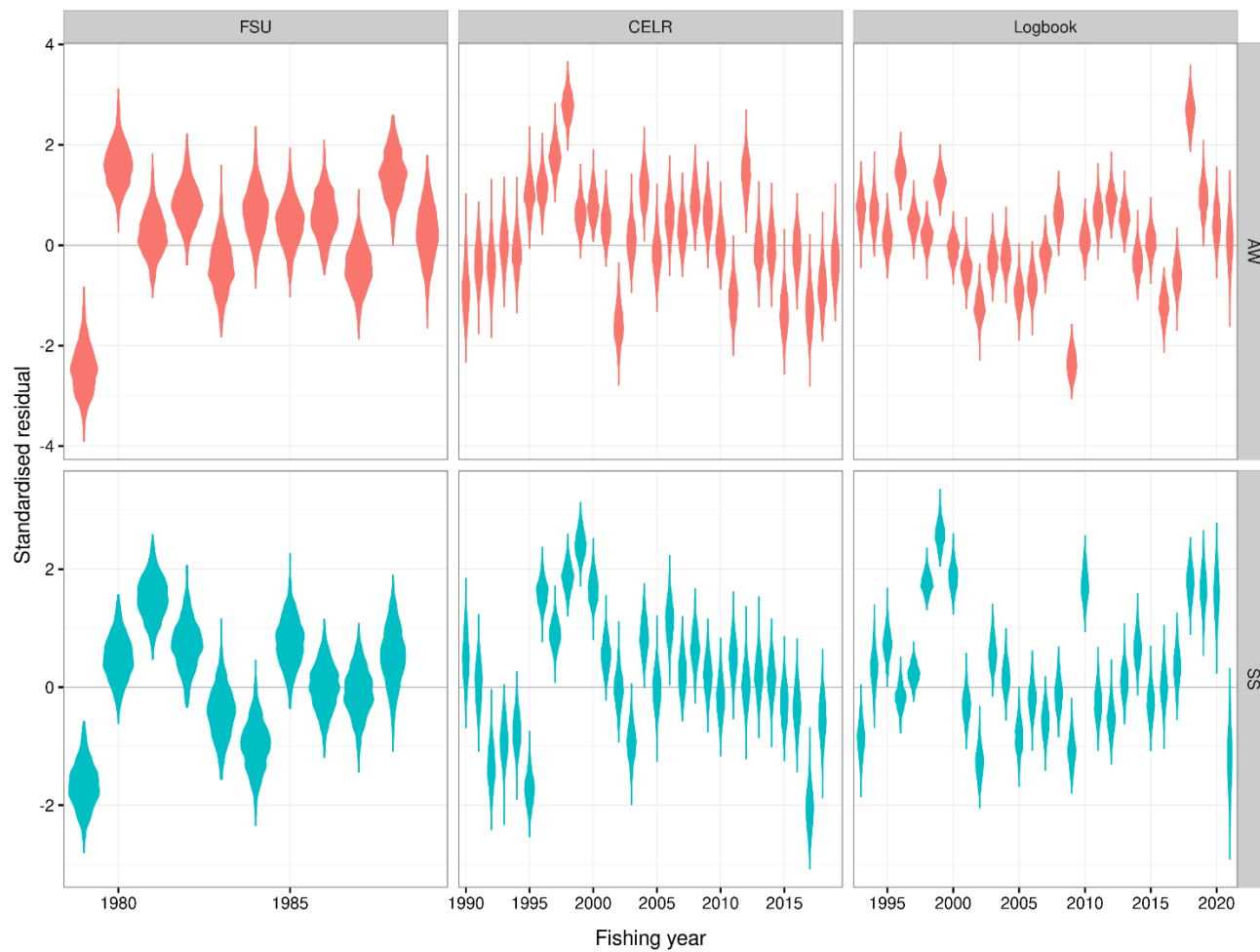


Figure 46: CPUE residuals for the FSU, CELR, and logbook series by fishing year and season in the base case model run.

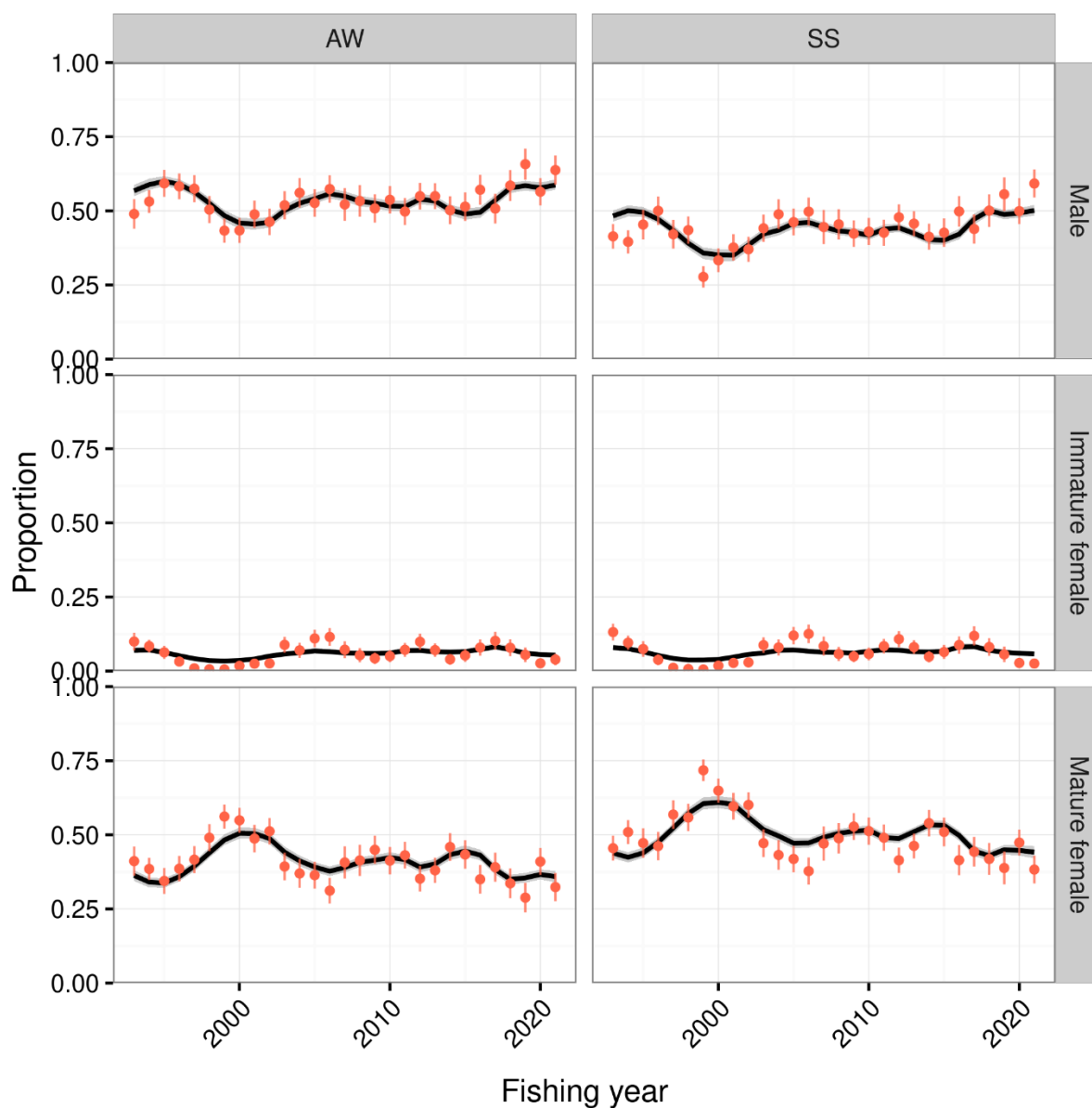


Figure 47: Posterior distribution of the sex ratios compared to the observed sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer) and sex, in the base case model run. The solid line indicates the posterior median and grey shading indicates the 90% credible intervals. Error bars are +/- one standard deviation.

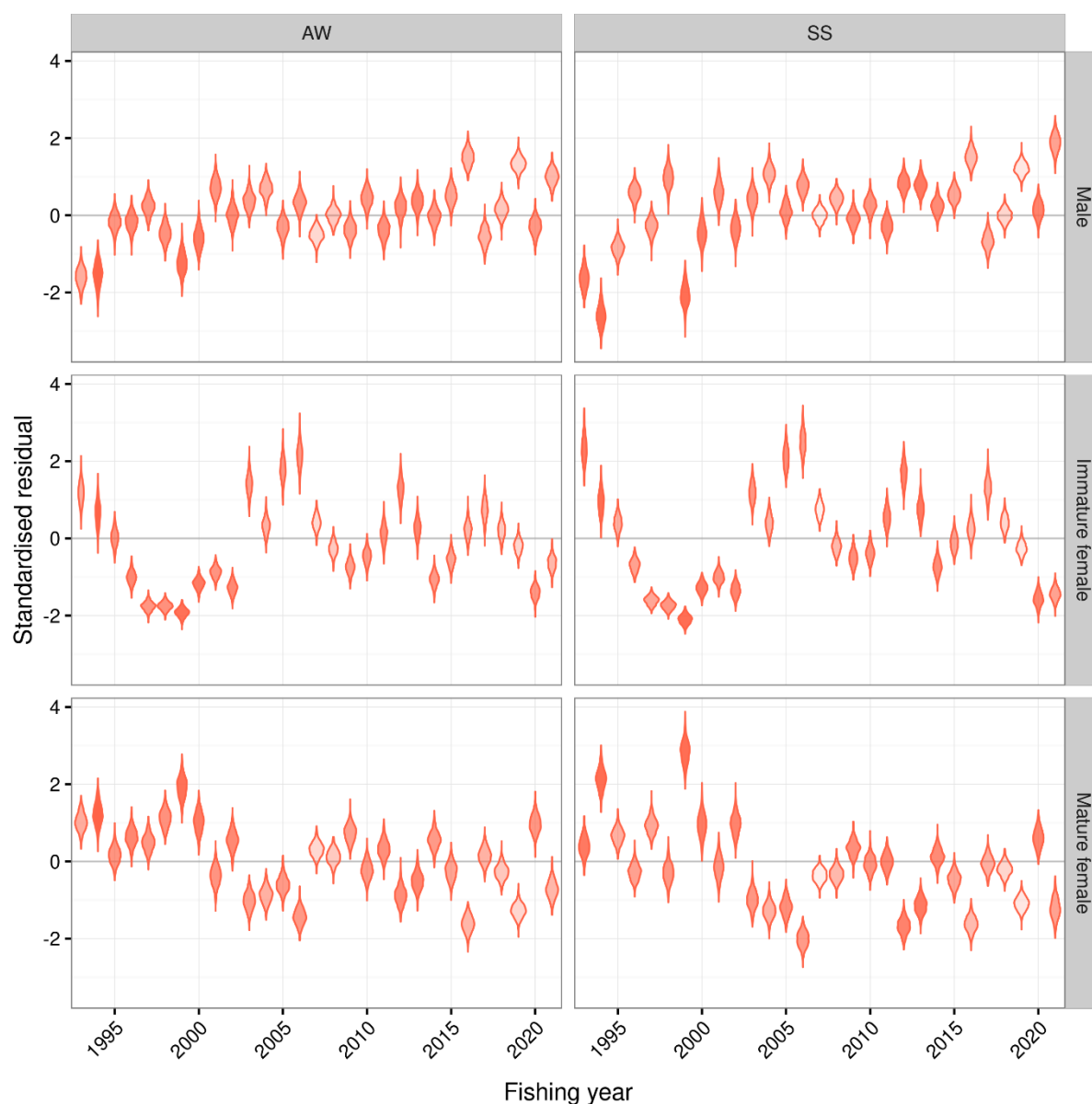


Figure 48: Posterior distribution of the standardised residuals of the sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex in the base case model run. The solid line indicates the posterior median and grey shading indicates the 90% credible intervals.

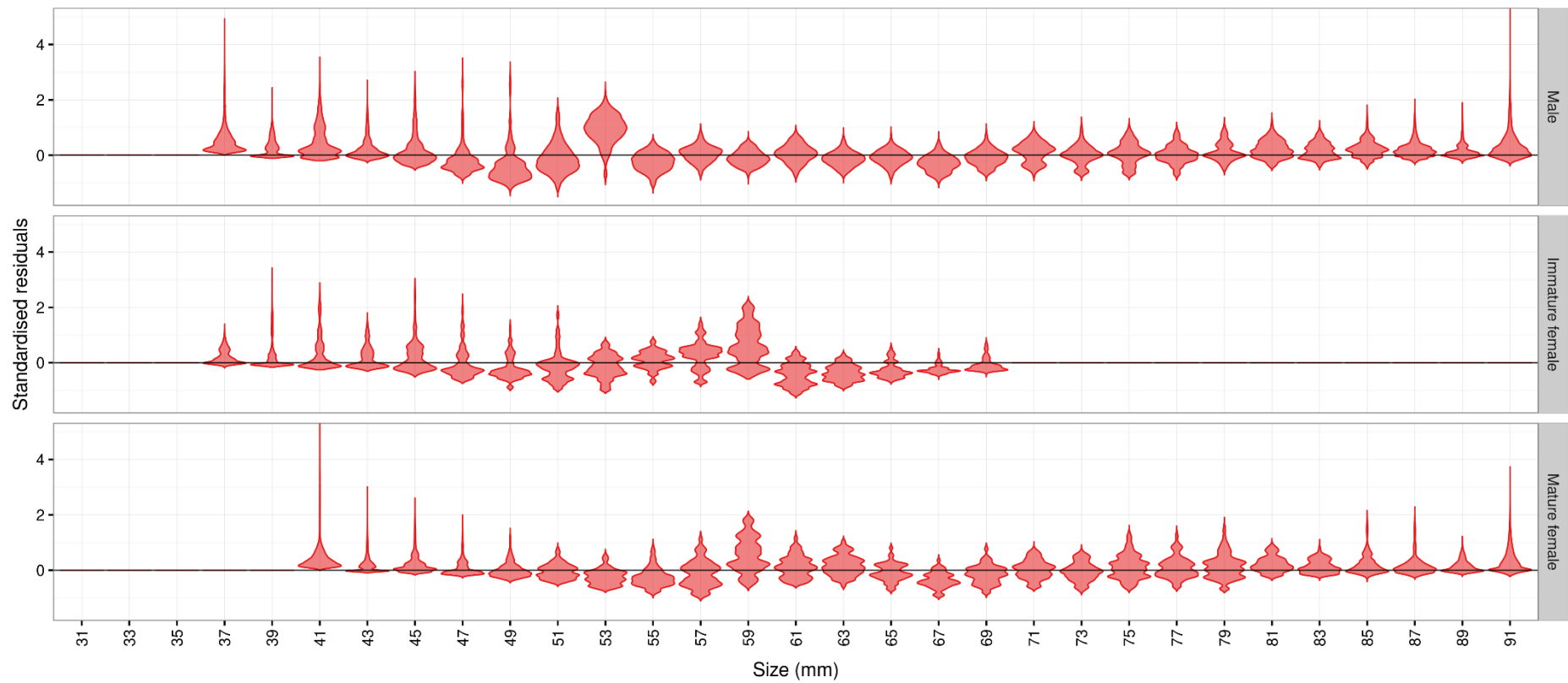


Figure 49: Posterior distribution of standardised residuals from fits to the LF data by sex and 2 mm TW bin.

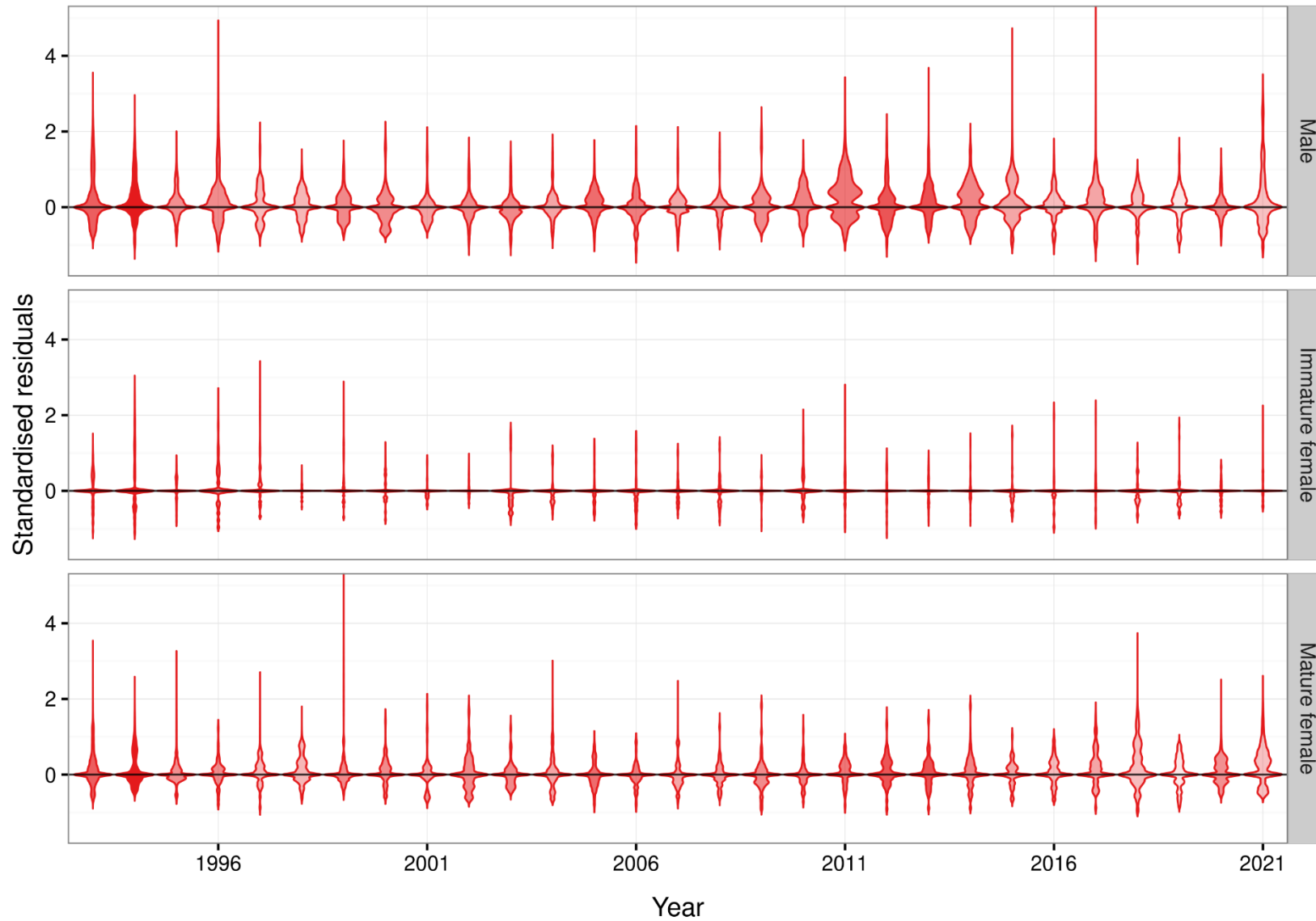


Figure 50: Posterior distribution of standardised residuals from fits to the LF data by sex and fishing year.

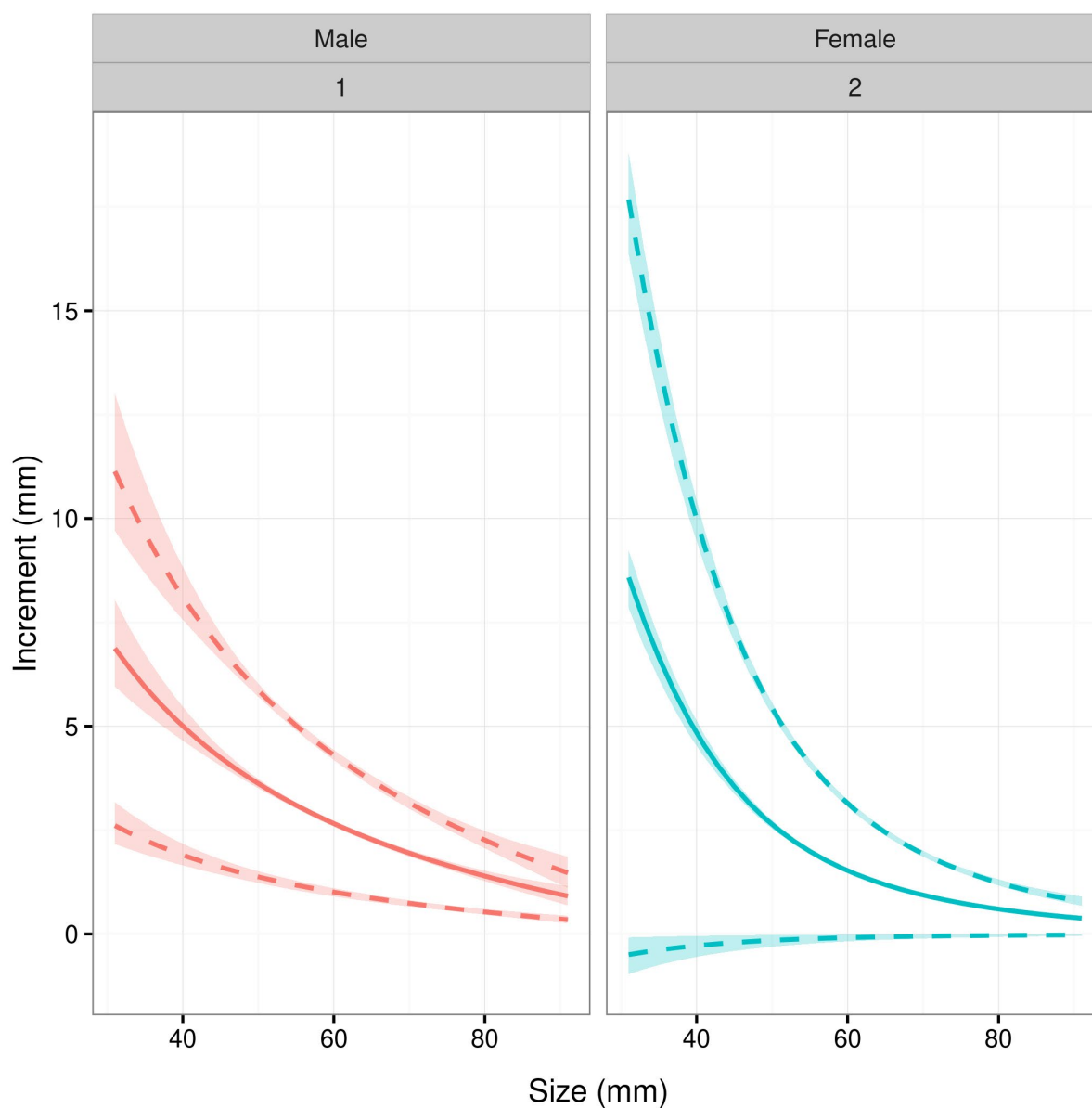


Figure 51: Posterior distribution of predicted 6-monthly growth increment by size and sex in the base case model run showing the mean (solid line), ± 1 standard deviation (dashed line). Shading shows 90% credible interval.

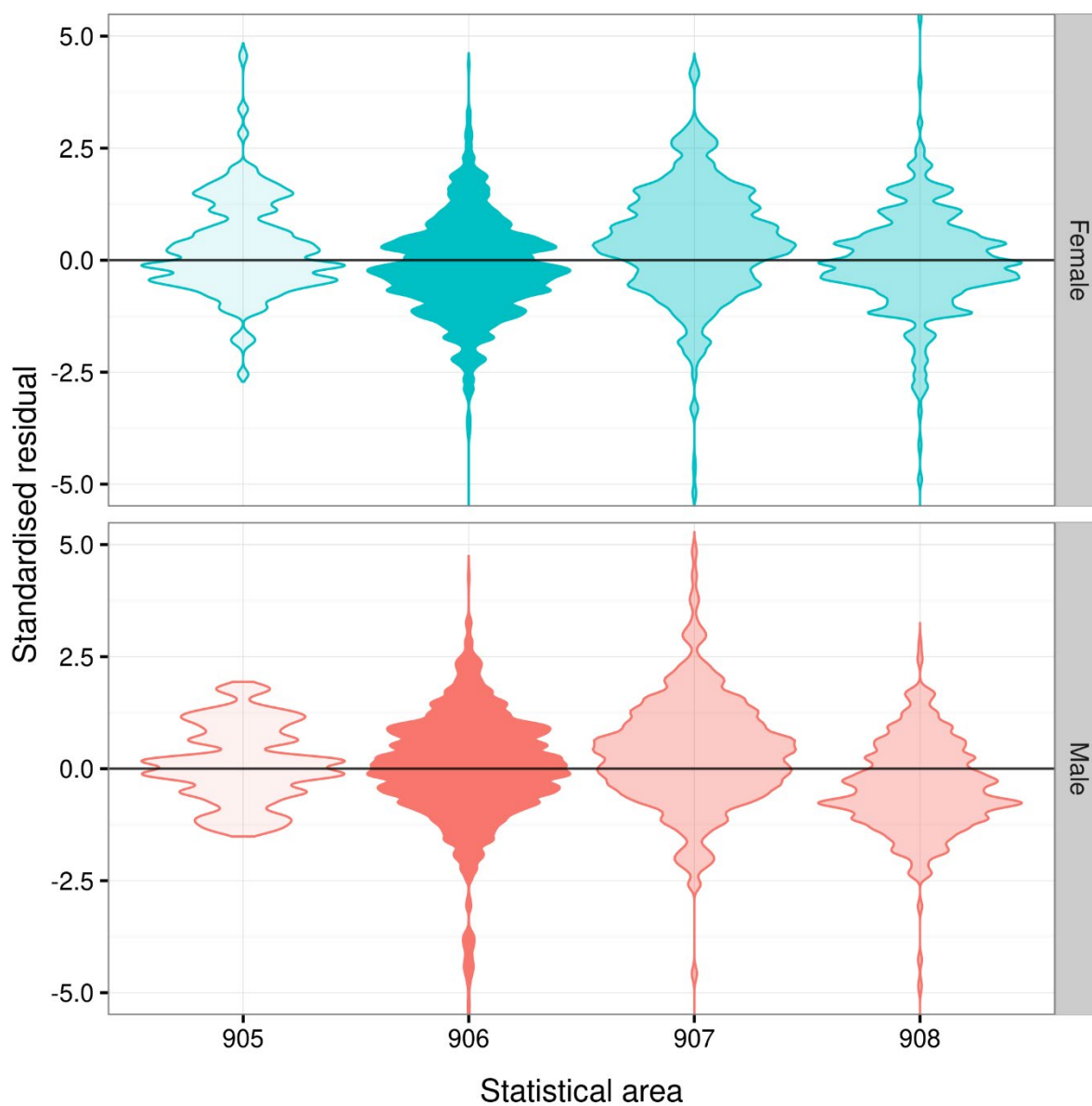


Figure 52: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release and sex in the base case model run. Shading intensity varies with number of observations.

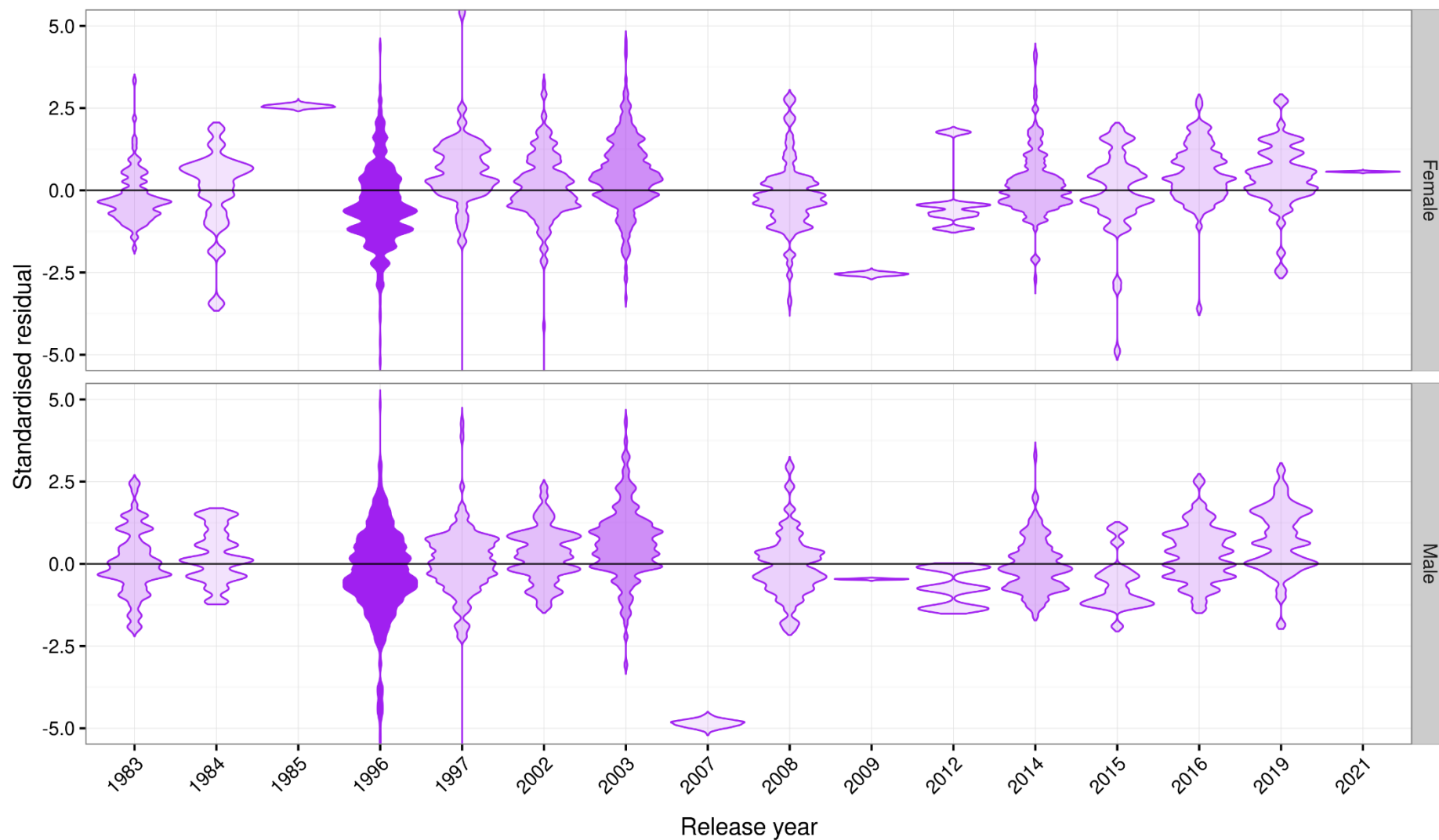


Figure 53: Posterior distribution of standardised residuals from model fit to the tag data by fishing year of release and sex in the base case model run. Shading intensity varies with number of observations.

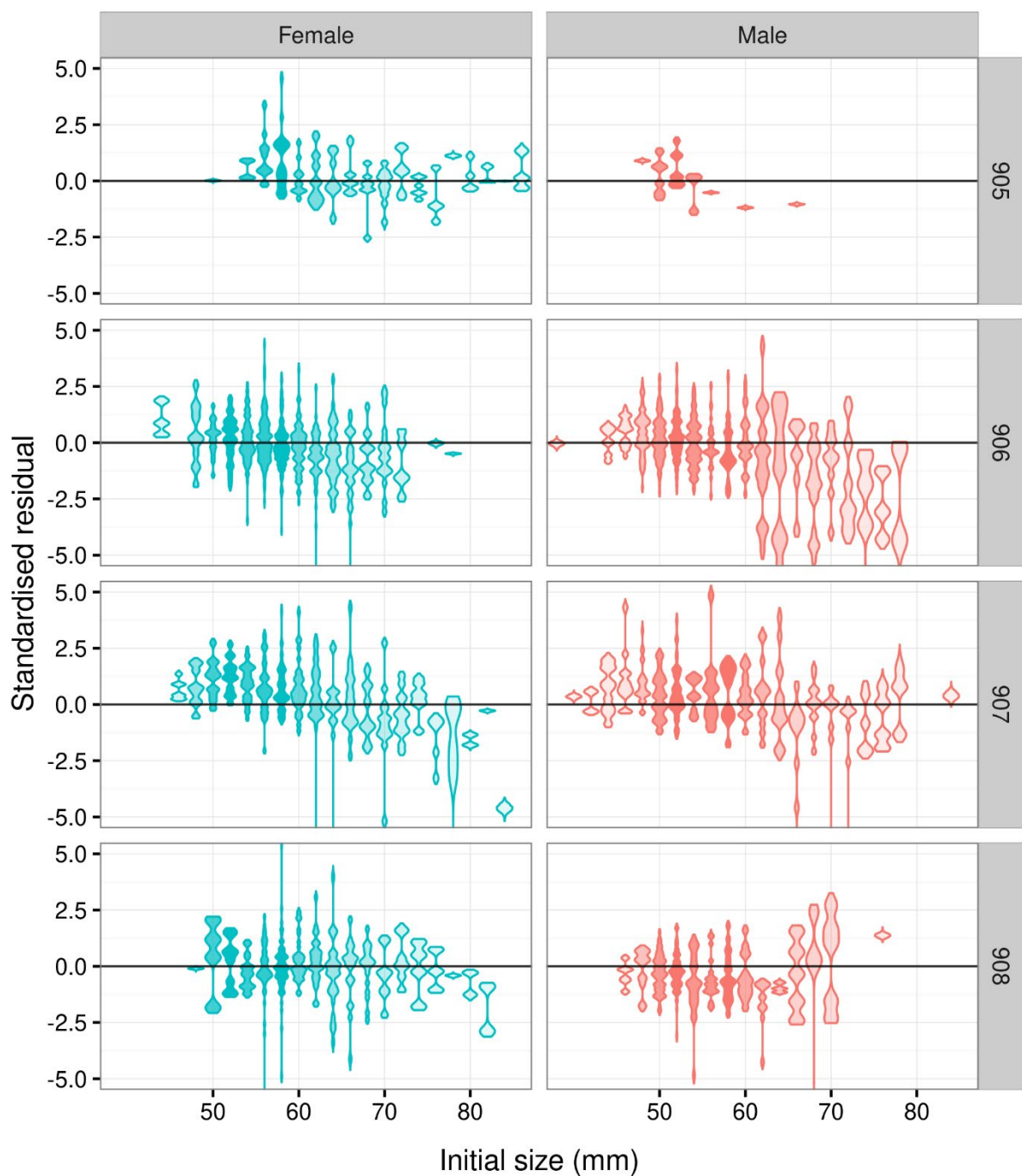


Figure 54: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release, initial size, and sex in the base case model run. Shading intensity varies with number of observations.

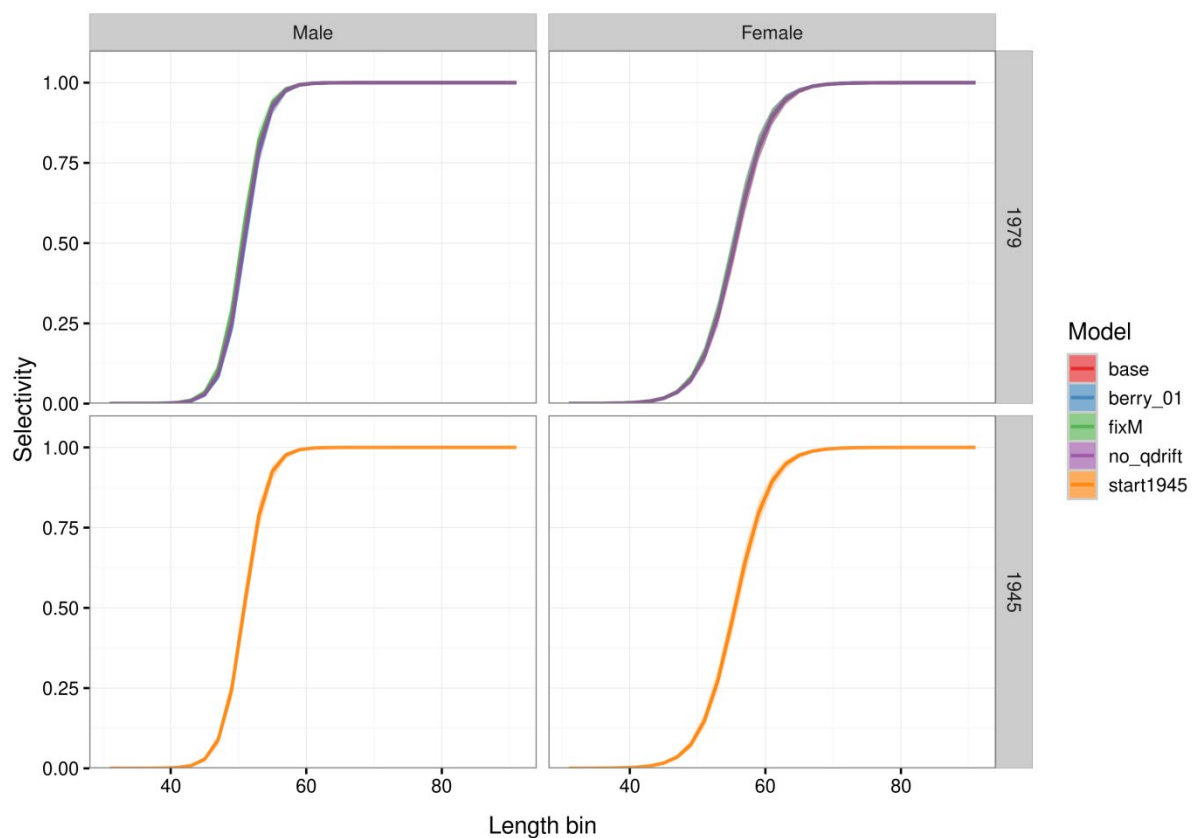


Figure 55: Posterior distribution of selectivity by sex and size comparing the base case with four key sensitivities. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

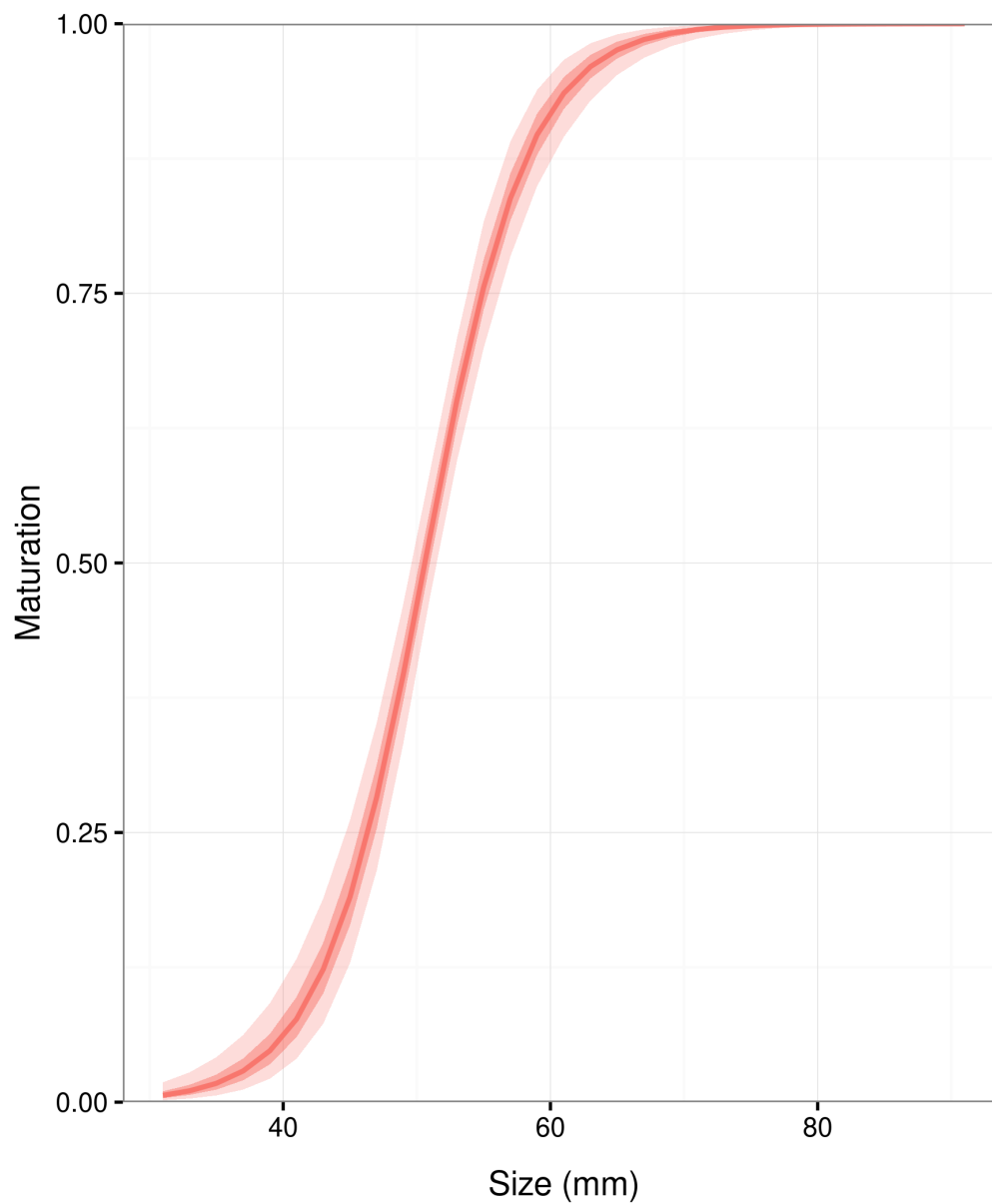


Figure 56: Posterior distribution of female maturation curve by size in the base case model run. The solid line indicates the posterior median and red shading indicates the 90% credible intervals.

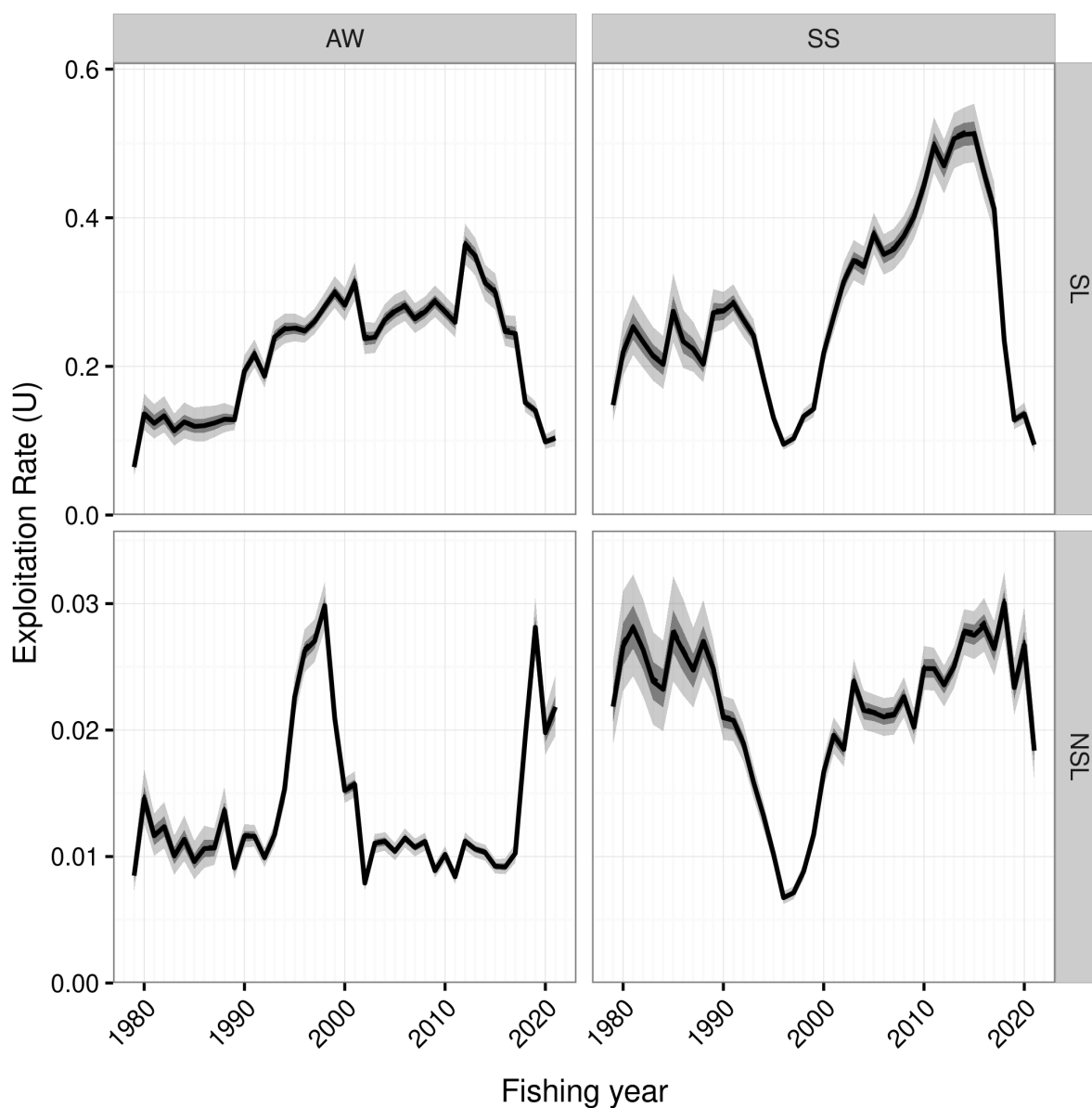


Figure 57: Posterior distribution of exploitation rate by year, season, and fishery (SL = size limited; NSL = non size limited) for the base case model run. The solid black line indicates the median of the posterior and variable shading intensity indicating the 50% and 90% credible intervals.

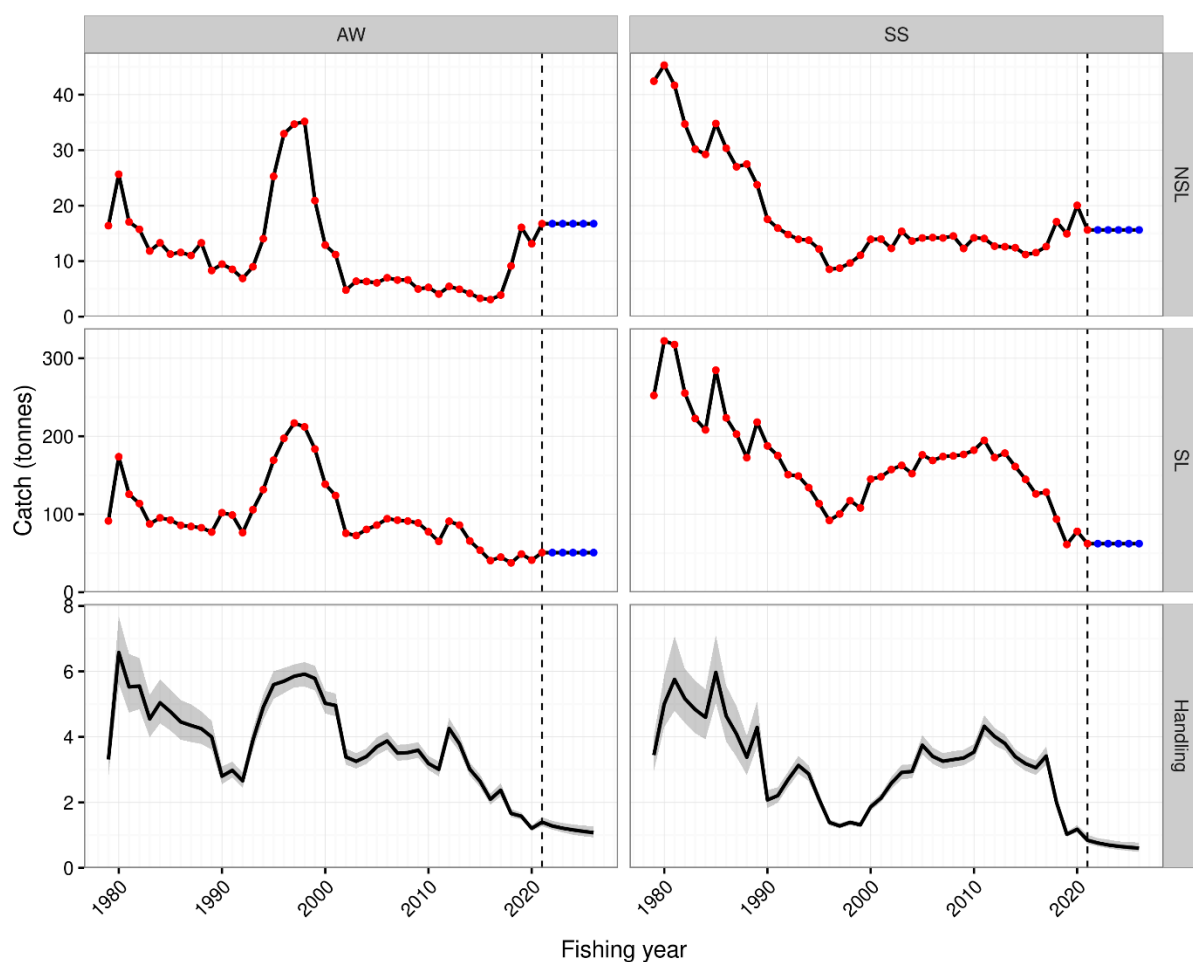


Figure 58: Posterior distribution of the catch and handling mortality by fishing year, season, region, and fishery (SL = size limited; NSL = non size limited) for the base case model run. The solid black line indicates the median of the posterior and shading indicates the 90% credible interval. The vertical dashed line is the final year of the reconstruction period after which the projected catch is shown.

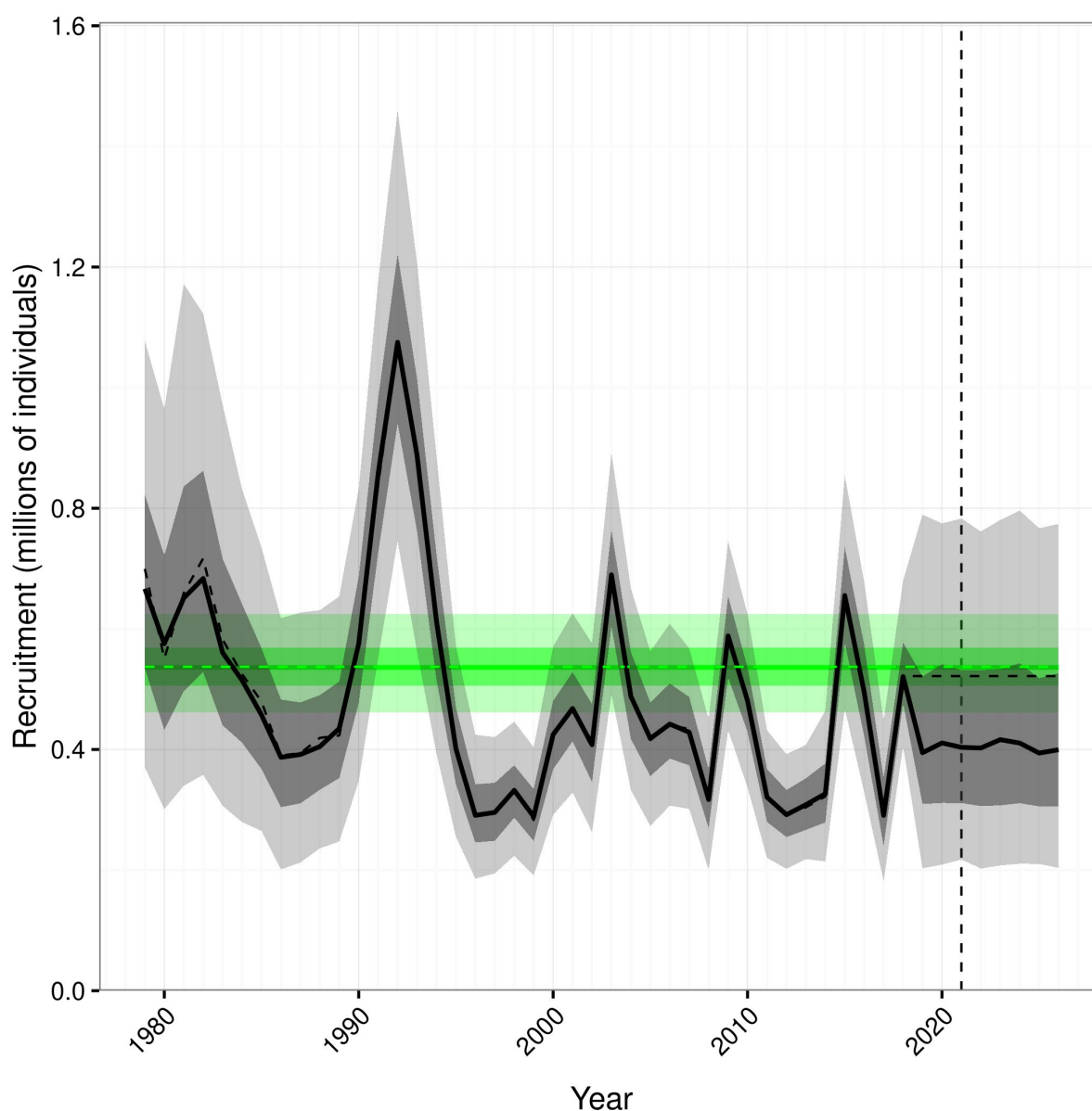


Figure 59: Posterior distribution of recruitment for the base case model run. The horizontal green line is R_0 and the vertical dashed line is the final year of the reconstruction period after which the projected recruitment is shown. The solid black line indicates the median of the posterior and variable shading intensity indicates the 50% and 90% credible intervals.

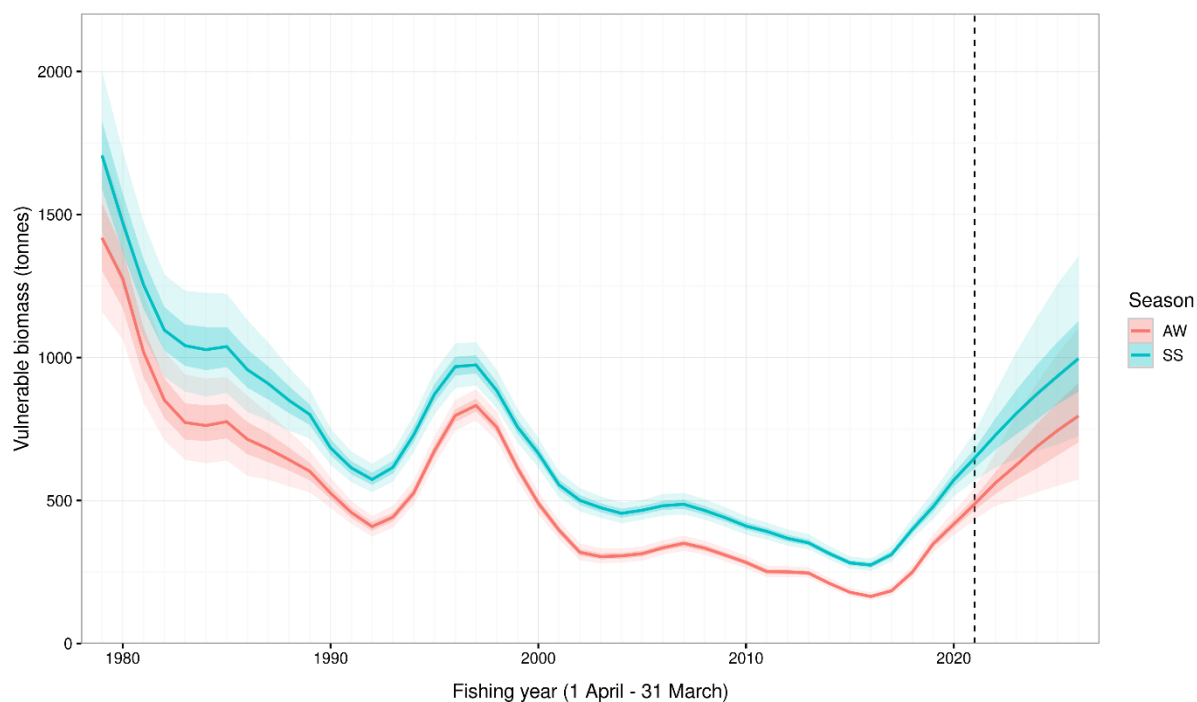


Figure 60: Posterior distribution of the adjusted vulnerable biomass by season for the base case model run. Variable shading intensity indicates the 50% and 90% credible intervals.

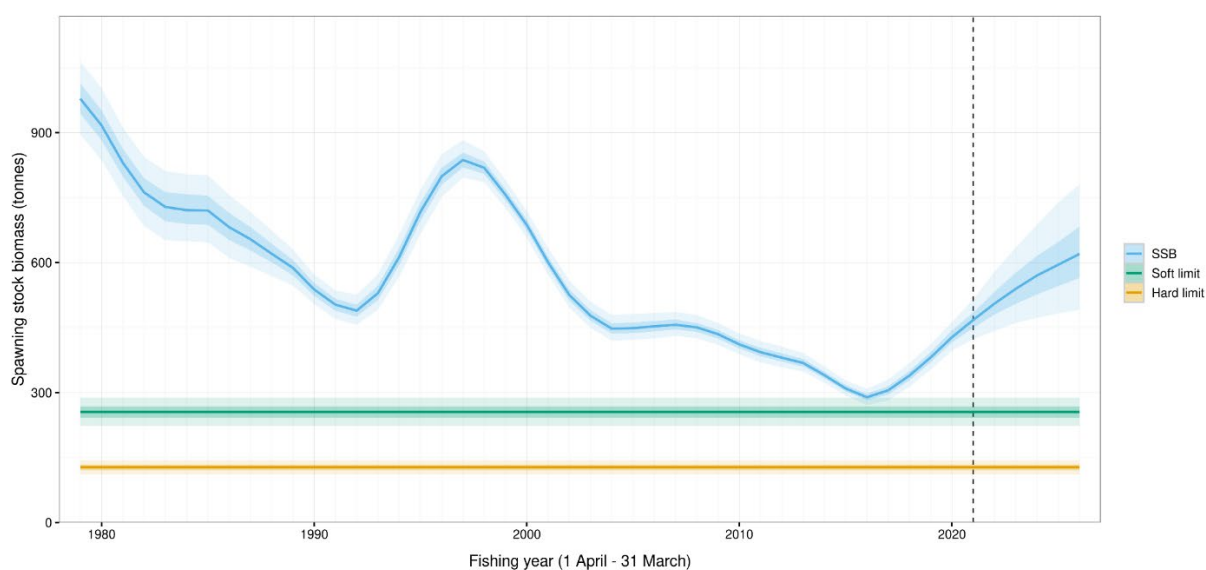


Figure 61: Posterior distribution of beginning year spawning stock biomass (tonnes) by fishing year, including the projections years (beyond the dashed vertical line), for the base case model run. The associated soft limits (20% SSB_0), and hard limits (10% SSB_0) are also shown.

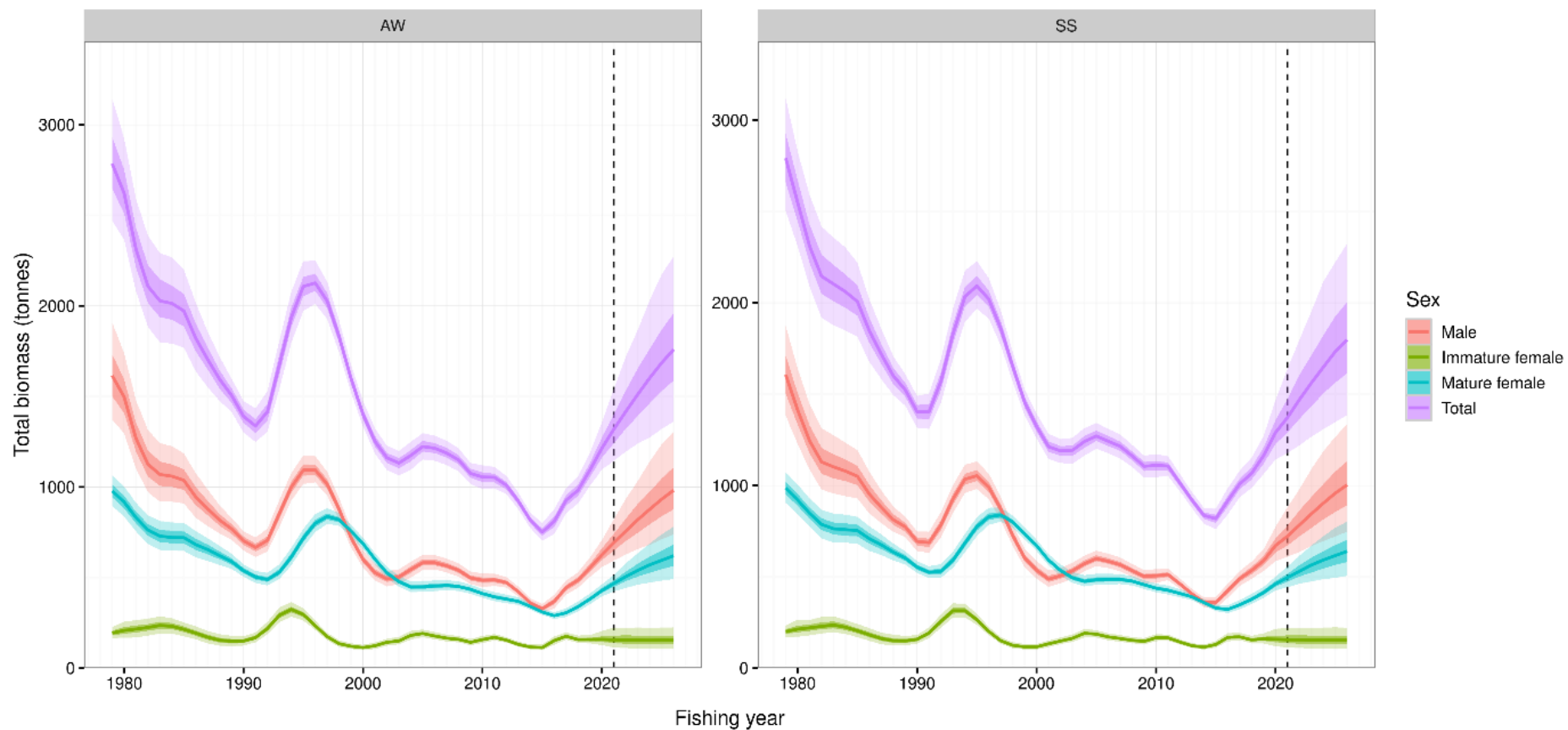


Figure 62: Posterior distribution of the beginning year total biomass by sex and season for the base case model run. Variable shading intensity indicates the 50% and 90% credible intervals.

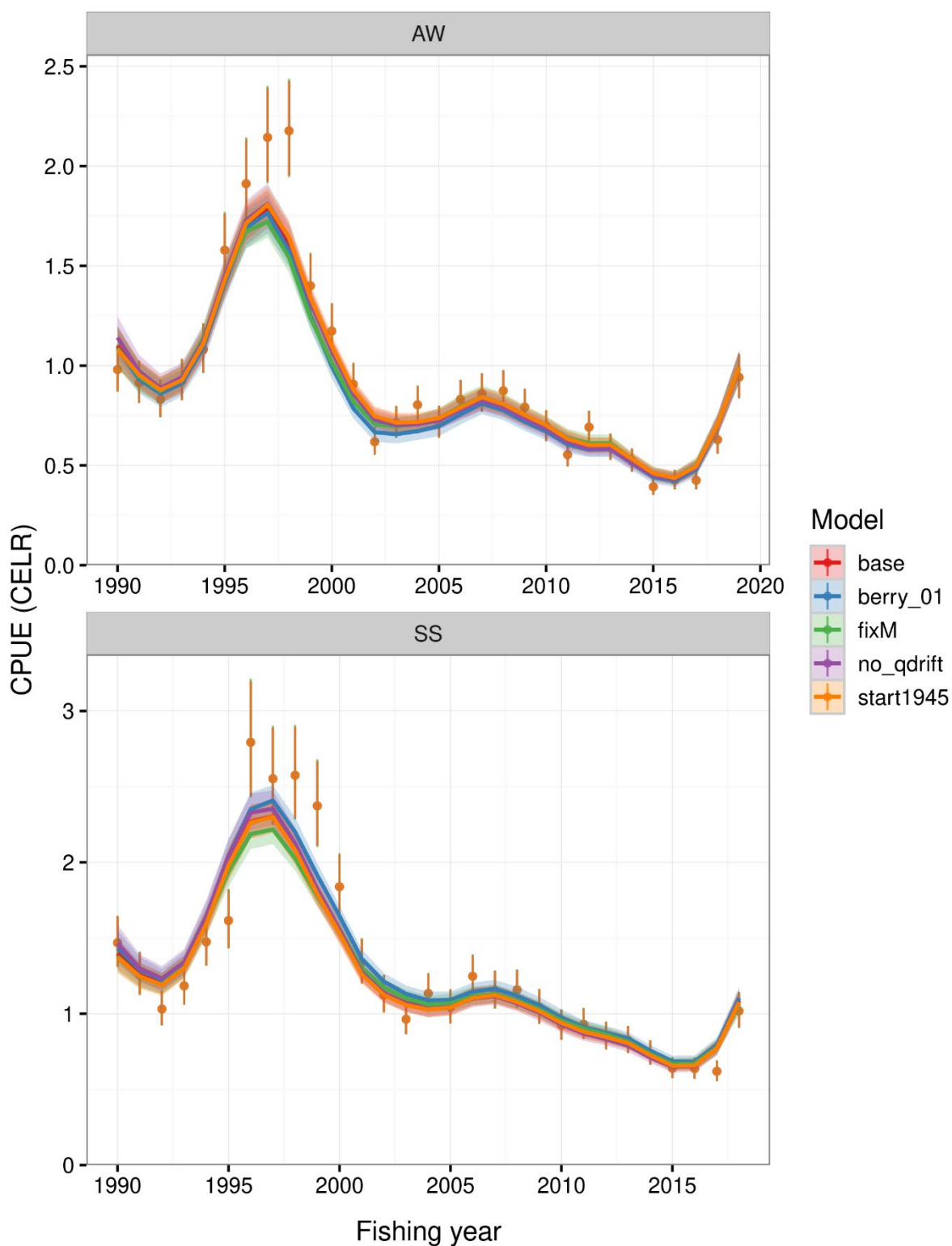


Figure 63: Posterior predicted CPUE compared to the CELR CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) for key sensitivities and the base case. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

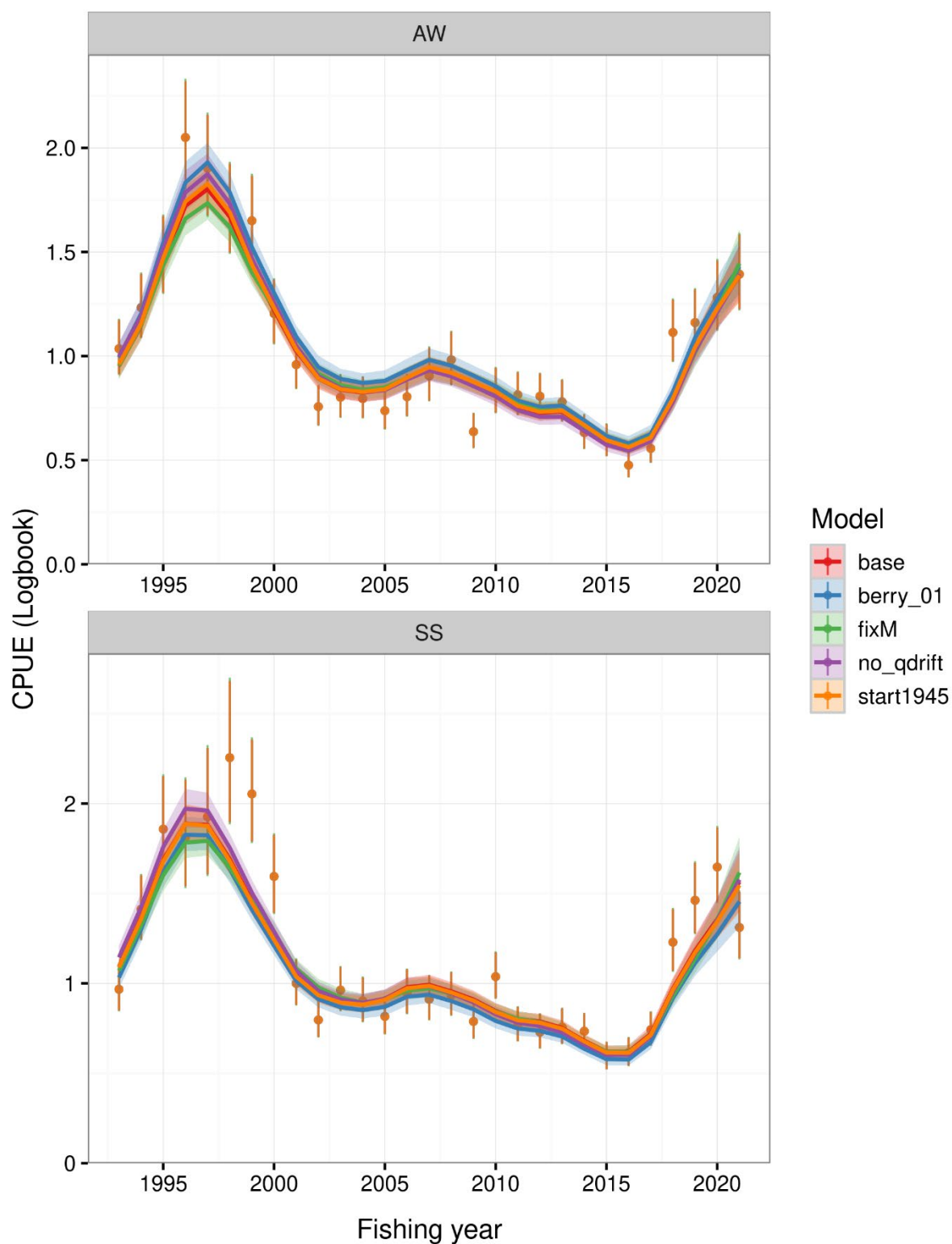


Figure 64: Posterior predicted CPUE compared to the logbook CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) for key sensitivities. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

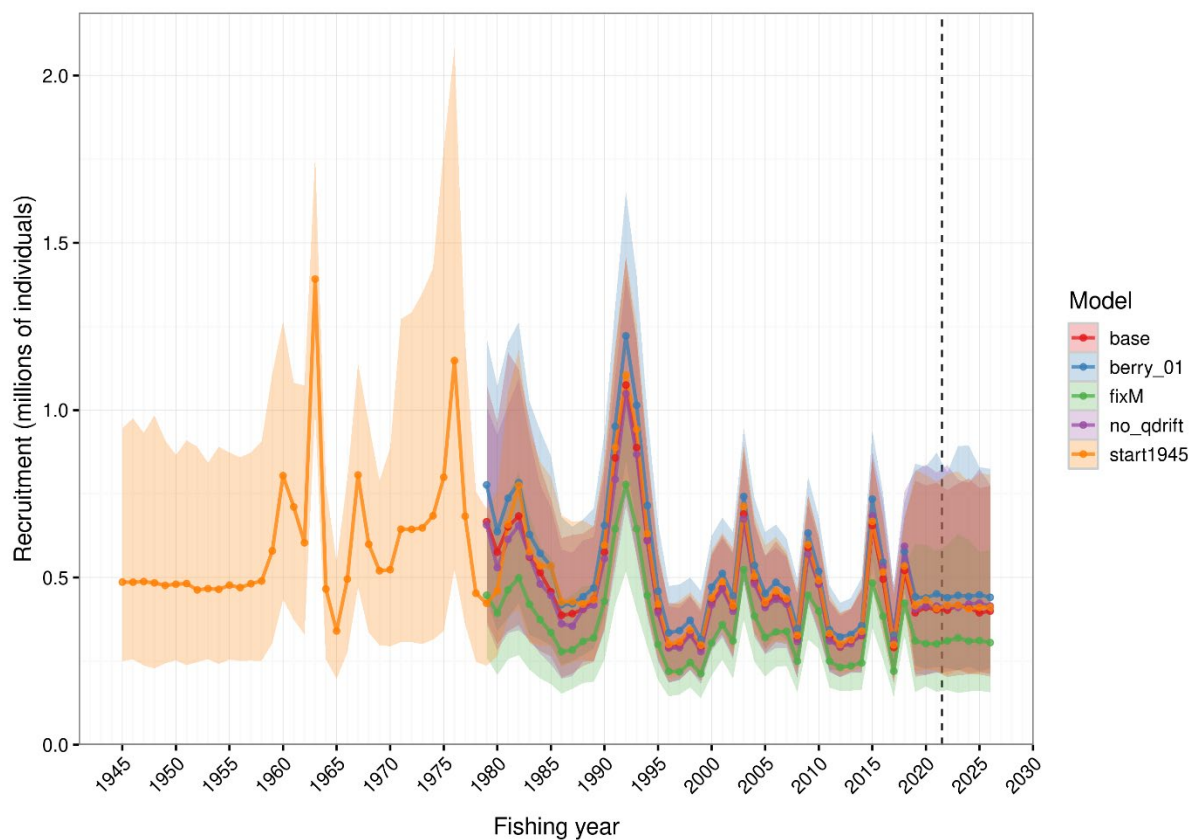


Figure 65: Posterior distribution of recruitment trajectories between the base run and key sensitivities, including projection years (beyond the dashed vertical line).

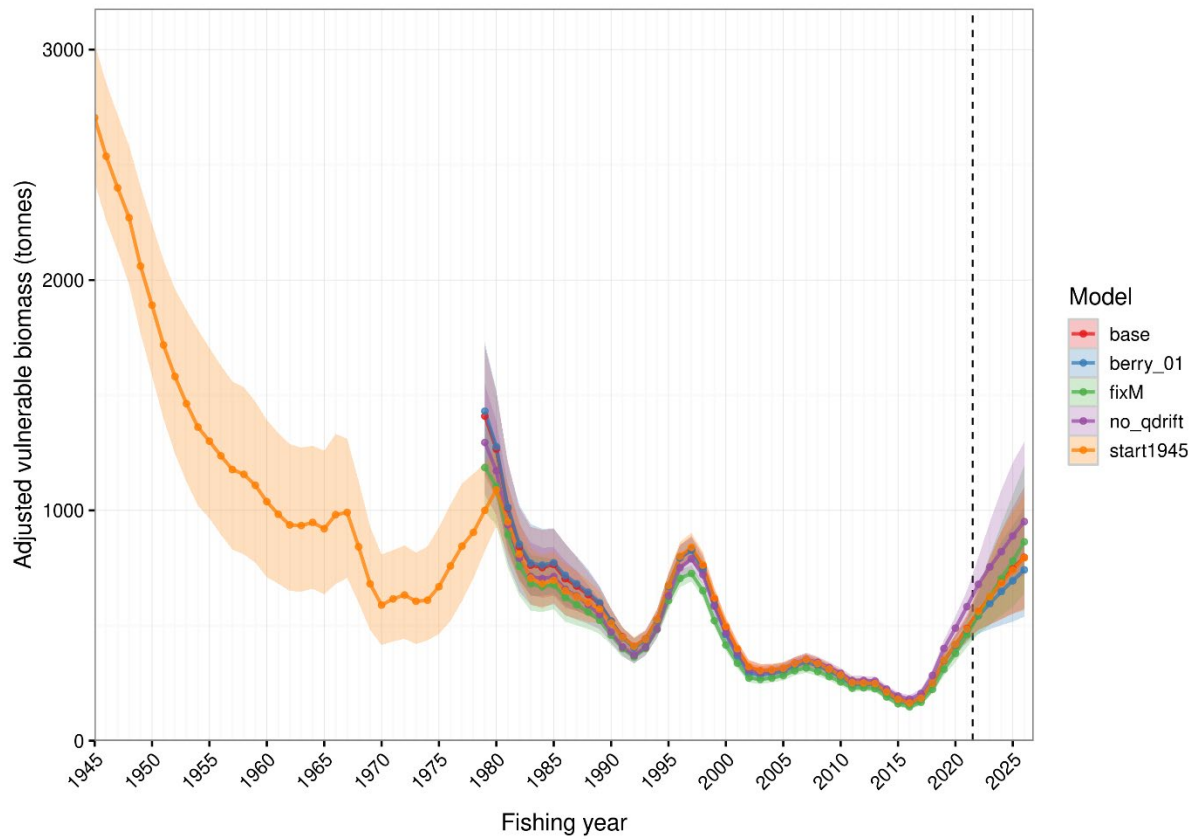


Figure 66: Posterior distribution of adjusted vulnerable biomass comparing the base case and key sensitivities, including projection years (beyond the dashed vertical line). In this plot the base case model run is directly behind the *berry_01* sensitivity.

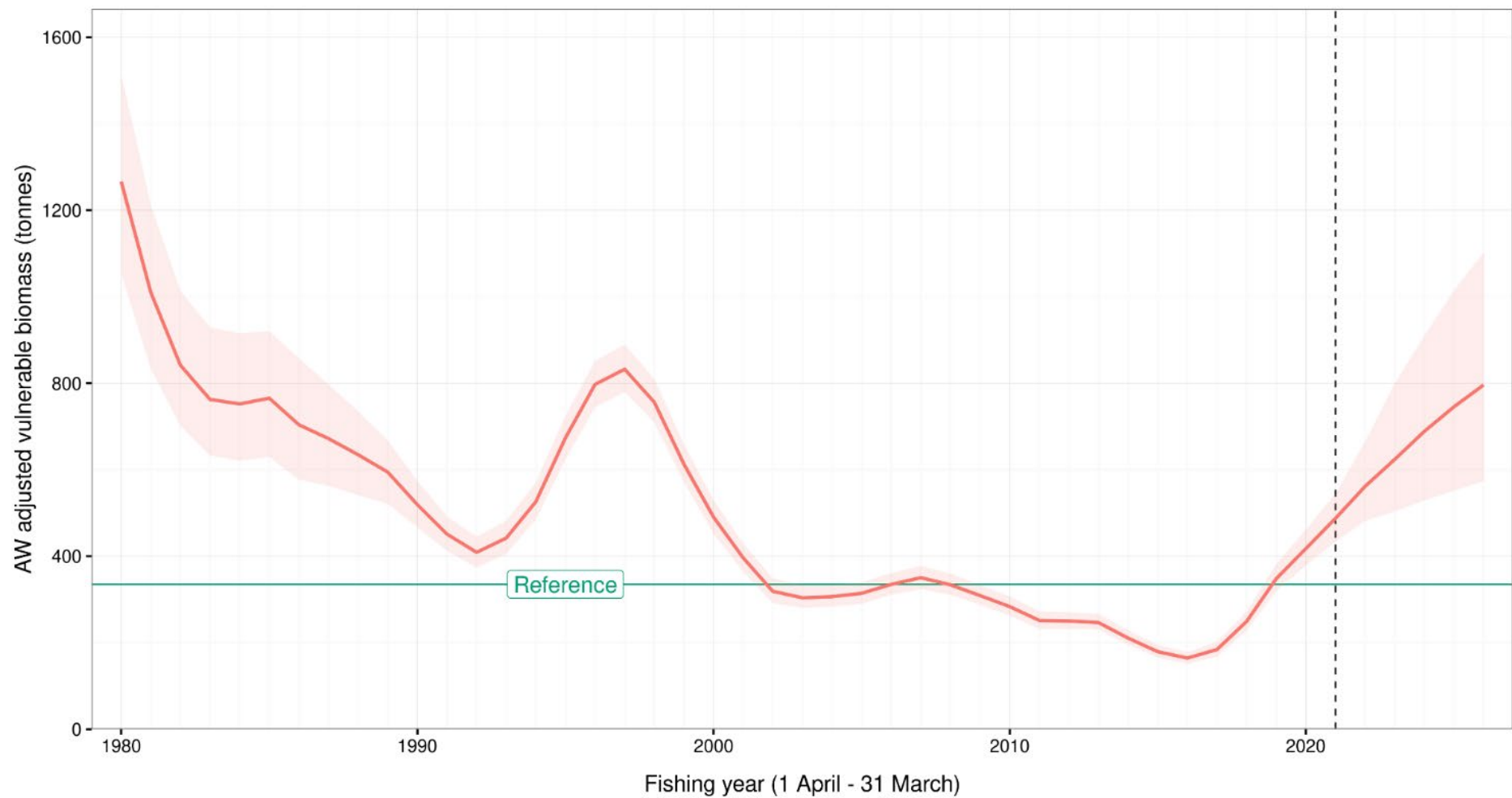


Figure 67: Posterior distribution of adjusted vulnerable biomass (tonnes) by fishing year, including the projections years (beyond the dashed vertical line), for the base case model run compared with the reference level.

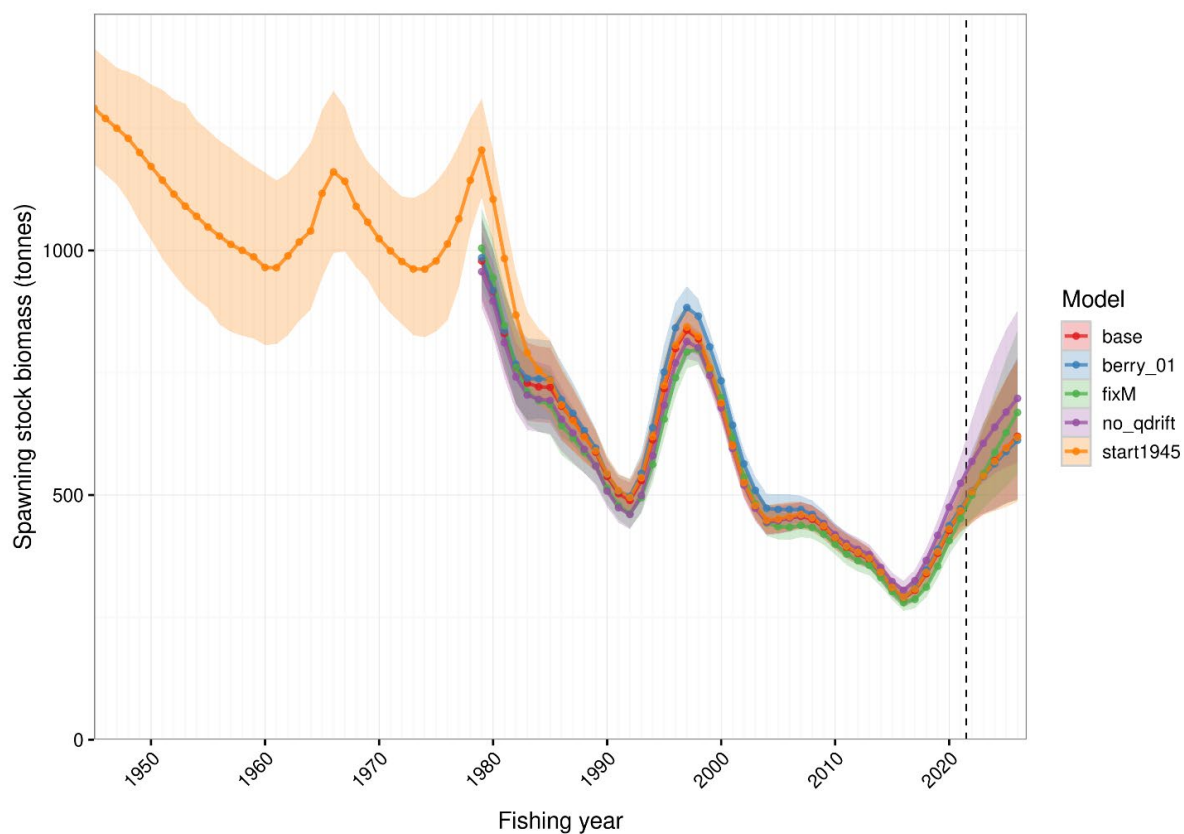


Figure 68: Posterior distribution of spawning stock biomass comparing the base case model run and key sensitivities, including projection years (beyond the dashed vertical line). In this plot the base case model run is directly behind the *berry_01* sensitivity.

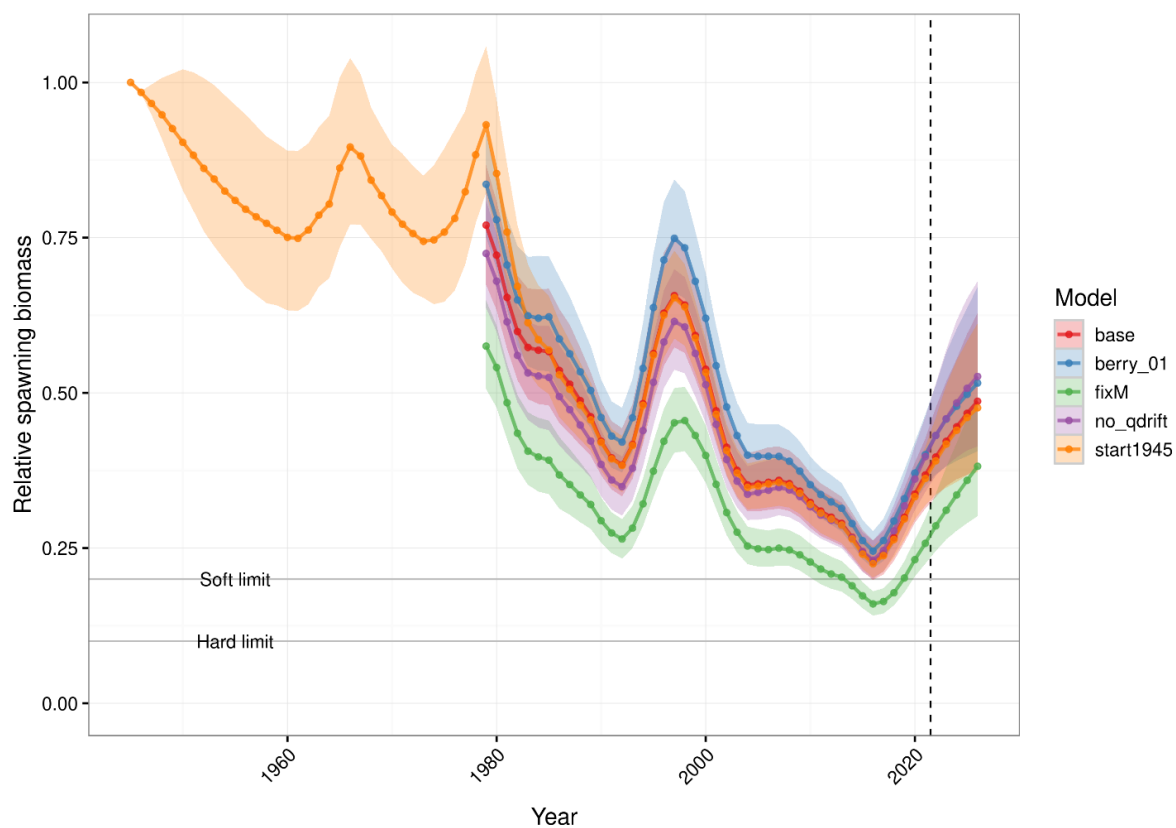


Figure 69: Posterior distribution of relative spawning stock biomass comparing the base case model run and key sensitivities, including projection years (beyond the dashed vertical line).

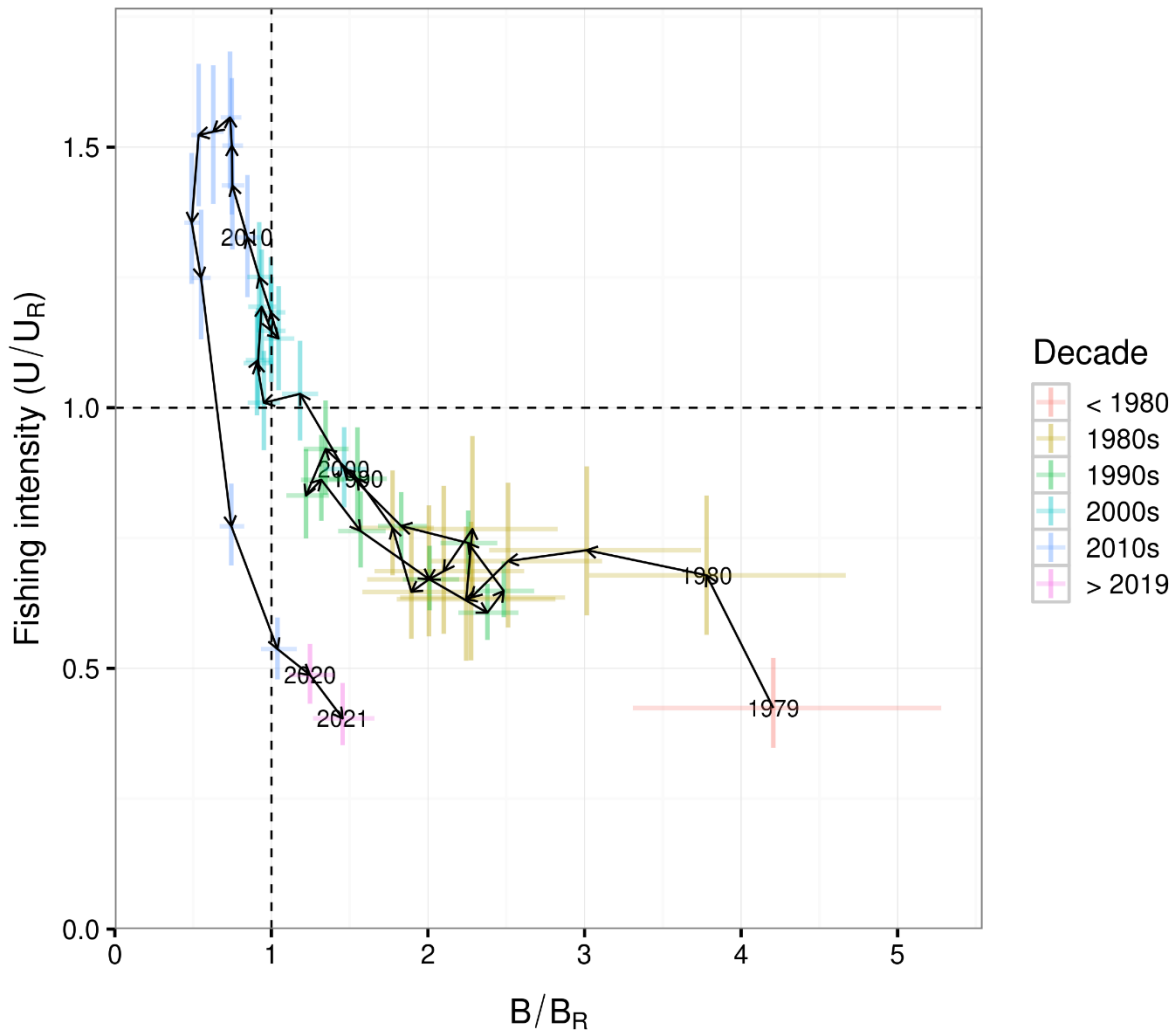


Figure 70: Phase plot showing the AW vulnerable biomass (B) time series of the CRA 2 stock as a proportion of the reference vulnerable biomass (B_R). The y-axis is fishing intensity in each year as a proportion of the fishing intensity (U_R) that gives B_R under equilibrium conditions. Each point on the figure shows the median of the posterior distributions of biomass ratio and fishing intensity ratio for that year. The horizontal and vertical grey bars show the 90% credible interval from the posterior distribution of each ratio for that year. The dashed horizontal line denotes the fishing intensity at U_R and the dashed vertical line denotes the biomass at B_R .

APPENDIX A. Glossary

This glossary is intended to make the rock lobster stock assessment more accessible to non-technical readers. A knowledge of statistical terms is assumed and such terms are not explained here. Technical terms are defined with specific reference to rock lobster stock assessment and the lobster stock dynamics (LSD) model and may not be applicable in other contexts.

Underlining indicates a cross-reference to a separate entry.

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

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

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

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

B_R : see reference level.

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

B_{curr} : the LSD model estimate of vulnerable biomass in the last year with data.

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

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

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

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

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

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

B : see vulnerable biomass.

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

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

catch sampling: see logbooks and observer catch sampling.

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

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

CPUE: catch per unit of effort; can have units kg of catch per potlift or be unit-less; assumed to be an abundance index such that $CPUE = \frac{\text{catchability}}{\text{vulnerable biomass}}$; can be estimated in several ways (see standardisation).

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

CR: an historical CPUE abundance index in kilograms per day from 1963 to 1973.

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

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

derived parameter: any quantity that depends on the model’s estimated parameters; e.g., average recruitment R_0 is an estimated parameter but initial biomass is a derived parameter that is determined by model parameters for growth, natural mortality, and recruitment.

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

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

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

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

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

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

F : instantaneous rate of fishing mortality.

fishing intensity: informal term with no specific definition; higher fishing intensity involves higher fishing mortality or higher exploitation rate, or (as in the snail trail) a higher ratio of F to F_{MSY} .

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

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

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

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

F_{MSY} : the instantaneous fishing mortality rate F that gives MSY under some simplistic constant conditions.

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

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

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

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

hyperdepletion: see CPUE_{pow.}

hyperstability: see CPUE_{pow.}

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

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

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

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

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

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

M: instantaneous rate of natural mortality.

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

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

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

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

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

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

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

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

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

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

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

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

MPI: Ministry for Primary Industries (formerly Ministry of Fisheries or MFish; includes Fisheries New Zealand).

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

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

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

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

NRLMG: National Rock Lobster Management Group, a stakeholder group comprising representatives from Fisheries New Zealand (part of MPI) and commercial, customary, and recreational sectors, that provides rock lobster management advice to the Minister for Oceans and Fisheries.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

R_0 : the base recruitment value in numbers of fish.

R_{devs} : estimated model parameters that determine whether recruitment in a given year is above or below average; they modify the base recruitment parameter R_0 .

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

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

reference level: calculated as the average vulnerable biomass between fixed catch and fixed U harvest control rules that maximise catch while meeting risk constraints. This is called B_R .

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

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

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

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

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

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

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

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

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

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

spawning stock biomass: *SSB*, the weight of all mature females in the AW, without regard to MLS, selectivity, or vulnerability; three specific forms are *SSB_{current}*, the estimated *SSB* in the last year with data; *SSB₀*, the equilibrium *SSB*; *SSB_{MSY}*, the *SSB* at equilibrium *B_{MSY}*.

SS: spring/summer season, 1 October to 30 March; see AW.

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

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

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

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

stock-recruit relation: a relation between biomass and recruitment, with low recruitment at lower biomass.

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

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

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

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

TW: tail width (mm) measured between the second abdominal spines.

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

vulnerable biomass: the biomass that is available to be caught legally: above the MLS, not egg-bearing if female, modified by selectivity and vulnerability; in the model this is called *B*; for comparing biomass

with B_R and for reporting historical trajectories, the model calculates adjusted B using the last year's selectivity and MLS for consistency of comparison.

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

Appendix B. MCMC length frequency fits

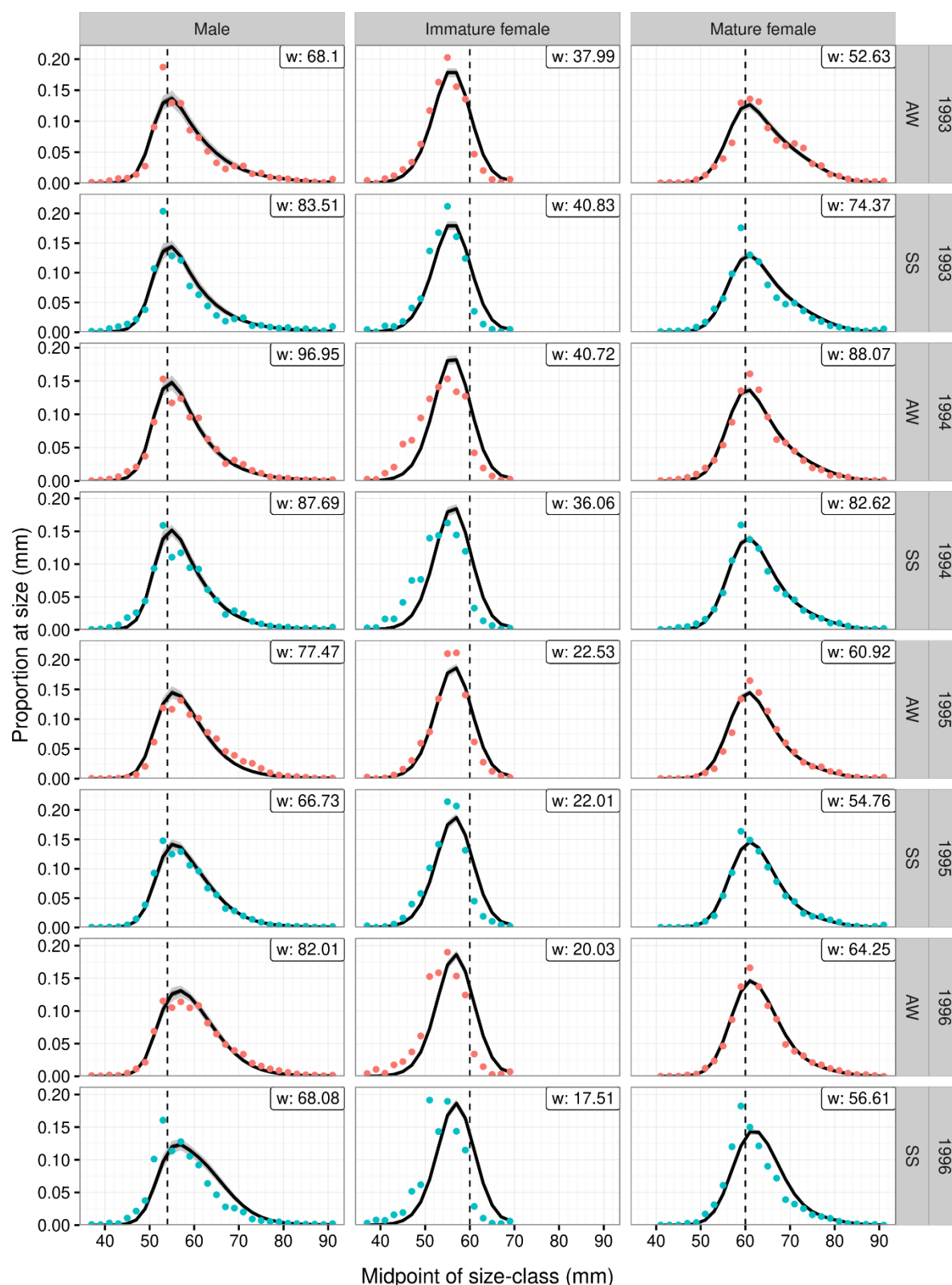


Figure B.1: Posterior distribution of the LF fits compared with the observed LF by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex category in the base case model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. In each panel 'w' is the effective sample size. (Continued on next 5 pages)

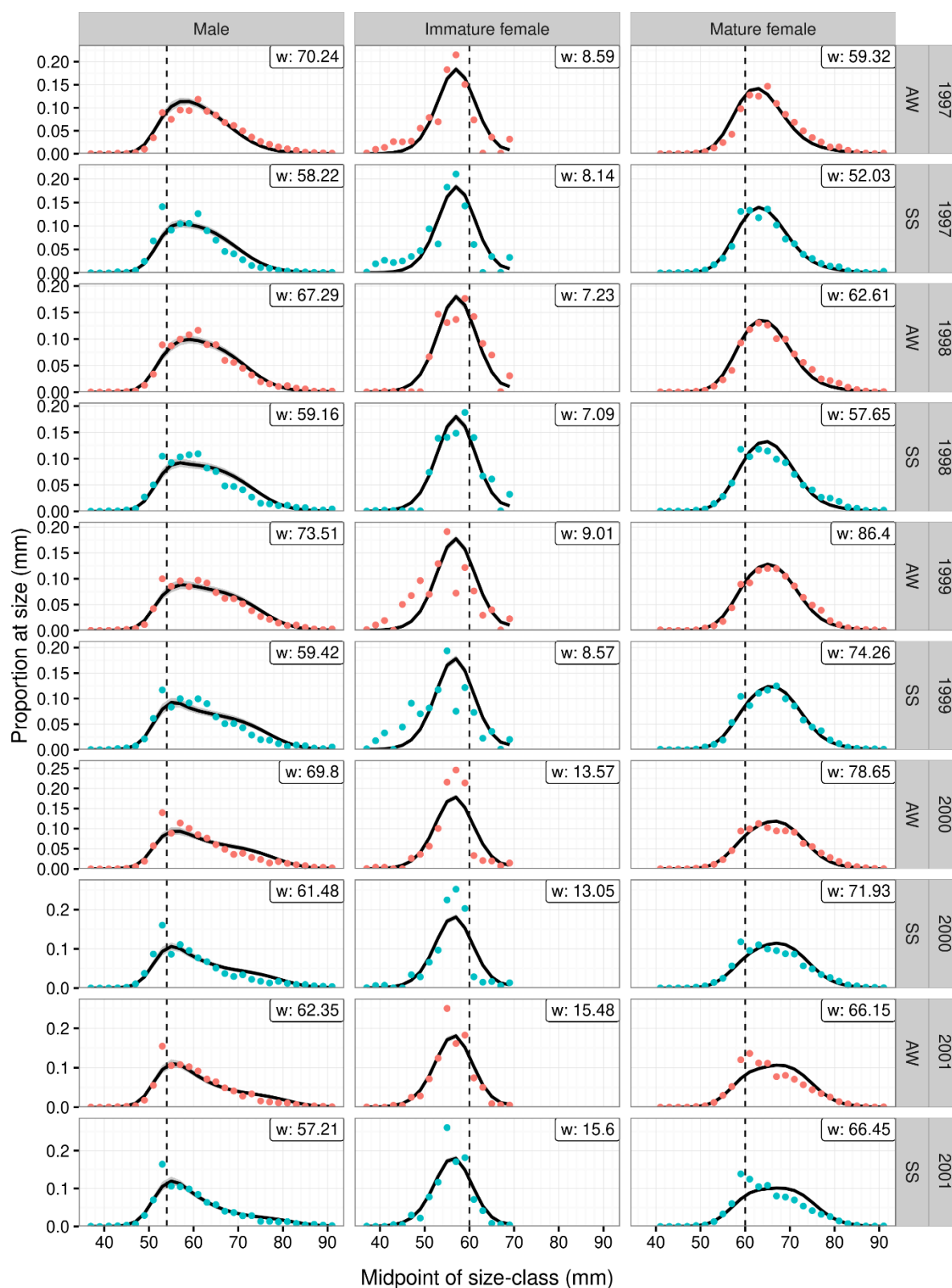


Figure B.1 (cont.):

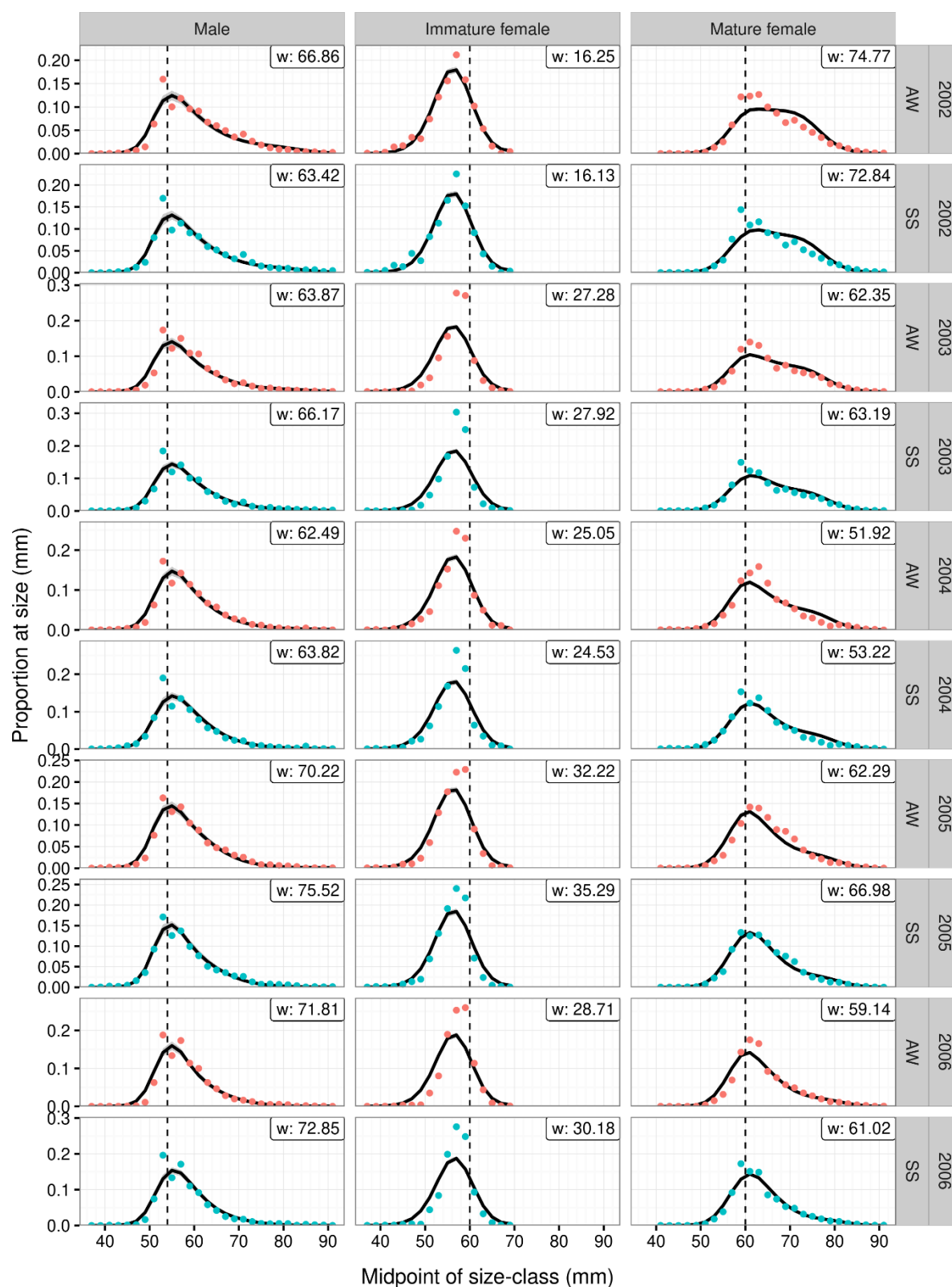


Figure B.1 (cont.):

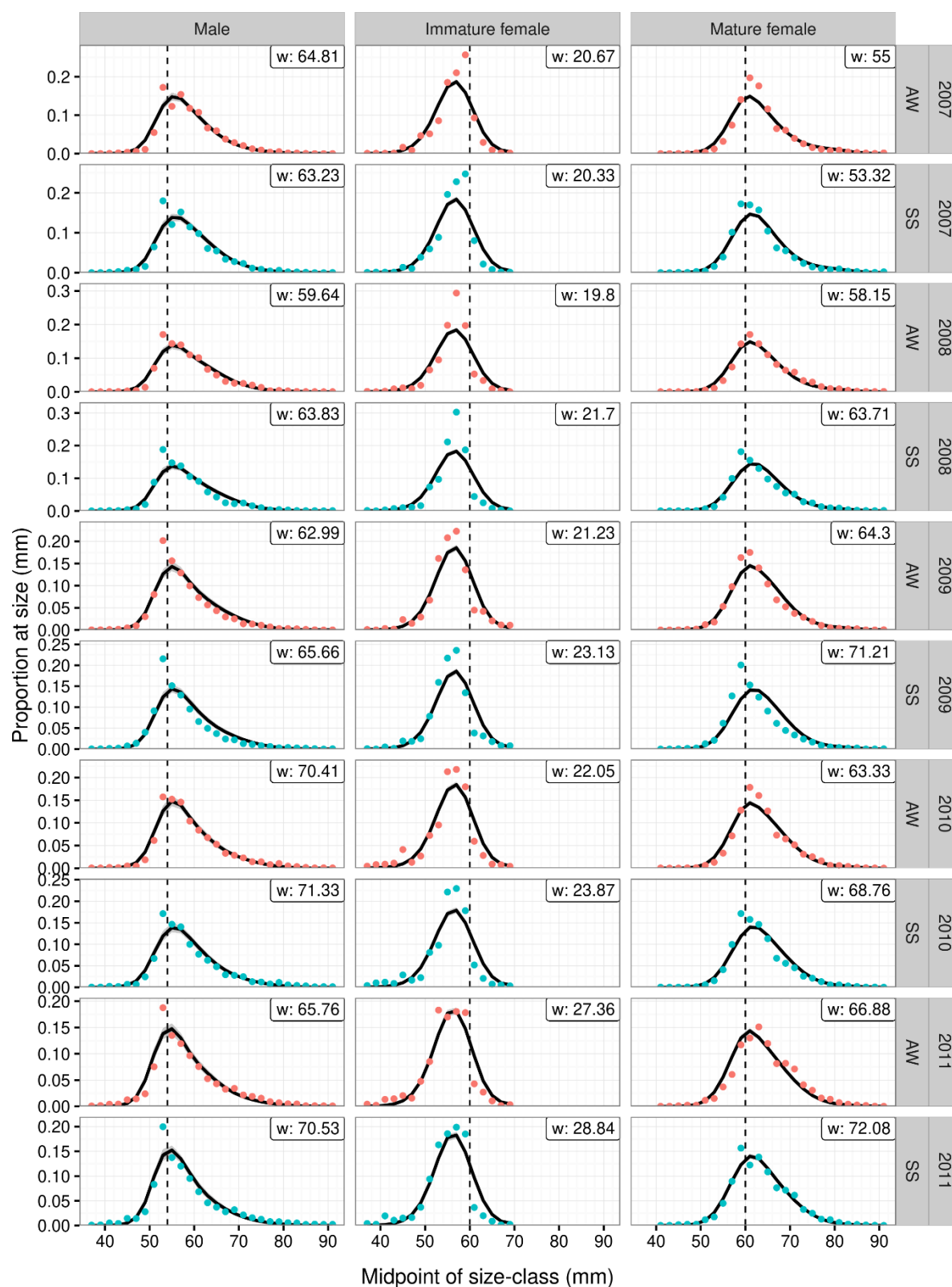


Figure B.1 (cont.):

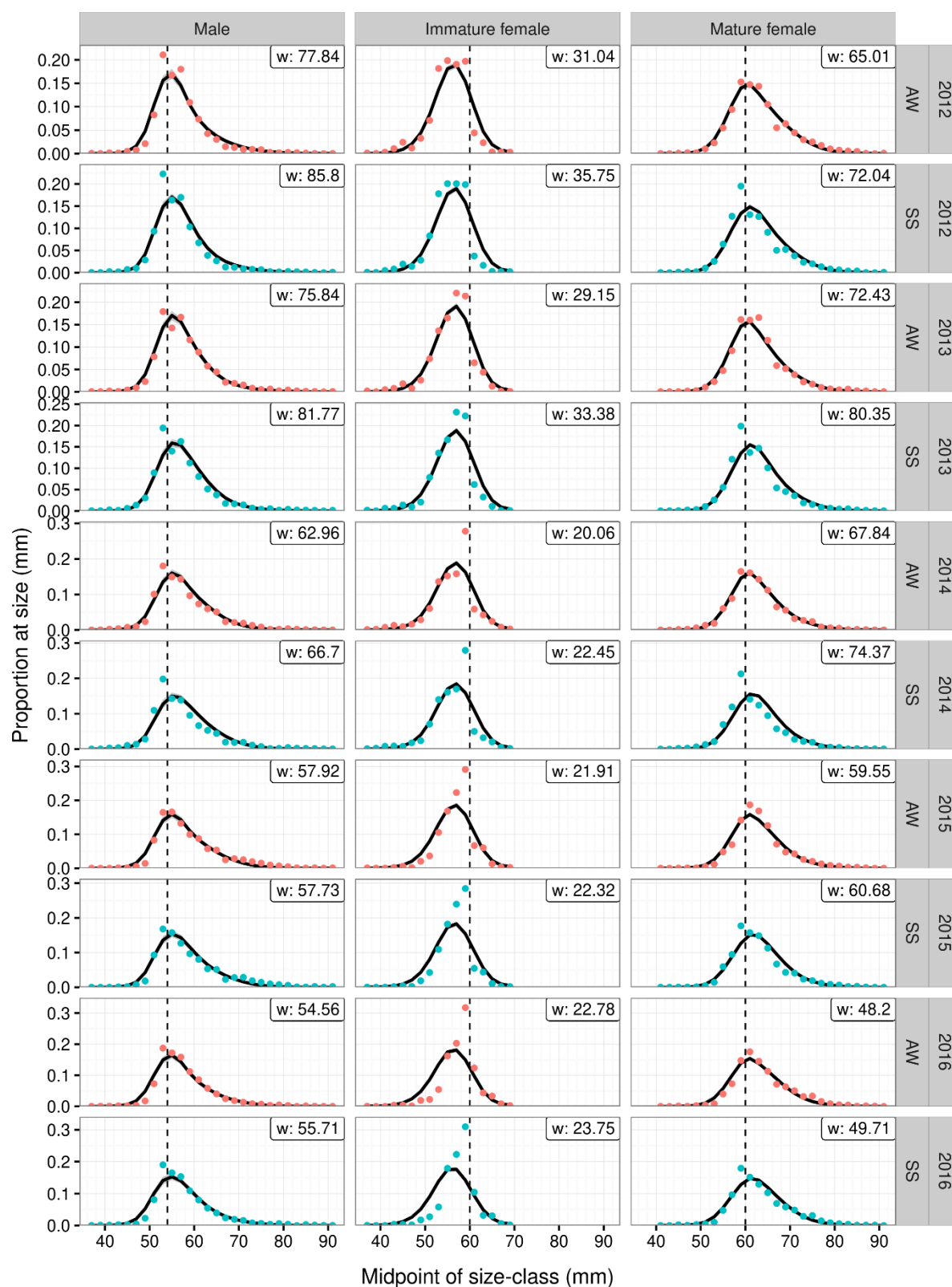


Figure B.1 (cont.):

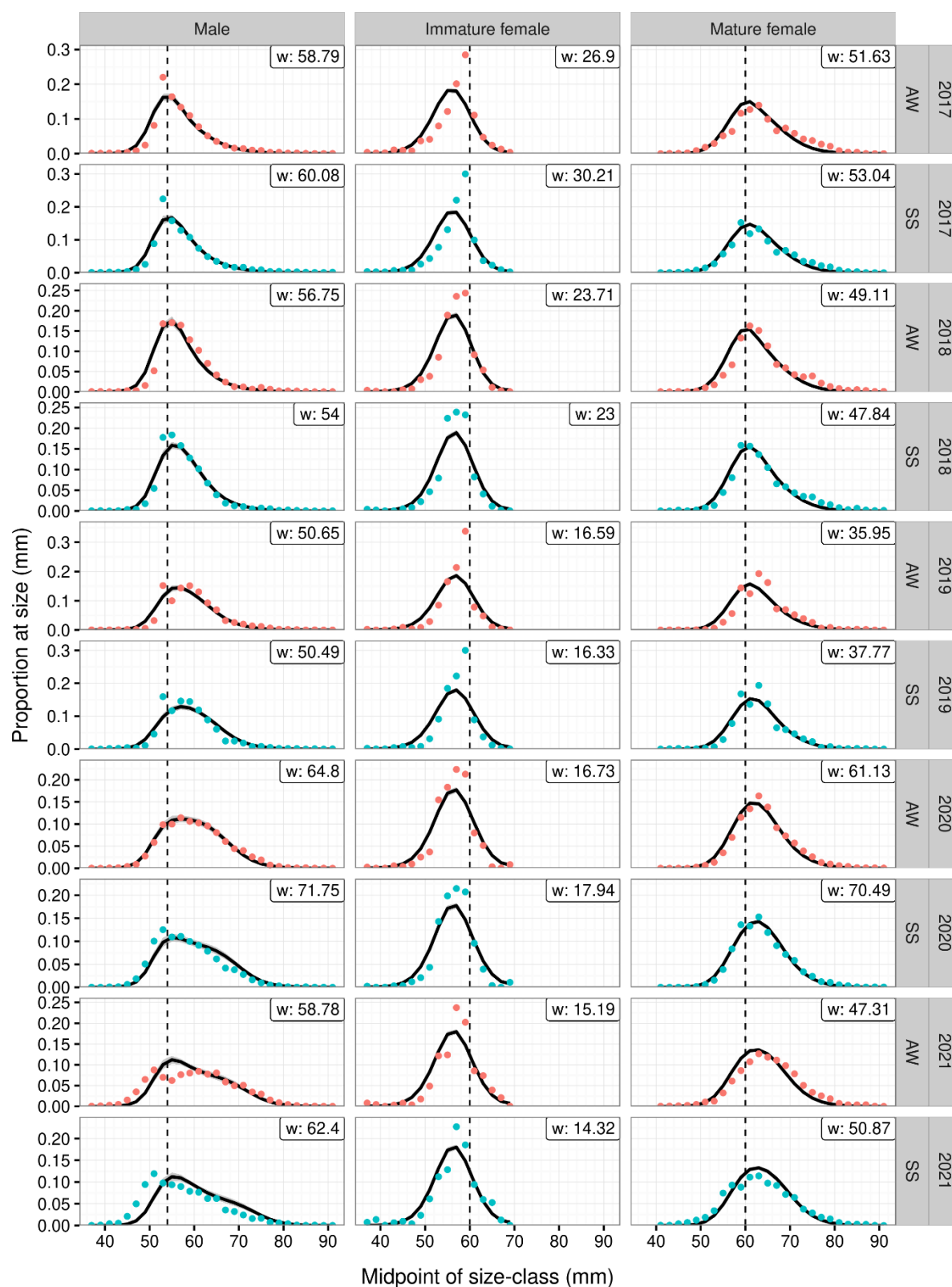


Figure B.1 (cont.):