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Tini a Tangaroa

The 2023 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 6

New Zealand Fisheries Assessment Report 2024/23

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Plain language summary

The red rock lobster supports the most valuable inshore commercial fishery in New Zealand.

This fishery has been managed with catch quotas in nine Quota Management Areas (QMAs), which are usually treated as independent populations or stocks.

To estimate those quotas, a stock assessment is done for each QMA approximately every five years. These stock assessments include a review of the previous stock assessments and data inputs, the addition of new data, data processing, and development of a new stock assessment model.

This document describes the development of a new stock assessment model for the CRA 6 stock (the Chatham Islands).

The stock assessment estimated that since 1995, the stock size has steadily increased and is projected to increase over the next five years assuming current catches and recent recruitment patterns.

EXECUTIVE SUMMARY

Rudd, M.B.¹; Webber, D.N.²; Starr, P.J.³; Roberts, J.O.⁴; Pons, M.⁵ (2024). The 2023 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 6.

New Zealand Fisheries Assessment Report 2024/23. 106 p.

This document describes the 2023 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 6. The stock assessment used the lobster stock dynamics model. Data inputs and technical decisions were discussed and agreed upon by the Rock Lobster Working Group, who oversaw this work.

The model was fitted to length frequencies and sex ratios of the commercial catch, tag-recapture growth increment data, and standardised catch-per-unit-effort indices. The tag recapture sample size from CRA 6 was small, necessitating the inclusion of tag recapture growth increment data from the Fiordland region of CRA 8, where the catch size composition and sea temperatures are comparable with CRA 6. 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* fits and Markov chain Monte Carlo simulations.

This stock assessment assumed a single-region model that combined data across all CRA 6 statistical areas. There were some differences in the size composition of sampled lobsters among the four statistical areas, but a multi-region assessment was not possible due to the limited amount of data from most individual statistical areas. The reconstruction of the base model began in 1965, because this was the year that the commercial fishery began.

The stock assessment estimated a period of initial heavy exploitation resulting in rapid decline of the stock size between 1965 and 1975, followed by a slower but steady decline until 1995, when the stock approached the soft limit (20% SSB_0). Since 1995, the stock size has steadily increased and is projected to increase over the next five years assuming current catches and recent recruitment patterns.

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1. INTRODUCTION

The CRA 6 Quota Management Area (QMA) for red rock lobster (*Jasus edwardsii*, CRA) comprises all of the Chatham Islands archipelago, including the two main islands (Chatham and Pitt) (Figure 1). There are four rock lobster statistical areas (940, 941, 942, and 943), which roughly divide the Chatham Islands rock lobster habitat into four quadrants.

The National Rock Lobster Management Group (NRLMG) decided that a stock assessment for red rock lobsters in CRA 6 should be done in 2023. This stock assessment was completed in a workshop during May and June 2023. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Working Group (RLWG), and a summary of the data used is given by Webber et.al. (2024) The stock assessment was presented to and approved by the Fisheries New Zealand mid-year Plenary on 16 October 2023 (Fisheries New Zealand 2023).

The early Chatham Islands rock lobster fishery (now called CRA 6) was characterised by very high catches, intense fishing from a large number of vessels, and a rapid decline of the stock over a short period of time. Catch estimates are uncertain, but it is thought that over 17 000 tonnes of lobsters were harvested from CRA 6 between 1966 and 1970. An early paper by Kensler (1969), who worked for the Fisheries Research Division, Marine Department, Wellington, documented the capture of 3000 tonnes of lobsters from September 1966 to August 1967, which equated to 40% of the total harvest of New Zealand lobsters during that 12-month period. A significant fraction of that catch was taken by bottom trawling.

The CRA 6 commercial fishery is primarily a trap or pot fishery, fished by small boats on day trips in relatively shallow waters. However, a few fishers still collect rock lobsters by hand around the Chatham Islands⁶. The number of vessels operating in CRA 6 has remained relatively constant (32–42 vessels) since the late 1990s, with 32 vessels counted in 2021–22 and 36 in 2022–23 catching at least 1 tonne/year (Starr 2024). A fixed annual Total Allowable Commercial Catch (TACC) allocation was set for CRA 6 at 360 tonnes in 1998–99. Allowances of 6 tonnes for recreational catch and 4 tonnes for customary catch were added by the Minister of Fisheries in the same year to produce a Total Allowable Catch (TAC) of 370 tonnes. The TAC and TACC have remained unchanged since 1998–99. The current minimum legal size (MLS) for red rock lobsters in the CRA 6 commercial and recreational fisheries is 54 mm tail width (TW) for males and 60 mm TW for females. There is also a general prohibition for the commercial and recreational fisheries on the taking of berried females and soft-shelled individuals, and a closed season applies in CRA 6 from 1 March to 30 April in each year.

The previous CRA 6 stock assessment in 2018 was the first assessment using a length-structured model for CRA 6, which estimated that the spawning stock biomass (SSB) was above the 20% SSB_0 soft limit in 2018–19 (Rudd et al. 2019). This document presents a new stock assessment for CRA 6, which includes updates to the catch-per-unit-effort (CPUE) standardisation procedure and other inputs up to the end of the 2022⁷ fishing year.

The research described in this document was completed under the Fisheries New Zealand contract CRA2022-01, with the Overall Objective “Conduct assessments of rock lobster stocks including estimation of biomass and sustainable yields and contribute to operationalising new management approaches” to meet Specific Objective 6 “Carry out full stock assessments for around two rock lobster stocks annually including estimating biomass and sustainable yields, the status of the stock in relation to management reference points, and future projections of stock status as required to support management”.

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.

⁶ This is a legacy fishery which is only allowed in the Chatham Islands.

⁷ The 2022–23 fishing year is referred to in this document as 2022, i.e., the first year of the 1 April 2022 to 31 March 2023 rock lobster fishing year.

2. STOCK ASSESSMENT

The 2018 stock assessment for CRA 6, which replaced the 1996 surplus production model (Breen & Kendrick 1998), was an integrated length-based model fitted to length frequency data, sex ratio data, tag-recapture growth increment data, and standardised CPUE indices. It was concluded from the 2018 stock assessment that the initial high catches and consequent high exploitation rates resulted in a rapid decline of the stock size between 1965 and 1975, followed by a slower but steady decline up until 1995, when the stock approached the soft limit (20% SSB_0). After that year, the stock subsequently grew and was projected to continue to increase to 2023, assuming current catches and recent recruitment.

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

Maximum *a posteriori* (MAP) estimation and Markov chain Monte Carlo (MCMC) simulations were used to make inferences about the CRA 6 stock. MAP runs were used to develop and determine 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 6 reference level (Rudd et al. 2021b). Finally, the posterior distribution from the base case was used to project forward five years, to provide management advice.

The covariates and data used in this stock assessment were documented by Webber et al. (2024) and are summarised briefly here in Section 2.1 and Section 2.2 below. The stock assessment model settings are described in Section 2.3, model parameters and priors are defined in Section 2.4, and 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 of the commercial catch, and tag-recapture data collected by commercial and recreational fishers (Webber et al. 2024). Puerulus settlement indices were not available in CRA 6. Each of these data sets have different temporal extents (Figure 2).

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

- A catch rate (CR) series, which is an annual arithmetic daily catch rate from 1966 to 1973.
- A Fisheries Statistics Unit (FSU) series, which is a seasonal standardised index from autumn/winter (AW) 1979 to AW 1989. The standardisation model included year, month, statistical area, and vessel explanatory variables. The FSU CPUE standardisation included all vessels.
- A Catch Effort Landing Return (CELR) series, which is a seasonal standardised series from spring/summer (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 6.
- A logbook series, which is a seasonal standardised series from AW 2014 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 in CRA 6.

The apparent change in reporting behaviour associated with the change in commercial catch and effort data collection from paper forms to electronic monitoring in 2019 prevented the extension of the CELR

CPUE abundance series beyond the AW of the 2019 fishing year (see appendix B of Starr 2022 for the evidence supporting this decision).

Biological sampling in CRA 6 was done intermittently by observer catch sampling from 1982 to 2022 and a voluntary logbook programme from 2001 to 2022 (Webber et al. 2024). Both sets of data were used in the 2023 stock assessment to derive standardised sex ratios and LFs of the commercial catch and CPUE. The voluntary logbook data collected before AW 2014 were deemed unreliable by the RLWG (see Webber et al. 2024 for the basis of this decision), resulting in the exclusion of the 2001–2013 LF and CPUE data from the stock assessment model. However, the 2001–2013 and subsequent data were used to calculate standardised sex ratios.

This assessment used paired individual tag-recapture observations from initial tags releases in all four CRA 6 statistical areas (940, 941, 942, and 943) (Figure 1). During the 2018 assessment, the RLWG determined the available tagging data for CRA 6 were sparse. A decision was made at that time to supplement the CRA 6 tag-recapture data with the tag release-recapture data from the Fiordland region of CRA 8 (statistical areas 926, 927, and 928), where the catch size composition and sea temperatures were comparable to CRA 6. That decision was carried forward for the 2023 stock assessment. Tag-recapture data were used to inform growth within the stock assessment model and were also used to qualitatively assess the degree of movement within CRA 6 and among other QMAs. Consistent with the base case model of the 2018 assessment (Rudd et al. 2019), initial model exploration suggested that individuals that were recaptured multiple times tended to have slower growth rates, resulting in a decision to only fit to the first tag recapture event.

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 (Table 1).

The commercial catch time series was based on a range of data sources from 1965 to the present, described by Webber et al. (2024). Similarly, the development of the non-commercial catches is also described by Webber et al. (2024). All catches were split between the AW and SS seasons, from 1965 to 2022. For the commercial and illegal catches, when monthly or seasonal catches were not directly reported, the assumed proportions of catch by season were based on estimates from periods when that information was available. For the recreational and customary catch histories, the seasonal proportions were assumed to be constant at 10%/90% for the AW/SS, respectively. The commercial and recreational catches were combined within the model to determine the annual size-limited (SL) catch, being the component that conformed to the regulations which govern 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, based on catch-at-sea observer sampling and voluntary logbook discard rate reporting. This step-reduction in handling mortality after 1990 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 in order 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 returned to the water by both the AW and SS SL fisheries. It was assumed that there were no discards in the NSL fishery.

Prior 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 current MLS in CRA 6 is 54 mm and 60 mm TW for males and females, respectively (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 during the SS season. This assessment used logbook data to derive standardised proportions of berried females for AW and SS for all of CRA 6, that were averaged over all years. Based on logbook data, the unstandardised average proportion of mature females in berry was 0.866 in AW and 0.142 in SS (Webber et al. 2024). Standardised and catch-weighted proportions were also used for each season, which were estimated to be 0.818 in AW and 0.116 in SS, and the respective proportions were also estimated by fishing year (Webber et al. 2024).

2.3 Model

The lobster stock dynamics (LSD) model (Webber et al. 2023) tracks the numbers of individual lobsters in three sex categories (immature females, mature females, and males) for each of 46 two-mm TW bins (from 30–31 mm to 120+ mm), by year and season. Like the previous CRA 6 stock assessment model, the first model year was set to 1965. The last year in the reconstruction of the stock was 2022, but this was extended to 2027 for projections of the base case model. The model was partitioned into two six-month seasons within a model year: AW (April to September) and SS (October to March). The 2023 stock assessment treated CRA 6 as a single homogenous area, as was done in the previous assessment for this stock in 2018 (Rudd et al. 2019). 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 over time.

New recruits to the model were added equally for each sex, for each season, as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the mean recruitment parameter (R_0) and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero and standard deviation of 0.4. Recruitment deviations were estimated for the years 1965 to 2019. 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 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 meeting were uncomfortable with including this recruitment spike and wanted to wait until more years of data were available to inform it. This practice (used for CRA 2, Rudd et al. 2023) was continued for the 2023 CRA 6 stock assessment, so the most recent estimated recruitment deviate was 2019 in this stock assessment. The 2020 to 2022 recruitment deviations were fixed to be the same as the 2019 recruitment deviation during the model fitting phase.

A CRA 6 length-weight model estimated by Breen & Kendrick (1997, unpublished) and documented by Starr et al. (2019) was adopted in the base case CRA 6 stock assessment model. A comparison of the length-weight relationship estimated for the Chatham Islands stock, with an alternative South Island length-weight relationship, differed by sex, with CRA 6 males generally heavier for the same length while the CRA 6 females were lighter at length (see figure 22 of Starr et al. 2019).

For each sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or transitioning to another size class. Maturation of females was estimated as a two-parameter logistic curve.

logistic selectivity ogive was assumed to define the size composition of the catch, which was assumed to be size class and sex specific and the same for both immature and mature females. Selectivity was also assumed to be the same during the AW and SS seasons. Note that the assumed selectivity ogive differs from the 2018 assessment (Rudd et al. 2019), which assumed a double normal ogive with an estimated right-hand limb. 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 are estimated relatively, with the vulnerability for the sex/season category with the greatest assumed vulnerability fixed to one (usually males during the AW), and the remaining vulnerability parameters estimated to be between zero and one.

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 6, 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.

Natural, fishing, and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and size. Exploitation rates were determined from observed catch and model biomass, modified by sex-specific MLS, proportions of mature females in berry, sex/season specific vulnerabilities, and sex-specific selectivity. Discarding of large lobsters appeared to be infrequent in CRA 6, given the low use made of destination code 'X' in this QMA; it is not known if this reflected a lack of discarding or a failure to record discards, but discarding of large lobsters was not modelled in this stock assessment. Exploitation rates for each fishery were calculated from the catch, model biomass, and natural mortality.

The LSD model removed catch from the population using discrete exploitation rates. 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.

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) (see Table 3).

Four vulnerability parameters (i.e., *vuln1*, *vuln2*, *vuln3*, and *vuln4*) were estimated including AW and SS immature and mature females separately (Table 4). These parameters were estimated relative to the maximum selectivity of one for males during the AW and SS respectively.

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 (Table 5). Beta distributions, with both shape parameters set to one, were used for priors for all parameters bounded between zero and one, including the growth parameter *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

This assessment used the same reference points and indicators that were used in the 2022 CRA 2 assessment (Rudd et al. 2023), using a discrete exploitation rate in place of the instantaneous fishing mortality rate that was used in previous rock lobster stock assessments (Table 6, Table 7). The

exploitation rate associated with the reference level (U_R , see Section 2.8) was updated to be defined as the fixed exploitation rate associated with a median vulnerable biomass equal to B_R at equilibrium. The main indicators were related to the relative estimates of adjusted vulnerable biomass⁸, 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 (see Section 2.9). Probabilities were calculated over all samples of the posterior distribution.

In the past, vulnerable biomass was defined as start-of-season AW biomass, which did not include any mature females which were not harvestable in this season because they were all assumed to be in berry. However, in this assessment, a small proportion of mature females (the proportion not in berry—see the 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 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 probability of the SSB being below the soft and hard limits was calculated. 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.

The value H_{2022} is the model estimate of the amount of handling mortality (in tonnes) in the final fishing year (2022).

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 to 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 model assumptions.

2.6.1 MAP base case

2.6.1.1 Matching the previous assessment model

Each year the LSD model is improved upon to ensure that the model is up to date with current best practices in stock assessment. Because there are usually several updates to the LSD code between full assessments, it is necessary to match the results from the new model to the previous base case assessment. Key updates for the 2023 assessment included:

1. Updated assumptions about commercial, illegal, recreational, and customary catches: the RLWG agreed to discontinue the use of the export discrepancy approach for illegal catch in early years, as has been done for recent assessments of other QMAs. The RLWG agreed on the assumption of illegal catch as 5% of reported legal catch before 1990 and 2% of the Quota Management Report or Monthly Harvest Return catch since 1990. This resulted in a net shift of catch from illegal to commercial catch. The RLWG agreed on a minor reduction in recreational and customary catches, resulting in very minor changes in overall catch magnitude for all years. Commercial take was assumed to be about 95% of total catch in recent years.
2. Development and inclusion of logbook CPUE series: updated model code to include newly developed logbook CPUE series from 2014–2022 with units in numbers per potlift, while the FSU

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.

- (1979–1989) and overlapping CELR (1990–2019 AW) were included with units of kilogram/potlift. CPUE weights were halved for the years of CELR and logbook series overlap (i.e., 2014–2019 AW).
3. Standardised length frequencies (using a Bayesian Poisson-decomposed multinomial GLMM model) and sex ratios (using a Bayesian multinomial GLMM model): the 2018 assessment kept catch sampling and logbook data separate using ad hoc weightings; the updated approach used standardised LF and sex ratios, resulting in a single series for each year, season, and sex category.
 4. Calculation of discrete exploitation rates instead of instantaneous fishing mortality rates: this resulted in negligible changes to model estimates and no longer required running the iterative Newton-Raphson algorithm to calculate fishing mortality rates which improves speed of model runs.
 5. Estimated recruitment deviates to 2019 (three years prior to final model year) rather than 2020 (other rock lobster stock assessments have typically used two years prior to final model year). This approach was adopted during the 2022 CRA 2 assessment because of concern over whether recent data could adequately inform recent recruitment deviates.
 6. Used average proportion of mature females in berry covariate estimated using logbook data to update the 2018 assumption of 100% berried in AW and 0% berried in SS. The 2023 stock assessment used an average over years by season. This is expected to model the SSB and vulnerable biomass more accurately.
 7. Updated model for predicting TW from CL, used for older tag data.
 8. Estimated four vulnerability parameters (AW and SS immature and mature females) relative to males by season (both AW and SS males fixed to 1, previously only AW males fixed to 1 and single vulnerability parameter was used for both SS female categories).
 9. Changed from double-normal to logistic selectivity by sex: 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.
 10. Fix *qdrift* parameter at 1% for CELR and logbook series.

2.6.1.2 Searching for a 2023 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 6 base case as model changes were implemented:

1. Including all input data up to the end of 2022
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 0.866/0.142 for AW/SS.

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

- **Years:** 1965 to 2022⁹, assuming an initial population at equilibrium with average recruitment (R_0).
- **Seasons:** two six-month seasons AW (April–September) and SS (October–March) during each fishing year.
- **Sex categories:** males, immature females, and mature females.
- **Tail width bins:** 46 two-mm wide bins from 30–31 mm to 120+ mm tail width (last bin was a ‘plus group’ or accumulator bin).
- **Regions:** a single region including statistical areas 940, 941, 942, and 943.
- **Recruitment:** recruitment deviations ($Rdevs$) estimated from 1965 to 2019. The final three model years were set to the 2019 estimate, given no real information in data for these recruitments and no puerulus settlement index. No stock recruitment relationship was assumed. Size at recruitment was assumed to have a mean of 32 mm and standard deviation 2 mm, based on recent studies of juvenile growth (Figure 3, Roberts & Webber 2022).

⁹ April–March fishing years from 1979–80 to 2022–23.

- **Growth:** sex-specific using the Schnute-Francis growth model. No density-dependent growth. Only fit to the first tag-recapture event, discarding all subsequent recovery events following re-releases of the same lobster.
- **Maturation:** female only logistic ogive.
- **Natural mortality:** a single M , shared between sexes.
- **Selectivity:** logistic and sex specific.
- **Vulnerability:** four estimated parameters, one each for immature/mature females in each season (see Table 4).
- **Handling mortality:** two periods: 1965 to 1989 fixed at 0.1, and 1990 to 2027 fixed at 0.05.
- **Catch:** from 1979 to 2022 using updated assumptions commercial, illegal, recreational, and customary (see sections 2.2, 2.3, and 2.4 of Webber et al. 2024). Removed using discrete exploitation rates.
- **Abundance indices:** four CPUE series (CR, FSU, CELR, and logbook), each with a separate catchability coefficient (q). 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 or the CR series (Figure 4).
- **Likelihoods:**
 - Lognormal for all CPUE series (CR, FSU, CELR, and logbook)
 - 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
 - Multinomial for sex ratios.
- **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 model fits to the different CPUE series (CR, from 1966 to 1973; FSU, from 1979 to 1989 AW; CELR, from 1989 SS to 2019 AW; and logbook, since 2014) were adequate (Figure 5), with the exception of a small number of years when the standardised residuals were outside of the ± 2 range (Figure 6).

With the exception of only a few points, the base case model fit to the sex ratio data was reasonably good (Figure 7), with no pronounced residual pattern by year/season (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 was a major difference to the standardised residuals of LF fits in previous stock assessments for CRA 6 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 was no reliable indicator of 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). Furthermore, the growth rate information from the Fiordland region of CRA 8 (statistical areas 926, 927, and 928) appeared to be consistent with the sparse information from CRA 6 (tag recaptures in areas 940, 941, and 942) (Figure 12).

The estimated size distribution of the unfished population (Figure 13) suggested there were many large males (in terms of TW) as indicated by the relatively large number of males greater than 100 mm TW which is consistent with the one LF observation from the early fishery (Figure B.1).

The selectivity functions by sex (Figure 14) were simplified from previous assessments that fixed the right limb at nearly logistic selectivity. The 2023 stock assessment assumed logistic selectivity. Selectivity multiplied by vulnerability provided an improved visualisation of the relative probabilities of each sex being captured by the gear in the fishery (Figure 15).

The size at 50% of female maturation was estimated to occur at just over 50 mm TW in CRA 6 (Figure 16), indicating that the fishery probably takes few sub-mature females, because the MLS for this QMA is 60 mm TW. This CRA 6 maturity is considerably smaller than the equivalent maturity estimated for CRA 7&8, where 50% maturity is estimated to be near 60 mm TW (Webber et al. 2022).

Given the large early catches in this fishery, both the SL and NSL exploitation rates were high in the initial years of this fishery, followed by substantial reductions as catches moved to a more sustainable level (Figure 17). The NSL exploitation rates were very low compared with the SL exploitation rates (Figure 17). NSL exploitation rates were lower in the 1970s and 1980s compared with the earliest years of the fishery, and then dropped again to a relatively stable, lower level since 1990, reflecting the lower handling mortality assigned to this sector by the RLWG. The SL exploitation rates dropped significantly in the 1970s, increased in the 1980s and 1990s, and have remained relatively stable since then (Figure 17).

Three strong temporal recruitment pulses were estimated; one in the late 1960s, the second in the mid-1990s, and the largest pulse which has been occurring since the early 2010s (Figure 18). Recent mean (2010–2019) recruitment was estimated to be above R_0 , as indicated by the derived parameters B_0^{now} and SSB_0^{now} being larger than the equivalent parameters B_0 and SSB_0 , which were based on the mean recruitment (i.e., R_0) for 1965–2019 (Table 9).

After the initial high exploitation period of the CRA 6 fishery, the vulnerable biomass remained relatively stable (Figure 19). There is indication that there has been an increase in vulnerable biomass in recent years, perhaps associated with recent high recruitment greater than R_0 (Figure 18, Figure 19).

2.6.2 MAP sensitivity trials

The RLWG decided on fifteen sensitivity trials as single variants relative to the *base case* (Table 8). These included sensitivities testing assumptions relating to the model start year and estimating right-limb selectivity (Group 1: *start1979*, *sel_est_dome*), fixing model parameters (Group 2: *fixM*, *fix_early_recdevs*), treatment of tag and LF data (Group 3: *tags_CRA6*, *LF_1966*), assumptions about the CPUE series (Group 4: *no_qdrift*, *drop_CELR*), adjustments to the LF and sex ratio series (Group 5: *dropLF_lowN*, *drop_early_LF_SR*), assumptions about proportions of mature females in berry (Group 6: *propberry_std*, *propberry_year*), and down-weighting data sets (Group 7: *downwtCPUE*, *downwtLF*, *downwtSR*).

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the fifteen sensitivity trials were compared with each other and the base case (Table 9). The estimated *base case* selectivities, recruitment, and vulnerable biomass were compared with the sensitivity runs, grouped in seven blocks of related runs (as indicated above), as well as a comparison with the previous 2018 CRA 6 stock assessment (Rudd et al. 2019) (Figure 20 to Figure 43).

The 2018 assessment assumed nearly logistic selectivity, but the fixed right-limb selectivity did have a slight downward curvature, accounting for some large individuals not selected by the gear (Figure 20). The 2023 stock assessment assumed logistic selectivity, which eliminated this effect. The MAP sensitivities estimated very similar selectivity ogives to those estimated by the base model (Figure 21 to

Figure 27). The estimated right-limb selectivity in *sel_est_dome* was very minor (Figure 21), and the *fixM* model estimated only a very small shift right for female selectivity (Figure 22).

The 2023 base model estimated three general periods of higher recruitment, one of which was in the mid to late 1990s, whereas the 2018 base model estimated two higher recruitment periods in the middle of the time series, one in the early 1990s and one in the early 2000s (Figure 28). Note that the 2018 assessment included the 2001–2013 logbook LF data, which were not used in the 2023 assessment. This data difference was probably the main reason the two recruitment time series differ. However, the two estimated recruitment patterns were broadly comparable, with wide and substantially overlapping credible intervals in the overlapping years.

The estimated recruitment time series (Figure 29 to Figure 35) and adjusted vulnerable biomass time series (Figure 36 to Figure 43) from the 15 MAP sensitivity runs were compared by sensitivity group (Table 8) with the base model. The *fixM* model estimated much higher recruitments but a similar pattern as the base model, in keeping with the higher productivity level implied by a higher assumed M than estimated by the base model run (Figure 30). The vulnerable biomass estimated by this model was also much higher than the base model after the late 1970s while the *fixM* run dropped to a lower level in the early part of the series than did the base model because the same amount of catch was extracted from a lower initial biomass (Figure 38).

The two Group 3 models (*tags_CRA6* and *LF_1966*) estimated negligible changes in selectivity and recruitment (Figure 23, Figure 31). There were differences in the estimated growth parameters (Table 9), which led to slightly higher adjusted vulnerable biomass for the *LF_1966* model and slightly lower adjusted vulnerable biomass for the *tags_CRA6* model (Figure 39).

In the *no_qdrift* model, the fishery is assumed to have a lower effective removal rate in recent years. To meet recent catches, this model estimated higher recent recruitments and higher recent adjusted vulnerable biomass (Figure 40). Dropping the CELR series (*dropCELR*) estimated lower recruitment during each of the three pulses (Figure 32), leading to lower recent adjusted vulnerable biomass (Figure 40).

Dropping early sex ratio and LF data resulted in an estimated recruitment pulse in the early 1980s that was absent in the other model runs, that was perhaps confounded with the higher early recruitment estimated by the other models (Figure 33). The *drop_early_LF_SR* model estimated a slightly lower, but similar recruitment pattern to the base run (Figure 33). However, these differences in recruitment patterns led to negligible differences to the trend for the estimated adjusted vulnerable biomass for all three model runs (Figure 41).

Down-weighting the four CPUE series led to generally flatter estimated recruitment, whereas down-weighting the LF data led to flatter recruitment in the early and most recent periods (Figure 35). Overall, these sensitivities were consistent with estimated recruitment patterns being primarily driven by the CPUE data. The differences in estimated recruitment led to much lower estimated recent adjusted vulnerable biomass in the *downwtCPUE* model (Figure 43).

A summary of the sensitivity runs is provided below (also see Table 9 for detailed parameter and derived parameter estimates).

- **start1979:** start model in 1979. This run matched the base run from 1979 onwards. MCMC was done for this model run. This model estimated slightly higher vulnerable biomass for 1979–2022 when compared with the base model.
- **sel_est_dome:** estimate dome-shaped right-limb selectivity. MCMC was done for this model run. This model estimated nearly the same recruitment series and vulnerable biomass as the base model.
- **fixM:** fix M to 0.10. MCMC was done for this model run. This model had the largest impact on the predicted vulnerable biomass trajectory, as $M = 0.10$ is much higher than the estimated M

of about 0.05 by the base model and the other MAP sensitivities. This model estimated lower vulnerable biomass during the early years due to the lower initial biomass estimate and then higher vulnerable biomass since approximately 1975 because of higher mean recruitment than the base run.

- ***fix_early_recdevs***: begin estimating recruitment deviates 3 years prior to the first LFs and use constant recruitment from 1965 to 1984. MCMC was done for this model run. This model resembled the base model in recent years, but had a slightly higher vulnerable biomass than the base model before 1976 and slightly lower between 1977 and 1990. These differences can be ascribed to differences in the recruitment assumptions (Figure 38) and to a slightly lower overall mean recruitment.
- ***tags_CRA6***: CRA 6 tags only (excluding tags used in the base model from CRA 8 statistical areas). MCMC was done for this model run. This model estimated lower recent recruitment and lower vulnerable biomass throughout the time series when compared with the base model.
- ***LF_1966***: force the model to fit to 1966 LF. This model had a similar recruitment trajectory and a slightly higher vulnerable biomass than the base model.
- ***no_qdrift***: set *qdrift* to 0. This model was nearly identical to the base model up to approximately 2003 but then vulnerable biomass drifted larger than the base model from 2003 to 2022 because of the drop in relative exploitation by this model.
- ***dropCELR***: drop entire CELR series. MCMC was done for this model run. This model was generally similar to the base model up to 2005 and then vulnerable biomass dropped below the base model in recent years, reflecting the need for annual biomass information in these size-based models.
- ***dropLF_lowN***: drop LFs with less than 100 measured lobsters. There were negligible differences between this model and the base model.
- ***drop_early_LF_SR***: drop the block of sex ratio and observer length frequency data prior to 2014. This model estimated slightly lower vulnerable biomass than the base model between 1976 and 1992 but was otherwise the same as the base run despite of the differences in the early recruitment series.
- ***propberry_std***: catch-weighted and standardised proportion berried females by season. This model was negligibly different from the base model.
- ***propberry_year***: catch-weighted and standardised proportion berried females by year, 1993–2022, use catch-weighted and standardised proportion by season prior to 1993 (and for projection years). This model was negligibly different from the base model. This result, as with the *propberry_std* model, indicates that the standardisation procedure did not change the data much compared with the unstandardised series in terms of model impact.
- ***downwtCPUE***: down-weight the likelihood for all CPUE series to 10% of the base case. This model estimated much lower vulnerable biomass in recent years compared with the base model.
- ***downwtLF***: down-weight the likelihood for the LF data to 10% of the base case. This model estimated slightly lower vulnerable biomass from about 1980 when compared with the base model.
- ***downwtSR***: down-weight the likelihood for sex ratios to 10% of the base case. There were negligible differences between this and the base model.

2.7 Bayesian inference using Markov chain Monte Carlo (MCMC)

Bayesian inference was used to characterise parameter uncertainty. The LSD model 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 six selected sensitivity tests (*start1979*, *sel_est_dome*, *fixM*, *fix_early_recdevs*, *tags_CRA6*, and *dropCELR*), the posterior distributions were explored with a total of 1000 samples across four chains, each with a warm-up phase of 250 iterations and length of 250 samples, retaining every sample.

2.7.1 MCMC base case

MCMC model runs were 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 44, Figure 45, Figure 46, and Figure 47). 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 48, Figure 49, and Figure 50).

Likelihoods, SDNRs, MARs, and parameter estimates were inspected (Table 10), as were the derived parameters and probabilities, including projections, for the base case (Table 11). Figures were presented for the MCMC outputs of the *base* case model only. These outputs were comparable with those provided for the *base* case MAP results.

Fits to the CR series, FSU CPUE series, the CELR CPUE series, and the logbook CPUE series were acceptable (Figure 51, Figure 52). The fits to the CELR CPUE mirrored the MAP fits to each series (Figure 5, Figure 6).

The fits to the sex ratio data (Figure 53, Figure 54) mirrored the MAP fits, with some uncertainty in the last few years of data.

The fits to the LF data (all MCMC LF fits are presented in Appendix B, Figure B.2) and the associated residuals (Figure 55, Figure 56) showed similar properties to those described for the equivalent MAP fits. Generally, the fits to the LFs in the centre of the distributions were acceptable, with some bias around the respective MLS for both males and females.

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 57). Tag residual plots by statistical area (Figure 58) confirmed the conclusions reached from the MAP fits: growth was highly uncertain in the CRA 6 statistical areas due to low sample sizes across the size distribution. Two further plots show tag residuals by year of release (Figure 59) and by the size at release for each statistical area (Figure 60).

The selectivity posterior plot (Figure 61) 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 49 and Figure 50). However, there is much more uncertainty in vulnerability by sex and season when estimated separately for mature and particularly for immature females (Figure 62). Note that some of the uncertainty in the female vulnerabilities likely incorporates uncertainty in the male vulnerabilities which are fixed at 1.0 as part of the estimation procedure.

The posterior distribution of the maturation curve was only slightly more uncertain than for the selectivity curve, with most females estimated to be mature well below the 60 mm TW MLS (Figure 63). The median estimate for *mat50* (at 53.3 mm) was slightly larger than the MAP estimate (at 51.0 mm). As noted in the MAP discussion, these estimates for *mat50* are much lower than the equivalent estimates made for this parameter in the CRA 7&8 stock assessment (median *mat50* = 59.9 mm, Webber et al. 2022).

As noted for the equivalent MAP plot, the exploitation rate was highest at the beginning of the fishery when removals were very high, rising to about 0.3 for the SL fishery in the SS period during the late 1960s (Figure 64). However, SL exploitation rates have declined to about 0.15 or lower in both the AW and SS and remained relatively constant over time. NSL exploitation rates were significantly lower than for the SL fishery (Figure 64). The model had no apparent difficulty in accommodating the large catches in the late 1960s (Figure 65).

As for most of these *base* case posteriors, the recruitment posteriors resembled the equivalent MAP plots, with three periods of higher recruitment, including a relatively high period of recruitment in recent years (Figure 66).

As seen in the equivalent MAP plot, the plot of adjusted vulnerable biomass showed a steep decline in biomass at the start of the fishery in 1965 and has since remained relatively stable once exploitation rates plateaued, with some variability in biomass over time generally reflecting the pulses in recruitment (Figure 67). The SSB plot shows a period of decline lasting longer than the adjusted vulnerable biomass to a trough in the 1990s, followed by a slow rise in SSB to present (Figure 68). The pattern in total biomass generally mimics that of adjusted vulnerable biomass (Figure 69).

2.7.2 MCMC sensitivity trials

The RLWG chose five of the MAP sensitivity trials to be explored using MCMC, the four from Group 1 and Group 2, and one from Group 3 (Table 8): *start1979*, *sel_est_dome*, *fixM*, *fix_early_recdevs*, and *tags_CRA6*. The *start1979* and *fix_early_recdevs* models test the sensitivity of the model to the information and uncertainty in early data years. The *sel_est_dome* sensitivity examines the possibility that large lobsters in CRA 6 are not selected by the gear. The *tags_CRA6* model explored how population parameters were estimated based only on the small number of CRA 6 tag recoveries. 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 provided here).

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the *base* case and the five MCMC sensitivity trials were compared (Table 12 and Table 13). Probabilities associated with model indicators for the five sensitivity runs and the *base* run were also compared (Table 14). Comparisons of these sensitivity trials to the *base* case were shown for selectivity (Figure 70), fits to the CELR CPUE indices (Figure 71), the logbook CPUE indices (Figure 72), recruitment (Figure 73), and adjusted vulnerable biomass (Figure 74). Also, comparison plots were shown for the trajectories of SSB (Figure 75) and SSB relative to SSB_0 (Figure 76).

The only sensitivity run which differed markedly from the *base* case run was the *fixM* run. This run estimated a substantially higher R_0 and much lower B_0 compared with the *base* run (median R_0 : *base* = 389 403; *fixM* = 938 688, Table 12; median B_0 : *base* = 17 734; *fixM* = 13 679, Table 13). This translated to a much higher productivity for this run, as well as a higher level of stock status (median B_{2023} / B_0 : *base* = 0.160; *fixM* = 0.348; median SSB_{2023} / SSB_0 : *base* = 0.385; *fixM* = 0.540, Table 13). The higher productivity can be seen in the adjusted vulnerable biomass trajectories, with the *fixM* run lying well above the *base* run and the other four sensitivity runs (Figure 74).

The remaining four sensitivity runs resembled the *base* run, particularly the *start1979* run which mirrored the *base* run in terms of parameter (Table 12), derived parameter (Table 13), and probability estimates (Table 14). The selectivity curves estimated by all five sensitivity runs were similar to that of the *base* run (Figure 70), as were the fits to the CELR CPUE (Figure 71) and the logbook CPUE (Figure 72). Apart from the *fixM* run, the remaining four sensitivity runs all had trajectory patterns that resembled that of the *base* run, including the recruitment trajectories (Figure 73), the adjusted vulnerable biomass trajectories (Figure 74), and SSB trajectories (Figure 75). Finally, the sensitivity runs *start1979*, *sel_est_dome*, *fix_early_recdevs*, and *tags_CRA6* were all evaluated to be well above the soft limit, with median SSB_{2023} / SSB_0 ratios of 42%, 37%, 38%, and 42%, respectively (compared with the equivalent *base* estimate for the same quantity of 39%, Table 13 and Figure 76).

All five 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

Model-based reference levels for red rock lobster stocks have been calculated for the past few years (see more detailed discussion by Rudd et al. 2021b). An interim target reference level for the population vulnerable to fishing (B_R) was developed using the stock assessment model to project the vulnerable biomass through simulation. Starting with the CRA 6 *base* case model, projections were made across a range of fixed catch and fixed U levels. These simulations were run for 60 years across the 1000 MCMC posterior samples, with each simulation replicate drawing random recruitment deviates from a normal distribution based on the mean, standard deviation, and autocorrelation of model-estimated recruitment deviates starting in the first year with a reasonable amount of length data and ending three years before the final model year (the ‘data period’). For CRA 6, the data period included 31 years from 1989 to 2019. This is also the period on which to base the estimate of SSB_0 over the data period (SSB_{0_data}).

Only the size-limited catches changed in these projections, with the non-size-limited catch (sum of illegal and customary catch) held constant at the 2022 level. Rules that went below 20% SSB_{0_data} more than 5% of the time for the final 20 simulation years were rejected. The constant catch rules were further constrained by the requirement that at least 99% of the expected catch had to be taken from at least 95% of years in the final 20 simulation years. The vulnerable biomass associated with the fixed catch and fixed U levels that maximised the catch for each harvest strategy, while satisfying the constraints over the final 20 simulation years, were then averaged to obtain the interim target reference level for CRA 6 (see Rudd et al. 2021b).

To provide an exploitation rate indicator (U_R), the exploitation rate associated with B_R was calculated, which was defined as the U that resulted in an equilibrium biomass equal to the B_R . U_R was identified by finding the fixed seasonal U resulting in a median vulnerable biomass of B_R over the final 20 simulation years of the 60-year projections described above. The seasonal U was then weighted based on the vulnerable biomass each season to obtain U_R as an annual rate.

The CRA 6 stock was predicted to be just below B_R at the beginning of 2023 AW but unlikely to be above U_R (not undergoing overfishing and recovering from an overfished state) (Figure 77, Figure 78).

2.9 Projections

A five-year projection, for the fishing years 2023 to 2027, 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 (2022) and were set to be constant when projecting forward (Table 15). The projected commercial catch in 2022 was set to the current CRA 6 TACC of 360 tonnes, split into the two seasons. The projected commercial and illegal catches were allocated to each season based on the 2022 commercial catch distribution while 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 2010–2019 recruitment deviates, the standard deviation set to σ_{maR} (Table 1), and recruitment autocorrelation derived from the 1989–2019 recruitment deviates. Projected recruitment deviates replaced the 2020, 2021, and 2022 deviates because recruitment was not estimated in the reconstruction model for these years (Figure 66).

The projection predicted an increase in the adjusted vulnerable biomass and SSB over the next five years (Figure 77, Figure 68). The median adjusted vulnerable biomass at the beginning of 2023 was estimated to be 16% of B_0 ($B_{2023} / B_0 = 0.160$ [90% credible interval (CI) = 0.138–0.190]) and was projected to increase to a median value of 22% of B_0 by 2027, at current catch ($B_{2027} / B_0 = 0.220$ [90% CI = 0.176–0.276]) (Table 11). The median SSB at the beginning of 2023 was estimated to be 39% of SSB_0

($SSB_{2023} / SSB_0 = 0.385$ [90% CI = 0.345–0.428]) and was projected to increase to a median value of 45% of SSB_0 ($SSB_{2027} / SSB_0 = 0.453$ [90% CI = 0.396–0.524]; Table 11) by the beginning of 2027.

The projection for the *base* case predicted that the CRA 6 stock will increase from 92% of B_R ($B_{2023} / B_R = 0.920$ [90% CI = 0.794–1.073]) to 26% greater than B_R ($B_{2027} / B_R = 1.260$ [90% CI = 1.016–1.571]) by the beginning of 2027 (Table 11).

3. DISCUSSION

The 2023 CRA 6 stock assessment made several improvements over the previous stock assessment of CRA 6 (Rudd et al. 2019), including: fitting to a new logbook CPUE index of relative abundance from 2014–2022; fitting to standardised sex ratios and length frequencies, with more defensible data weightings for these observation types and with improvements in model fits to these data; revised assumptions about the magnitude of historical recreational and illegal catches; and using observed rather than assumed values for the proportions of mature females in berry by season. These improvements resulted in ‘defensible’ changes to model outputs, with probable improvements in the accuracy of model estimates of SSB and vulnerable biomass.

The *base* case model for CRA 6 fitted the data well (Figure 51 to Figure 60) and generated parameter estimates that were considered to be plausible by the RLWG and Plenary reviewers. As such, the *base* run was considered a good representation of the stock.

The fits to the tag recapture growth data were good and indicated that the Fiordland region of CRA 7&8 may be a reasonable proxy area from which to estimate CRA 6 growth, given the small sample of tag recapture data in this QMA (Figure 58). The *tags_CRA6* model run, fitted only to the CRA 6 tag data, estimated faster growth at smaller sizes than the *base* run (although with greater uncertainty) (Table 12), which resulted in a slight shift in the timing of the estimated recruitment pattern over time (Figure 73). While using tags from CRA 8 does not appear to have biased this assessment, CRA 6 tagging should continue in order to reduce the dependency on this borrowed data set and to provide QMA-specific data for future stock assessments. We note that this QMA, along with CRA 9, is amongst the lowest of all the red rock lobster QMAs in terms of reporting tag recaptures (Webber et al. 2024). Consequently, there should be an increased awareness in the commercial fleet that it is important to return recovered tags to improve the stock assessment and to protect their investment in tagging research.

The base case estimate of natural mortality rate ($M = 0.052$; 95% credible interval = 0.047–0.058) was at the lower end of the assumed prior for M (Figure 48), although the estimate was not deemed to have been constrained by this prior. The *fixM* run, which fixed M to be equal to 0.1, a value consistent with estimates from recent assessments of CRA 1 and CRA 7&8 (Rudd et al. 2021a, Webber et al. 2022), resulted in increased estimates of recruitment, as well as increased estimates for adjusted vulnerable biomass and SSB (Table 9, Figure 73, Figure 74, Figure 75). While the estimated M for CRA 6 is much lower compared with other New Zealand red rock lobster stocks, this apparent discrepancy might be explained by the large size distribution of lobsters taken from this fishery (used to inform M) and the assumption across all stock assessments of constant M with respect to size. Allowing M to decay with increasing size (e.g., consistent with the approach of Lorenzen 1996), may result in more consistent estimates of M across QMAs.

The *base* case run vulnerable biomass was estimated to be below B_R at the beginning of 2023 but was expected to increase to above B_R by 2027 (Table 11). At the status quo future catch level specified in the projection, the *base* model predicted that the stock will increase over the next five years to a level well above the current interim management target (Figure 77). A similar pattern was observed for the SSB, which was estimated to be well above the soft limit of 20% SSB_0 at the beginning of 2023 AW and was predicted to rise to near 40% of SSB_0 at the beginning of 2027 (Table 13, Figure 68).

4. POTENTIAL RESEARCH

The RLWG and Plenary identified several potentially useful avenues of exploration to evaluate or improve this assessment in the future. Improvements relating to the development of the CPUE standardisation and its use in the stock assessment model include:

- Continue to consider alternative CPUE series, from different standardisation models, for use by sensitivity model runs.
- Investigate sequential coding of the same vessel in CPUE models, to determine whether there are ‘learning’ effects, or examine individual vessels for trends in residuals over time.
- Investigate the alternative weightings of vessel data given their vessel correction factors (VCF) that scale estimated catch into landed greenweight in the ‘F2 LFX’ algorithm (see Webber et al. 2024 for a description of this).

Other improvements that apply to most, if not all, rock lobster stocks include:

- Consider different time periods for resampling recruitment within projections for sensitivity analysis.
- Explore the use of aggregating over multiple size bins in the LF standardisation, and when fitting within the assessment model, to avoid saw-toothed LFs.
- Include random effects for certain LSD model parameters (e.g., selectivity parameters).
- Explore the parameterisation of vulnerability by sex, potentially using a simplex approach rather than fixing male vulnerability to equal 1.
- Conduct additional morphometric work; for example, collect data and analyse relationships between tail width, carapace length, weight, sex, and somatic condition.
- Merge mature and immature female partitions within the assessment model and estimate maturity outside the assessment model.
- Collect more tag-recapture data in CRA 6 to estimate growth, so that the assessment is less reliant on data from proxy growth QMAs.
- Develop and evaluate alternative growth models.
- Investigate the utility of estimating independent M parameters for each sex and/or size-based M .
- Develop computer code to include the effects of density-dependent growth and environmental effects in the LSD model.
- Investigate potential fisheries-independent survey designs.
- Improve estimates of non-commercial catch.
- Continue strong support for the logbook sampling programme.

5. FULFILMENT 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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8. TABLES

Table 1: Fixed quantities used in the CRA 6 base case stock assessment model.

Quantity	Value	Quantity	Value
Relative data set weights		Length-weight parameters	
Tags	1.000	male length-weight <i>a</i>	6.630236e-
CR CPUE	1.040	male length-weight <i>b</i>	3.3629
FSU CPUE	0.810	female length-weight <i>a</i>	1.049454e-
CELR CPUE	1.048	female length-weight <i>b</i>	2.6025
LB CPUE	1.480	Recruitment	
Sex ratio	4.550	<i>sigmaR</i>	0.4
LFs	2.818	last year of estimated <i>Rdevs</i>	2019
Catch and handling mortality		years for estimating <i>Rdevs</i> for	2010–2019
Handling mortality 1965–1989	0.10	years for estimating autocorrelation	1989–2019
Handling mortality 1990–2027	0.05	recruitment size mean	32 mm
Growth		recruitment size SD	2 mm
length at <i>Galpha</i>	50 mm	Other	
length at <i>Gbeta</i>	80 mm	Tail compression: male bins	7 to 40
<i>Gmin</i>	0.0001 m	Tail compression: immature female bins	5 to 20
Catch per unit effort		Tail compression: mature female bins	10 to 40
<i>qdrift</i>	0.01	Proportion of mature females in berry	
		AW	0.866
		SS	0.142

Table 2: The tail width (mm) minimum legal size (MLS) limits for males and females over time in CRA 6. 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
1965–1987	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
$selL$	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	1
immature female	$vuln1$	$vuln2$
mature female	$vuln3$	$vuln4$

Table 5: Specifications for estimated parameters in the CRA 6 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 6 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_{2023}	beginning of season AW adjusted vulnerable biomass for 2023
B_{2027}	beginning of season AW adjusted vulnerable biomass for 2027
SSB_{2023}	female spawning stock biomass at beginning of 2023 AW season
SSB_{2027}	female spawning stock biomass at beginning of 2027 AW season
T_{2023}	beginning of season AW total biomass for 2022
T_{2027}	beginning of season AW total biomass for 2027
H_{2022}	total handling mortality for 2022 (tonnes)
H_{2026}	total handling mortality for 2026 (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 6 stock assessment.

Type	Description
Performance indicators	
B_{2023} / B_0	Ratio of B_{2023} to B_0
B_{2027} / B_0	Ratio of B_{2027} to B_0
B_{2023} / B_{0now}	Ratio of B_{2023} to B_{0now}
B_{2027} / B_{0now}	Ratio of B_{2027} to B_{0now}
B_{2027} / B_{2023}	Ratio of B_{2027} to B_{2023}
SSB_{2023} / SSB_0	Ratio of SSB_{2023} to SSB_0
SSB_{2027} / SSB_0	Ratio of SSB_{2027} to SSB_0
SSB_{2023} / SSB_{0now}	Ratio of SSB_{2023} to SSB_{0now}
SSB_{2027} / SSB_{0now}	Ratio of SSB_{2027} to SSB_{0now}
SSB_{2027} / SSB_{2023}	Ratio of SSB_{2027} to SSB_{2023}
T_{2023} / T_0	Ratio of T_{2023} to T_0
T_{2023} / T_{0now}	Ratio of T_{2023} to T_{0now}
T_{2027} / T_0	Ratio of T_{2027} to T_0
T_{2027} / T_{0now}	Ratio of T_{2027} to T_{0now}
T_{2027} / T_{2023}	Ratio of T_{2027} to T_{2023}
T_{male} / T_{female}	Ratio of the total male to total female biomass in the final model year (2022)
B_{2023} / B_R	Ratio of B_{2023} to B_R
B_{2027} / B_R	Ratio of B_{2027} to B_R
U_{2023} / U_R	Ratio of U_{2023} to U_R
U_{2027} / U_R	Ratio of U_{2027} to U_R
U_{2027} / U_{2023}	Ratio of U_{2027} to U_{2023}
Probabilities	
$P(B_{2023} > B_{MIN})$	Probability B_{2023} is greater than B_{MIN}
$P(SSB_{2023} > 20\% SSB_0)$	Probability SSB_{2023} is greater than 20% SSB_0
$P(SSB_{2023} > 10\% SSB_0)$	Probability SSB_{2023} is greater than 10% SSB_0
$P(SSB_{2023} > 20\% SSB_{0now})$	Probability SSB_{2023} is greater than 20% SSB_{0now}
$P(SSB_{2023} > 10\% SSB_{0now})$	Probability SSB_{2023} is greater than 10% SSB_{0now}
$P(SSB_{2027} > 20\% SSB_0)$	Probability SSB_{2027} is greater than 20% SSB_0
$P(SSB_{2027} > 10\% SSB_0)$	Probability SSB_{2027} is greater than 10% SSB_0
$P(SSB_{2027} > 20\% SSB_{0now})$	Probability SSB_{2027} is greater than 20% SSB_{0now}
$P(SSB_{2027} > 10\% SSB_{0now})$	Probability SSB_{2027} is greater than 10% SSB_{0now}
$P(B_{2027} > B_{2023})$	Probability B_{2027} is greater than B_{2023}
$P(SSB_{2027} > SSB_{2023})$	Probability SSB_{2027} is greater than SSB_{2023}
$P(T_{2027} > T_{2023})$	Probability T_{2027} is greater than T_{2023}
$P(U_{2026} > U_{2022})$	Probability U_{2026} is greater than U_{2022}
$P(B_{2023} > B_R)$	Probability B_{2023} is greater than B_R
$P(B_{2027} > B_R)$	Probability B_{2027} is greater than B_R
$P(U_{2023} > U_R)$	Probability U_{2023} is greater than U_R
$P(U_{2027} > U_R)$	Probability U_{2027} 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>	Model years 1965–2022, logistic selectivity, estimated M , $qdrift$ fixed at 1% per year for CELR and logbook CPUE series, empirical average proportion berried females by season, combined CRA 6 and Fiordland (CRA 8) tags	Yes
1	<i>start1979</i>	Start model in 1979	Yes
1	<i>sel_est_dome</i>	Estimate dome-shaped right-limb selectivity	Yes
2	<i>fixM</i>	Fix M at 0.10	Yes
2	<i>fix_early_recdevs</i>	Begin estimating recruitment deviates 3 years prior to first LFs in 1989 and using constant recruitment for the early years	Yes
3	<i>tags CRA6</i>	CRA 6 tags only	Yes
3	<i>LF_1966</i>	Include 1966 LF data with high weight to force the fit	No
4	<i>no_qdrift</i>	Drop $qdrift$ adjustment to CELR and logbook CPUE series	No
4	<i>dropCELR</i>	Drop entire CELR series	No
5	<i>dropLF_lowN</i>	Drop LFs with < 100 measured lobsters	No
5	<i>drop_early_LF_SR</i>	Drop block of length frequency + sex ratio data prior to 2014 ¹⁰	No
6	<i>propberry_std</i>	Catch-weighted and standardised proportion berried females by season	No
6	<i>propberry_year</i>	Catch-weighted and standardised proportion berried females by year, 1993–2022, use catch-weighted and standardised proportion by season prior to 1993 (and for projection years)	No
7	<i>downwtCPUE</i>	Down-weight CPUE data to 10% of base case weight	No
7	<i>downwtLF</i>	Down-weight LF data to 10% of base case weight	No
7	<i>downwtSR</i>	Down-weight sex ratio data to 10% of base case weight	No

¹⁰ This drops the block of observer data from the late 1980s and the 1990s. The pre-2014 logbook data had already been dropped from the base run.

Table 9: CRA 6 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 LFs are not included because the tag likelihood is self-weighting and the LFs were iteratively reweighted using the Francis method (Francis 2011). (Continued on next page)

	----- Group 1 -----			----- Group 2 -----		----- Group 3 -----		----- Group 4 -----		----- Group 5 -----		----- Group 6 -----		----- Group 7 -----		
	<i>base</i>	<i>start1979</i>	<i>sel_est dome</i>	<i>fixM</i>	<i>fix_early recdevs</i>	<i>tags CRA6</i>	<i>LF_1966</i>	<i>no_qdrift</i>	<i>drop CELR</i>	<i>dropLF loN</i>	<i>drop early_LF SR</i>	<i>propberry std</i>	<i>propberry year</i>	<i>downwt CPUE</i>	<i>downwt LF</i>	<i>downwt SR</i>
Likelihoods																
Total	21 513	20 308	21 349	16 652	18 421	15 594	21 121	19 445	22 151	15 235	32 119	21 514	21 514	21 574	9 641	19 503
Prior	-7.648	4.091	-0.849	14.295	8.438	-7.620	-4.794	-4.869	-11.762	-10.376	-13.964	-7.768	-7.772	-13.453	-17.469	-5.505
tag	6086	5791	6085	6092	6085	238	6086	6086	6085	6085	6090	6086	6086	6085	6084	6085
Sex ratio	2 229	2 324	2 229	1 893	2 348	2 233	2 221	2 062	2 444	2 228	1 475	2 230	2 230	2 222	2 223	224
LF	13 176	12 251	13 005	8 622	9 948	13 103	12 790	11 271	13 541	6 904	24 540	13 177	13 176	13 172	1 324	13 172
CR	92.740	–	93.009	86.892	94.105	91.448	93.288	92.542	93.670	93.181	94.219	92.878	92.896	56.084	94.043	92.153
FSU	-10.878	-10.005	-10.845	-6.897	-11.974	-9.778	-11.482	-11.065	-10.688	-11.734	-13.011	-11.389	-11.384	4.979	-14.139	-11.169
CELR	-59.459	-60.323	-59.289	-54.419	-58.608	-60.938	-60.134	-57.014	–	-60.507	-60.730	-59.084	-57.973	26.209	-61.482	-59.705
Logbook CPUE	7.308	8.197	7.388	6.141	7.780	7.771	7.055	6.823	10.103	7.527	7.024	7.170	7.142	21.385	8.643	6.284
Standard deviation of normalised residual (SDNR)																
Sex ratio	1.011	0.993	0.996	1.017	0.998	0.991	1.021	1.019	0.988	0.995	1.005	1.018	1.019	0.923	0.937	0.349
CR	1.011	–	1.021	1.030	1.025	0.981	0.998	0.999	1.027	1.023	1.013	1.021	1.023	0.111	1.095	0.973
FSU	1.028	1.019	1.023	1.016	0.985	1.017	1.023	1.005	1.011	0.991	0.982	1.002	1.002	0.102	0.853	1.013
CELR	0.987	0.993	0.991	0.993	1.002	0.983	0.996	1.022	–	0.985	0.996	0.993	1.012	0.241	0.951	0.982
Logbook CPUE	1.006	1.003	1.010	1.002	1.026	1.021	1.030	1.004	1.043	1.018	1.002	0.997	0.995	0.147	1.080	0.941
Median of absolute residual (MAR)																
Sex ratio	0.563	0.636	0.579	0.535	0.591	0.596	0.566	0.584	0.636	0.554	0.648	0.567	0.580	0.610	0.593	0.207
CR	0.568	–	0.593	0.716	0.590	0.537	0.601	0.545	0.589	0.602	0.576	0.578	0.580	4.318	0.649	0.526
FSU	0.747	0.718	0.757	0.682	0.733	0.728	0.745	0.731	0.737	0.727	0.735	0.700	0.702	2.188	0.728	0.689
CELR	0.718	0.703	0.708	0.694	0.645	0.722	0.689	0.689	–	0.677	0.664	0.659	0.747	1.350	0.635	0.709
Logbook CPUE	0.673	0.477	0.672	0.564	0.673	0.441	0.602	0.614	0.722	0.721	0.700	0.680	0.682	2.213	0.804	0.447
Likelihood weights																
Sex ratio	4.550	4.750	4.550	3.850	4.800	4.560	4.530	4.200	5.000	4.550	9.000	4.550	4.550	4.550	4.550	0.455
LF	2.818	2.620	2.780	1.842	2.123	2.802	2.472	2.409	2.897	1.791	7.796	2.818	2.818	2.818	0.282	2.818
CR	1.040	–	1.030	1.560	0.960	1.100	0.980	1.040	0.990	1.020	0.940	1.040	1.040	0.104	1.040	1.040
FSU	0.810	0.770	0.805	0.660	0.820	0.760	0.830	0.800	0.790	0.815	0.860	0.810	0.810	0.081	0.810	0.810
CELR	1.048	1.070	1.049	0.970	1.048	1.070	1.070	1.042	–	1.065	1.080	1.048	1.048	0.105	1.048	1.048
Logbook CPUE	1.480	1.400	1.480	1.580	1.470	1.460	1.530	1.520	1.300	1.480	1.500	1.480	1.480	0.148	1.480	1.480
Parameters																
<i>R</i> ₀	397 741	385 896	395 793	961 070	308 289	402 536	445 978	422 566	356 582	384 925	381 955	383 978	384 315	332 013	363 654	434 737
<i>M</i>	0.052	0.053	0.052	0.10	0.043	0.057	0.054	0.054	0.048	0.051	0.052	0.051	0.051	0.045	0.052	0.055
<i>mat50</i>	50.953	52.425	52.377	52.564	50.575	47.798	51.240	50.974	51.980	50.877	53.377	50.913	50.931	52.117	50.475	51.216
<i>mat95add</i>	10.033	8.691	10.516	8.364	10.648	7.568	9.644	9.849	9.686	10.700	8.712	9.834	9.884	9.647	9.947	9.795
<i>Galpha</i> [male]	5.295	5.366	5.308	5.288	5.319	6.257	5.343	5.293	5.329	5.316	5.215	5.294	5.293	5.334	5.352	5.315
<i>Gbeta</i> [male]	2.481	2.338	2.456	2.410	2.513	2.794	2.332	2.466	2.447	2.473	2.621	2.474	2.473	2.432	2.566	2.472

	----- Group 1 -----			----- Group 2 -----		----- Group 3 -----		----- Group 4 -----		----- Group 5 -----		----- Group 6 -----		----- Group 7 -----		
	base	start1979	sel_est dome	fixM	fix_early recdevs	tags CRA6	LF_1966	no_qdrift	drop CELR	dropLF loN	drop early_LF SR	propberry std	propberry year	downwt CPUE	downwt LF	downwt SR
Gshape [male]	2.015	2.346	2.061	2.192	2.081	2.232	2.221	2.043	2.077	2.070	1.723	2.015	2.016	2.101	2.401	2.062
GCV [male]	0.459	0.465	0.459	0.462	0.458	0.369	0.459	0.459	0.457	0.458	0.459	0.459	0.459	0.457	0.457	0.458
Galpha [female]	4.022	4.142	4.023	4.116	4.042	5.147	4.100	4.051	3.985	4.028	3.955	4.032	4.029	3.962	3.982	4.013
Gbeta [female]	1.492	1.514	1.492	1.619	1.458	1.586	1.455	1.495	1.478	1.476	1.574	1.494	1.495	1.487	1.482	1.487
Gshape [female]	3.288	3.443	3.290	3.708	3.304	3.973	3.449	3.350	3.222	3.321	3.356	3.292	3.283	3.150	3.204	3.305
GCV [female]	0.528	0.528	0.527	0.525	0.528	0.510	0.525	0.528	0.528	0.529	0.531	0.528	0.528	0.529	0.530	0.529
Gobs	0.315	0.324	0.315	0.304	0.317	0.501	0.319	0.314	0.317	0.315	0.310	0.315	0.314	0.317	0.315	0.315
U ₀	—	0.055	—	—	—	—	—	—	—	—	—	—	—	—	—	—
qCR	4.020E-02	—	4.020E-02	7.095E-02	3.494E-02	4.720E-02	3.807E-02	4.092E-02	3.692E-02	3.861E-02	3.644E-02	3.964E-02	3.973E-02	9.777E-06	3.577E-02	4.162E-02
qFSU	3.358E-04	2.921E-04	3.290E-04	2.152E-04	3.844E-04	3.878E-04	3.101E-04	3.412E-04	3.098E-04	3.430E-04	3.845E-04	3.347E-04	3.342E-04	3.820E-05	3.846E-04	3.328E-04
qCELR	4.212E-04	3.626E-04	4.107E-04	2.410E-04	4.504E-04	4.826E-04	3.838E-04	4.535E-04	—	4.326E-04	4.415E-04	4.245E-04	4.233E-04	1.928E-04	4.801E-04	4.101E-04
qLogbook	6.888E-07	5.958E-07	6.703E-07	4.150E-07	7.385E-07	7.694E-07	6.257E-07	7.413E-07	8.989E-07	7.119E-07	7.044E-07	7.076E-07	7.081E-07	1.281E-07	7.888E-07	6.507E-07
vuln1 AW IF	0.935	0.641	0.579	0.682	0.928	0.926	0.898	0.933	0.643	0.930	0.631	0.933	0.933	0.612	0.930	0.934
vuln2 SS IF	0.971	0.976	0.974	0.976	0.972	0.972	0.974	0.971	0.982	0.972	0.979	0.971	0.971	0.980	0.972	0.971
vuln3 AW MF	0.314	0.379	0.321	0.448	0.289	0.282	0.325	0.324	0.308	0.310	0.450	0.312	0.312	0.299	0.311	0.330
vuln4 SS MF	0.774	1.000	0.794	1.000	0.727	0.709	0.789	0.769	0.817	0.767	0.999	0.761	0.762	0.859	0.782	0.711
selL male	5.552	5.303	5.488	5.379	5.495	5.435	5.634	5.481	5.565	5.620	5.057	5.558	5.553	5.543	5.956	5.569
selM male	52.019	51.586	57.529	51.993	51.848	51.808	52.067	51.993	51.889	52.065	51.665	52.040	52.034	51.800	52.389	52.054
selL female	7.335	8.017	7.830	8.213	7.219	7.346	7.582	7.336	7.684	7.492	8.269	7.324	7.341	7.724	7.088	7.380
selM female	57.279	57.467	65.263	58.220	56.888	56.174	57.448	57.300	57.180	57.356	57.544	57.285	57.297	57.103	56.923	57.406
Derived parameters: adjusted vulnerable biomass																
B ₀	18 073	16 602	17 724	13 955	19 304	17 336	18 103	17 948	18 452	18 407	18 163	18 156	18 090	18 475	19 437	18 018
B _{0now}	23 769	23 439	23 295	14 432	19 047	21 945	23 065	26 396	20 403	23 556	23 396	24 107	23 975	18 286	22 913	24 219
B _{MIN}	1 446	1 693	1 483	1 582	1 354	1 249	1 616	1 453	1 345	1 407	1 402	1 440	1 431	1 235	1 283	1 519
B ₂₀₂₂	2 801	3 237	2 854	4 825	2 538	2 734	3 173	3 736	1 704	2 628	2 559	2 760	2 725	1 237	2 134	3 132
B ₂₀₂₂ / B ₀	0.155	0.195	0.161	0.346	0.131	0.158	0.175	0.208	0.092	0.143	0.141	0.152	0.151	0.067	0.110	0.174
Derived parameters: spawning stock biomass (females only)																
SSB ₀	6 673	6 375	6 688	5 868	6 673	6 563	6 963	6 699	6 738	6 704	6 892	6 695	6 698	6 760	6 021	6 629
SSB _{0now}	8 776	9 000	8 789	6 069	6 584	8 308	8 871	9 852	7 451	8 579	8 878	8 890	8 877	6 690	7 098	8 911
SSB ₂₀₂₂	2 592	2 482	2 548	3 139	2 573	2 692	2 785	3 123	1 845	2 509	2 063	2 530	2 529	1 491	2 107	2 847
SSB ₂₀₂₂ / SSB ₀	0.388	0.389	0.381	0.535	0.386	0.410	0.400	0.466	0.274	0.374	0.299	0.378	0.378	0.221	0.350	0.429
Derived parameters: total biomass																
T ₀	25 005	23 189	25 054	20 714	26 132	24 057	25 359	24 924	25 418	25 350	25 226	24 997	25 008	25 440	25 693	24 946
T _{0now}	32 885	32 737	32 927	21 422	25 785	30 455	32 310	36 657	28 107	32 441	32 494	33 190	33 144	25 179	30 288	33 531
T ₂₀₂₂	6 092	6 472	6 117	9 262	5 660	6 006	6 748	7 703	4 053	5 768	5 345	5 942	5 927	3 118	4 657	6 814
Other derived parameters																
H ₂₀₂₁	2.800	2.862	2.792	2.680	2.816	2.854	2.747	2.615	3.197	2.790	3.264	2.558	2.825	3.420	2.760	2.793
T _{male} / T _{female}	1.048	1.211	1.068	1.404	0.966	1.005	1.094	1.145	0.908	1.022	1.140	1.047	1.046	0.833	0.994	1.058

Table 10: CRA 6 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.

	Mean	SD	5%	Median	95%	Effective N	Rhat
Likelihoods							
Total	21 551.000	6.058	21 541.000	21 551.000	21 561.000	971	1.001
Prior	12.692	5.000	4.958.000	12.308	21.352	905	1.002
Tags	6 089.000	2.176	6 086.000	6 089.000	6 093.000	902	1.004
Sex ratio	2 231.000	2.626	2 227.000	2 230.000	2 235.000	944	1.000
LFs	13 185.000	4.656	13 178.000	13 185.000	13 193.000	1029	0.999
CPUE [CR]	92.804	1.178	91.059	92.722	94.841	1034	1.000
CPUE [FSU]	9.805	1.417	-11.793	-9.941	-7.335	893	1.001
CPUE [CELR]	57.444	2.248	-60.640	-57.689	-53.147	876	0.999
CPUE [LB]	8.034	0.970	6.771	7.874	9.875	894	1.001
SDNR							
Tag	2.088	0.053	1.996	2.087	2.180	969	0.999
Sex ratio	1.024	0.032	0.976	1.023	1.078	910	1.000
LFs	0.377	0.006	0.368	0.376	0.387	1006	1.001
CPUE [CR]	0.980	0.065	0.861	0.985	1.076	980	1.000
CPUE [FSU]	1.054	0.060	0.966	1.048	1.155	934	0.999
CPUE [CELR]	1.012	0.036	0.959	1.008	1.077	854	0.999
CPUE [LB]	1.019	0.037	0.961	1.017	1.084	816	1.000
MAR							
Tag	0.736	0.010	0.719	0.736	0.751	1036	0.999
Sex ratio	0.599	0.039	0.538	0.598	0.668	953	0.999
LFs	0.075	0.006	0.065	0.075	0.085	937	0.999
CPUE [CR]	0.640	0.128	0.469	0.619	0.859	1036	0.999
CPUE [FSU]	0.779	0.079	0.673	0.766	0.931	953	0.999
CPUE [CELR]	0.709	0.053	0.622	0.707	0.803	961	1.000
CPUE [LB]	0.603	0.111	0.425	0.596	0.780	1160	1.001
Parameters							
R_0	391 575	32 053	340 937	389 403	447 188	968	0.999
M	0.052	0.003	0.047	0.052	0.058	984	1.000
q_{CR}	4.26E-02	4.50E-03	3.55E-02	4.24E-02	5.00E-02	771	1.000
q_{FSU}	3.36E-04	1.89E-05	3.06E-04	3.35E-04	3.68E-04	969	1.000
q_{CELR}	4.18E-04	2.36E-05	3.78E-04	4.18E-04	4.56E-04	912	1.001
q_{LB}	6.84E-07	4.74E-08	6.11E-07	6.84E-07	7.62E-07	979	1.002
mat_{50}	53.511	1.567	51.160	53.334	56.175	1010	1.001
mat_{95}	9.451	1.360	7.494	9.336	11.896	1026	0.999
$Galpha$ [M]	5.291	0.074	5.168	5.290	5.412	892	0.999
$Galpha$ [F]	4.024	0.082	3.894	4.022	4.162	838	1.002
$Gbeta$ [M]	0.469	0.017	0.442	0.468	0.496	833	0.999
$Gbeta$ [F]	0.373	0.014	0.350	0.373	0.395	1009	0.999
$Gshape$ [M]	2.039	0.201	1.725	2.036	2.374	850	0.999
$Gshape$ [F]	3.314	0.187	3.029	3.305	3.624	963	0.999
GCV [M]	0.460	0.009	0.444	0.460	0.475	760	0.999
GCV [F]	0.530	0.012	0.511	0.530	0.549	942	0.999
$Gobs$	0.317	0.029	0.272	0.317	0.369	985	0.999
$vuln_{AW}$ [IF]	0.450	0.198	0.172	0.425	0.823	998	1.000
$vuln_{SS}$ [IF]	0.606	0.228	0.236	0.602	0.960	1085	1.002
$vuln_{AW}$ [MF]	0.320	0.027	0.277	0.319	0.366	905	1.003
$vuln_{SS}$ [MF]	0.791	0.060	0.698	0.788	0.890	881	1.000
$sell$ [M]	5.640	0.526	4.803	5.630	6.507	914	0.999
$sell$ [F]	7.950	0.487	7.198	7.938	8.785	905	0.999
$selM$ [M]	52.040	0.379	51.432	52.039	52.681	882	1.001
$selM$ [F]	56.531	0.835	54.855	56.692	57.560	1074	1.003

Table 11: CRA 6 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	17 708.700	553.595	16 740.900	17 733.500	18 609.700
B_{0now}	24 057.100	2 054.370	20 758.800	23 971.300	27 713.900
B_{MIN}	1 461.660	99.793	1 307.200	1 453.880	1 635.030
B_R	3 090.000	0.000	3 090.000	3 090.000	3 090.000
B_{2023}	2 853.980	266.285	2 451.990	2 842.630	3 316.160
B_{2027}	3 931.420	525.795	3 138.930	3 893.180	4 853.030
B_R / B_0	0.175	0.005	0.166	0.174	0.184
B_R / B_{0now}	0.129	0.011	0.111	0.129	0.149
B_{2023} / B_0	0.161	0.016	0.138	0.160	0.190
B_{2027} / B_0	0.222	0.031	0.176	0.220	0.276
B_{2023} / B_{0now}	0.119	0.011	0.102	0.118	0.139
B_{2027} / B_{0now}	0.164	0.019	0.135	0.162	0.198
B_{2027} / B_{2023}	1.375	0.105	1.222	1.366	1.561
B_{2023} / B_R	0.924	0.086	0.794	0.920	1.073
B_{2027} / B_R	1.272	0.170	1.016	1.260	1.571
Exploitation					
U_R	—	—	0.055	0.055	0.055
U_{2023}	0.052	0.005	0.045	0.052	0.060
U_{2027}	0.041	0.005	0.033	0.041	0.050
U_{2027} / U_{2023}	0.788	0.047	0.710	0.790	0.861
U_{2023} / U_R	0.948	0.084	0.816	0.945	1.085
U_{2027} / U_R	0.748	0.089	0.606	0.741	0.901
Spawning stock biomass					
SSB_0	6 496.130	198.816	6 179.170	6 488.700	6 825.950
SSB_{0now}	8 824.410	745.536	7 629.560	8 791.370	10 141.100
SSB_{2023}	2 510.980	177.055	2 225.040	2 514.820	2 803.910
SSB_{2027}	2 961.610	266.560	2 538.700	2 944.240	3 410.690
SSB_{2023} / SSB_0	0.387	0.026	0.345	0.385	0.428
SSB_{2027} / SSB_0	0.456	0.040	0.396	0.453	0.524
SSB_{2023} / SSB_{0now}	0.286	0.022	0.252	0.285	0.323
SSB_{2027} / SSB_{0now}	0.337	0.027	0.293	0.334	0.384
SSB_{2027} / SSB_{2023}	1.179	0.053	1.102	1.174	1.271
Total biomass					
T_0	24 515.400	675.237	23 355.000	24 527.300	25 590.200
T_{0now}	33 300.400	2 759.070	28 827.100	33 176.700	38 143.700
T_{2023}	6 108.110	477.522	5 369.280	6 097.380	6 960.290
T_{2027}	7 366.490	774.282	6 146.970	7 338.980	8 697.870
T_{2023} / T_0	0.249	0.021	0.219	0.248	0.284
T_{2027} / T_0	0.301	0.032	0.252	0.298	0.357
T_{2023} / T_{0now}	0.184	0.015	0.162	0.183	0.210
T_{2027} / T_{0now}	0.222	0.021	0.191	0.220	0.258
T_{2027} / T_{2023}	1.204	0.052	1.121	1.202	1.291
T_{male} / T_{female}	1.062	0.054	0.981	1.060	1.152
Other quantities					
R_{mean}	529 918.000	386 00.400	473 266.000	527 489.000	599 035.000
R_{rho}	0.037	0.028	-0.013	0.037	0.082
H_{2022}	2.797	0.105	2.638	2.792	2.987
H_{2027}	2.355	0.138	2.140	2.348	2.598
Probabilities					
$P(B_{2023} > B_{MIN})$	1.000	—	—	—	—
$P(B_{2023} > B_R)$	0.182	—	—	—	—
$P(B_{2027} > B_R)$	0.960	—	—	—	—
$P(B_{2027} > B_{2023})$	1.000	—	—	—	—
$P(SSB_{2023} > 20\% SSB_0)$	1.000	—	—	—	—

	Mean	SD	5%	50%	95%
$P(SSB_{2023} > 10\% SSB_0)$	1.000	—	—	—	—
$P(SSB_{2027} > 20\% SSB_0)$	1.000	—	—	—	—
$P(SSB_{2027} > 10\% SSB_0)$	1.000	—	—	—	—
$P(SSB_{2023} > 20\% SSB_{now})$	1.000	—	—	—	—
$P(SSB_{2023} > 10\% SSB_{now})$	1.000	—	—	—	—
$P(SSB_{2027} > 20\% SSB_{now})$	1.000	—	—	—	—
$P(SSB_{2027} > 10\% SSB_{now})$	1.000	—	—	—	—
$P(SSB_{2027} > SSB_{2023})$	1.000	—	—	—	—
$P(T_{2027} > T_{2023})$	1.000	—	—	—	—
$P(U_{2023} > U_R)$	0.272	—	—	—	—
$P(U_{2027} > U_R)$	0.003	—	—	—	—
$P(U_{2027} > U_{2023})$	0.000	—	—	—	—

Table 12: CRA 6 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 five 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 on next page)

	<i>base</i>			<i>start1979</i>			<i>sel est dome</i>			<i>fix M</i>			<i>fix early recdevs</i>			<i>tags CRA6</i>		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods																		
Total	21 541	21 551	21 561	20 326	20 334	20 345	21 373	21 382	21 393	16 680	16 690	16 701	18 441	18 449	18 459	15 622	15 631	15 643
Prior	4.958	12.308	21.352	9.690	15.030	22.330	11.325	19.086	27.513	24.843	33.316	42.377	13.197	18.738	26.018	5.305	13.185	22.125
Tag	6 086	6 089	6 093	5 791	5 794	5 798	6 086	6 088	6 092	6 090	6 094	6 100	6 085	6 088	6 093	237	241	247
Sex ratio	2 227	2 230	2 235	2 323	2 327	2 331	2 226	2 230	2 235	1 891	1 896	1 902	2 346	2 349	2 354	2 229	2 233	2 238
LFs	13 178	13 185	13 193	12 251	12 258	12 266	13 003	13 010	13 019	8 623	8 630	8 638	9 950	9 957	9 965	13 102	13 110	13 119
CPUE [CR]	91.059	92.722	94.841	–	–	–	91.149	92.983	95.074	86.878	88.201	90.703	93.769	94.640	96.256	89.908	91.627	93.761
CPUE [FSU]	-11.793	-9.941	-7.335	-12.550	-10.520	-7.680	-11.956	-10.043	-7.252	-8.850	-6.304	-3.122	-13.361	-11.698	-9.368	-11.011	-8.804	-5.527
CPUE [CELR]	-60.640	-57.689	-53.147	-61.350	-58.270	-53.370	-60.399	-57.497	-53.290	-54.909	-51.949	-48.363	-60.132	-56.669	-52.262	-62.141	-59.032	-54.764
CPUE [LB]	6.771	7.874	9.875	7.010	8.110	9.910	6.780	7.953	9.744	5.555	6.647	8.532	7.172	8.401	10.533	7.097	8.652	11.044
SDNR																		
Tag	1.996	2.087	2.180	1.999	2.098	2.186	2.009	2.094	2.174	1.988	2.068	2.148	2.009	2.094	2.186	3.116	3.613	4.202
Sex ratio	0.976	1.023	1.078	0.983	1.028	1.080	0.971	1.017	1.073	0.986	1.046	1.116	0.962	1.007	1.061	0.951	0.993	1.046
LFs	0.368	0.376	0.387	0.354	0.362	0.372	0.370	0.379	0.389	0.307	0.316	0.327	0.343	0.351	0.361	0.362	0.369	0.379
CPUE [CR]	0.861	0.985	1.076	–	–	–	0.872	0.989	1.088	1.012	1.081	1.203	0.987	1.036	1.088	0.847	0.969	1.064
CPUE [FSU]	0.966	1.048	1.155	0.871	0.969	1.093	0.956	1.041	1.156	0.903	1.021	1.155	0.902	0.977	1.052	0.937	1.044	1.179
CPUE [CELR]	0.959	1.008	1.077	0.970	1.017	1.092	0.965	1.012	1.080	0.975	1.025	1.079	0.971	1.027	1.097	0.956	1.007	1.077
CPUE [LB]	0.961	1.017	1.084	0.916	0.974	1.047	0.960	1.019	1.088	0.953	1.009	1.078	0.974	1.040	1.124	0.967	1.051	1.152
MAR																		
Tag	0.719	0.736	0.751	0.723	0.739	0.756	0.720	0.737	0.751	0.719	0.736	0.751	0.719	0.736	0.754	0.728	0.797	0.866
Sex ratio	0.538	0.598	0.668	0.549	0.607	0.675	0.546	0.602	0.676	0.523	0.573	0.639	0.558	0.621	0.692	0.541	0.608	0.679
LFs	0.065	0.075	0.085	0.061	0.070	0.080	0.068	0.080	0.090	0.056	0.064	0.071	0.064	0.072	0.081	0.065	0.076	0.086
CPUE [CR]	0.469	0.619	0.859	–	–	–	0.459	0.621	0.872	0.559	0.735	0.936	0.591	0.680	0.897	0.459	0.612	0.794
CPUE [FSU]	0.673	0.766	0.931	0.596	0.713	0.849	0.670	0.764	0.949	0.497	0.659	0.900	0.627	0.738	0.906	0.656	0.755	0.922
CPUE [CELR]	0.622	0.707	0.803	0.638	0.724	0.823	0.633	0.712	0.801	0.638	0.744	0.830	0.628	0.722	0.823	0.637	0.725	0.816
CPUE [LB]	0.425	0.596	0.780	0.388	0.550	0.744	0.435	0.616	0.788	0.419	0.597	0.781	0.444	0.652	0.817	0.366	0.503	0.766
Parameters																		
R_0	340 937	389 403	447 188	333 213	378 132	429 355	339 134	386 738	440 707	875 091	938 688	1 000 916	274 222	304 120	334 480	352 772	408 707	482 745
U_0	0.000	0.000	0.000	0.049	0.058	0.069	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
M	0.047	0.052	0.058	0.047	0.053	0.060	0.047	0.052	0.057	0.10	0.10	0.10	0.039	0.043	0.047	0.052	0.058	0.065
$q[CR]$	3.55E-2	4.24E-2	5.00E-2	–	–	–	3.53E-2	4.20E-2	5.06E-2	6.35E-2	7.42E-2	8.68E-2	3.02E-2	3.47E-2	4.00E-2	4.13E-2	4.93E-2	6.07E-2
$q[FSU]$	3.06E-4	3.35E-4	3.68E-4	2.87E-4	3.22E-4	3.63E-4	3.01E-4	3.33E-4	3.66E-4	1.93E-4	2.18E-4	2.49E-4	3.46E-4	3.80E-4	4.18E-4	3.25E-4	3.76E-4	4.28E-4
$q[CELR]$	3.78E-4	4.18E-4	4.56E-4	3.60E-4	4.03E-4	4.50E-4	3.73E-4	4.12E-4	4.53E-4	2.13E-4	2.44E-4	2.78E-4	4.09E-4	4.49E-4	4.95E-4	3.93E-4	4.58E-4	5.34E-4
$q[LB]$	6.11E-7	6.84E-7	7.62E-7	5.80E-7	6.62E-7	7.43E-7	5.92E-7	6.72E-7	7.58E-7	3.65E-7	4.22E-7	4.87E-7	6.58E-7	7.35E-7	8.25E-7	6.03E-7	7.25E-7	8.57E-7
$mat50$	51.160	53.334	56.175	50.663	53.203	56.086	53.680	56.171	57.912	51.830	53.850	56.736	50.577	52.855	55.929	48.366	53.275	55.988
$mat95$	7.494	9.336	11.896	7.257	9.229	11.916	7.166	8.491	10.410	6.547	8.429	10.847	7.722	9.975	13.212	6.027	7.803	9.832
G_{α} male	5.168	5.290	5.412	5.177	5.306	5.429	5.192	5.299	5.419	5.165	5.279	5.394	5.189	5.309	5.435	5.246	5.853	6.432
G_{β} male	2.371	2.478	2.593	2.320	2.435	2.562	2.357	2.460	2.577	2.318	2.421	2.528	2.389	2.518	2.649	2.444	2.724	3.057

	<i>base</i>			<i>start1979</i>			<i>sel est dome</i>			<i>fix M</i>			<i>fix early recdevs</i>			<i>tags CRA6</i>		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
<i>Gshape male</i>	1.725	2.036	2.374	1.787	2.115	2.461	1.769	2.063	2.390	1.870	2.194	2.526	1.740	2.082	2.458	1.165	1.978	2.800
<i>GCV male</i>	0.444	0.460	0.475	0.451	0.466	0.481	0.445	0.460	0.474	0.449	0.463	0.478	0.443	0.459	0.476	0.364	0.468	0.608
<i>Galpha female</i>	3.894	4.022	4.162	4.079	4.226	4.373	3.898	4.025	4.166	3.995	4.128	4.268	3.911	4.039	4.170	4.578	5.071	5.493
<i>Gbeta female</i>	1.443	1.499	1.558	1.417	1.468	1.522	1.439	1.494	1.550	1.569	1.615	1.667	1.408	1.461	1.517	1.449	1.555	1.660
<i>Gshape female</i>	3.029	3.305	3.624	3.369	3.677	4.005	3.029	3.308	3.622	3.390	3.754	4.188	3.020	3.305	3.603	3.379	3.999	4.485
<i>GCV female</i>	0.511	0.530	0.549	0.509	0.530	0.552	0.510	0.529	0.551	0.507	0.527	0.548	0.510	0.529	0.549	0.476	0.549	0.635
<i>Gobs</i>	0.272	0.317	0.369	0.278	0.327	0.385	0.269	0.314	0.364	0.263	0.305	0.355	0.273	0.318	0.372	0.358	0.482	0.616
<i>vuln AW IF</i>	0.172	0.425	0.823	0.168	0.412	0.816	0.096	0.177	0.407	0.175	0.480	0.843	0.180	0.453	0.850	0.124	0.271	0.735
<i>vuln SS IF</i>	0.236	0.602	0.960	0.248	0.586	0.954	0.129	0.251	0.580	0.233	0.601	0.949	0.272	0.650	0.964	0.180	0.376	0.919
<i>vuln AW MF</i>	0.277	0.319	0.366	0.273	0.314	0.361	0.279	0.321	0.368	0.394	0.439	0.491	0.257	0.294	0.335	0.243	0.287	0.349
<i>vuln SS MF</i>	0.698	0.788	0.890	0.694	0.788	0.891	0.702	0.789	0.889	0.909	0.975	0.998	0.654	0.742	0.836	0.612	0.728	0.858
<i>selL male</i>	4.803	5.630	6.507	4.772	5.554	6.428	4.822	5.530	6.363	4.591	5.458	6.380	4.676	5.578	6.630	4.808	5.562	6.433
<i>selL female</i>	7.198	7.938	8.785	51.327	51.959	52.550	56.442	57.597	58.905	51.403	52.027	52.711	51.163	51.846	52.557	51.247	52.008	52.757
<i>selM male</i>	51.432	52.039	52.681	7.386	8.111	9.000	7.385	8.103	8.813	7.680	8.644	9.761	6.965	7.737	8.566	7.298	8.124	9.054
<i>selM female</i>	54.855	56.692	57.560	54.673	56.531	57.389	60.203	63.195	65.329	55.547	57.747	58.698	54.727	56.327	57.186	52.694	55.052	56.436
<i>selR</i>	—	—	—	—	—	—	135.514	416.087	1050.124	—	—	—	—	—	—	—	—	—

Table 13: CRA 6 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.

Variable	<i>base</i>			<i>start1979</i>			<i>sel est dome</i>			<i>fix M</i>			<i>fix early recdevs</i>			<i>tags CRA6</i>		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
AW adjusted vulnerable biomass																		
B_0	16 741	17 734	18 610	14 382	16 518	19 209	16 420	17 600	18 511	12 848	13 679	14 521	18 870	19 360	19 964	15 914	16 927	17 871
B_{0now}	20 759	23 971	27 714	19 572	23 509	28 012	20 278	23 564	27 111	12 641	14 370	16 391	17 264	19 237	21 532	19 420	22 589	26 159
B_{min}	1 307	1 454	1 635	1 325	1 504	1 720	1 318	1 473	1 663	1 217	1 490	1 829	1 212	1 352	1 515	1 109	1 309	1 538
B_R	3 090	3 090	3 090	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
B_{2023}	2 452	2 843	3 317	2 494	2 927	3 418	2 440	2 843	3 354	3 963	4 746	5 653	2 166	2 552	2 982	2 401	2 866	3 490
B_{2023}/B_0	0.138	0.160	0.190	0.139	0.177	0.222	0.139	0.161	0.193	0.291	0.348	0.412	0.111	0.132	0.155	0.140	0.170	0.210
B_{2023}/B_{0now}	0.102	0.118	0.139	0.101	0.125	0.152	0.104	0.121	0.141	0.302	0.331	0.359	0.107	0.132	0.163	0.106	0.128	0.155
B_{2023}/B_R	0.794	0.920	1.073	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
U_{2023}	0.045	0.052	0.060	0.043	0.050	0.059	0.044	0.052	0.060	0.027	0.033	0.039	0.049	0.057	0.067	0.042	0.051	0.061
U_{2023}/U_R	0.816	0.945	1.085	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Spawning biomass (females only)																		
SSB_0	6 179	6 489	6 823	5 498	6 225	7 100	6 115	6 460	6 782	5 270	5 679	6 102	6 230	6 623	6 939	6 071	6 460	6 891
SSB_{0now}	7 630	8 791	10 141	7 491	8 858	10 391	7 567	8 696	9 985	5 185	5 957	6 858	5 876	6 559	7 352	7 435	8 628	10 032
SSB_{2023}	2 225	2 515	2 804	2 327	2 607	2 929	2 136	2 400	2 696	2 625	3 069	3 575	2 206	2 491	2 797	2 268	2 720	3 265
SSB_{2023}/SSB_0	0.345	0.385	0.428	0.356	0.420	0.490	0.333	0.373	0.415	0.473	0.540	0.614	0.333	0.378	0.421	0.360	0.421	0.489
SSB_{2023}/SSB_{0now}	0.252	0.285	0.323	0.255	0.297	0.342	0.245	0.276	0.312	0.485	0.515	0.543	0.322	0.380	0.444	0.268	0.315	0.362
Total biomass																		
T_0	23 355	24 527	25 590	20 255	23 034	26 483	23 524	24 669	25 736	19 077	20 318	21 476	25 738	26 178	26 616	22 471	23 697	24 835
T_{0now}	28 827	33 177	38 144	27 621	32 797	38 592	28 934	33 091	37 711	18 741	21 281	24 406	23 489	26 028	28 947	27 319	31 598	36 542
T_{2023}	5 373	6 097	6 961	5 482	6 245	7 139	5 373	6 099	7 030	7 685	9 167	10 978	4 940	5 661	6 463	5 387	6 331	7 525
T_{2023}/T_0	0.219	0.248	0.284	0.222	0.271	0.327	0.217	0.247	0.287	0.383	0.452	0.535	0.189	0.216	0.246	0.226	0.268	0.322
T_{2023}/T_{0now}	0.162	0.183	0.210	0.161	0.192	0.226	0.164	0.184	0.210	0.399	0.431	0.461	0.181	0.217	0.261	0.172	0.201	0.235
Other derived parameters																		
H_{2022}	2.638	2.792	2.987	2.640	2.799	2.982	2.617	2.789	2.982	2.478	2.665	2.866	2.642	2.824	3.034	2.647	2.841	3.081
T_{male}/T_{female}	0.981	1.060	1.152	0.966	1.059	1.155	0.978	1.062	1.151	1.317	1.386	1.452	0.889	0.979	1.061	0.911	1.010	1.120

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

Variable	<i>base</i>	<i>start1979</i>	<i>sel_est_dome</i>	<i>fix_M</i>	<i>fix_early_recdevs</i>	<i>tags_CRA6</i>
$P(B_{2023} > B_{min})$	1.000	1.000	1.000	1.000	1.000	1.000
$P(B_{2023} > B_R)$	0.182	—	—	—	—	—
$P(SSB_{2023} > 20\% SSB_0)$	1.000	1.000	1.000	1.000	1.000	1.000
$P(SSB_{2023} > 10\% SSB_0)$	1.000	1.000	1.000	1.000	1.000	1.000
$P(U_{2023} > U_R)$	0.272	—	—	—	—	—

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	90.948	268.161	0.468	4.214	0.2	1.8	1.819	5.363
2023–24	90.948	268.161	0.468	4.214	0.2	1.8	1.819	5.363
2024–25	90.948	268.161	0.468	4.214	0.2	1.8	1.819	5.363
2025–26	90.948	268.161	0.468	4.214	0.2	1.8	1.819	5.363
2027–28	90.948	268.161	0.468	4.214	0.2	1.8	1.819	5.363

9. FIGURES

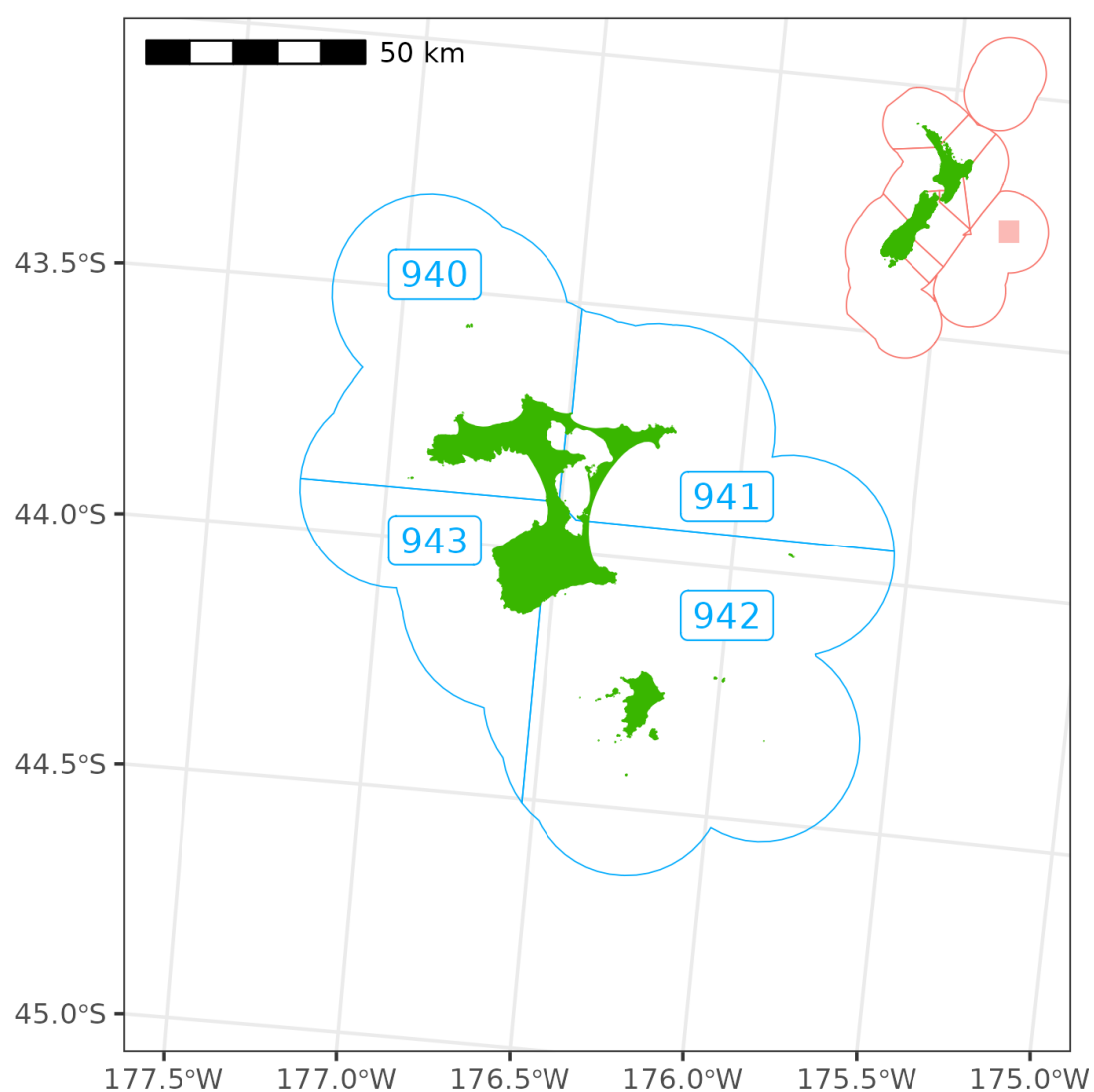


Figure 1: The CRA 6 Quota Management Area (QMA) boundaries (solid red lines) and statistical area boundaries (solid blue lines).

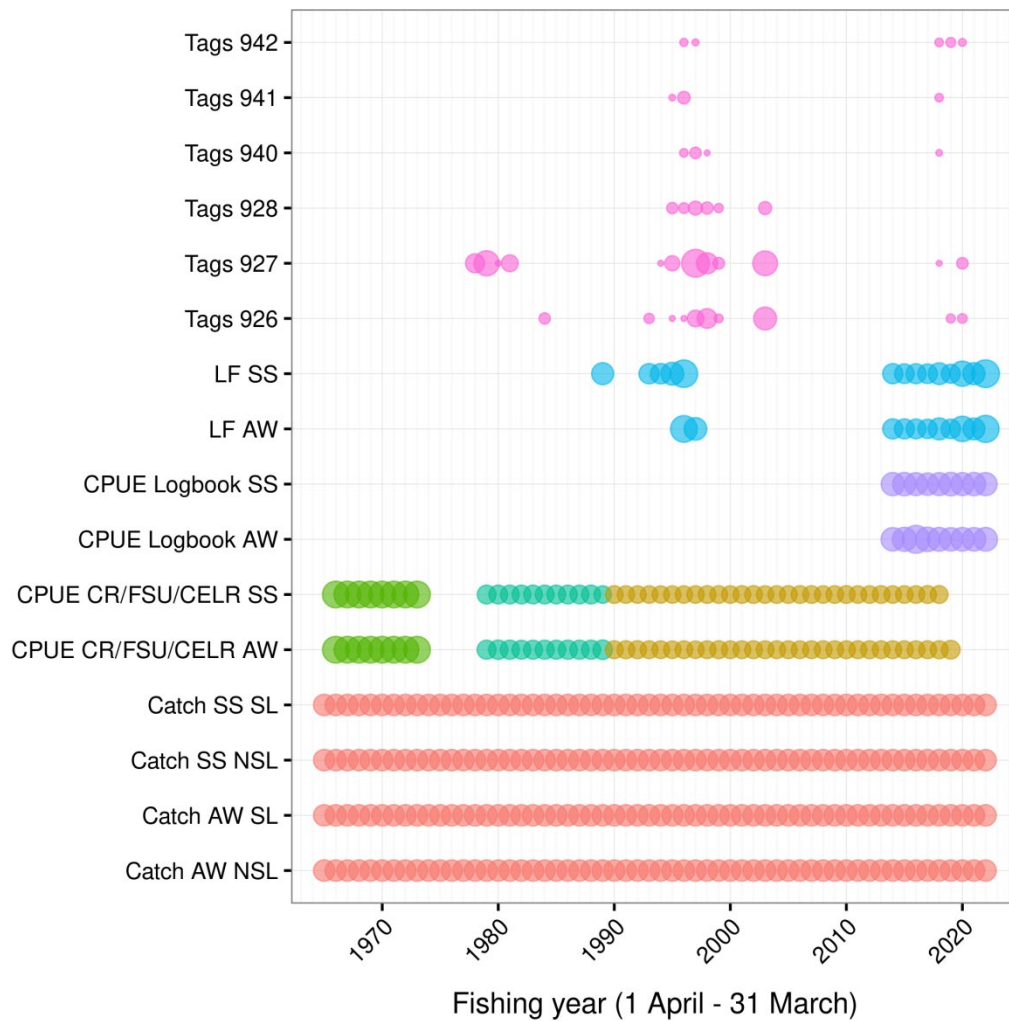


Figure 2: Data extent by fishing year used in the CRA 6 stock assessment. The size of the bubbles represents the relative number of recaptured tags, the effective sample size for length frequency distributions, the standard deviation for CPUE, or a fixed size for catch. Bubble colours vary for the different data sets (CPUE colours: CR = green, FSU = teal, CELR = gold, LB = purple). See Webber et al. (2024) for a detailed description of these data.

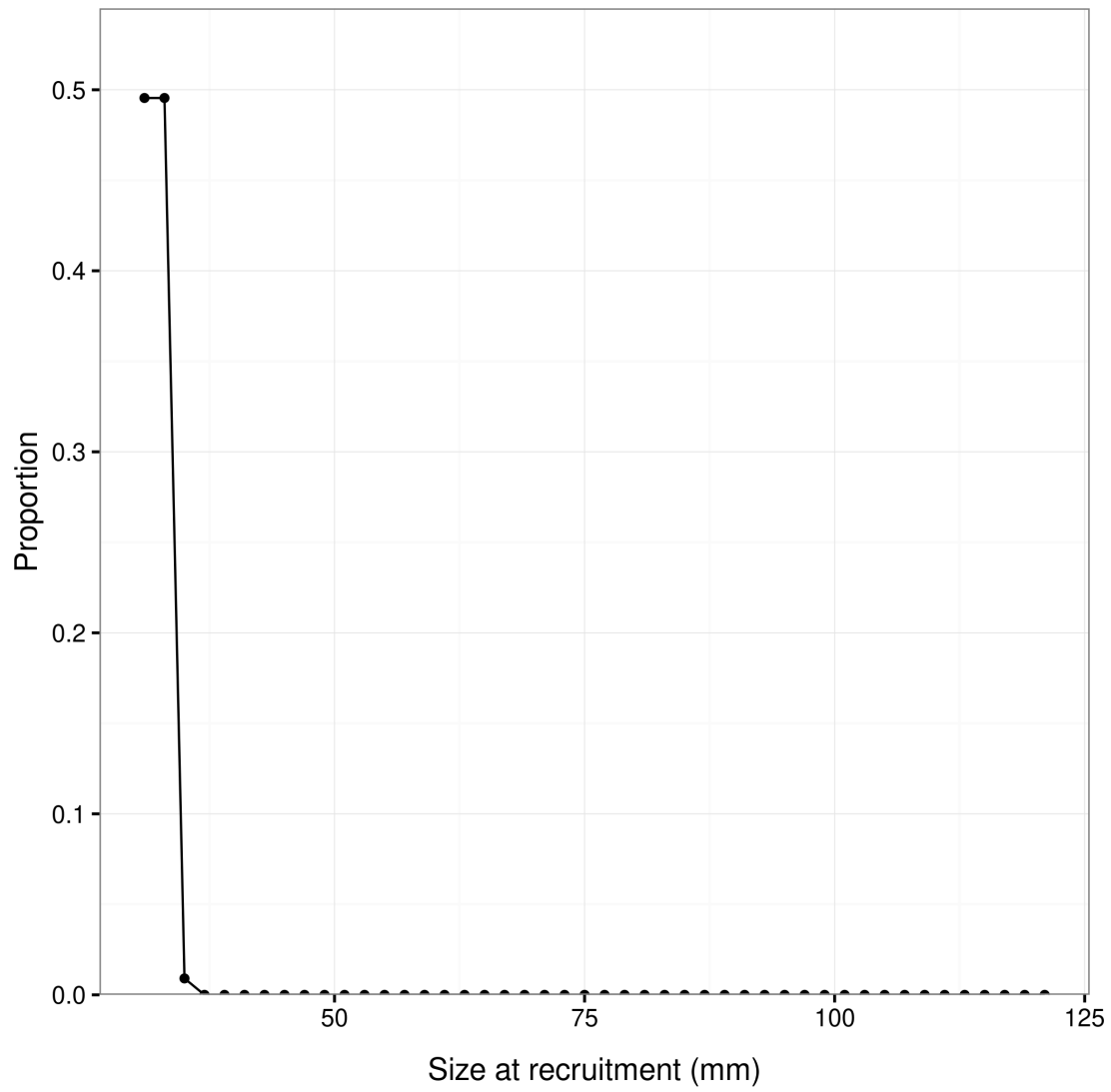


Figure 3: Distribution of size at recruitment size (mm) assumed in the CRA 6 stock assessment.

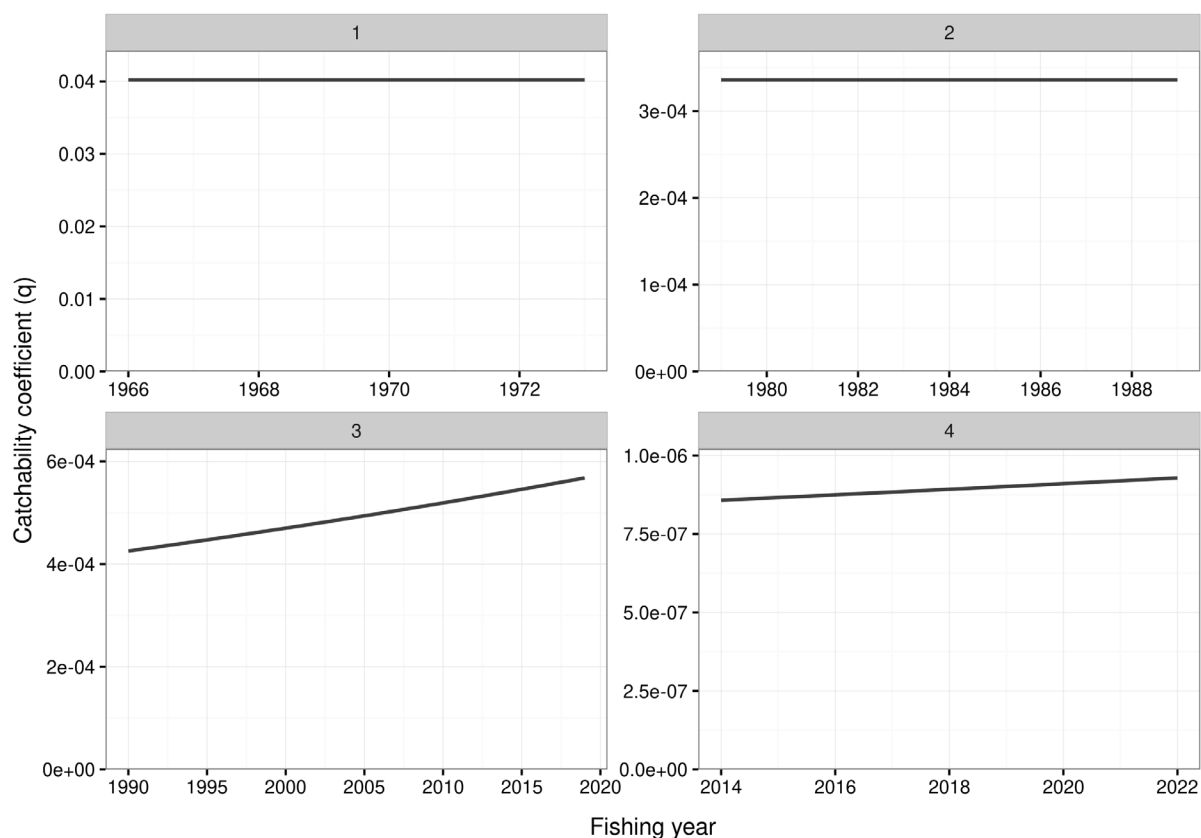


Figure 4: MAP catchability coefficient (q) for the CR (1) FSU (2), CELR (3), and logbook (4 CPUE indices by fishing year in the base case model run.

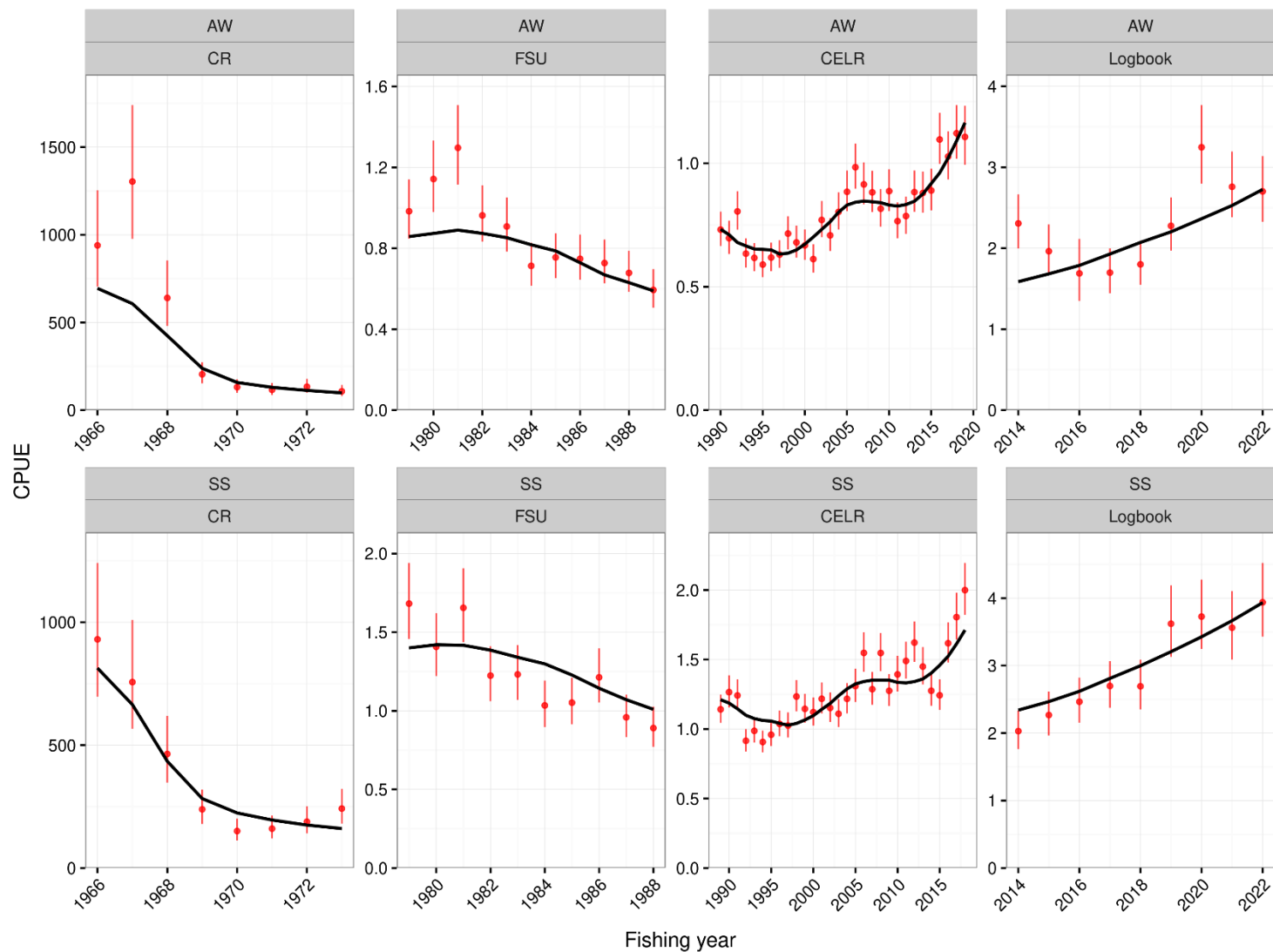


Figure 5: MAP model fits to the CR, FSU, CELR, and logbook CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) in the base case model run. Error bars are +/- one standard deviation.

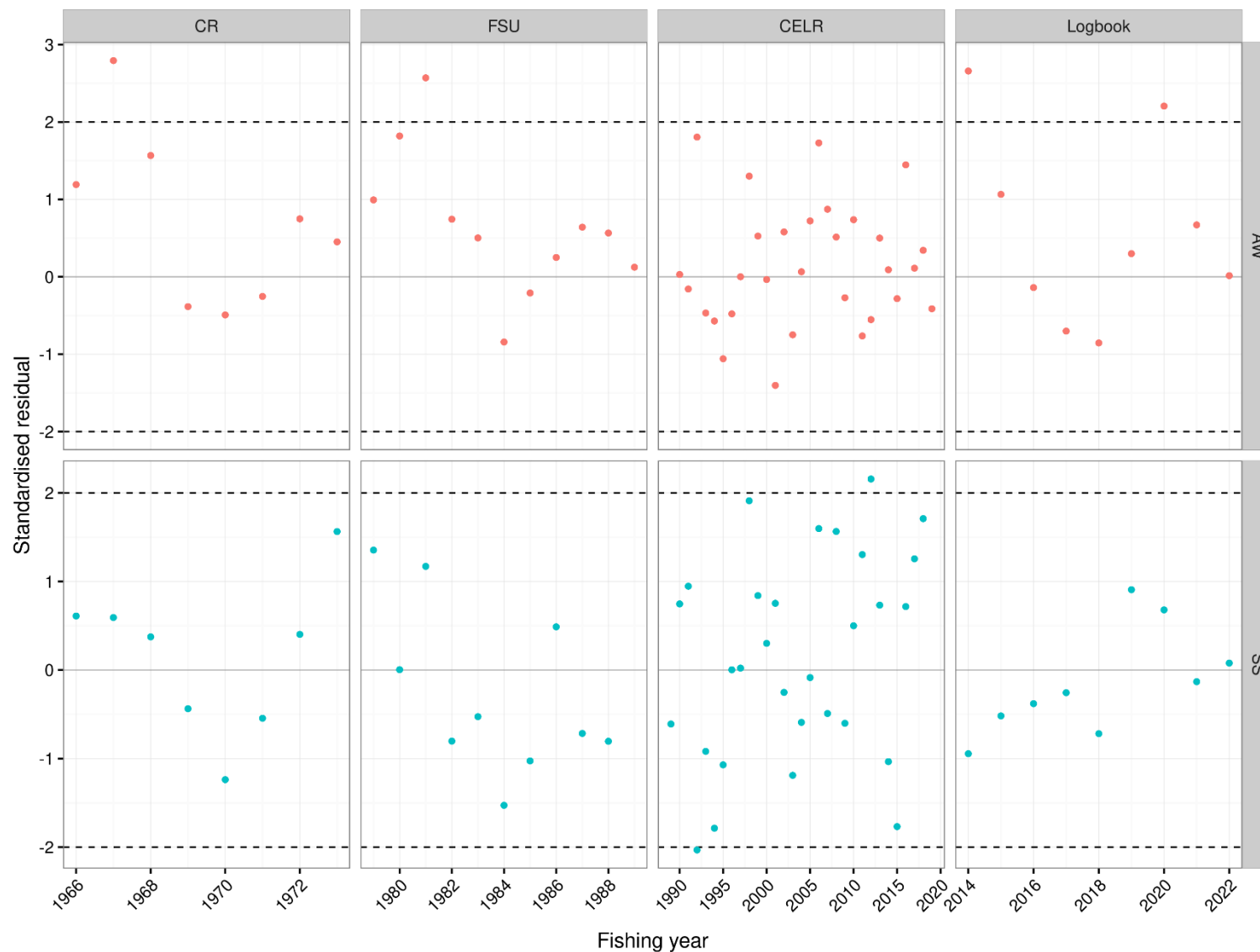


Figure 6: MAP standardised residuals from model fits to the CR, FSU, CELR, and logbook CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) in the base case model run.

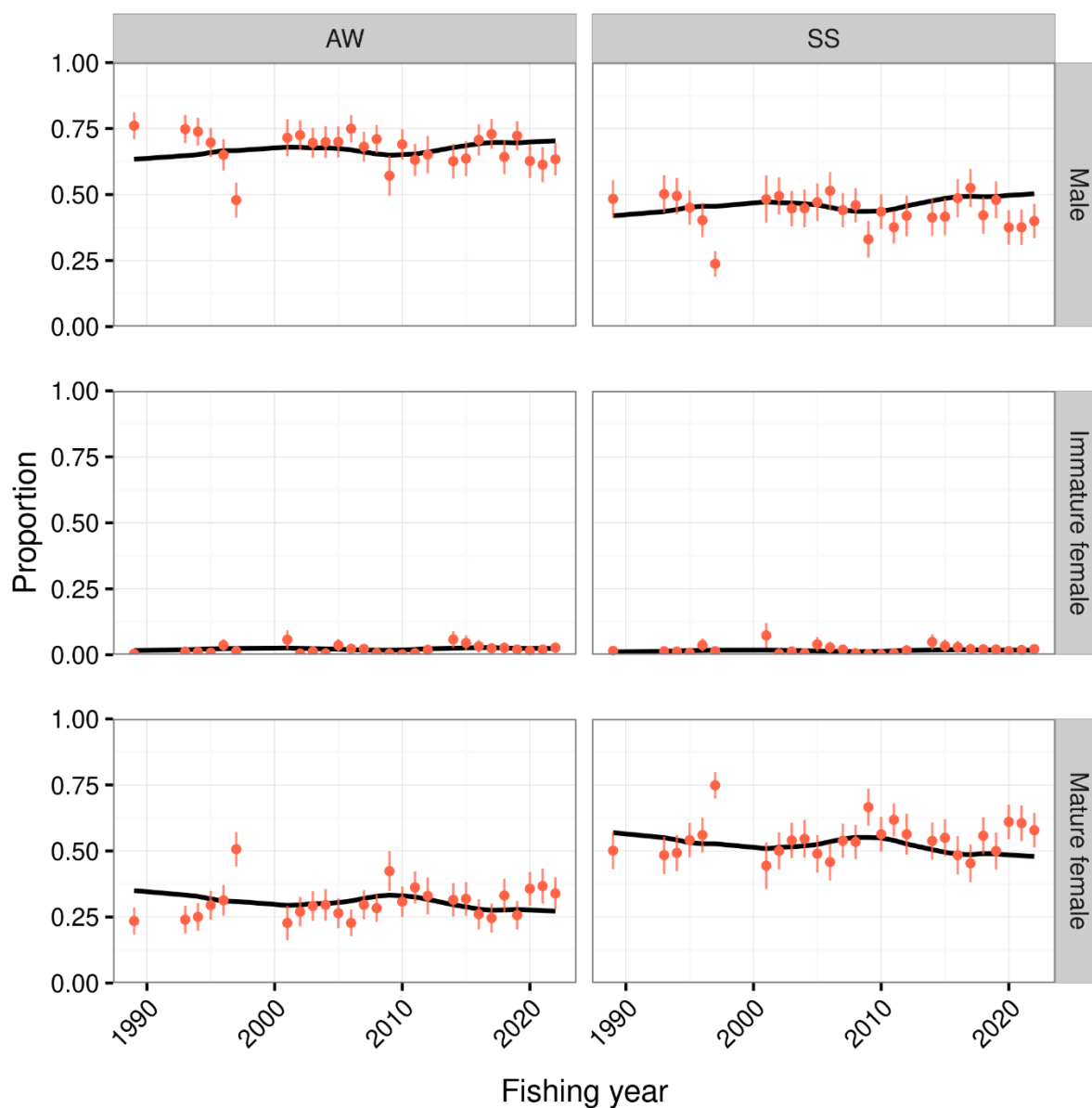


Figure 7: MAP model fits to the sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex in the base case model run. Error bars are $\pm$ one standard deviation.

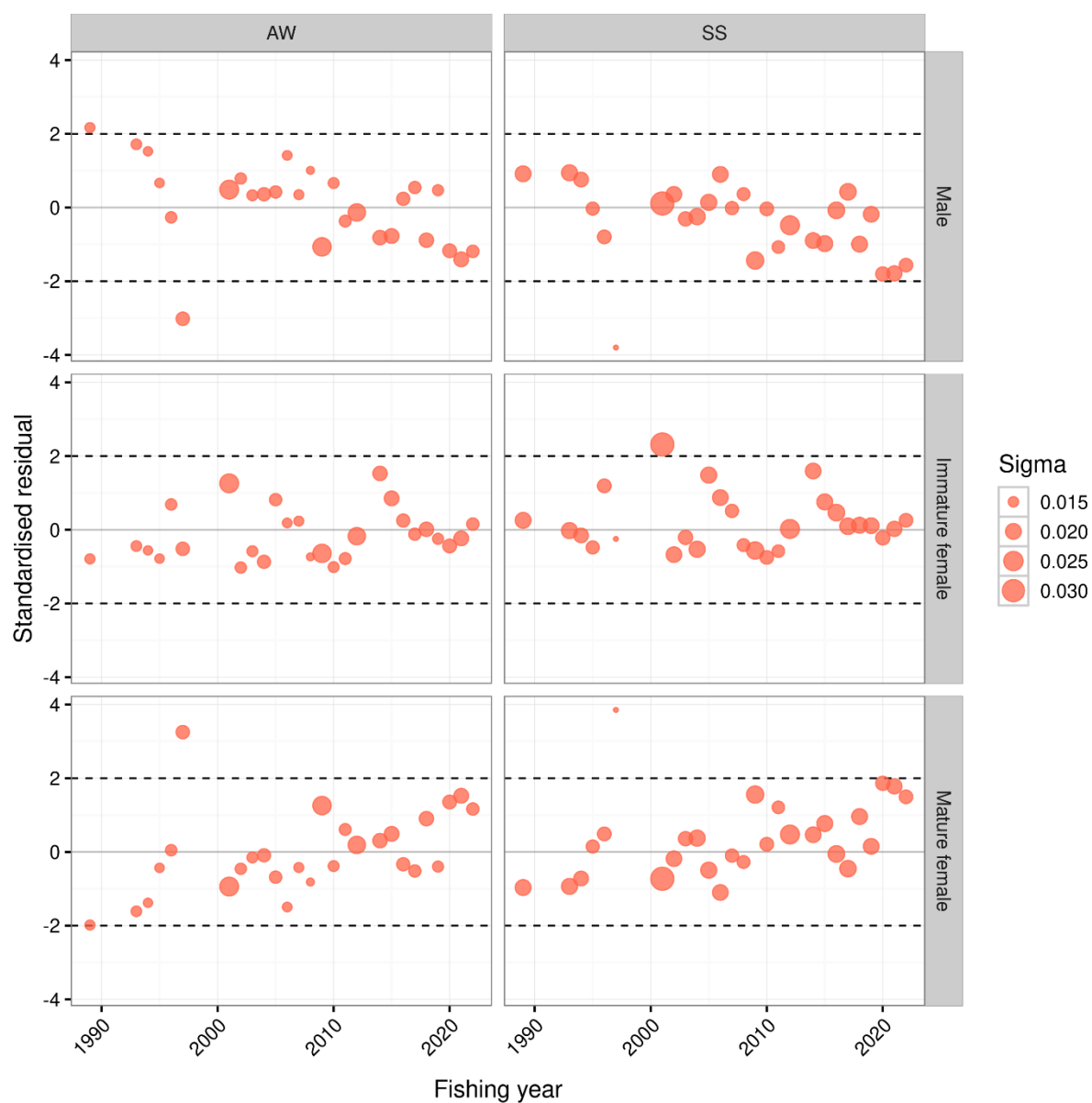


Figure 8: MAP standardised residuals for the model fits to the sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex in the base case model run.

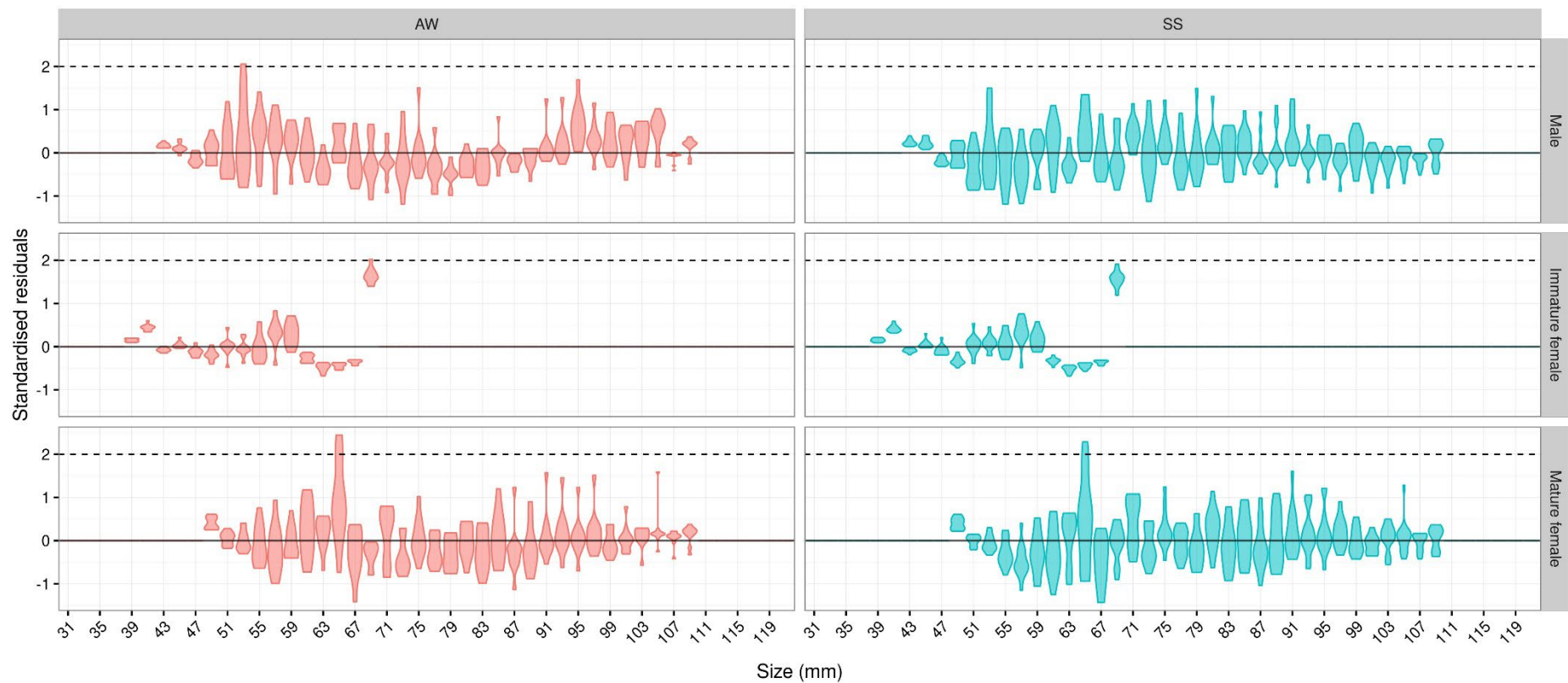


Figure 9: MAP standardised residuals from fits to the LF data by sex, season (AW = autumn/winter, SS = spring/summer), and 2 mm TW bin.

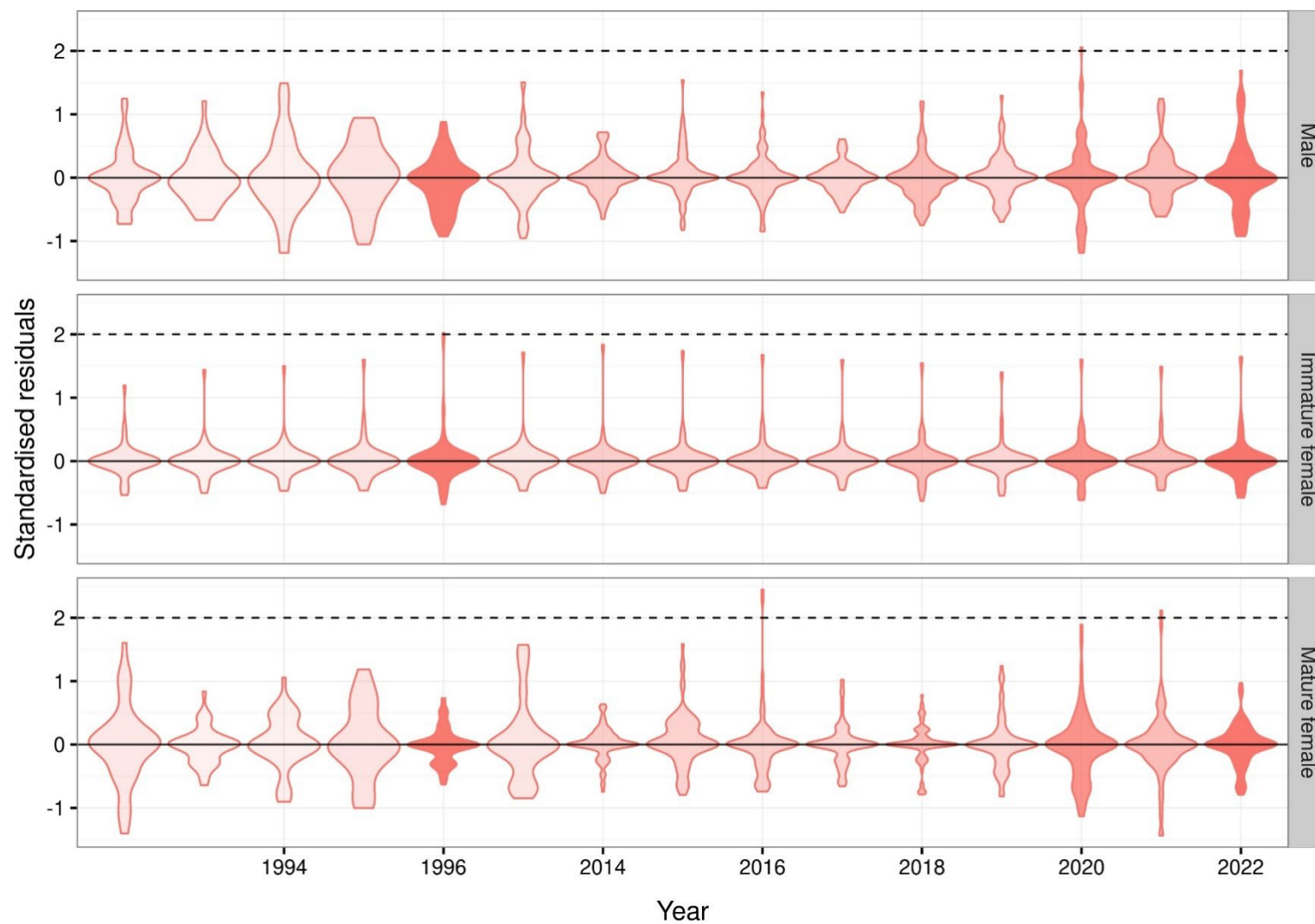


Figure 10: MAP standardised residuals from fits to the LF data by sex and fishing year.

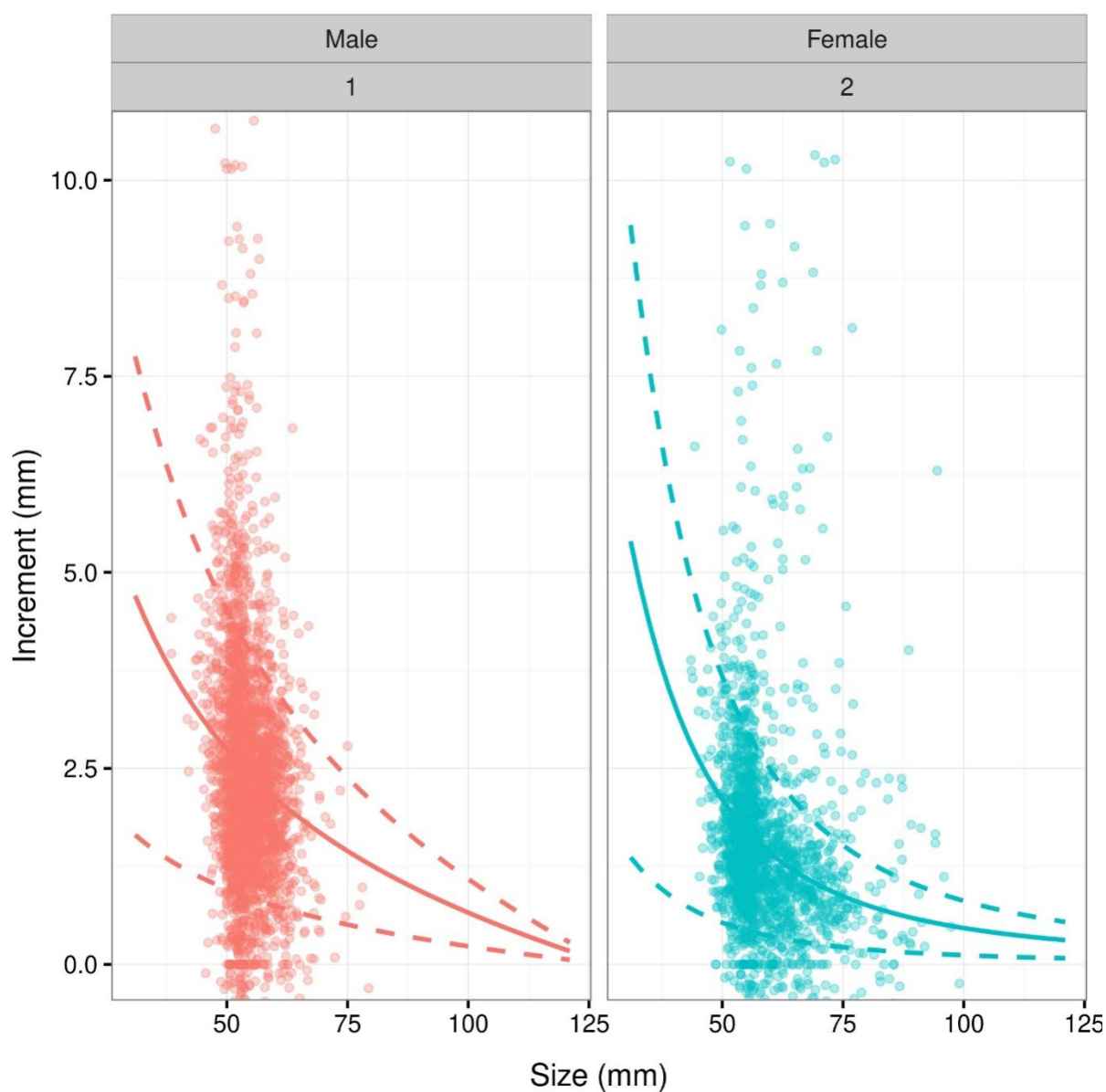


Figure 11: MAP predicted six-monthly growth increment by size and sex in the base case model run showing the mean (solid line), ± 1 standard deviation (dashed line), and observed growth increments divided by time-at-liberty (points).

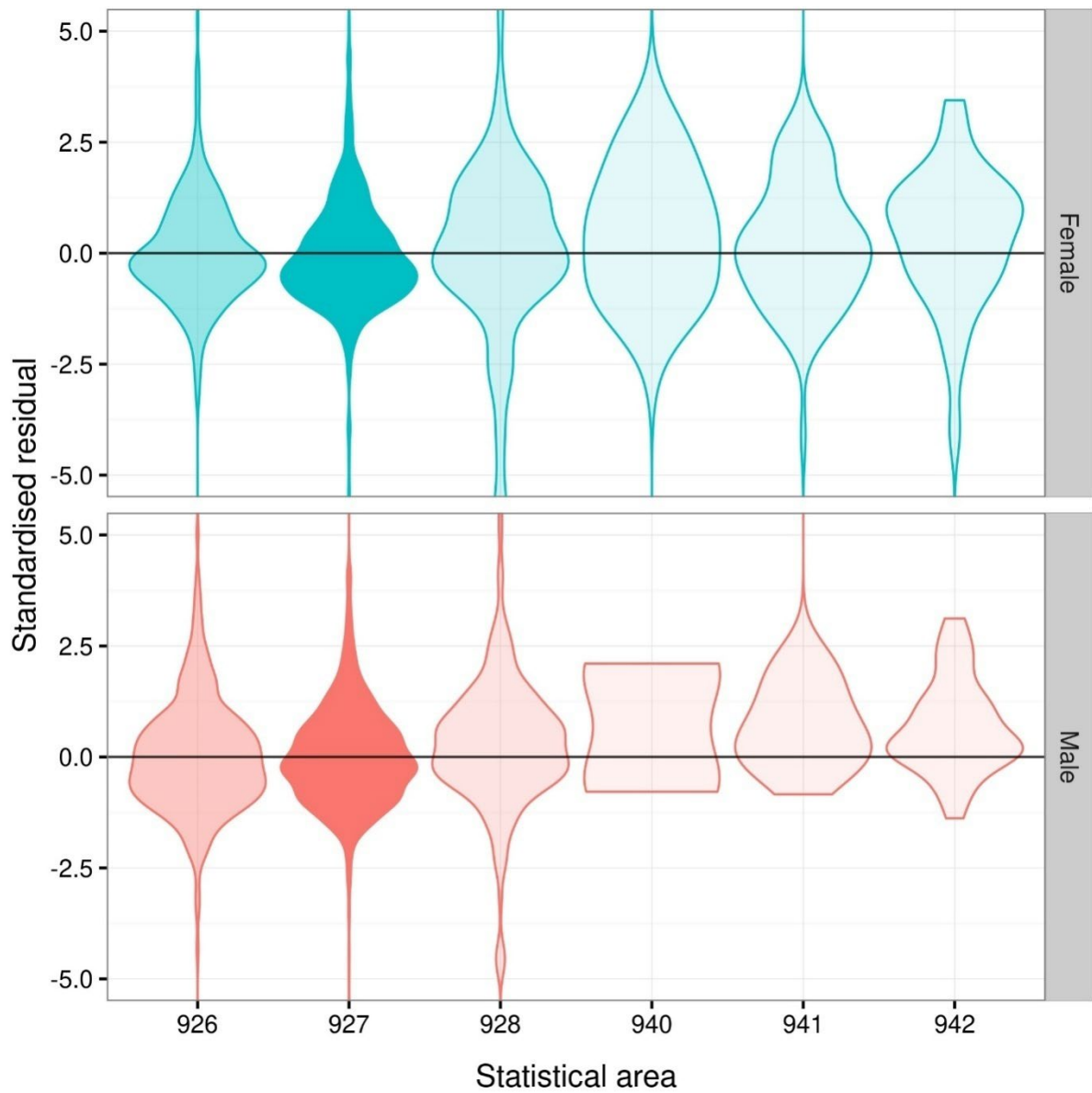


Figure 12: MAP standardised residuals of fits to tag-recapture data by statistical area of release and sex in the base case model run. Darker shading represents a higher number of tags.

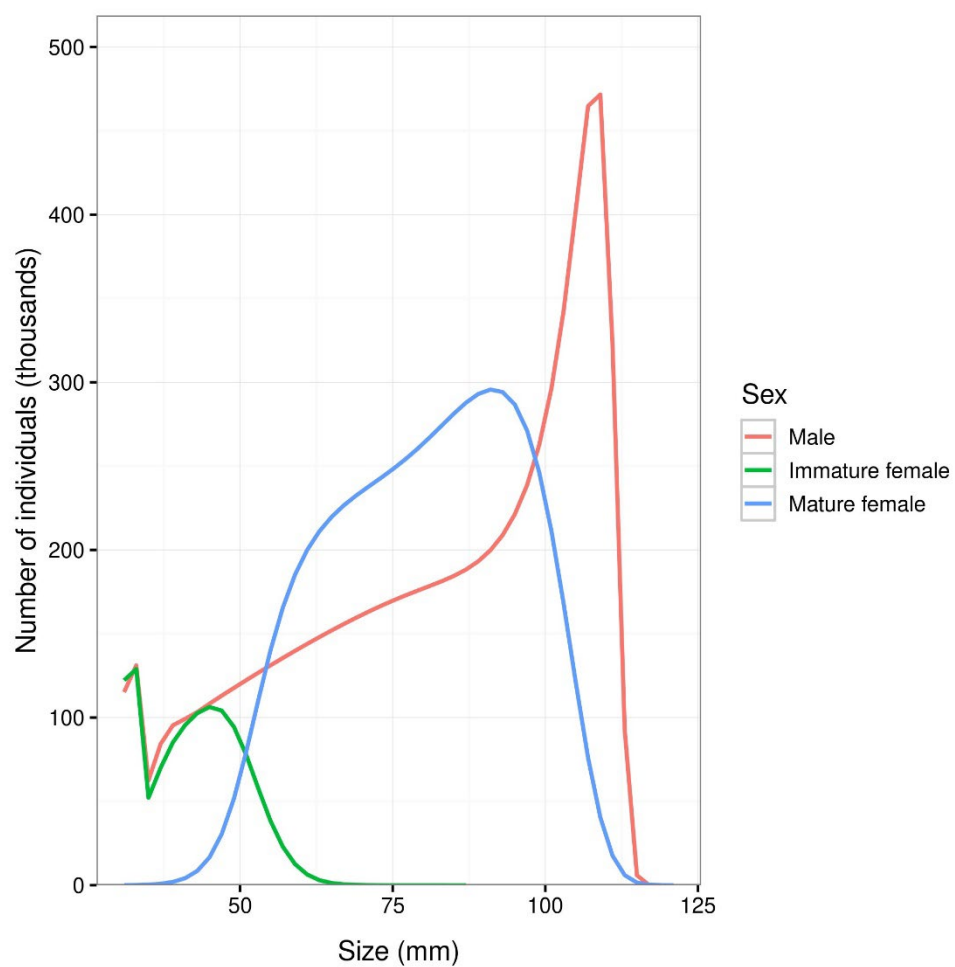


Figure 13: MAP initial number of individuals by size and sex category in the base case model run.

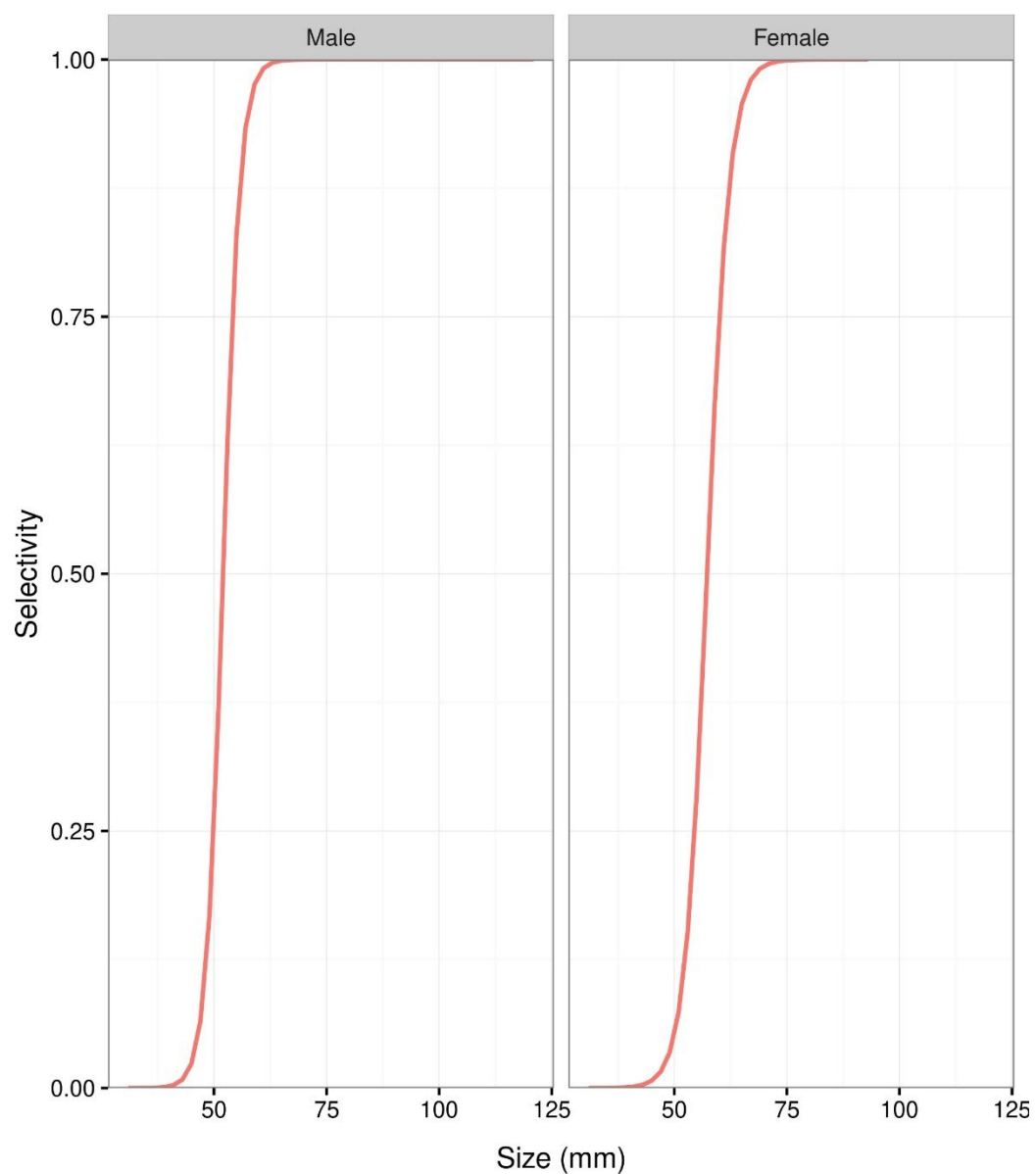


Figure 14: MAP of selectivity by sex and size in the base case model run.

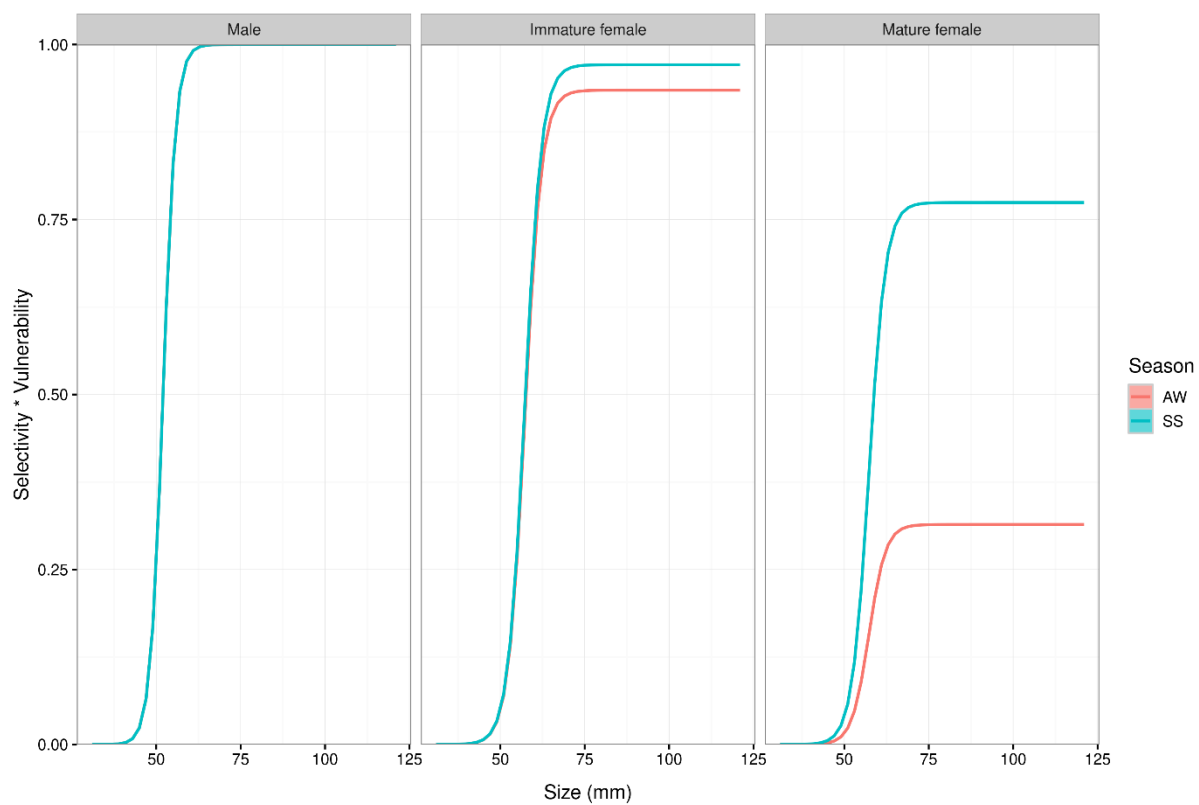


Figure 15: MAP of selectivity multiplied by vulnerability by sex and size in the base case model run.

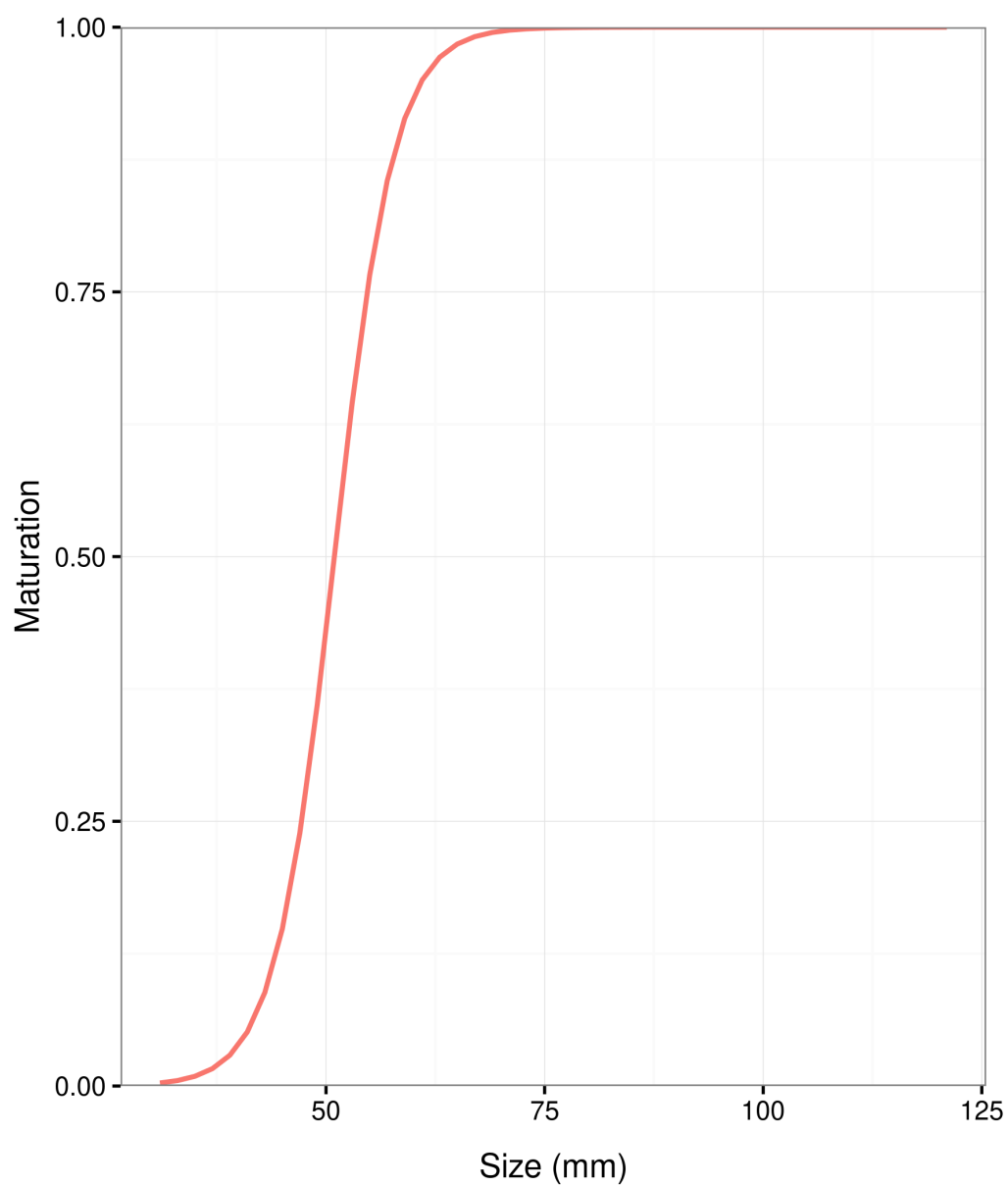


Figure 16: MAP of female maturation curve by size in the base case model run.

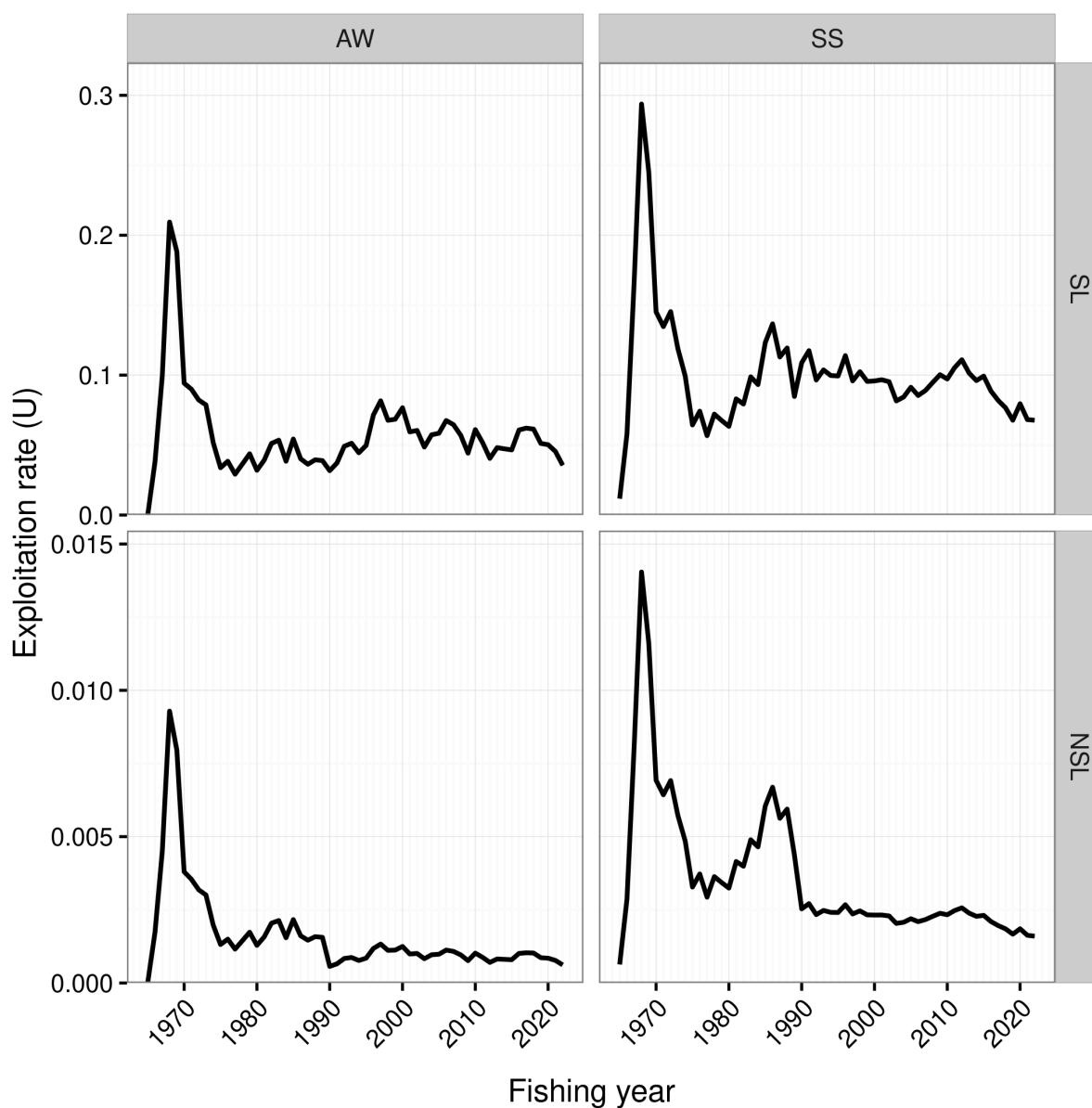


Figure 17: MAP of exploitation rate by fishing year and season (AW = autumn/winter, SS = spring/summer) for the size-limited (SL) and non-size-limited (NSL) fisheries in the base case model run.

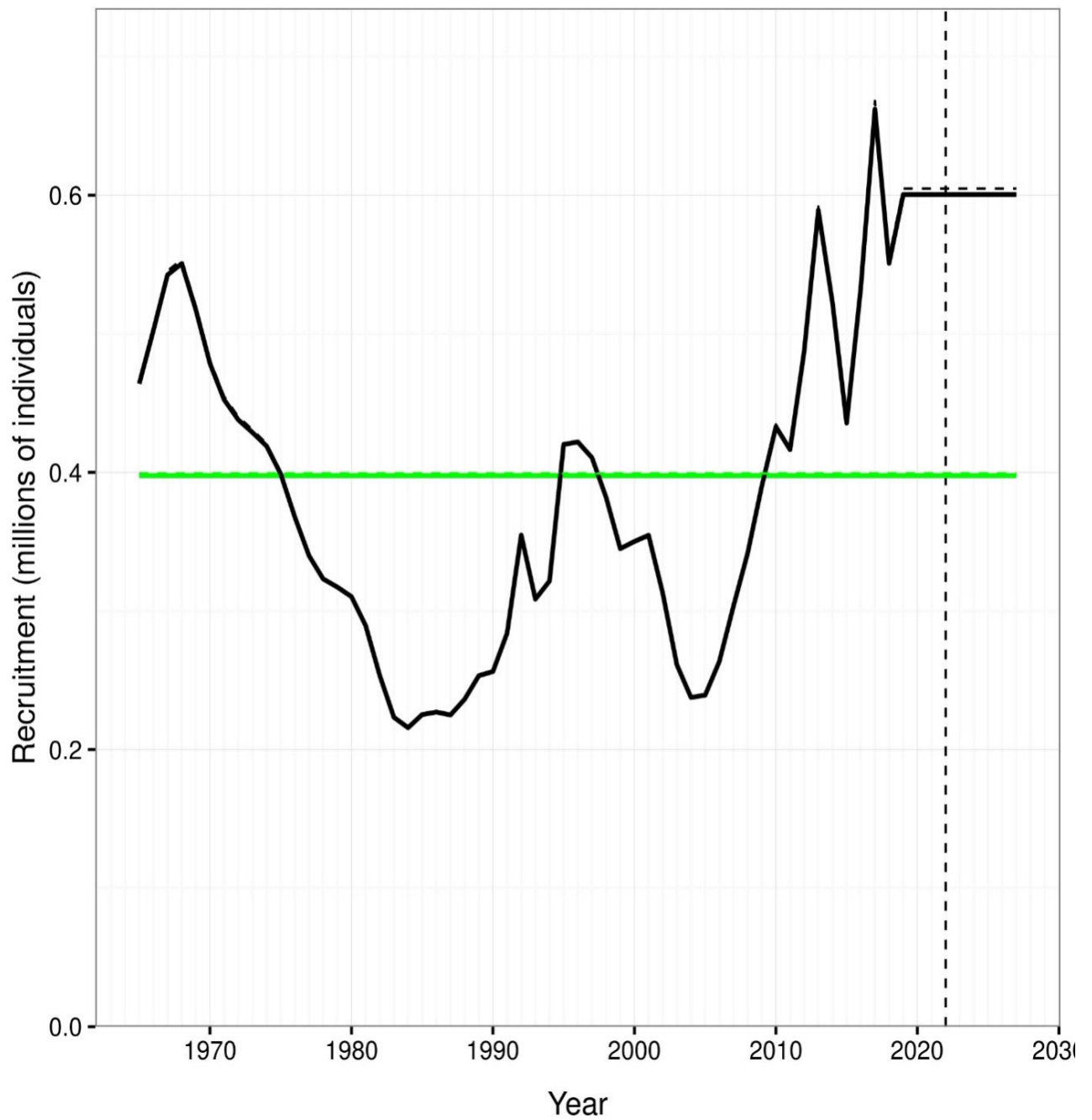


Figure 18: MAP of recruitment for the base case model run. Horizontal green line is R_0 and vertical dashed line is the final year of the reconstruction period.

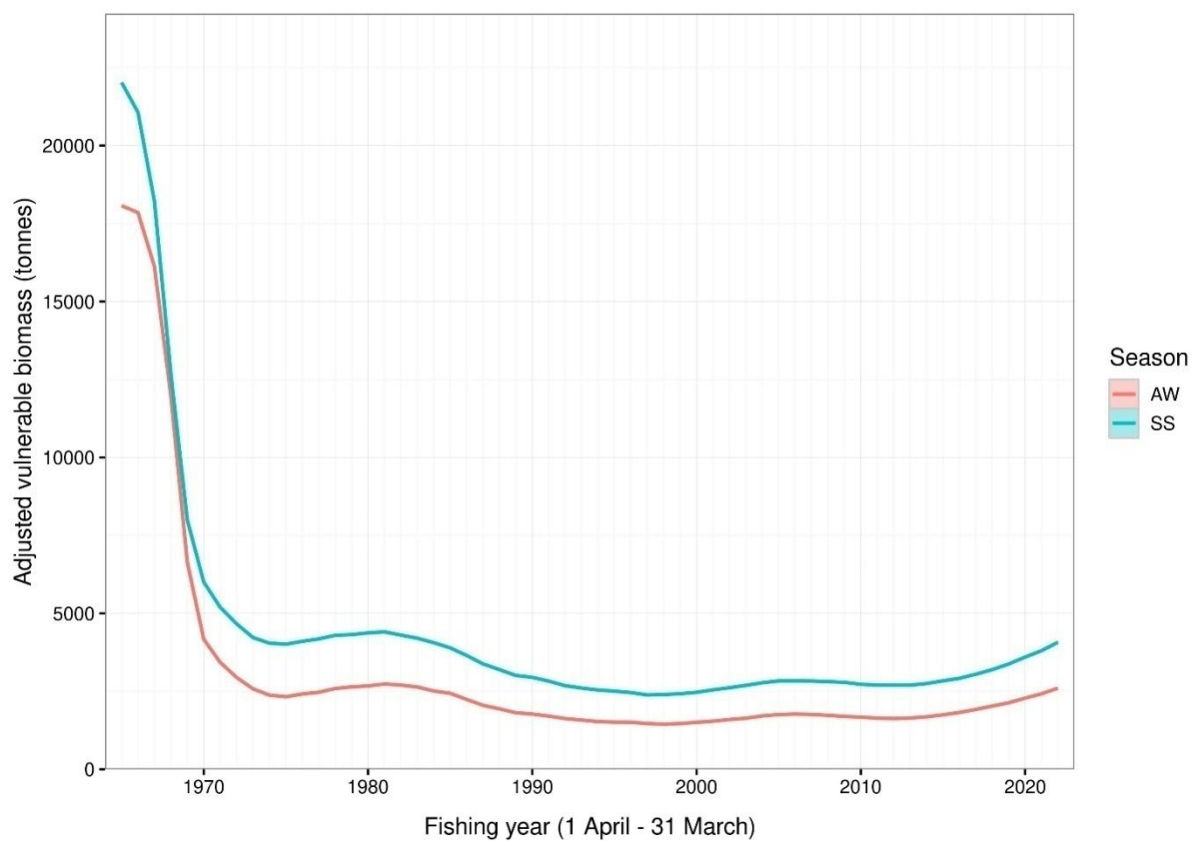


Figure 19: MAP of adjusted vulnerable biomass (tonnes) by season (AW = autumn/winter, SS = spring/summer) and fishing year in the base case model run.

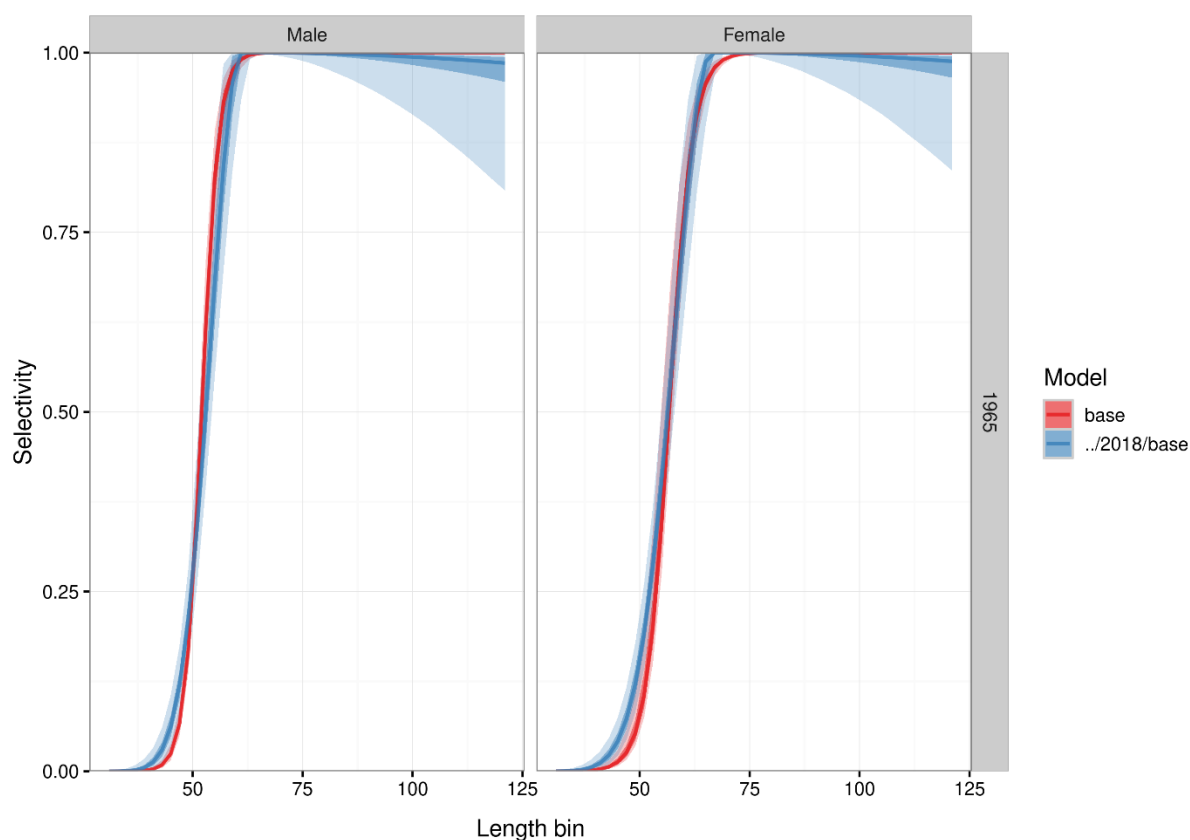


Figure 20: MAP selectivity curves by sex and time period for *base* and the 2018 assessment. The row label year shows the start of the time period.

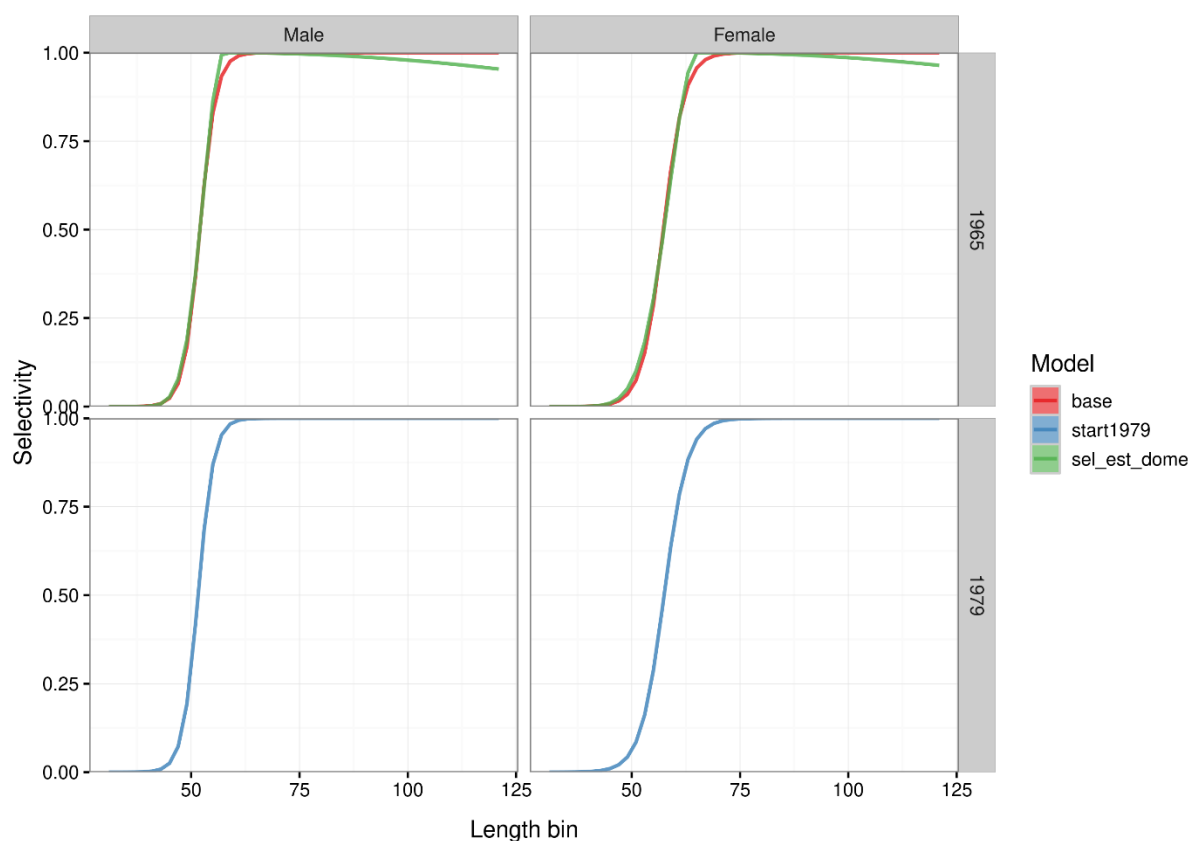


Figure 21: MAP selectivity curves by sex and time period for *base* and Group 1 sensitivity runs (*start1979*, *sel_est_dome*). The row label year shows the start of the time period.

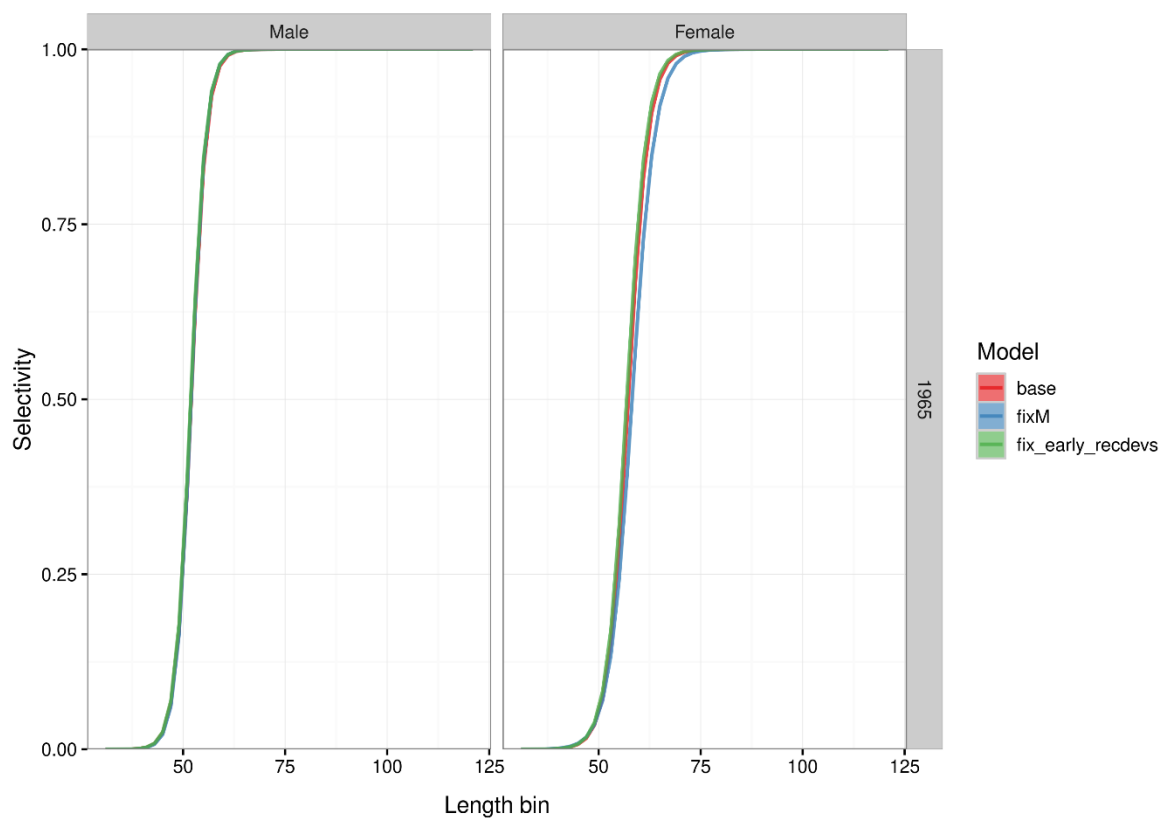


Figure 22: MAP selectivity curves by sex for *base* and Group 2 sensitivity runs (*fixM*, *fix_early_recdevs*). The row label year shows the start of the time period.

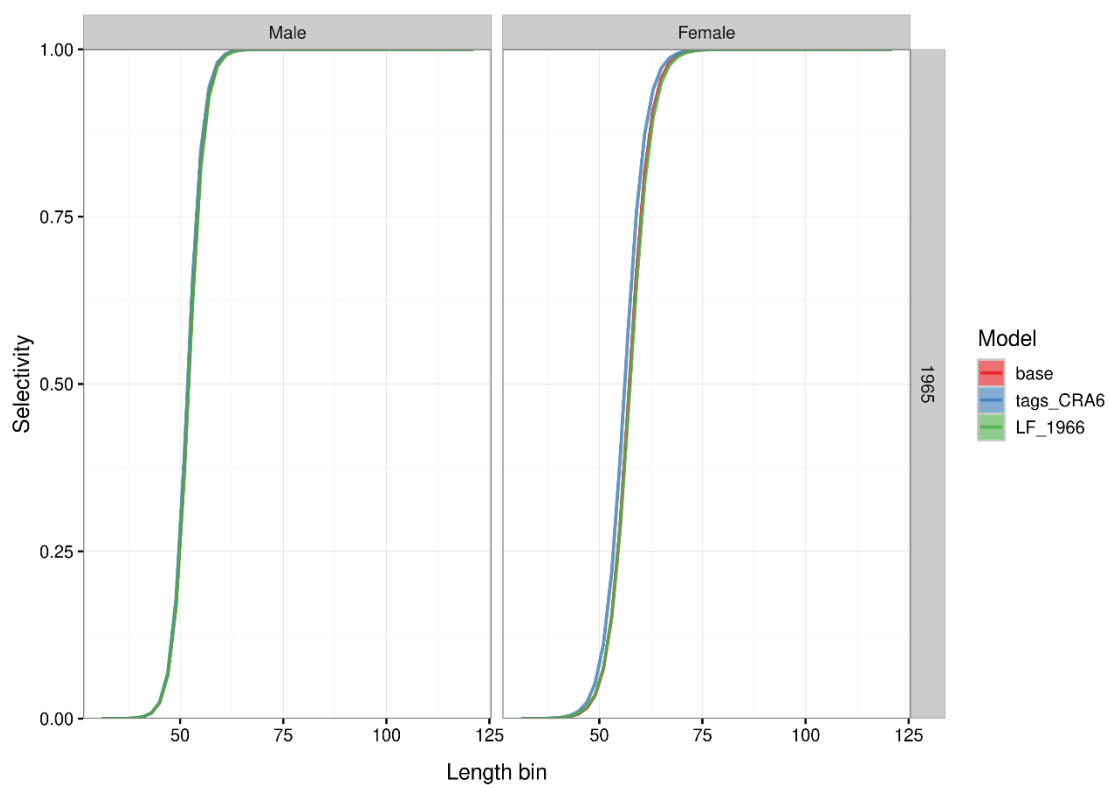


Figure 23: MAP selectivity curves by sex and time period for *base* and Group 3 sensitivity runs (*tags_CRA6*, *LF_1966*). The row label year shows the start of the time period.

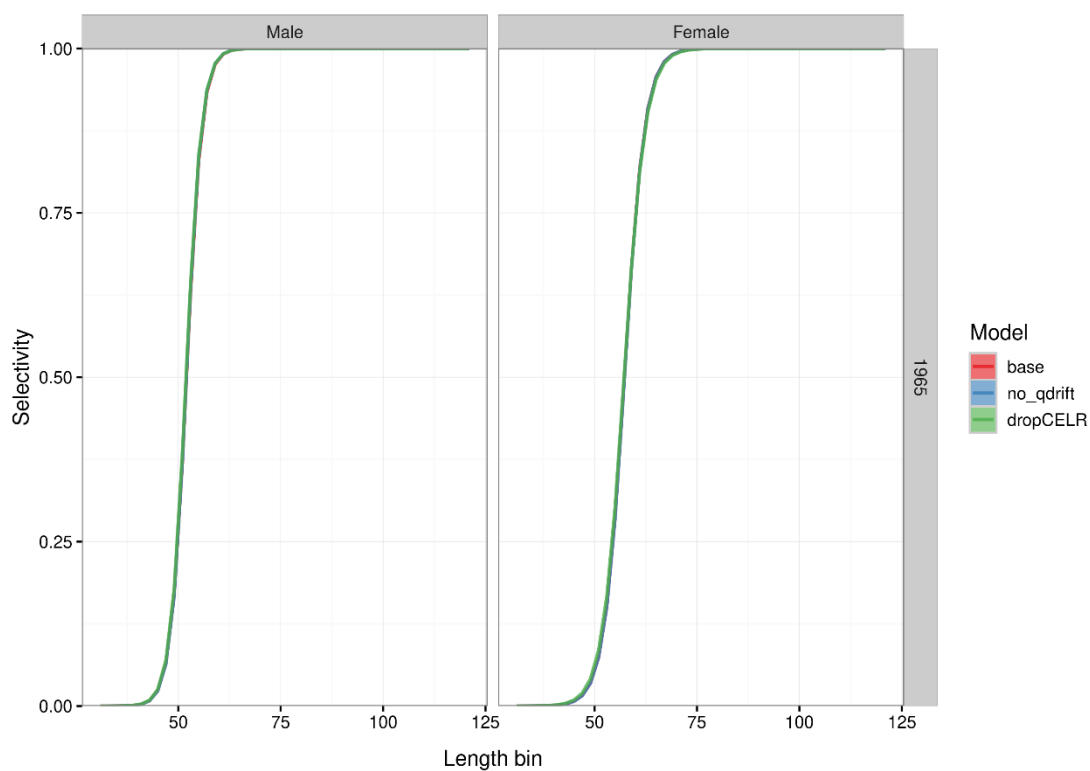


Figure 24: MAP selectivity curves by sex and time period for *base* and Group 4 sensitivity runs (*no_qdrift*, *dropCELR*). The row label year shows the start of the time period.

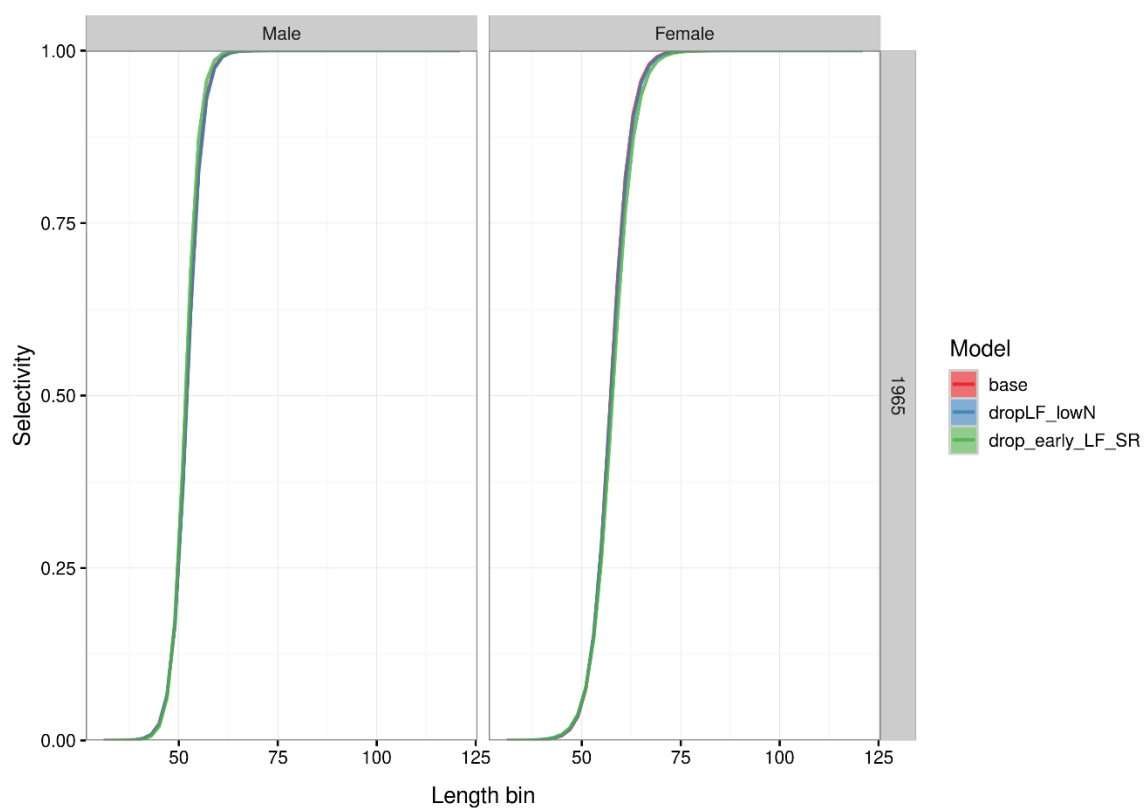


Figure 25: MAP selectivity curves by sex for *base* and Group 5 sensitivity runs (*dropLF_lowN*, *drop_early_LF_SR*). The row label year shows the start of the time period.

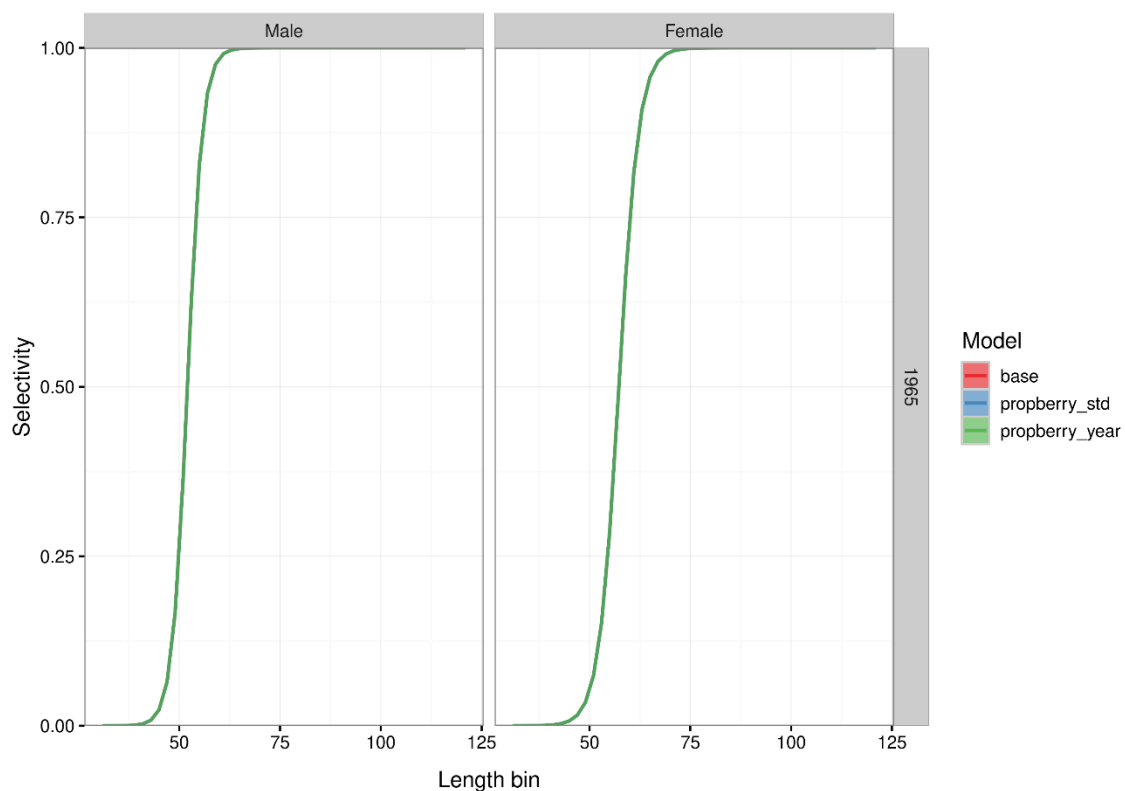


Figure 26: MAP selectivity curves by sex for *base* and Group 6 sensitivity runs (*propberry_std*, *propberry_year*). The row label year shows the start of the time period.

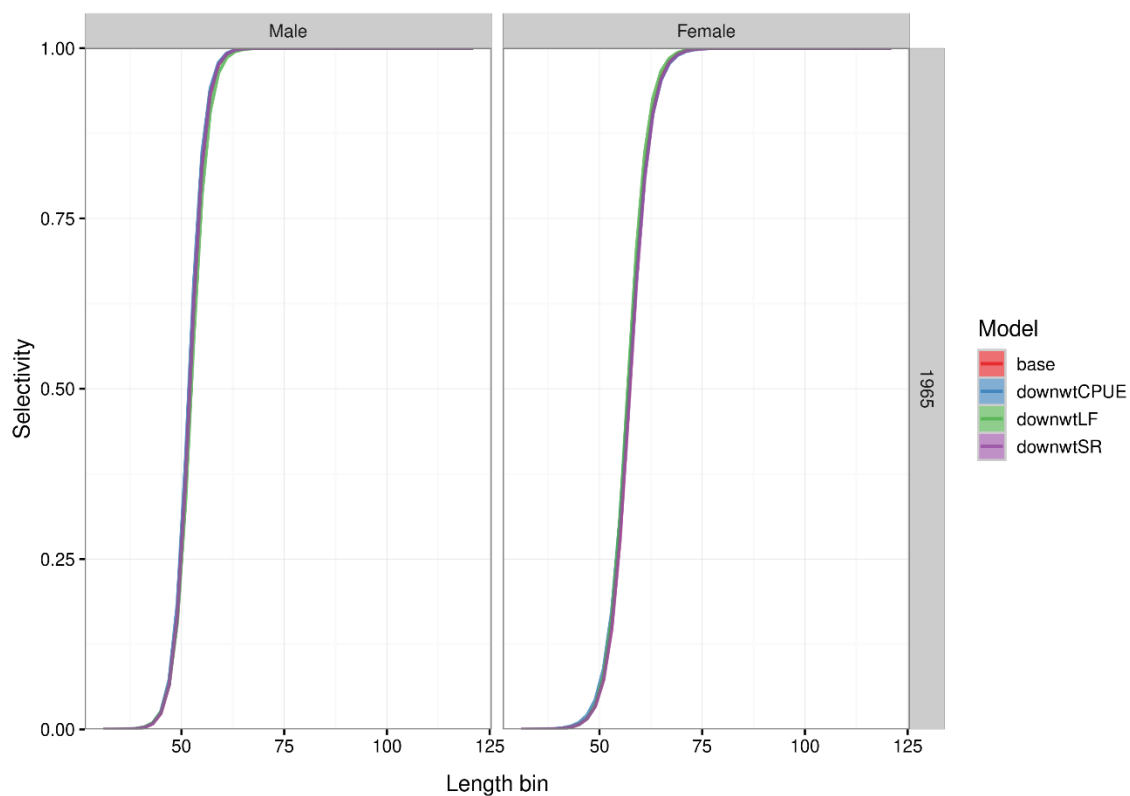


Figure 27: MAP selectivity curves by sex for *base* and Group 7 sensitivity runs (*downwtCPUE*, *downwtLF*, *downwtSR*). The row label year shows the start of the time period.

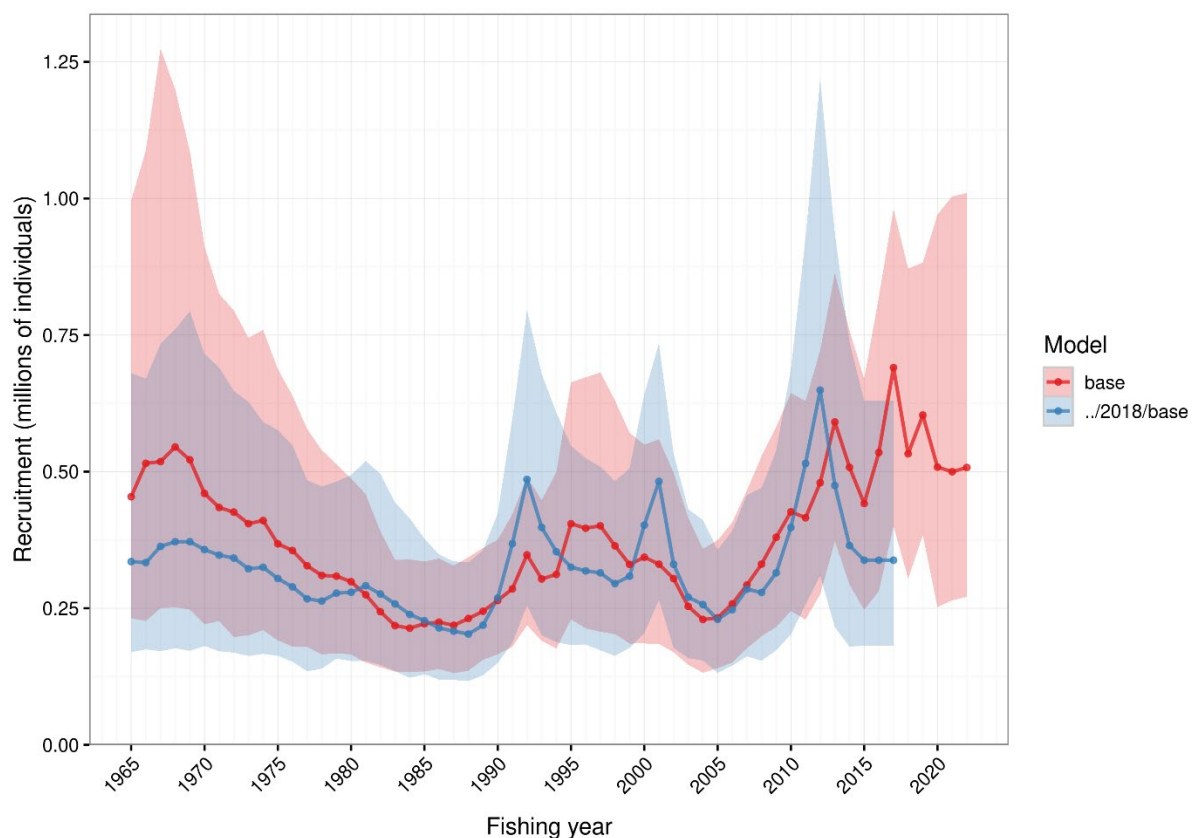


Figure 28: MAP recruitments for *base* and the 2018 assessment.

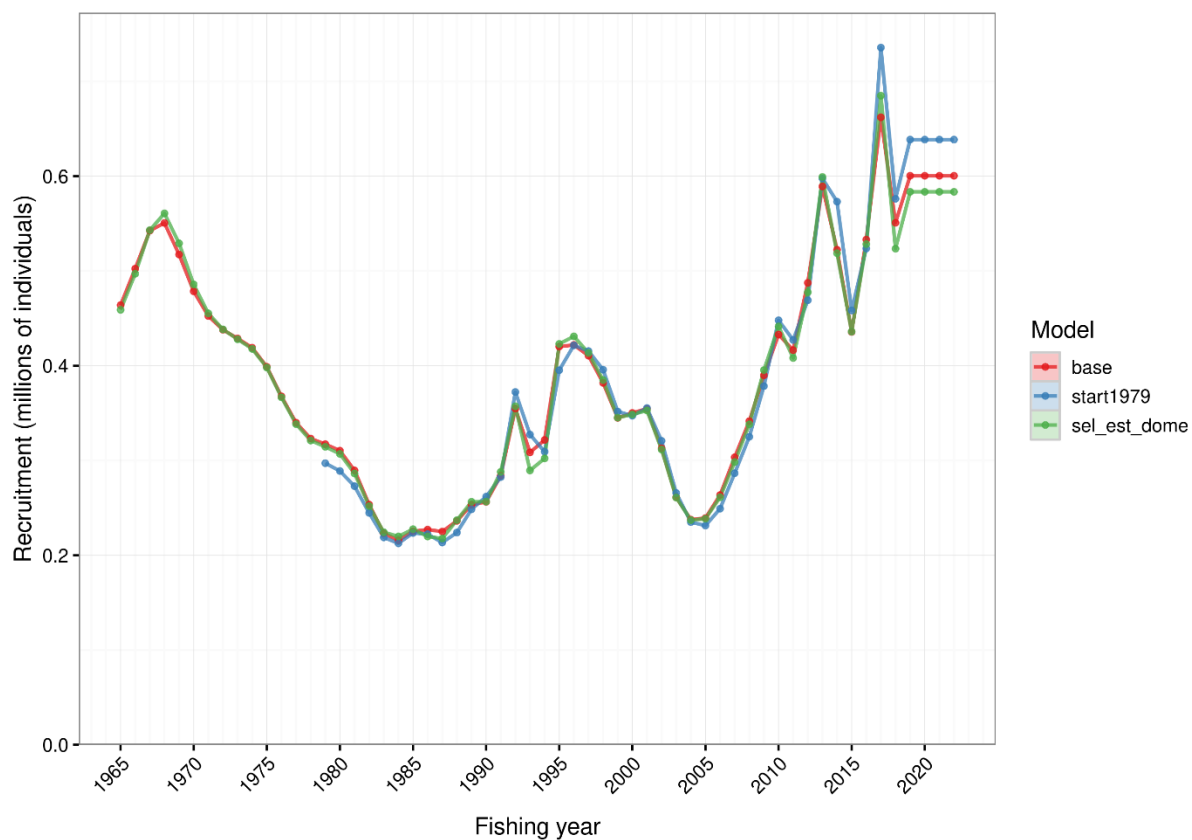


Figure 29: MAP recruitments for *base* and Group 1 sensitivity runs (*start1979*, *sel_est_dome*).

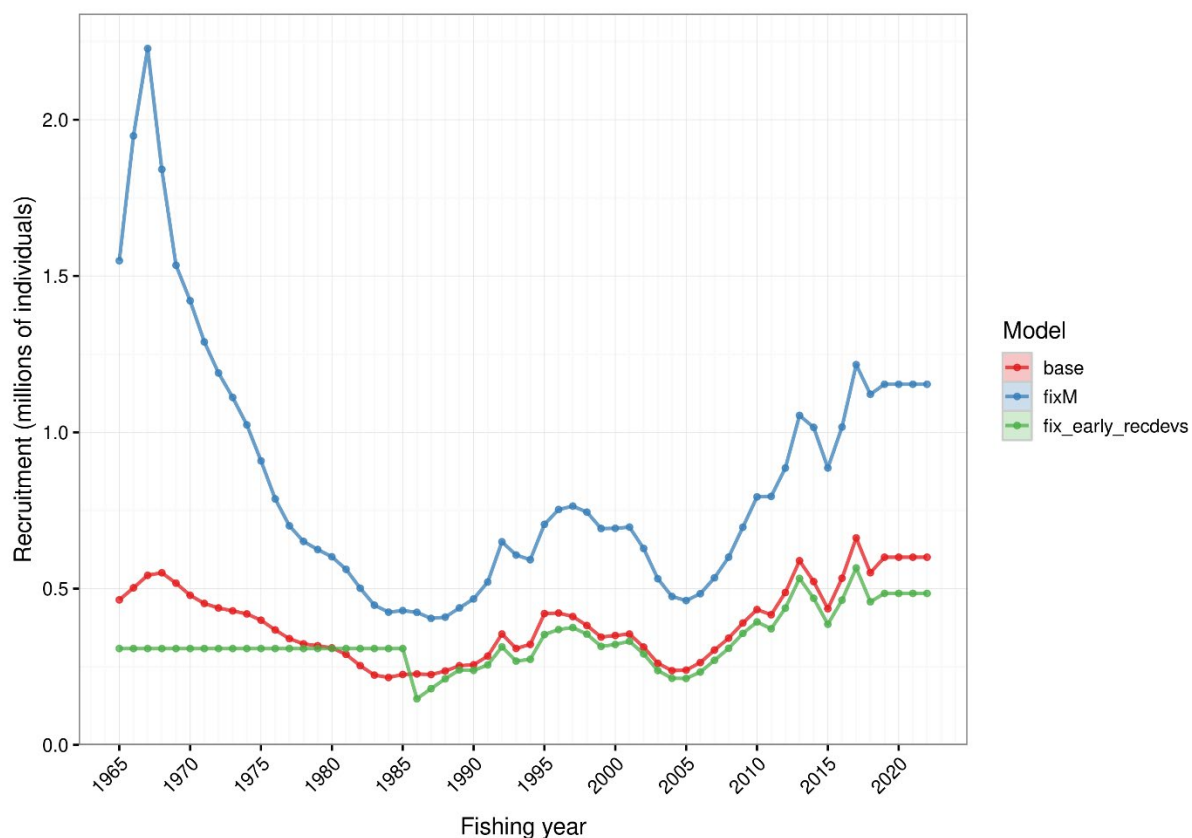


Figure 30: MAP recruitments for *base* and Group 2 sensitivity runs (*fixM*, *fix_early_recdevs*).

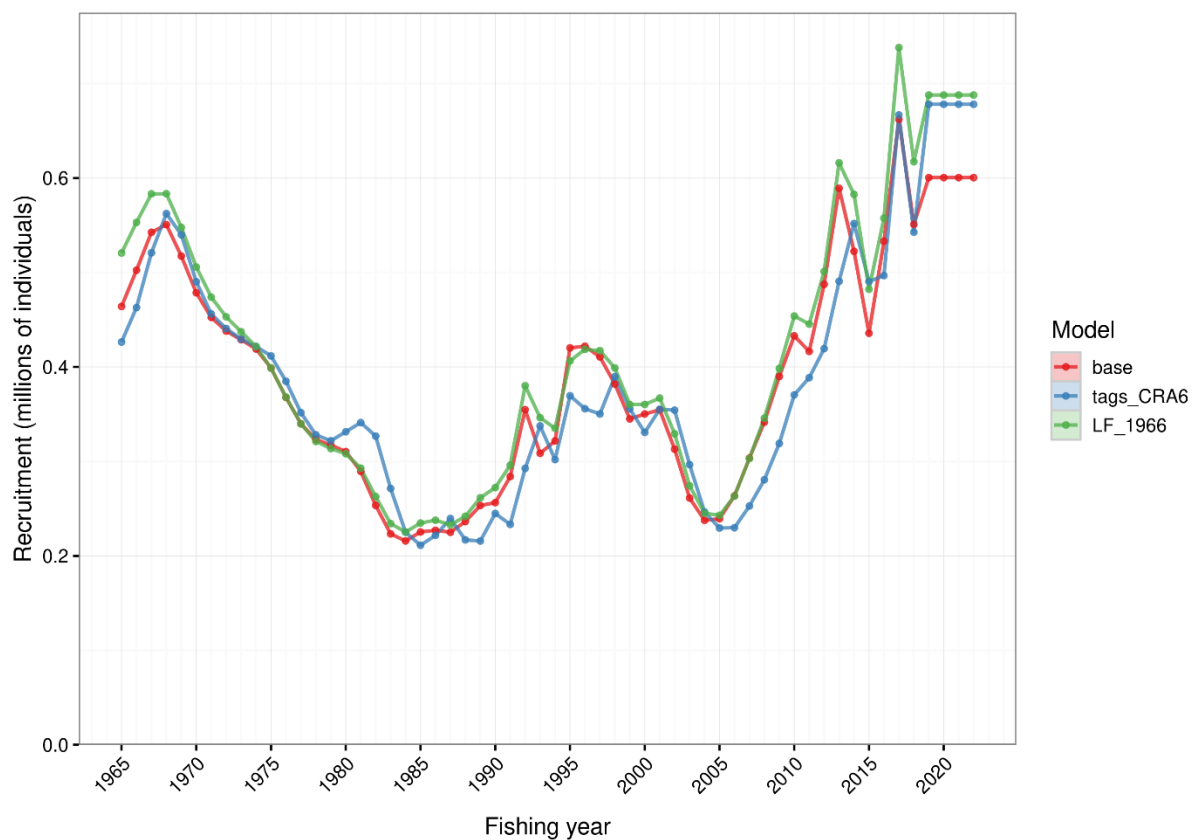


Figure 31: MAP recruitments for *base* and Group 3 sensitivity runs (*tags_CRA6*, *LF_1966*).

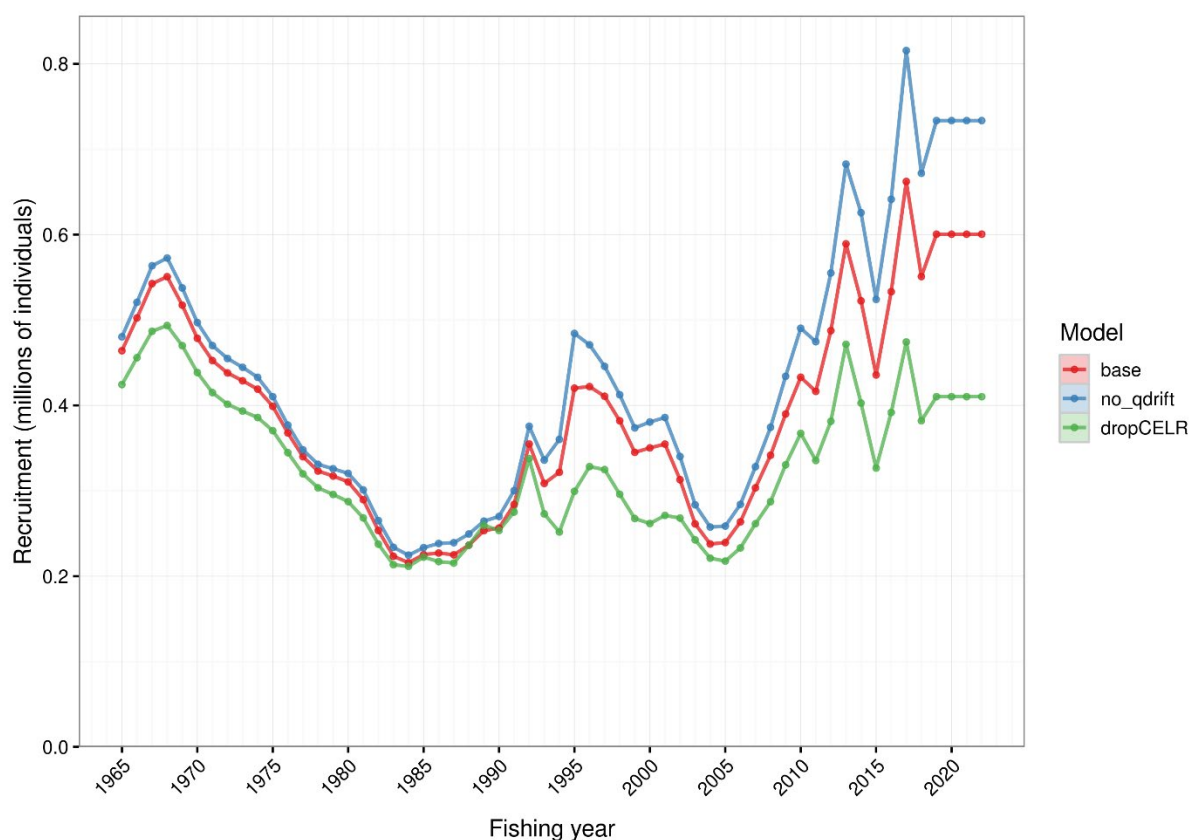


Figure 32: MAP recruitments for *base* and Group 4 sensitivity runs (*no_qdrift*, *dropCELR*).

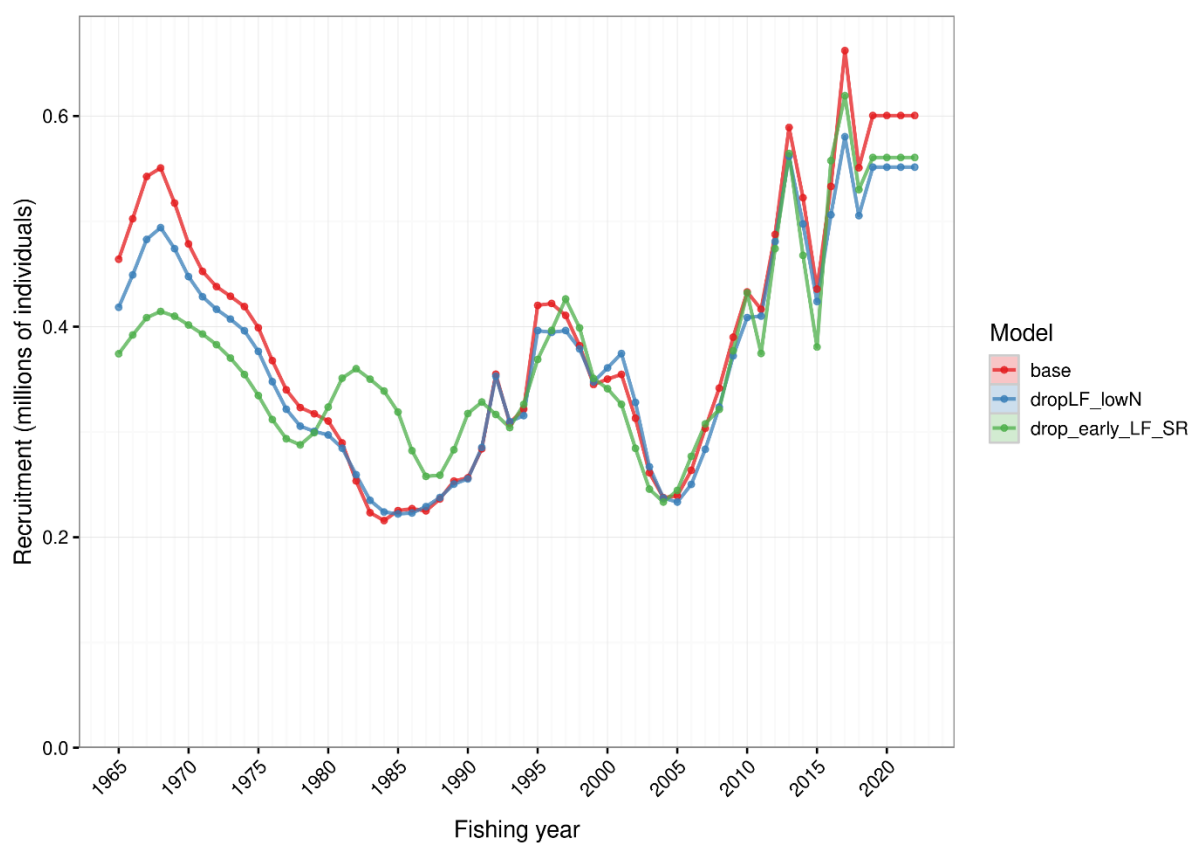


Figure 33: MAP recruitments for *base* and Group 5 sensitivity runs (*dropLF_lowN*, *drop_early_LF_SR*).

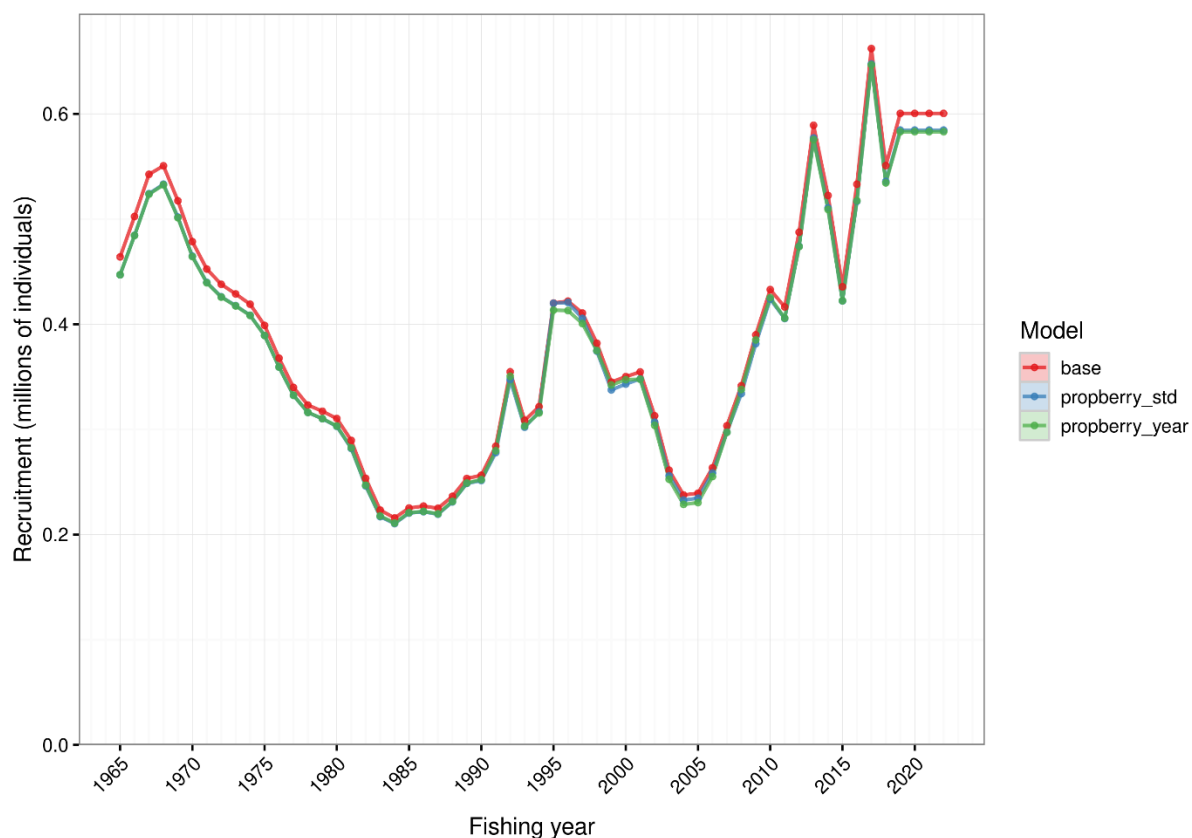


Figure 34: MAP recruitments for *base* and Group 6 sensitivity runs (*propberry_std*, *propberry_year*).

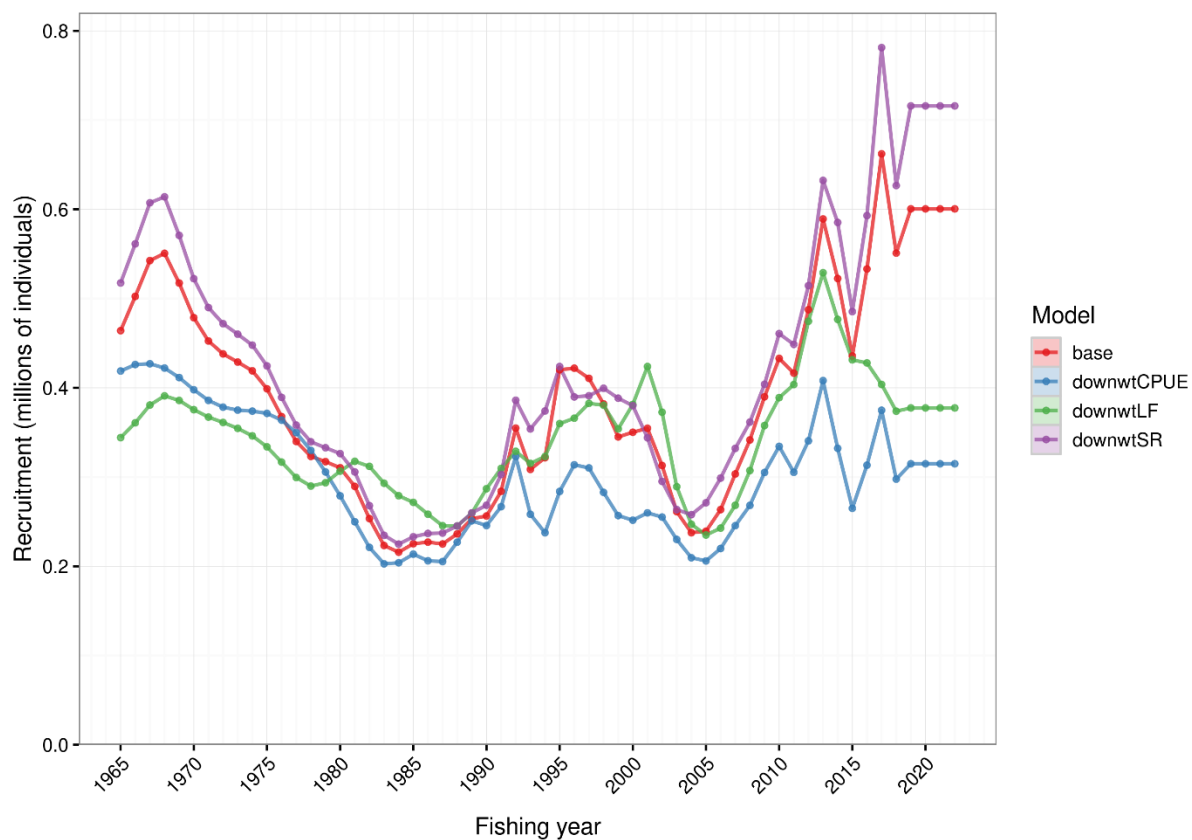


Figure 35: MAP recruitments for *base* and Group 7 sensitivity runs (*downwtCPUE*, *downwtLF*, *downwtSR*).

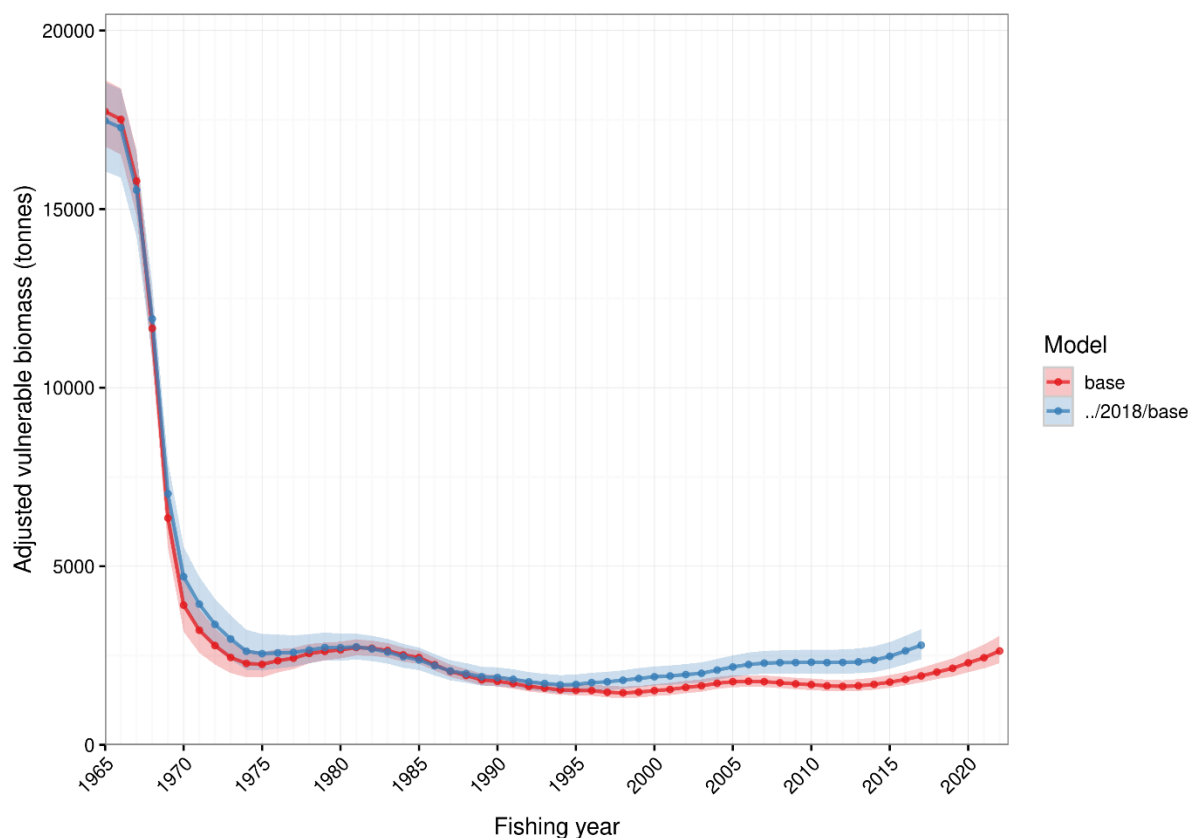


Figure 36: MAP adjusted vulnerable biomass for *base* and the 2018 assessment.

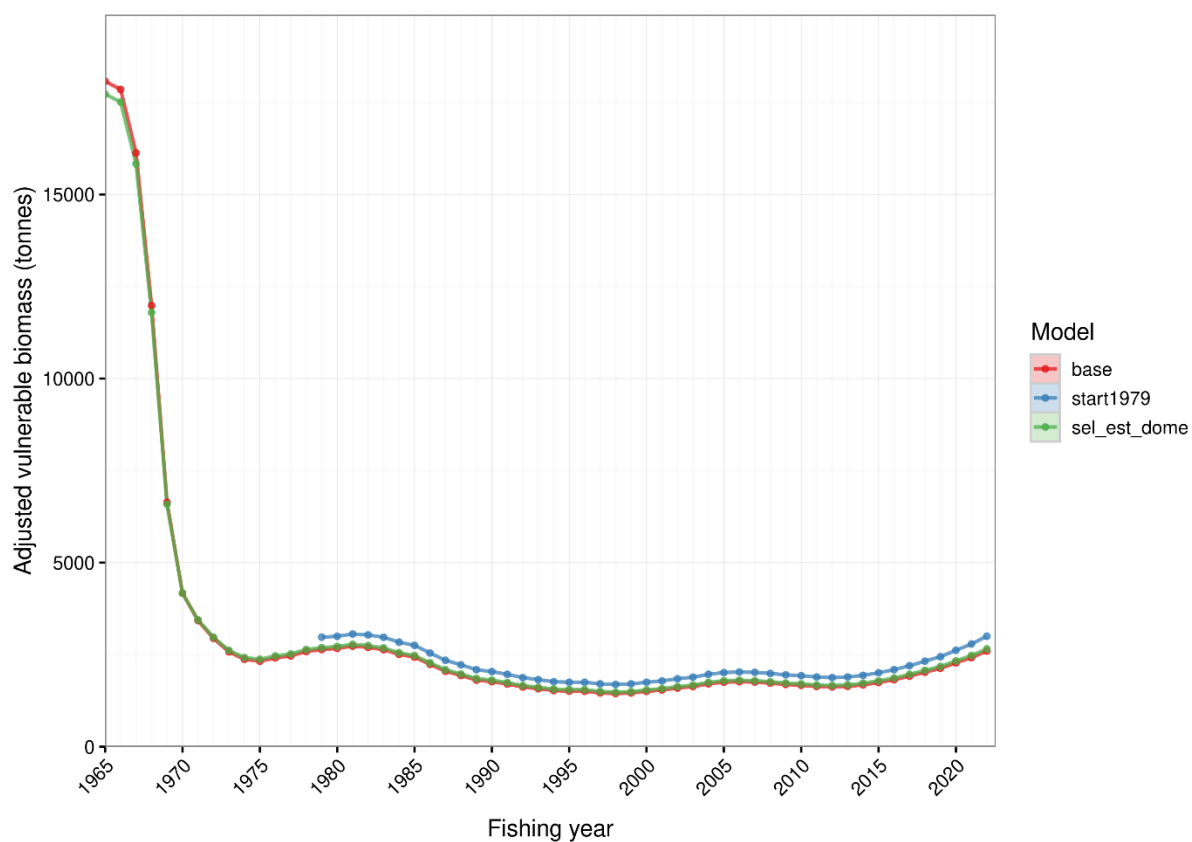


Figure 37: MAP adjusted vulnerable biomass for *base* and Group 1 sensitivity runs (*start1979*, *sel_est_dome*).

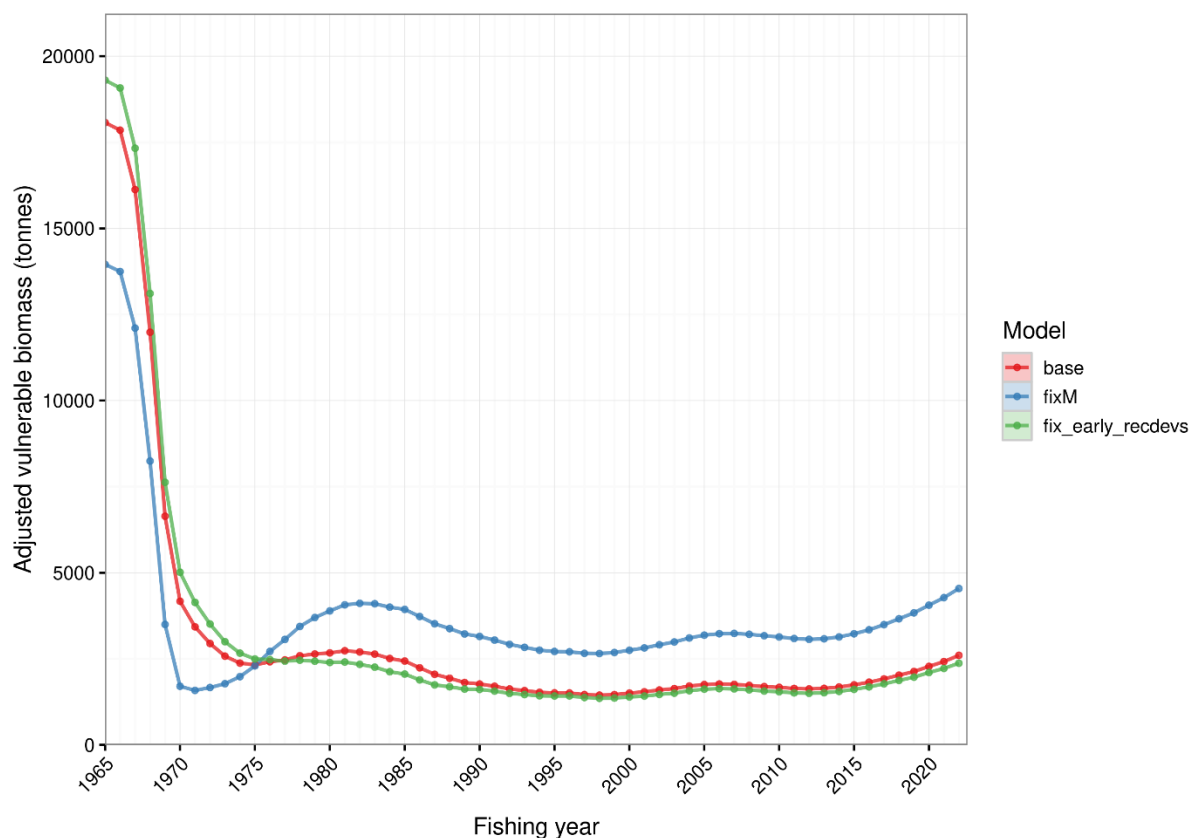


Figure 38: MAP adjusted vulnerable biomass for *base* and Group 2 sensitivity runs (*fixM*, *fix_early_recdevs*).

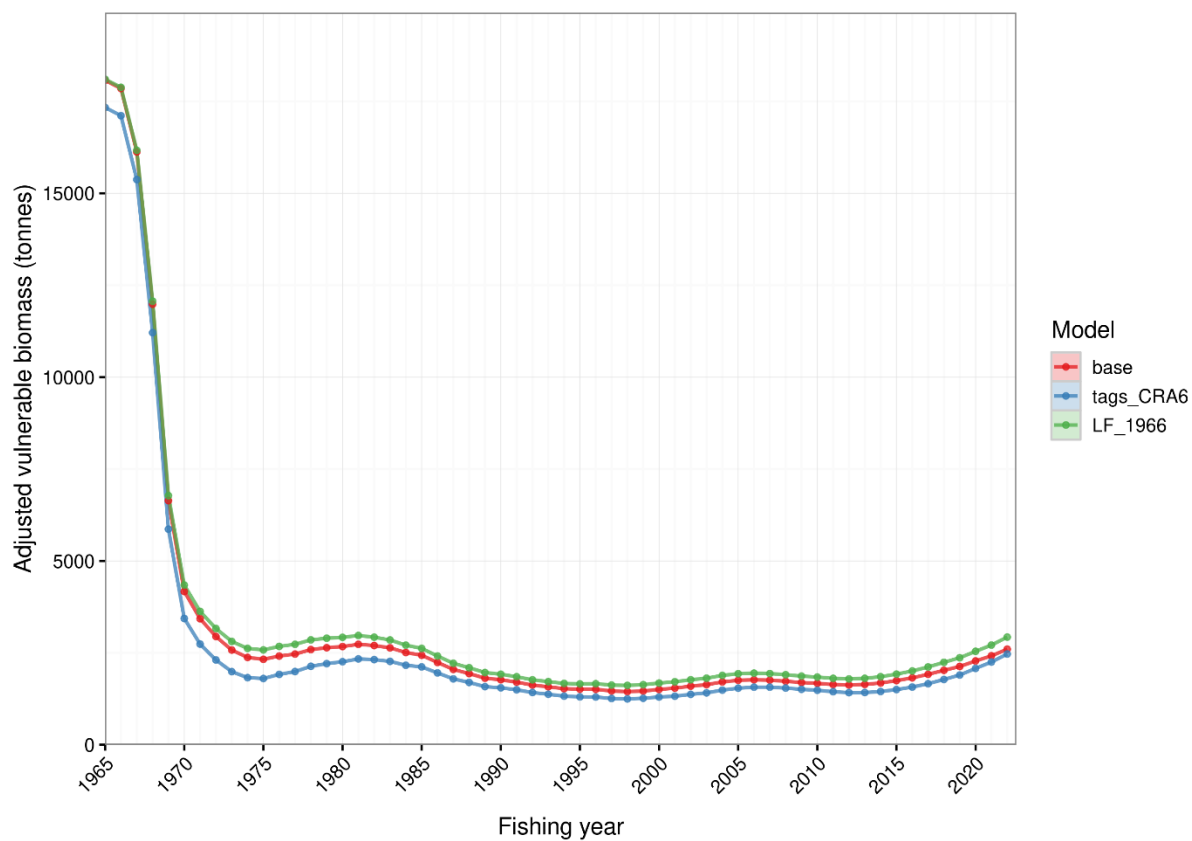


Figure 39: MAP adjusted vulnerable biomass for *base* and Group 3 sensitivity runs (*tags_CRA6*, *LF_1966*).

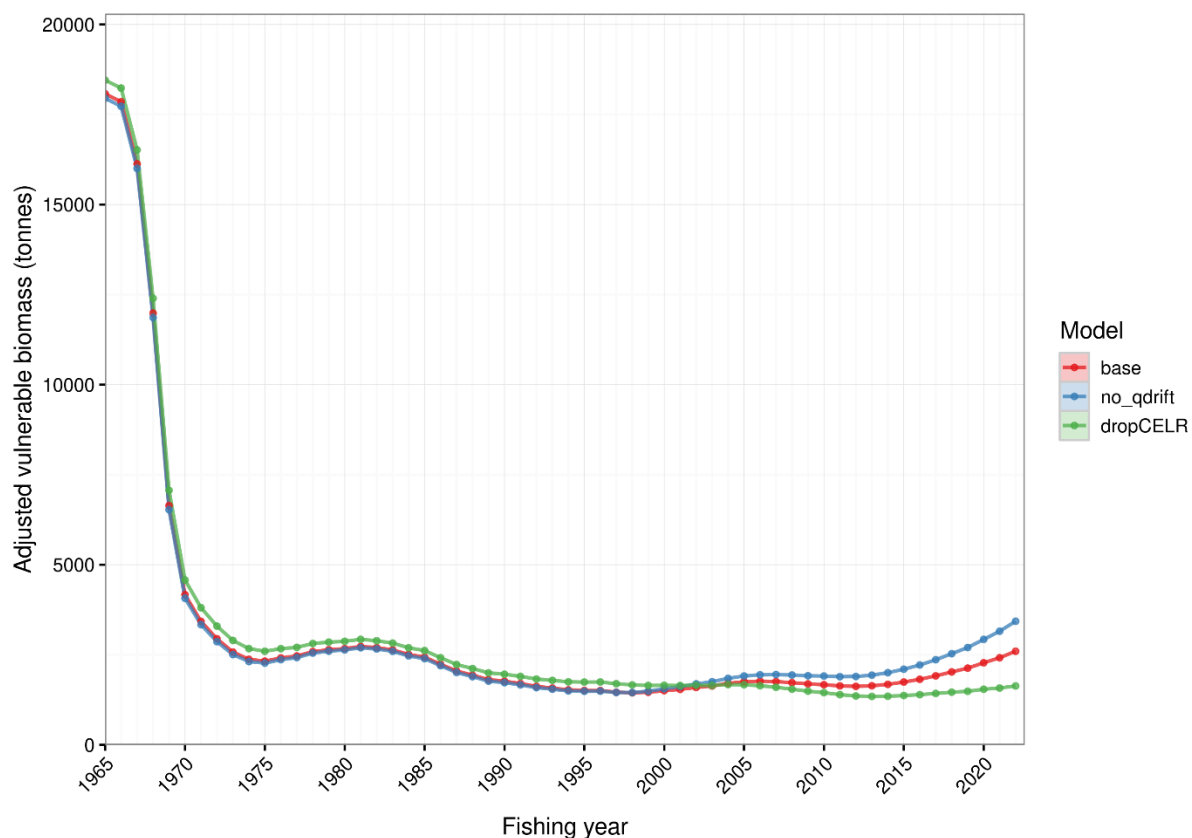


Figure 40: MAP adjusted vulnerable biomass for *base* and Group 4 sensitivity runs (*no_qdrift*, *dropCELR*).

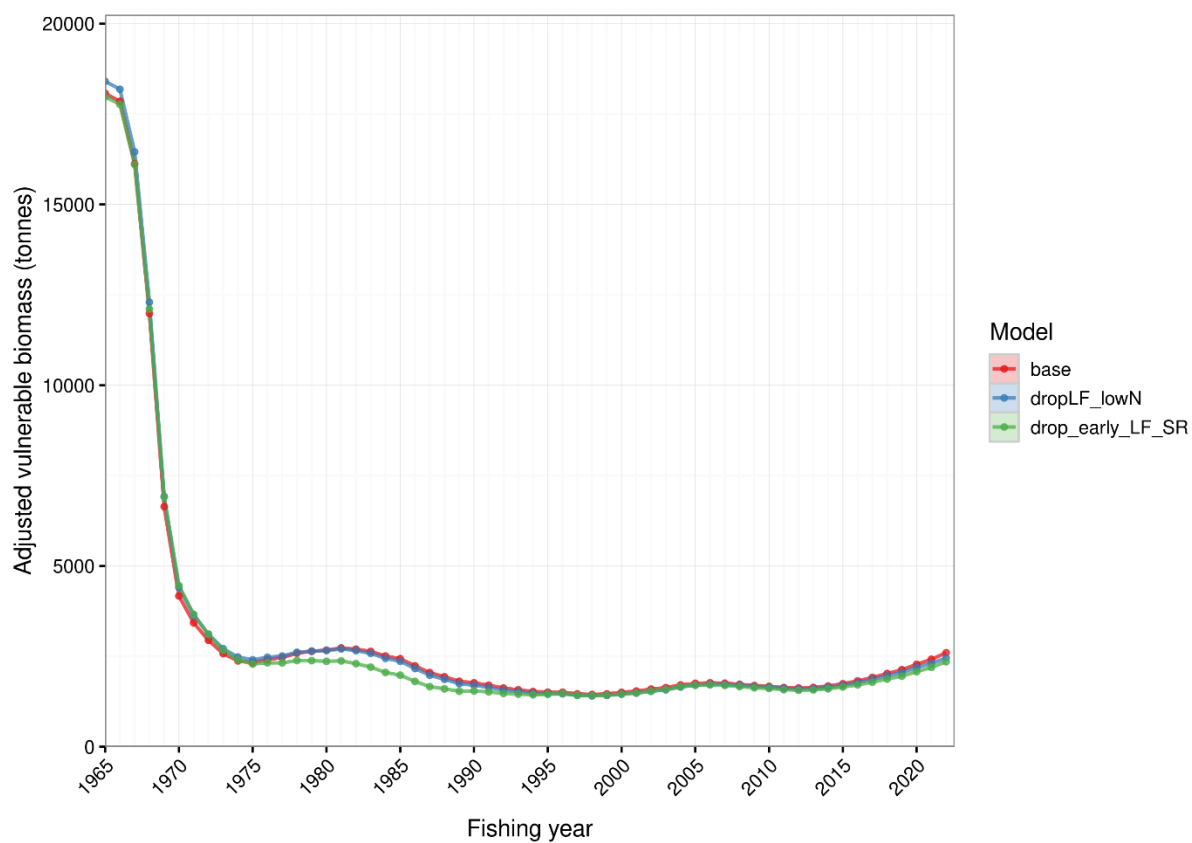


Figure 41: MAP adjusted vulnerable biomass for *base* and Group 5 sensitivity runs (*dropLF_lowN*, *drop_early_LF_SR*).

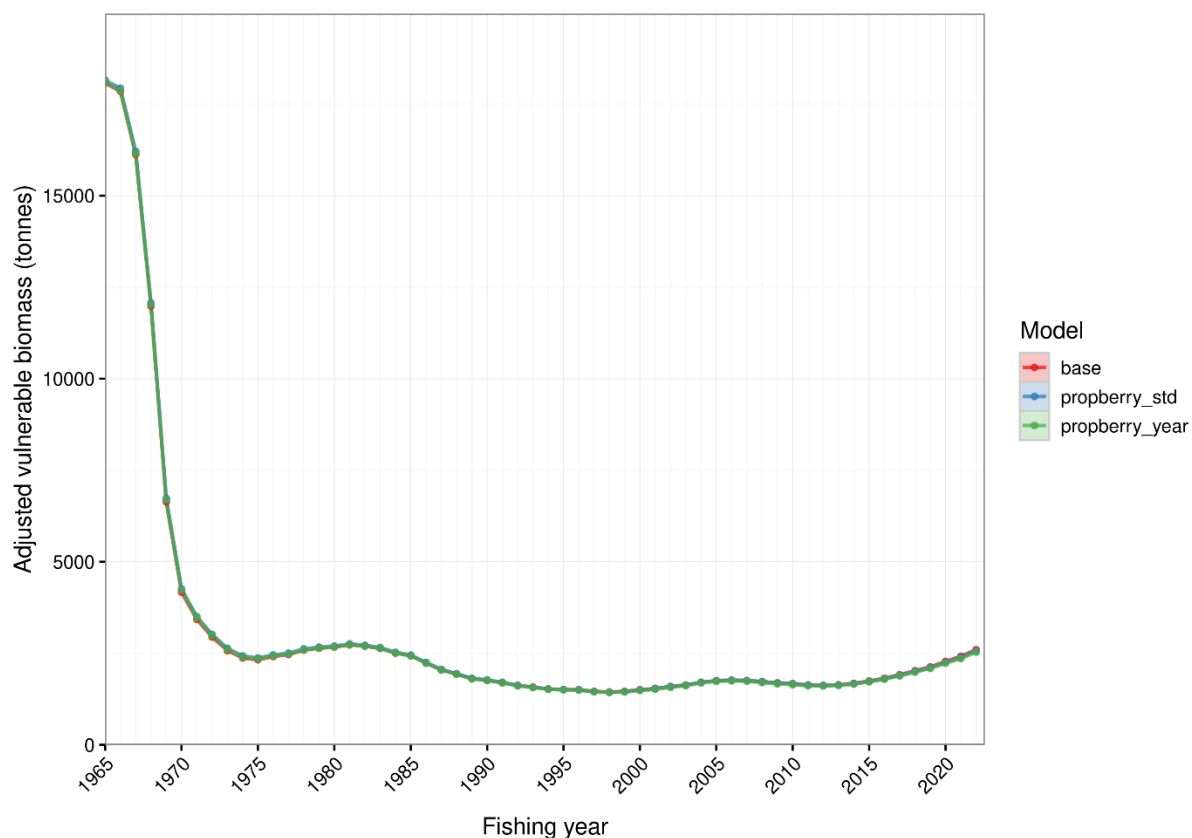


Figure 42: MAP adjusted vulnerable biomass for *base* and Group 6 sensitivity runs (*propberry_std*, *propberry_year*).

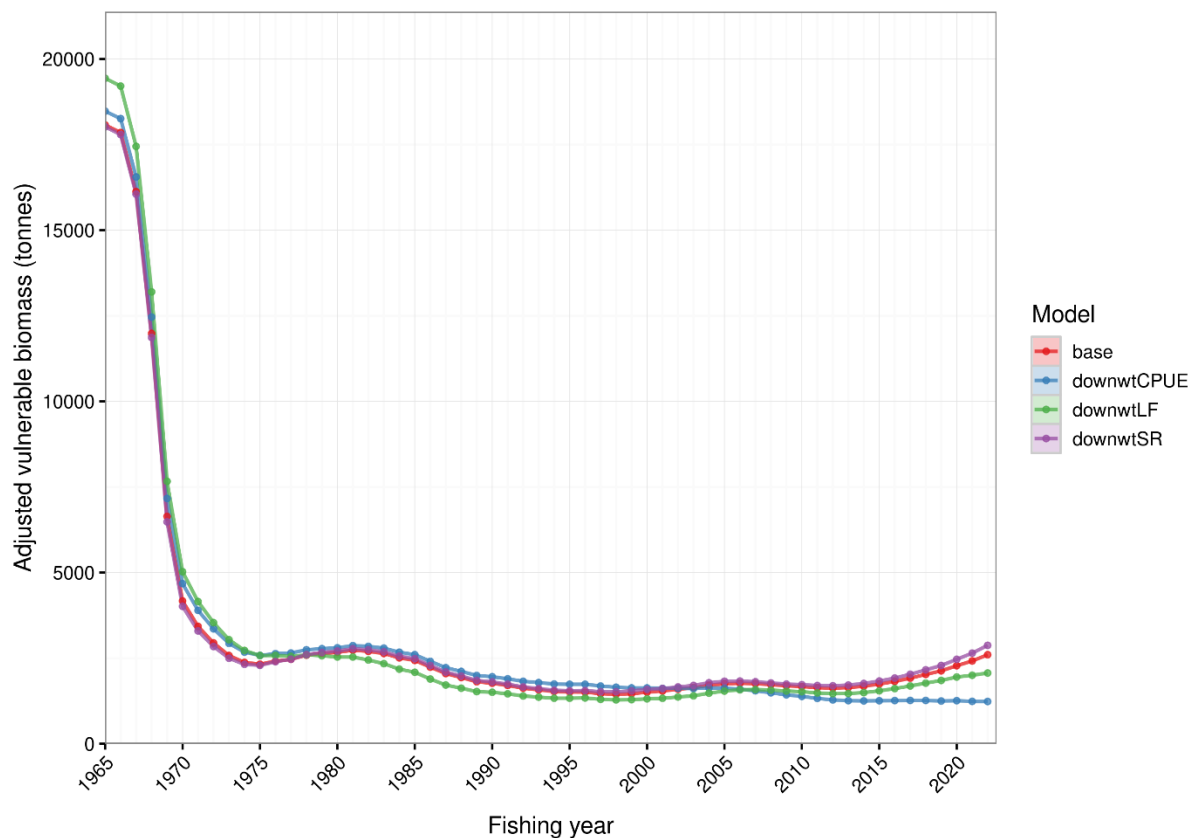


Figure 43: MAP adjusted vulnerable biomass for *base* and Group 7 sensitivity runs (*downwtCPUE*, *downwtLF*, *downwtSR*).

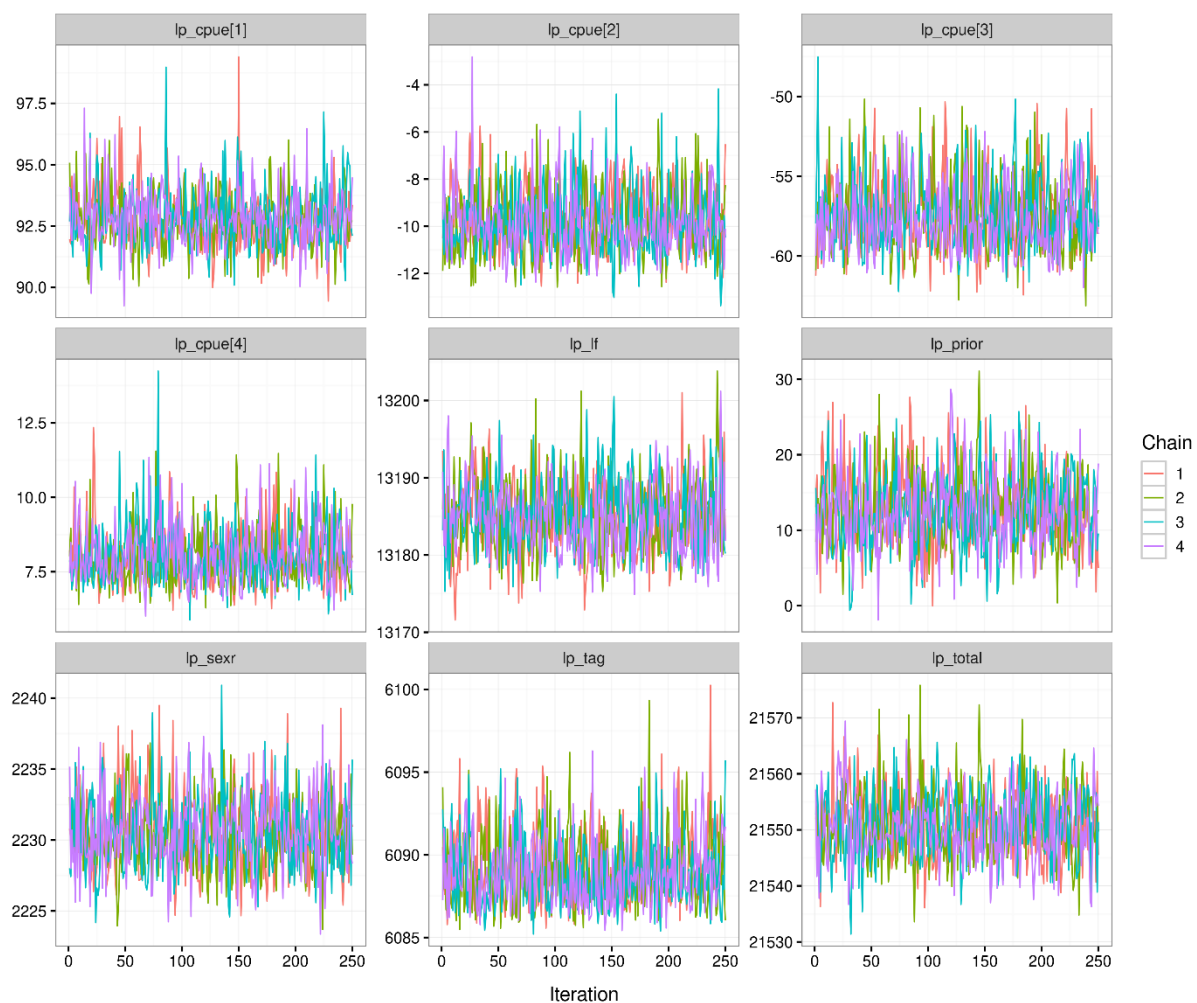


Figure 44: MCMC trace plots by independent chain for likelihood components for the base case model run.

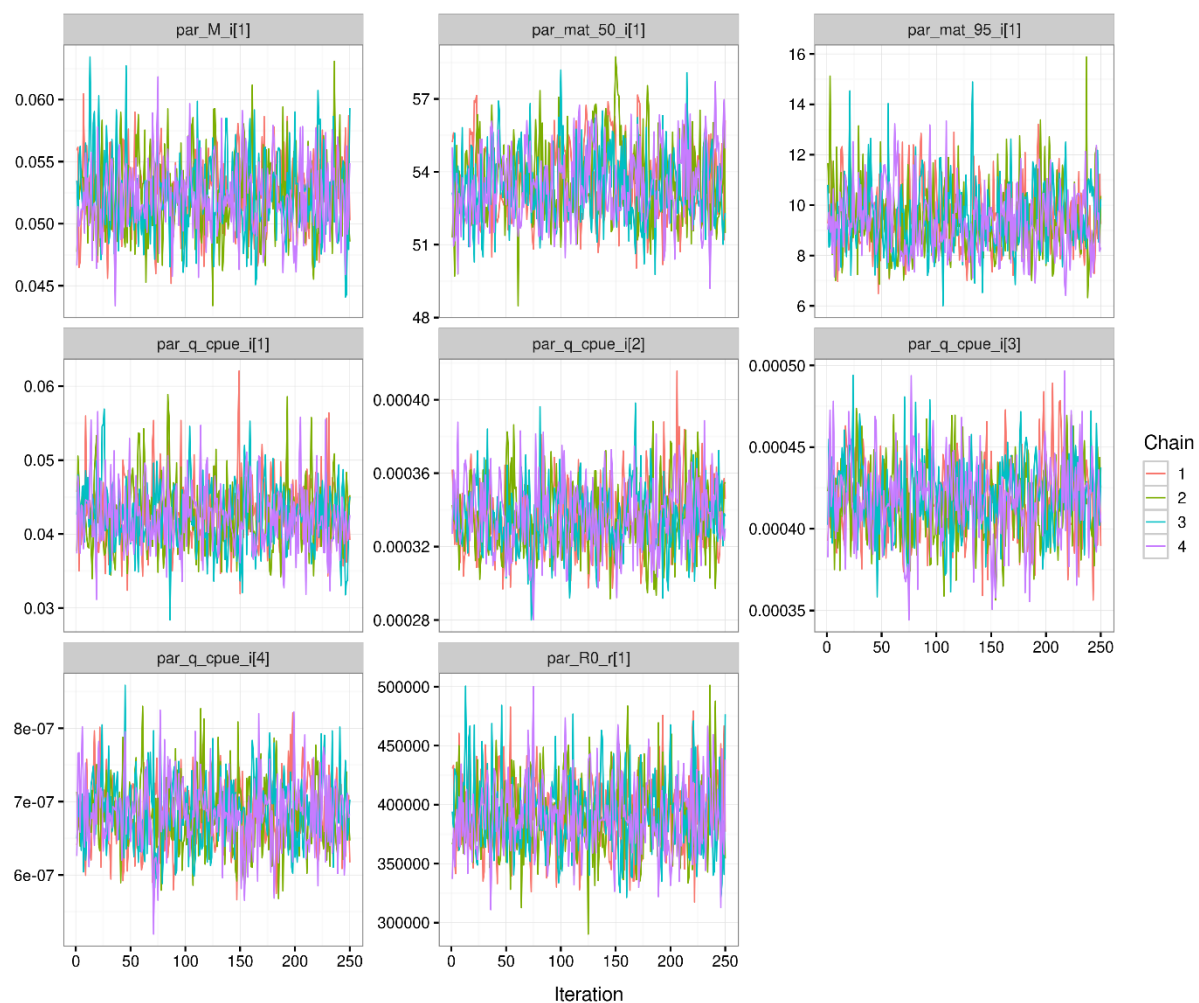


Figure 45: MCMC trace plots by independent chain for M , R_0 , maturation, and CPUE parameters for the base case model run.

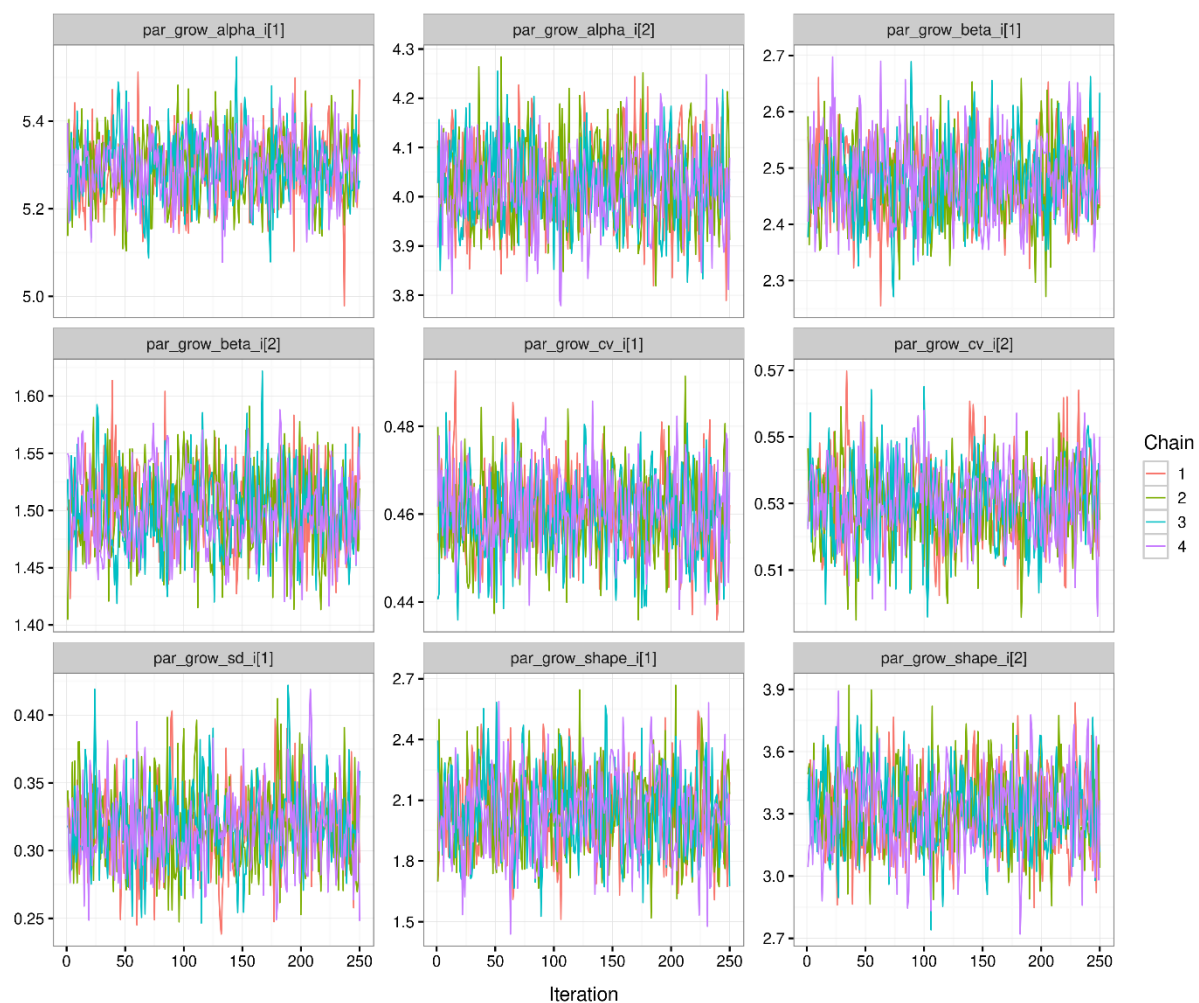


Figure 46: MCMC trace plots by independent chain for growth parameters for the base case model run.

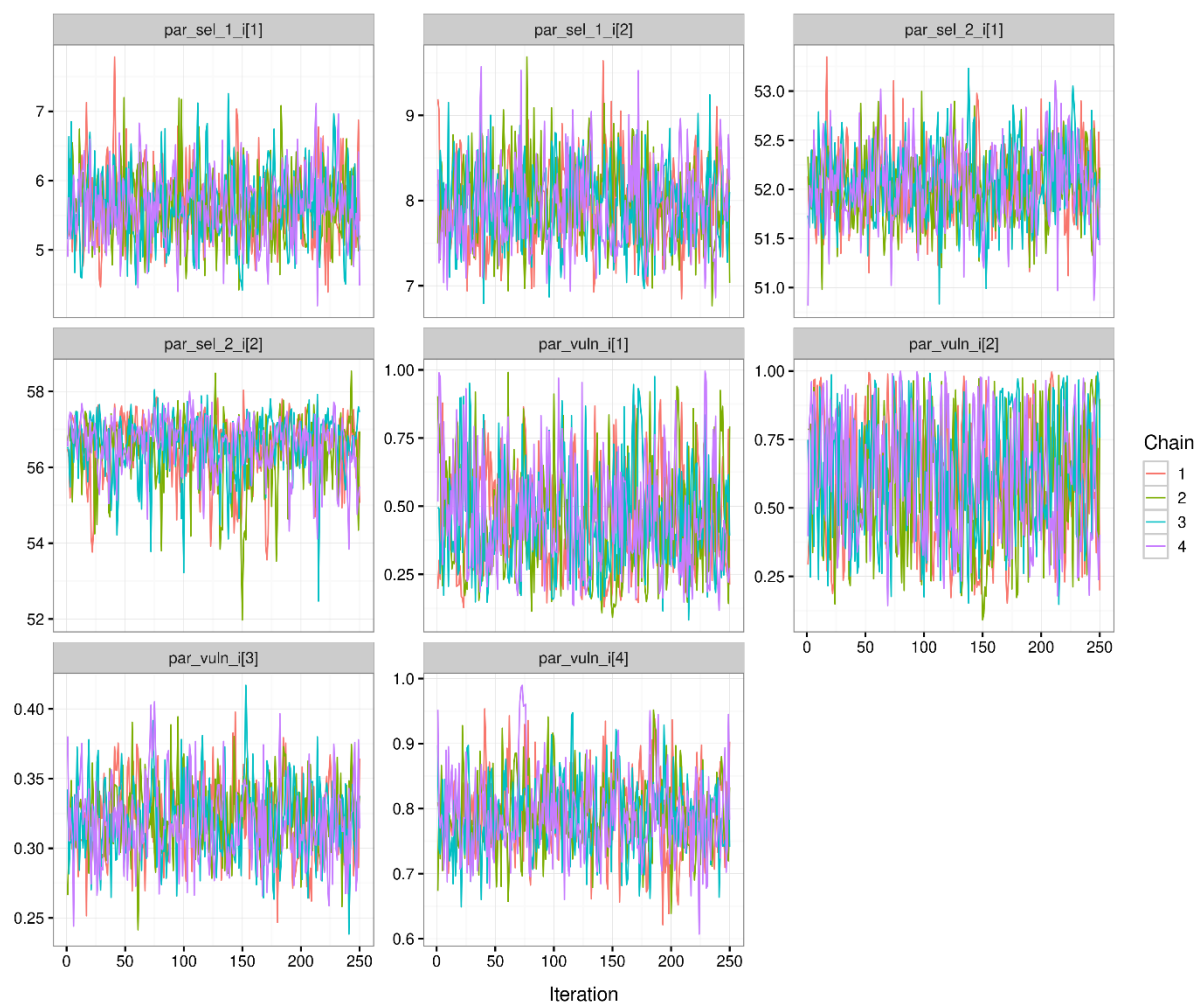


Figure 47: MCMC trace plots by independent chain for selectivity and vulnerability parameters for the base case model run.

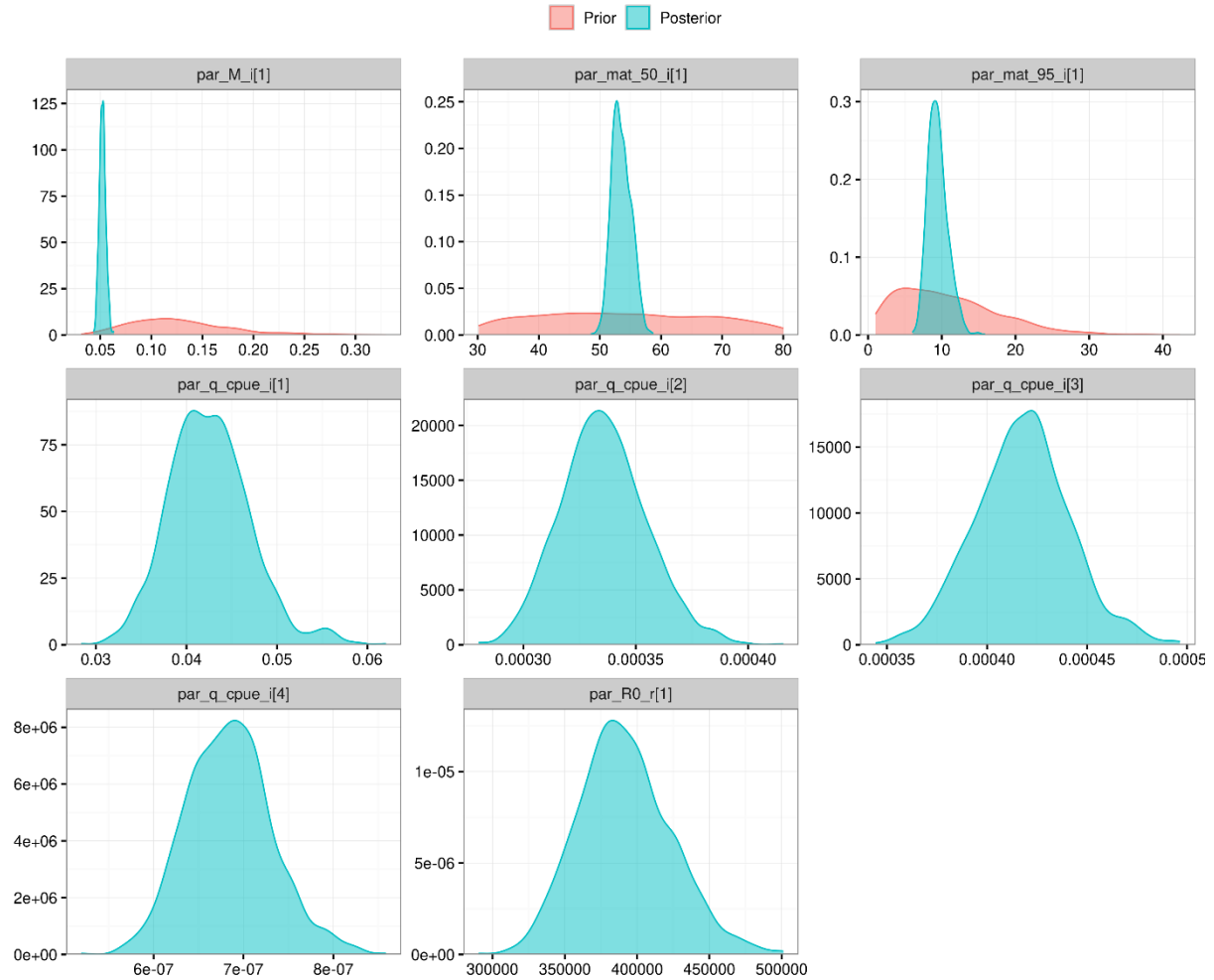


Figure 48: Density plots showing prior (red) and posterior distributions (blue) for natural mortality (M), the R_0 parameter, maturation, and CPUE parameters for the base case model run.

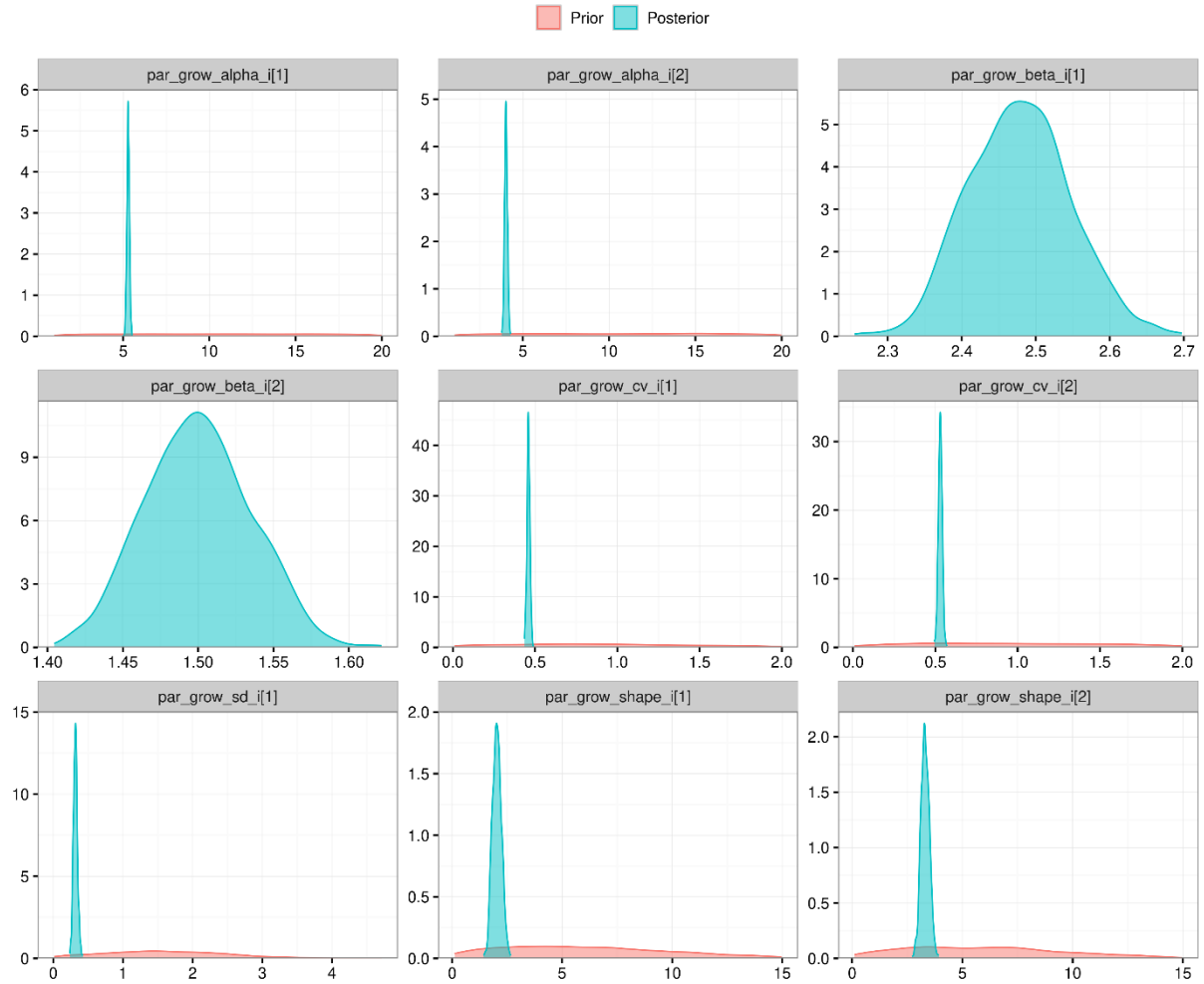


Figure 49: Density plots showing prior (red) and posterior distributions (blue) for parameters for the base case model run.

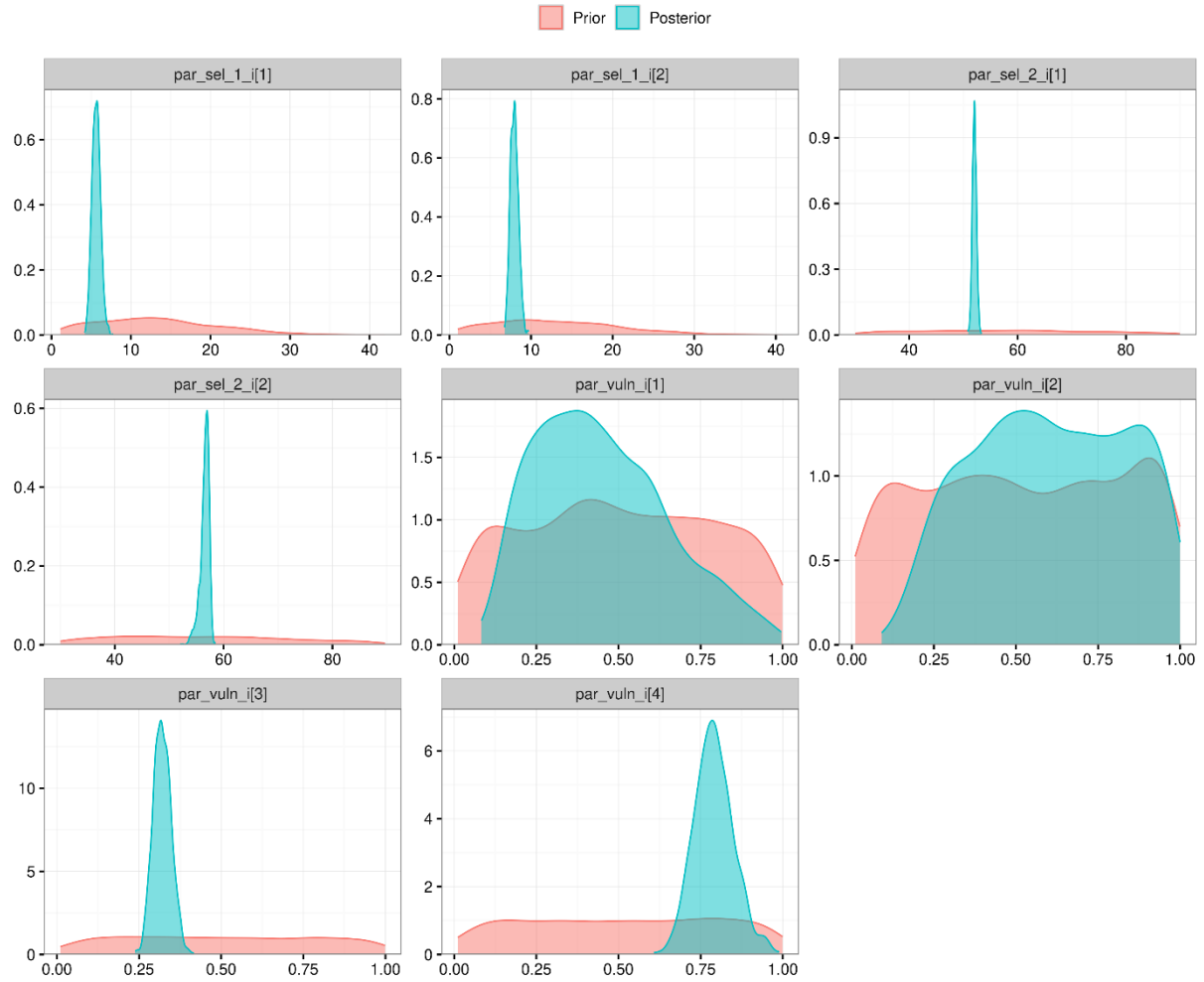


Figure 50: Density plots showing prior (red) and posterior distributions (blue) for selectivity and vulnerability parameters for the base case model run.

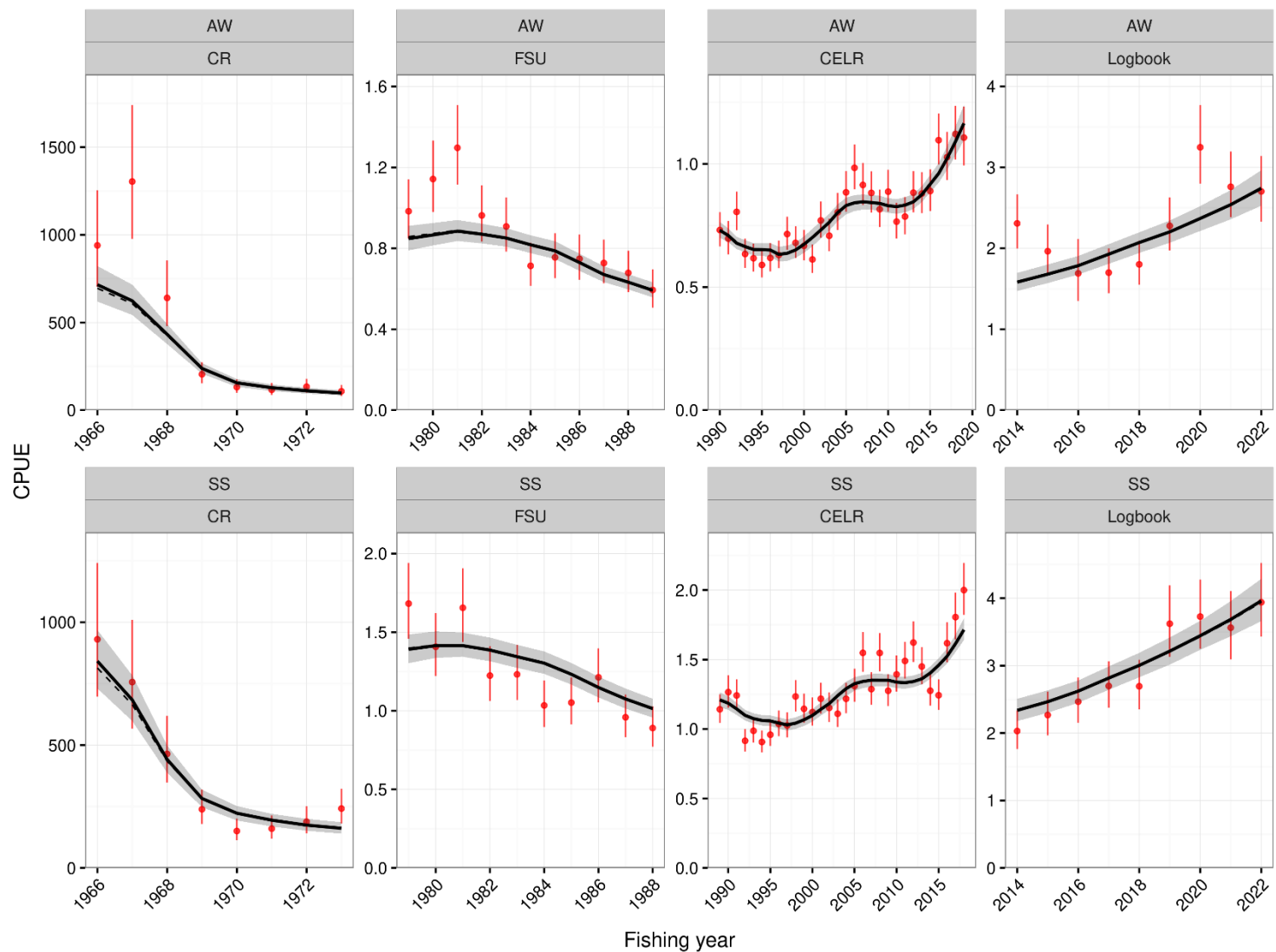


Figure 51: Posterior predicted CPUE for the CR, FSU, CELR, and logbook series by fishing year in the base case model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. A dashed line (often not visible as it is covered by the median line) indicates the corresponding MAP estimates. Error bars are +/- one standard deviation.

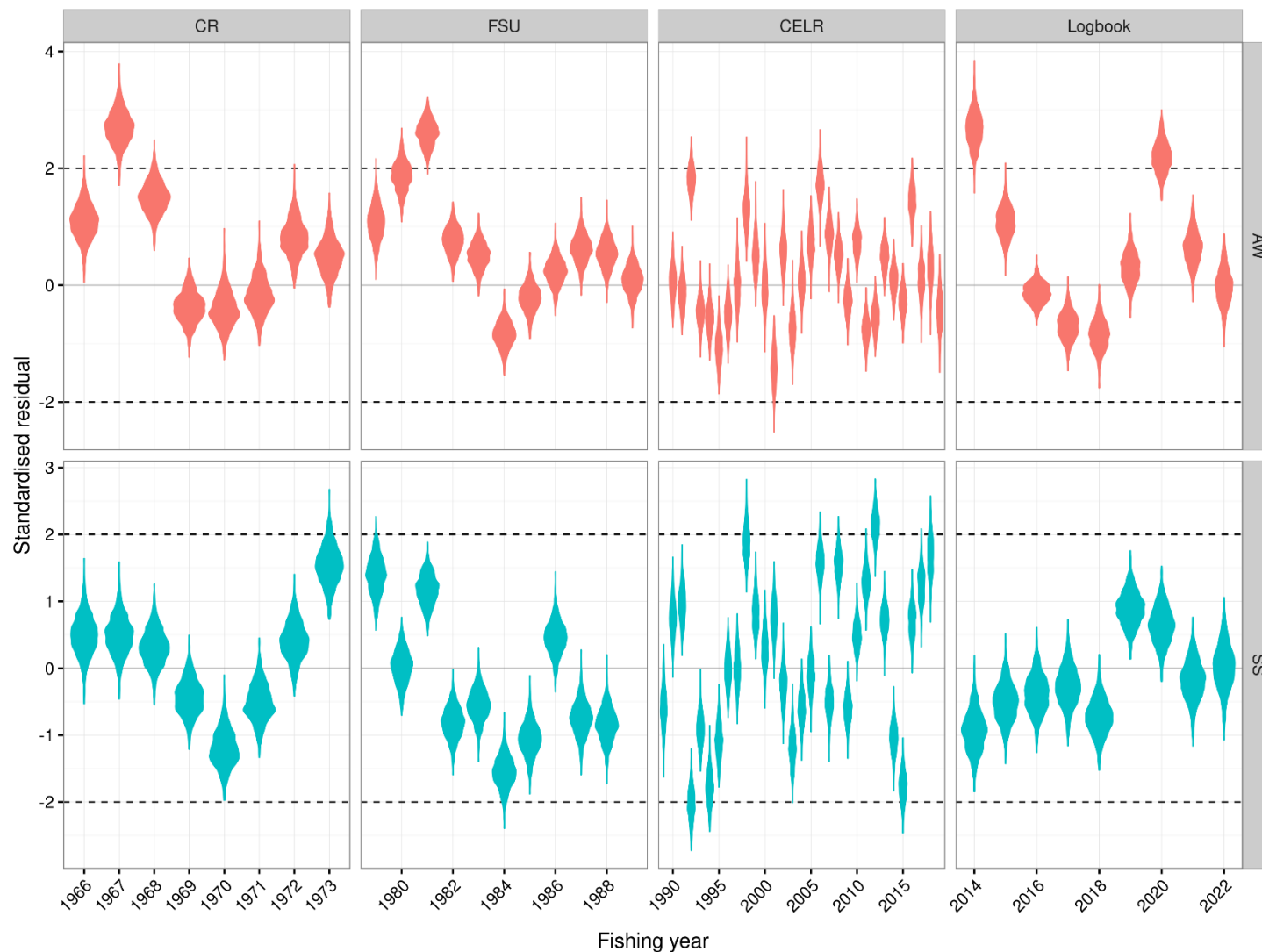


Figure 52: CPUE residuals for the CR, FSU, CELR, and logbook series by fishing year and season in the base case model run.

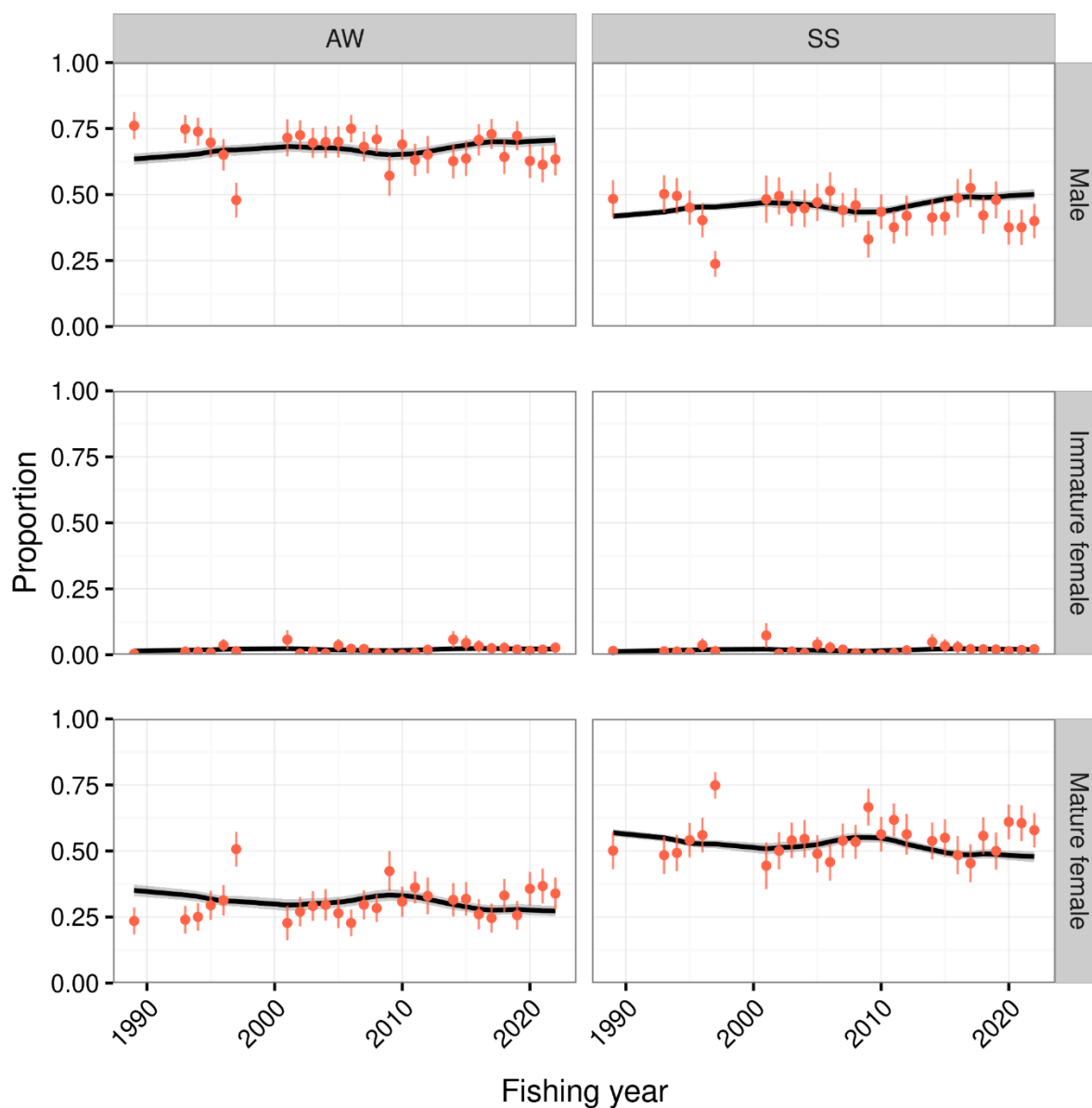


Figure 53: Posterior distribution of the sex ratios compared to the observed sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer) and sex, in the base case model run. The solid line indicates the posterior median and grey shading indicates the 90% credible intervals. Error bars are +/- one standard deviation.

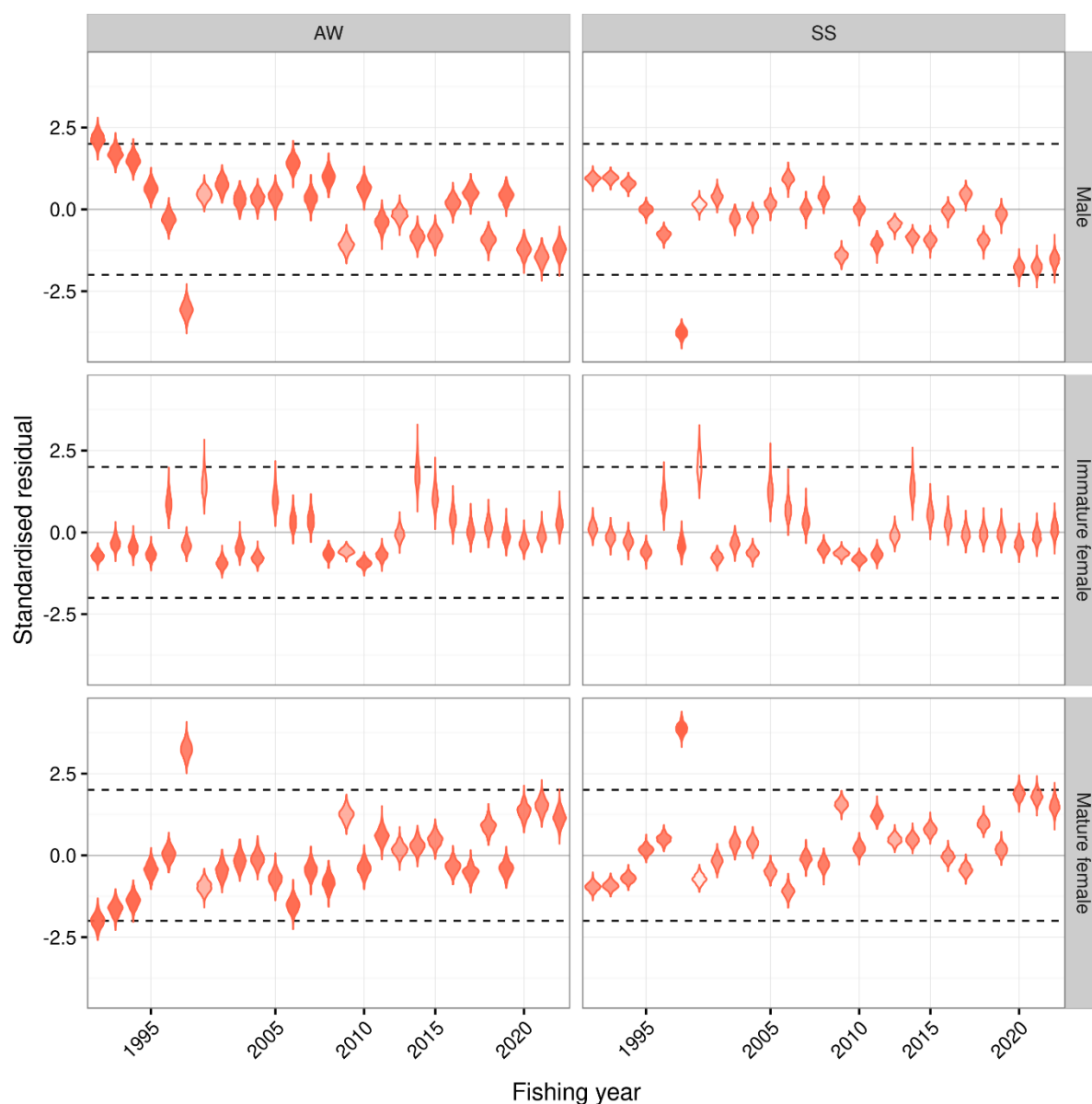


Figure 54: Posterior distribution of the standardised residuals of the sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex in the base case model run. The solid line indicates the posterior median and grey shading indicates the 90% credible intervals.

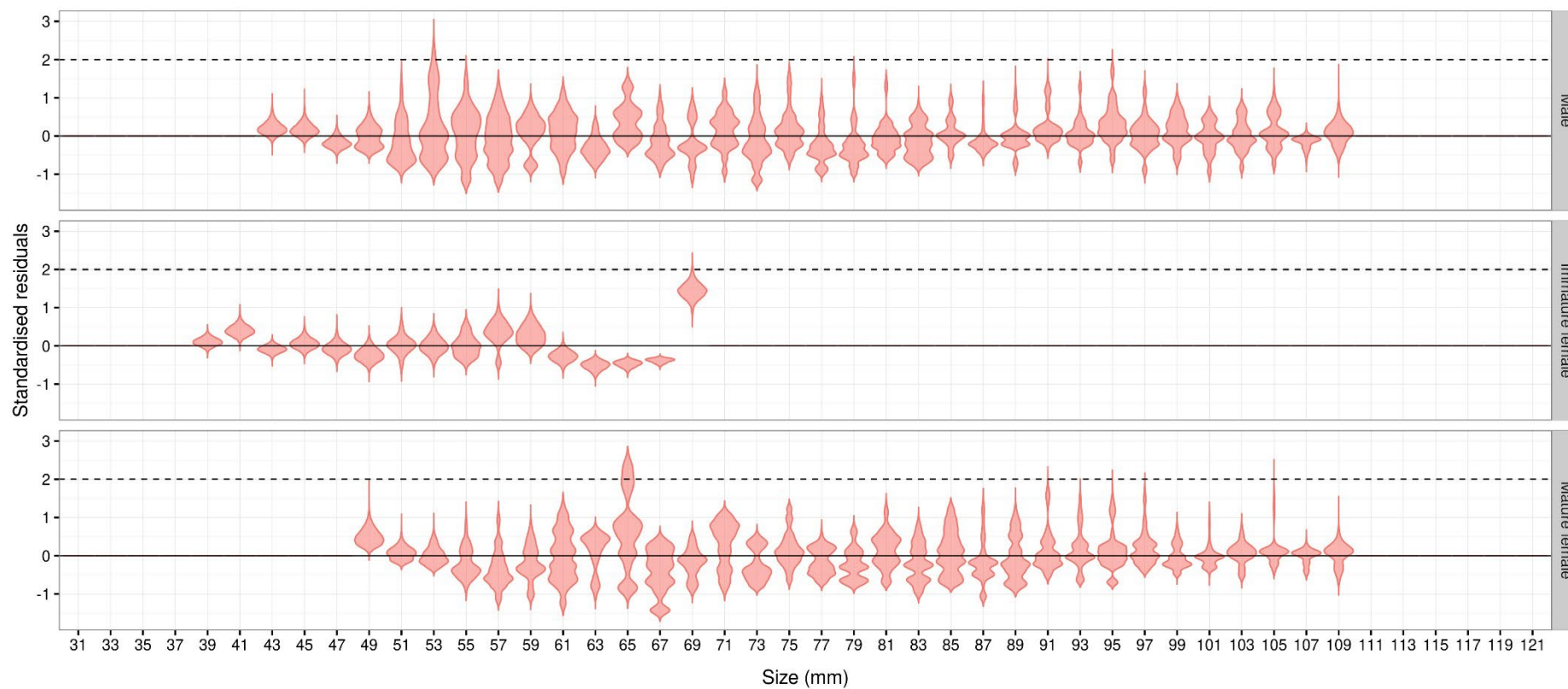


Figure 55: Posterior distribution of standardised residuals from fits to the LF data by sex and 2 mm TW bin.

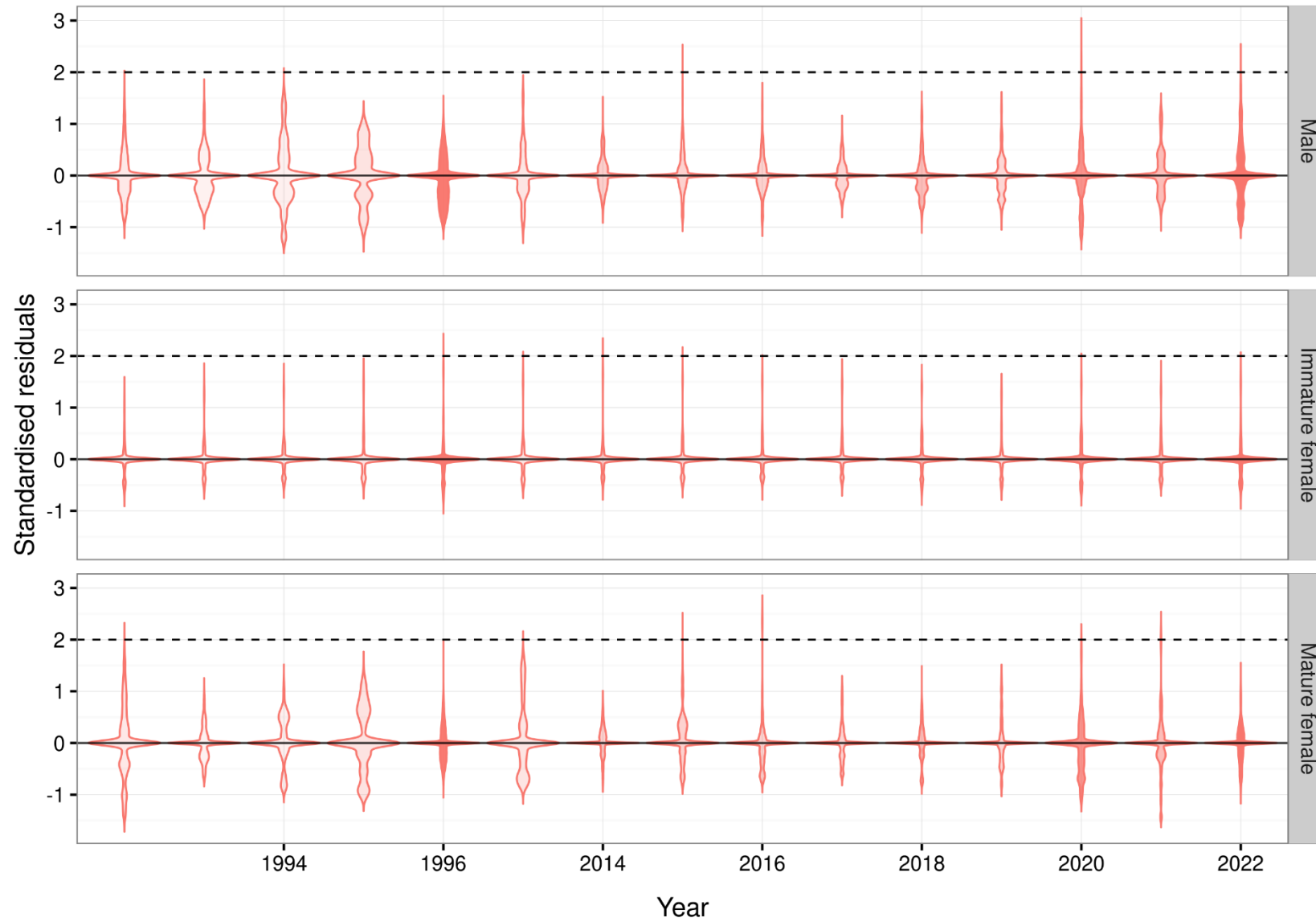


Figure 56: Posterior distribution of standardised residuals from fits to the LF data by sex and fishing year.

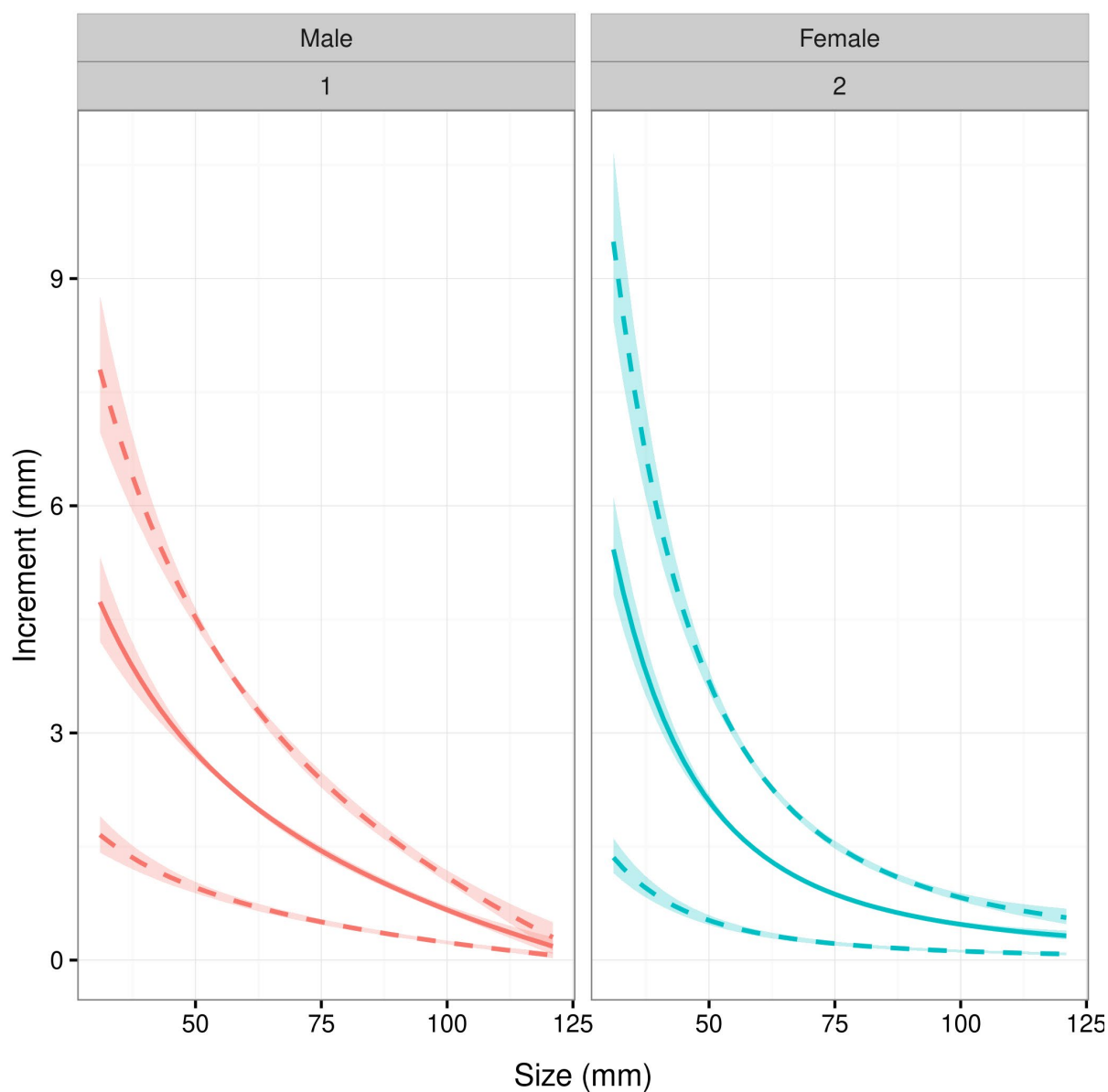


Figure 57: Posterior distribution of predicted six-monthly growth increment by size and sex in the base case model run showing the mean (solid line), ± 1 standard deviation (dashed line). Shading shows 90% credible interval.

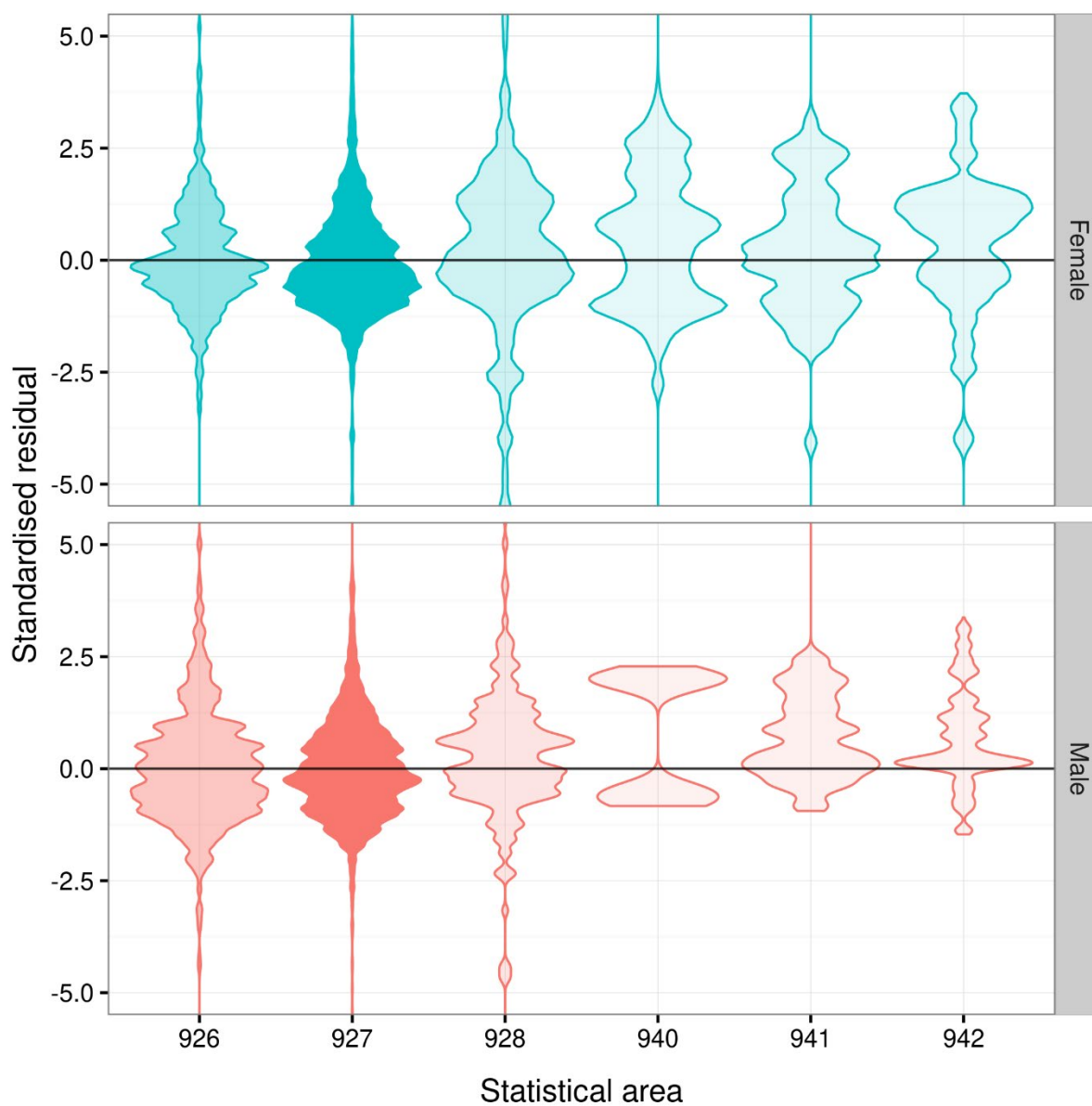


Figure 58: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release and sex in the base case model run. Shading intensity varies with number of observations.

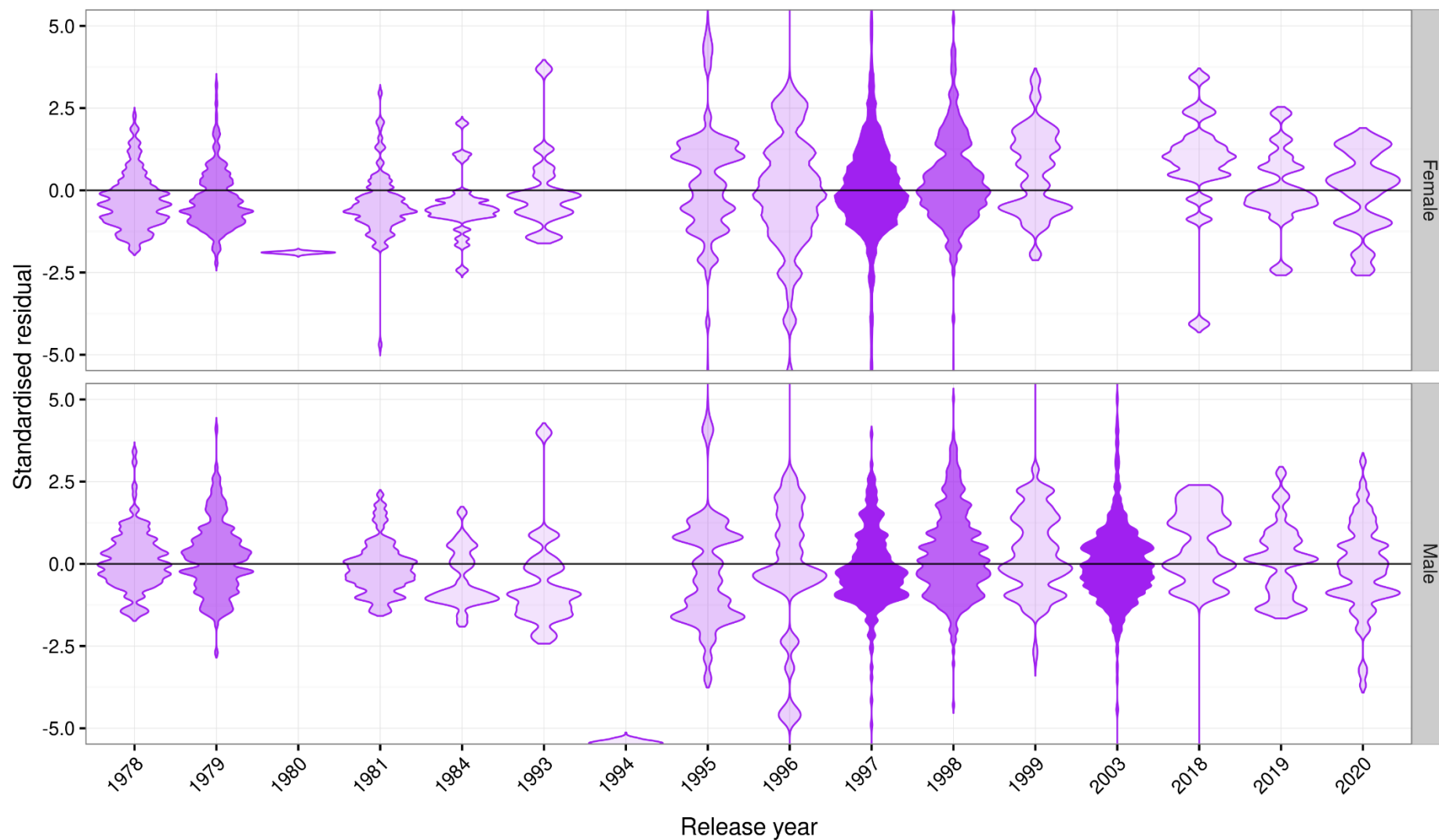


Figure 59: Posterior distribution of standardised residuals from model fit to the tag data by fishing year of release and sex in the base case model run. Shading intensity varies with number of observations.

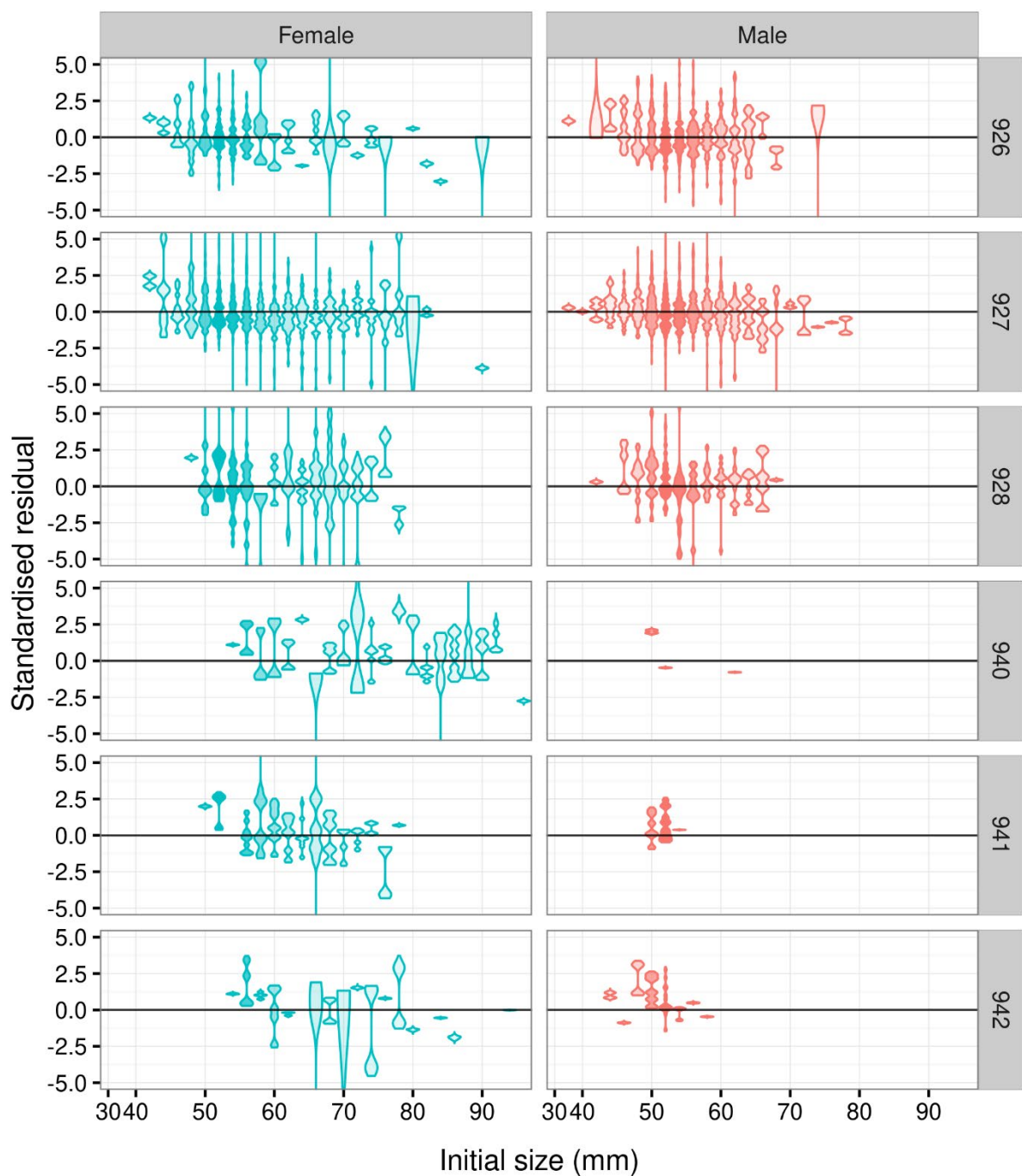


Figure 60: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release, initial size, and sex in the base case model run. Shading intensity varies with number of observations.

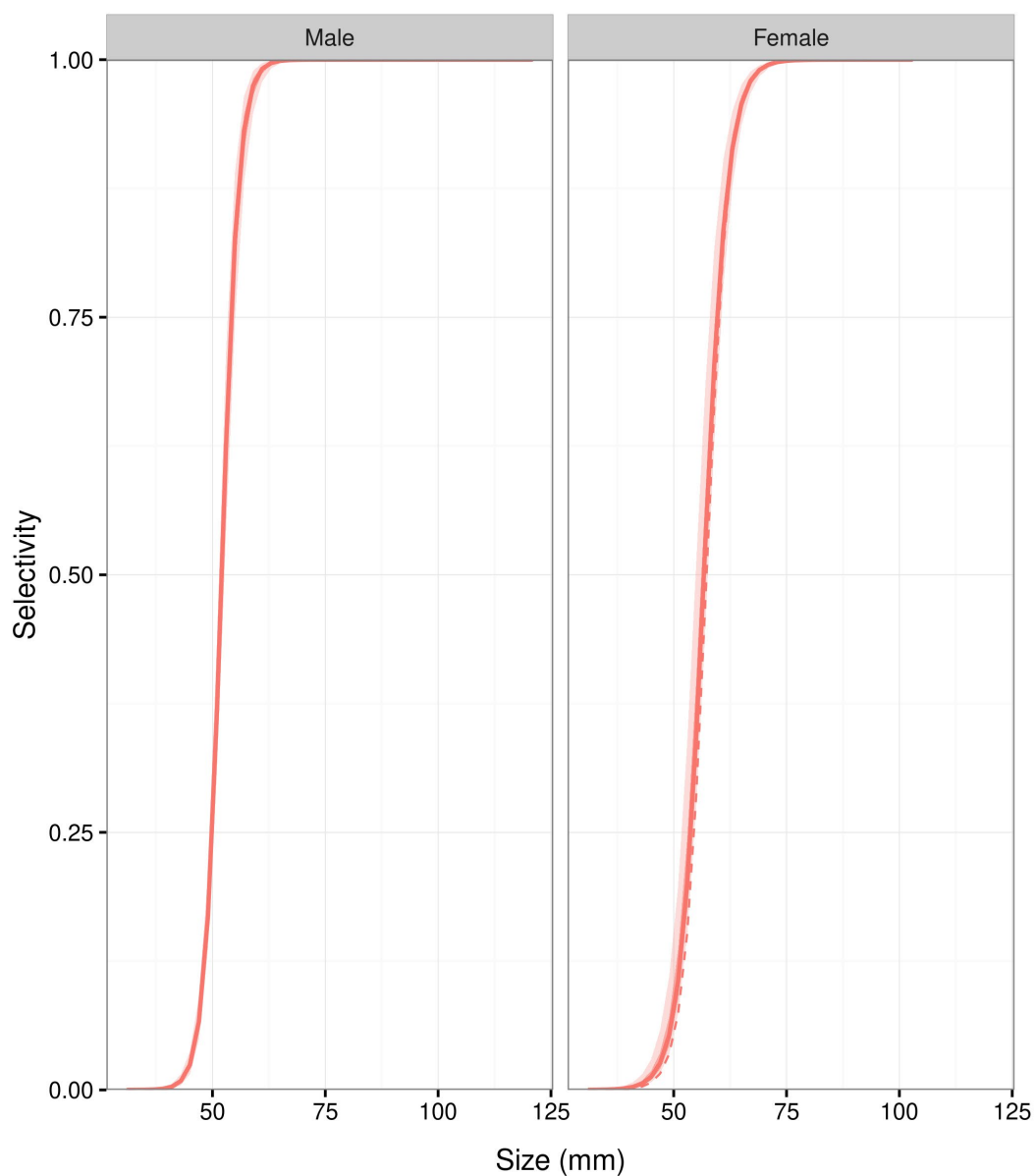


Figure 61: Posterior distribution of selectivity curve by size in the base case model run. The solid line indicates the posterior median and red shading indicates the 90% credible intervals.

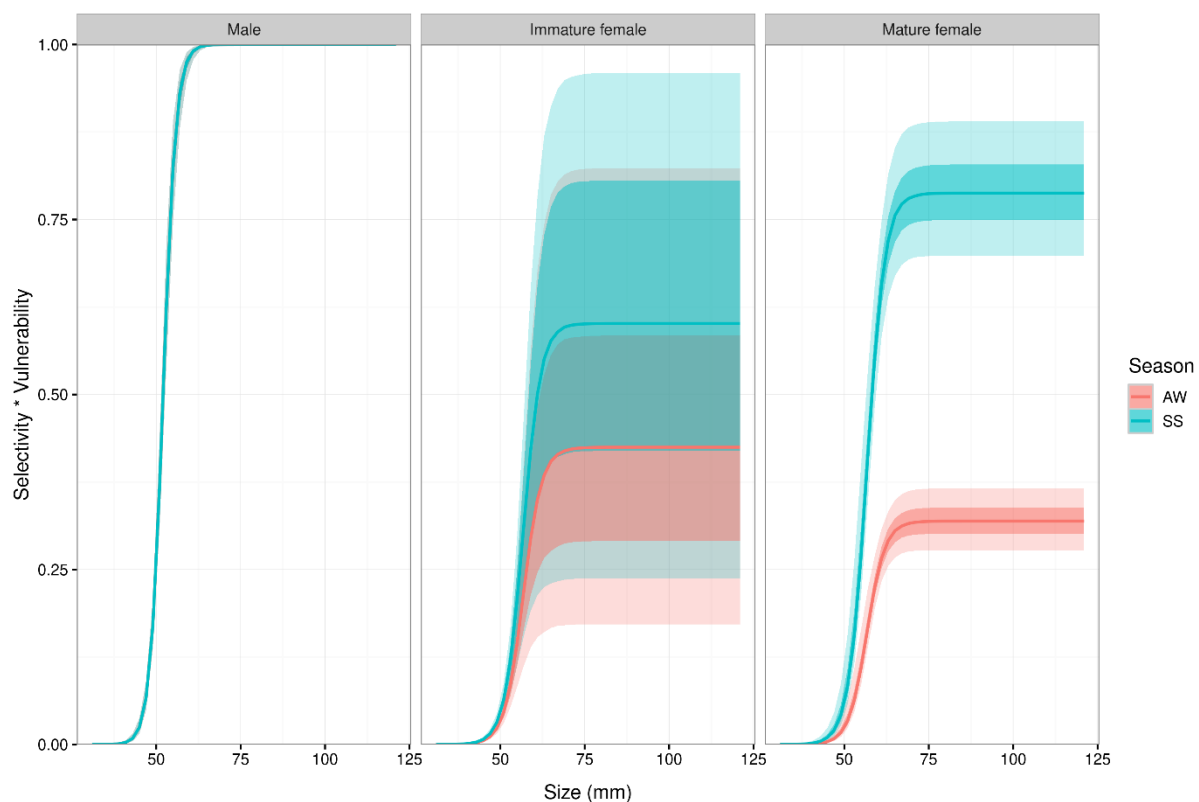


Figure 62: Posterior distribution of selectivity by size multiplied by vulnerability by sex and season in the base case model run. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

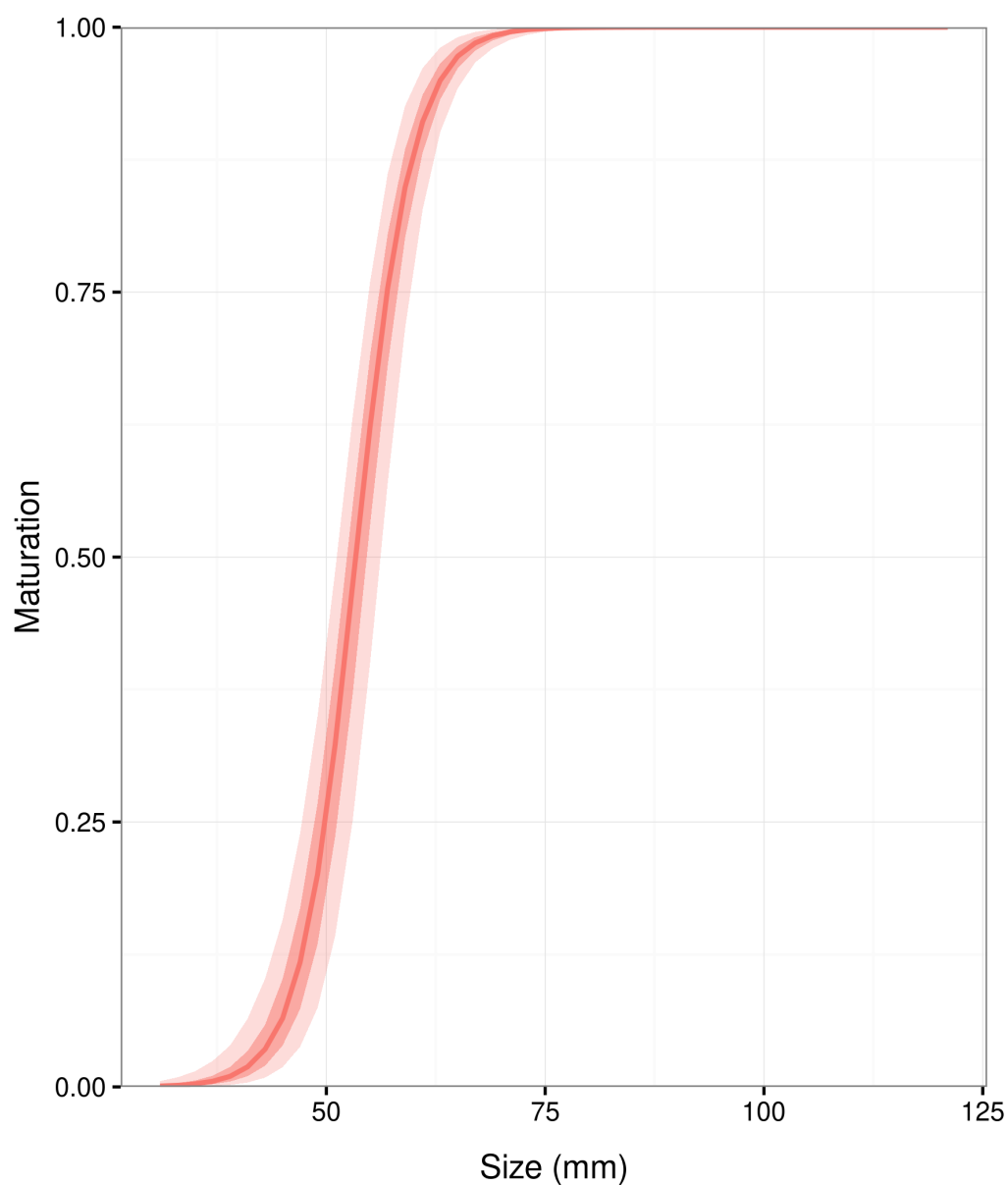


Figure 63: Posterior distribution of female maturation curve by size in the base case model run. The solid line indicates the posterior median and red shading indicates the 90% credible intervals.

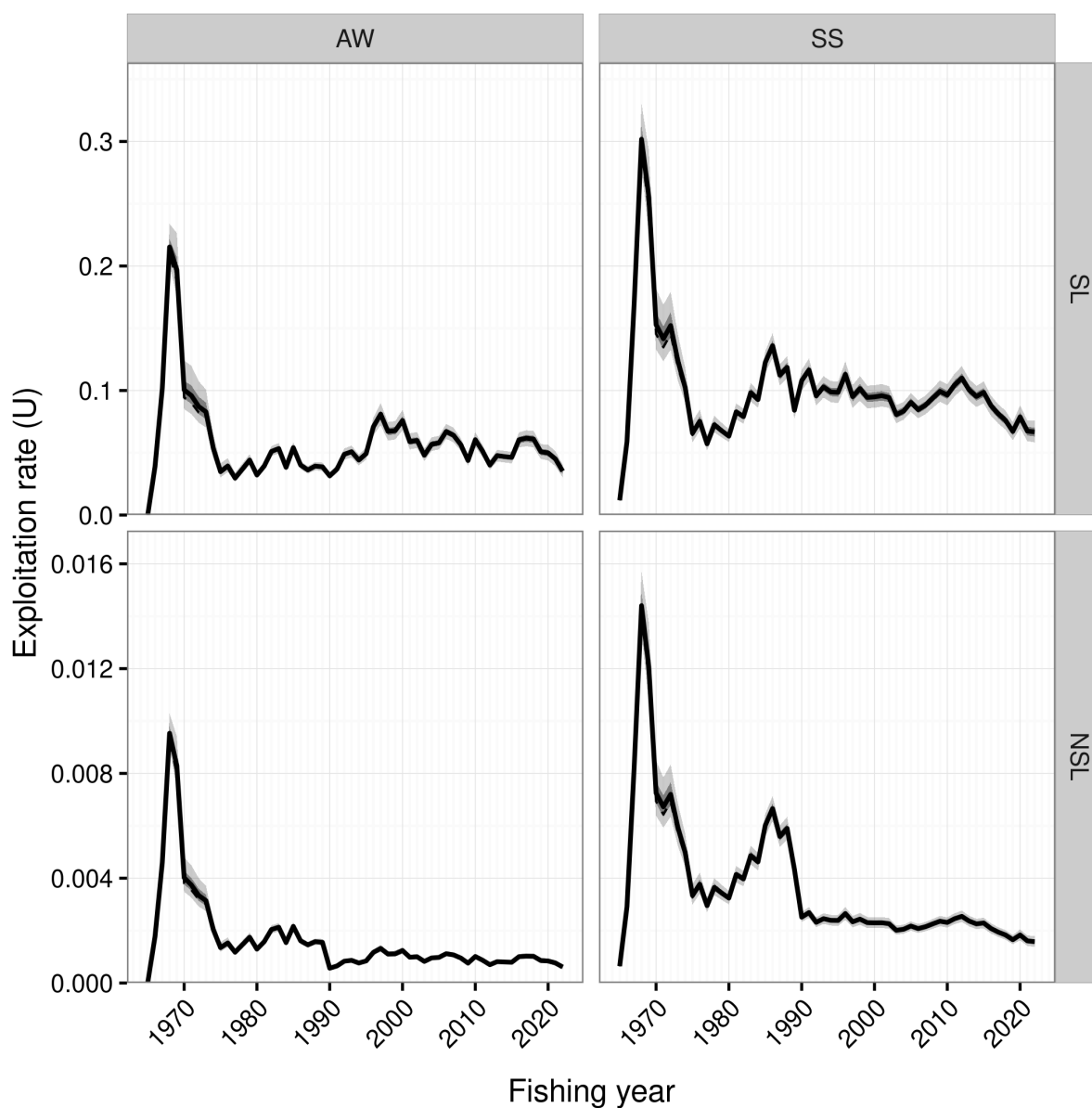


Figure 64: Posterior distribution of exploitation rate by year, season, and fishery (SL = size-limited; NSL = non-size-limited) for the base case model run. The solid black line indicates the median of the posterior and variable shading intensity indicating the 50% and 90% credible intervals.

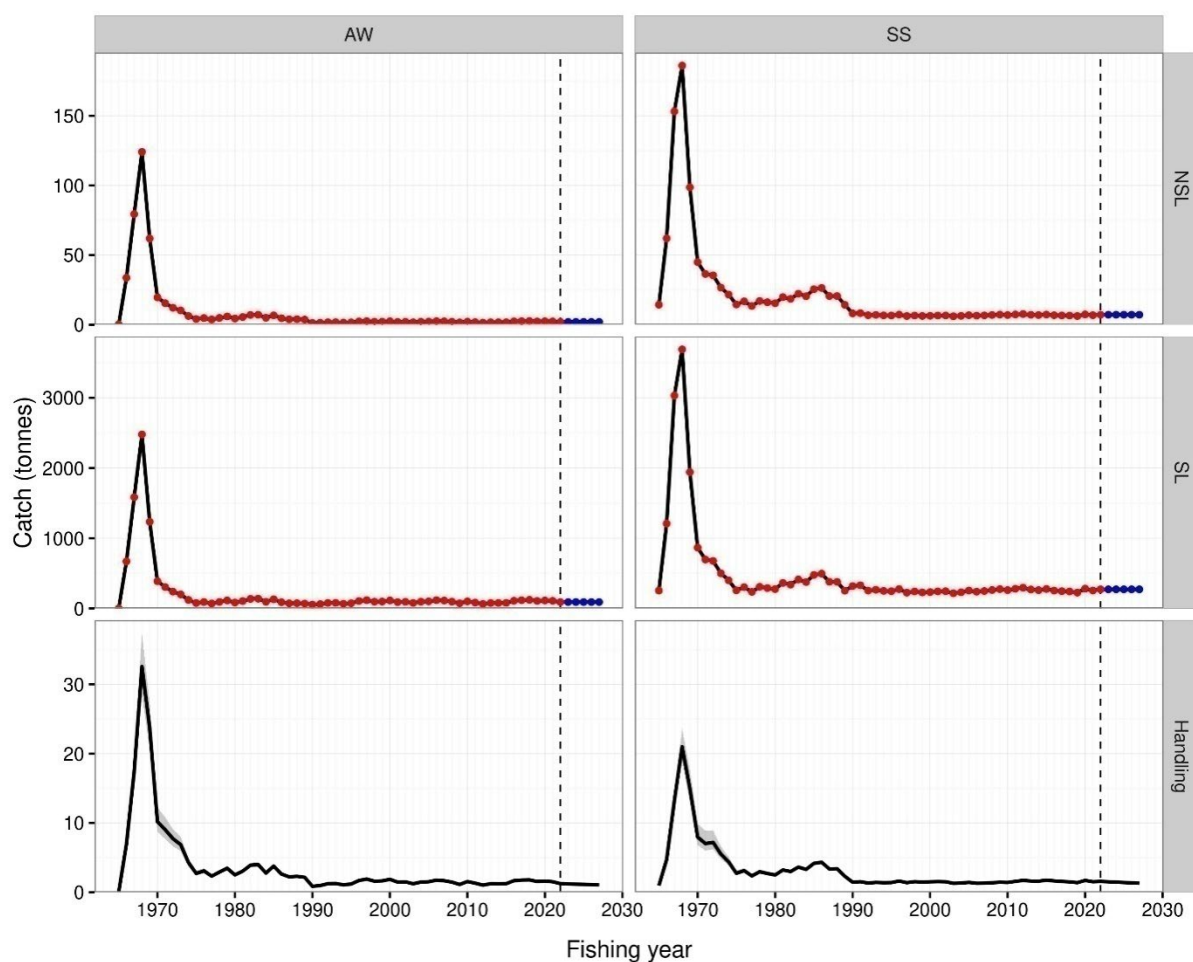


Figure 65: Posterior distribution of the catch and handling mortality by fishing year, season, region, and fishery (SL = size-limited; NSL = non-size-limited) for the base case model run. The solid black line indicates the median of the posterior and shading indicates the 90% credible interval. The vertical dashed line is the final year of the reconstruction period after which the projected catch is shown.

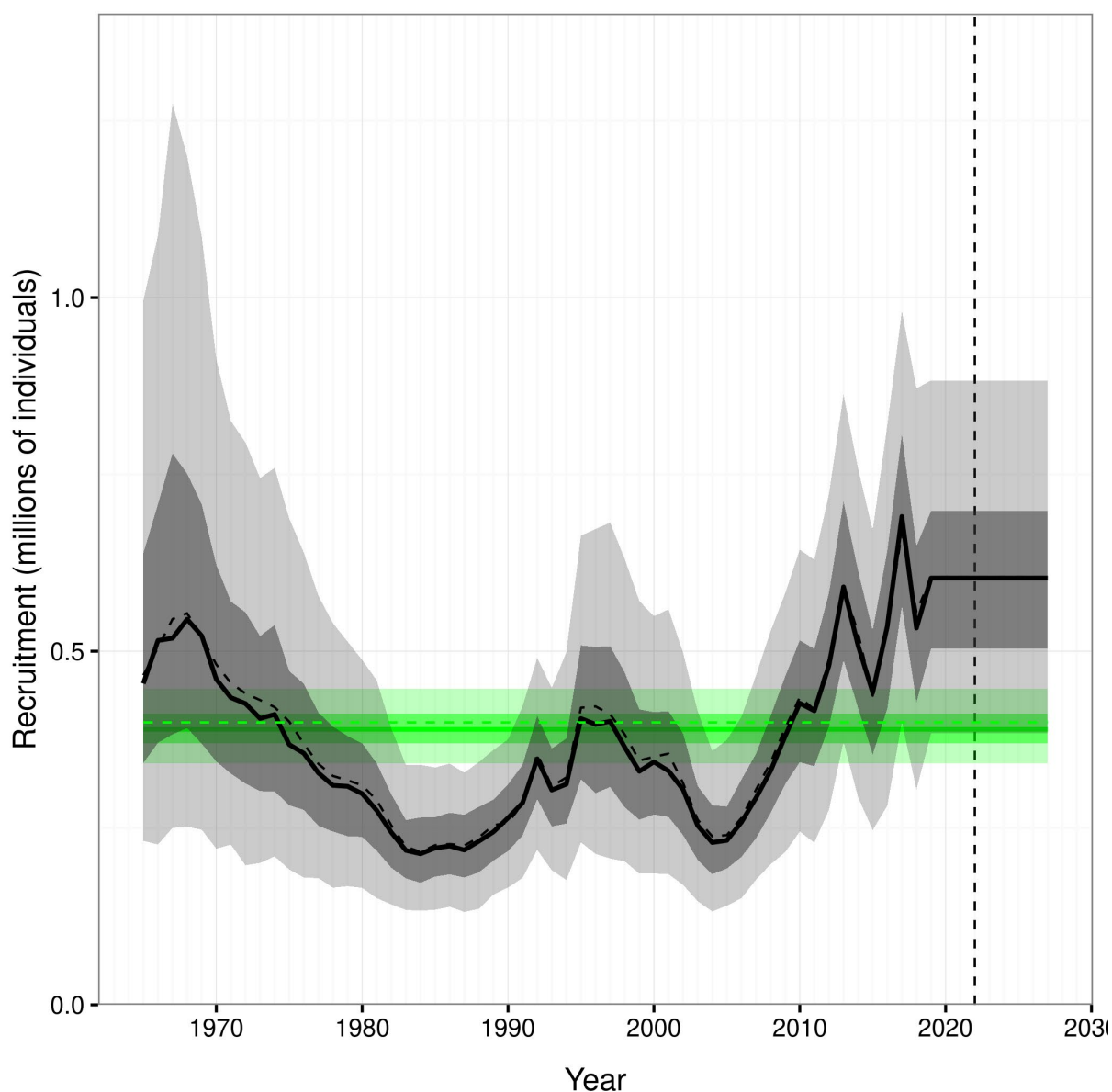


Figure 66: Posterior distribution of recruitment for the base case model run. The horizontal green line is R_0 and the vertical dashed line is the final year of the reconstruction period after which the projected recruitment is shown. The solid black line indicates the median of the posterior and variable shading intensity indicates the 50% and 90% credible intervals.

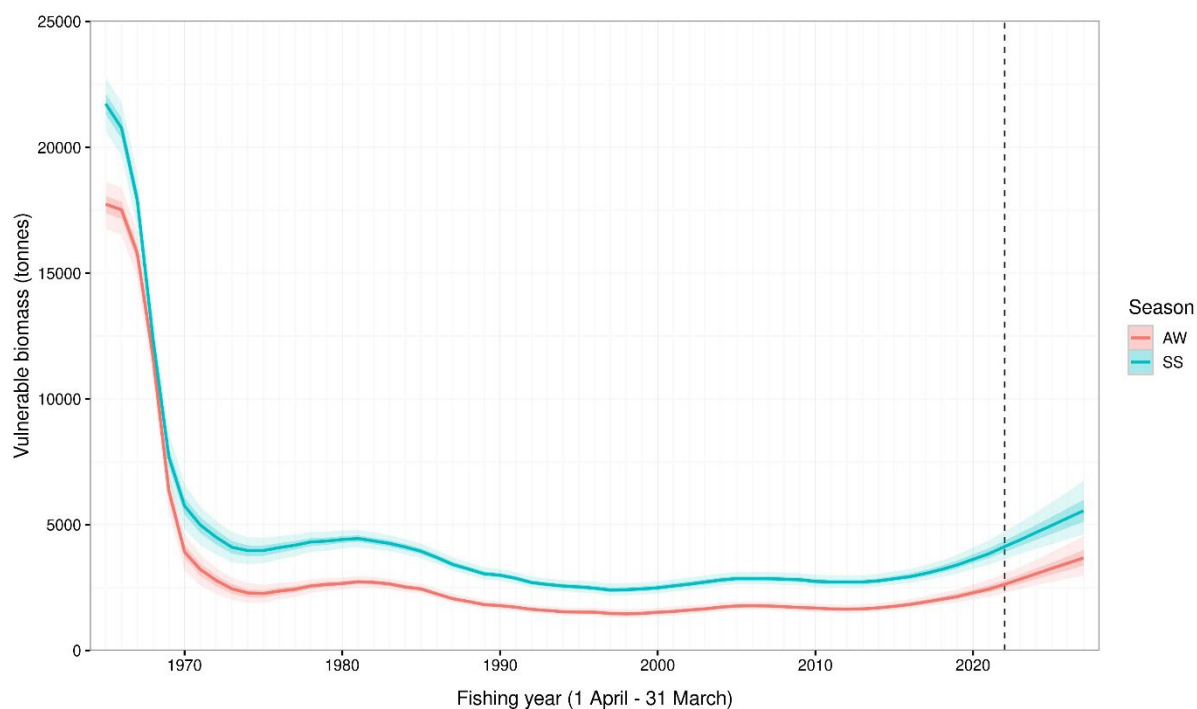


Figure 67: Posterior distribution of the adjusted vulnerable biomass by season for the base case model run. Variable shading intensity indicates the 50% and 90% credible intervals.

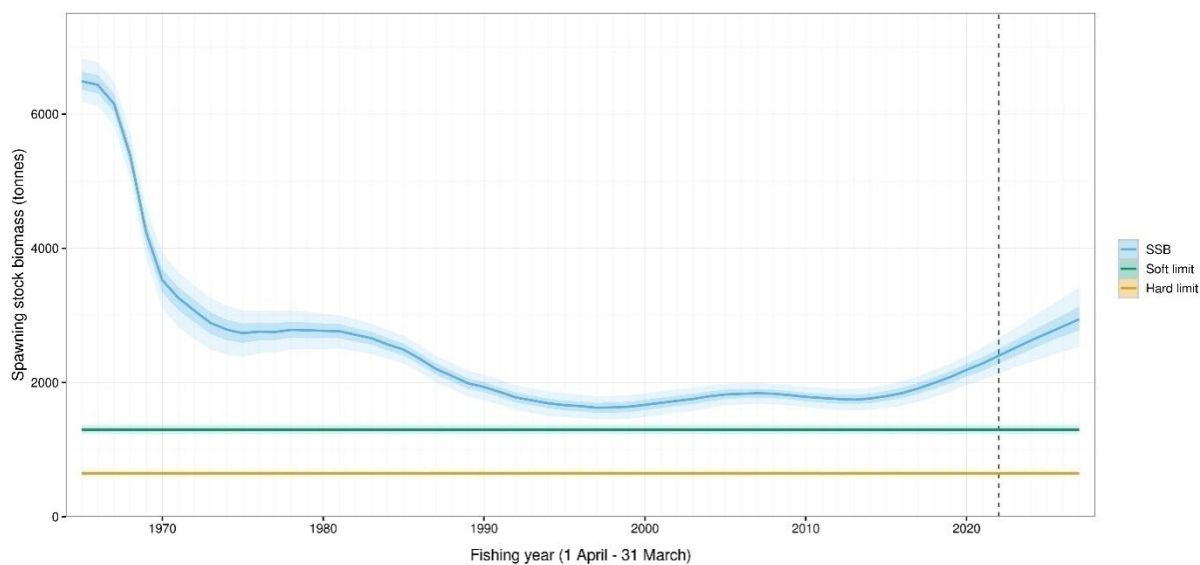


Figure 68: Posterior distribution of beginning year spawning stock biomass (tonnes) by fishing year, including the projections years (beyond the dashed vertical line), for the base case model run. The associated soft limits (20% SSB_0), and hard limits (10% SSB_0) are also shown.

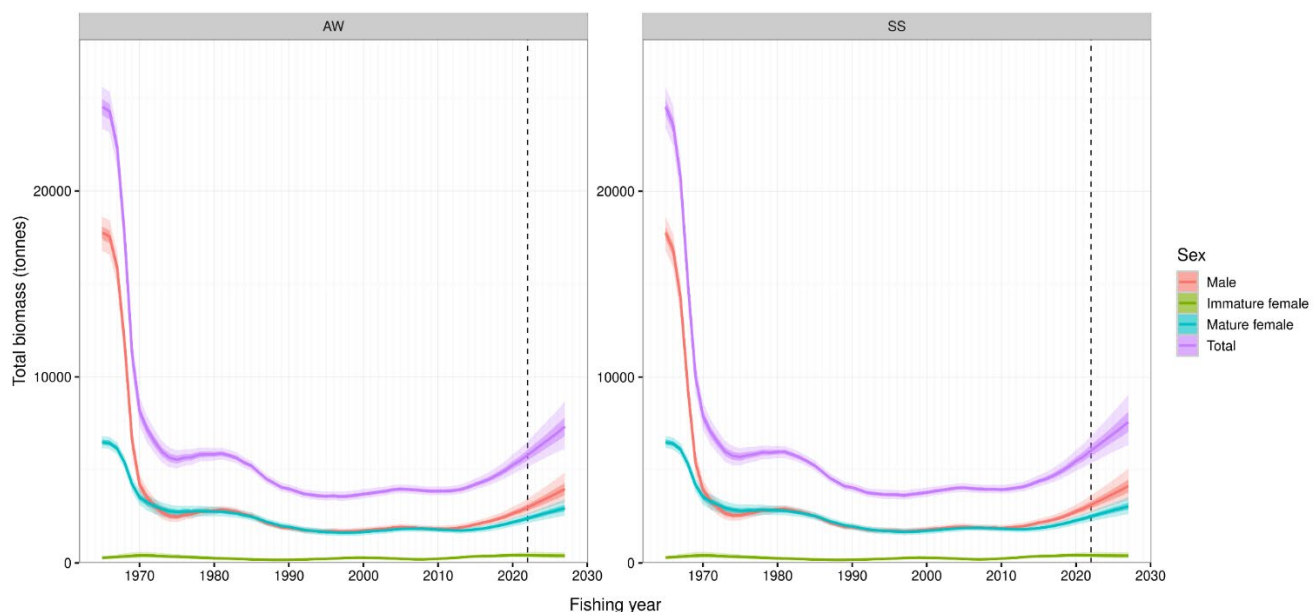


Figure 69: Posterior distribution of the beginning year total biomass by sex, season, and fishing year for the base case model run. Variable shading intensity indicates the 50% and 90% credible intervals.

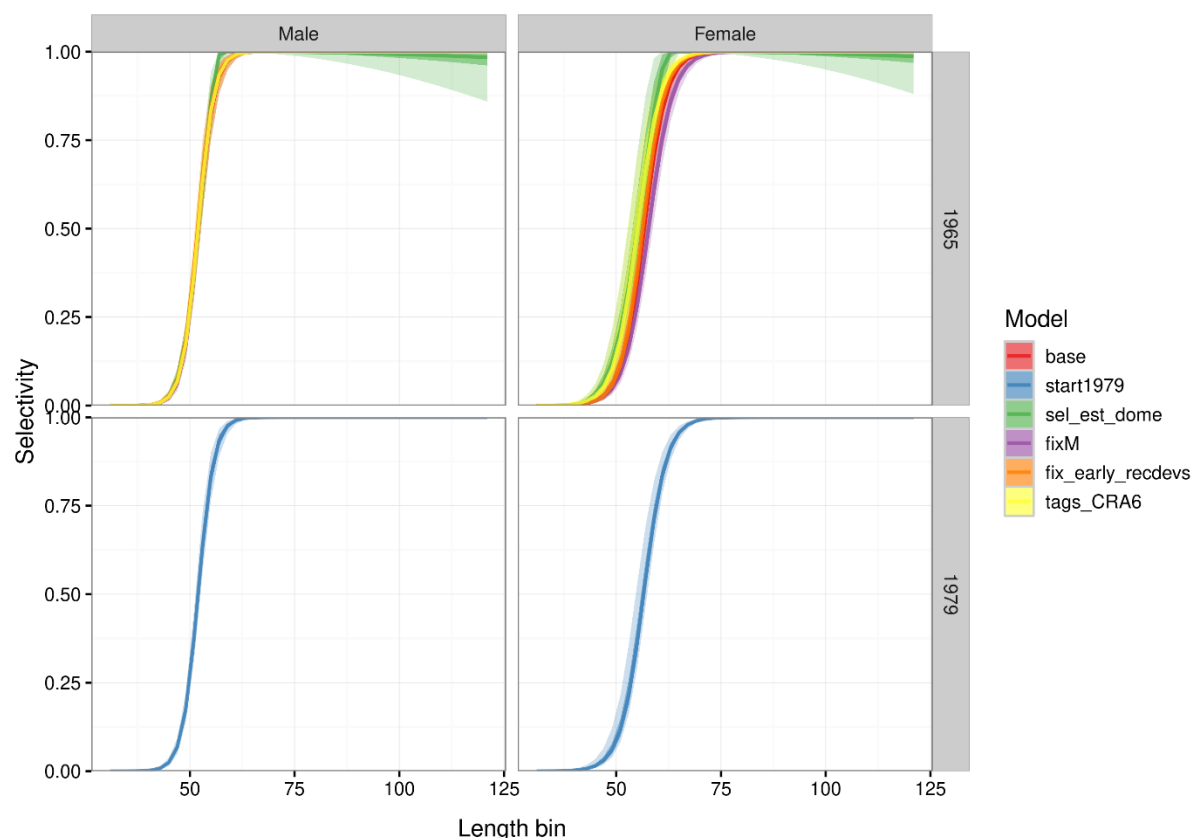


Figure 70: Posterior distribution of selectivity by sex and size comparing the base case with five key sensitivities. The solid line indicates the posterior median and shading indicates the 90% credible intervals. The bottom row shows the selectivity curve that applies from 1979-2022 in the start1979 model, which can be compared to those starting in 1965 for all other models.

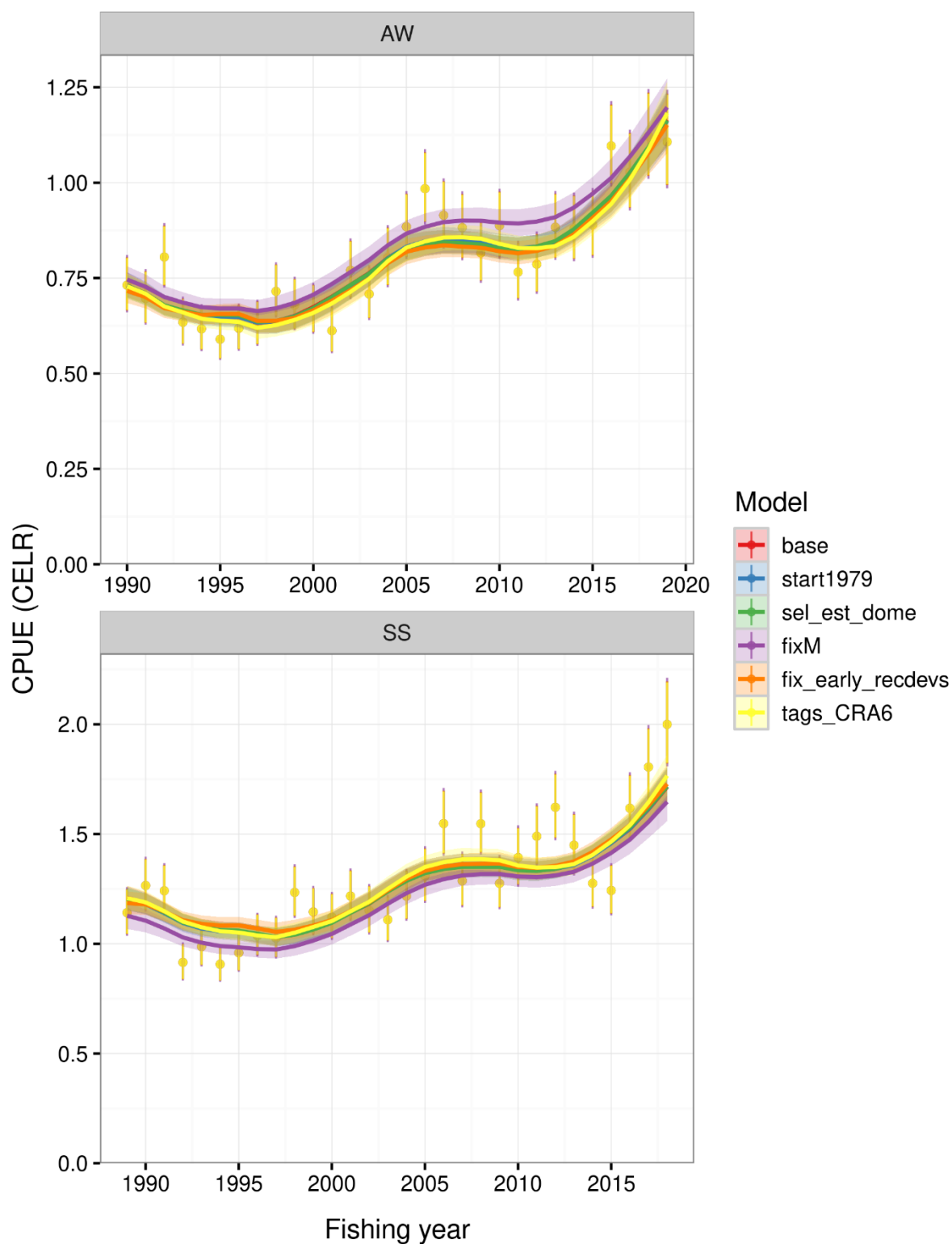


Figure 71: Posterior predicted CPUE compared to the CELR CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) for key sensitivities and the base case. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

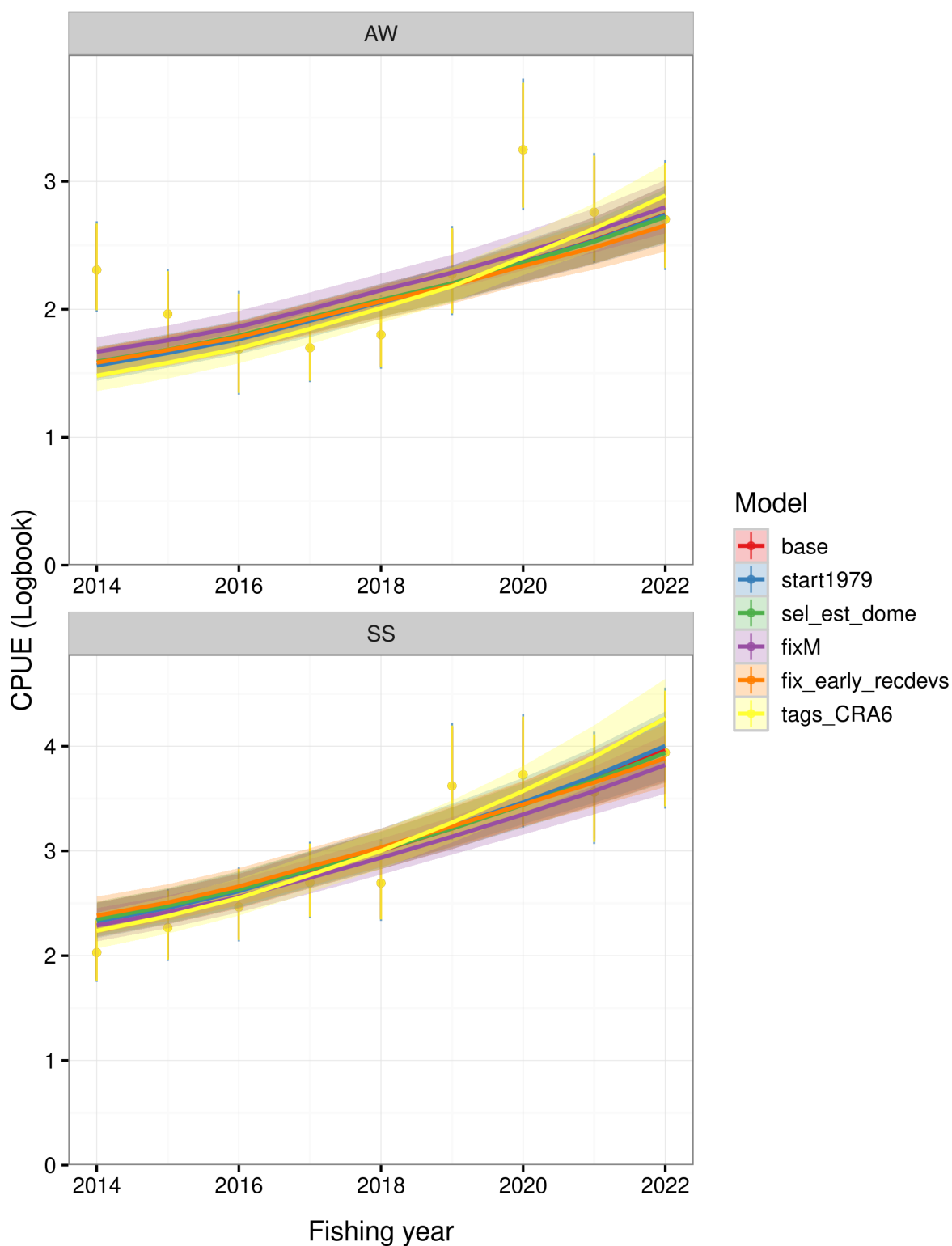


Figure 72: Posterior predicted CPUE compared to the logbook CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) for key sensitivities. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

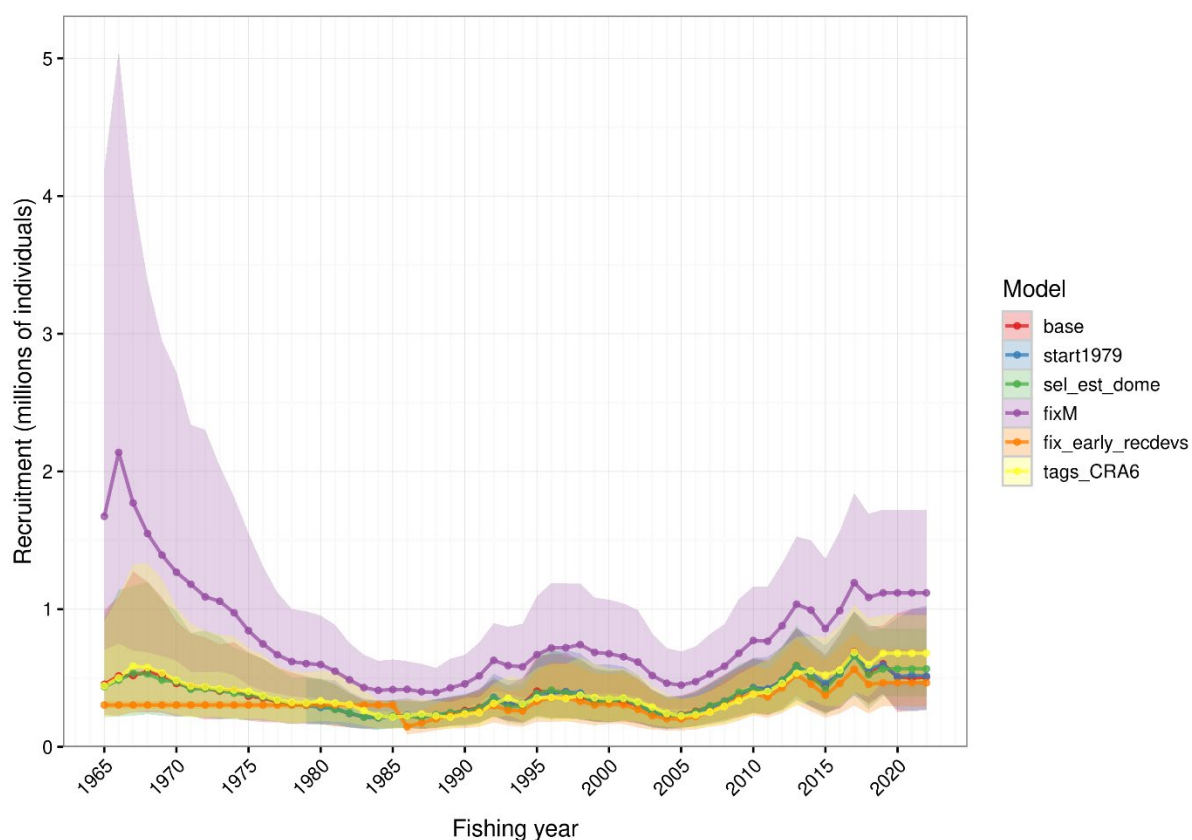


Figure 73: Posterior distribution of recruitment trajectories between the base run and key sensitivities. In this plot the *fixM* run has very high uncertainty.

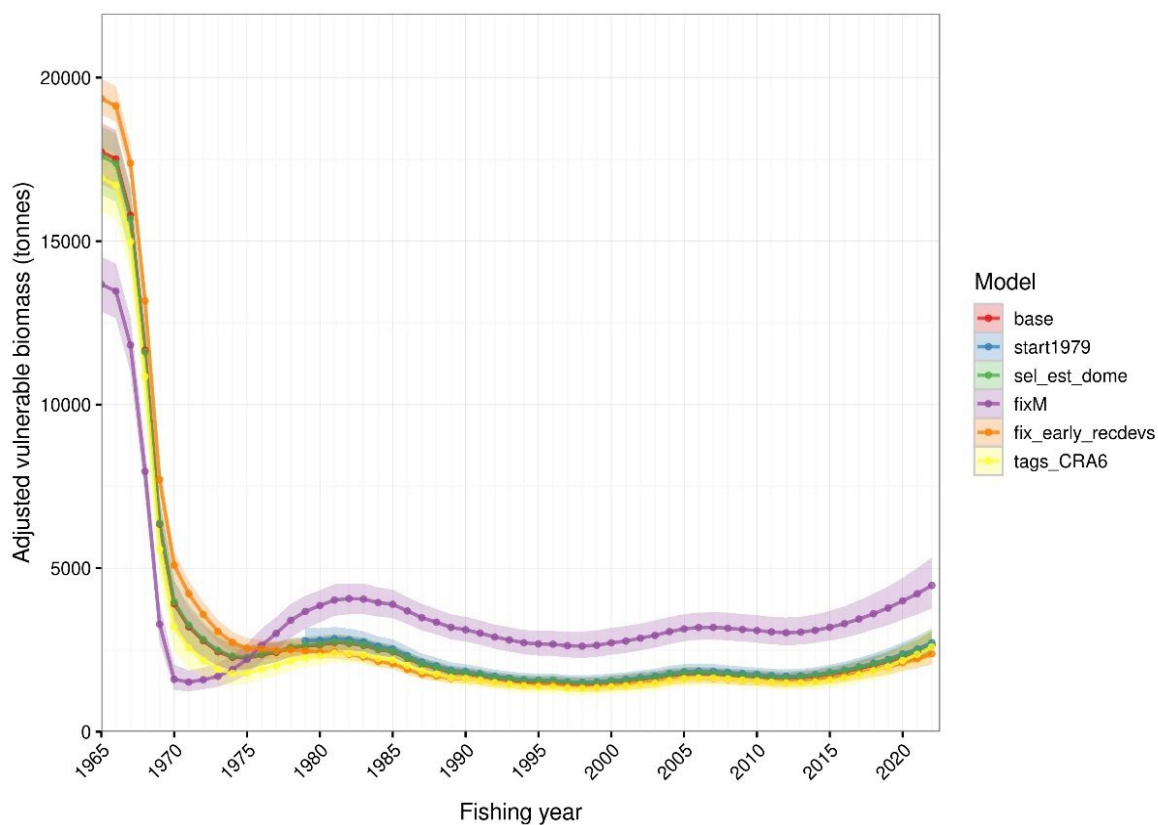


Figure 74: Posterior distribution of adjusted vulnerable biomass comparing the base case and key sensitivities. In this plot the *fixM* run is the most different from other trajectories.

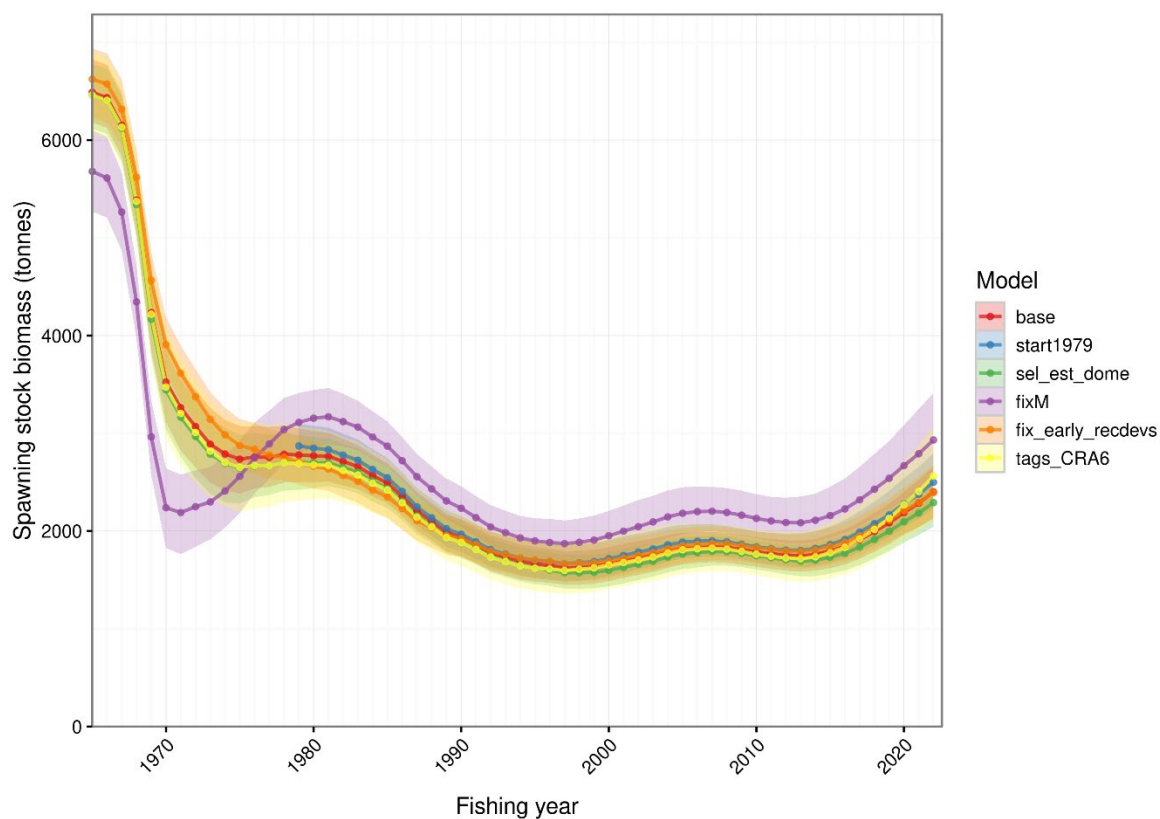


Figure 75: Posterior distribution of spawning stock biomass comparing the base case model run and key sensitivities, including projection years (beyond the dashed vertical line).

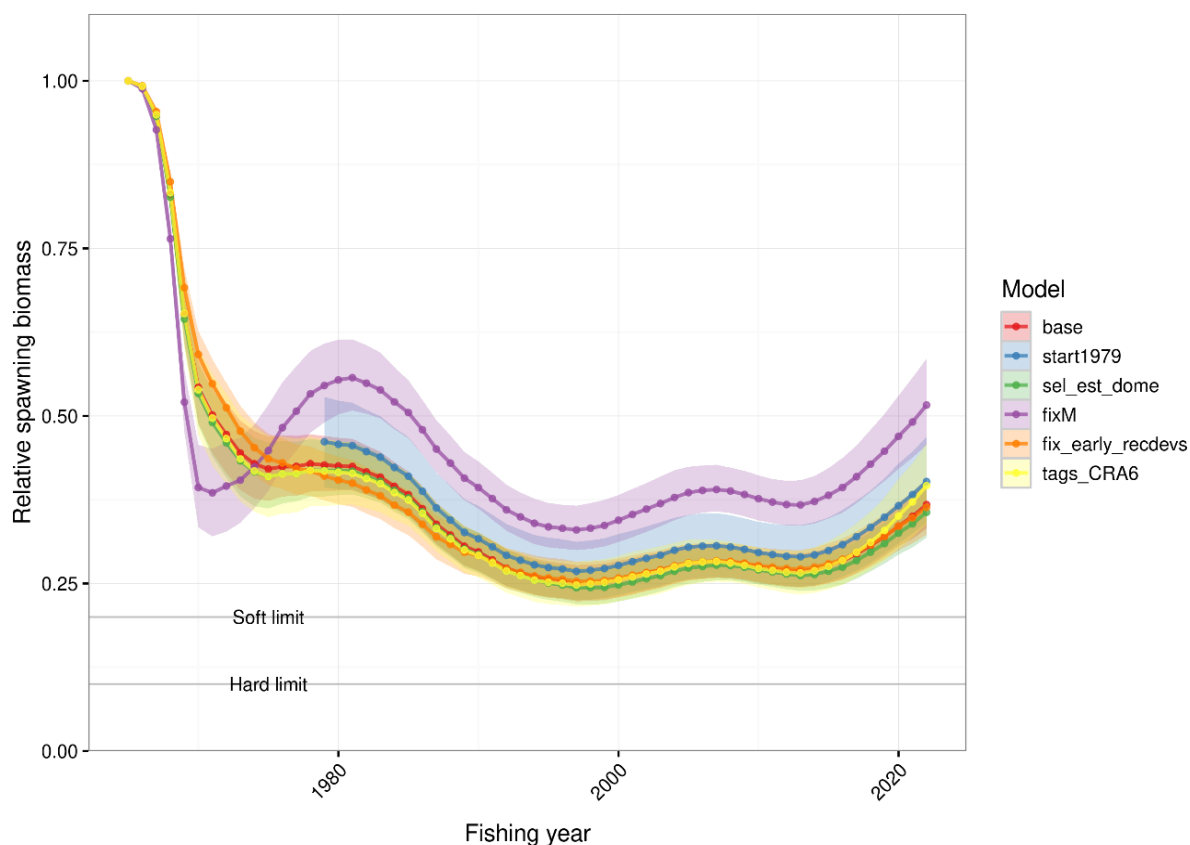


Figure 76: Posterior distribution of relative spawning stock biomass comparing the base case model run and key sensitivities, including projection years (beyond the dashed vertical line).

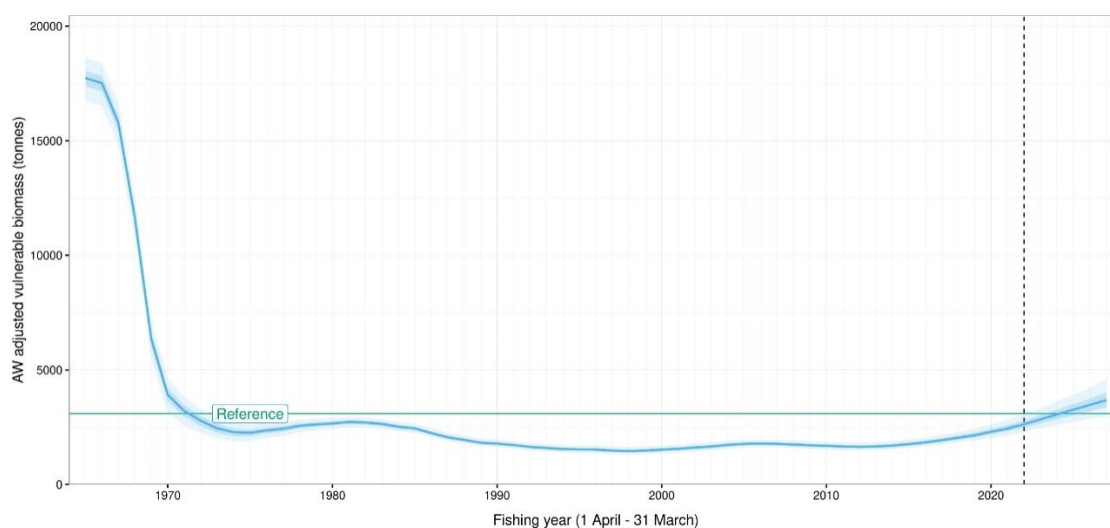


Figure 77: Posterior distribution of adjusted vulnerable biomass (tonnes) by fishing year, including the projection years (beyond the dashed vertical line), for the base case model run compared with the reference level.

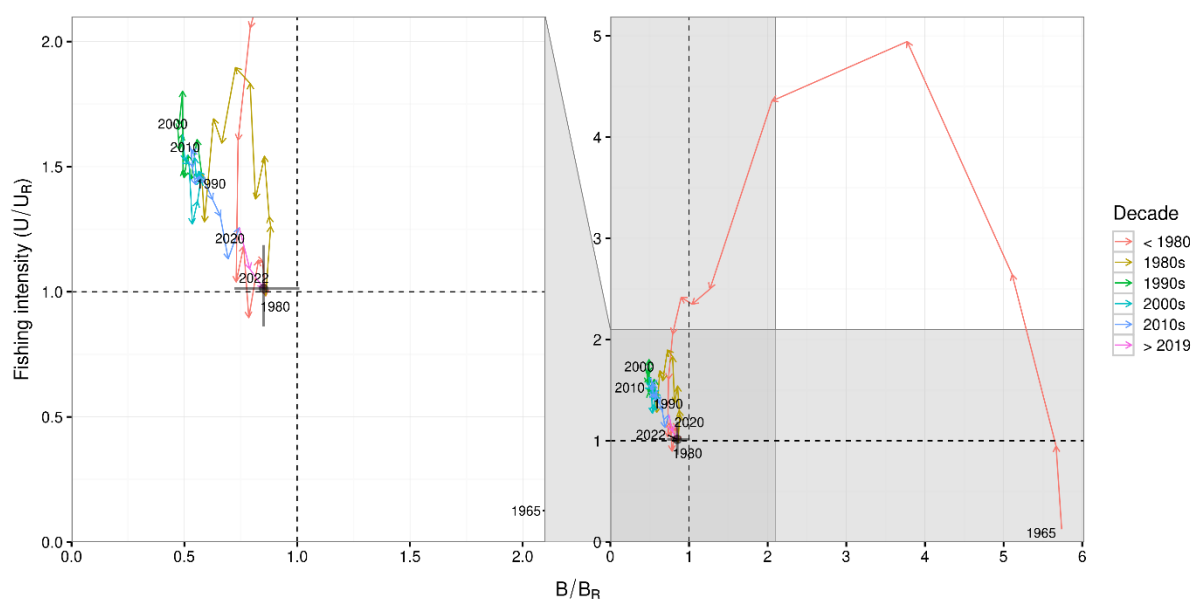


Figure 78: Snail trail from the CRA 6 base case MCMC. The figure shows the median of the posterior distribution of the AW vulnerable biomass as a proportion of the vulnerable biomass reference level in each year against the fishing intensity (exploitation rate relative to the overfishing threshold, the exploitation rate associated with the reference level). The 95th percentiles are shown for the final year. The left plot zooms in on the area where B/B_R is less than or equal to 2.0 and U/U_R is less than or equal to 2.0.

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).

Adjusted 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_{vuln}*; for comparing biomass with *B_R* and for reporting historical trajectories, the model calculates *B_{vulref}* using the last year's selectivity and MLS for consistency of comparison.

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.

***B₀*:** the biomass that would be attained if there were no fishing and recruitment were constant at its average 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_{current}*:** the LSD model estimate of adjusted **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}*:** adjusted vulnerable biomass in the last projection year, determined by running the model dynamics forward with specified catches and resampled recruitment.

***B_{vuln}*:** see vulnerable biomass.

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

catchability: a proportionality constant that relates an abundance index such as **CPUE** 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.

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

CR: an historical CPUE abundance index in kilograms per day.

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 trial) a higher ratio of F to F_{MSY} .

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

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

fishing year: for rock lobsters, the year from 1 April 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.

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

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.

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.

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 data set 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 data set. In a good estimation with multiple data sets, this should be close to 0.7; a common procedure is to weight data sets 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 relationship between female size and the probability that an immature female will become mature in the next specified time step.

MCMC: Markov chain Monte Carlo. 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 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 (includes Fisheries New Zealand; formerly Ministry of Fisheries or MFish).

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

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

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, MPI, 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 a government observer on a vessel measures all the fish in as many pots as possible on one trip.

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

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

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

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

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

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

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

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

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

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

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

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

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

R_0 : the base recruitment value in numbers of fish.

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’.

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 data sets to try to obtain SDNRs close to 1.

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

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

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

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

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

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

spawning stock biomass: SSB, the weight of all mature females in the AW, without regard to MLS, selectivity or vulnerability; three specific forms are $SSB_{current}$, the estimated SSB in the last year with data; SSB_0 , the equilibrium SSB; SSB_{MSY} , the SSB at equilibrium B_{MSY} .

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

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

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

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

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

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

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

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

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

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

TW: tail width measured (in millimetres) 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_{vuln} ; for comparing biomass with B_{REF} and for reporting historical trajectories, the model calculates B_{vulref} using the last year's selectivity and MLS for consistency of comparison.

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

Appendix B. Length frequency fits

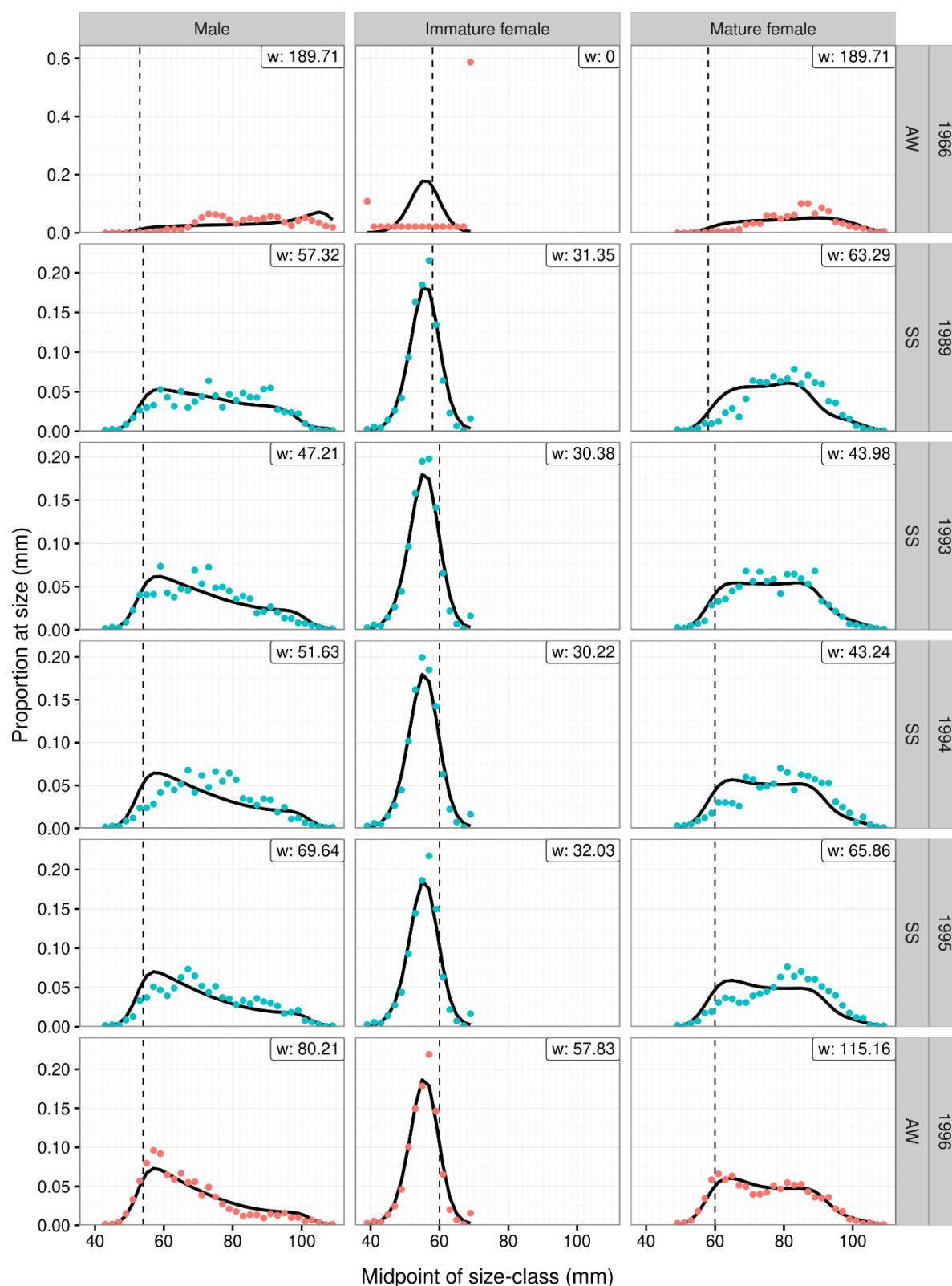


Figure B.1: MAP model fits to the early fishery LFs (specifically including fits to the 1966 LF, as well as 1989, 1993-1966), compared with the observed LFs by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex category in the LF 1966 model run. In each panel 'w' is the effective sample size.

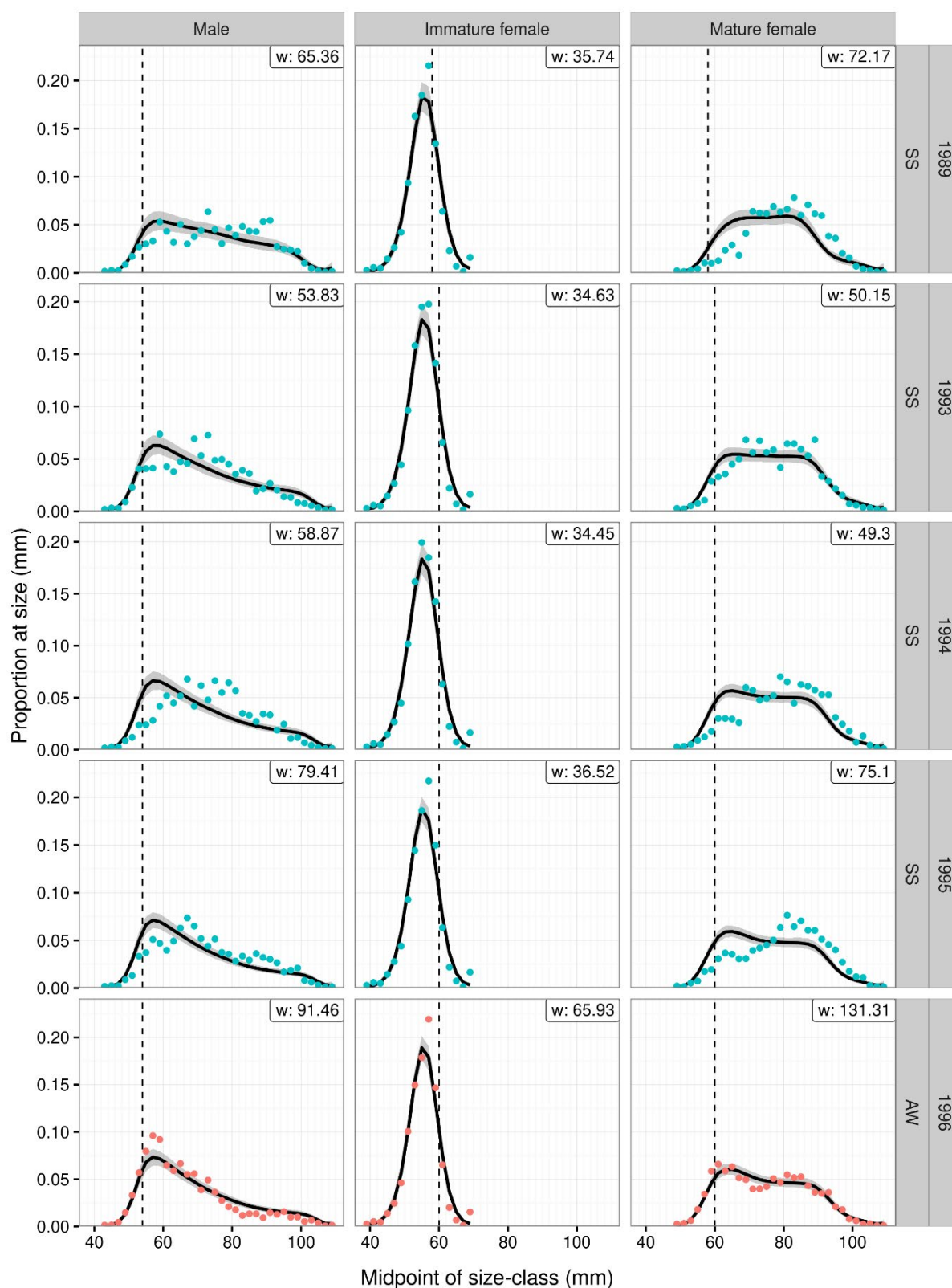


Figure B.2: Posterior distribution of the LFs compared with the observed LFs by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex category in the base case model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. In each panel 'w' is the effective sample size.

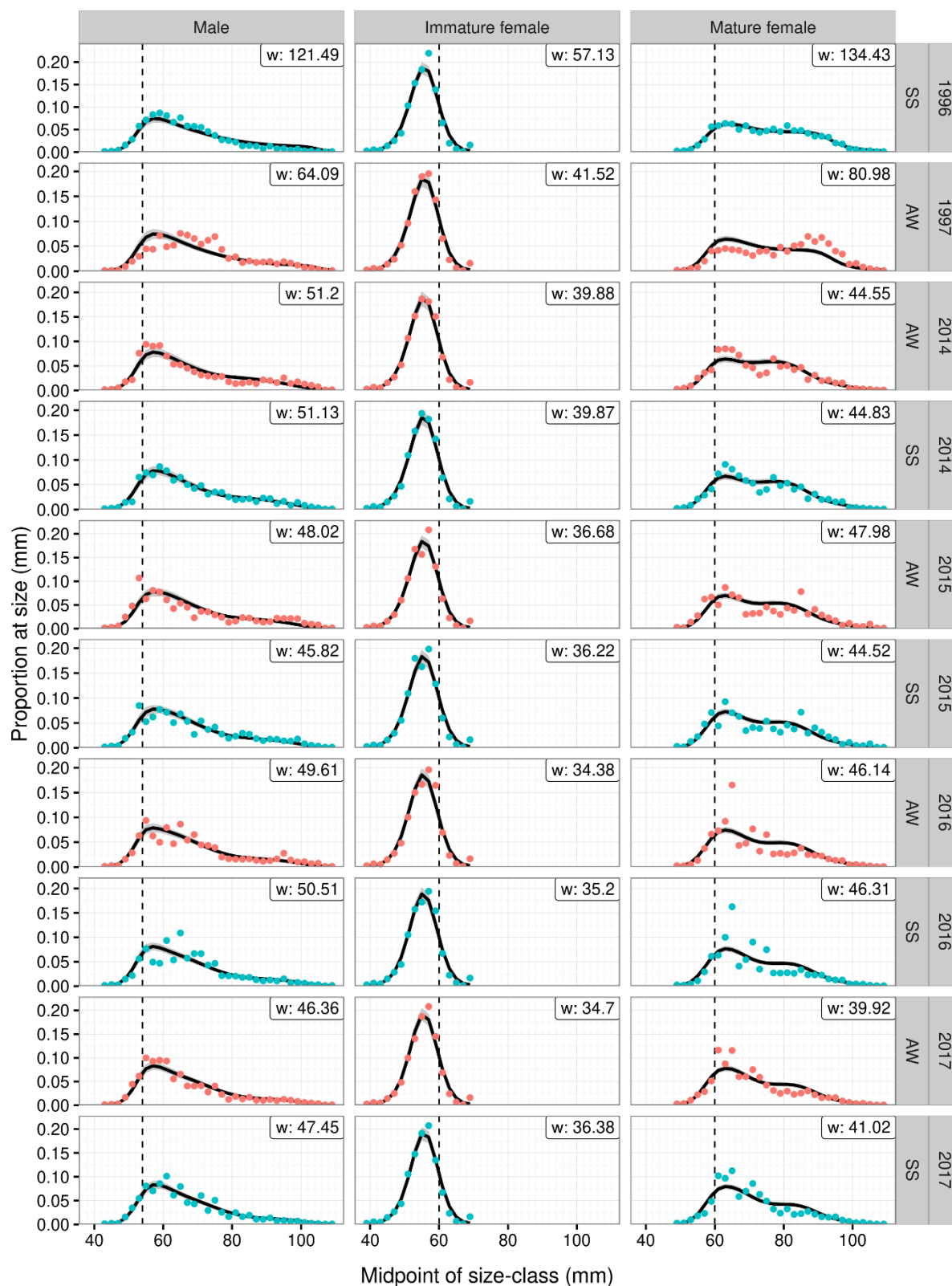


Figure B.2 (cont.):

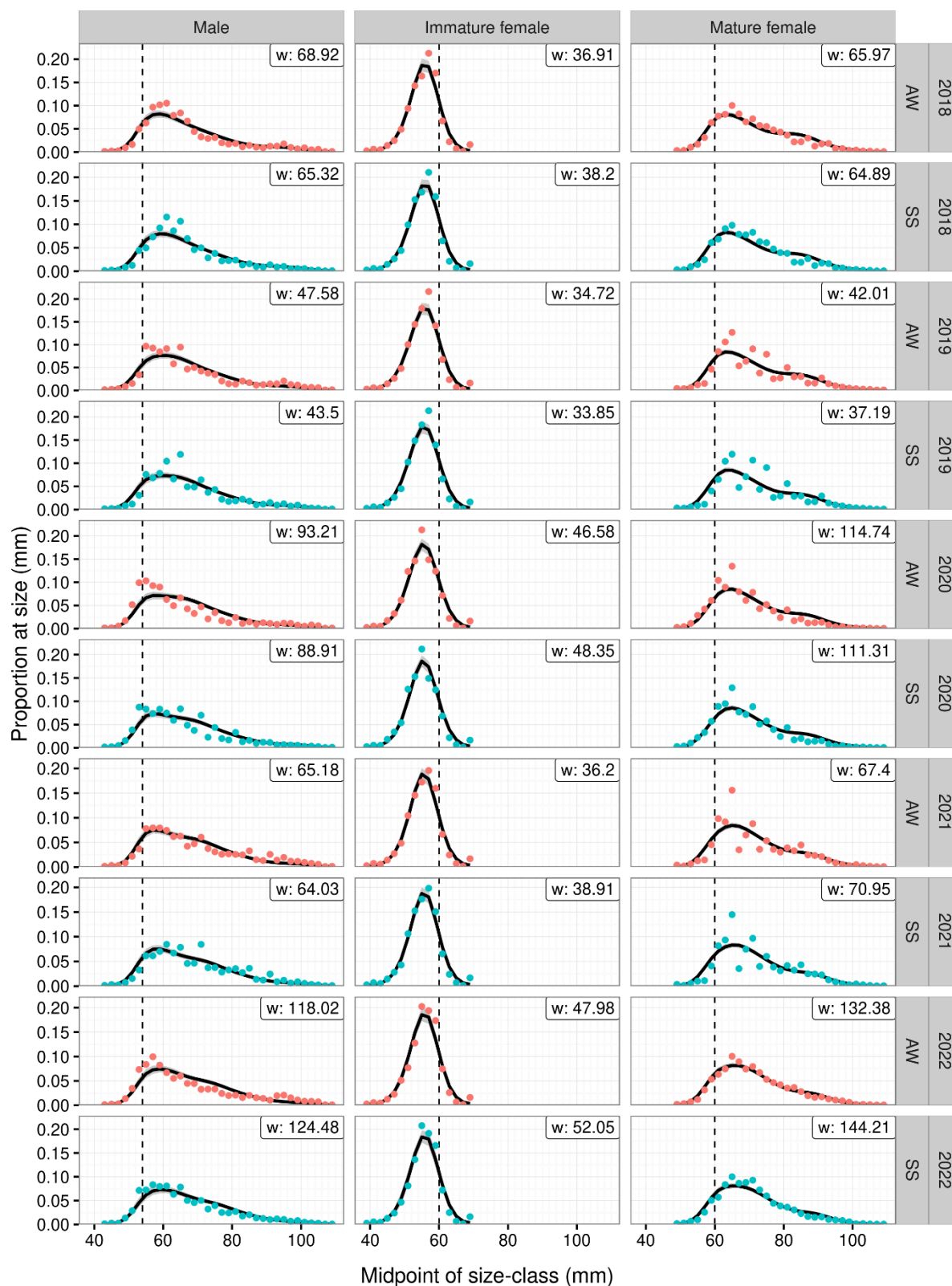


Figure B.2 (cont.)