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The 2021 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8

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TABLE OF CONTENTS

EXECUTIVE SUMMARY **1**

1. INTRODUCTION **2**

2. STOCK ASSESSMENT **2**

2.1 Data 3

2.2 Covariates 4

2.3 Model 4

2.4 Parameters and priors 6

2.5 Assessment indicators 7

2.6 Maximum *a posteriori* (MAP) inference 7

2.6.1 MAP base case 7

2.6.2 MAP sensitivity trials 11

2.7 Bayesian inference using Markov chain Monte Carlo (MCMC) 12

2.7.1 MCMC base case 12

2.7.2 MCMC sensitivity trials 13

2.8 Projections 14

3. DISCUSSION **15**

3.1 Future research 17

4. ACKNOWLEDGEMENTS **17**

5. REFERENCES **18**

6. TABLES **20**

7. FIGURES **35**

8. APPENDIX I: FISHING MORTALITY AND CATCH **94**

9. APPENDIX II: MCMC LENGTH FREQUENCY FITS **95**

EXECUTIVE SUMMARY

Webber, D.N.[1]; Starr, P.J.[2]; Rudd, M.B.[3]; Roberts, J.[2]; Pons, M.[2] (2022). The 2021 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8.

***New Zealand Fisheries Assessment Report 2022/17.* 113 p.**

This document describes the 2021 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8. The stock assessment used the lobster stock dynamics (LSD) model. Data inputs and technical decisions were discussed and agreed upon by the Rock Lobster Working Group (RLWG), who oversaw this work.

The model was fitted to length frequency data, sex ratio data, tag-recapture data, and standardised catch-per-unit-effort (CPUE) indices. This document describes the procedure used to find an acceptable base case model and shows the model fits. Several sensitivity trials were done to test assumptions in the base case model. Model inference for this assessment was based on maximum *a posteriori* (MAP) fits and Markov chain Monte Carlo (MCMC) simulations.

This stock assessment assumed a two-region model that combined the two CRA 7 statistical areas with the four Southland CRA 8 statistical areas (including Stewart Island and Snares Islands) as one region and a second region consisting of the three Fiordland CRA 8 statistical areas. This partitioning was informed by a regional characterisation of the fishery data, which identified an almost total lack of mature females captured across the Southland region, contrasting with the relatively high proportion of mature females in the Fiordland catch. The requirement to estimate movement between CRA 7 and CRA 8, as was done in 2015, was removed by combining CRA 7 with Southland and was supported by the lack of tag-recapture evidence for movement between the two model regions. The reconstruction began in 1945 instead of 1963, as was done in the 2015 assessment, because estimates of initial exploitation rate were not credible.

This stock assessment estimated a period of high fishing mortality rates in both regions until 1990, with particularly high fishing mortality rates in the CRA 7 and the Southland region during this early period. Fishing mortality rates generally decreased from the early 1990s through to the present, although were relatively stable for the Fiordland commercial fishery in the autumn/winter (AW) season. In turn, spawning stock biomass (*SSB*) and AW adjusted vulnerable biomass were estimated to decrease steadily until 1990. *SSB* was estimated to remain above the soft limit in CRA 7 and Southland, but was estimated to dip below the hard limit in Fiordland in the mid-1980s through to the early 2000s. The *SSB* was estimated to increase above the soft limit in both regions in the years from 2000 to the present. Recruitment in Fiordland was estimated in the base case assessment run to be above average in most years since 2010, and slightly below average in Southland across the same period.

This stock assessment also estimated reference levels for each region. The CRA 7 and Southland region was estimated to be above the reference level and Fiordland was estimated to be at the reference level.

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1. INTRODUCTION

The National Rock Lobster Management Group (NRLMG) decided that a stock assessment(s) for red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8 should be done in 2021. This document describes work done to address Objective 3 of the Fisheries New Zealand contract CRA2021-01:

To carry out full stock assessments for the CRA 7 (Otago) and CRA 8 (Southern) rock lobster stocks, 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.

This stock assessment was completed in a workshop during September and October 2021. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Working Group (RLWG). The stock assessment was presented to and approved by the Fisheries New Zealand mid-year Plenary in November 2021 (Fisheries New Zealand 2021).

The CRA 7 Quota Management Area (QMA) extends from the Waitaki River south along the Otago coastline to Long Point. The CRA 8 QMA extends from Long Point south to Stewart Island and the Snares Islands, including the islands and coastline of Foveaux Strait, then north along the Fiordland coastline to Bruce Bay (Figure 1).

The CRA 7 and CRA 8 Total Allowable Commercial Catch (TACC) have been set using management procedures (MPs) since 1996 (combined CRA 7 and CRA 8) through to the 2019–20 fishing year. The MPs were suspended after 2020, because the introduction of electronic reporting changed the reporting of rock lobster catch/effort data, resulting in a lack of comparability with data collected on the previous paper forms. The current CRA 7 and CRA 8 TACCs for commercial catch are 106 tonnes and 1192 tonnes, respectively. The CRA 7 allowances set by the Minister of Fisheries were 10 tonnes for customary catch, 5 tonnes for recreational catch, and 5 tonnes for illegal removals for a Total Allowable Catch (TAC) of 126 tonnes. For CRA 8, the Minister of Fisheries set allowances of 30 tonnes of customary catch, 33 tonnes for recreational catch, and 38 tonnes for illegal catch, for a total TAC of 1282 tonnes. Each component of the fishery is meant to stay within its allowance, but only the TACC is actively constrained through the application of the Quota Management System (QMS). Other management tools include: minimum legal sizes (MLS) in CRA 7 (47 mm tail width (TW) for males and 49 mm TW for females) and CRA 8 (54 mm TW for males and 57 mm TW for females), for both the commercial and recreational fisheries; and a general prohibition of the take of berried females and soft-shelled individuals.

Potting and hand-gathering are the preferred methods for recreational fishers in CRA 7 and CRA 8. Most of the recreational catch here is taken during the summer months, consistent with all other red rock lobster stocks. The region also sustains a dive charter industry catering to recreational fishing during summer. The customary allowance allows lobsters to be taken under permit.

The previous stock assessment of CRA 7 and CRA 8 was done in 2015 (Haist et al. 2016). This document presents a new stock assessment for CRA 7 and CRA 8, which includes updates to the catch-per-unit-effort (CPUE) standardisation procedure and other inputs up to the end of the 2020[4] fishing year. All tables referred to in this document can be found in Section 6 and all figures are in Section 7.

2. STOCK ASSESSMENT

The previous stock assessment of CRA 7 and CRA 8 (Haist et al. 2016) used the multi-stock length-based model (MSLM, Haist et al. 2009). The updated stock assessment for 2021, presented here, used the lobster stock dynamics (LSD) model (Webber et al. 2018a). The LSD model was coded in Stan (Stan Development Team 2016, 2017) and has been used as the main assessment software for all of the

[4] The 2020–21 fishing year is referred to in this document with the first year (2020) of the pair of years.

assessed rock lobster stocks in New Zealand, including CRA 2 (2017), CRA 6 (2018), CRA 1 (2019), CRA 3 (2019), CRA 4 (2020), and CRA 5 (2020).

Maximum *a posteriori* (MAP) estimation and Markov chain Monte Carlo (MCMC) simulation were used to make inference about the CRA 7 and CRA 8 stock(s). An MAP base case model was developed and then a series of MAP trials were run to explore the sensitivity of model outputs to changes in model structure and inputs. MCMC runs were then completed for the base case model run and other selected models to estimate reference levels and other outputs for management.

The data and covariates used in this stock assessment were documented by Starr et al. (2022) and are summarised briefly in Section 2.1 and Section 2.2 below. The stock assessment model settings are described in Section 2.3 and model parameters and priors are defined in Section 2.4. Finally, the stock assessment outputs including the agreed indicators are presented 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. Puerulus settlement indices were not used in this stock assessment. Puerulus series were prepared for each region (see appendix C in Starr et al. 2022), but were discarded because there were too many inconsistencies between the series and recruitment to the model, which was estimated by fitting to the fishery data. The temporal extents of these input data and covariates are illustrated in Figure 2 and Figure 3.

The apparent change in reporting behaviour associated with the change in commercial catch and effort data collection from paper forms to electronic monitoring prevented the extension of the CPUE abundance series beyond the autumn/winter (AW) of the 2019 fishing year (see appendix B in Starr 2021 for the evidence supporting this decision). Following the procedure adopted by the six most recent stock assessments (CRA 2, Webber et al. 2018b; CRA 6, Rudd et al. 2019; CRA 1, Rudd et al. 2021a; CRA 3, Webber et al. 2020; CRA 4, Rudd et al. 2021b; and CRA 5, Webber et al. 2021), a vessel explanatory variable was included in the CPUE standardisation model to account for vessel specific behaviour (see Starr et al. 2022). Six separate CPUE series were included in this stock assessment including:

- The catch rate (CR) series is an annual arithmetic daily catch rate from 1963 to 1973, with separate time series prepared for region 1 and region 2. Catchability (q) for each region was assumed constant over this period.
- The Fisheries Statistics Unit (FSU) series is a seasonal standardised index from AW 1979 to AW 1989. The standardisation model included year, month, statistical area, and vessel explanatory variables. The FSU CPUE standardisation included all vessels. Separate series were prepared for region 1 and region 2. The q coefficients for each region were assumed constant over this period.
- The Catch Effort Landing Return (CELR) series is a seasonal standardised series from SS 1989 to AW 2019. The standardisation model included year, month, statistical area, and vessel explanatory variables, filtered for vessels that had fished for at least five years in either QMA. Separate series were prepared for region 1 and region 2.

Biological sampling in CRA 7 has been done by observer catch sampling since 1987. The CRA 8 fishing industry made a commitment to the voluntary logbook programme when it was first introduced in 1993 and has used this design as the primary source of stock monitoring information. CRA 8 observer catch sampling information is available from 1987, and the two programmes operated in tandem up until 1997. Both sets of data were used in the 2021 stock assessment to derive LFs and sex ratios of the commercial catch. The derivation of the LFs within the model are described in Appendix I. Sex ratio observations were calculated from the weighted normalised data records by region, seasonal period, and sample origin.

This assessment used tag-recapture observations from tags released in CRA 7 and CRA 8, including statistical areas 920 to 928 (Figure 1), identified either by the statistical area of release or the project ID. Tag-recapture data were primarily used to inform growth within the stock assessment, but also helped to inform the characterisation of movement among statistical areas, outside of the model.

2.2 Covariates

The covariates used in this stock assessment included the catch, the handling mortality associated with the commercial and recreational catch, the retention rate of lobsters, and the MLS.

The commercial catch time series came from a range of sources from 1945 up to the present, described by Starr et al. (2022). Similarly, the development of the non-commercial catches was also described by Starr et al. (2022). All catches remained as annual catches up to 1978, after which catches were divided into 6-month seasons (April-September and October-March). Each CRA 7 and CRA 8 catch category was split into the respective regional components using the procedure described by Starr et al. (2022). The commercial and recreational catches were summed within the model to form the size-limited (SL) catch component, which conforms to the MLS and the discard rule for berried females, while the customary and illegal catches were summed to form the non-size-limited (NSL) catch, whereby the full range of captured lobsters were kept without discarding undersized or berried lobsters.

Handling mortality was assumed to be 10% for all lobsters returned to sea before 1990, and 5% from 1990 onwards. This step-reduction in handling mortality was agreed by the RLWG to coincide with the start of the live export market and the introduction of rock lobsters into the QMS, under the assumption that fishers would take more care in the handling of lobsters once they became quota owners to maintain a high-quality product for live export. Handling mortality was applied to undersized lobsters of each sex taken in either season by the SL fishery as well as to mature females taken in the AW SL fishery. It was assumed that there were no discards in the NSL fishery. The value H_{2020} is the model estimate of the amount of handling mortality (in tonnes) in the final fishing year (2020).

Retention is an important process in CRA 8, with fishers tending to return larger male lobsters (most males over ~80 mm TW were returned to the sea). Retention rates were estimated in an analysis of logbook data described in appendix D of Starr et al. (2022) for inclusion as a process in this stock assessment model, by specifying the proportion of lobsters caught that were returned by TW for each sex/year. Retention cannot be estimated in CRA 7, because there are no logbook data from this QMA and the catch sampling programme does not record retention information. However, very few males captured in CRA 7 were greater than 60 mm TW, and, if the predicted curves for CRA 8 are representative of this QMA, then retention rates in CRA 7 should be relatively high across the total catch.

From 1945 to 1949, there was no MLS for red rock lobster in New Zealand. MLS restrictions were initially implemented for New Zealand red rock lobster as measurements of tail length in inches. This measurement standard was subject to some abuse because tails could be stretched, but it was accepted 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) in 1988 for all New Zealand red rock lobsters, requiring the conversion of the pre-1988 regulations into equivalent TW measurements for use in the stock assessment model (Breen et al. 1988). The TW values used for the MLS in the model are provided in Table 1.

2.3 Model

The model tracks the numbers of individual lobsters in three sex categories ($s =$ immature females, mature females, and males) for each of 36 two-mm TW bins ($l = \{[30, 32), [32, 34), \dots, [100, \infty)\}$), by year ($y$), season ($t$), and region ($r$). The number of individuals in each category is denoted mathematically as

$$N_{y,t,r,s,l}.$$

The first model year was set to 1945, because this was the first year of available commercial fishery catch data and the available data indicate that there were significant removals from CRA 7 and CRA 8 in the late 1940s and early 1950s (see figure 2 in Starr et al. 2022). The previous assessment (Haist et al. 2016) modelled CRA 7 and CRA 8 from 1963 to 2014. Catches before 1963 were considered unrealistic in the previous assessment. However, initial exploratory model runs suggested that there was not enough information to estimate an initial exploitation rate for deriving the initial state. The last year in the model was 2020. The years from 1945 to 1978 were January–December calendar years and January–March 1979 catches were added to 1978 to facilitate the transition from calendar year to fishing year. Fishing years in the model started in 1979–80 (denoted as 1979) and extend from 1 April to 31 March. The model delineates two six-month seasons within a model year: AW (April to September) and spring/summer (SS, October to March).

The previous CRA 7 and CRA 8 stock assessment was a two-region model, treating each QMA as a separate region and estimating parameters for both CRA 7 and CRA 8 from the CRA 7 and CRA 8 data simultaneously. This model linked the two regions by estimating movements from CRA 7 to CRA 8. However, movement in a length-based model is difficult to estimate since many of the process in stock assessment are confounded (e.g., movement, natural mortality, recruitment, etc.).

The 2021 stock assessment was also a two-region model but with different regional definitions compared to the previous assessment. This stock assessment combined CRA 7 with the four Southland statistical areas from CRA 8, designated as region 1 (statistical areas 920, 921, 922, 923, 924, and 925). A second region (region 2) comprised the three Fiordland statistical areas (926, 927, and 928) (Figure 1). Data analyses supporting this separation and describing the estimation of catch histories are presented by Starr et al. (2022). There was no strong evidence of movement between these two regions in the tag-recapture data, removing the need to estimate movement as was done in the 2015 assessment. Notably, mature females were almost totally absent from the catches of CRA 7 and the Southland region of CRA 8, although comprised a relatively large proportion of the catch in Fiordland.

A logistic maturation curve specified the proportion of immature female individuals by size class that become mature within a time step

$$m_l = 1/\left(1 + e^{-\log(19)/\kappa^m(\ell_l - \mu^m)}\right)$$

The estimated parameters μ^m and κ^m defined the curve's midpoint and steepness, respectively. Maturation was assumed to be the same in both regions.

Individual growth rate was assumed to be the same in both regions. This choice was informed by the lack of regional variation in growth rate from the available tag recapture data, evidenced by consistent residual patterns by statistical area when applying the same growth across both regions. Consequently, growth in both regions was based on a single model fitted to all the CRA 7 and CRA 8 tag recoveries. There was no apparent pattern of biased residuals in the growth estimates for tags with multiple recapture events for the same tagged lobster. Because of this, the stock assessment used all CRA 7 and CRA 8 tag-recapture data for each lobster, instead of just the initial recapture event, as has been done in other New Zealand rock lobster stock assessments.

Fishery selectivity was assumed to be region (r), sex (s), and size class (l) specific and is denoted as $s_{r,s,l}$ with support $s_{r,s,l} \in (0,1)$. A double-normal ogive was assumed and was defined as

$$s_{r,s,l} = j_{r,s,l} e^{\log(0.5)\left(\frac{\ell_l - \mu^s_{r,s}}{\sigma^s_{r,s}}\right)} + \left(1 - j_{r,s,l}\right) e^{\log(0.5)\left(\frac{\ell_l - \mu^s_{r,s}}{\gamma^s_{r,s}}\right)}$$
$$j_{r,s,l} = 1/\left(1 + e^{-5\left(\ell_l - \mu^s_{r,s}\right)}\right)$$

where $\gamma^s_{r,s}$ defined the curvature of the left-hand limb, $\sigma^s_{r,s}$ defined the curvature of the right-hand limb (which was fixed to 200 to prevent estimating a descending limb, see Table 3), and $\mu^s_{r,s}$ was the midpoint. Because the commercial and recreational catch were combined into a single SL fishery, only one selectivity function was required, which was assumed to be the same during the AW and SS, and the same for both immature and mature females.

Vulnerability parameters defined the relative scaling of the selectivity curves (i.e., the height of the selectivity curve) by sex (s) and season (t) and was denoted $v_{s,t}$. There were six vulnerabilities for each region, with one per sex category and season. These parameters were estimated relatively, with the vulnerability for the sex/season category with the greatest vulnerability assumed to be fixed to one, and the remaining vulnerability parameters were estimated to be between zero and one, thus $v_{s,t} \in (0,1)$.

The combination of selectivity and vulnerability was region, sex, and size class specific and denoted

$$\eta_{y,t,s,l} = \begin{cases} s_{r,s,l} \sum_t \frac{v_{s,t}}{2} & \text{if 1 season} \\ s_{r,s,l} v_{s,t} & \text{if 2 seasons} \end{cases}$$

To account for retention and discarding, retention ($\zeta_{y,t,s,l}$) was defined as the probability of retaining an individual by year (y), season (t), sex (s), and size class (l). This included any legal status rules (MLS and berried females) and any information on other forms of retention, such as high-grading.

The combination of selectivity, vulnerability, and retention was then used to define fishing mortality rates for the SL and NSL fisheries (Appendix I).

2.4 Parameters and priors

Estimated model parameters included productivity parameters (i.e., average recruitment, natural mortality, and growth), maturation parameters, and fishery parameters (i.e., catchability, selectivity, and vulnerability). All model parameters are listed in Table 2, and fixed values for some parameters and model settings are provided in Table 3.

Nine (of a possible ten) vulnerability parameters were estimated: one for each region, sex, and season, with two of the region 1 parameters conflated (SS males and AW immature females, Table 4).

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

2.5 Assessment indicators

Work has been completed to develop model-based reference levels for red rock lobster stocks. To calculate the reference level, a wide range of fixed catch and fixed *F* rules were projected forward 30 years, and the performance of each rule was assessed over the final 20 years of the projection period. Recruitment deviates in the projection were based on estimated recruitment deviates starting in the first year with reasonable length data. For CRA 7 and CRA 8, this included 32 years from 1987 to 2018. Evaluated performance indicators included the average annual catch, the CV of catch over time, and the probability of falling below the soft limit. The rule that maximised catch while maintaining less than 5% chance of falling below the soft limit was identified for each rule type (fixed catch or fixed *F*). Fixed catch rules were further constrained by requiring 99% of the fixed catch amount to be able to be taken for more than 95% of years and simulation replicates. The reference level (B_R) was defined as the average adjusted vulnerable biomass between the maximum constrained fixed catch and fixed *F* rules combined. The methods used to estimate the reference levels are more thoroughly discussed by Rudd et al. (2021c).

This assessment used the same indicators as were used in the 2019 CRA 1 and CRA 3 stock assessments and 2020 CRA 4 and CRA 5 assessments (Table 6, Table 7; Webber et al. 2020, Rudd et al. 2021b), with the addition of the reference level (B_R), previously referred to as an interim reference level, and exploitation rate associated with the reference level (U_R). The main indicators were related to the relative estimates of adjusted vulnerable biomass[5], spawning stock biomass (*SSB*), and total biomass, including the probabilities of each of the biomass indicators falling below current levels, after projecting the current catch forward for five years. Probabilities were calculated from all samples of the posterior distribution.

Vulnerable biomass was defined as start-of-season AW biomass, which did not include mature females, which are not harvestable in this season, because they are assumed to be in berry. 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 alternative regulations were applicable.

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

2.6 Maximum *a posteriori* (MAP) inference

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

2.6.1 MAP base case

2.6.1.1 Matching the previous assessment model

The 2015 CRA 7 and CRA 8 stock assessment model used the MLSM (Haist et al. 2016) as the software platform. Although the LSD model was extensively tested against the MLSM when it was developed

[5] 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.

and was found to produce the same results, there have been several updates to the LSD code over the past few years, so the first step in the 2021 assessment involved matching the results from the LSD model to the 2015 MLSM base case assessment. However, attempts to match the results of the 2015 MLSM base case model were unsuccessful, likely due to changes in the way length frequency data set weights were specified in the LSD model and a bug identified in the previous CRA 7 and CRA 8 model code.

In the MLSM assessment, the same effective sample size was specified for all three sex categories: males, immature females, and mature females, and the sex-specific data set weights were specified iteratively. The LSD model changed this specification to a separate effective sample size for each sex category, using an overall length frequency data set weight. This subtle difference led to some difference in past assessments, but none as large as for the CRA 7 and CRA 8 assessment. In addition, a mistake was found in the way movement was coded in the MLSM model. Movement was coded as the seasonal proportion of individuals that moved from CRA 7 to CRA 8 (i.e., applied twice per year). Movement rates were estimated from 1985 to the final year in the model and the mean of the estimated movement parameters was applied for years prior to 1985. Because the model was annual before 1979, this meant that the movement rate was applied only once per year, resulting in movement that was half what it should have been. The RLWG and stock assessment team decided not to continue matching the previous stock assessment using the LSD model.

2.6.1.2 Searching for a 2020 base case

Exploratory model runs were done to develop a new base case stock assessment model, with the most important change being the move to a two-region model, where: **region 1** included CRA 7 (statistical areas 920 and 921), Southland (areas 922 and 923), Stewart Island and Snares Island (statistical areas 924 and 925); and **region 2** comprised Fiordland only (statistical areas 926 to 928). The selection of a CRA 7 and CRA 8 base case run involved many steps and several dead-ends. The following is an abbreviated sequence of steps that led to the CRA 7 and CRA 8 base case:

1. Including all input data up to the end of 2020.
2. Creating a two-region model, with separate catch histories and CPUE series; no movement between regions, four selectivities (by sex and region), nine vulnerabilities (by region, sex, and season), a sex-specific growth model, a shared estimated M, and retention rates that were constant across all years starting in 2000.
3. This model was pushing the immature female AW vulnerability parameters up against 1, so this parameter was set to share the value of the SS male vulnerability parameter (this was initially a mistake that was identified after the base model and related sensitivity tests were already running MCMCs and the assessment workshop was running short of time. An MCMC sensitivity (not reported) was run to account for this mistake, fixing the immature female AW vulnerability to one, and there was no significant difference in results from the base model presented in this assessment).
4. Dropped some of the logbook (LB) LFs, which were based on data from only one vessel.
5. Attempted to fit the assessment model to the puerulus settlement series, but failed.

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

- Model years: 1945 to 2020[6], assuming an unfished population in 1945.
- Two regions: region 1 included statistical areas 920, 921, 922, 923, 924, and 925; and region 2 included 926, 927, and 928.
- Two six-month seasons: AW (April-September) and SS (October-March) during each fishing year, starting in 1979.
- Three sex categories: immature females, mature females, and males.

[6] Calendar years from 1945 to 1978 and April-March fishing years from 1979–80 to 2020–21. January 1979 to March 1979 catches were added to 1978

- Tail width bins: 36 two-mm wide bins from 30 mm to 100 mm tail width (last bin was a 'plus group' or accumulator bin).
- Recruitment deviations (*Rdevs*): estimated from 1945 to 2018. The final two model years were set to the 2018 estimate, given no real information in data for these recruitments and the lack of a coherent puerulus settlement index. No stock recruitment relationship was assumed.
- Size at recruitment specified with a mean of 33.35 mm and standard deviation 4 mm, based on recent studies of juvenile growth (Figure 4, Roberts & Webber in prep.).
- Sex-specific growth shared between the regions using the Schnute-Francis growth model. No density-dependent growth.
- Selectivity: 'double-normal' with right-hand limb parameter fixed at 200 (i.e., no descending right-hand limb).
- female only maturation ogive shared between the regions; nine vulnerability parameters: one per region per sex per season, with region 1 immature females during the AW sharing a vulnerability parameter with SS males (see Table 4).
- a single natural mortality shared between the regions and sexes.
- instantaneous fishing mortality dynamics using the Newton-Raphson algorithm (three iterations) to iteratively solve the Baranov catch equation.
- Handling mortality, two periods: 1945 to 1989 fixed at 0.1, and 1990 to 2025 fixed at 0.05.
- Six CPUE series (CR, FSU, and CELR for region 1 and region 2), each with a separate catchability (*q)* coefficient.
- Catch from 1945 to 2020, with illegal catch set at 10% of the commercial catch from 1945 to 1989, and 2% of the commercial catch from 1990 to present. The illegal catch time series was scaled to the FSU and CELR CPUE when available.
- Results of the new retention analysis.
- Likelihoods:
  - Lognormal for all CPUE series (CR, FSU, and CELR)
  - Robust normal for tags
  - Multinomial for LFs, fitted to proportions for males, immature females, and mature females, with each sex category normalised separately
  - Multinomial for sex ratios
- Data weighting: determined iteratively. No re-weighting of tag data because they are self-weighting through the estimation of an observation error parameter.

The base case model fitted the CELR CPUE series (since 1990) acceptably in both regions (Figure 5), although some points were not fitted well in the mid-2000s and 2010s in the SS season in both regions (Figure 6). The fit to the FSU series (from 1979 to 1988) was also adequate (Figure 7), although there were a lot of positive residuals in AW region 1, followed by negative residuals in the SS region 2, implying some underlying shift in the seasonal data that was not being modelled (Figure 8). The fit to the unstandardised CR series was satisfactory, apart from not fitting the first data point in region 2. The overall downward trend (from 1963 to 1973) was captured by the model (Figure 9), without a strong residual pattern (Figure 10).

Model fits to the LF data were generally acceptable in region 2, but there were some examples of poor fits in region 1, particularly for males (Figure 11, Appendix II). The poor fits to the region 1 LF data are likely due to combining the CRA 7 catch sampling data with the CRA 8 (Southland) logbook data and the implications of selectivity and vulnerability assumptions for the combined region. Besides being collected under different protocols, the data also differ because different MLS regimes operated in the two QMAs, while the model parameterisation forced these two data sets to use the same selectivity function. This can be seen in the residual plots for region 1, where all the catch sampling residuals (which originated from CRA 7) for small males and immature females are positive, indicating that the model is underestimating these proportions because of the MLS mismatch (Figure 11, Figure 12). The current configuration of the LSD model precludes having more than one MLS regime in the same region, so the resulting selectivity function will be an average between the two sets of data. The lack of residuals for mature females reflects the lack of mature female observations in both CRA 7 and CRA 8-Southland (see figure 26 in Starr et al. 2022).

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 13). This variation could be attributed to measurement error, individual variability in growth, or spatio-temporal variability. 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 were unsuccessful because there is no reliable observation that indicates whether an individual lobster has recently moulted. However, while the residuals in this growth model are large, there is little evidence for a systematic bias in terms of statistical area of release (Figure 14), or in subsequent recaptures (Figure 15).

The sex ratio fits (Figure 16) in region 2 were reasonably good, although the model seemed incapable of fitting the extreme high and low observed proportions. The fits to the sex ratio proportions in region 1 were hampered by the same problem described above for the LF data: i.e., the CRA 7 and CRA 8 data were collected under different protocols and MLS regimes, with the model incapable of fitting the male/immature female ratios from about 2000 onward (Figure 16). This figure also shows very low proportions of mature females in this region. The poor sex ratio fits in region 1 are borne out in the standardised residuals, with almost all the region 1 male residuals negative in both seasons, while the immature female residuals were mainly positive except after 2010 where they had no pattern (Figure 17).

The LF distributions of the unfished population for both regions appeared to be similar, differing only in absolute scale (Figure 18). This similarity was due to both regions having the same growth function and sharing the estimated M parameter, although with different R_0 values.

The selectivity functions by region and sex look very similar (Figure 19). Fifty percent of female maturation was estimated to occur near to the 60 mm TW bin in this model (Figure 20), indicating that the fishery takes some sub-mature females, because the MLS is 57 mm TW.

Annual fishing mortality (F) in the 1970s was estimated to be very high in region 1, possibly exceeding 3 near the end of 1970s (Figure 21). These high mortality rates may reflect a poor division of catch between the two regions. Recent SL fishing mortalities in region 1 were low in both seasons, while the AW SL fishing mortality in region 2 was the highest among the four categories.

Both regions appeared to have experienced a strong recruitment pulse, estimated around 1980 (possibly to support the high catches in the 1980s) (Figure 22). Early recruitment in region 1 was estimated to be very strong, which was likely to be an artefact of the high early catches specified in this region. This response may be overstated if too much catch was allocated to this region in the historical reconstruction. Recruitment in region 1 was well below average after 1980, while there were two pulses of good recruitment in region 2 around 2000 and 2015 (Figure 22).

Plots of the adjusted vulnerable biomass showed a strong declining trend from 1945 to around 1980 in both regions (Figure 23). Vulnerable stock size remained low until near 2000, when stock size began to increase in both regions to higher levels, but never approached the levels estimated at the beginning of the model reconstruction. Note that the male and female biomass levels are much more similar in region 1, while the female biomass level is much higher in region 2, reflecting the presence of mature females in the region 2 sampling data, which are almost totally absent in region 1 (where immature females and males are present in almost equal numbers).

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

2.6.2 MAP sensitivity trials

The RLWG decided on twelve sensitivity trials as single variants relative to the *base* case (Table 8). These included sensitivities testing assumptions relating to parameterisation (*fix_M, sel_rh2, growth2r, qdrift, start_1979*), catch series (*base_cshift, illegal_20early*), MLS (*CRA7_MLS*), retention (*annual_retention)*, and successively down-weighting the CPUE, sex ratio, or LF data sets (*downCPUE*, *downSR*, *downLF*). The runs which down-weighted the primary data components were instructive as diagnostics, but cannot be used as credible runs.

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the twelve sensitivity trials are presented in Table 9. The estimated *base* case selectivities by region were compared with the sensitivity runs, grouped in four blocks of three runs each (Figure 24, Figure 25, Figure 26, and Figure 27). The *base* case recruitment trajectories were compared with the twelve sensitivity runs, grouped in four blocks (Figure 28, Figure 29, Figure 30, and Figure 31). The *base* case adjusted vulnerable biomass trajectories were compared with the twelve sensitivity runs arranged in four blocks (Figure 32, Figure 33, Figure 34, and Figure 35).

The *fix_M, growth2r, CRA7_MLS,* and *annual_retention* MAP sensitivity runs were within plus or minus 10% of the *base* run value in terms of the size of the unfished vulnerable biomass, the relative size of each region, and the 2020 status relative to the unfished vulnerable biomass (Table 9). The sensitivity run *base_cshift* maintained the same overall stock size and stock status, but shifted the relative size and stock status between regions based on the arbitrary change the regional catch split (Table 8, Table 9). This indicates that regional long-term yields are a product of an uncertain catch history.

The *qdrift* sensitivity run estimated a similar stock size and regional split to the *base* run, but the 2020 stock status was lower because the model assumed a compounding 1%/year increasing exploitation rate over the model period (Table 9). The *start_1979* sensitivity run estimated a much smaller overall stock size and current stock status, suggesting that a later starting model would be unreliable, given the nature of the data. The *illegal_20early* sensitivity run, which increased the illegal catch before 1989 by 20% (Table 8), resulted in an increased stock size and a lower 2020 stock status. Finally, the *sel_rh2* model run estimated a much smaller initial vulnerable stock size due to the descending right-hand limb, but estimated a similar current stock size, resulting in a much higher level of stock status (Table 9).

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

- ***fix_M***: as *base* except fix natural mortality to the *base* case MAP estimate of 0.09. MCMC was done for this model run.
- ***sel_rh2***: as *fix_M* except estimate a descending right-hand selectivity limb. MCMC was done for this model run. This run was the most different from the *base* model, with a dome-shaped right-limb selectivity curve resulting in less than half the initial vulnerable biomass and slightly higher initial *SSB* and *SSB* in the final years compared with the *base* model.
- ***growth2r***: as *base*, except growth is by region and sex and tags without statistical area were dropped. This run differed little from the *base* model run.
- ***base_cshift***: shift 30% of region 1 catch to region 2 up to 1978: resulted in a predictable change in the relative size of each region but not to the size of the overall stock. This run indicates that there will be considerable uncertainty in the estimate of the regional stock status and yields.
- ***CRA7_MLS***: as *base*, except use the CRA 7 MLS rather than the CRA 8 MLS in region 1. Overall stock size increased for this run while 2020 stock size remained the same, indicating a shift in abundance under a different MLS regime.
- ***illegal_20early***: as *base* except set the illegal catch to 20% of total commercial catch prior to 1990. This run predictably increased the initial biomass and the current biomass, resulting in a small reduction in stock status relative to the *base* run.

- ***downweight_CPUE***: as *base* except down-weight the likelihood for all CPUE series to 10%. Down-weighting CPUE had a major effect on the estimated recruitment deviates (Figure 31).
- ***downweight_SexRatio***: as *base* except down-weight the likelihood for the sex ratios to 10%.
- ***downweight_LFs***: as *base* except down-weight the likelihood for the LF data to 10%.
- ***start_1979***: as *base* except the first model year was set to 1979 to avoid years with high catch uncertainty. This parameterisation led to a much lower relative vulnerable biomass and relative spawning biomass in region 1 compared with the *base* model, while the region 2 biomass was similar in size and stock status to that of the *base* model.
- ***annual_retention***: as *base* except annual estimates of retention rates were used. This model run differed little from the *base* model.
- ***qdrift***: as *base* except the *qdrift* parameter was fixed at 1% per year for the CELR CPUE series. This run estimated a similar initial stock size as did the *base* model, but the 2020 stock status was about 25% lower than the *base* model resulting from the increased exploitation. It is not known how realistic this model is.

2.7 Bayesian inference using Markov chain Monte Carlo (MCMC)

Bayesian inference was used to characterise parameter uncertainty. LSD uses the Stan software to run MCMC simulations using the Hamiltonian Monte Carlo (HMC) algorithm. The MAP values (Table 9) were used as starting values. For the *base* case and two selected sensitivity tests *(fix_M* and *sel_rh2),* the posterior distributions were explored with a total of 1000 samples across four chains, each with a warm-up phase of 500 iterations and length of 500 samples, retaining every second sample.

2.7.1 MCMC base case

MCMC was used to obtain samples from the posterior distribution for the *base* case model described in Section 2.6.1. The trace plots indicate that MCMC chains were well-mixed (Figure 36, Figure 37, Figure 38, and Figure 39). 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 40, Figure 41, and Figure 42). However, the posterior distributions of the male *Gshape* parameter (labelled as *par_grow_gshape_i[1]* in Figure 40) and the *Gobs* parameter (labelled as *par_grow_sd* in Figure 41) were beyond the traction of their respective priors. The male *Gshape* parameter defines the curvature of the growth model, and the posterior values were higher than expected *a priori*, although this difference is of little concern. However, the lower *Gobs* posterior is somewhat concerning because this parameter defines the observation error associated with the tagging data and, if less error is attributed to observation error, then, by definition, more error is attributed to process error. This process error was used in defining the growth transition matrix, where a higher process error smeared individuals over a wider range of size classes when the transition matrix was applied. These priors were derived from an unpublished meta-analysis based on the tag release-recovery data available in 2015.

Figures were presented for the MCMC outputs of the *base* case model only. These outputs are comparable with those provided for the *base* case MAP results, including fits to the CR CPUE series (Figure 43), the FSU CPUE series (Figure 44), and the CELR CPUE series (e.g., compare Figure 5 with Figure 45).

The fits to the LF data (all MCMC LF fits are presented in Appendix II) and the associated residuals (Figure 46, Figure 47) showed similar properties to those described for the equivalent MAP fits (e.g., poor fits to large males in region 1 and better fits to mature females). The catch sampling residuals for males and immature females were all positive, reflecting the estimation of a joint selectivity for data collected under two different MLS regimes. There was also a failure to fit small males and immature females in region 2, and there were poor fits to the catch sampling data collected before the implementation of the logbook programme in 1993 in both regions. The fits to the sex ratio data mirrored the MAP fits, with the model unable to reconcile the disparity in the region 1 MLS regimes, leading to overestimates of the proportion of males beginning in the early 2000s, combined with an underestimate of the proportion of immature females (compare Figure 16 with Figure 48). The region 2 sex ratio fits were also similar to the MAP fits, with the model predictions following the overall trend, but failing to match the extremes of the observations.

The selectivity posterior plots for the *base* model showed little uncertainty in these parameters, indicating that the model did not deviate very much from the MAP estimates, noting that the right-hand limb was fixed (compare Figure 19 with Figure 49). The posterior distribution of the maturation curve was only slightly more uncertain than the uncertainty around the selectivity curve, with considerable weight above the 60 mm TW estimate for the inflection point (Figure 50). The median estimate for *mat50* (at 59.95 mm) was very close to the MAP estimate (at 59.94 mm).

The plot of growth increments showed surprisingly tight credible intervals despite the large amount of variability shown in the equivalent MAP plot (compare Figure 13 with Figure 51). Tag residual plots by statistical areas (Figure 52) and re-release category (Figure 53) confirmed the conclusions reached from the MAP fits: growth was reasonably consistent across the four main CRA 8 statistical areas with the most tagging data, across re-release categories, and by sex. Two further plots show tag residuals by year of release (Figure 54) and by the size at release for each statistical area (Figure 55). The year of release appeared to have little or no bias in the residuals, noting the very small number of recaptures in CRA 7 statistical areas, with growth consistent across the more than 50 years spanning the tag release data (Figure 54). There appeared to be little negative bias in growth as the initial size at release became larger, except possibly in statistical area 924.

As noted for the MAP plot, fishing mortality appeared to be very large for region 1 in the late 1970s, with the estimates well above $F = 2$ for a few years (Figure 56). With the early catches shown in Figure 57, it is apparent that the model was sufficiently flexible to allow for the capture of the full values.

As for most of these *base* case posteriors, the recruitment posteriors for regions 1 and 2 resemble the equivalent MAP plots, with region 1 recruitment being well above average up to the mid-1980s, followed by a period of higher recruitment but still below average (Figure 58). Recruitment in region 2 was less variable, with a period of recent (2010–2016) good recruitment.

As seen in the equivalent MAP plot, the plot of adjusted vulnerable biomass showed a long continuous decline in biomass from the beginning of the reconstruction to the early 1980s, when the decline ceased (Figure 59). This was followed by a period of no trend until around 2000, when the stock began to increase in both regions. The *SSB* plot shows similar trends for each region, with a long period of decline followed by an increasing trend (Figure 64). The two regions differ in that region 2 went below the ‘soft limit’ in the late 1970s and below the ‘hard limit’ at the end of the 1980s, but has since recovered to fairly high levels now. Summaries of posterior distributions are presented in Table 10 (parameter estimates) and in Table 11 (derived quantities). *Base* case probabilities are presented in Table 12.

2.7.2 MCMC sensitivity trials

The RLWG chose two of the MAP sensitivity trials to be explored using MCMC: *fix_M* and *sel_rh2*. The *sel_rh2* run represented an alternative hypothesis that differed in the parameter space investigated (i.e., biomass trajectories affected by the alternate selectivity curve and different estimates of growth) relative to the *base* case. The *fix_M* MCMC run was undertaken in case *M* could not be estimated well by the *base* model, a circumstance which did not occur (see trace plot in Figure 37). Furthermore, the value of *M* chosen for the *fix_M* run ($M = 0.0900$) was close to the median value from the *base* case run ($M = 0.0932$), leading to very similar outputs for both runs. Because of this, the *fix_M* sensitivity run requires no further discussion in this report. Both sensitivity runs had acceptable MCMC diagnostics (not presented).

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for these MCMC sensitivity trials are presented in Table 13. Probabilities associated with model indicators are shown in Table 14 for the two sensitivity runs and the *base* run. Comparisons of these sensitivity trials to the *base* case are shown for fits to the CELR CPUE indices (Figure 45), selectivity (Figure 49), recruitment (Figure 61), and adjusted vulnerable biomass (Figure 62).

The *sel_rh2* run estimated much higher levels of R_0 in region 1 than did the *base* run and the MAP *sel_rh2* run (the median R_0 for the *base* run was 1 218 000 compared with 2 337 000 for *sel_rh2*; Table 13). The R_0 estimates for region 2 are similar for both runs. The high estimates for R_0 translate to larger biomass estimates for the *sel_rh2* run. While the vulnerable biomass estimates are lower because of the strong descending right-hand selectivity limb, estimates of the region 1 SSB_0 and B_{0tot} are much higher for the *sel_rh2* run compared to *base* run.

The differences in the region 1 stock size estimated by the *sel_rh2* run compared with the *base* run also result in a very different set of region 1 recruitments for the *sel_rh2* run compared with the *base* run (Figure 61). These differences are the result of the strongly descending right-hand limb of region 1 *sel_rh2* selectivities for males (Figure 49). The *sel_rh2* estimated a very different time series of recruitment deviates for region 1 relative to the *base* model, which closely resembled the series for region 2 for the more data rich period since 1979, but which was offset to very high and unrealistic levels compared to region 2 (Figure 61).

The *sel_rh2* run appeared to be more responsive to changes in CPUE, apparently caused by the very low estimated selectivity of large males resulting in strong recruitment events moving more rapidly through the vulnerable size range. Generally, the *sel_rh2* run improved model fit to the CELR CPUE in region 1, particularly since 2005, although this model run did not fit the 2019 AW index very well (Figure 45).

The *sel_rh2* run produced a similar estimate of the 2021 vulnerable biomass across both regions compared with the *base* run (Table 13). However, the region 1 B_0 estimate for the *sel_rh2* run is very low, with a correspondingly high estimate of current stock status relative to B_0 (B_{2021} = ~75% B_0) (although B_{0now} is larger). The *sel_rh2* run estimated a much more optimistic current *SSB* in region 1 (median = 16 070 tonnes [90% CI = 12 540–20 730 tonnes]) than the *base* model run (median = 3705 tonnes [90% CI = 3247–4163 tonnes]) and *SSB* status (see Table 13). This outcome was deemed implausible by the RLWG because of the implied existence of a large cryptic biomass of large lobsters.

A summary of the sensitivity runs is provided below.

- *fix_M:* fix *M* to be equal to the 0.09.
  - turned out to be using virtually the same *M* as was estimated by the *base* run, had very similar model outputs and, so, provided no real additional insights;
- *sel_rh2*: as *fix_M* except estimate a descending right-hand selectivity limb.
  - estimated a strongly domed selectivity for males in region 1, and a slightly less domed shape for males in region 2. Female selectivity was superficially estimated to be close to a logistic shape, although this was confounded with vulnerability for this sex.
  - resulted in a very different estimated time series of recruitment for region 1 compared with the *base* model run, and that closely resembled the estimated series for region 2 since 1980.

estimated comparable current vulnerable biomass to the *base* model run for both regions, but a far more optimistic current *SSB* and *SSB* status in region 1, relative to the *base* model (Figure 65,

  - Figure 66).

2.8 Projections

The lack of a consistent CPUE abundance series for the most recent period prevented the development of a new MP based on the outcome of this stock assessment, resulting in the loss of MPs for setting the TACC over the next few years. Instead, five-year projections explored vulnerable biomass in relation to proposed reference levels, based on methods described by Rudd et al. (2021c). These five-year projections, for the fishing years 2021 to 2025, were done for the *base* case model only. These projections were repeated for each sample from the posterior distribution. Five sets of projections were done at:

- current catch levels (*status quo*);
- ±10% of current catch levels (across all sectors); and
- ±20% of current catch levels (across all sectors).

In the *status quo* projection, the recreational and NSL catches were assumed to be the same as the final model year (2020) and were set to be constant when projecting forward (Table 15, Figure 57). The projected commercial catch in 2020 was set to the combined TACC for CRA 7 and CRA 8 of 1298 tonnes, split into the two regions and two seasons (Table 15). These projected catches were allocated to each region and season based on the 2020 catch splits.

Projected recruitment deviates were simulated from a normal distribution with mean calculated from the mean of the 2009–2018 recruitment deviates, the standard deviation set to *sigmaR* (Table 3), and recruitment autocorrelation derived from the 1987–2018 recruitment deviates. Projected recruitment deviates replaced the 2019–2020 deviates because recruitment was not estimated in the reconstruction model for these years (Figure 58).

In the *status quo* projection, the adjusted vulnerable biomass and *SSB* were predicted to increase rapidly over the next five years in region 1, remain about the same in region 2, and increase for both regions combined (Figure 63, Figure 64). In the *base* case model run, the median 2021 adjusted vulnerable biomass for combined CRA 7 and CRA 8 was predicted to be 21% of B_0 (B_{2021} / B_0 = 0.214 [90% credible interval (CI) = 0.179–0.253]) and was projected to increase to a median value of 24.5% of B_0 by 2025, at current catch (B_{2025} / B_0 = 0.245 [90% CI = 0.187–0.316]) (Table 11). In the *base* case model run, the median 2021 *SSB* was predicted to be 48% of SSB_0 (SSB_{2021} / SSB_0 = 0.480 [90% CI = 0.442–0.521]) and was projected to increase to a median value of 54% of SSB_0 (SSB_{2025} / SSB_0 0.536 [90% CI = 0.480–0.606];Table 11) by 2025.

The *status quo* projection predicted that the total CRA 7 and CRA 8 stock will increase from 46% greater than B_R (B_{2021} / B_R = 1.463 [90% CI = 1.270–1.688]) to 69% greater than B_R (B_{2025} / B_R = 1.687 [90% CI = 1.307–2.119]) by the beginning of 2025 (Table 11).

In region 1, the projections at ±10% and ±20% of current catch levels all result in increases in the median adjusted vulnerable biomass (Figure 63). In region 2, the projections that increase the catch by 10 and 20% result in the adjusted vulnerable biomass declining over the next five years, while the projections that decrease the catch by 10 and 20% result in the adjusted vulnerable biomass increasing (Figure 63). When combined across both regions, the adjusted vulnerable biomass increases for all projections except for the run that increases the projected catch by 20%.

3. DISCUSSION

This assessment, like all New Zealand rock lobster assessments, describes a stock that was initially heavily fished (Figure 56), resulting in a rapid decline in vulnerable biomass through to the mid-1960s, followed by a long period over which the vulnerable biomass stabilised from the mid-1960s to the early-2000s (Figure 59). The overall stock size has been increasing since around 2000, although there was an apparent slowing of the increase in Fiordland (region 2) between 2009 and 2014 (Figure 60). Recruitment has been relatively strong in region 2 in most years since 1998, and less optimistic (although increasing from the mid-2000s) in region 1 (Figure 61). The period of decline in region 2 from 2009 to 2014 was due to the drop in the region 2 recruitment in the mid to late-2000s (Figure 61).

The overall stock size is estimated to be well above the biomass reference level (B_R) and is expected to continue to increase (Table 11). At the *status quo* future catch levels specified in the projections, the *base* model estimated that overall the stock will increase over the next 5 years (Figure 63). A similar pattern is observed for the *SSB* (Figure 64).

In general, the *base* case model fitted the CRA 7 and CRA 8 data reasonably well. Some exceptions included the fits to the CELR CPUE series in region 1 (Figure 45), the fit to the FSU CPUE series in region 1 during the SS (Figure 44), LF fits to larger males in region 1 (Figure 46), and the fits to the sex ratios in region 1 (Figure 48). These issues may partly have arisen from assuming a near-logistic selectivity curve, when large individuals of both sexes are almost totally absent in the catch of region 1. These issues may also partly be caused by combining CRA 7 with the southern CRA 8 statistical areas, given the different MLS in place for these two regions. This is not an ideal situation. Future stock assessments for CRA 7 and CRA 8 should allow different MLS regimes and different selectivities to be estimated for different portions of the catch within a region so that the different dynamics in CRA 7 and the southern CRA 8 statistical areas can be captured. Despite these issues, the model was considered to have done a reasonable job at representing the CRA 7 and CRA 8 stock(s).

The lack of mature females in region 1 (Figure 48) is dealt with in the model by estimating a low relative vulnerability for this demographic (see *vuln3* and *vuln4* in Table 13). When the right-hand limb of the selectivity curve was estimated (this was fixed in the *base* model, so that large males and females were almost fully selected), a strongly-domed shape was estimated, so that larger lobsters were essentially hidden from the fishery (Figure 49). From the very small number of recaptures of lobsters tagged in CRA 7 that spent a sufficient time at liberty to allow for movement, it is likely that a significant proportion of lobsters of both sexes move in a counter-current direction from CRA 7 towards Stewart Island CRA 8 (Starr et al. 2022). Previous tagging studies show that movement rates are likely to be greatest prior to maturation (Annala & Bycroft 1993), although the fishery does not appear to catch mature lobsters in any great quantities across the Southland region.

The stock assessment model avoided needing to estimate this movement between CRA 7 and Southland by rolling these areas into a single model region (region 1). But it is also known that counter-current movement continues around the coast of the Stewart Island (predominantly from east to west, via the south) and that some lobsters move from Stewart Island to Fiordland (McKoy 1983). Unfortunately, the tagging approach currently used for New Zealand rock lobsters is inadequate to quantitatively estimate movement within region 1 or between region 1 and region 2. The current approach of relying on voluntary recoveries of tags that were released relatively haphazardly might be useful for determining if movement does occur at some scale and for identifying the probable direction of movement, but cannot be used to reliably estimate movement rates, as needed for stock assessment.

The 2021 assessment is an improvement over the previous assessment of CRA 7 and CRA 8 for several reasons. In the attempt to match the LSD model to the previous MLSM model, a mistake in the code that described movement between the two areas was found, resulting in a model where the twice-yearly seasonal movement rate after 1979 was only applied once yearly before 1979. Furthermore, it was not possible to reliably estimate the movement parameters, likely because the available data are not informative of movement and many of the processes within stock assessment models are confounded (e.g., movement, natural mortality, recruitment, etc.). The re-definition of each region such that the estimation of movement rates was not required was consistent with the available evidence of movement in the region, resulting in a model which estimated all model parameters based on the information available, given the history of catch and location of landings in the region. The 2015 assessment started the model in 1963 to avoid the problem of uncertain catches before that year, but initial exploitation rate estimated by that model was very close to zero, which was considered an unreasonable outcome given the knowledge that early exploitation in the fishery was large (despite the exact magnitude of removals in these early years being uncertain). The 2021 model estimates of stock size and exploitation rates were generally similar to the equivalent estimates from the 2015 assessment (Table 16, Figure 67, Figure 68) but the contributing hypotheses on movement and early exploitation were more defensible.

3.1 Future research

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

- explore ways of speeding up the model, such as changing from removing the catch using fishing mortalities (*F*s) to exploitation rates (*U*s) or estimate growth outside of the stock assessment;
- allow different fisheries within the same region (i.e., the areas as fisheries concept using different selectivities, this would enable different selectivities for the CRA 7 catch in region 1 and the CRA 8 catch within region 1);
- further explore the relative weightings of length frequency data;
- investigate the influence of priors where the posteriors are substantially different from the prior (e.g., *Gobs*) to determine whether these priors are appropriate and influential, and/or whether the growth meta-analysis needs to be redone;
- further explore the growth function, including separation by season;
- look into estimating the growth transition matrix directly (i.e., rather than estimating a continuous growth function and then translating this into a growth matrix);
- explore alternative selectivity curves;
- consider use of an estimable parameter within the model to scale the early catch history up or down;
- run additional sensitivities to MCMC, particularly those that will result in lower productivity: (e.g., alternative fixed M, downweighing of CPUE);
- start estimating recruitment deviates from the year when length frequencies are available (and fix them to R_0 prior to this);
- develop a filter on F for the reference level projections to prevent the possibility of the simulation taking the full vulnerable biomass in a single year and then fishing a depleted population for the rest of the projection series, since this scenario is highly unlikely and undesirable; and
- explore the use of dynamic B_0 indicators, including in the context of the poor availability of historical catch data and potentially shifting productivity (this issue goes beyond rock lobster).

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

- revisit the CR data calculation, applying the same methodology as used for the FSU and CELR data;
- develop an alternative CPUE index, in the first instance based on CRA 8 logbook data and as soon as possible based on electronic reporting data;
- trial CPUE models where catch is the dependent variable and number of pots lifted as an explanatory variable;
- separate the length frequency and sex ratio data sets in the model inputs (i.e., so that the sex ratio inputs are not derived from the LFs within the model);
- further consideration of the retention rate in CRA 7;
- plot retention by sex using weight (not just length) to test the hypothesis that retention is primarily based on weight;
- investigate alternative handling mortality assumptions;
- investigate the development of climate covariates for predicting temporal recruitment variability, as experienced by the fishery; and
- investigate fishery-independent methods for the collection of growth information across the vulnerable size range, such as direct ageing.

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6. TABLES

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

	MLS (mm)			
	Used in stock assessment		CRA 7	
Period	Males	Females	Males	Females
1945–1949	None	None	None	None
1950–1951	47	49	47	49
1952–1958	51	53	47	49
1959–1989	53	56	47	49
1990–2025	54	57	47	49

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

Parameter	Definition
R_0	initial numbers recruiting
M	instantaneous rate of natural mortality
Rdevs	annual recruitment deviations
sigmaR	standard deviation of *Rdevs*
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)
Mat50	TW at which 50% of immature females become mature
Mat95add	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* × *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
SelR	shape of the right-hand limb of the selectivity curve (as if it were a standard deviation)
vuln	relative vulnerability by sex and season
qdrift	additive change in catchability coefficient each year
U_0	initial exploitation rate (the first model year is in equilibrium using this estimate)
Gdd	density-dependent growth parameter

Table 3: Fixed quantities used in the CRA 7 and CRA 8 assessment models. Region is denoted by either [1] for region 1 or [2] for region 2.

Quantity	Value	Quantity	Value
Relative data set weights		**Fixed parameters**	
Tags	1.00	male length-weight *a*	3.39E-6
CR CPUE [1]	2.70	male length-weight *b*	2.9665
CR CPUE [2]	4.00	female length-weight *a*	1.04E-5
FSU CPUE [1]	1.20	female length-weight *b*	2.6323
FSU CPUE [2]	2.90	U_0	0
CELR CPUE [1]	1.30	*qdrift*	0
CELR CPUE [2]	2.45	*selR*	200
sex ratio [1]	16.00	**Recruitment**	
sex ratio [2]	3.10	*sigmaR*	0.4
LFs [1]	1.91	last year of estimated *Rdevs*	2018
LFs [2]	1.00	years for estimating *Rdevs* for projections	2009–2018
Catch and handling mortality		years for estimating autocorrelation	1987–2018
Handling mortality, 1945–1989	0.10	recruitment size mean	33.35 mm
Handling mortality, 1990–2025	0.05	recruitment size SD	4 mm
Growth		**Other**	
length at *Galpha*	50 mm	Newton-Raphson iterations	3
length at *Gbeta*	80 mm	Tail compression: male bins [1]	2 to 34
Gmin	0.0001 mm	Tail compression: immature female bins [1]	2 to 22
Gdd	0	Tail compression: mature female bins [1]	7 to 36
		Tail compression: male bins [2]	4 to 34
		Tail compression: immature female bins [2]	5 to 19
		Tail compression: mature female bins [2]	9 to 32

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

	Region 1		Region 2	
Sex	AW	SS	AW	SS
male	1	*vuln1*	1	*vuln5*
immature female	*vuln1*	*vuln2*	*vuln6*	*vuln7*
mature female	*vuln3*	*vuln4*	*vuln8*	*vuln9*

Table 5: Specifications for estimated parameters in the CRA 7 and CRA 8 models including the upper and lower bounds, prior type, and prior parameters.

Sex	Parameters	Lower bound	Upper bound	Prior type	Prior parameter 1	Prior parameter 2
	R_0	exp(1)	exp(25)	uniform		
	*Rdev*s	-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		
	qPuerulus	exp(-25)	1	uniform		
	Mat50	30	80	normal	50	30
	Mat95add	1	60	normal	5	10
	Galpha	1	20	normal	2	30
	Gdiff	0.001	0.99	beta	1	1
M	*Gshape*	0.1	15	normal	4.81	0.48
F	*Gshape*	0.1	15	normal	4.51	0.45
M	*GCV*	0.01	2	normal	0.59	0.18
F	*GCV*	0.01	2	normal	0.82	0.25
	Gobs	0.00001	10	normal	1.48	0.015
	SelL	1	50	normal	10	10
	SelM	30	90	normal	50	30
	vuln	0.01	1	beta	1	1

Table 6: Reference points for the CRA 7 and CRA 8 stock assessment.

Type	Description
B_0	beginning of season AW adjusted vulnerable biomass before fishing (1945)
SSB_0	female AW spawning stock biomass before fishing (1945)
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_{2021}	beginning of season AW adjusted vulnerable biomass for 2021
B_{2025}	beginning of season AW adjusted vulnerable biomass for 2025
SSB_{2021}	female spawning stock biomass at beginning of 2021 AW season
SSB_{2025}	female spawning stock biomass at beginning of 2025 AW season
T_{2021}	beginning of season AW total biomass for 2021
T_{2025}	beginning of season AW total biomass for 2025
$CPUE_{2021}$	AW CPUE at beginning of 2021 (in kg/potlift)
$CPUE_{2025}$	AW CPUE at beginning of 2025 (in kg/potlift)
H_{2020}	total handling mortality for 2020 (tonnes)
H_{2024}	total handling mortality for 2024 (tonnes)
B_R	average AW vulnerable biomass between projected fixed catch and fixed *F* rules that maximise catch while meeting constraints
U_R	average AW exploitation rate (AW catch / adjusted AW vulnerable biomass) associated with B_R
U_{2021}	ratio of AW catch to beginning of season AW adjusted vulnerable biomass for 2021
U_{2025}	ratio of AW catch to beginning of season AW adjusted vulnerable biomass for 2025

Table 7: Performance indicators and stock status probabilities for the CRA 7 and CRA 8 stock assessment.

Type	Description
Performance indicators	
B_{2021} / B_0	Ratio of B_{2021} to B_0
B_{2025} / B_0	Ratio of B_{2025} to B_0
B_{2021} / B_{0now}	Ratio of B_{2021} to B_{0now}
B_{2025} / B_{0now}	Ratio of B_{2025} to B_{0now}
B_{2025} / B_{2021}	Ratio of B_{2025} to B_{2020}
SSB_{2021} / SSB_0	Ratio of SSB_{2021} to SSB_0
SSB_{2025} / SSB_0	Ratio of SSB_{2025} to SSB_0
SSB_{2021} / SSB_{0now}	Ratio of SSB_{2021} to SSB_{0now}
SSB_{2025} / SSB_{0now}	Ratio of SSB_{2025} to SSB_{0now}
SSB_{2025} / SSB_{2021}	Ratio of SSB_{2025} to SSB_{2020}
T_{2021} / T_0	Ratio of $B_{2021TOT}$ to B_{0TOT}
T_{2021} / T_{0NOW}	Ratio of $B_{2021TOT}$ to $B_{0TOTNOW}$
T_{2025} / T_0	Ratio of $B_{2025TOT}$ to B_{0TOT}
T_{2025} / T_{0NOW}	Ratio of $B_{2025TOT}$ to $B_{0TOTNOW}$
T_{2025} / T_{2021}	Ratio of $B_{2025TOT}$ to $B_{2020TOT}$
B_{2021} / B_R	Ratio of B_{2021} to B_R
B_{2025} / B_R	Ratio of B_{2025} to B_R
U_{2021} / U_R	Ratio of U_{2021} to U_R
U_{2025} / U_R	Ratio of U_{2025} to U_R
Probabilities	
P($B_{2021} > B_{MIN}$)	Probability B_{2021} is greater than B_{MIN}
P($SSB_{2021} < 20\%SSB_0$)	Probability SSB_{2021} is less than 20% SSB_0
P($SSB_{2021} < 10\%SSB_0$)	Probability SSB_{2021} is less than 10% SSB_0
P($SSB_{2021} < 20\%SSB_{0now}$)	Probability SSB_{2021} is less than 20% SSB_{0NOW}
P($SSB_{2021} < 10\%SSB_{0now}$)	Probability SSB_{2021} is less than 10% SSB_{0NOW}
P($SSB_{2025} < 20\%SSB_0$)	Probability SSB_{2025} is less than 20% SSB_0
P($SSB_{2025} < 10\%SSB_0$)	Probability SSB_{2025} is less than 10% SSB_0
P($SSB_{2025} < 20\%SSB_{0now}$)	Probability SSB_{2025} is less than 20% SSB_{0NOW}
P($SSB_{2025} < 10\%SSB_{0now}$)	Probability SSB_{2025} is less than 10% SSB_{0NOW}
P($B_{2025} > B_{2021}$)	Probability B_{2025} is greater than B_{2020}
P($SSB_{2025} > SSB_{2021}$)	Probability SSB_{2025} is greater than SSB_{2020}
P($T_{2025} > T_{2021}$)	Probability $Btot_{2025}$ is greater than $Btot_{2020}$
P($B_{2021} > B_R$)	Probability B_{2021} is greater than B_R
P($B_{2025} > B_R$)	Probability B_{2025} is greater than B_R
P($U_{2021} > U_R$)	Probability U_{2021} is greater than U_R
P($U_{2025} > U_R$)	Probability U_{2025} 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.

Model name	Model description	MCMC
base	1945–2020, sex-specific growth, selectivity by sex and region, updated retention analysis (constant overall years starting in 2000), recruitment @33.35 mm (SD=4 mm) TW, no movement, all tag data included, illegal catch equal to 10% of total commercial catch prior to 1990, 2% of total commercial catch 1990 onwards, 9 vulnerability parameters, drop LB LFs with only one vessel, drop LFs with <100 observations	Yes
fix_M	As *base*, except *M* fixed at 0.09 (i.e., approximately the base MAP estimate for *M*)	Yes
sel_rh2	As *fix_M*, except estimate the right-hand limb of selectivity	Yes
growth2r	As *base*, except growth by region and sex and drop tags missing statistical area	No
base_cshift	Shift 30% of region 1 catch to region 2 up to 1978	No
CRA7_MLS	Use CRA 7 MLS instead of CRA 8 MLS for region 1	No
illegal_20early	As *base*, except illegal catch equal to 20% of total commercial catch prior to 1990	No
downweight_CPUE	As *base*, except down-weight all CPUE series to 10%	No
downweight_SexRatio	As *base*, except down-weight sex ratio to 10%	No
downweight_LFs	As *base*, except down-weight LF data to 10%	No
start_1979	As *base*, except start the model in 1979 to avoid years with high catch uncertainty	No
annual_retention	As *base*, except retention rates change annually rather than fixed constant	No
qdrift	As *base*, except the *qdrift* parameter was fixed at 1% per year for the CELR CPUE series. This parameter is intended to explicitly model technological 'creep' in the fishery.	No

Table 9: **CRA 7 and CRA 8 MAP outputs showing likelihoods, standard deviation of normalised residuals (SDNRs), median absolute residuals (MARs), likelihood weights, parameter estimates, and reference points. These values are by region where appropriate (regional values denoted by [1] and [2]) for the base case and all sensitivity runs. 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 2 pages)**

	base	*fix_M*	*sel_rh2*	*growth2r*	*base_cshift*	*CRA7_MLS*	illegal_20early	*downweight_CPUE*	*downweight_SexRatio*	*downweight_LFs*	*start_1979*	*annual retention*	*qdrift*
Likelihoods													
Total	30 986	30 897	31 121	29 346	30 872	30 289	30 853	3 955 820	20 027	24 917	28 828	30 688	30 888
Prior	116	66	92	53	44	60	71	37	50	59	52	64	66
tag	12 432	12 430	12 427	11 405	12 429	12 430	12 430	12 425	12 409	12 431	10 264	12 430	12 429
Sex ratio	6 629	6 623	6 414	6 608	6 624	6 331	6 573	6 623	6 600	673	6 125	6 415	6 626
LF	12 041	12 027	12 444	11 535	12 025	11 726	12 028	12 003	1 225	12 000	12 577	12 027	12 022
CR [1]	-12.935	-15.407	-15.528	-18.060	-15.684	-16.968	-15.666	6.229	-16.107	-16.193	–	-15.532	-15.554
CR [2]	-18.340	-19.296	-21.016	-19.574	-20.103	-19.326	-19.389	0.788	-20.389	-20.225	–	-19.430	-19.446
FSU [1]	-18.147	-20.021	-21.129	-22.517	-20.960	-22.692	-20.314	20.276	-19.219	-21.452	-9.080	-20.233	-20.068
FSU [2]	-36.980	-39.609	-39.451	-39.668	-39.345	-39.536	-39.491	-0.450	-40.370	-39.115	-25.834	-39.554	-39.816
CELR [1]	-53.048	-55.740	-59.096	-56.065	-55.811	-60.288	-55.400	54.154	-56.415	-56.902	-55.551	-56.234	-57.919
CELR [2]	-94.909	-98.267	-99.721	-99.553	-97.937	-100.124	-98.424	11.171	-104.721	-92.516	-100.140	-97.350	-101.245
Standard deviation of normalised residual (SDNR)													
Sex ratio [1]	1.033	1.031	1.016	1.047	1.026	1.0030	1.021	1.025	0.382	0.964	1.037	1.021	1.020
Sex ratio [2]	1.009	1.007	1.003	1.004	1.013	1.0003	1.007	1.007	0.393	0.941	0.979	1.005	1.022
CR [1]	0.995	0.995	1.023	0.999	0.967	0.9904	1.009	0.500	0.913	0.915	–	1.003	1.000
CR [2]	1.025	1.038	0.971	0.983	0.957	1.0076	1.015	0.167	0.944	0.925	–	0.997	0.996
FSU [1]	0.990	1.001	1.029	1.037	0.953	0.9906	1.004	0.443	0.927	1.045	0.982	0.990	0.998
FSU [2]	0.999	0.996	1.004	1.029	1.010	0.9996	1.002	0.271	1.022	0.958	0.993	0.999	1.004
CELR [1]	0.997	1.001	1.020	0.996	1.000	0.9992	1.007	0.212	0.981	0.985	1.042	0.993	1.003
CELR [2]	1.001	0.997	1.032	1.035	1.002	1.0058	0.994	0.141	1.089	0.882	1.025	1.012	1.006
Median of absolute residual (MAR)													
Sex ratio [1]	0.000	0.000	0.000	0.000	0.000	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sex ratio [2]	0.000	0.000	0.000	0.000	0.000	0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CR [1]	0.764	0.798	0.759	0.738	0.853	0.7261	0.647	0.489	0.665	0.732	–	0.709	0.660
CR [2]	0.677	0.658	0.744	0.646	0.727	0.6306	0.654	0.104	0.701	0.686	–	0.650	0.639
FSU [1]	0.727	0.757	0.802	0.695	0.768	0.8150	0.737	0.340	0.788	0.867	0.778	0.737	0.765
FSU [2]	0.472	0.486	0.599	0.382	0.570	0.4784	0.529	0.179	0.670	0.636	0.675	0.469	0.550
CELR [1]	0.714	0.701	0.808	0.763	0.724	0.6578	0.698	0.133	0.770	0.693	0.727	0.704	0.706
CELR [2]	0.832	0.832	0.852	0.776	0.862	0.8074	0.826	0.119	0.989	0.607	0.776	0.816	0.810
Likelihood weights													
Sex ratio [1]	16.00	16.00	15.50	15.90	16.00	14.20	15.70	16.00	1.600	16.00	14.50	15.00	16.00
Sex ratio [2]	3.10	3.10	3.00	3.10	3.10	3.10	3.10	3.10	0.310	3.10	2.90	3.00	3.10
LF [1]	1.91	1.91	1.95	1.80	1.91	1.73	1.91	1.91	1.91	0.191	1.92	1.91	1.91
LF [2]	1.00	1.00	1.04	0.96	1.00	0.99	1.00	1.00	1.00	0.100	1.06	1.00	1.00
CR [1]	2.70	2.70	2.80	3.45	2.70	3.10	2.80	0.270	2.70	2.70	–	2.75	2.75
CR [2]	4.00	4.00	4.40	3.90	4.00	3.90	3.95	0.400	4.00	4.00	–	3.90	3.90
FSU [1]	1.20	1.20	1.30	1.40	1.20	1.35	1.22	0.120	1.20	1.20	0.700	1.20	1.20
FSU [2]	2.90	2.90	2.90	3.00	2.90	2.90	2.90	0.290	2.90	2.90	1.500	2.90	2.95
CELR [1]	1.30	1.30	1.40	1.30	1.30	1.40	1.30	0.130	1.30	1.30	1.350	1.30	1.35
CELR [2]	2.45	2.45	2.60	2.60	2.45	2.55	2.45	0.245	2.45	2.45	2.600	2.45	2.60

	base	fix_M	sel_rh2	growth2r	base_cshift	CRA7_MLS	illegal_20early	downweight_CPUE	downweight_SexRatio	downweight_LFs	start_1979	annual retention	qdrift
Parameters													
R_0 [1]	1 218 670	1 236 220	1 407 780	1 317 350	1 054 390	1 148 020	1 301 230	1 010 210	1 317 720	1 366 460	665 204	1 260 680	1 233 000
R_0 [2]	1 444 830	1 441 680	1 559 760	1 292 580	1 684 330	1 416 660	1 513 670	1 067 900	1 484 870	1 572 790	1 503 040	1 477 320	1 439 530
M	0.093	0.090[1]	0.090[1]	0.089	0.091	0.089	0.089	0.067	0.093	0.097	0.105	0.092	0.091
mat50	59.937	59.806	59.869	59.515	59.783	60.128	59.784	59.289	60.759	59.901	59.928	59.759	59.803
mat95add	9.527	9.523	9.339	9.231	9.609	8.918	9.442	10.381	7.777	10.794	9.691	9.450	9.604
Galpha [male]	4.423	4.445	4.469	3.496	4.442	4.446	4.440	4.468	4.508	4.458	4.715	4.441	4.453
Gbeta [male]	2.798	2.782	2.673	2.427	2.793	2.803	2.787	2.857	2.324	2.844	2.599	2.788	2.785
Gshape [male]	1.913	1.933	1.706	5.313	1.960	2.005	1.932	2.130	1.400	2.170	2.317	1.940	1.963
GCV [male]	0.427	0.422	0.420	0.278	0.423	0.423	0.422	0.424	0.418	0.422	0.425	0.423	0.422
Galpha [female]	3.846	3.862	3.868	3.716	3.864	3.846	3.858	3.842	3.898	3.853	3.992	3.868	3.854
Gbeta [female]	1.602	1.600	1.615	1.660	1.597	1.611	1.601	1.514	1.482	1.585	1.592	1.606	1.594
Gshape [female]	3.507	3.548	3.515	4.764	3.524	3.496	3.554	3.350	3.322	3.445	3.425	3.556	3.527
GCV [female]	0.376	0.371	0.368	0.266	0.370	0.372	0.371	0.375	0.363	0.369	0.416	0.370	0.371
Gobs	1.316	1.318	1.319	1.318	1.318	1.318	1.318	1.316	1.320	1.319	1.353	1.319	1.319
qdrift	–	–	–	–	–	–	–	–	–	–	–	–	0.01[1]
U_0 [1]	–	–	–	–	–	–	–	–	–	–	0.034	–	–
U_0 [2]	–	–	–	–	–	–	–	–	–	–	0.184	–	–
qCR [1]	0.067	0.075	0.096	0.091	0.063	0.056	0.073	0.177	0.049	0.064	–	0.077	0.078
qCR [2]	0.034	0.031	0.065	0.032	0.030	0.031	0.030	0.030	0.038	0.035	–	0.032	0.032
qFSU [1]	0.002	0.002	0.002	0.001	0.002	0.002	0.002	0.074	0.001	0.002	0.001	0.002	0.002
qFSU [2]	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
qCELR [1]	0.002	0.002	0.001	0.001	0.002	0.002	0.002	0.041	0.001	0.001	0.002	0.002	0.002
qCELR [2]	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
vuln1 [1] SS M/AW IF	0.861	0.915	0.921	0.920	0.846	0.949	0.915	0.941	0.932	0.883	0.937	0.915	0.914
vuln2 [1] SS IF	0.833	0.977	0.973	0.976	0.977	0.975	0.977	0.979	0.974	0.974	0.999	0.977	0.977
vuln3 [1] AW MF	0.043	0.041	0.046	0.041	0.042	0.063	0.041	0.026	0.080	0.062	0.037	0.041	0.040
vuln4 [1] SS MF	0.075	0.074	0.080	0.074	0.073	0.127	0.075	0.051	0.148	0.058	0.066	0.075	0.071
vuln5 [2] SS M	0.787	0.782	0.795	0.807	0.785	0.781	0.782	0.776	0.764	0.878	0.862	0.785	0.774
vuln6 [2] AW IF	0.543	0.548	0.523	0.564	0.554	0.500	0.548	0.661	0.332	0.825	0.647	0.546	0.555
vuln7 [2] SS IF	0.421	0.422	0.406	0.440	0.426	0.383	0.423	0.513	0.258	0.702	0.531	0.422	0.428
vuln8 [2] AW MF	0.800	0.777	0.805	0.810	0.782	0.829	0.775	0.658	0.801	0.792	1.000	0.778	0.768
vuln9 [2] SS MF	0.714	0.696	0.718	0.719	0.690	0.737	0.695	0.612	0.792	0.615	1.000	0.696	0.695
selL male [1]	7.893	7.752	7.335	8.996	7.618	7.072	7.695	7.998	6.876	7.573	7.758	7.731	7.760
selM male [1]	57.901	57.599	56.821	59.646	57.172	57.881	57.514	58.251	55.363	56.871	57.304	57.602	57.684
selL female [1]	8.243	8.284	8.162	8.315	8.345	9.039	8.221	8.453	8.172	8.377	8.412	8.250	8.285
selM female [1]	58.465	58.821	58.527	58.187	59.164	61.850	58.664	59.424	56.096	59.898	59.234	58.815	58.950
selL male [2]	4.062	4.065	4.040	4.096	4.065	4.070	4.067	4.089	4.504	4.028	3.962	4.073	4.072
selM male [2]	55.172	55.168	55.161	54.799	55.173	55.189	55.175	55.119	56.656	55.036	54.665	55.197	55.177
selL female [2]	4.807	4.799	4.770	4.829	4.798	4.749	4.799	4.923	4.709	4.941	4.853	4.805	4.812
selM female [2]	57.525	57.519	57.420	57.302	57.550	57.227	57.519	58.028	56.115	58.241	57.646	57.536	57.573

	base	*fix_M*	*sel_rh2*	*growth2r*	*base_cshift*	*CRA7_MLS*	illegal_20early	*downweight_CPUE*	*downweight_SexRatio*	*downweight_LFs*	*start_1979*	*annual retention*	*qdrift*
Derived parameters: adjusted vulnerable biomass													
B_0 [1]	15 317	16 565	5 568	15 980	13 787	16 297	17 659	22 367	15 917	16 101	7 055	16 255	16 301
B_0 [2]	17 998	19 208	8 280	19 196	21 884	19 308	20 427	23 539	17 757	18 493	15 811	18 941	18 925
B_0 [total]	33 343	35 773	13 848	35 175	35 671	35 605	38 086	45 905	33 673	34 594	22 865	35 196	35 226
B_{0now} [1]	13 540	13 882	4 938	14 737	12 389	13 462	14 654	19 311	13 766	13 832	7 945	13 639	13 032
B_{0now} [2]	26 510	27 274	11 651	27 165	27 936	28 067	28 133	35 408	22 420	26 416	23 714	27 170	25 198
B_{0now} [total]	40 215	41 156	16 590	41 902	40 325	41 529	42 786	54 719	36 186	40 248	31 658	40 809	38 230
B_{MIN} [1]	282	291	318	356	296	292	296	121	471	312	262	290	282
B_{MIN} [2]	627	619	613	572	624	617	619	561	544	660	725	621	627
B_{MIN} [total]	911	910	932	928	920	910	915	682	1 014	972	987	911	909
B_{2021} [1]	2 793	2 751	2 694	3 210	2 492	2 852	2 947	2 314	4 204	3 219	1 611	2 705	2 299
B_{2021} [2]	4 317	4 197	4 014	4 075	4 413	4 319	4 330	3 281	3 347	4 603	5 046	4 075	3 414
B_{2021} [total]	7 140	6 948	6 708	7 285	6 905	7 170	7 278	5 595	7 551	7 823	6 657	6 780	5 713
B_{2021} / B_0[1]	0.182	0.166	0.484	0.201	0.181	0.175	0.167	0.103	0.264	0.200	0.228	0.166	0.141
B_{2021} / B_0 [2]	0.241	0.219	0.485	0.212	0.202	0.224	0.212	0.139	0.188	0.249	0.319	0.215	0.180
B_{2021} / B_0 [total]	0.214	0.194	0.484	0.207	0.194	0.201	0.191	0.122	0.224	0.226	0.291	0.193	0.162
Derived parameters: spawning stock biomass (females only)													
SSB_0 [1]	8 678	9 433	10 751	10 331	7 832	8 862	10 061	12 752	9 090	9 007	3 614	9 264	9 240
SSB_0 [2]	10 244	11 000	11 911	10 599	12 511	10 936	11 704	13 480	10 244	10 367	8 167	10 856	10 788
SSB_0 [total]	18 910	20 433	22 662	20 930	20 343	19 798	21 766	26 232	19 334	19 375	11 782	20 119	20 028
SSB_{0now} [1]	7 069	7 272	8 708	8 264	6 463	6 740	7 685	9 820	7 043	7 095	4 071	7 161	6 786
SSB_{0now} [2]	13 966	14 405	15 483	13 877	14 712	14 694	14 874	18 108	11 649	13 584	12 249	14 383	13 227
SSB_{0now} [total]	21 167	21 677	24 191	22 141	21 175	21 433	22 559	27 929	18 692	20 679	16 320	21 544	20 013
SSB_{2021} [1]	3 690	3 772	4 515	4 564	3 554	2 538	3 900	4 498	3 896	3 979	2 758	3 746	3 464
SSB_{2021} [2]	5 397	5 464	6 212	4 880	5 582	5 315	5 561	5 532	4 608	5 513	4 901	5 636	4 808
SSB_{2021} [total]	9 099	9 236	10 727	9 444	9 136	7 853	9 461	10 030	8 504	9 492	7 659	9 382	8 272
SSB_{2021} / SSB_0 [1]	0.425	0.400	0.420	0.442	0.454	0.286	0.388	0.353	0.429	0.442	0.763	0.404	0.375
SSB_{2021} / SSB_0 [2]	0.528	0.497	0.522	0.460	0.446	0.486	0.475	0.410	0.450	0.532	0.600	0.519	0.446
SSB_{2021} / SSB_0 [total]	0.481	0.452	0.473	0.451	0.449	0.397	0.435	0.382	0.440	0.490	0.650	0.466	0.413
Derived parameters: total biomass													
B_{0tot} [1]	26 656	28 689	32 482	29 211	23 885	27 165	30 568	37 614	27 898	27 948	11 953	28 235	28 212
B_{0tot} [2]	31 449	33 457	35 988	32 369	38 156	33 521	35 559	39 763	31 437	32 168	27 009	33 087	32 937
B_{0tot} [total]	58 084	62 146	68 470	61 581	62 041	60 686	66 126	77 377	59 335	60 116	38 962	61 322	61 148
$B_{0totnow}$ [1]	22 967	23 389	27 771	25 515	20 862	21 819	24 680	31 279	23 283	23 348	13 462	23 056	21 933
$B_{0totnow}$ [2]	45 258	46 329	49 375	44 751	47 486	47 568	47 767	57 680	38 507	44 703	40 509	46 312	42 751
$B_{0totnow}$ [total]	68 521	69 718	77 146	70 267	68 348	69 387	72 447	88 959	61 790	68 050	53 971	69 369	64 684
$B_{2021tot}$ [1]	8 775	8 689	11 169	10 188	7 871	6 911	9 134	8 641	10 447	9 537	5 449	8 647	7 905
$B_{2021tot}$ [2]	12 856	12 638	14 842	11 461	13 321	12 741	13 014	11 083	10 986	13 213	12 937	12 742	11 090
$B_{2021tot}$ [total]	21 732	21 327	26 011	21 648	21 192	19 652	22 149	19 724	21 433	22 751	18 386	21 389	18 995
Other derived parameters													
$CPUE_{2020}$ [1]	1.529	1.558	1.555	1.993	1.431	1.633	1.660	2.879	2.694	1.757	0.814	1.529	1.562
$CPUE_{2020}$ [2]	2.449	2.449	2.341	2.530	2.532	2.509	2.503	4.279	2.201	2.555	2.409	2.378	2.431
H_{2020} [1]	16.447	16.512	15.821	15.665	16.687	8.557	16.508	14.670	18.315	16.272	15.440	21.666	16.982
H_{2020} [2]	81.245	81.400	80.187	77.057	80.626	81.500	80.874	86.489	79.159	80.415	79.583	105.908	84.830
H_{2020} [total]	97.861	97.913	96.008	92.721	97.313	90.058	97.383	101.159	97.473	96.686	95.023	127.574	101.812
B_{male} / B_{female} [1]	0.705	0.685	0.824	0.690	0.668	0.809	0.701	0.523	0.906	0.743	0.590	0.682	0.639
B_{male} / B_{female} [2]	0.736	0.716	0.788	0.724	0.732	0.730	0.722	0.598	0.688	0.749	0.856	0.688	0.680

[1] fixed parameter

Table 10: CRA 7 and CRA 8 MCMC outputs, reporting the 5%, 50% (median), and 95% credible intervals of the posterior distribution, showing likelihoods, diagnostics, and parameter estimates by region where appropriate for the base case model. Growth increment values in mm TW, biomass values in t, and R_0 in numbers. '–': not applicable.

	Region 1			Region 2			Combined		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods									
Total							30 970	30 990	31 000
Prior							95.77	115.90	139.60
Tags							12 410	12 430	12 450
Sex ratio							6 622	6 629	6 638
LFs							12 030	12 040	12 050
CPUE [CR]	-15.41	-12.92	-9.231	-20.57	-18.33	-14.74			
CPUE [FSU]	-21.61	-18.18	-13.48	-39.48	-36.98	-32.94			
CPUE [CELR]	-57.78	-52.95	-47.5	-99.19	-94.89	-89.69			
SDNR									
Tag							1.405	1.428	1.452
Sex ratio	0.994	1.037	1.091	0.998	1.027	1.061			
LFs							1.007	1.615	3.99
CPUE [CR]	0.965	1.182	1.437	0.880	1.073	1.340			
CPUE [FSU]	0.902	1.069	1.255	0.985	1.096	1.257			
CPUE [CELR]	0.960	1.039	1.127	0.972	1.042	1.123			
Parameters									
R_0	1 095 000	1 218 000	1 355 000	1 274 000	1 434 000	1 606 000			
M							0.0848	0.0932	0.1007
qCR	0.0479	0.0669	0.0973	0.0258	0.0337	0.0439			
qFSU	0.0015	0.0018	0.0023	0.0006	0.0007	0.0008			
qCELR	0.0014	0.0017	0.0020	0.0006	0.0006	0.0007			
mat50							59.33	59.95	60.64
mat95add							8.538	9.598	10.76
Galpha [M]							4.356	4.424	4.497
Gbeta [M]							2.577	2.806	3.045
Gshape [M]							1.477	1.933	2.429
GCV [M]							0.411	0.427	0.444
Galpha [F]							3.790	3.849	3.913
Gbeta [F]							1.550	1.601	1.655
Gshape [F]							3.278	3.523	3.774
GCV [F]							0.357	0.376	0.395
Gobs							1.293	1.316	1.338
vuln AW [M][1]		1			1				
vuln SS [M]	0.785[2]	0.863[2]	0.937[2]	0.744	0.787	0.836			
vuln AW [IF]		–		0.469	0.547	0.626			
vuln SS [IF]	0.686	0.838	0.966	0.357	0.422	0.497			
vuln AW [MF]	0.033	0.042	0.054	0.718	0.798	0.895			
vuln SS [MF]	0.055	0.074	0.098	0.641	0.711	0.796			
selL [M]	6.994	7.878	8.884	3.741	4.060	4.407			
selL [F]	7.285	8.216	9.207	4.411	4.825	5.269			
selM [M]	56.410	57.840	59.400	54.670	55.170	55.710			
selM [F]	57.040	58.420	59.760	56.810	57.570	58.320			

[1] fixed parameter
[2] combined with *vuln AW* [immature female] in region 1

Table 11: CRA 7 and CRA 8 MCMC derived parameters, reporting the 5%, 50% (median), and 95% quantiles of the posterior distribution for the base case. All projections are based on the sum of the CRA 7 and CRA 8 TACCs with the 2020 non-commercial catches, split between regions and seasons using 2020 proportions. Biomass values are reported in tonnes, CPUE in kg/potlift, and handling mortality (*H*) in tonnes.

	Region 1			Region 2			Combined		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
Vulnerable biomass									
B_0	13 860	15 430	17 080	16 490	18 020	19 620	30 760	33 440	36 300
B_{0now}	11 270	13 540	16 680	23 430	26 650	30 650	36 050	40 370	45 780
B_{MIN}	239.4	282.1	332.4	579.3	625.9	683.3	845.6	910.0	983.7
B_R	–	–	–	–	–	–	–	4 863	–
B_{2021}	2 105	2 794	3 597	3 638	4 302	5 108	6 178	7 114	8 209
B_{2025}	2 702	3 799	5 403	2 966	4 304	6 166	6 355	8 203	10 310
B_{2021} / B_0	0.138	0.181	0.235	0.196	0.240	0.290	0.179	0.214	0.253
B_{2025} / B_0	0.173	0.244	0.353	0.162	0.240	0.344	0.187	0.245	0.316
B_{2021} / B_{0now}	0.167	0.204	0.247	0.137	0.162	0.186	0.152	0.176	0.202
B_{2025} / B_{0now}	0.218	0.276	0.349	0.117	0.162	0.217	0.162	0.202	0.246
B_{2025} / B_{2021}	1.104	1.357	1.698	0.746	0.998	1.319	0.955	1.145	1.368
B_{2021} / B_R	–	–	–	–	–	–	1.270	1.463	1.688
B_{2025} / B_R	–	–	–	–	–	–	1.307	1.687	2.119
Spawning stock biomass									
SSB_0	7 863	8 738	9 751	9 374	10 260	11 190	17 490	18 980	20 730
SSB_{0now}	5 909	7 088	8 695	12 250	14 020	16 280	18 920	21 270	23 870
SSB_{2021}	3 247	3 705	4 163	4 964	5 406	5 912	8 413	9 125	9 828
SSB_{2025}	3 761	4 432	5 203	4 914	5 716	6 774	9 007	10 180	11 430
SSB_{2021} / SSB_0	0.378	0.424	0.478	0.473	0.528	0.582	0.442	0.480	0.521
SSB_{2025} / SSB_0	0.435	0.508	0.597	0.476	0.559	0.656	0.480	0.536	0.606
SSB_{2021} / SSB_{0now}	0.446	0.521	0.591	0.346	0.385	0.423	0.392	0.430	0.468
SSB_{2025} / SSB_{0now}	0.574	0.623	0.670	0.371	0.408	0.446	0.447	0.480	0.512
SSB_{2025} / SSB_{2021}	1.104	1.193	1.316	0.956	1.055	1.184	1.041	1.117	1.201
Total biomass									
T_0	24 300	26 810	29 520	29 030	31 470	33 950	54 320	58 240	62 840
T_{0now}	19 120	22 950	28 120	40 290	45 400	52 040	61 830	68 760	77 080
T_{2021}	7 345	8 702	10 390	11 790	13 270	15 320	20 030	22 050	24 600
T_{2025}	8 112	10 020	12 810	11 250	14 020	17 630	20 770	24 230	28 370
T_{2021} / T_0	0.270	0.325	0.391	0.361	0.423	0.492	0.334	0.378	0.432
T_{2025} / T_0	0.301	0.375	0.486	0.353	0.447	0.563	0.353	0.415	0.493
T_{2021} / T_{0now}	0.341	0.376	0.417	0.262	0.293	0.325	0.292	0.321	0.350
T_{2025} / T_{0now}	0.385	0.435	0.500	0.258	0.308	0.367	0.308	0.352	0.397
T_{2025} / T_{2021}	1.065	1.156	1.272	0.931	1.056	1.184	1.015	1.100	1.186
Other quantities									
$CPUE_{2020}$	1.165	1.526	1.985	2.151	2.446	2.800	1.165	1.526	1.985
$CPUE_{2025}$	1.529	2.190	3.102	1.742	2.445	3.389	1.709	2.372	3.282
H_{2020}	14.17	16.43	19.54	75.52	81.41	87.88	91.14	98.15	104.90
H_{2025}	13.11	15.19	17.69	76.55	90.86	107.50	91.52	106.20	123.60
B_{male} / B_{female}	0.617	0.702	0.786	0.686	0.737	0.789	–	–	–
U_R	–	–	–	–	–	–	–	0.103	–
U_{2021}	–	–	–	–	–	–	0.094	0.108	0.124
U_{2025}	–	–	–	–	–	–	0.078	0.097	0.122

Table 12: CRA 7 and CRA 8 MCMC probabilities for the base case. All projections based on the sum of the CRA 7 and CRA 8 TACCs with the 2020 non-commercial catches, split between regions and seasons using 2020 proportions. "–" indicates that the value is not applicable.

Probability	Region 1	Region 2	Combined
P(B_{2021} > B_{MIN})	1	1	1
P(B_{2025} > B_{2021})	0.995	0.499	0.893
P(SSB_{2021} < 20% SSB_0)	0	0	0
P(SSB_{2021} < 10% SSB_0)	0	0	0
P(SSB_{2025} < 20% SSB_0)	0	0	0
P(SSB_{2025} < 10% SSB_0)	0	0	0
P(SSB_{2021} < 20% SSB_{0now})	0	0	0
P(SSB_{2021} < 10% SSB_{0now})	0	0	0
P(SSB_{2025} < 20% SSB_{0now})	0	0	0
P(SSB_{2025} < 10% SSB_{0now})	0	0	0
P(SSB_{2025} > SSB_{2021})	1	0.820	0.996
P(T_{2025} > T_{2021})	0.999	0.754	0.972
P(B_{2021} > B_R)	–	–	1
P(B_{2025} > B_R)	–	–	0.998
P(U_{2021} > U_R)	–	–	0.699
P(U_{2025} > U_R)	–	–	0.325

Table 13: CRA 7 and CRA 8 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), likelihood weights, parameter estimates, and reference points. These values are by region where appropriate (regional values denoted by [1] and [2]) for the base case and two sensitivity runs. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. '–': not applicable. (Continued on next 2 pages)

			base			fix_M			sel_rh2
	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods									
Total	30 970	30 990	31 000	30 970	30 990	31 000	31 170	31 190	31 210
Prior	95.77	115.90	139.60	97.34	118.30	140.00	90.10	113.20	137.60
Tags	12 410	12 430	12 450	12 410	12 430	12 450	12 410	12 420	12 440
Sex ratio	6 622	6 629	6 638	6 622	6 629	6 637	6 407	6 415	6 423
LFs	12 030	12 040	12 050	12 030	12 040	12 050	12 460	12 470	12 490
CR [1]	-15.41	-12.92	-9.231	-15.44	-12.98	-8.945	-15.86	-13.56	-9.998
CR [2]	-20.57	-18.33	-14.74	-20.38	-18.12	-14.55	-21.39	-19.13	-15.44
FSU [1]	-21.61	-18.18	-13.48	-22.08	-18.31	-13.48	-20.61	-16.33	-11.07
FSU [2]	-39.48	-36.98	-32.94	-39.55	-37.19	-33.28	-39.43	-37.02	-33.11
CELR [1]	-57.78	-52.95	-47.5	-57.6	-52.8	-46.84	-61.62	-54.95	-46.95
CELR [2]	-99.19	-94.89	-89.69	-99.41	-95.22	-90.12	-101.7	-97.18	-91.2
Standard deviation of normalised residuals (SDNR)									
Tag	1.405	1.428	1.452	1.408	1.430	1.451	1.409	1.431	1.453
Sex ratio [1]	0.994	1.037	1.091	0.996	1.038	1.090	0.954	1.001	1.060
Sex ratio [2]	0.998	1.027	1.061	0.995	1.023	1.055	0.985	1.012	1.043
LFs	1.007	1.615	3.990	1.018	1.670	4.261	7.210	29.080	144.000
CR[1]	0.965	1.182	1.437	0.965	1.176	1.459	0.960	1.161	1.427
CR [2]	0.880	1.073	1.340	0.904	1.102	1.352	0.900	1.103	1.371
FSU [1]	0.902	1.069	1.255	0.879	1.059	1.258	1.036	1.221	1.407
FSU [2]	0.985	1.096	1.257	0.984	1.088	1.257	0.987	1.095	1.257
CELR [1]	0.960	1.039	1.127	0.965	1.041	1.133	0.970	1.078	1.197
CELR [2]	0.972	1.042	1.123	0.969	1.040	1.118	0.991	1.066	1.153
Parameters									
R_0[1]	1 095 000	1 218 000	1 355 000	1 090 000	1 178 000	1 271 000	2 064 000	2 337 000	2 732 000
R_0[2]	1 274 000	1 434 000	1 606 000	1 301 000	1 388 000	1 487 000	1 384 000	1 493 000	1 614 000
M	0.0848	0.0932	0.1007		0.09*			0.09*	
qCR[1]	0.0479	0.0669	0.0973	0.0489	0.0710	0.1027	0.0617	0.0859	0.1209
qCR[2]	0.0258	0.0337	0.0439	0.0254	0.0316	0.0409	0.0391	0.0559	0.0850
$qFSU$[1]	0.0015	0.0018	0.0023	0.0015	0.0019	0.0024	0.0006	0.0009	0.0012
$qFSU$[2]	0.0006	0.0007	0.0008	0.0007	0.0007	0.0008	0.0007	0.0008	0.0009
$qCELR$[1]	0.0014	0.0017	0.0020	0.0014	0.0017	0.0021	0.0004	0.0005	0.0007
$qCELR$[2]	0.0006	0.0006	0.0007	0.0006	0.0006	0.0007	0.0006	0.0006	0.0007

	base			fix_M			sel_rh2		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
mat50	59.330	59.950	60.640	59.290	59.950	60.620	59.000	59.560	60.190
mat95add	8.538	9.598	10.760	8.502	9.581	10.840	8.328	9.351	10.510
Galpha[male]	4.356	4.424	4.497	4.357	4.431	4.506	4.426	4.497	4.570
Gbeta[male]	2.577	2.806	3.045	2.596	2.800	3.033	2.354	2.587	2.854
Gshape[male]	1.477	1.933	2.429	1.502	1.948	2.404	1.097	1.530	2.022
GCV[male]	0.411	0.427	0.444	0.410	0.427	0.442	0.407	0.423	0.439
Galpha[female]	3.790	3.849	3.913	3.782	3.848	3.909	3.774	3.835	3.896
Gbeta[female]	1.550	1.601	1.655	1.548	1.598	1.649	1.557	1.606	1.656
Gshape[female]	3.278	3.523	3.774	3.267	3.530	3.782	3.277	3.535	3.788
GCV[female]	0.357	0.376	0.395	0.357	0.376	0.395	0.356	0.375	0.395
Gobs	1.293	1.316	1.338	1.294	1.316	1.340	1.292	1.316	1.340
vuln1 [1] SS M/AW IF	0.785[2]	0.863[2]	0.937[2]	0.777	0.858	0.932	0.861	0.923	0.977
vuln2 [1] SS IF	0.686	0.838	0.966	0.681	0.826	0.969	0.861	0.955	0.997
vuln3 [1] AW MF	0.033	0.042	0.054	0.032	0.041	0.052	0.039	0.049	0.060
vuln4 [1] SS MF	0.055	0.074	0.098	0.054	0.071	0.094	0.064	0.080	0.097
vuln5 [2] SS M	0.744	0.787	0.836	0.743	0.786	0.830	0.747	0.789	0.832
vuln6 [2] AW IF	0.469	0.547	0.626	0.476	0.546	0.633	0.485	0.565	0.663
vuln7 [2] SS IF	0.357	0.422	0.497	0.355	0.422	0.500	0.367	0.436	0.524
vuln8 [2] AW MF	0.718	0.798	0.895	0.713	0.788	0.877	0.678	0.763	0.862
vuln9 [2] SS MF	0.641	0.711	0.796	0.641	0.706	0.783	0.607	0.676	0.766
selL male [1]	6.994	7.878	8.884	7.068	7.909	8.939	5.443	5.971	6.593
selM male [1]	56.410	57.840	59.400	56.430	57.930	59.670	53.240	54.070	54.970
selL female [1]	7.285	8.216	9.207	7.352	8.269	9.240	6.988	7.862	8.734
selM female [1]	57.040	58.420	59.760	57.150	58.420	59.850	56.140	57.320	58.460
selL male [2]	3.741	4.060	4.407	3.749	4.086	4.457	3.731	4.041	4.377
selM male [2]	54.670	55.170	55.710	54.650	55.200	55.760	54.580	55.120	55.650
selL female [2]	4.411	4.825	5.269	4.386	4.813	5.252	4.421	4.849	5.277
selM female [2]	56.810	57.570	58.320	56.820	57.510	58.270	56.990	57.690	58.460
B_0 [1]	13 860	15 430	17 080	14 620	15 790	16 970	2 053	2 330	2 659
B_0 [2]	16 490	18 020	19 620	17 320	18 500	19 830	6 659	8 346	11 340
B_0 [total]	30 760	33 440	36 300	32 570	34 300	36 190	8 978	10 700	13 700
B_{0now} [1]	11 270	13 540	16 680	11 740	13 920	17 230	3 025	3 719	4 635
B_{0now} [2]	23 430	26 650	30 650	24 820	27 540	30 840	9 823	12 460	16 940
B_{0now} [total]	36 050	40 370	45 780	37 930	41 720	46 160	13 450	16 230	20 680
B_{MIN} [1]	239	282	332	236	279	326	444	594	758
B_{MIN} [2]	579	626	683	577	621	670	568	616	670
B_{MIN} [total]	846	910	984	838	901	968	1 051	1 212	1 391
B_{2021} [1]	2 105	2 794	3 597	2078	2733	3566	2 281	3 031	4 131
B_{2021} [2]	3 638	4 302	5 108	3635	4286	5099	3 515	4 148	4 909
B_{2021} [total]	6 178	7 114	8 209	6097	7034	8189	6 187	7 231	8 522
B_{2021} / B_0 [1]	0.138	0.181	0.235	0.134	0.173	0.225	1.008	1.301	1.696
B_{2021} / B_0 [2]	0.196	0.240	0.290	0.196	0.231	0.276	0.356	0.496	0.654
B_{2021} / B_0 [total]	0.179	0.214	0.253	0.178	0.205	0.239	0.511	0.673	0.843
B_{2021} / B_{0now} [1]	0.167	0.204	0.247	0.164	0.195	0.227	0.677	0.818	0.977
B_{2021} / B_{0now} [2]	0.137	0.162	0.186	0.139	0.156	0.173	0.247	0.333	0.418
B_{2021} / B_{0now}[total]	0.152	0.176	0.202	0.153	0.169	0.185	0.343	0.446	0.538
SSB_0 [1]	7 863	8 738	9 751	8278	8951	9638	15 650	17 810	20 720
SSB_0 [2]	9 374	10 260	11 190	9872	10540	11310	10 540	11 360	12 300
SSB_0 [total]	17 490	18 980	20 730	18480	19500	20580	26 930	29 240	32 440
SSB_{0now}[1]	5 909	7 088	8 695	6135	7283	8998	19 160	24 450	31 360
SSB_{0now}[2]	12 250	14 020	16 280	13020	14520	16210	14 050	15 610	17 540
SSB_{0now}[total]	18 920	21 270	23 870	19900	21890	24330	34 490	40 140	47 400
SSB_{2021}[1]	3 247	3 705	4 163	3358	3754	4218	12 540	16 070	20 730
SSB_{2021}[2]	4 964	5 406	5 912	5024	5453	5938	5 581	6 159	6 817
SSB_{2021}[total]	8 413	9 125	9 828	8570	9220	9949	18 670	22 280	27 120
SSB_{2021} / SSB_0 [1]	0.378	0.424	0.478	0.374	0.421	0.472	0.773	0.903	1.053
SSB_{2021} / SSB_0 [2]	0.473	0.528	0.582	0.471	0.516	0.570	0.493	0.542	0.600
SSB_{2021} / SSB_0 [total]	0.442	0.480	0.521	0.438	0.473	0.511	0.674	0.764	0.865
SSB_{2021} / SSB_{0now} [1]	0.446	0.521	0.591	0.445	0.515	0.587	0.588	0.660	0.737
SSB_{2021} / SSB_{0now} [2]	0.346	0.385	0.423	0.346	0.376	0.404	0.363	0.395	0.426
SSB_{2021} / SSB_{0now} [total]	0.392	0.430	0.468	0.390	0.422	0.450	0.508	0.556	0.608
B_{0tot}[1]	24 300	26 810	29 520	7320	8743	10630	47 130	53 600	62 510
B_{0tot}[2]	29 030	31 470	33 950	11200	12750	14750	31 750	34 210	36 950
B_{0tot}[total]	54 320	58 240	62 840	19340	21610	24370	81 140	88 020	97 150
$B_{0totnow}$[1]	19 120	22 950	28 120	19760	23450	29080	60 560	77 400	99 270
$B_{0totnow}$[2]	40 290	45 400	52 040	42080	46820	52280	44 520	49 420	55 740
$B_{0totnow}$[total]	61 830	68 760	77 080	64370	70600	78200	109 100	127 100	149 700
$B_{2021tot}$[1]	7 345	8 702	10 390	7320	8743	10630	36 240	47 050	61 330

	base			fix_M			sel_rh2		
	5%	50%	95%	5%	50%	95%	5%	50%	95%
$B_{2021tot}$[2]	11 790	13 270	15 320	11200	12750	14750	12 930	14 790	17 200
$B_{2021tot}$[total]	20 030	22 050	24 600	19340	21610	24370	51 020	61 960	76 450
$B_{2021tot} / B_{0tot}$[1]	0.270	0.325	0.391	0.271	0.320	0.388	0.746	0.879	1.031
$B_{2021tot} / B_{0tot}$[2]	0.361	0.423	0.492	0.348	0.397	0.460	0.380	0.432	0.500
$B_{2021tot} / B_{0tot}$[total]	0.334	0.378	0.432	0.326	0.363	0.409	0.613	0.705	0.812
$B_{2021tot} / B_{0totnow}$[1]	0.341	0.376	0.417	0.348	0.371	0.396	0.555	0.608	0.672
$B_{2021tot} / B_{0totnow}$[2]	0.262	0.293	0.325	0.260	0.273	0.289	0.282	0.299	0.319
$B_{2021tot} / B_{0totnow}$[total]	0.292	0.321	0.350	0.294	0.306	0.320	0.450	0.487	0.532
$CPUE_{2020}$ [1]	1.165	1.526	1.985	1.167	1.520	1.994	1.605	2.163	2.931
$CPUE_{2020}$ [2]	2.151	2.446	2.800	2.178	2.462	2.819	2.113	2.392	2.726
H_{2020} [1]	14.17	16.43	19.54	14.12	16.41	19.57	16.21	19.31	23.73
H_{2020} [2]	75.52	81.41	87.88	75.41	81.27	87.92	75.27	81.60	88.36
H_{2020} [total]	91.14	98.15	104.90	91.43	97.92	105.10	94.17	101.10	109.00
B_{male} / B_{female} [1]	0.617	0.702	0.786	0.612	0.685	0.759	1.364	1.451	1.531
B_{male} / B_{female} [2]	0.686	0.737	0.789	0.682	0.725	0.773	0.737	0.796	0.858

[1] fixed parameter

[2] combined with *vuln AW* [immature female] in region 1

Table 14: Probabilities calculated from the MCMC posteriors for the indicated derived parameters. These probabilities are by region where appropriate (regional values denoted by [1] and [2]) for the base case and three sensitivity runs.

Probabilities	*basefix_Msel_rh2*		
$P(B_{2021} > B_{MIN})$ [1]	1.000	1.000	1.000
$P(B_{2021} > B_{MIN})$ [2]	1.000	1.000	1.000
$P(B_{2021} > B_{MIN})$ [total]	1.000	1.000	1.000
$P(SSB_{2021} < 20\% \ SSB_{0now})$ [1]	0.000	0.000	0.000
$P(SSB_{2021} < 20\% \ SSB_{0now})$ [2]	0.000	0.000	0.000
$P(SSB_{2021} < 20\% \ SSB_{0now})$ [total]	0.000	0.000	0.000
$P(SSB_{2021} < 10\% \ SSB_{0now})$ [1]	0.000	0.000	0.000
$P(SSB_{2021} < 10\% \ SSB_{0now})$ [2]	0.000	0.000	0.000
$P(SSB_{2021} < 10\% \ SSB_{0now})$ [total]	0.000	0.000	0.000

Table 15: Catch (tonnes) in the final model year and projected catch assumptions by fishing year, season, region, and fishing sector.

Fishing year	Commercial		Recreational		Customary		Illegal	
	AW	SS	AW	SS	AW	SS	AW	SS
Region 1								
2021–2025	180.46	125.57	1.02	9.19	0.38	3.40	4.96	3.45
Region 2								
2021–2025	562.40	429.46	3.31	29.79	1.22	11.00	15.46	11.81
Total								
2021–2025	742.86	555.03	4.33	38.98	1.60	14.40	20.42	15.26

Table 16: Comparison of the 2021 stock assessment with the 2015 stock assessment.

Parameter	2021 model			Parameter	2015 model		
	5%	50%	95%		5%	50%	95%
R_0	1 095 000	1 218 000	1 355 000		1 274 000	1 434 000	1 606 000
M	0.0848	0.0932	0.1007	CRA 7	0.094	0.102	0.113
				CRA 8	0.090	0.095	0.100
mat50	59.330	59.950	60.640		57.8	58.2	58.5
mat95add	8.538	9.598	10.760		6.56	6.15	6.87
Galpha [M]	4.356	4.424	4.497	CRA 7	3.38	3.65	3.97
				CRA 8 early	4.06	4.19	4.35
				CRA 8 late	4.52	4.64	4.76
Gbeta [M]	2.577	2.806	3.045	CRA 7	3.25	3.45	3.68
				CRA 8 early	2.72	3.68	4.11
				CRA 8 late	3.87	4.06	4.24
Gshape [M]	1.477	1.933	2.429	CRA 7	4.39	4.94	5.53
				CRA 8	4.65	5.19	5.73
GCV [M]	0.411	0.427	0.444	CRA 7	0.590	0.602	0.614
				CRA 8	0.592	0.603	0.613
Galpha [F]	3.790	3.849	3.913	CRA 7	3.25	3.45	3.68
				CRA 8 early	2.83	2.94	3.06
				CRA 8 late	3.83	3.95	4.09
Gbeta [F]	1.550	1.601	1.655	CRA 7	3.25	3.45	3.68
				CRA 8 early	1.78	1.94	2.10
				CRA 8 late	2.46	2.57	2.69
Gshape [F]	3.278	3.523	3.774	CRA 7	4.04	4.43	4.80
				CRA 8	5.42	5.70	5.99
GCV [F]	0.357	0.376	0.395	CRA 7	0.808	0.830	0.851
				CRA 8	0.592	0.603	0.613
Gobs	1.293	1.316	1.338		1.39	1.41	1.44

7. FIGURES

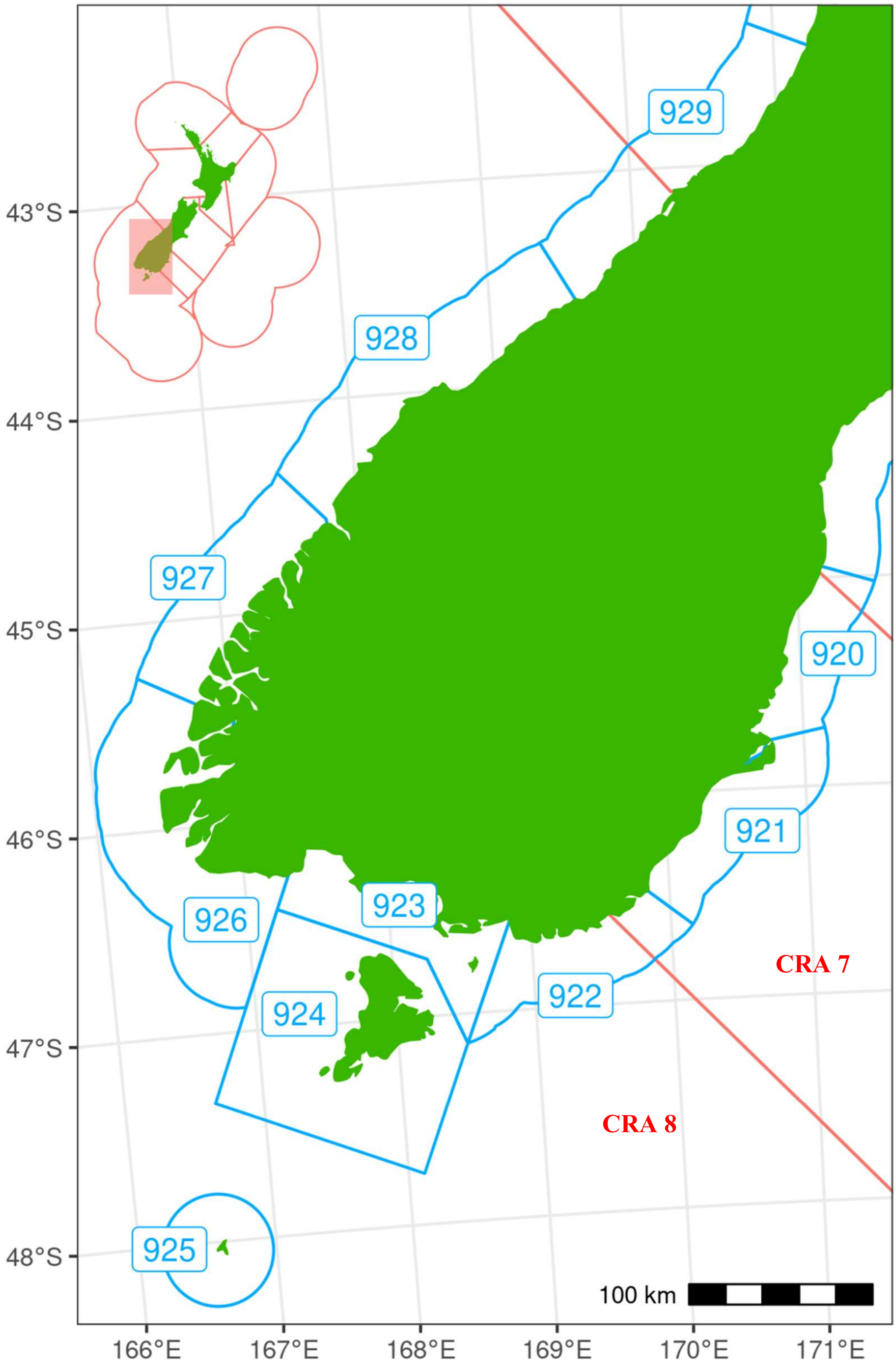


Figure 1: The CRA 7 and CRA 8 Quota Management Area (QMA) boundaries (solid red lines) and statistical area boundaries (solid blue lines).

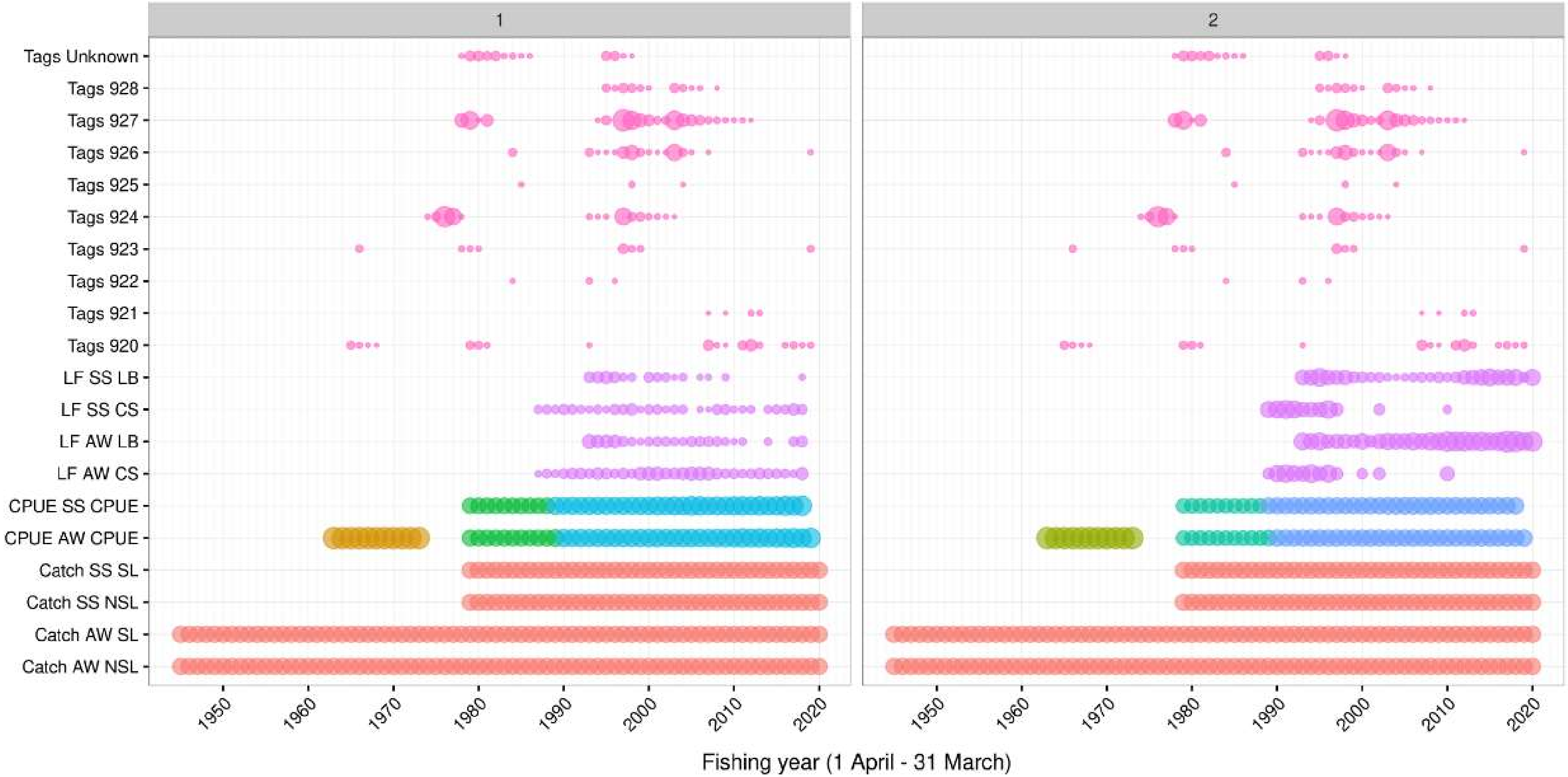


Figure 2: Data extent by fishing year used in the CRA 7 and CRA 8 stock assessment for each region (region 1 = 920+921+922+923+924+925, region 2 = 926+927+928). The size of the bubbles represents the relative number of recaptured tags, the effective sample size for length frequency distributions, the standard deviation for CPUE, or a fixed size for catch. Bubble colours vary for the different data sets (CPUE colours: CR = gold, FSU = green, and CELR = teal). LB = logbook, CS = catch sampling. See Starr et al. (2022) for a detailed description of these data.

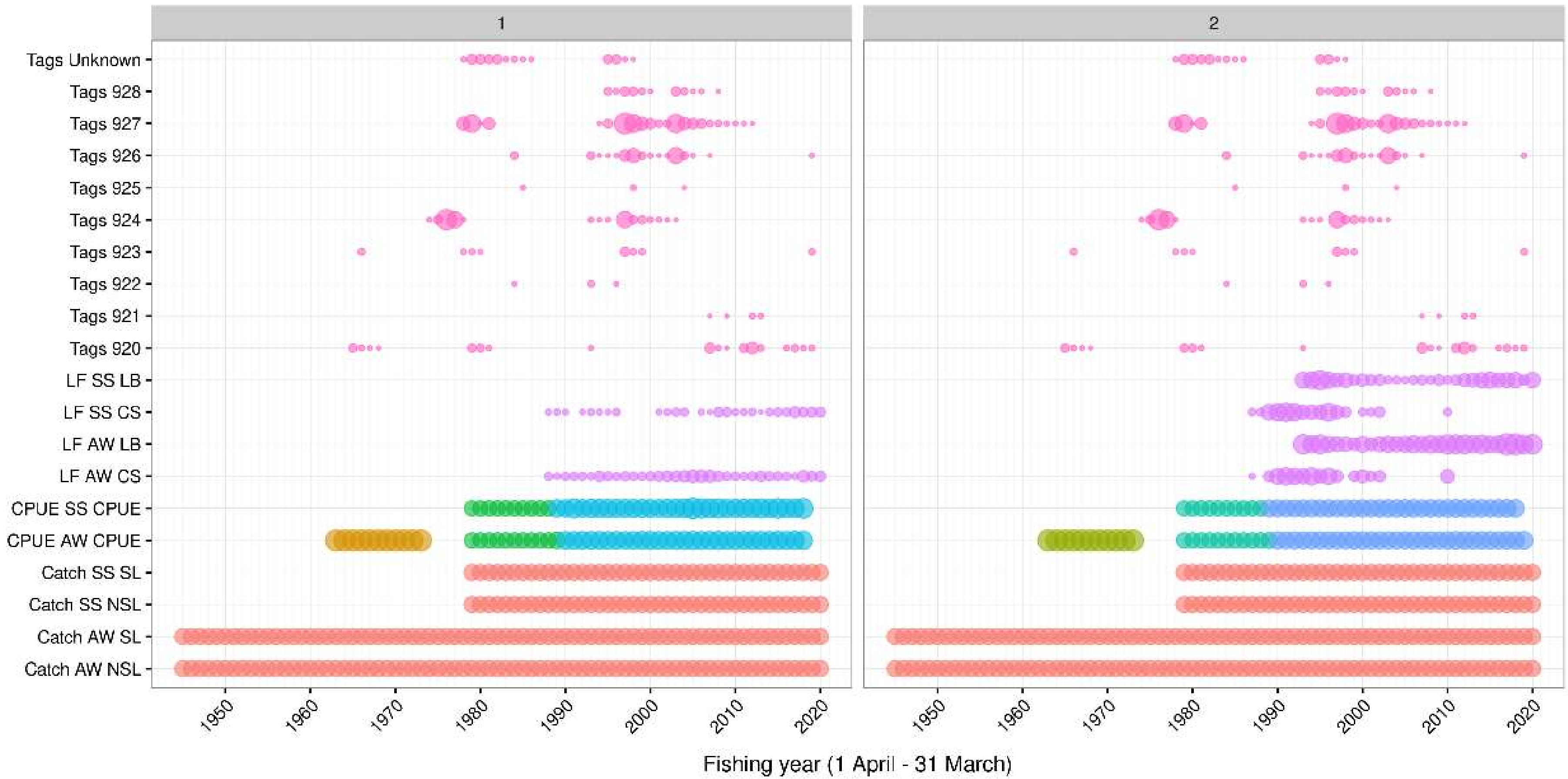


Figure 3: Data extent by fishing year for CRA 7 (left panel, labelled as 1) and CRA 8 (right panel, labelled as 2). The size of the bubbles represents the relative number of recaptured tags, the effective sample size for length frequency distributions, the standard deviation for CPUE, or a fixed size for catch. Bubble colours vary for the different data sets (CPUE colours: CR = gold, FSU = green, and CELR = teal). LB = logbook, CS = catch sampling. See Starr et al. (2022) for a detailed description of these data.

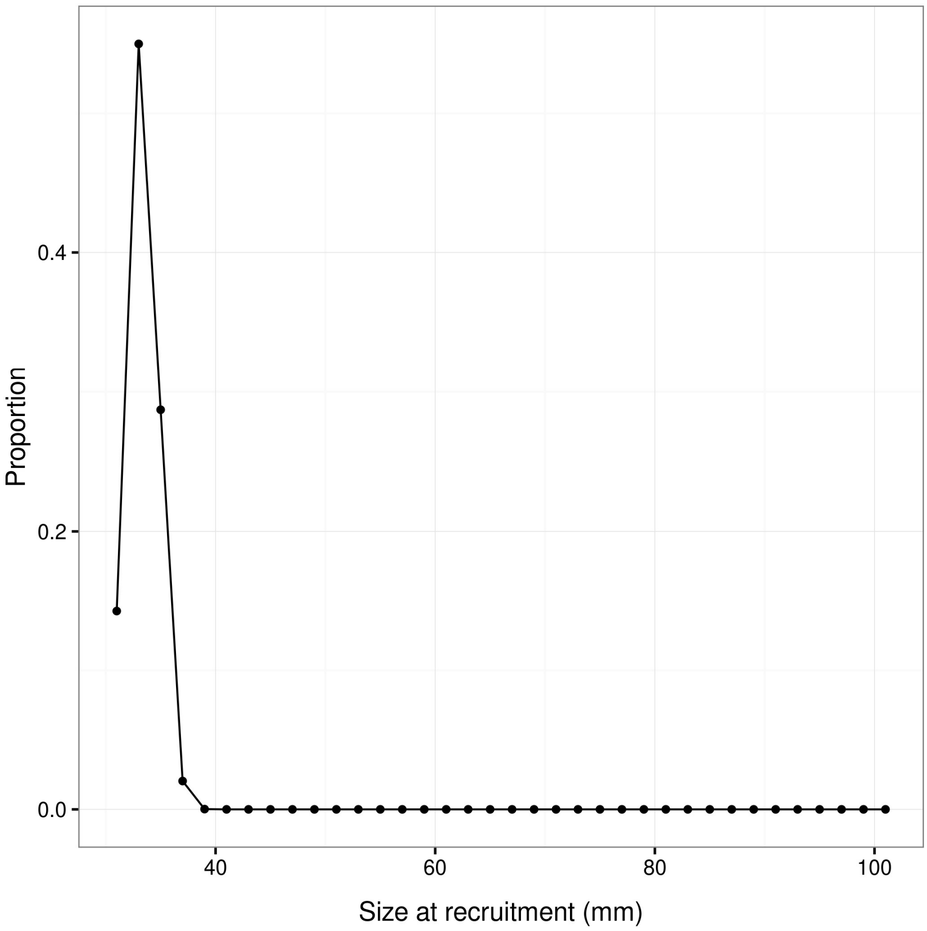


Figure 4: Distribution of size at recruitment size (mm) assumed in the CRA 7 and CRA 8 stock assessment.

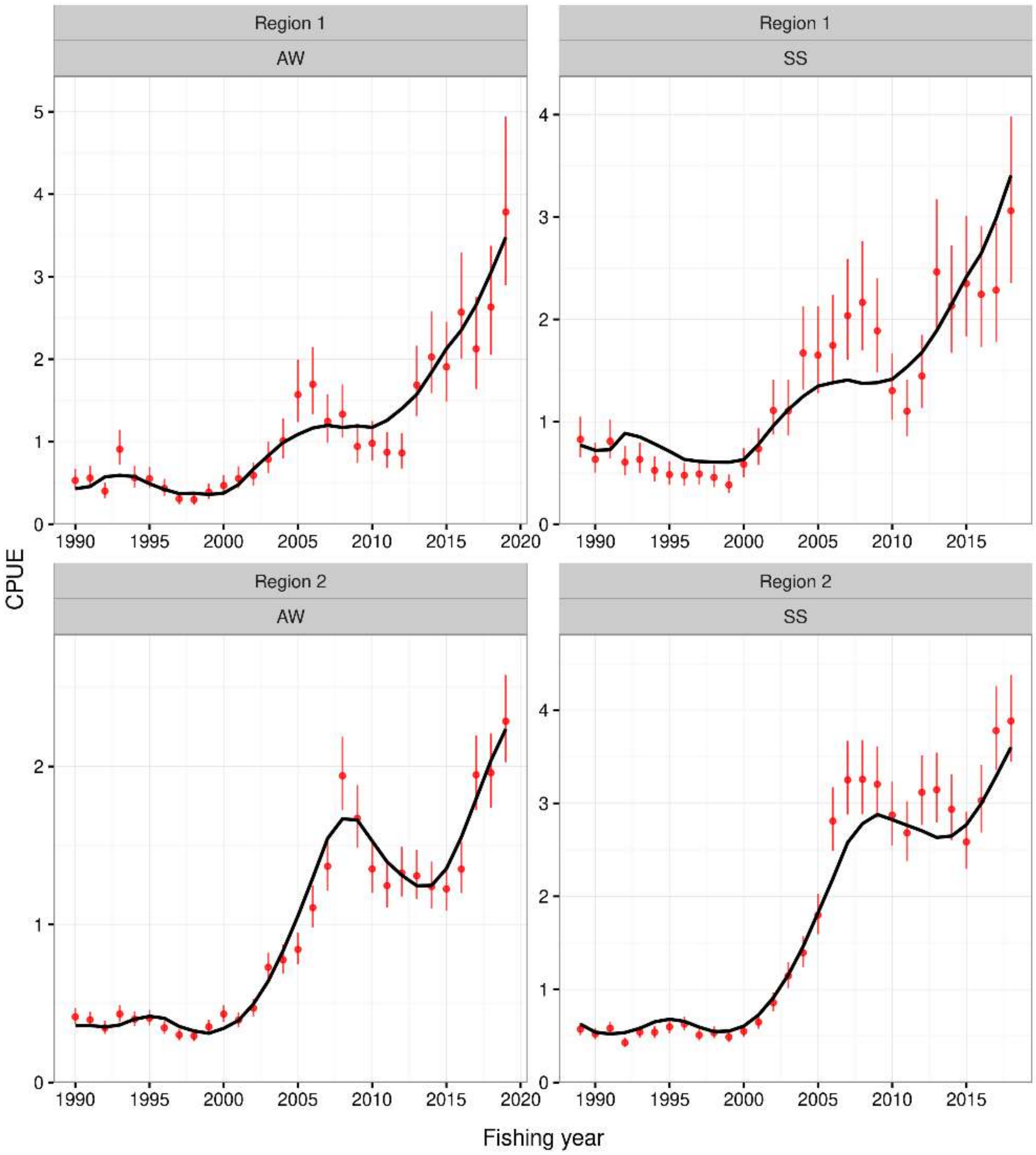


Figure 5: Model fit to the CELR CPUE indices by fishing year, season (AW = autumn-winter, SS = spring-summer), and region in the base case model run.

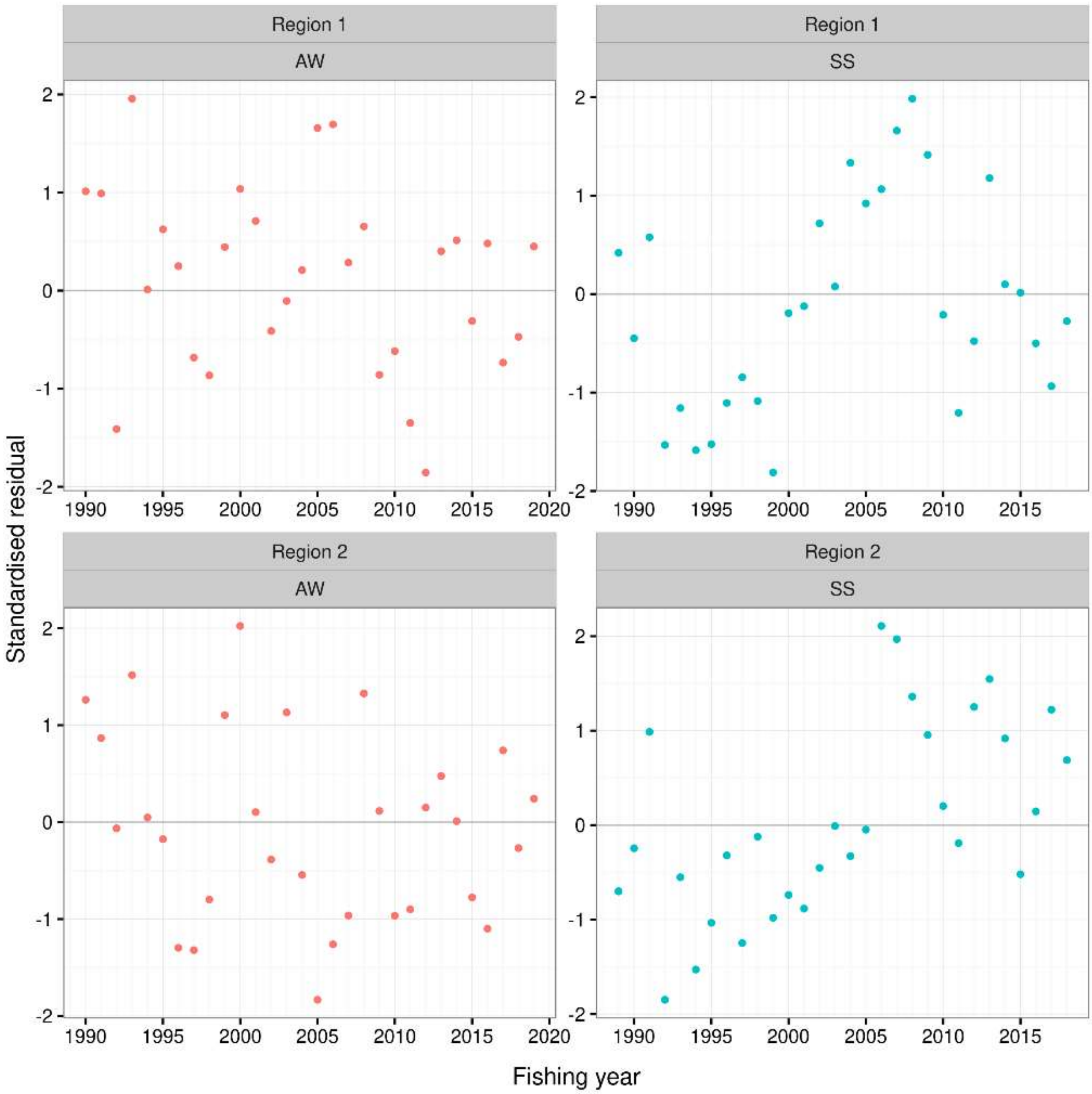


Figure 6: MAP standardised residuals from model fit to the CELR CPUE indices by fishing year, season (AW = autumn-winter, SS = spring-summer), and region in the <u>base case</u> model run.

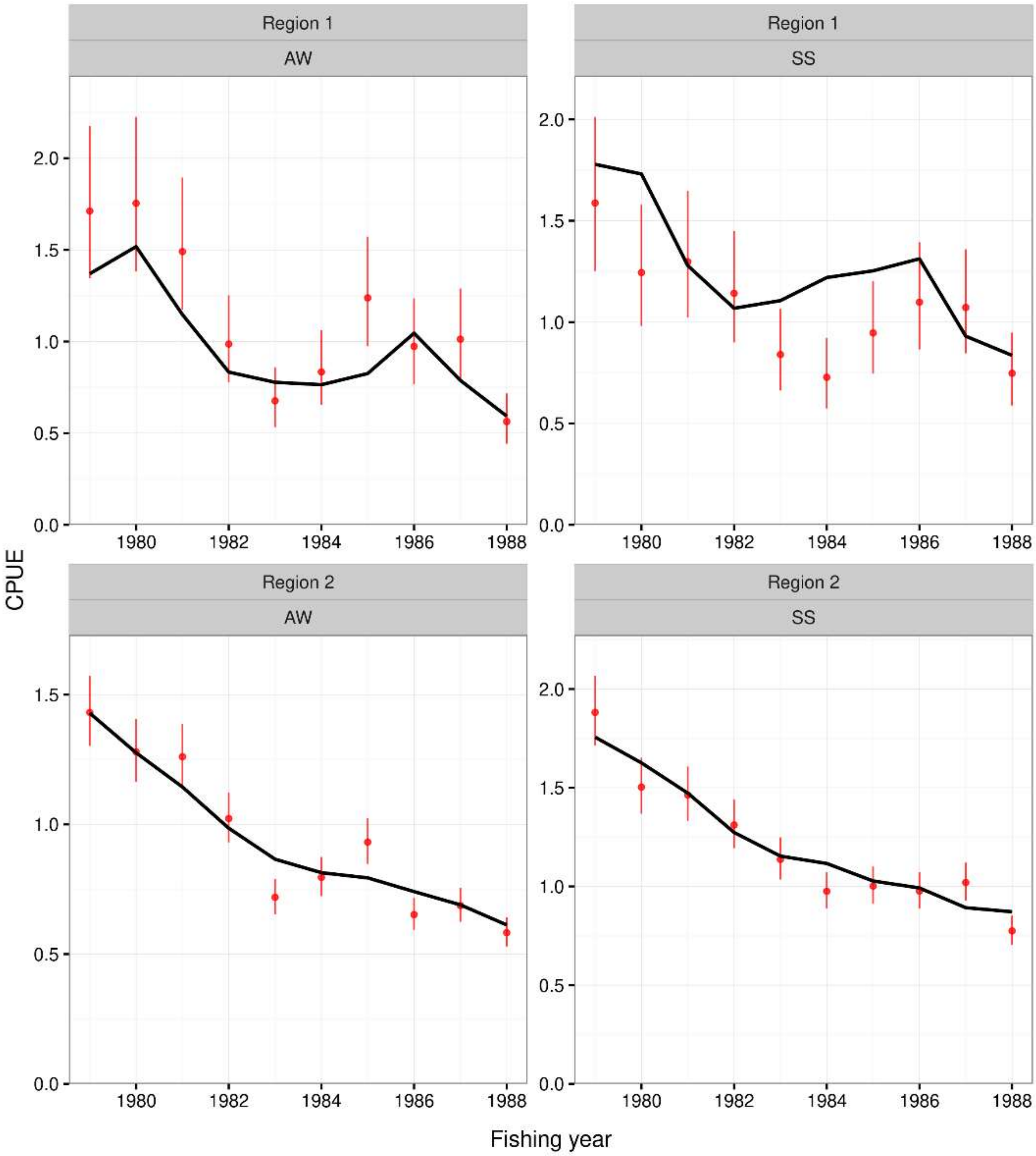


Figure 7: ` MAP model fit to the FSU CPUE indices by fishing year, season (AW = autumn-winter, SS = spring-summer), and region in the base case model run.

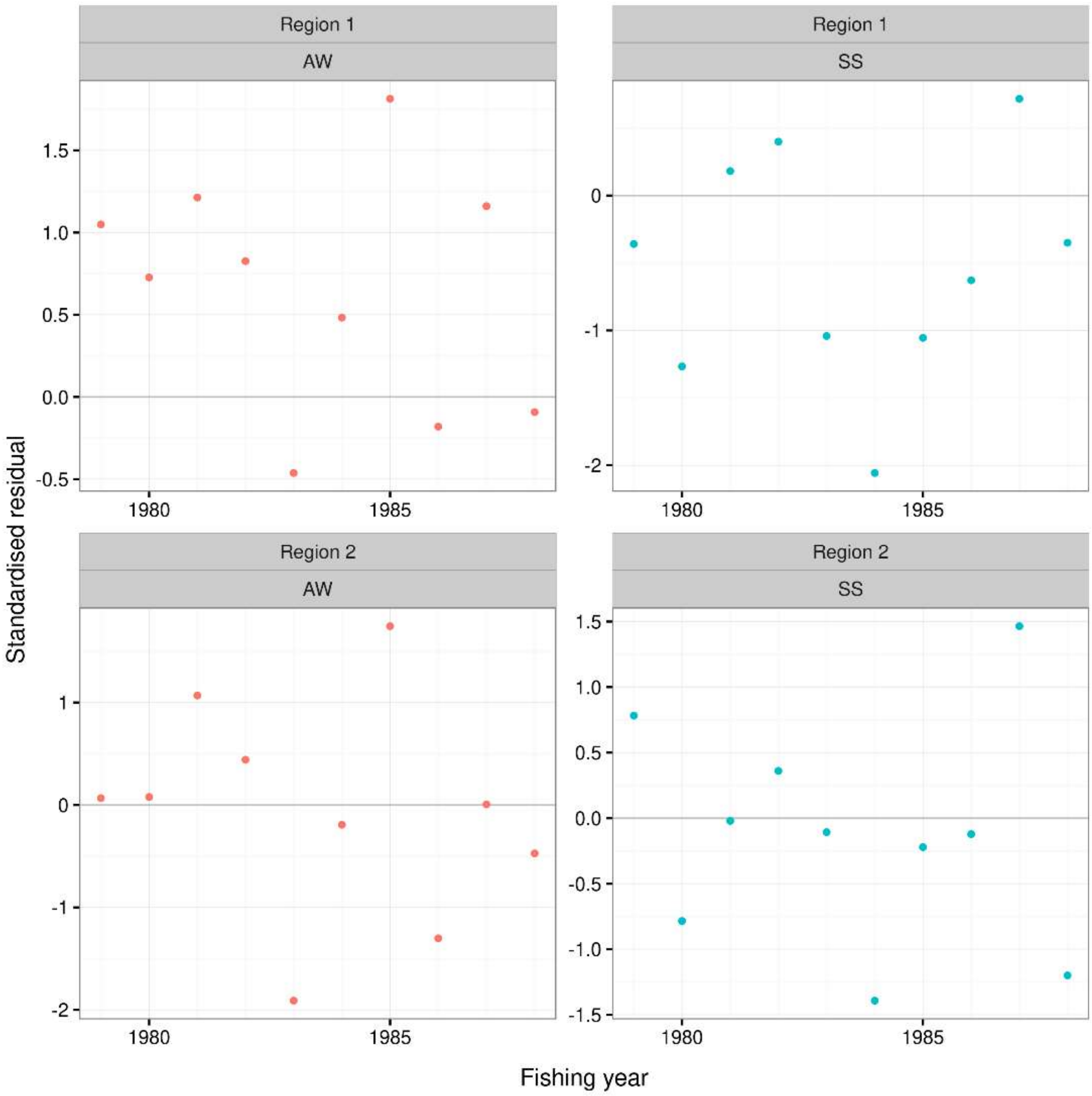


Figure 8: MAP standardised residuals from model fit to the FSU CPUE indices by fishing year, season (AW = autumn-winter, SS = spring-summer), and region in the <u>base case</u> model run.

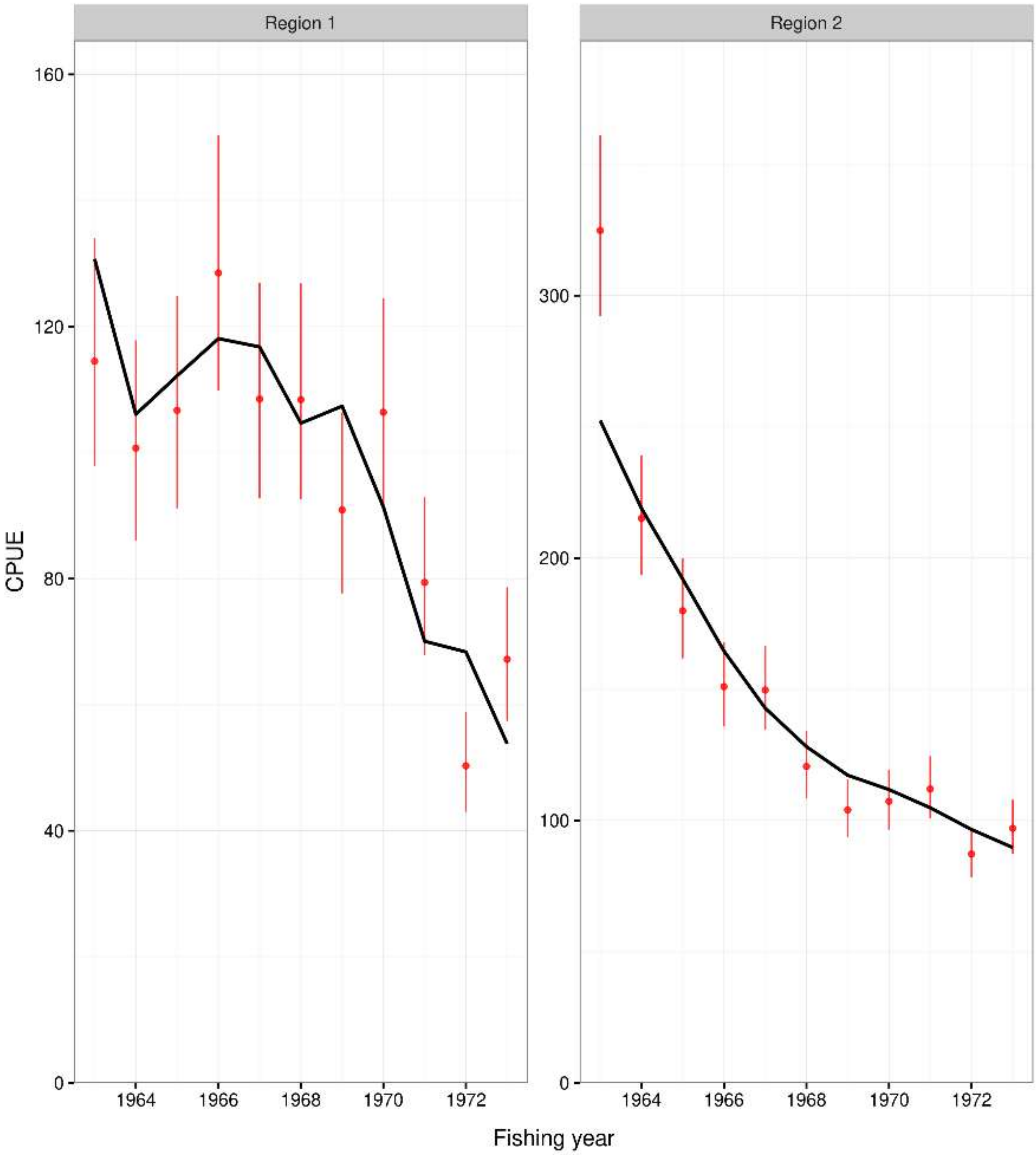


Figure 9: MAP model fit to the CR CPUE indices by fishing year in the base case model run.

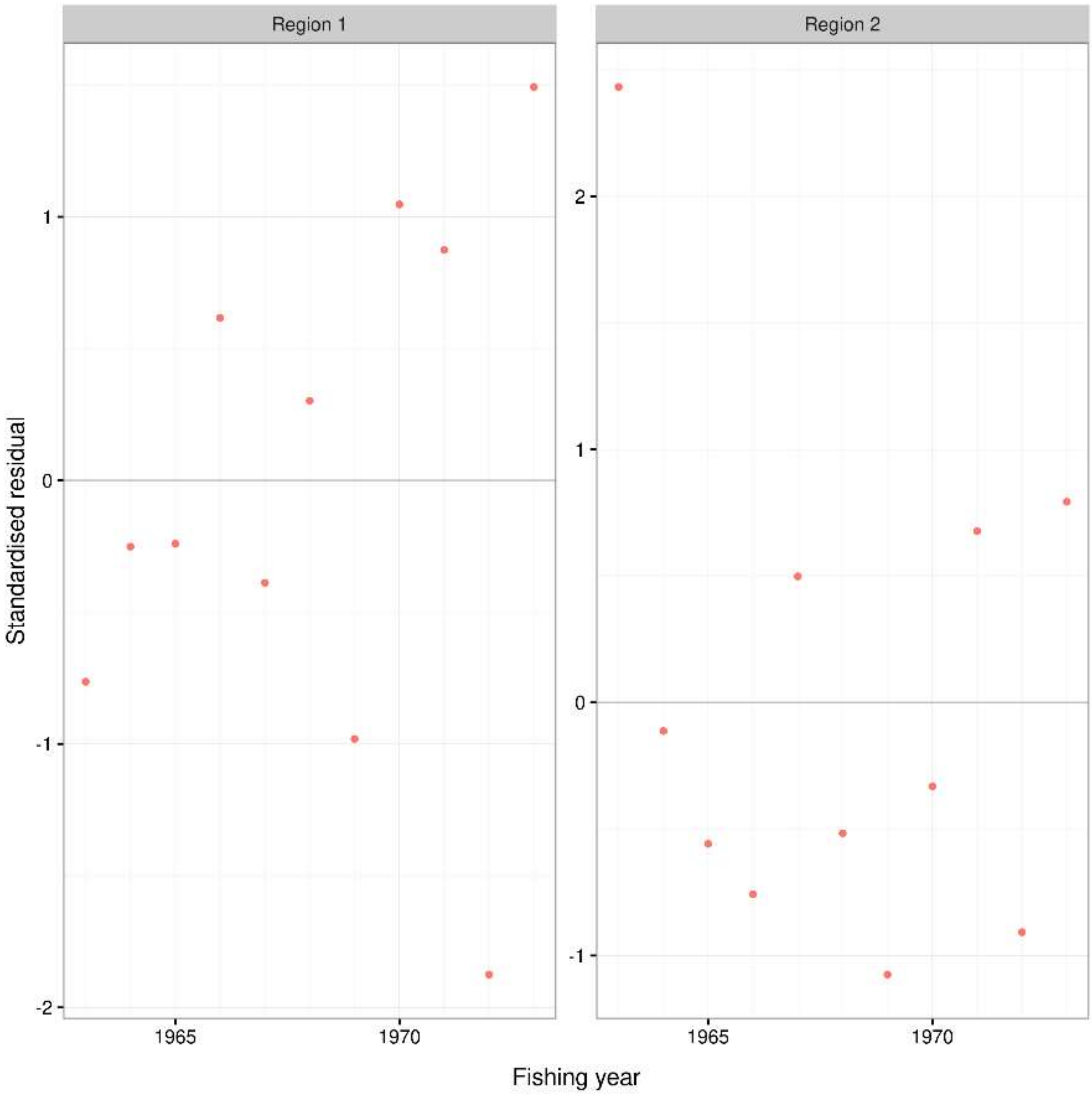


Figure 10: MAP standardised residuals from model fit to the CR CPUE indices by fishing year, season (AW = autumn-winter, SS = spring-summer), and region in the <u>base case</u> model run.

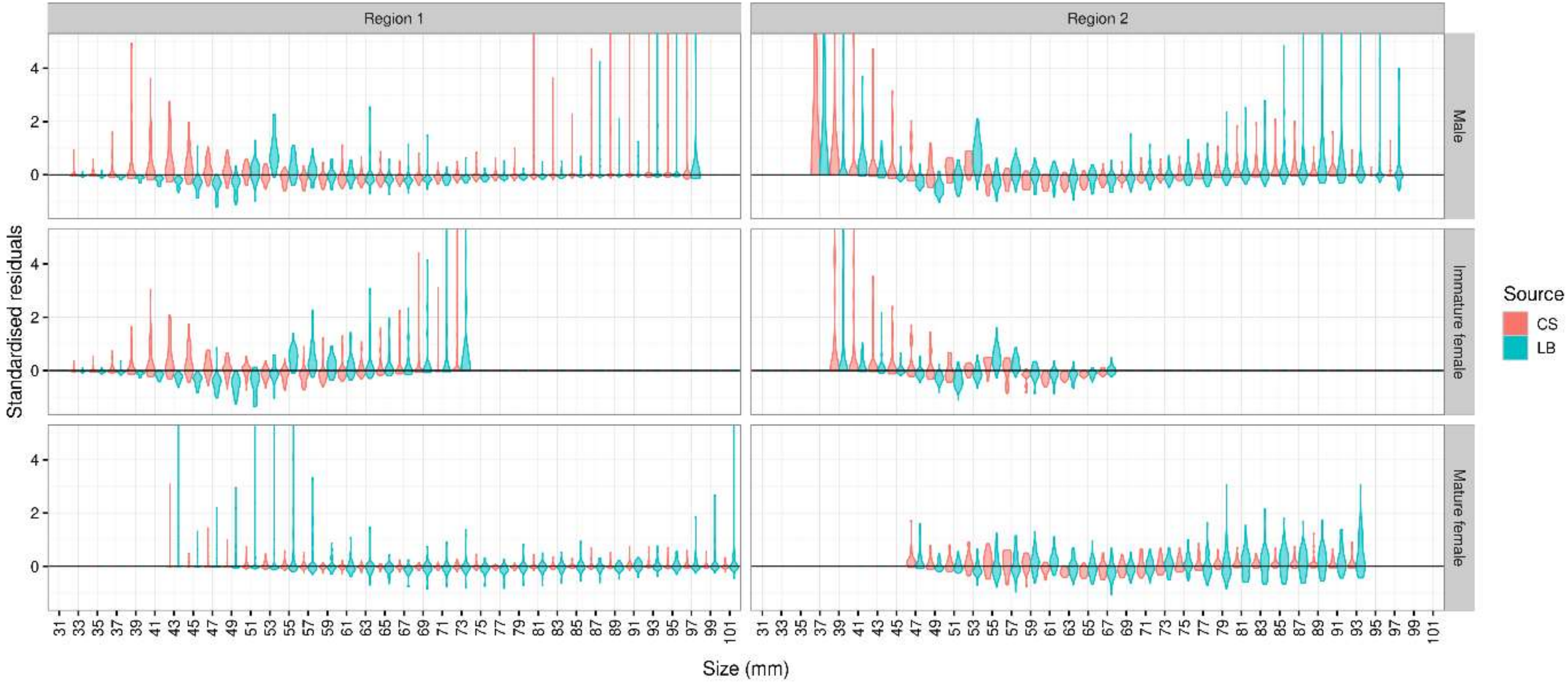


Figure 11: MAP standardised residuals from fits to the LF data by region, sex, 2 mm TW bin, and sampling source (CS = catch sampling, LB = logbook).

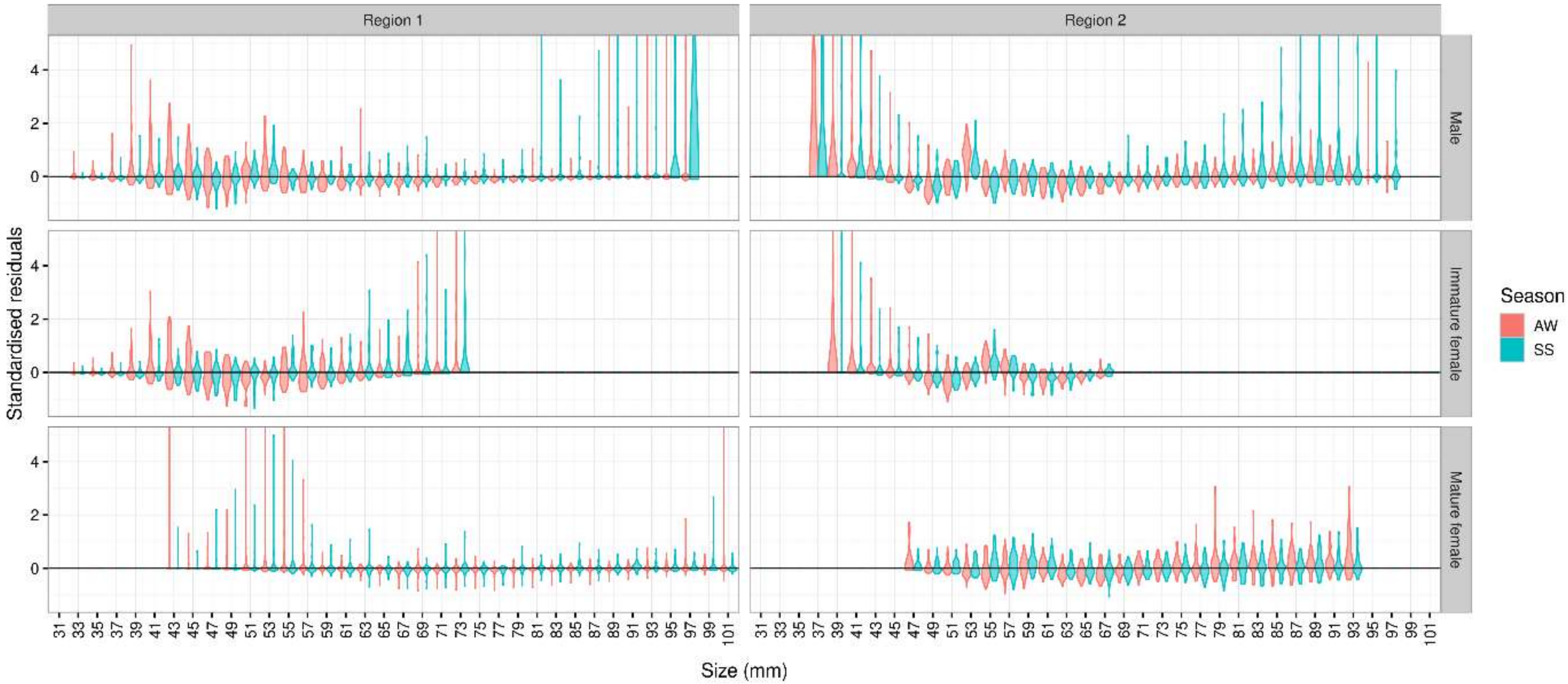


Figure 12: MAP standardised residuals from fits to the LF data by region, sex, year, 2 mm TW bin, and season (AW = autumn/winter, SS = spring/summer).

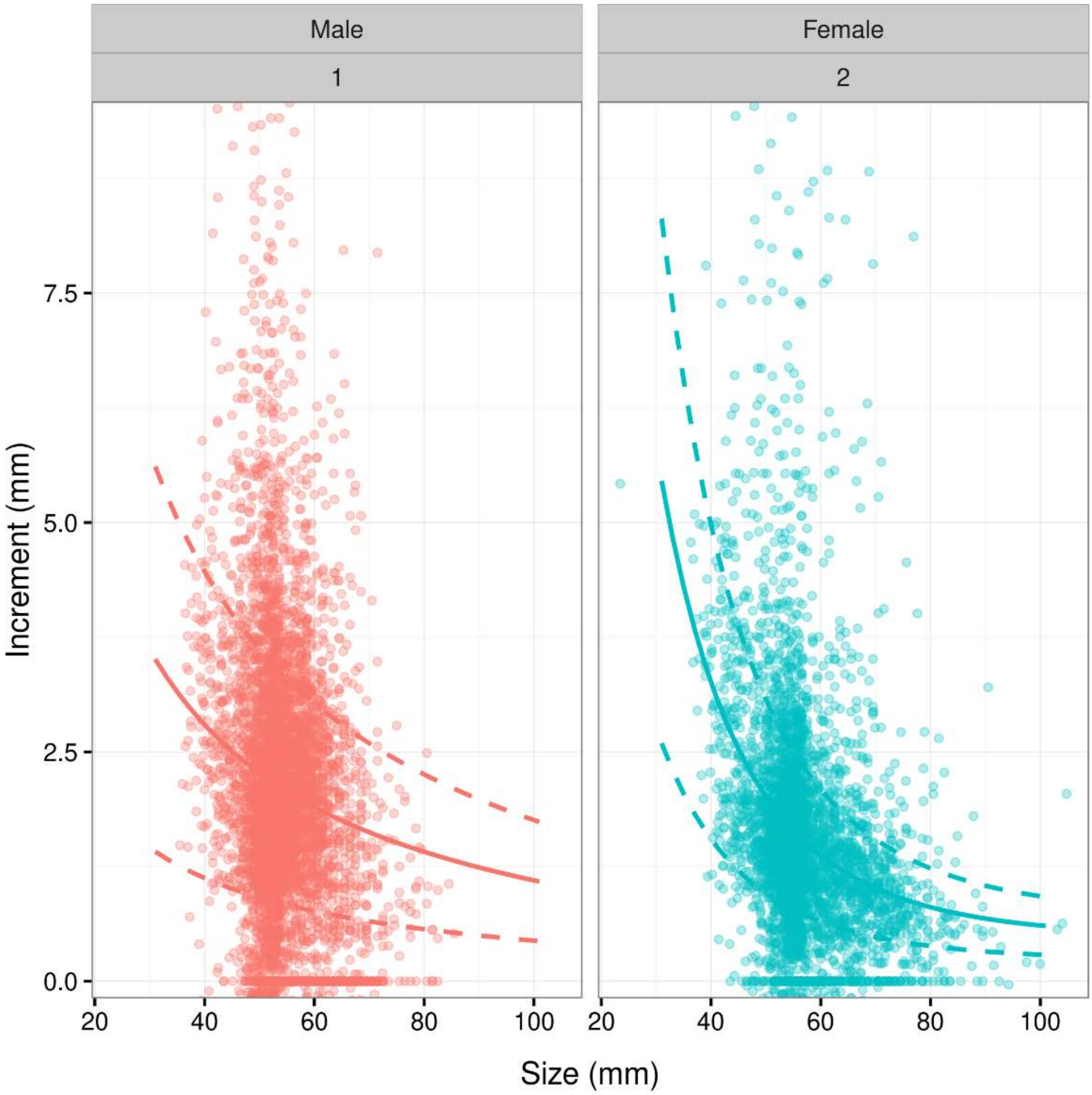


Figure 13: MAP predicted 6-monthly growth increment by size and sex in the base case model run showing the mean (solid line), ±1 standard deviation (dashed line), and observed growth increments divided by time-at-liberty (points).

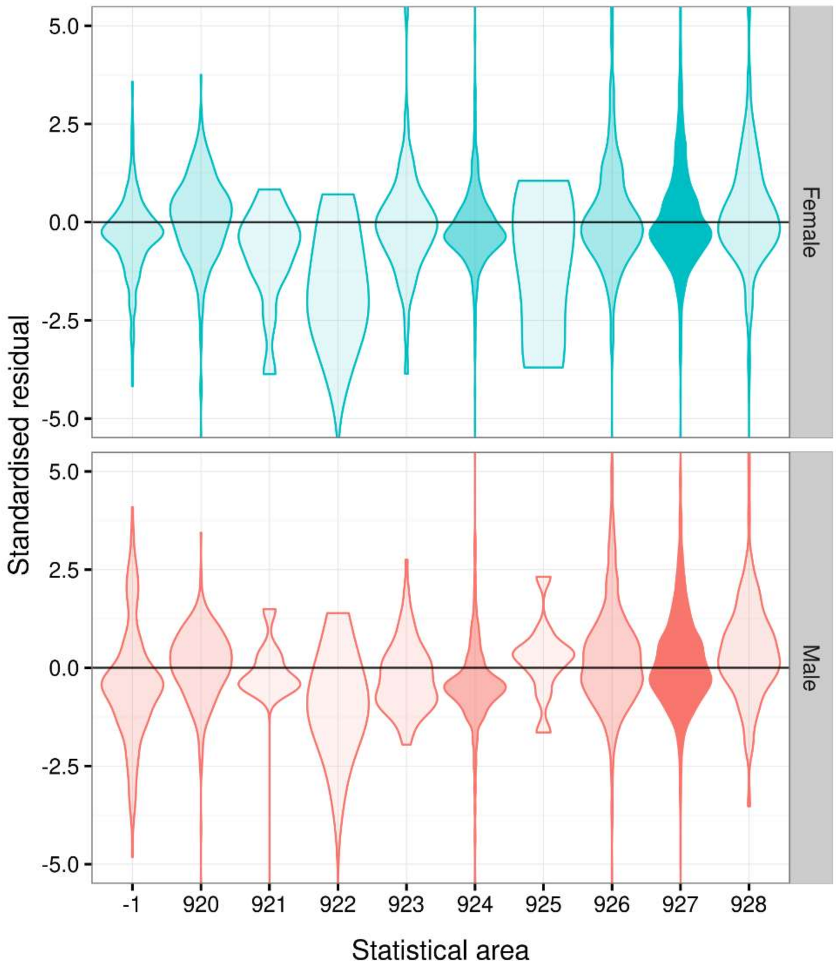


Figure 14: MAP standardised residuals of fits to tag-recapture data by statistical area of release and sex in the base case model run. Darker shading represents a higher number of tags. The group '-1' represents tags that could not be assigned to a statistical area but were tagged within CRA 7 or CRA 8.

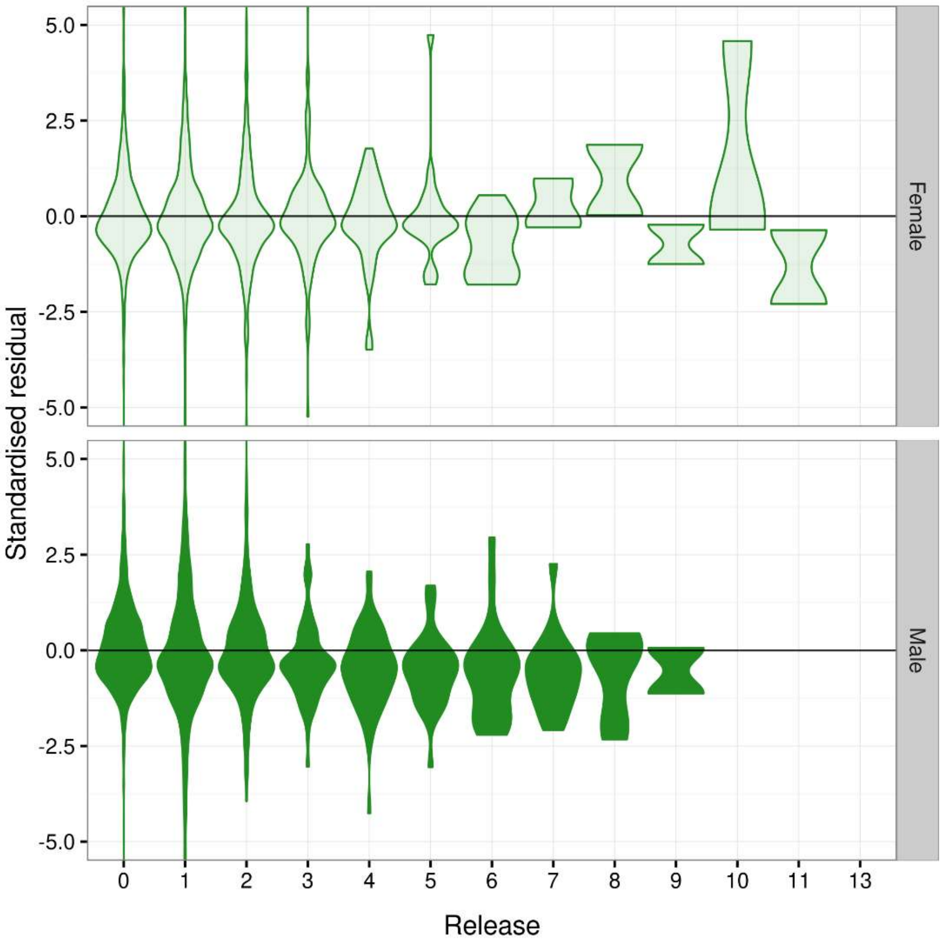


Figure 15: MAP standardised residuals of fits to tag-recapture data by re-release category and sex in the <u>base case</u> model run. Darker shading represents a higher number of tags.

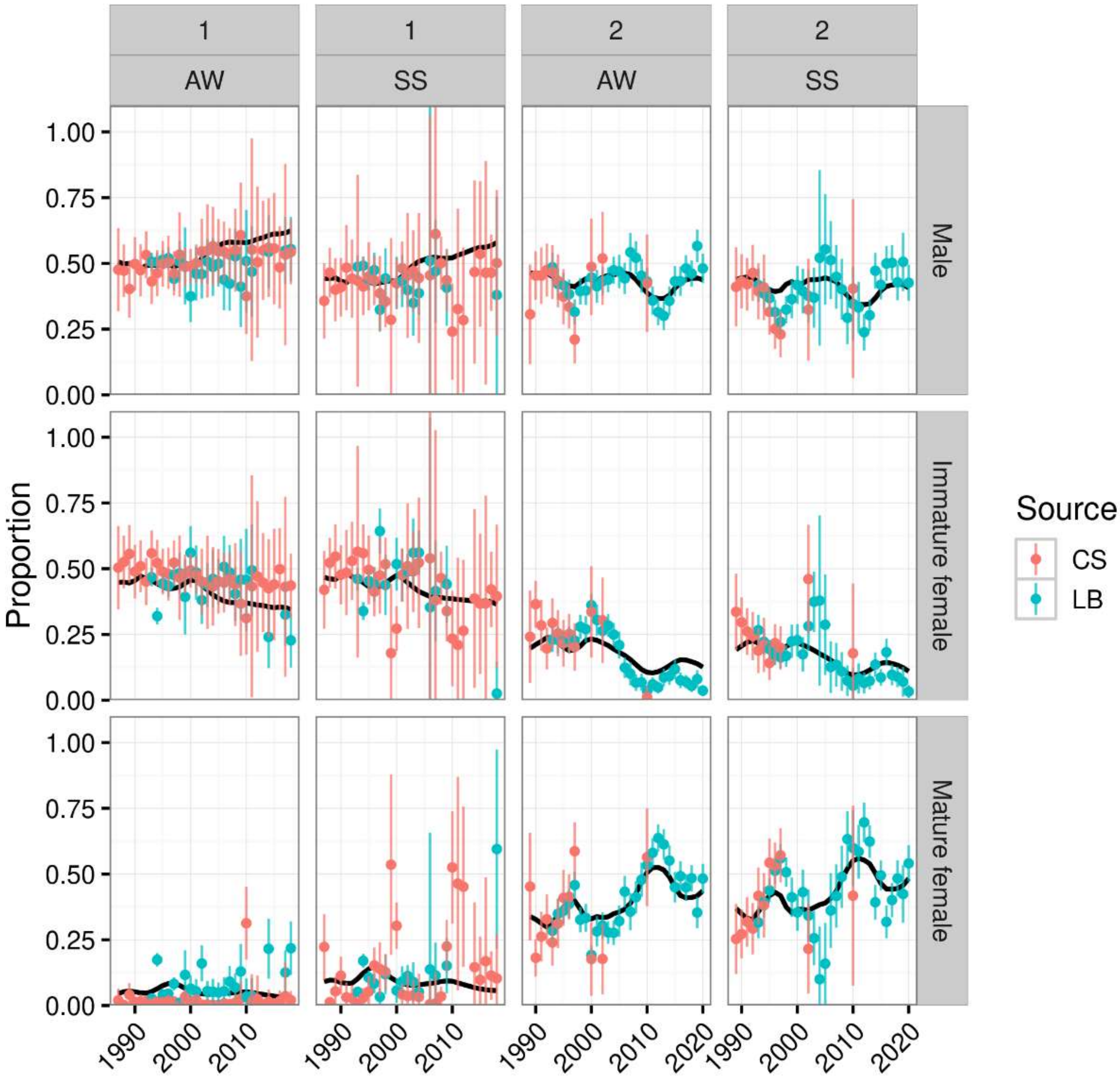


Figure 16: MAP model fit to the sex ratios by fishing year, season (AW = autumn-winter, SS = spring-summer), region (1 = region 1, 2 = region 2), sex, and LF data source (CS = catch sampling, LB = logbook) in the <u>base case</u> model run.

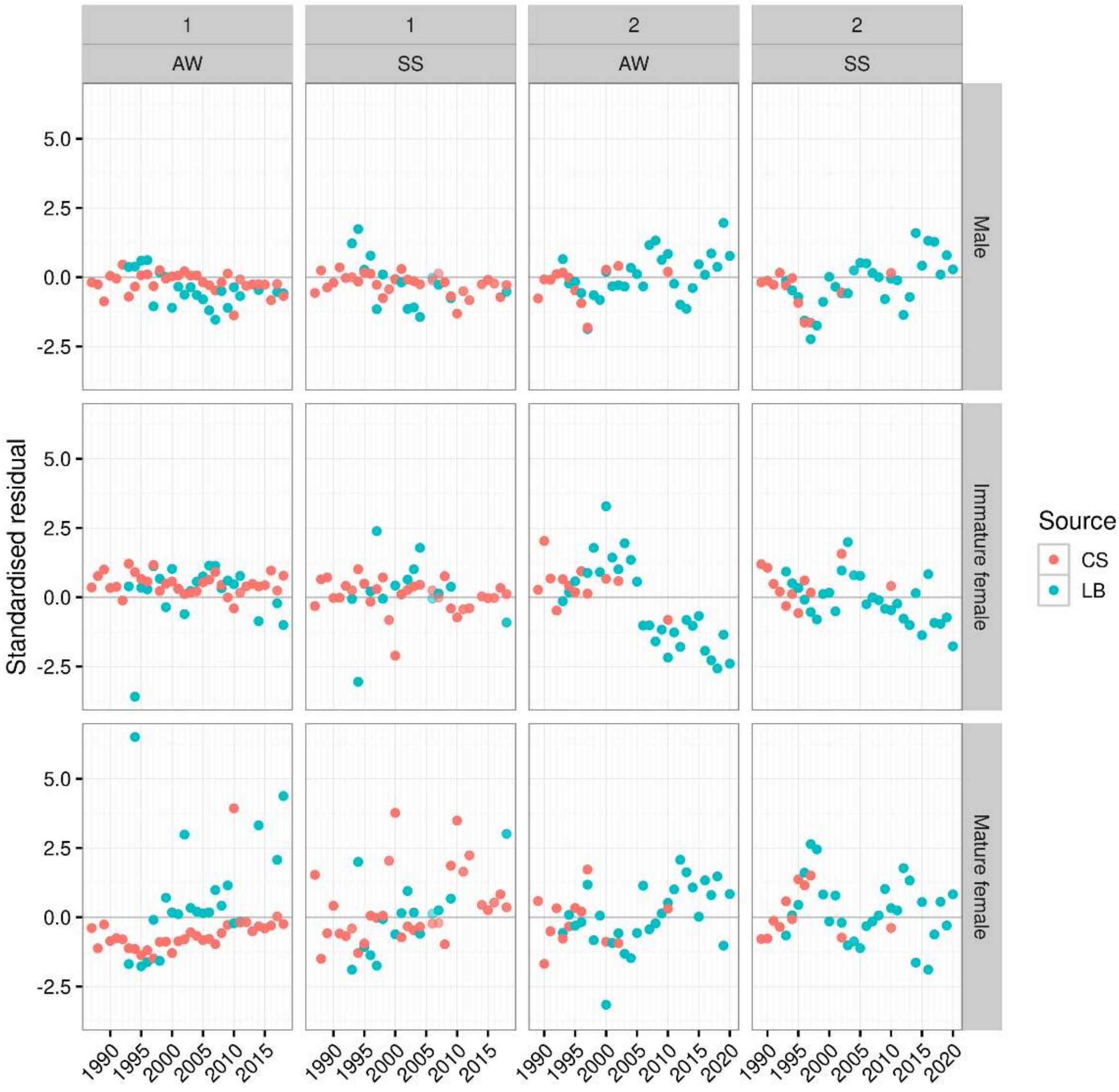


Figure 17: MAP standardised residuals for the model fit to the sex ratios by fishing year, season (AW = autumn-winter, SS = spring-summer), region (1 = region 1, 2 = region 2), sex, and LF data source (CS = catch sampling, LB = logbook) in the base case model run.

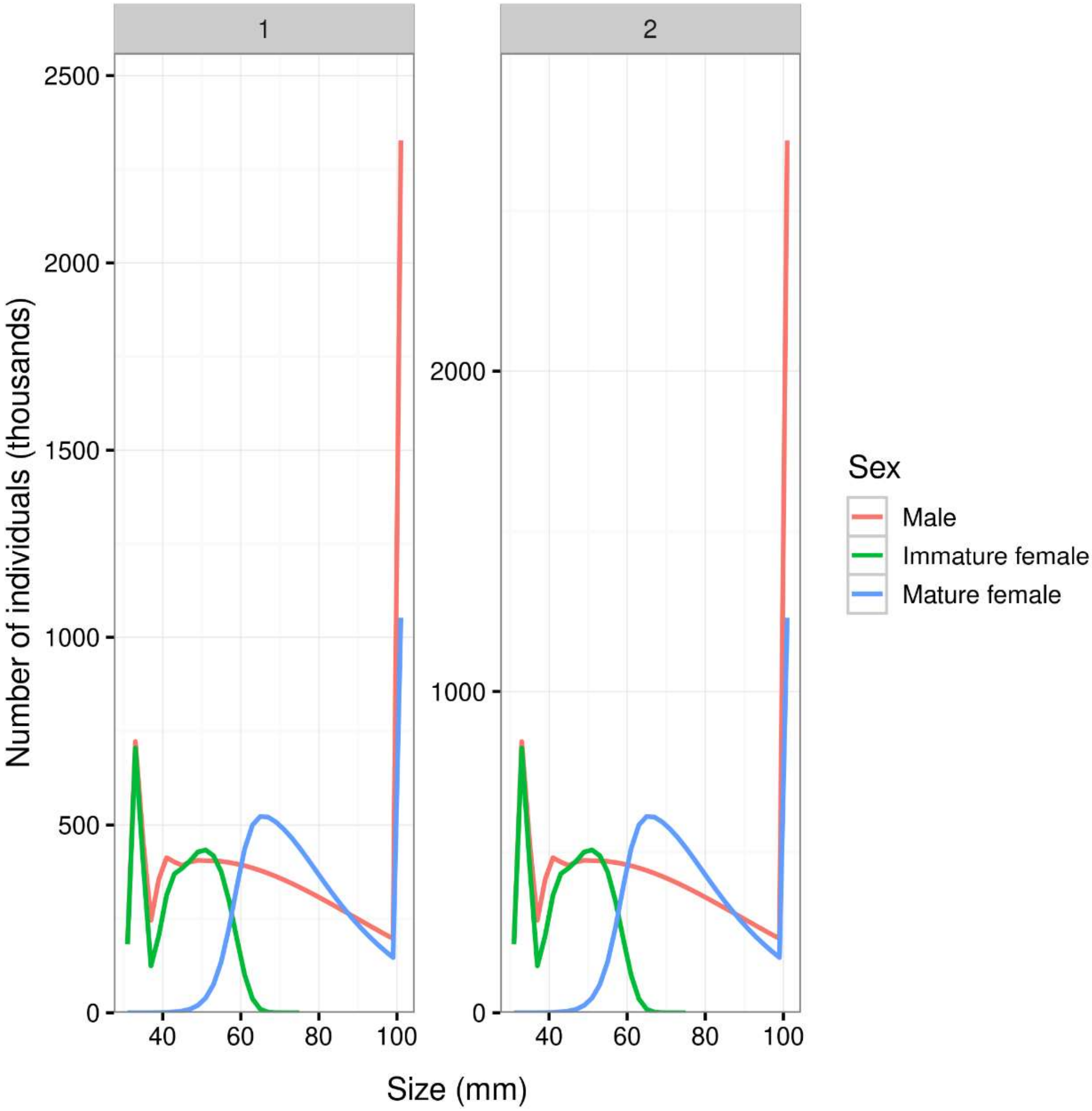


Figure 18: MAP initial number of individuals by size, sex category, and region in the base case model run.

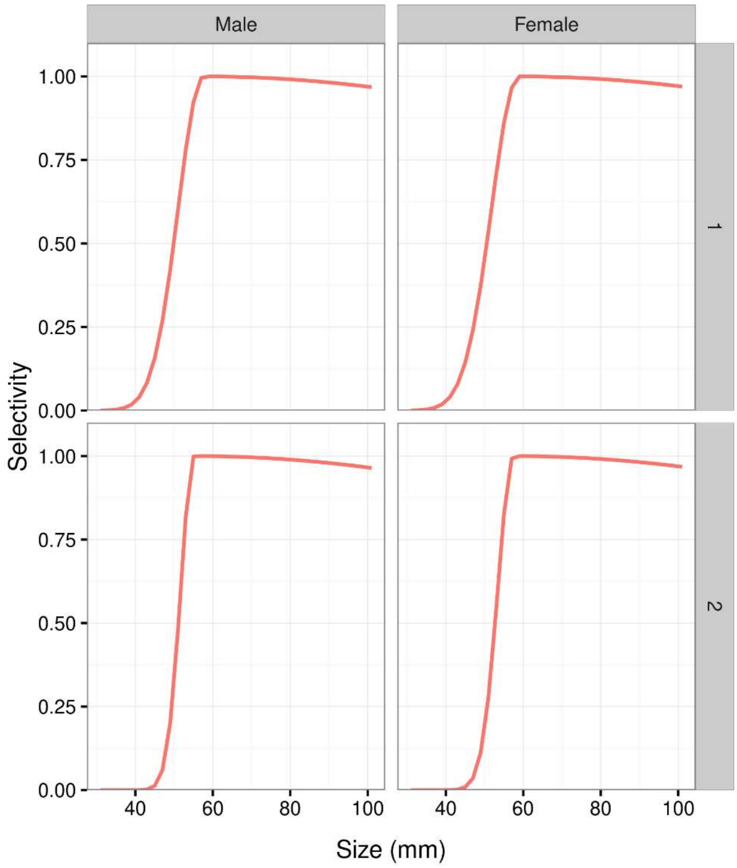


Figure 19: MAP of selectivity by sex and size for each region in the base case model run.

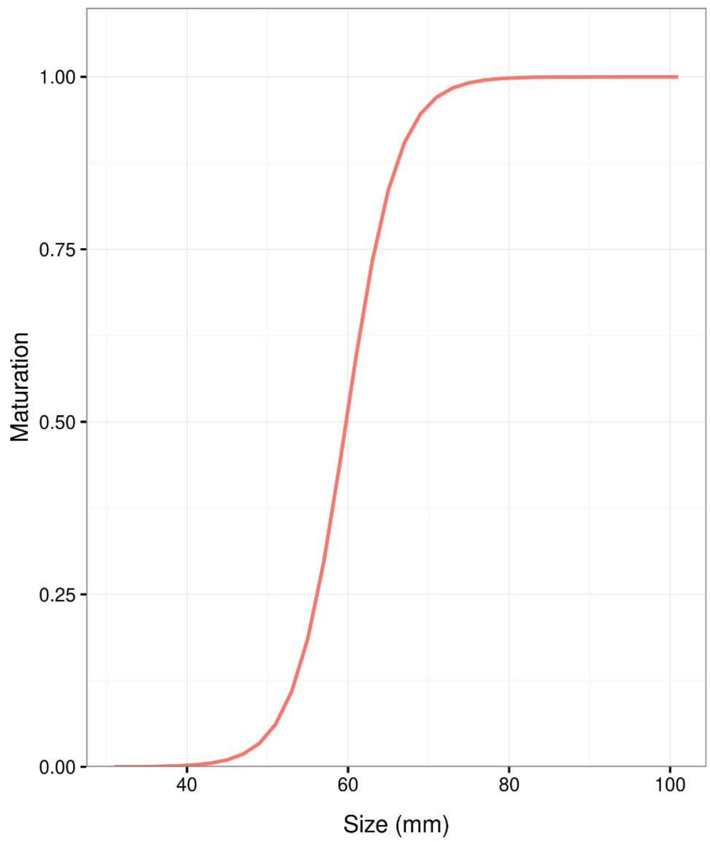


Figure 20: MAP of female maturation curve by size in the base case model run.

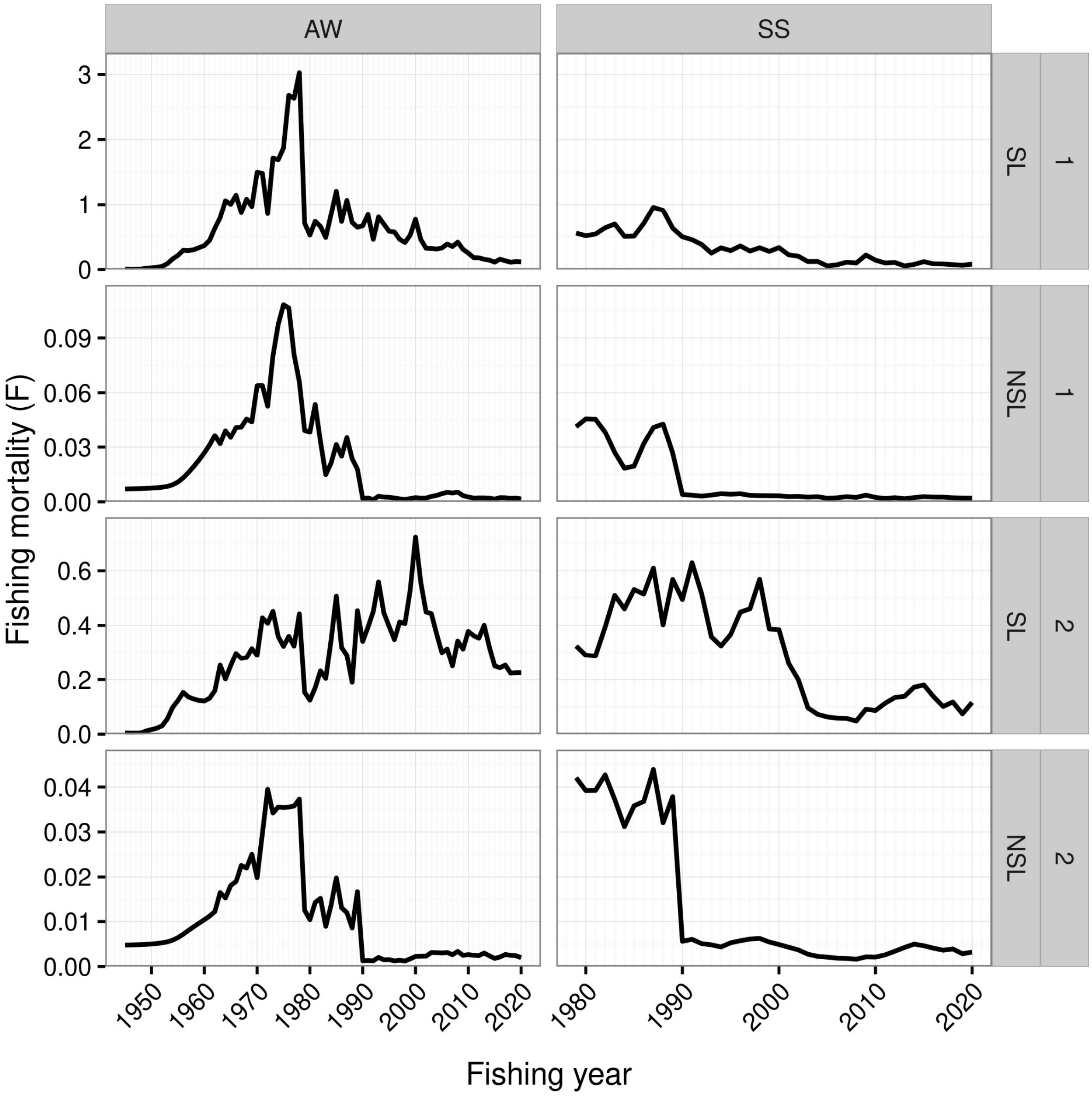


Figure 21: MAP of fishing mortality by fishing year, season (AW = autumn/winter, SS = spring/summer), and region for the size limited (SL) and non-size limited (NSL) fisheries in the <u>base case</u> model run. Note that the AW fishing mortalities before 1979 are annual rather than seasonal.

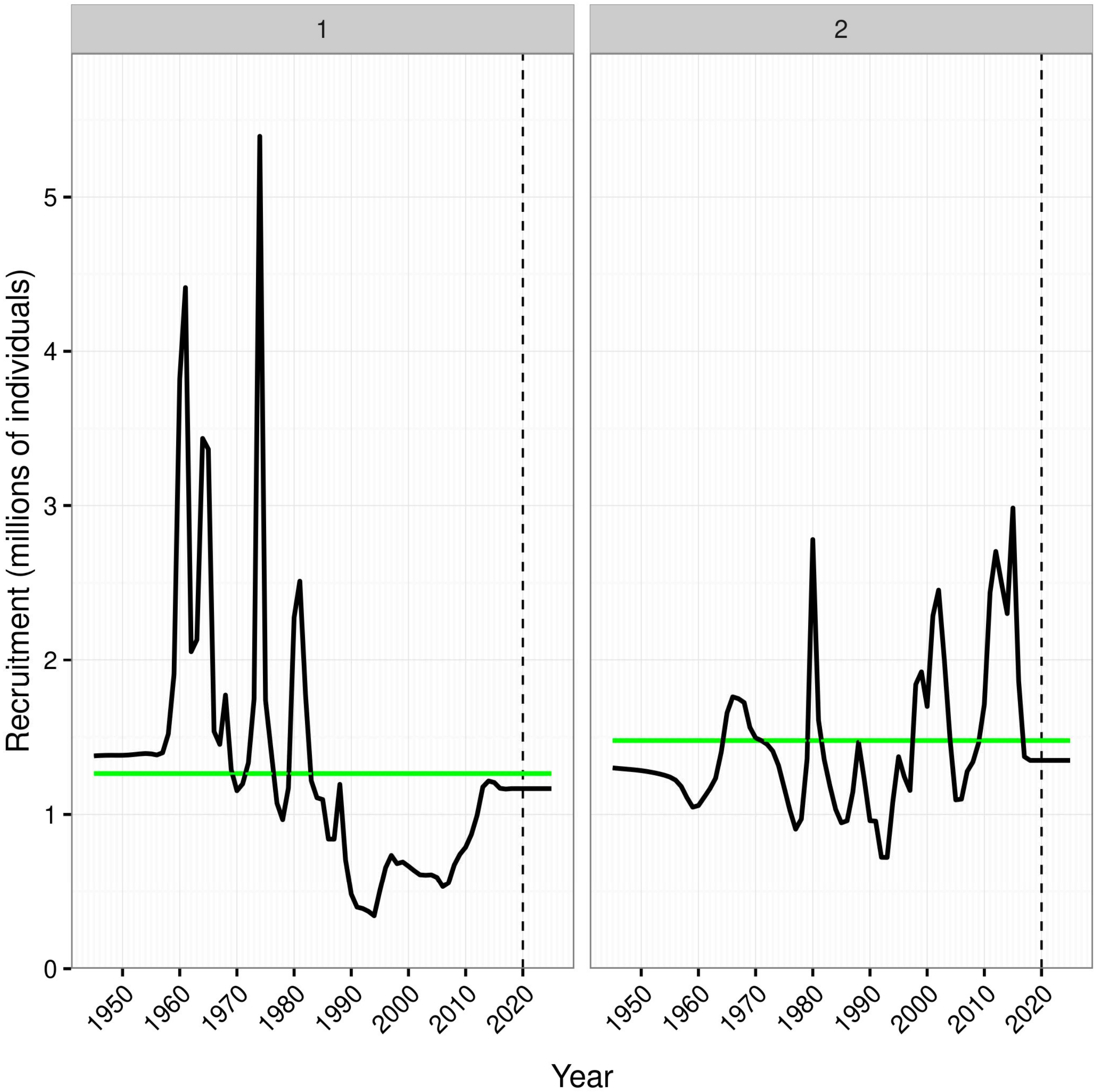


Figure 22: MAP of recruitment by region for the base case model run. Horizontal green line is R_0 and vertical dashed line is the final year of the reconstruction period.

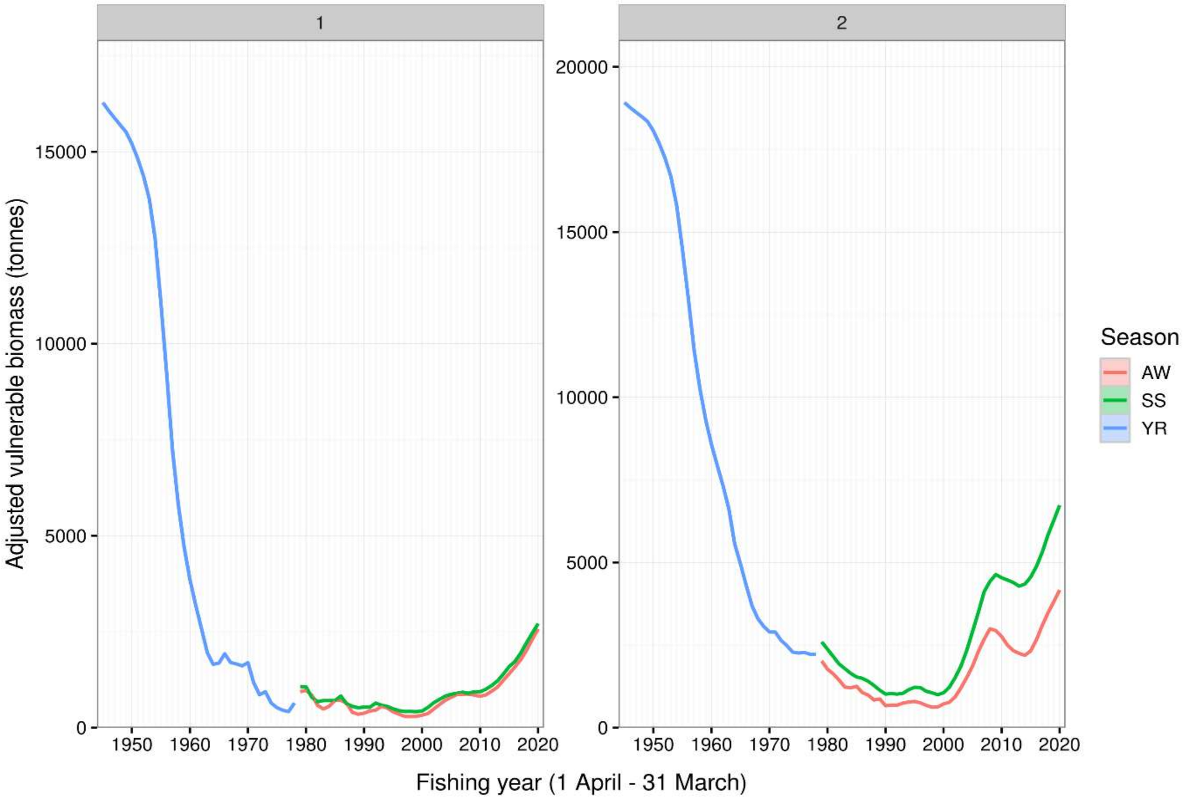


Figure 23: MAP of adjusted vulnerable biomass (tonnes) by region, season (AW = autumn/winter, SS = spring/summer, YR = single time step), and fishing year in the base case model run.

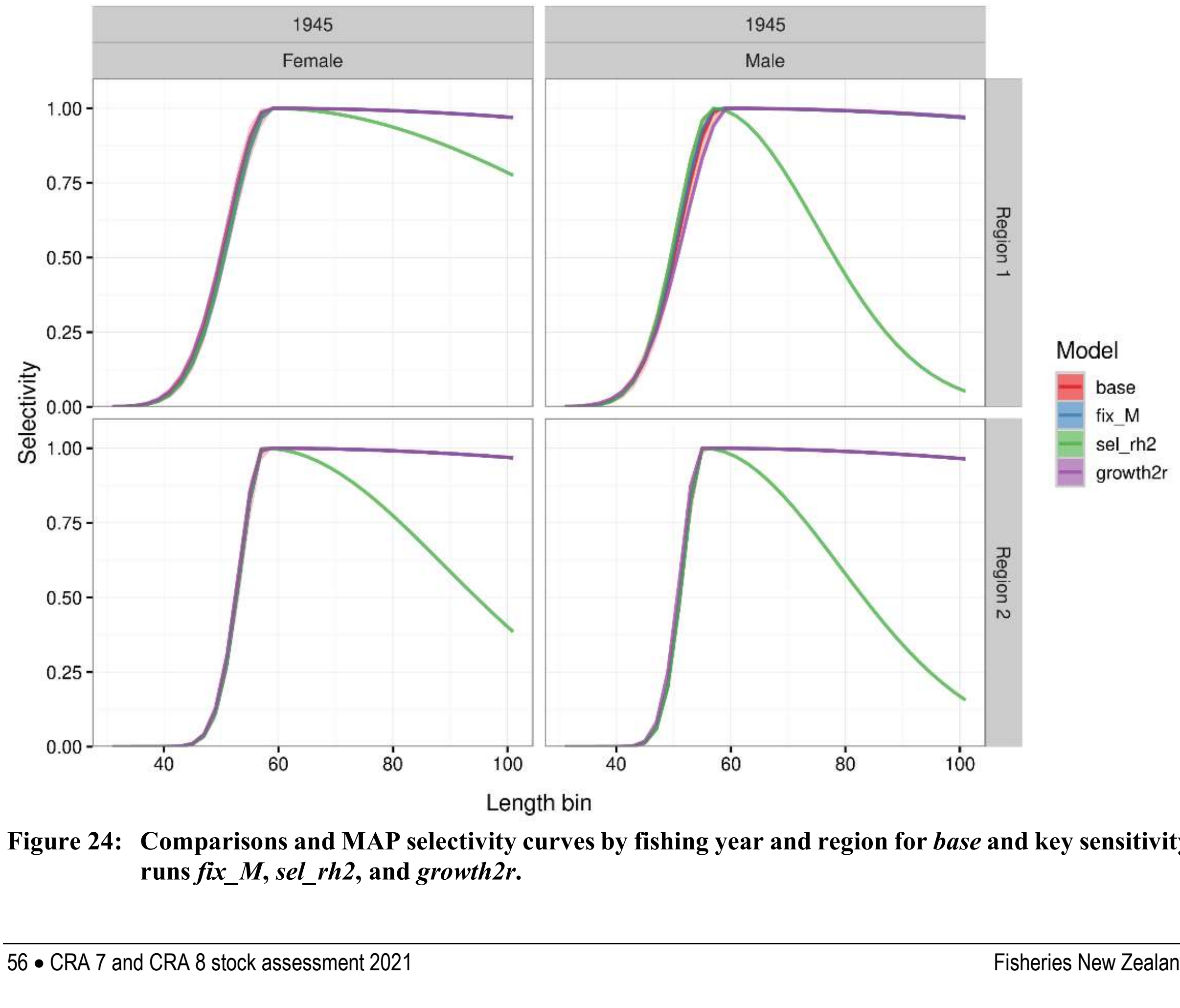


Figure 24: Comparisons and MAP selectivity curves by fishing year and region for *base* and key sensitivity runs *fix_M*, *sel_rh2*, and *growth2r*.

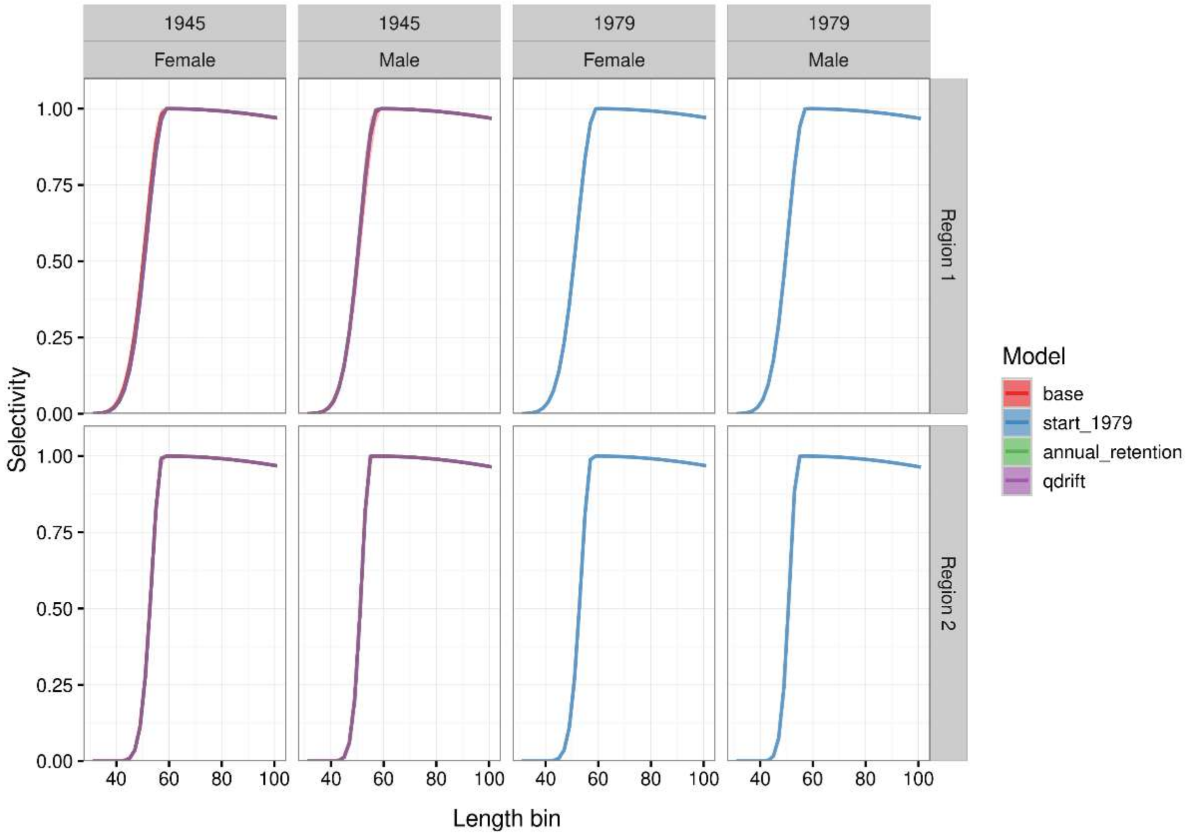


Figure 25: Comparisons and MAP selectivity curves by fishing year and region for *base* and sensitivity runs *start_1979*, *annual retention,* and *qdrift*.

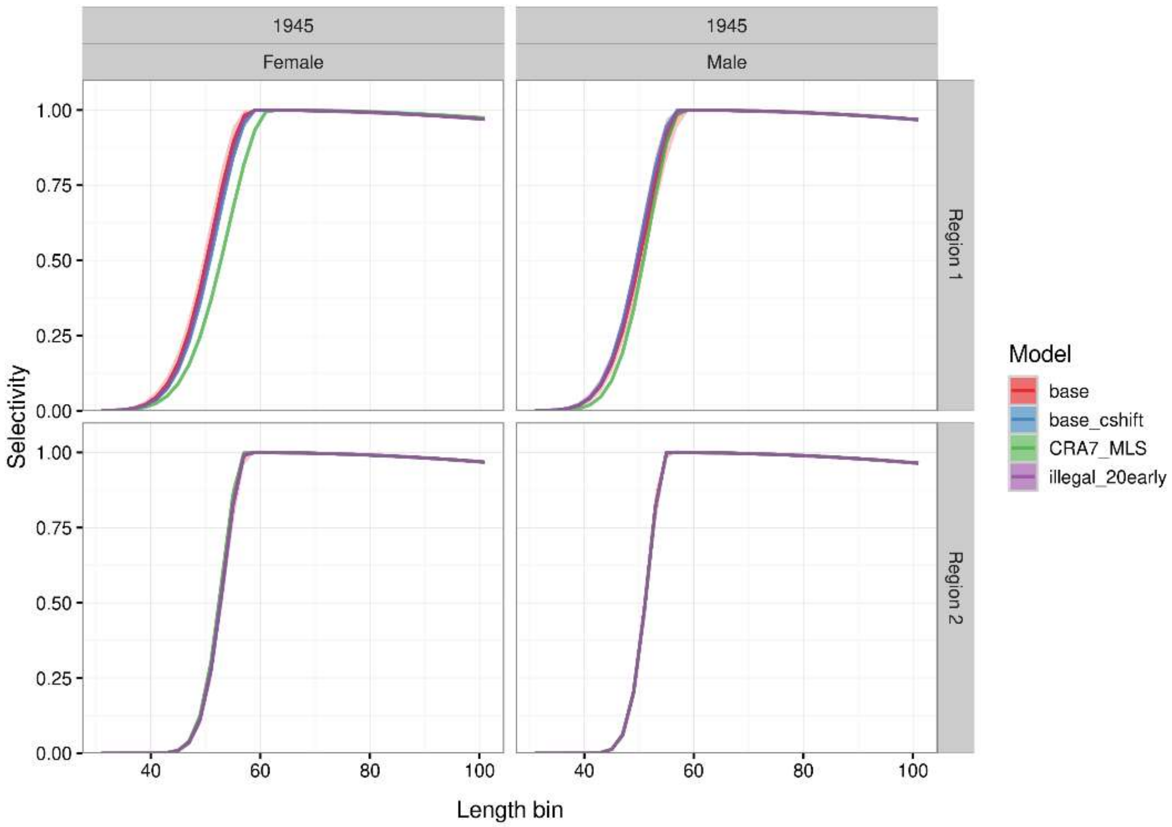


Figure 26: Comparisons and MAP selectivity curves by fishing year and region for *base* and sensitivity runs *base_cshift*, *CRA7_MLS*, and *illegal_20early*.

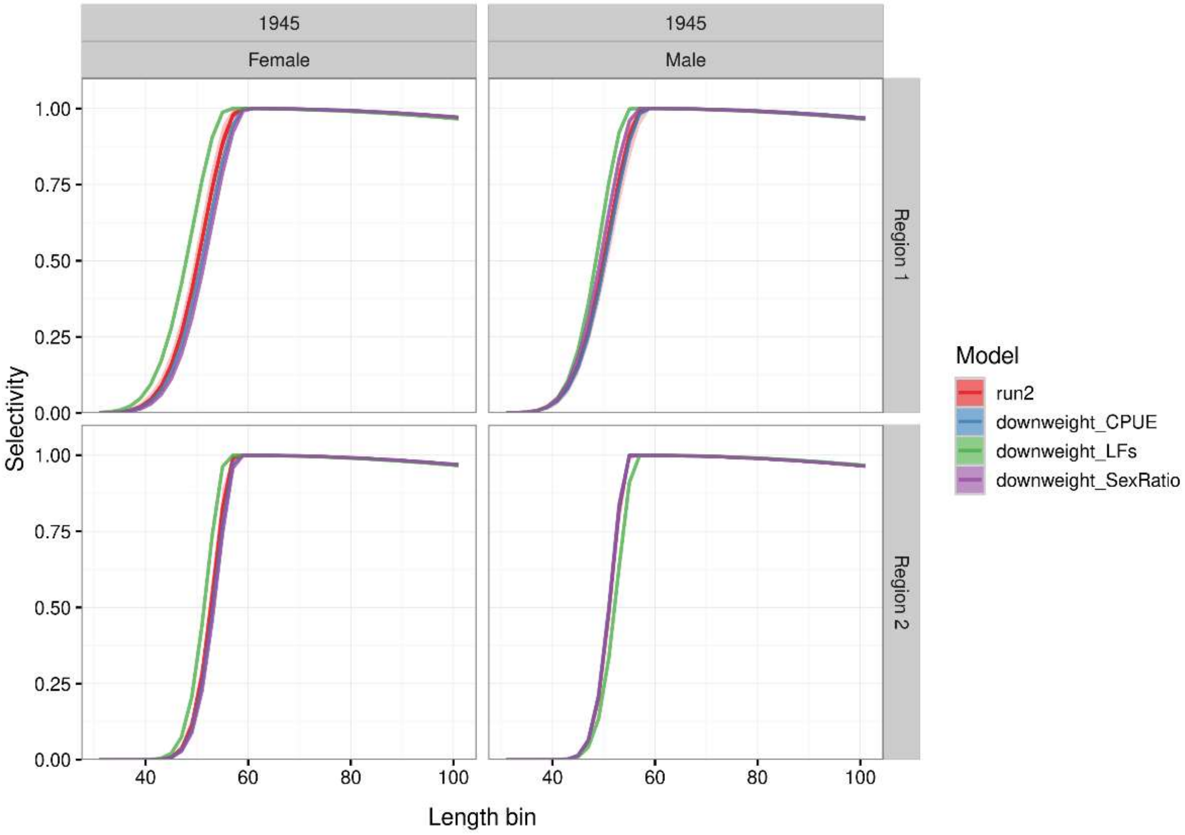


Figure 27: Comparisons and MAP selectivity curves by fishing year and region for *base* and sensitivity runs *downweight_CPUE*, *downweight_LFs*, and *downweight_SexRatio*.

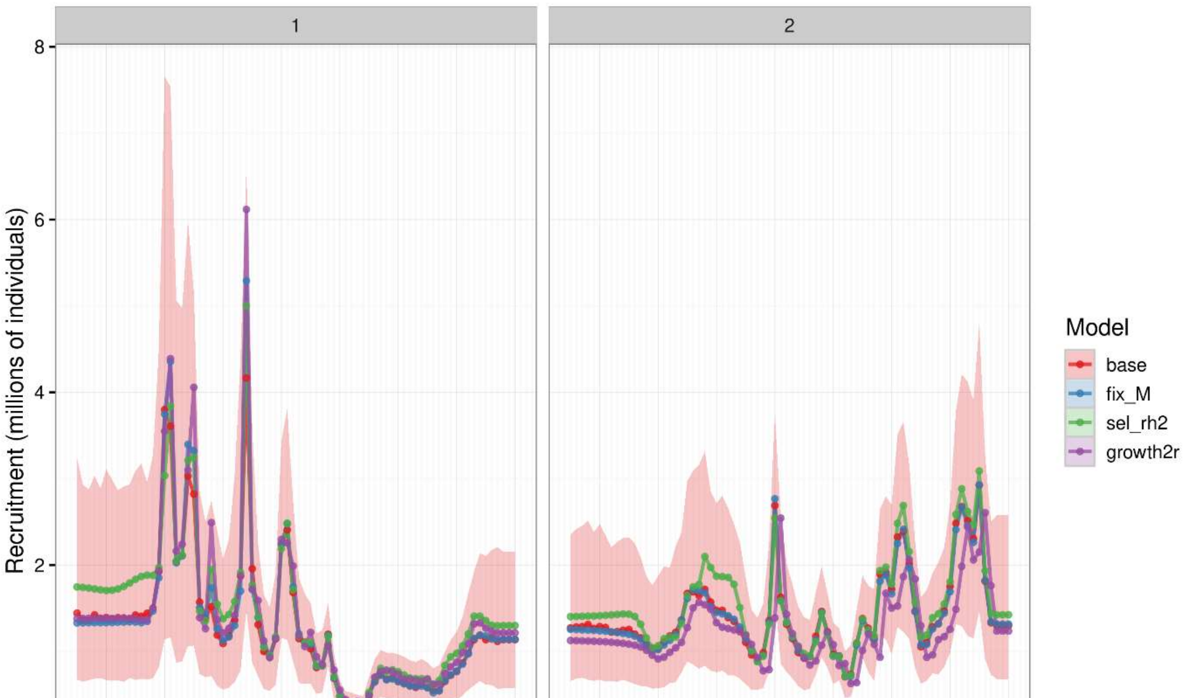


Figure 28: Comparisons of MAP recruitments by fishing year for the *base* run and sensitivity runs *fix_M*, *sel_rh2*, and *growth2r*.

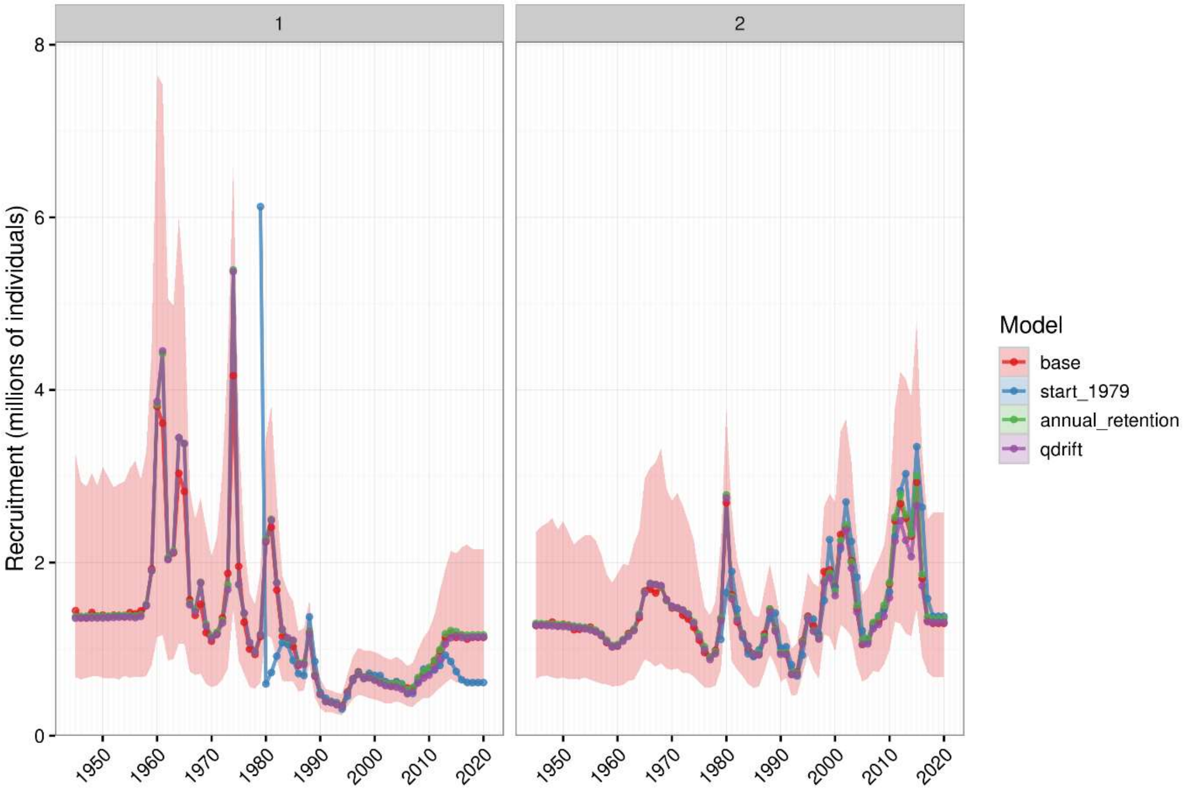


Figure 29: Comparisons of MAP recruitments by fishing year for the *base* run and sensitivity runs *start_1979, annual_retention*, and *qdrift*.

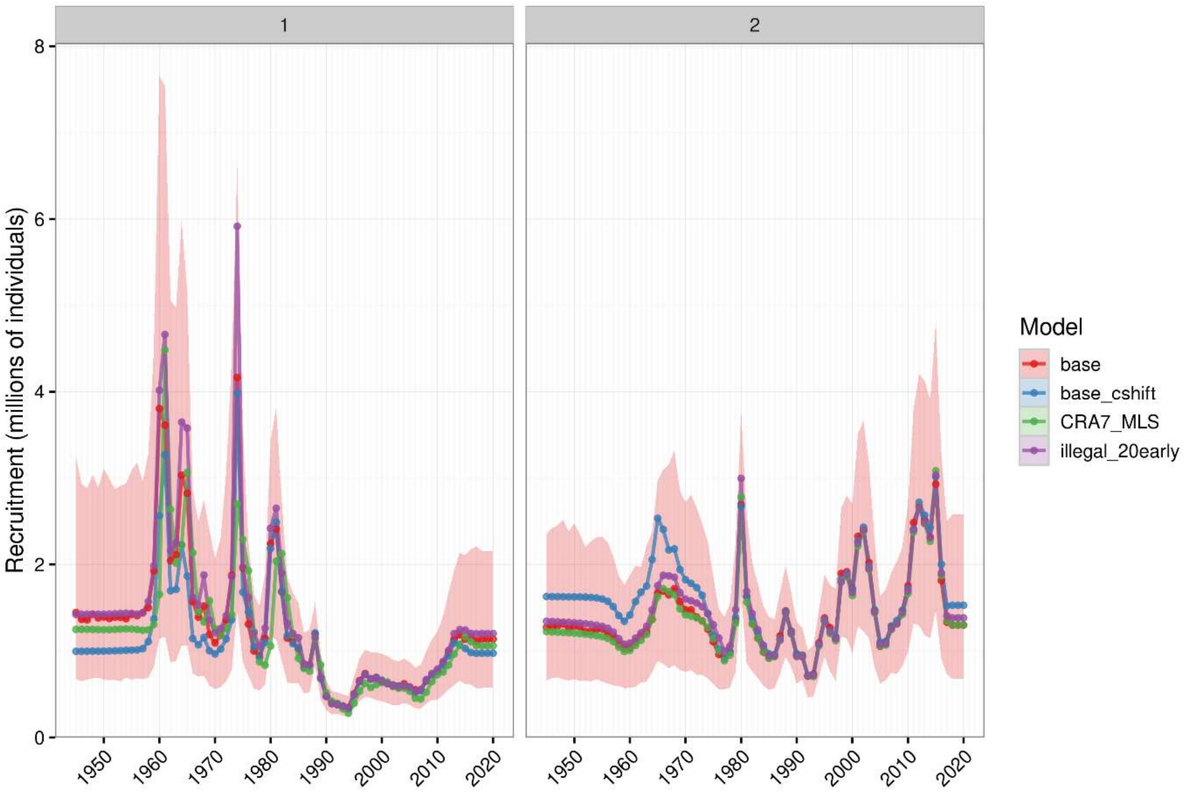


Figure 30: Comparisons of MAP recruitments by fishing year for the *base* run and sensitivity runs *base_cshift*, *CRA7_MLS*, and *illegal_20early*.

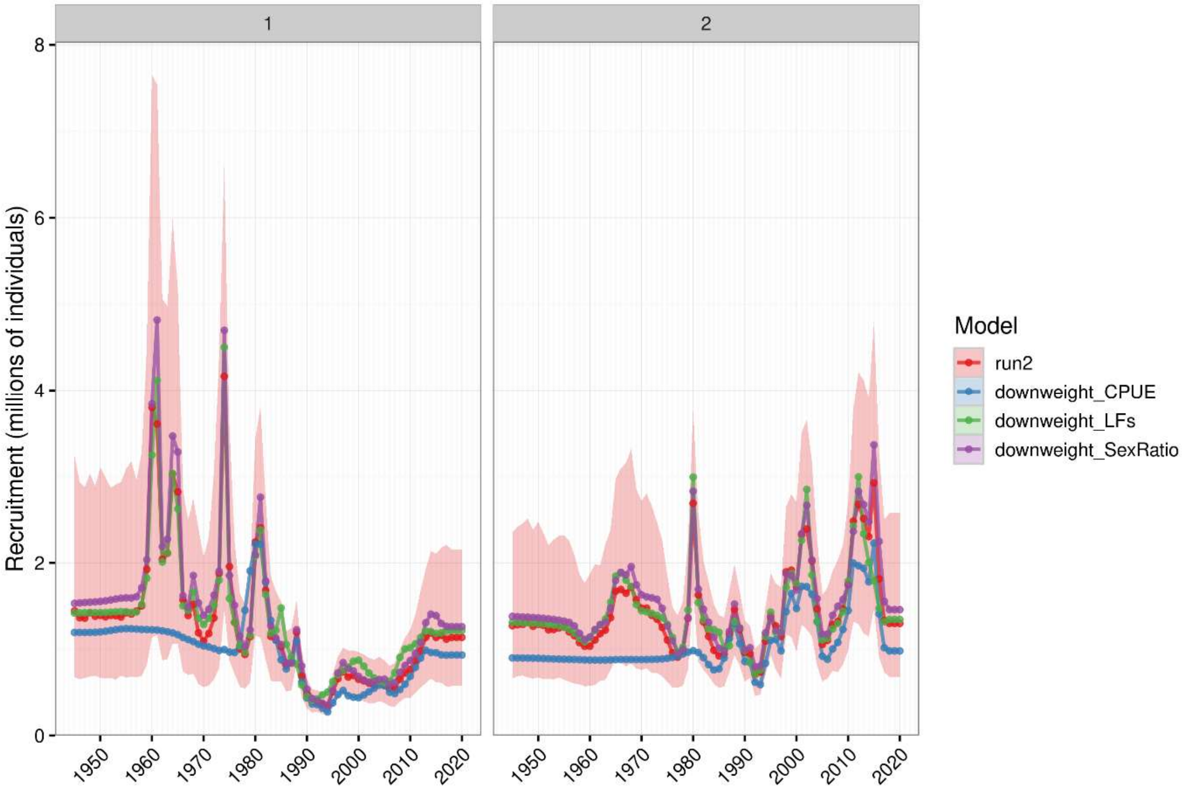


Figure 31: Comparisons of MAP recruitments by fishing year for the *base* run and sensitivity runs *downweight_CPUE, downweight_LFs*, and *downweight_SexRatio*.

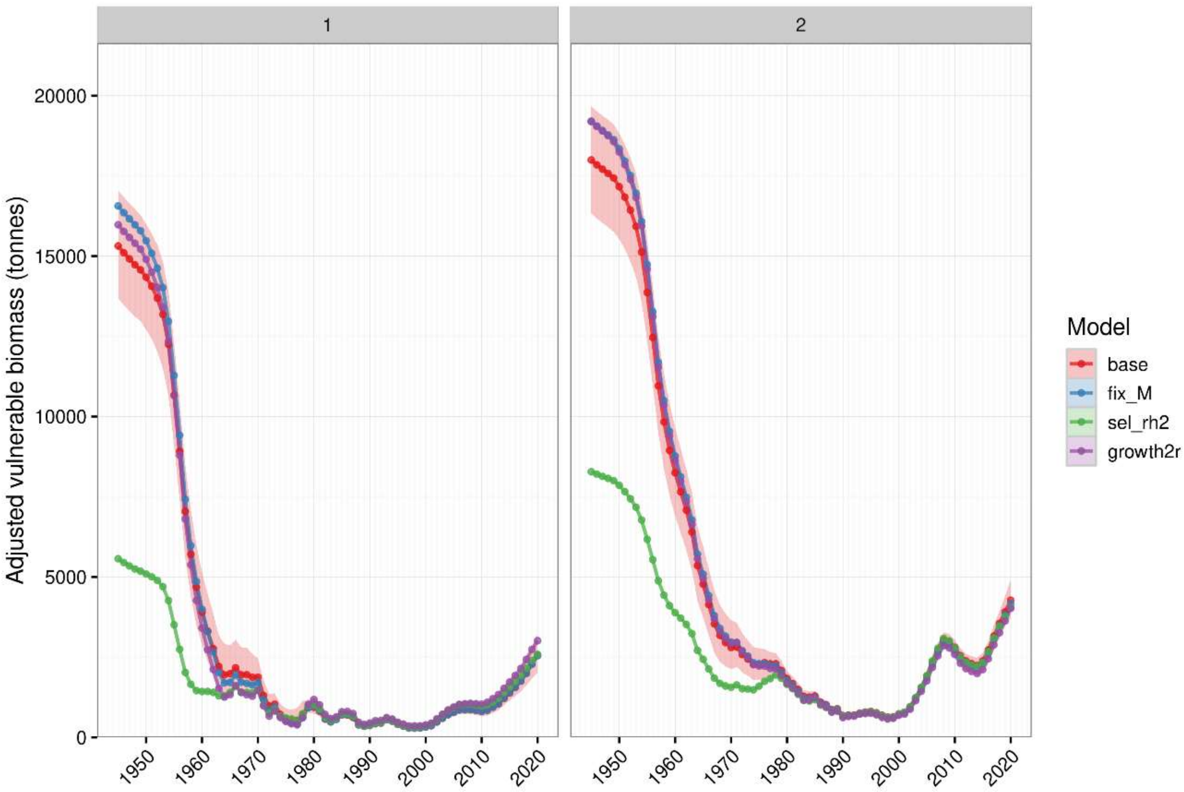


Figure 32: Comparisons of MAP adjusted vulnerable biomass by fishing year for the *base* model and sensitivity runs *fix_M, sel_rh2,* and *growth2r*.

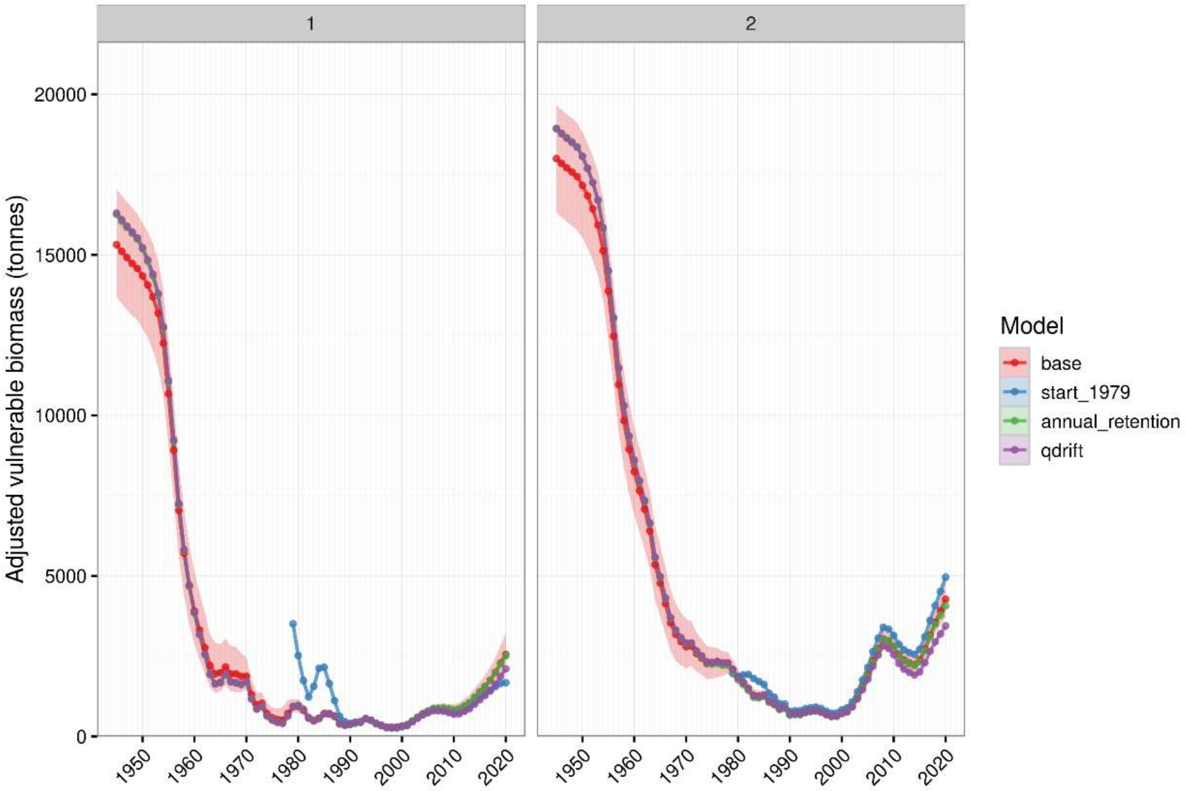


Figure 33: Comparisons of MAP adjusted vulnerable biomass by region and fishing year for the *base* model and sensitivity runs *start_1979, annual_retention*, and *qdrift*.

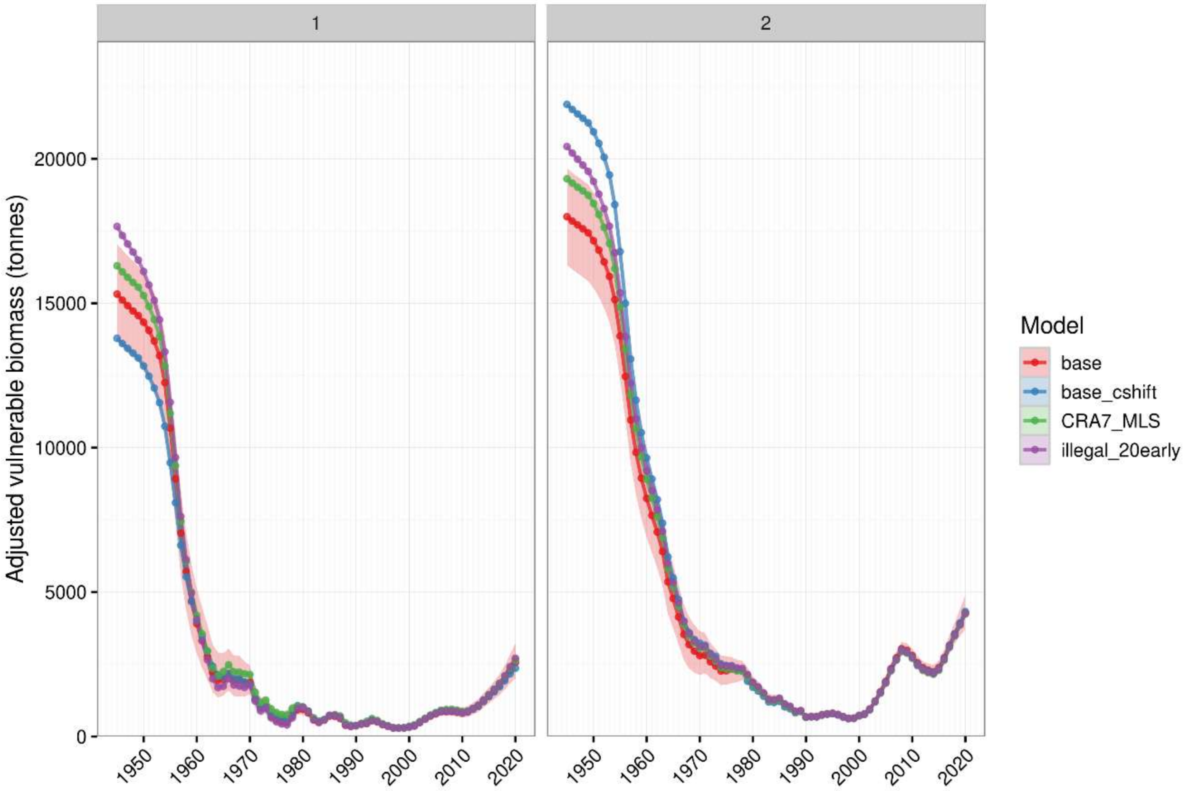


Figure 34: Comparisons of MAP adjusted vulnerable biomass by region and fishing year for the *base* model and sensitivity runs *base_cshift, CRA7_MLS,* and *illegal_20early*.

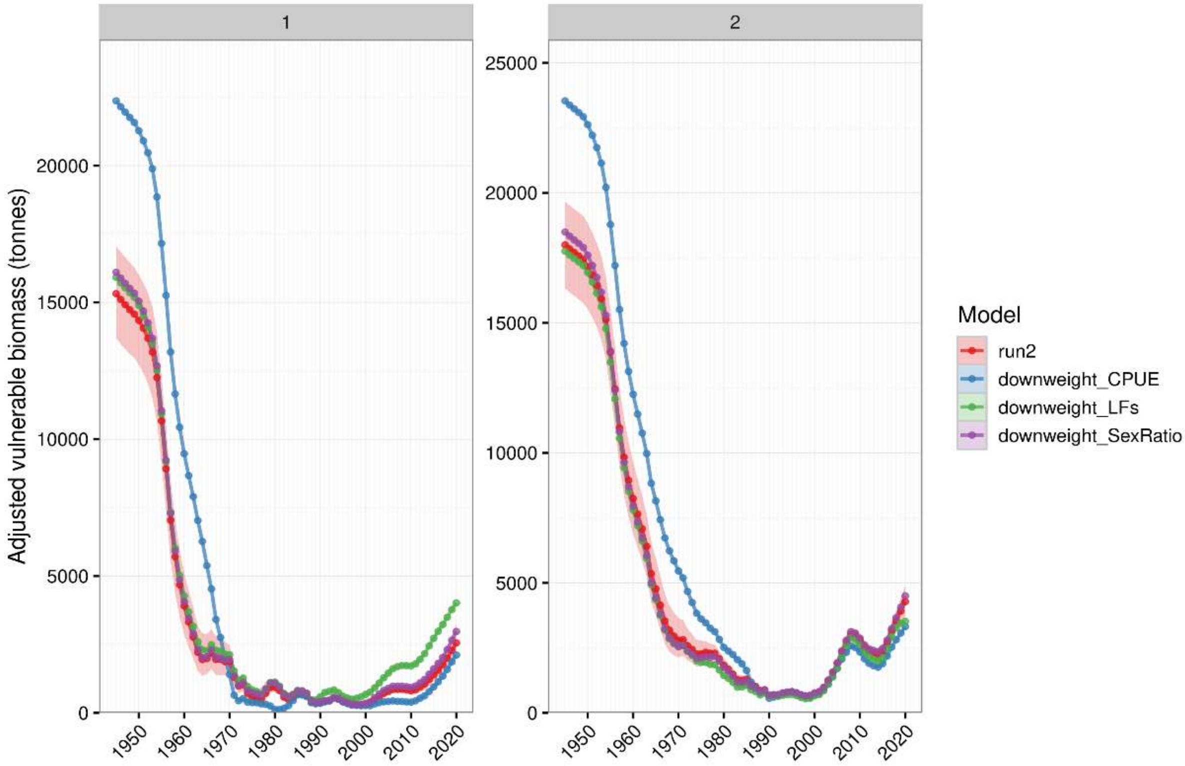


Figure 35: Comparisons of MAP adjusted vulnerable biomass by region and fishing year for the *base* model and sensitivity runs *downweight_CPUE*, *downweight_LFs*, and *downweight_SexRatio*.

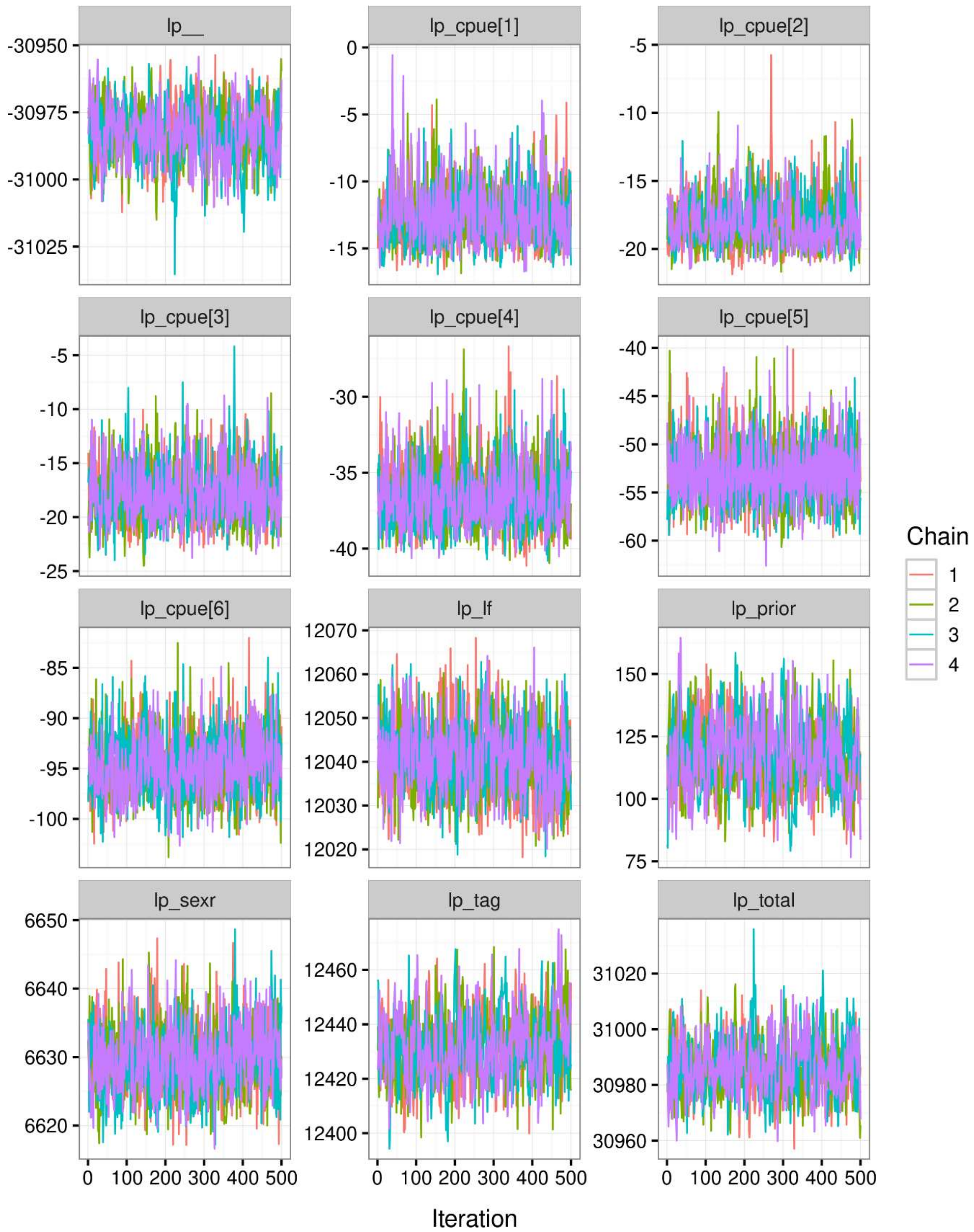


Figure 36: MCMC trace plots by independent chain for likelihood components for the base case model run.

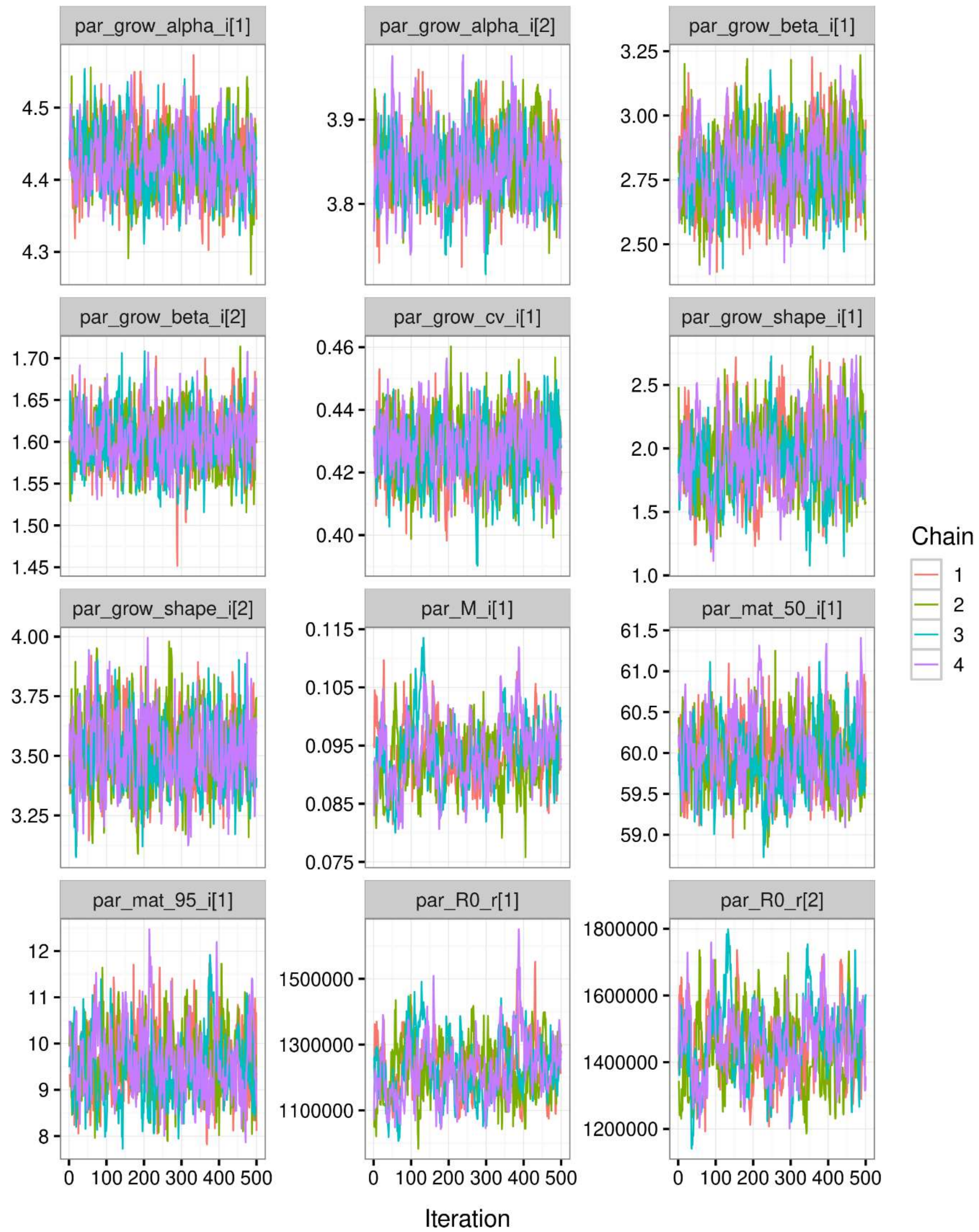


Figure 37: MCMC trace plots by independent chain for growth parameters, maturity parameters, natural mortality (*M*), and the region 2 R_0 parameter for the base case model run.

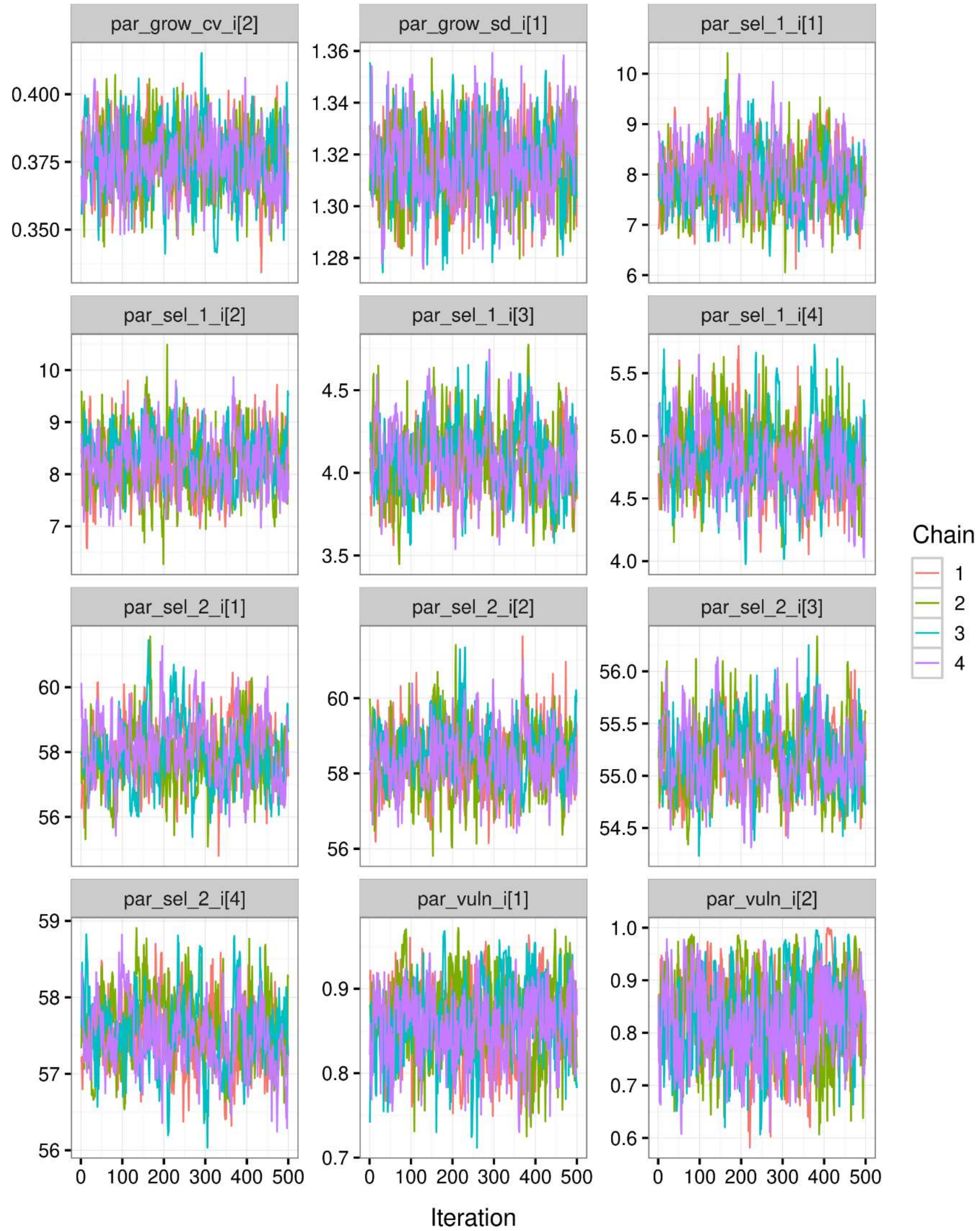


Figure 38: MCMC trace plots by independent chain for selectivity and vulnerability parameters, and one of the growth parameters for the base case model run.

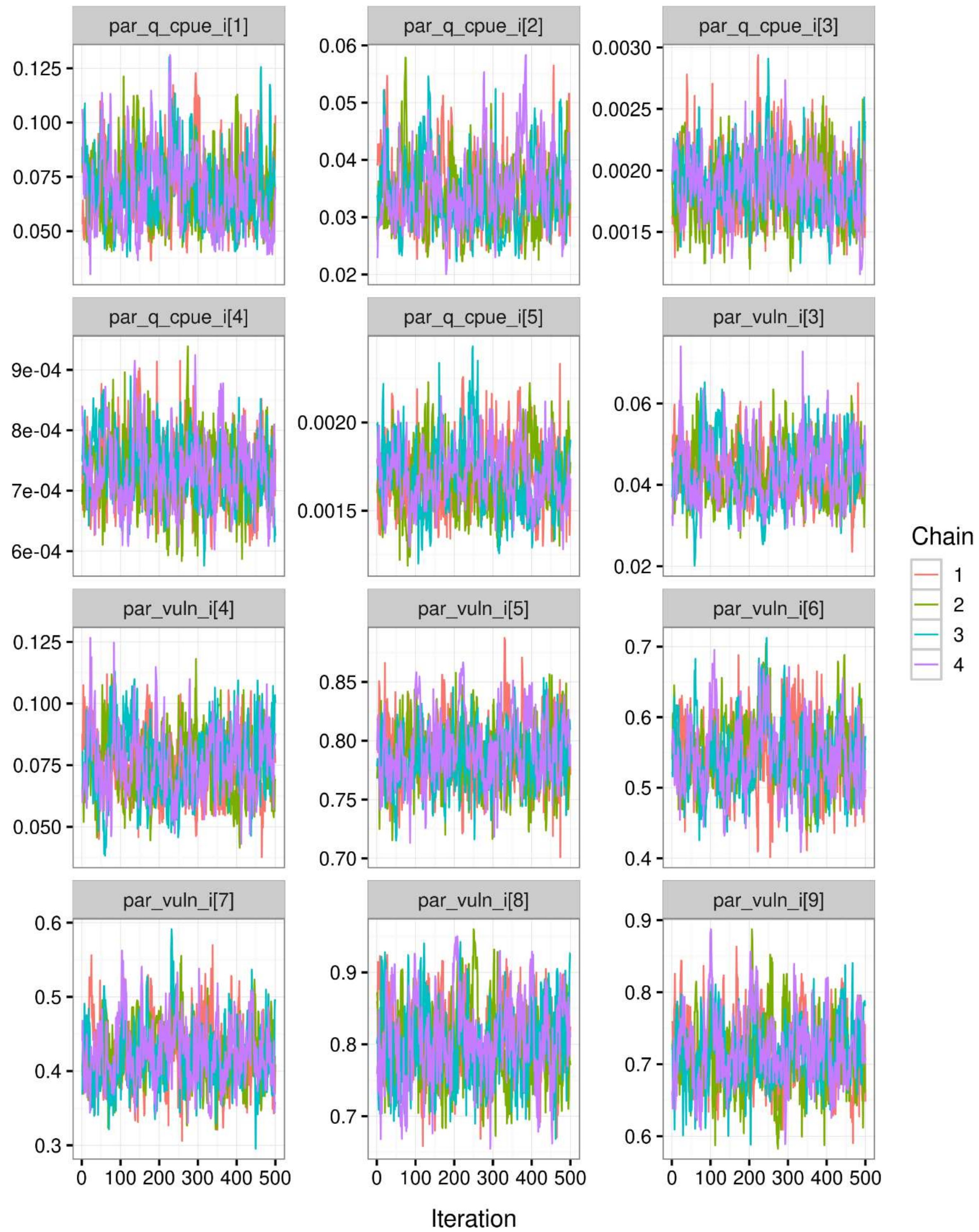


Figure 39: MCMC trace plots by independent chain for remaining vulnerability parameters, and catchability coefficients (*q*) for the <u>base case</u> model run.

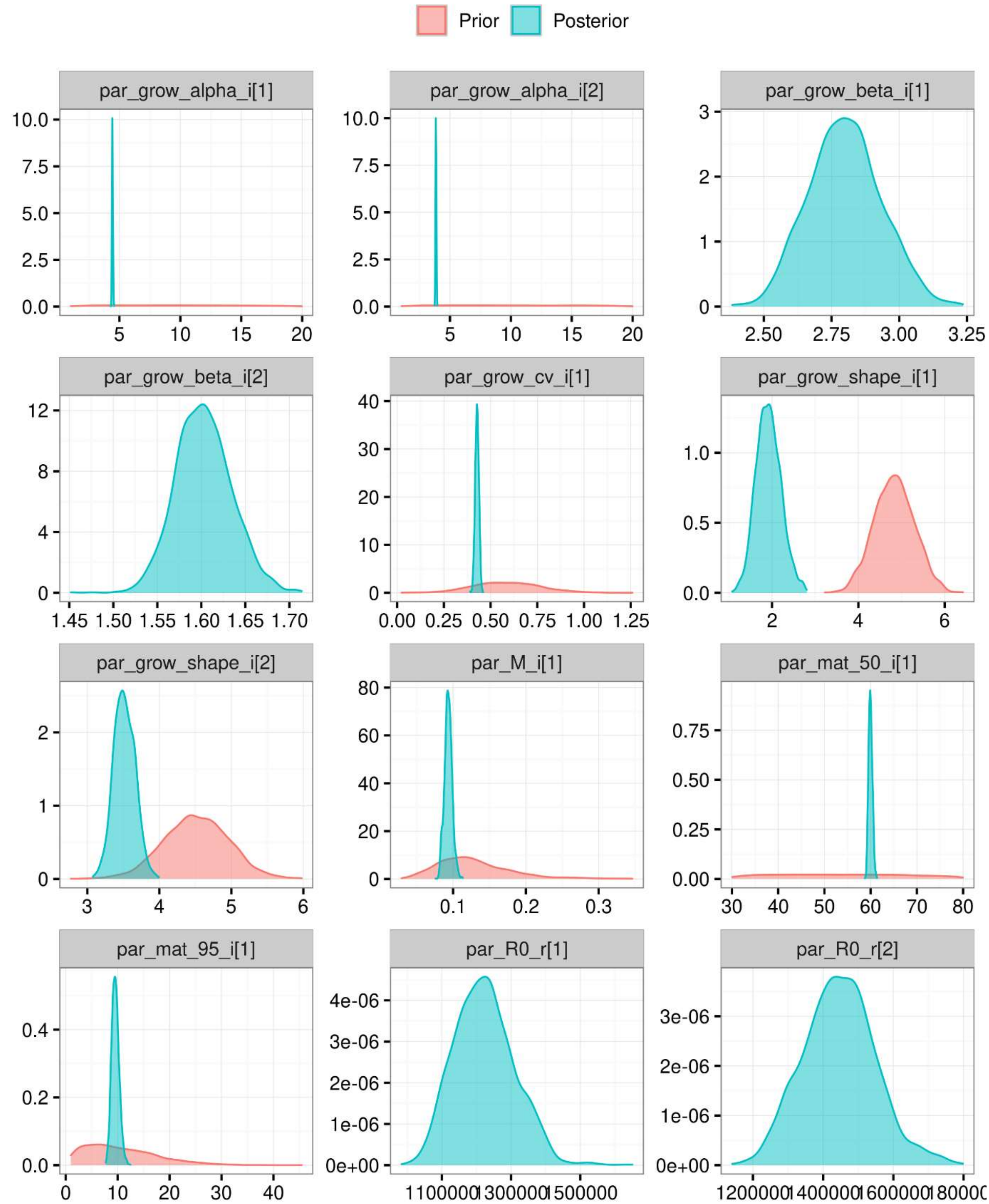


Figure 40: Density plots showing prior (red) and posterior distributions (blue) for growth, natural mortality (*M*), maturity, and average recruitment parameters for the base case model run.

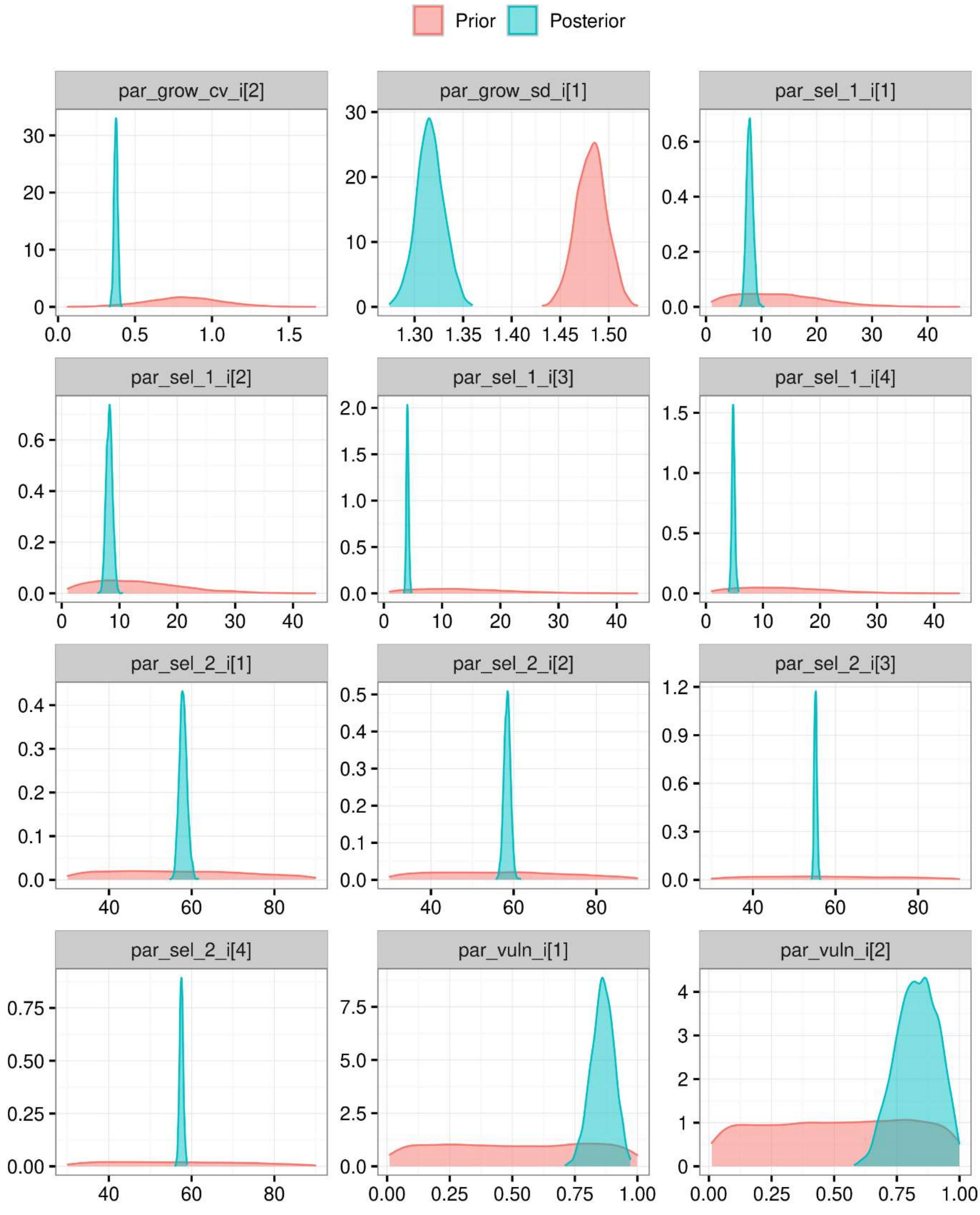


Figure 41: Density plots showing prior (red) and posterior distributions (blue) for growth, selectivity, and vulnerability parameters for the <u>base case</u> model run.

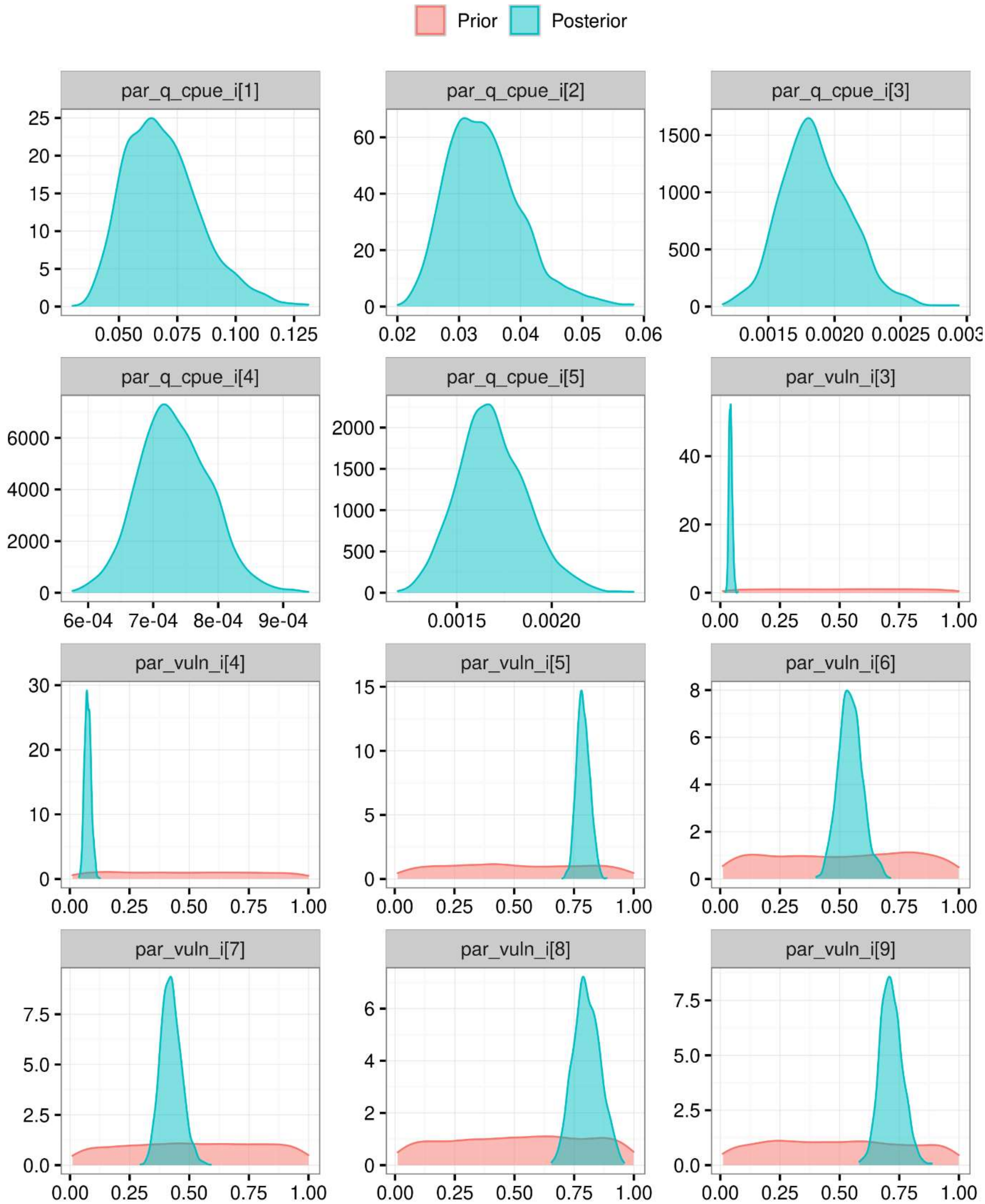


Figure 42: Density plots showing prior (red) and posterior distributions (blue) for catchability and vulnerability parameters for the base case model run.

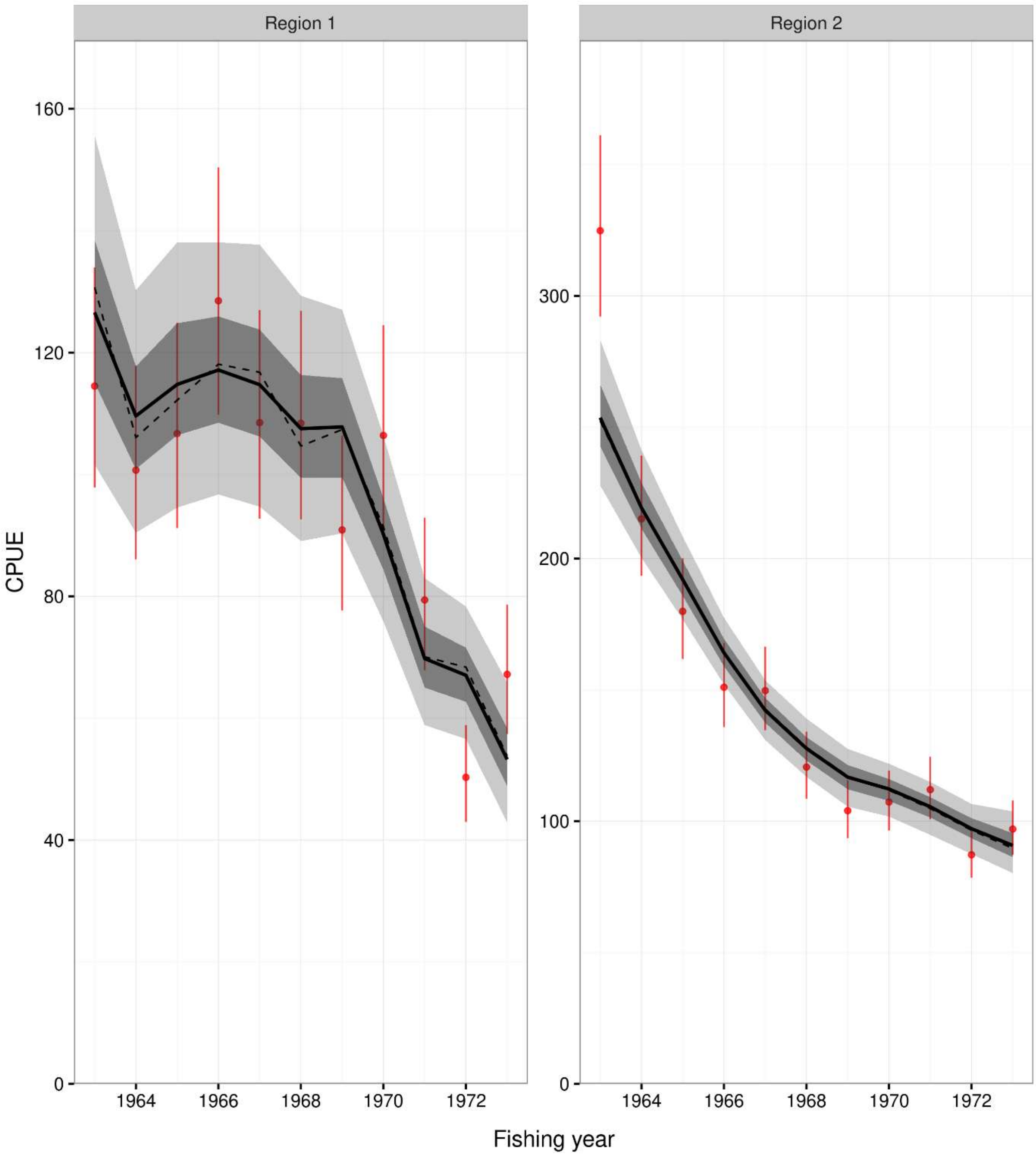


Figure 43: Posterior predicted CPUE compared to the CR CPUE indices by fishing year in the base case model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. A dashed line (often not visible as it is covered by the median line) indicates the corresponding MAP estimates.

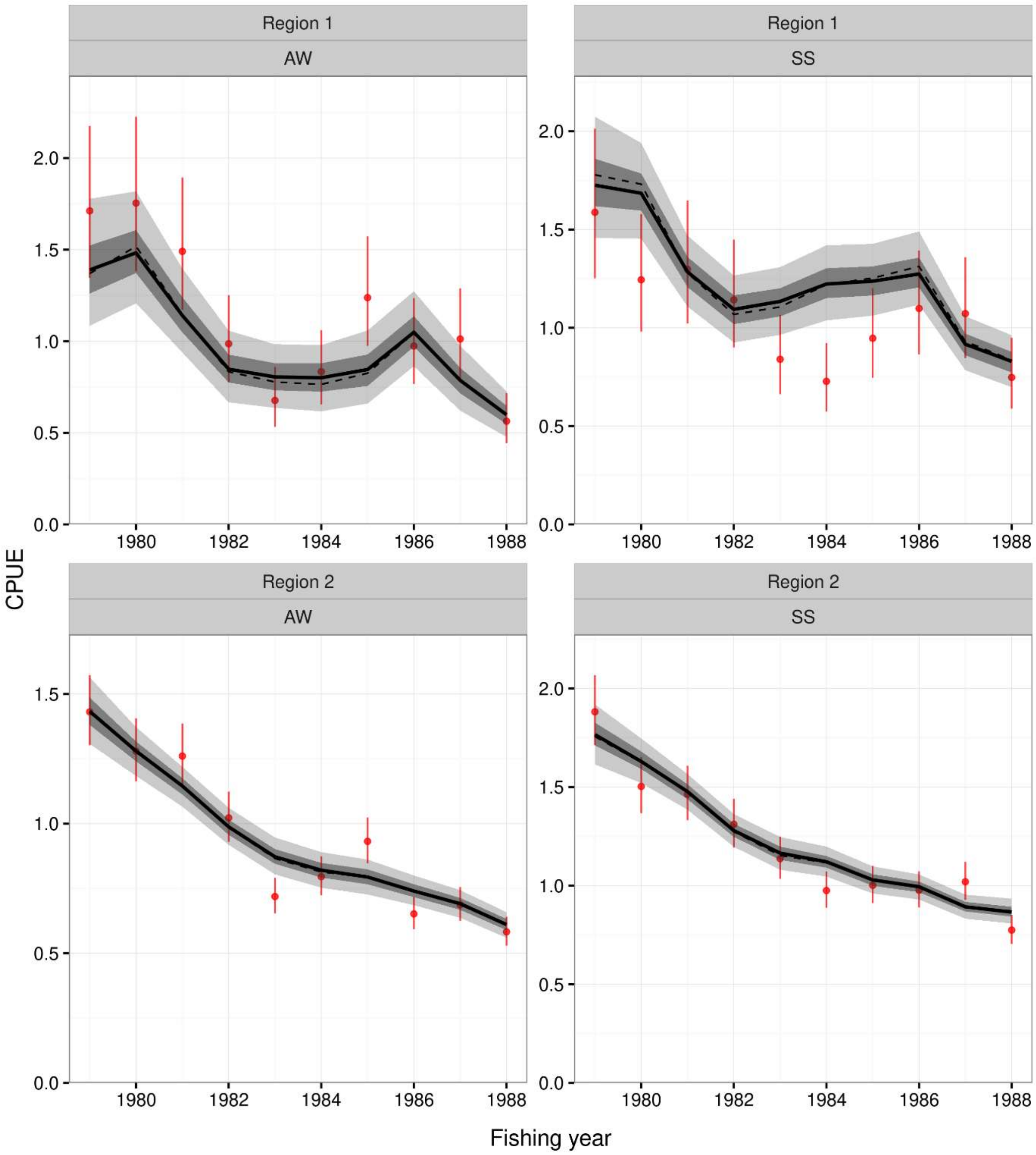


Figure 44: Posterior predicted CPUE compared to the FSU CPUE indices by fishing year, season (AW = autumn/winter, SS = spring/summer), and region in the <u>base case</u> model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. A dashed line (often not visible as it is covered by the median line) indicates the corresponding MAP estimates.

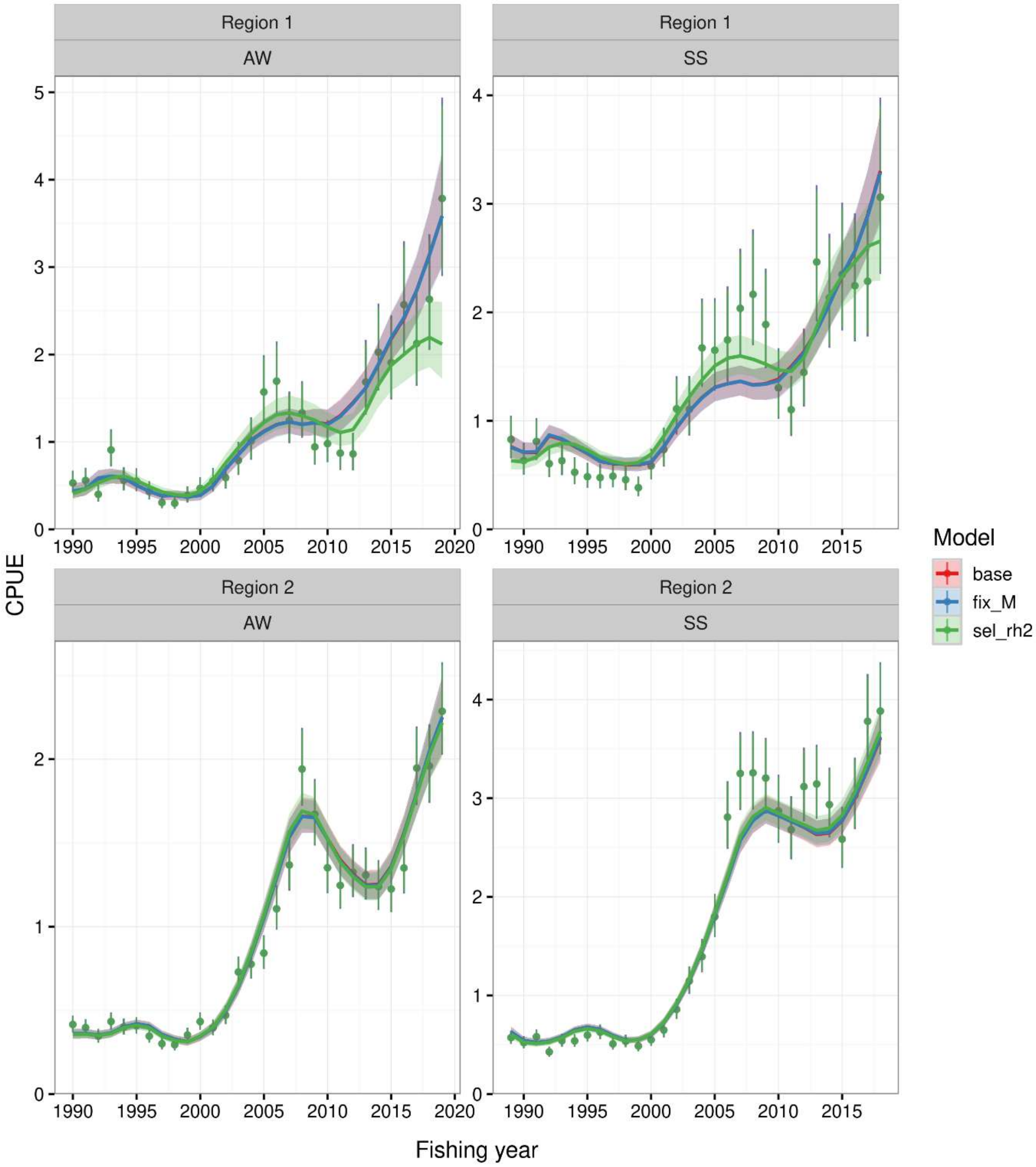


Figure 45: Posterior predicted CPUE compared to the CELR CPUE indices by fishing year, season (AW = autumn/winter, SS = spring/summer), and region in all model runs. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. A dashed line (often not visible as it is covered by the median line) indicates the corresponding MAP estimates.

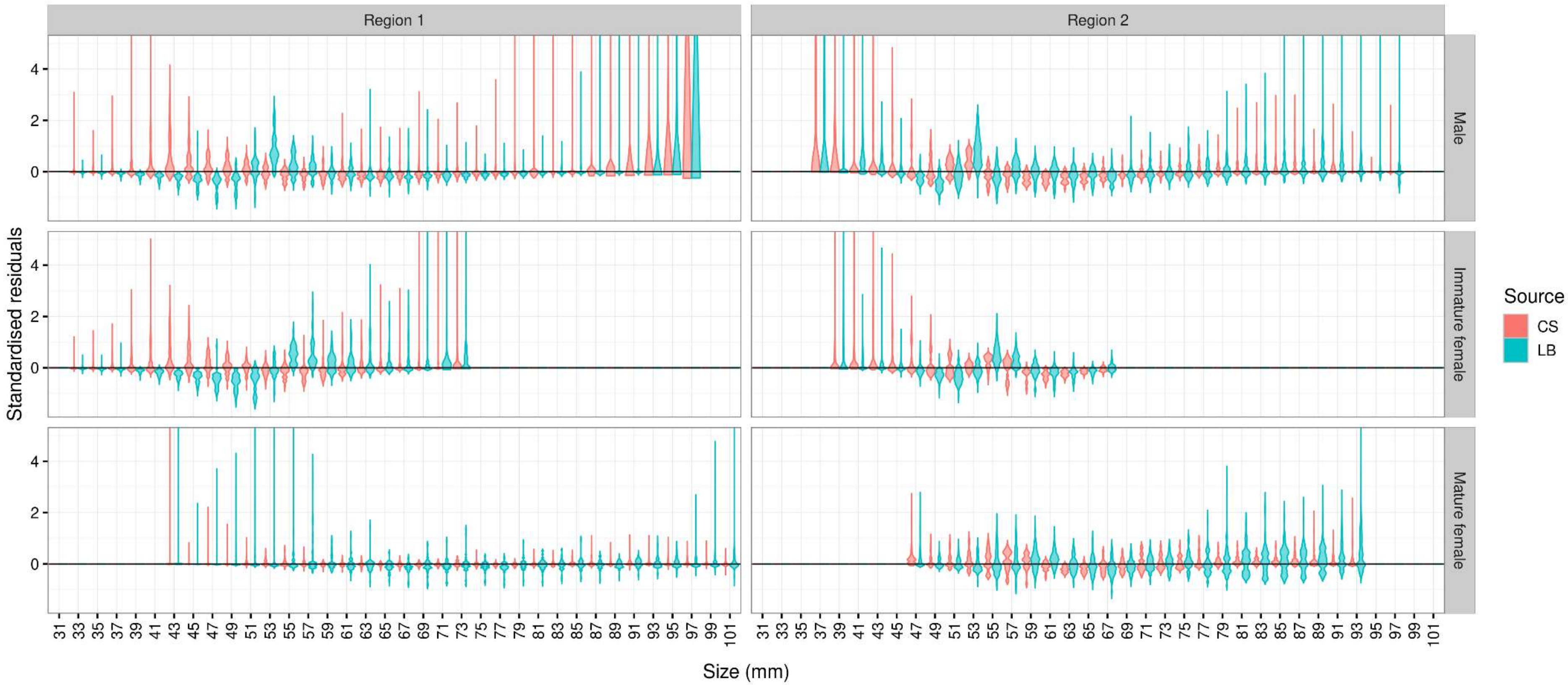


Figure 46: Posterior distribution of standardised residuals from fits to the LF data by region, sex, 2 mm TW bin, and sampling source (CS = catch sampling, LB = logbook).

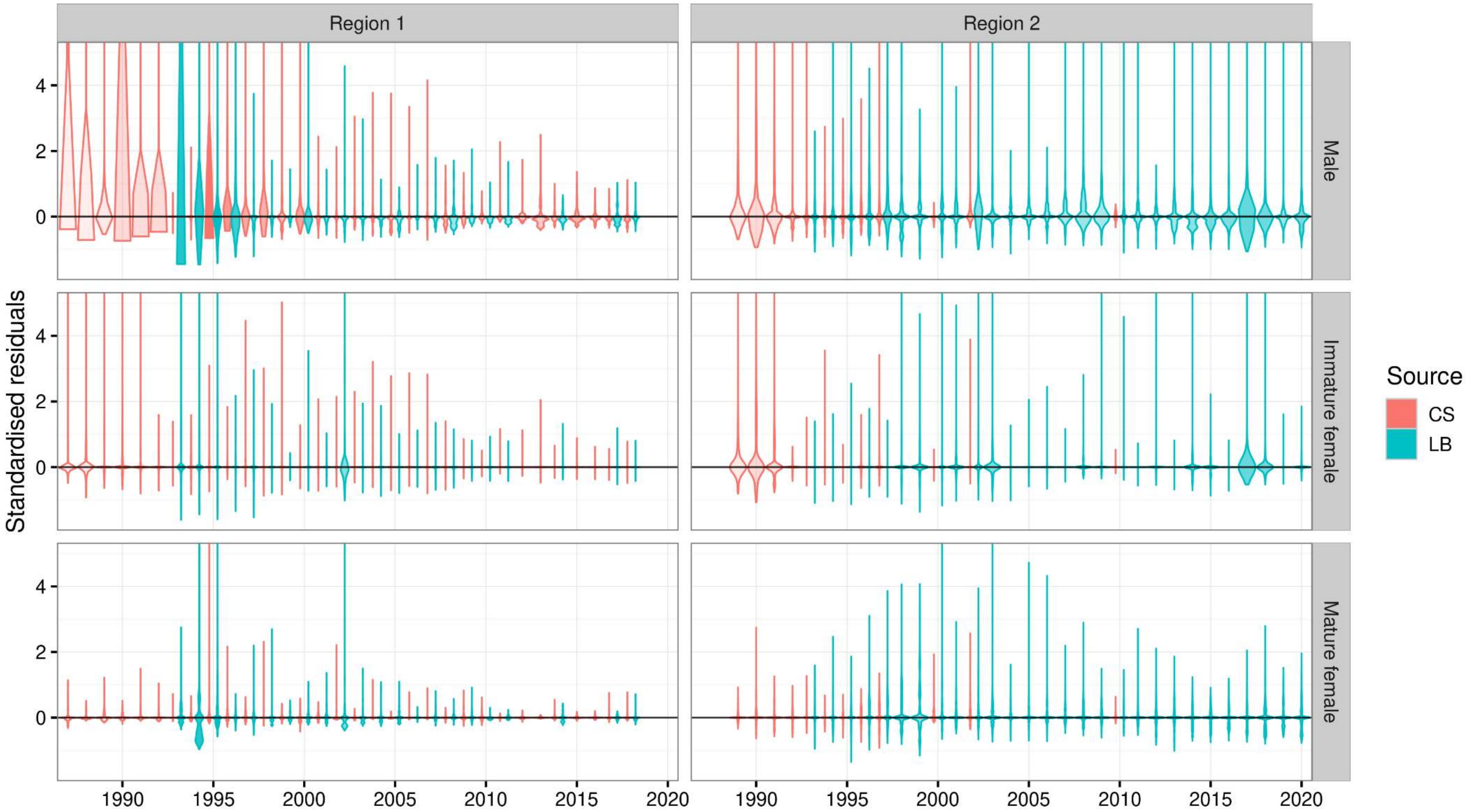


Figure 47: Posterior distribution of standardised residuals from fits to the LF data by region, sex, fishing year, and sampling source (CS = catch sampling, LB = logbook).

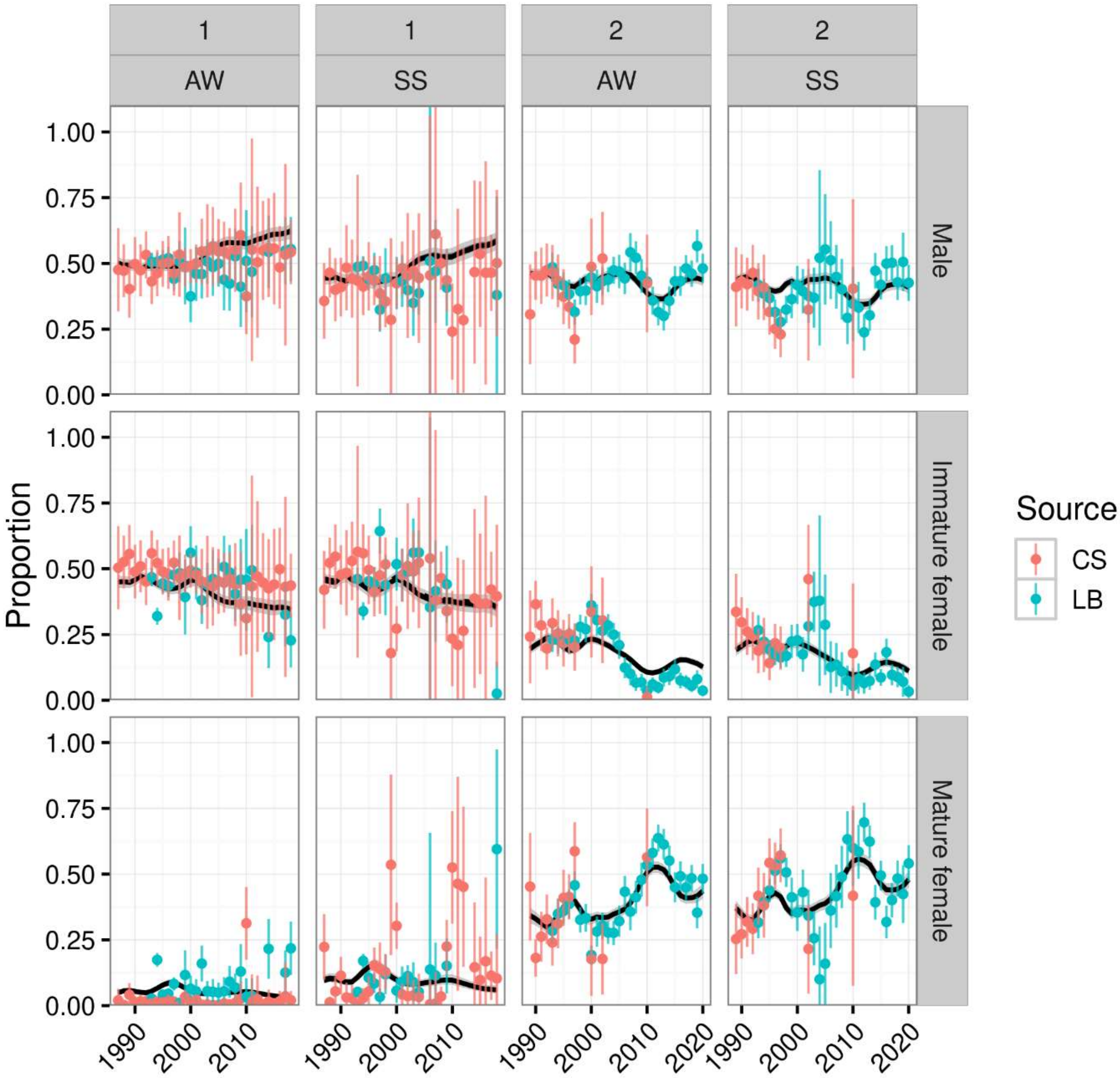


Figure 48: Posterior distribution of the sex ratios compared to the observed sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer), region (1 = region 1, 2 = region 2), sex, and LF data source (CS = catch sampling, LB = logbook) in the base case model run. The solid line indicates the posterior median and grey shading indicates the 90% credible intervals.

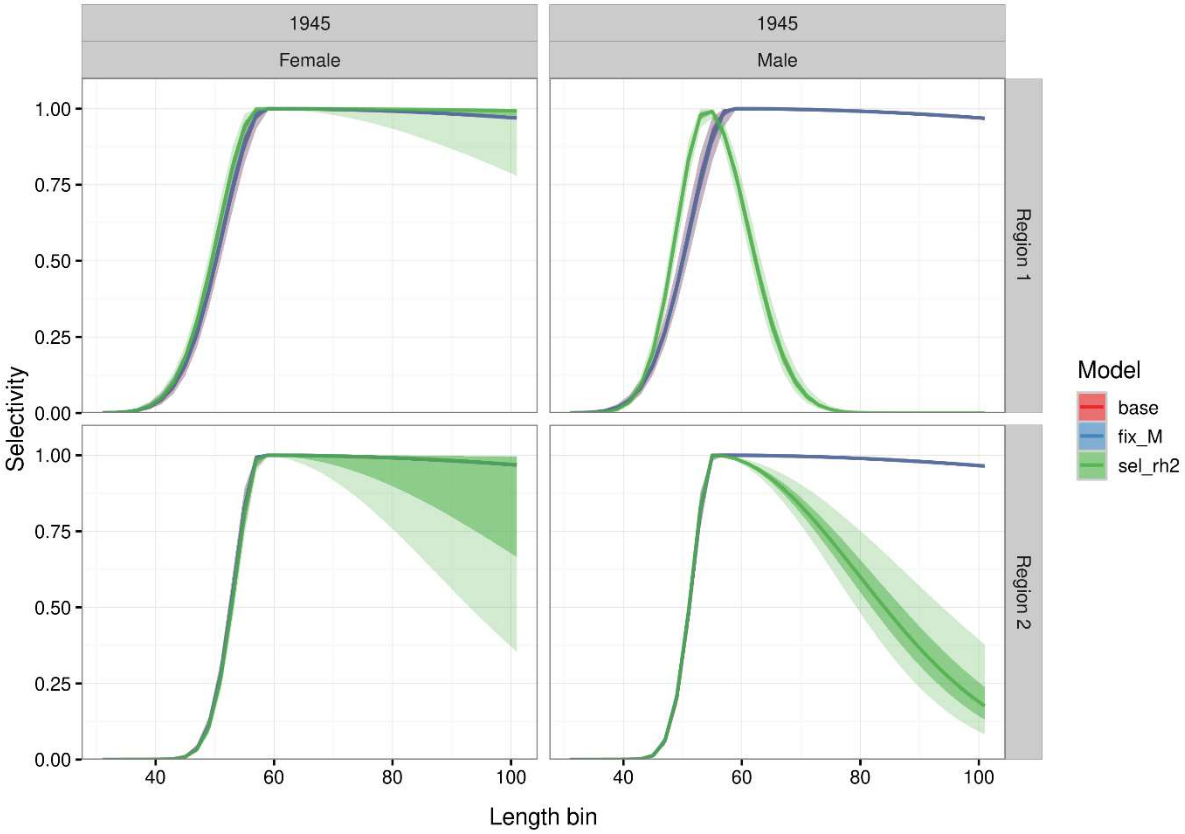


Figure 49: Posterior distribution of selectivity by sex, size, and region comparing the *base case* with sensitivities *fix_M* and *sel_rh2* (estimating dome-shaped selectivity). The solid line indicates the posterior median and shading indicates the 90% credible intervals.

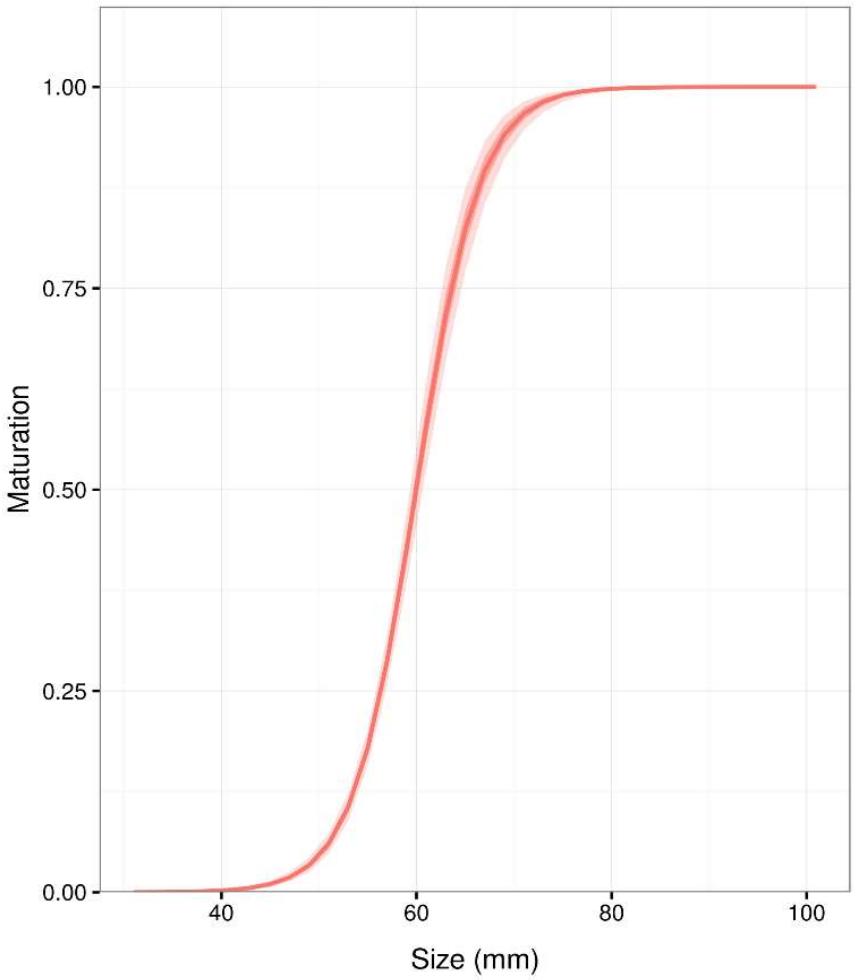


Figure 50: Posterior distribution of female maturation curve by size in the base case model run. The solid line indicates the posterior median and red shading indicates the 90% credible intervals.

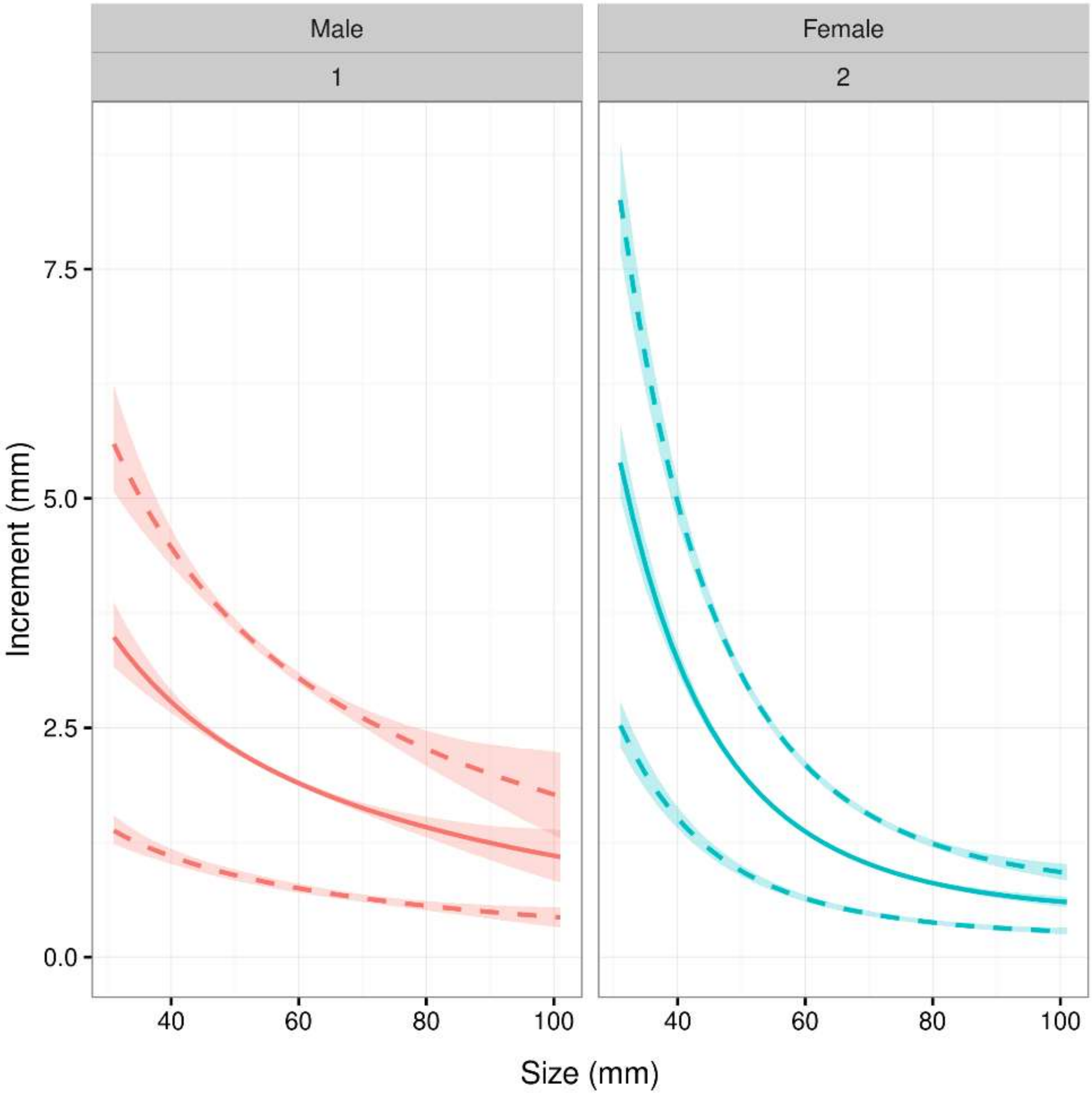


Figure 51: Posterior distribution of predicted 6-monthly growth increment by size and sex in the base case model run showing the mean (solid line), ±1 standard deviation (dashed line). Shading shows 90% credible interval.

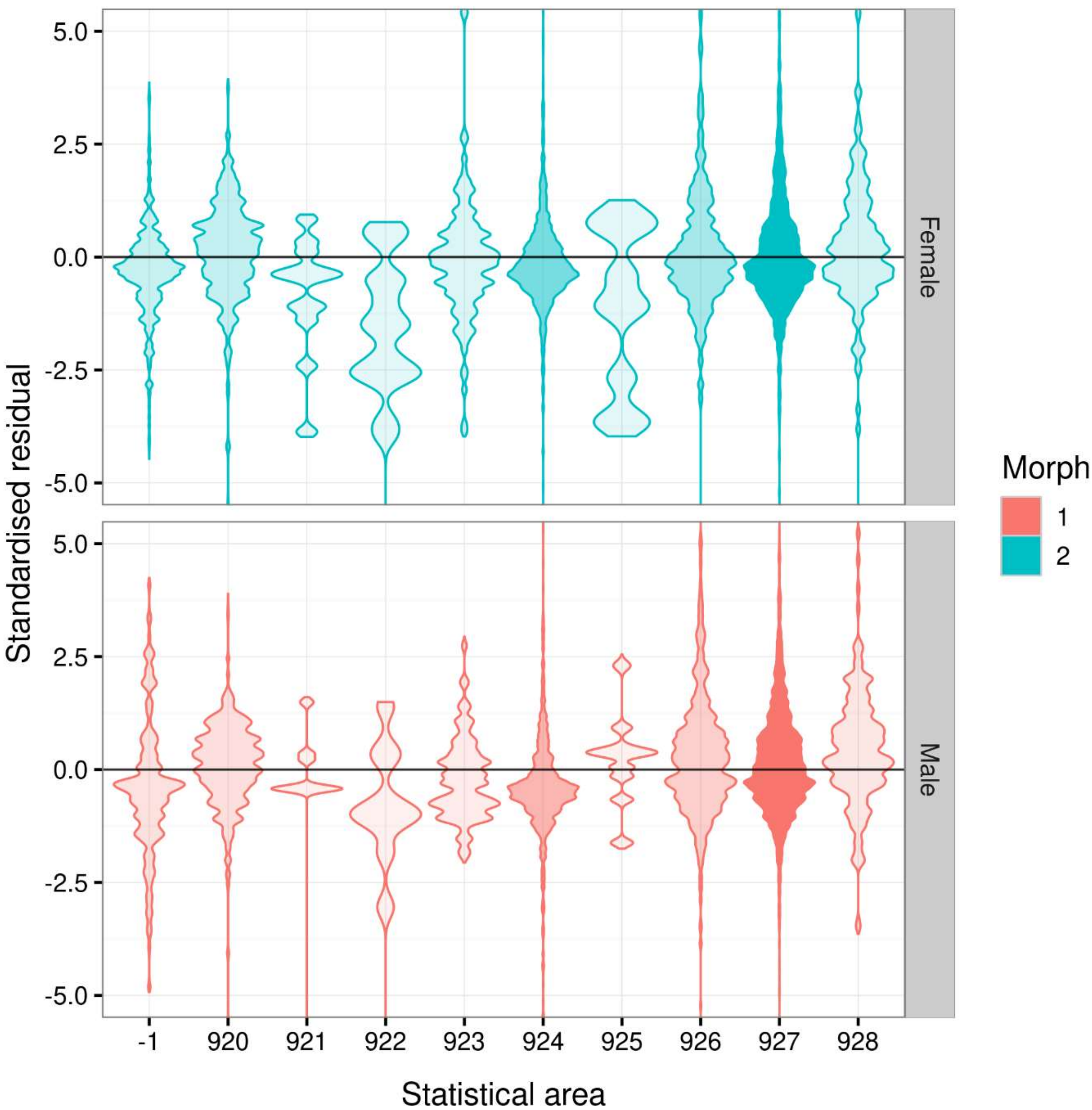


Figure 52: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release and sex in the base case model run. Shading intensity varies with number of observations.

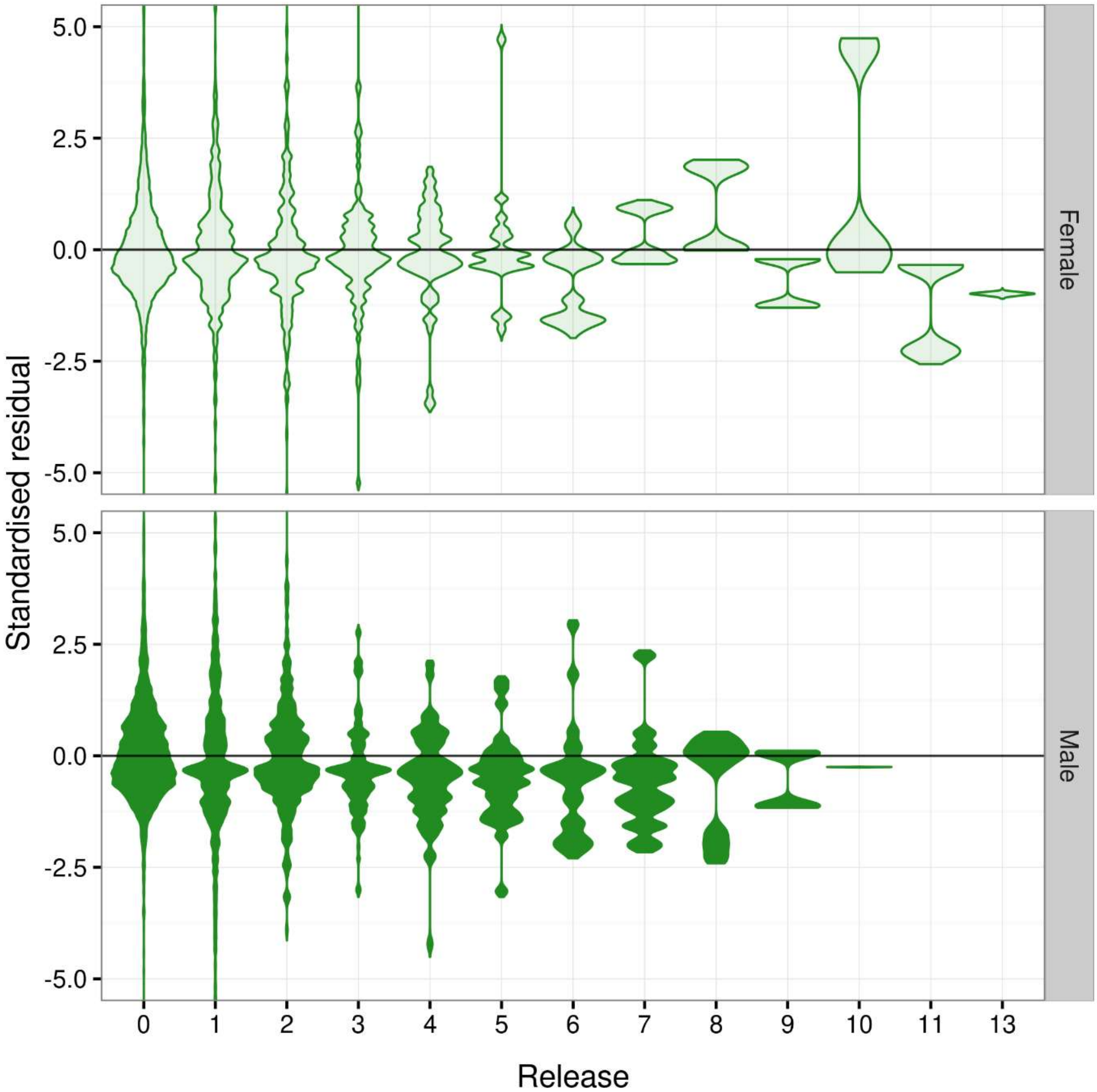


Figure 53: Posterior distribution of standardised residuals from model fit to the tag data by number of times released and sex in the base case model run. Shading intensity varies with number of observations.

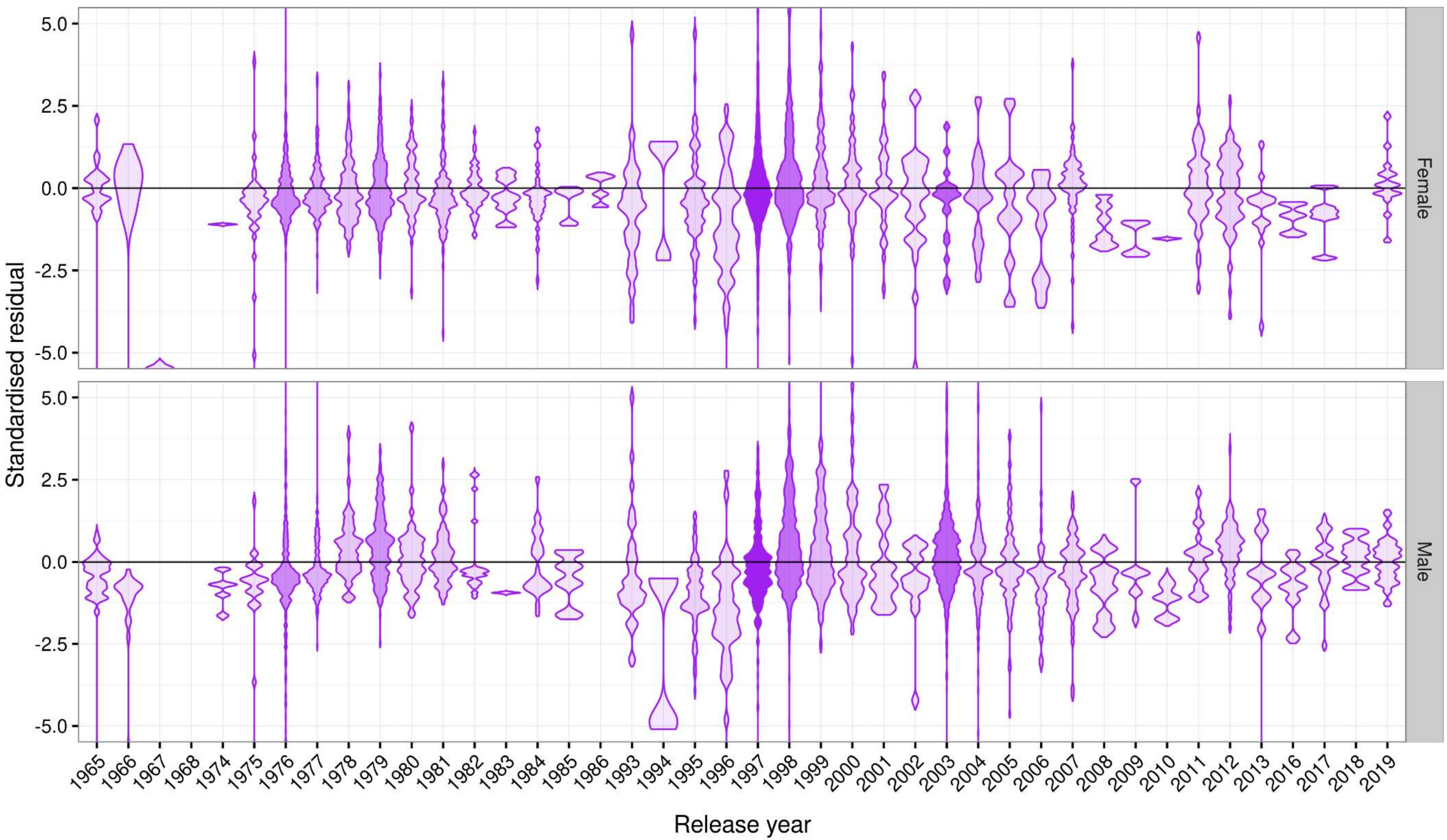


Figure 54: Posterior distribution of standardised residuals from model fit to the tag data by fishing year of release and sex in the <u>base case</u> model run. Shading intensity varies with number of observations.

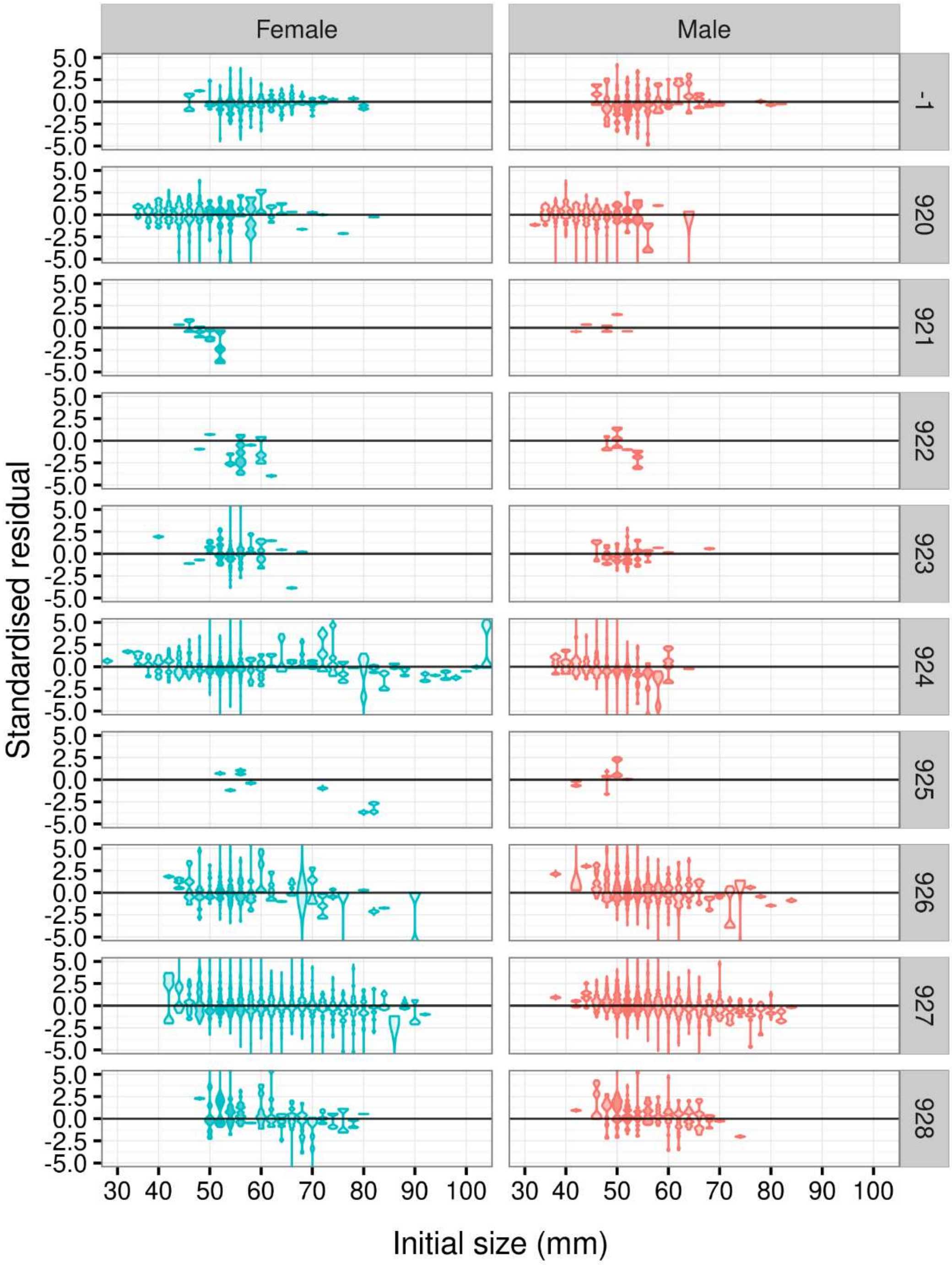


Figure 55: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release, initial size, and sex in the base case model run. Shading intensity varies with number of observations. '-1' indicates an unknown statistical area.

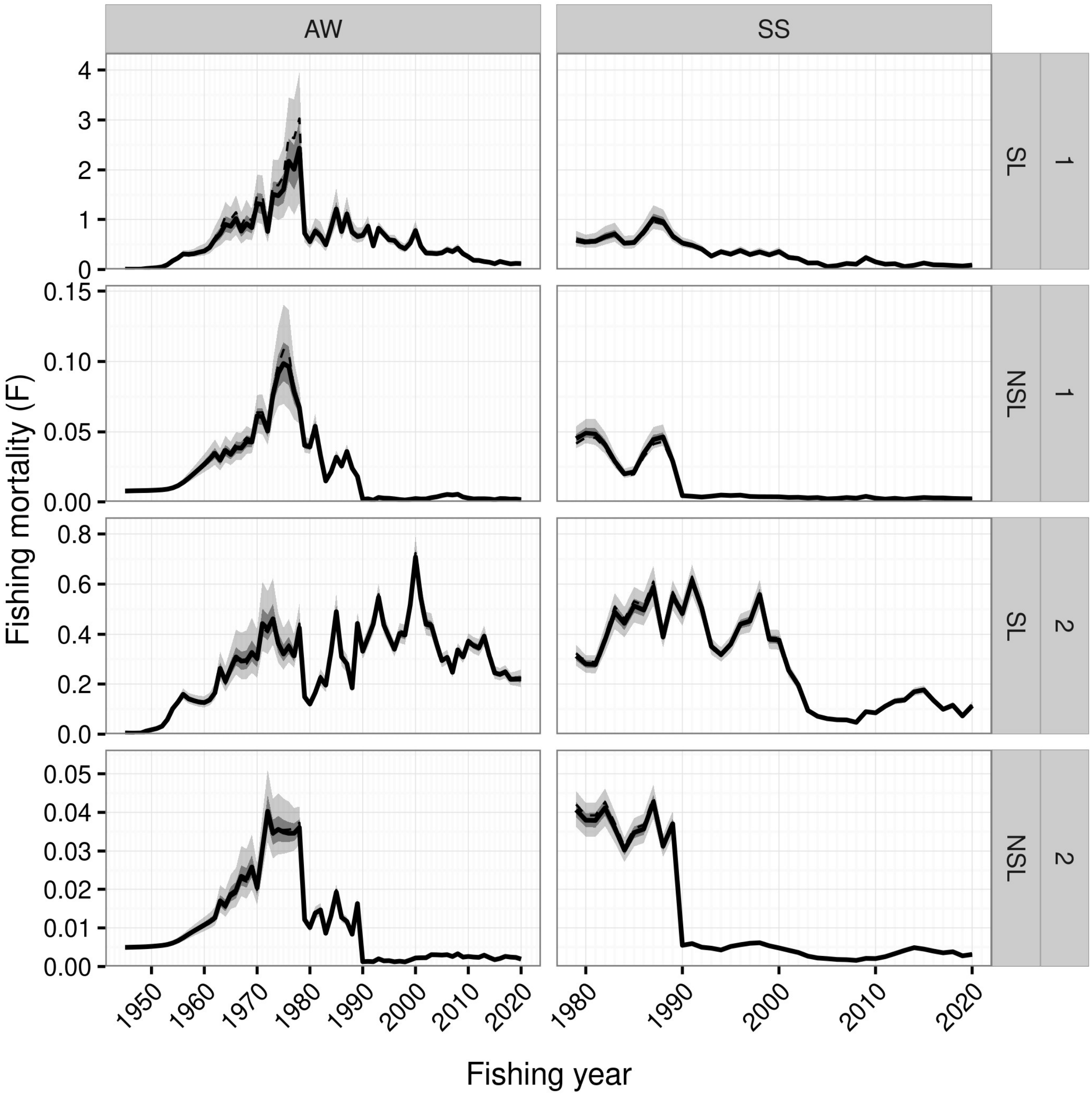


Figure 56: Posterior distribution of fishing mortality by year, season, region, and fishery (SL = size limited; NSL = non size limited) for the <u>base case</u> model run. The dashed black line (not always visible) indicates the MAP, the solid black line indicates the median of the posterior and variable shading intensity indicating the 50% and 90% credible intervals.

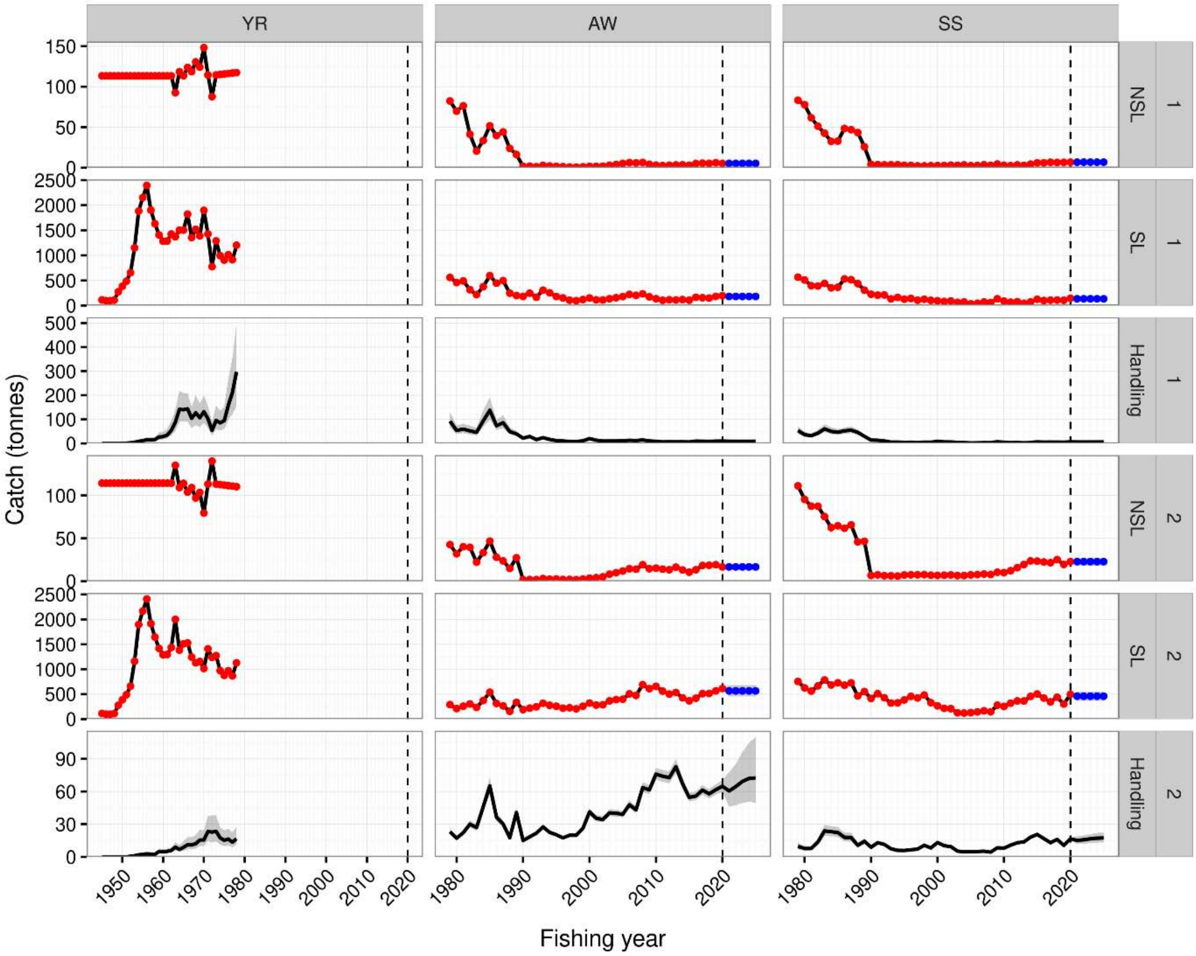


Figure 57: Posterior distribution of the catch and handling mortality by fishing year, season, region, and fishery (SL = size limited; NSL = non size limited) for the base case model run. The solid black line indicates the median of the posterior and shading indicates the 90% credible interval. Note that the columns separate the 1945–1978 annual catches (left column) from the 1979–2019 seasonal catches (right columns). The vertical dashed line is the final year of the reconstruction period after which the projected catch is shown.

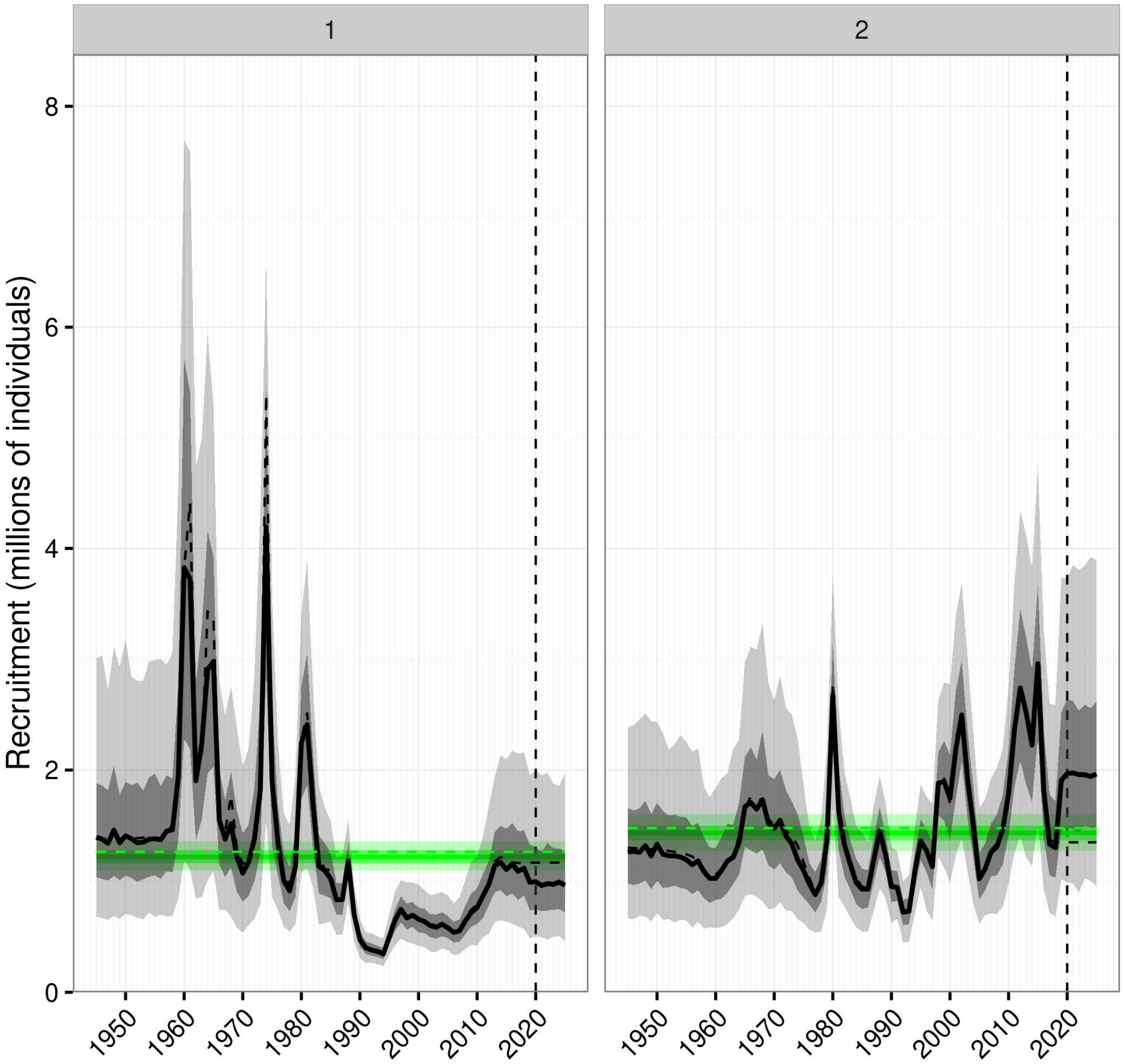


Figure 58: Posterior distribution of recruitment by region for the <u>base case</u> model run. The horizontal green line is R_0 and the vertical dashed line is the final year of the reconstruction period after which the projected recruitment is shown. The solid black line indicates the median of the posterior and variable shading intensity indicates the 50% and 90% credible intervals.

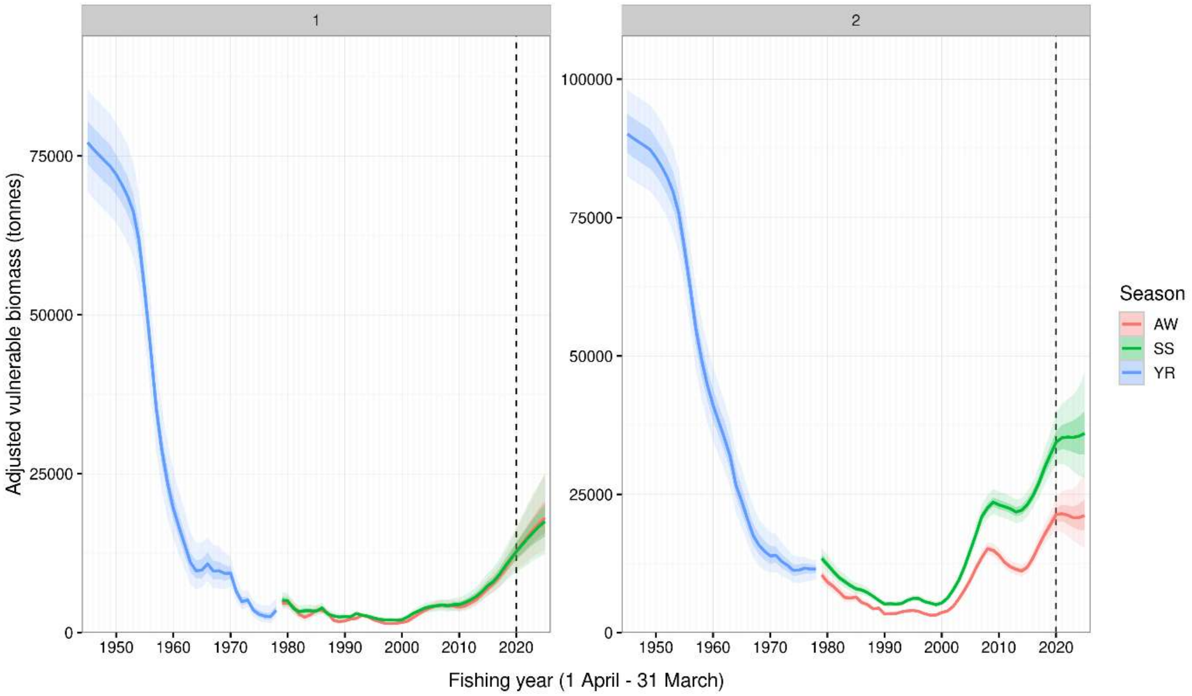


Figure 59: Posterior distribution of the adjusted vulnerable biomass by season and region for the <u>base case</u> model run. Variable shading intensity indicates the 50% and 90% credible intervals.

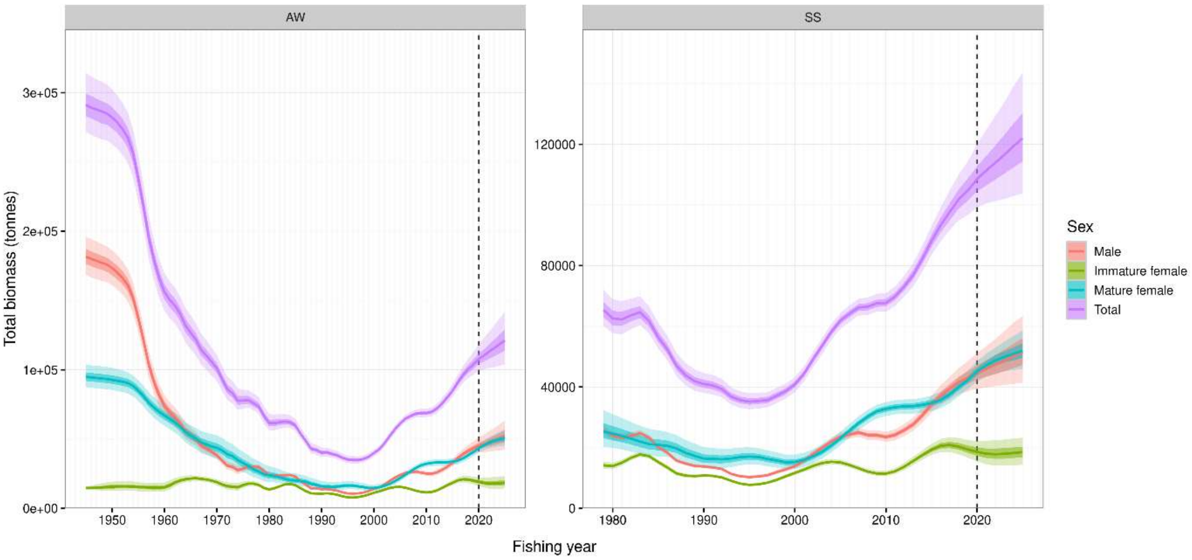


Figure 60: Posterior distribution of the total biomass by sex and season for the two regions combined for the <u>base case</u> model run. Variable shading intensity indicates the 50% and 90% credible intervals.

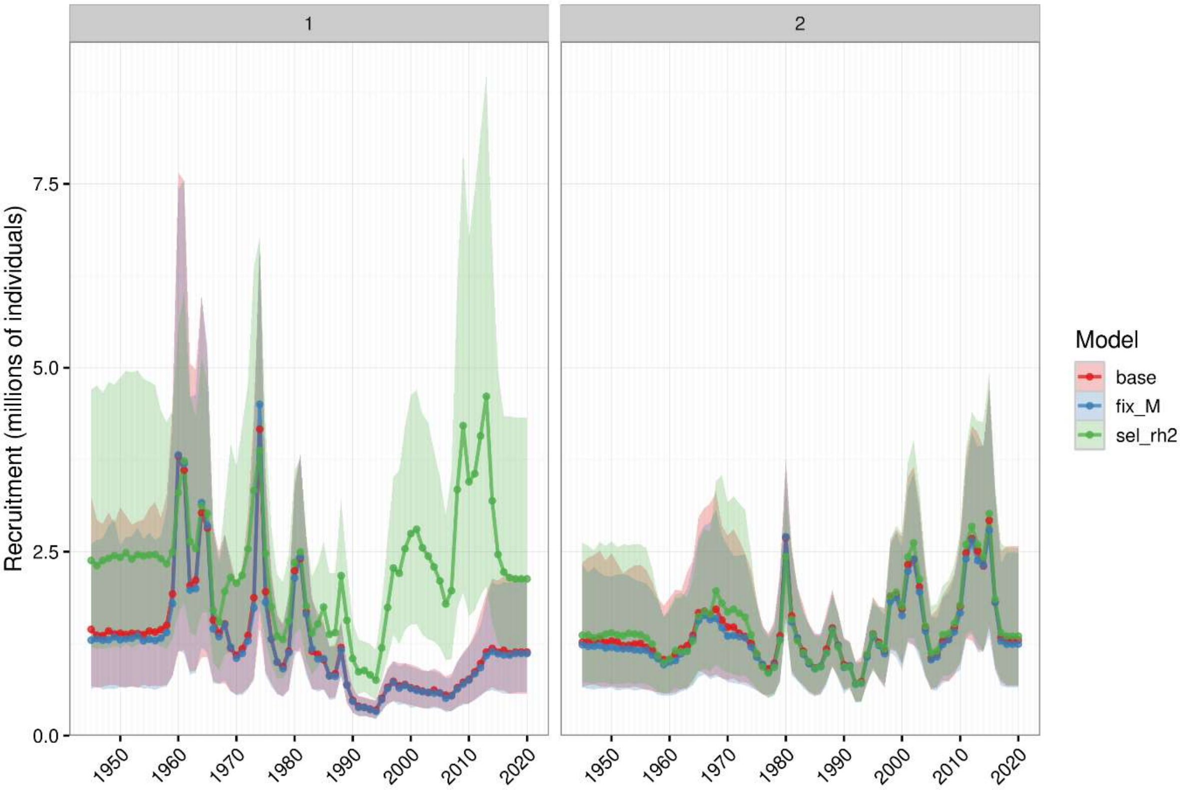


Figure 61: Posterior distribution of recruitment trajectories between the base run and the two sensitivity runs (*fix_M* and *sel_rh2*), including projection years (beyond the dashed vertical line), for all MCMC model runs.

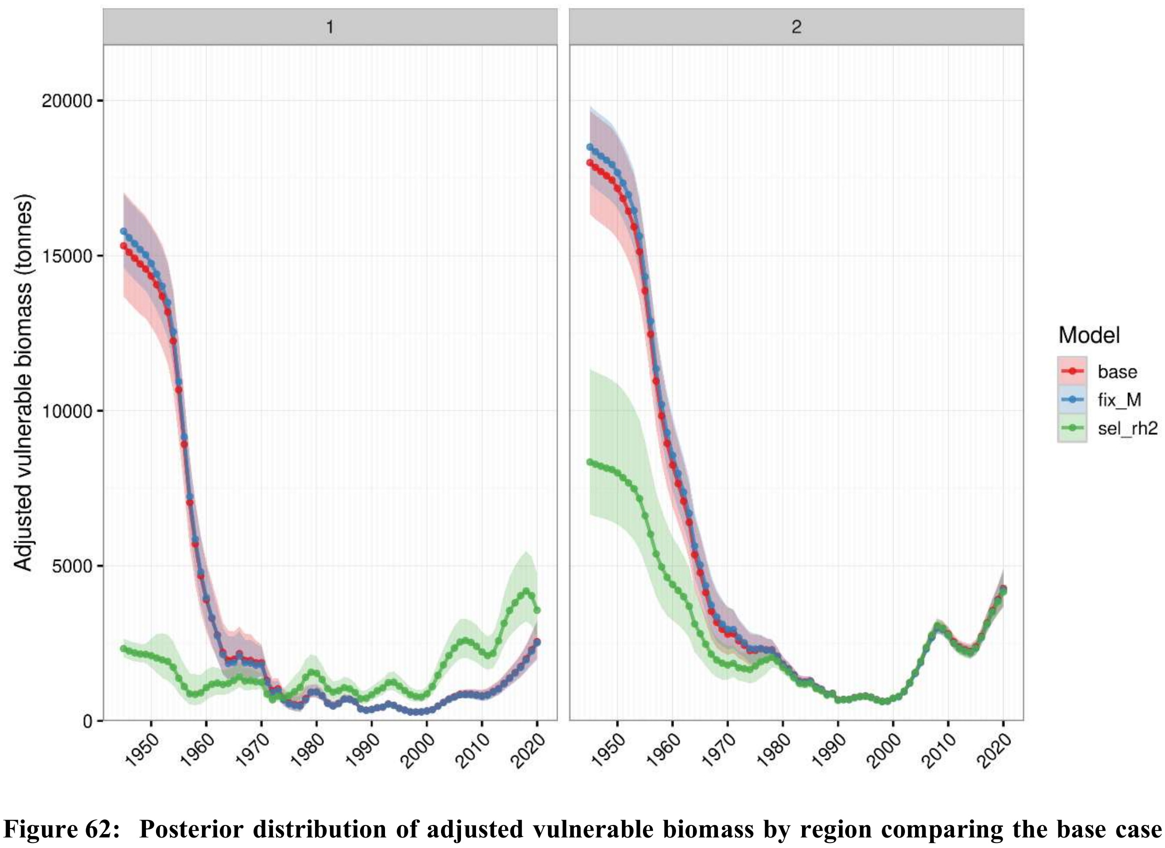


Figure 62: Posterior distribution of adjusted vulnerable biomass by region comparing the base case run and the two sensitivity runs (*fix_M* and *sel_rh2*).

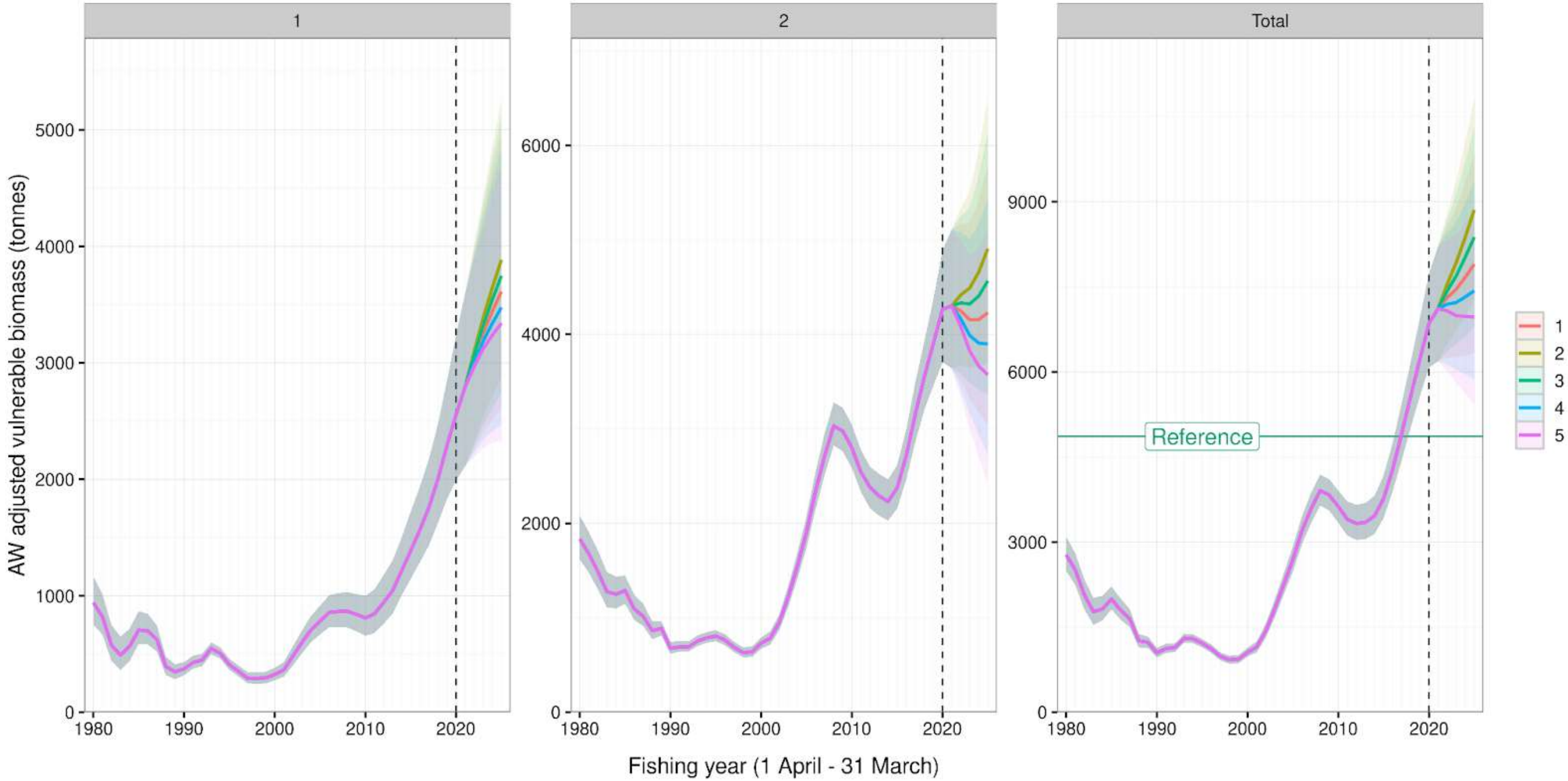


Figure 63: Posterior distribution of adjusted vulnerable biomass (tonnes) by fishing year and region (1 = region 1, 2 = region 2, Total = region 1+region 2), including the projections years (beyond the dashed vertical line), for the base case model run. Note that the regional biomass trajectories have been combined into an overall CRA 7 & 8 trajectory.

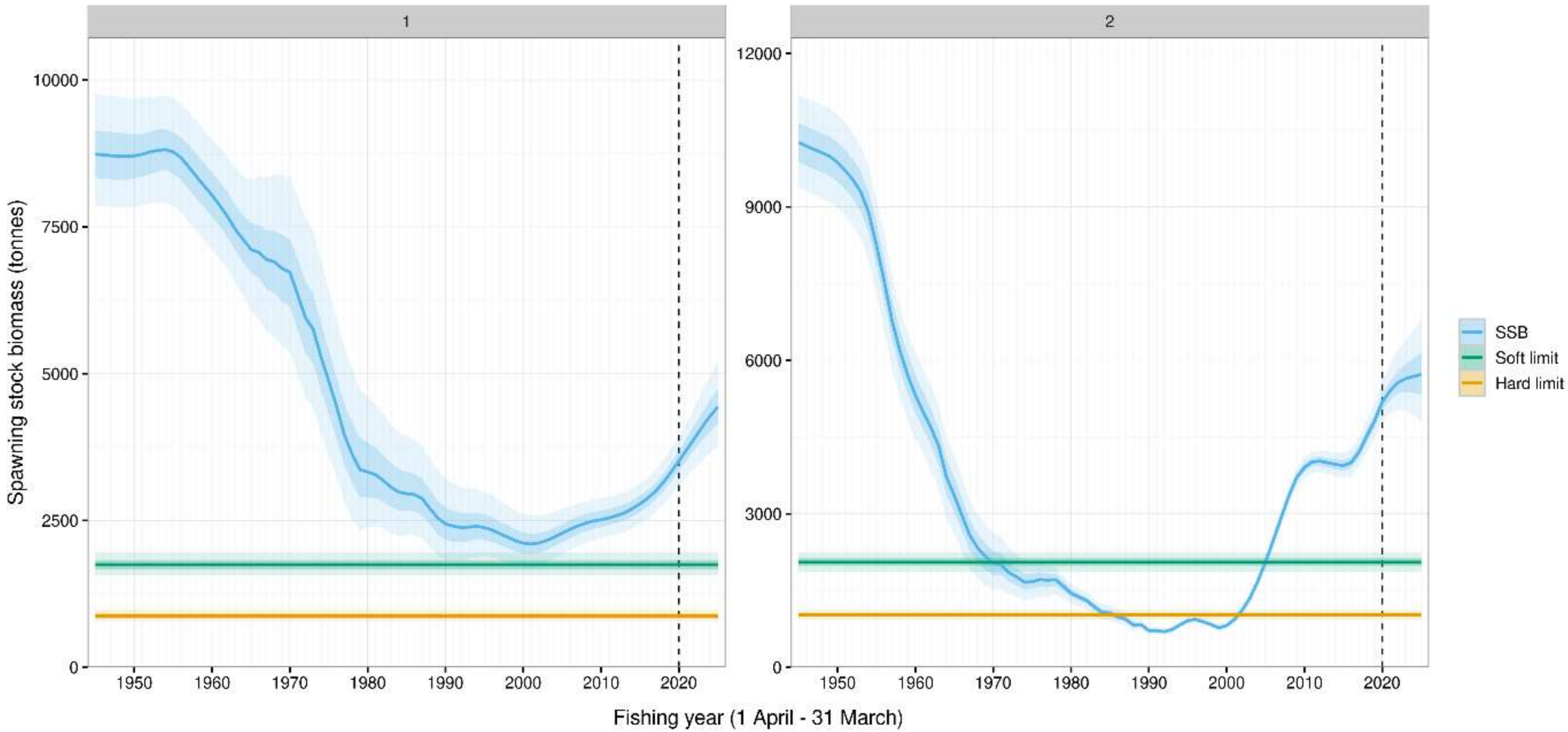


Figure 64: Posterior distribution of spawning stock biomass (tonnes) by fishing year and region, including the projections years (beyond the dashed vertical line), for the <u>base case</u> model run. The associated soft limits (20% SSB_0), and hard limits (10% SSB_0) are also shown.

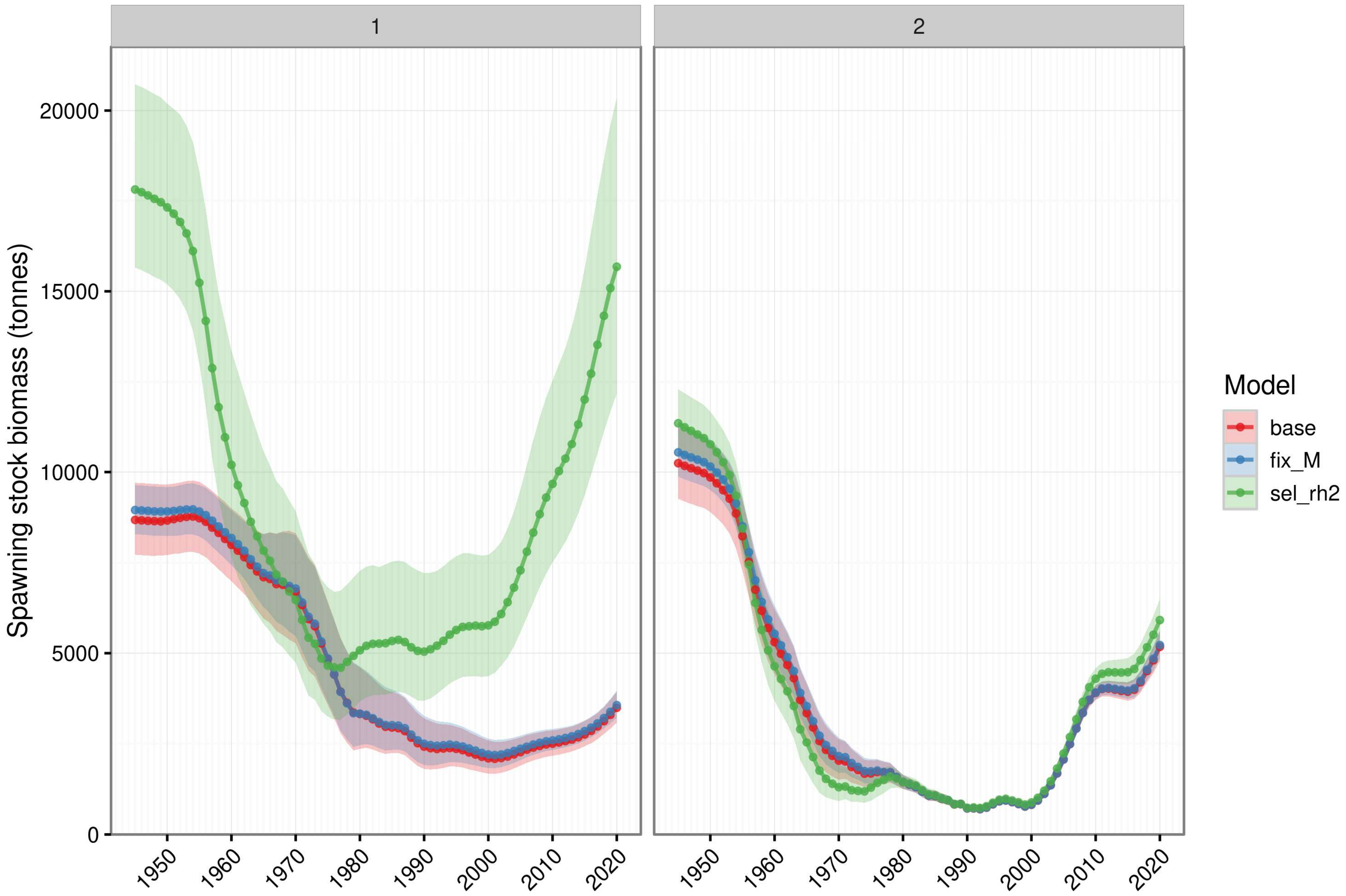


Figure 65: Posterior distribution of spawning stock biomass by region comparing the base case run and the two sensitivity runs (*fix_M* and *sel_rh2*).

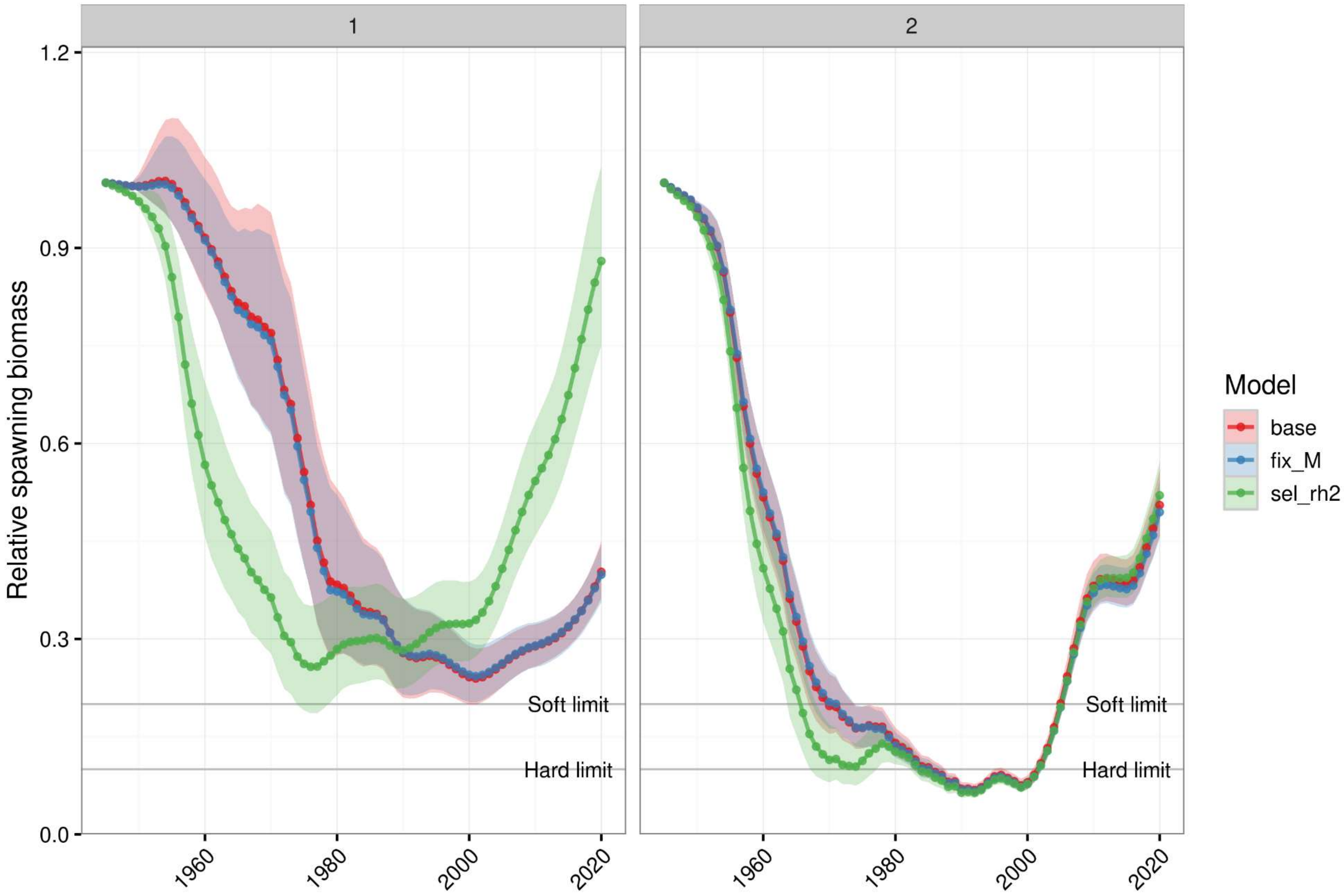


Figure 66: Posterior distribution of relative spawning stock biomass by region comparing the base case run and the two sensitivity runs (*fix_M* and *sel_rh2*).

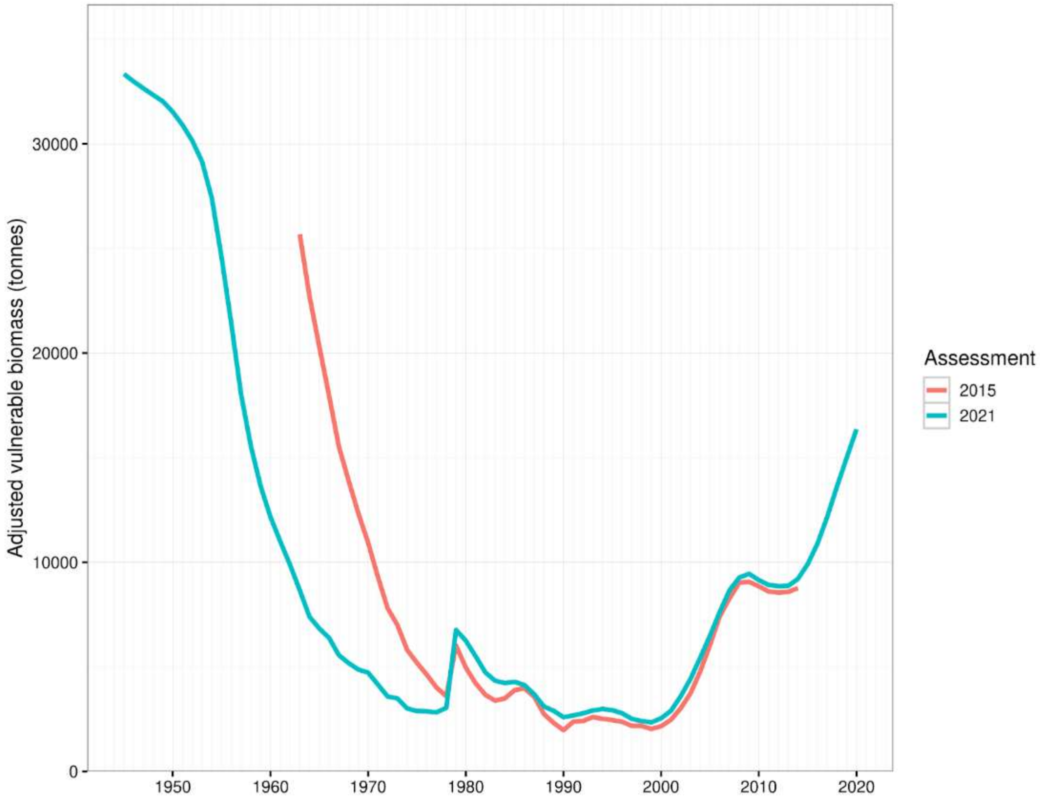


Figure 67: Comparison of the MAP combined region 1 and region 2 adjusted vulnerable biomass by fishing year estimated using the LSD model in 2021 (i.e., model run *base*) and the median MLSM in the 2015 stock assessment.

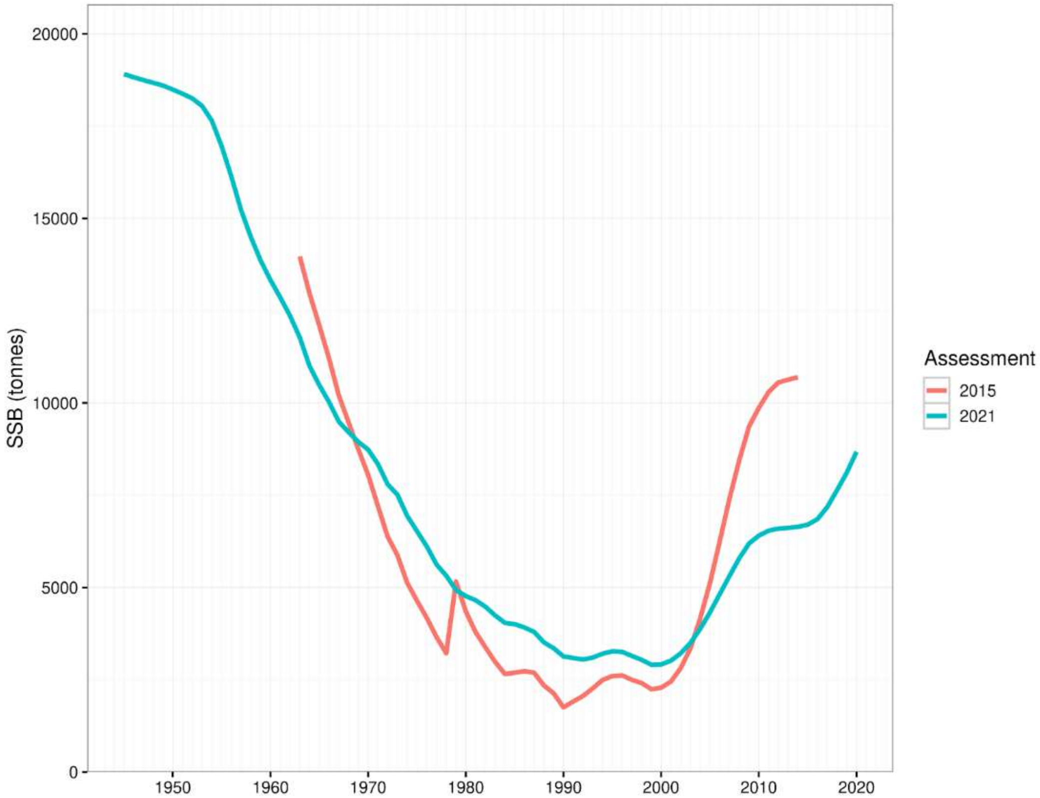


Figure 68: Comparison of the MAP combined region 1 and region 2 spawning stock biomass by fishing year estimated using the LSD model in 2021 (i.e., model run *base*) and the median MLSM in the 2015 stock assessment.

8. APPENDIX I: FISHING MORTALITY AND CATCH

There are two different types of rock lobster fisheries operating: the size limited (SL) fishery which is subject to input controls (MLS and no taking of berried females) and non-size limited (NSL) fishery that ignores these regulations. The SL fishery includes the commercial and recreational catch. The NSL fishery includes the illegal and customary catch. The catch (tonnes) taken each year (y) and season (t) in each of these fisheries is denoted $C_{y,t}^{\mathrm{SL}}$ and $C_{y,t}^{\mathrm{NSL}}$, respectively. In the model, there are fishing mortalities associated with these fisheries, these are year and season-specific and denoted $\bar{F}_{y,t}^{\mathrm{SL}}$ and $\bar{F}_{y,t}^{\mathrm{NSL}}$, respectively. A constant handling mortality rate is applied to those fish that are discarded (i.e., caught and returned to the water). The combination of selectivity and vulnerability ($\eta_{y,t,s,l}$), retention ($\zeta_{y,t,s,l}$), and handling mortality (ε_y) is used to translate the year and season-specific fishing mortality rates into fishing mortality rates by year, season, sex, and size class

$$\begin{aligned} F_{y,t,s,l}^{\mathrm{SL}} &= \bar{F}_{y,t}^{\mathrm{SL}} \eta_{y,t,s,l} \zeta_{y,t,s,l} \\ F_{y,t,s,l}^{\mathrm{NSL}} &= \bar{F}_{y,t}^{\mathrm{NSL}} \eta_{y,t,s,l} \\ F_{y,t,s,l}^{\mathrm{Handling}} &= \bar{F}_{y,t}^{\mathrm{SL}} \eta_{y,t,s,l} \left(1 - \zeta_{y,t,s,l}\right) \varepsilon_y \\ F_{y,t,s,l}^{\mathrm{LF}} &= \bar{F}_{y,t}^{\mathrm{SL}} \eta_{y,t,s,l} \end{aligned}$$

The total mortality rate is

$$Z_{y,t,s,l} = F_{y,t,s,l}^{\mathrm{SL}} + F_{y,t,s,l}^{\mathrm{NSL}} + F_{y,t,s,l}^{\mathrm{Handling}} + M\tau_y$$

where M is natural mortality and τ_y is one divided by the number of time steps each year. Total mortality is then removed from the model using

$$N_{y,t+1,s,l} = N_{y,t,s,l} e^{-Z_{y,t,s,l}}$$

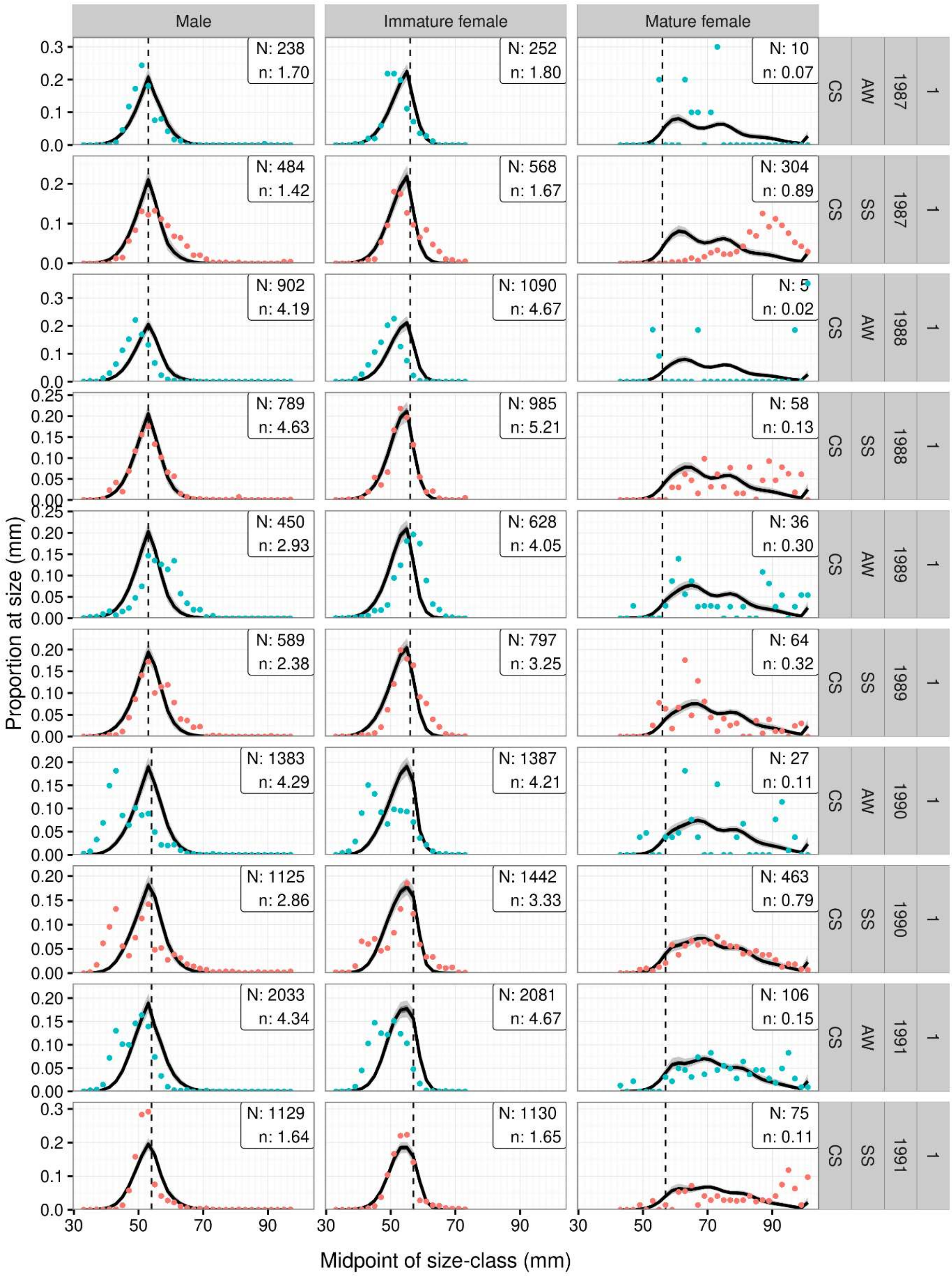
The catch associated with the SL and NSL fisheries, the mortality that is associated with the SL fishery due to handling, and the catch that is associated with the length frequencies are

$$\begin{aligned} C_{y,t}^{\mathrm{SL}} &= \sum_{s,l} \left[\frac{F_{y,t,s,l}^{\mathrm{SL}}}{Z_{y,t,s,l}} \left(1 - e^{-Z_{y,t,s,l}}\right) N_{y,t,s,l} w_{s,l} \right] \\ C_{y,t}^{\mathrm{NSL}} &= \sum_{s,l} \left[\frac{F_{y,t,s,l}^{\mathrm{NSL}}}{Z_{y,t,s,l}} \left(1 - e^{-Z_{y,t,s,l}}\right) N_{y,t,s,l} w_{s,l} \right] \\ C_{y,t}^{\mathrm{Handling}} &= \sum_{s,l} \left[\frac{F_{y,t,s,l}^{\mathrm{Handling}}}{Z_{y,t,s,l}} \left(1 - e^{-Z_{y,t,s,l}}\right) N_{y,t,s,l} w_{s,l} \right] \\ C_{y,t,s,l}^{\mathrm{LF}} &= \frac{F_{y,t,s,l}^{\mathrm{SL}}}{Z_{y,t,s,l}} \left(1 - e^{-Z_{y,t,s,l}}\right) N_{y,t,s,l} w_{s,l} \end{aligned}$$

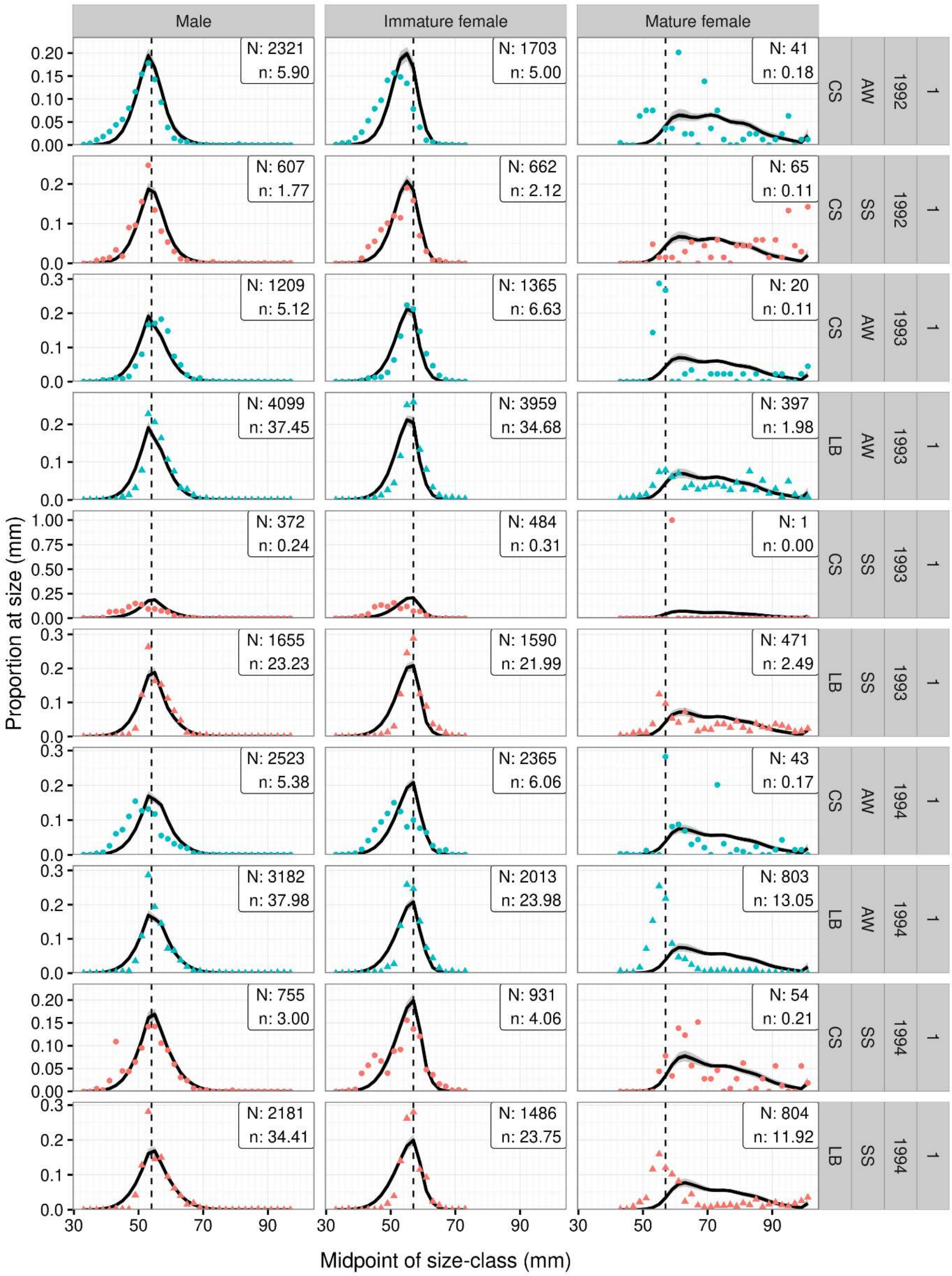
There is no closed form equation for the Baranov catch equation to solve for $\bar{F}_{y,t}^{\mathrm{SL}}$ and $\bar{F}_{y,t}^{\mathrm{NSL}}$ given the other parameters, so this equation must either be solved numerically (Pope's approximation or the Newton-Raphson method) or by treating $\bar{F}_{y,t}^{\mathrm{SL}}$ and $\bar{F}_{y,t}^{\mathrm{NSL}}$ as estimated parameters and the catches as observations with small standard deviations (so that the estimated catches are close to the observed catches). The LSD model uses the Newton-Raphson method for finding $\bar{F}_{y,t}^{\mathrm{SL}}$ and $\bar{F}_{y,t}^{\mathrm{NSL}}$.

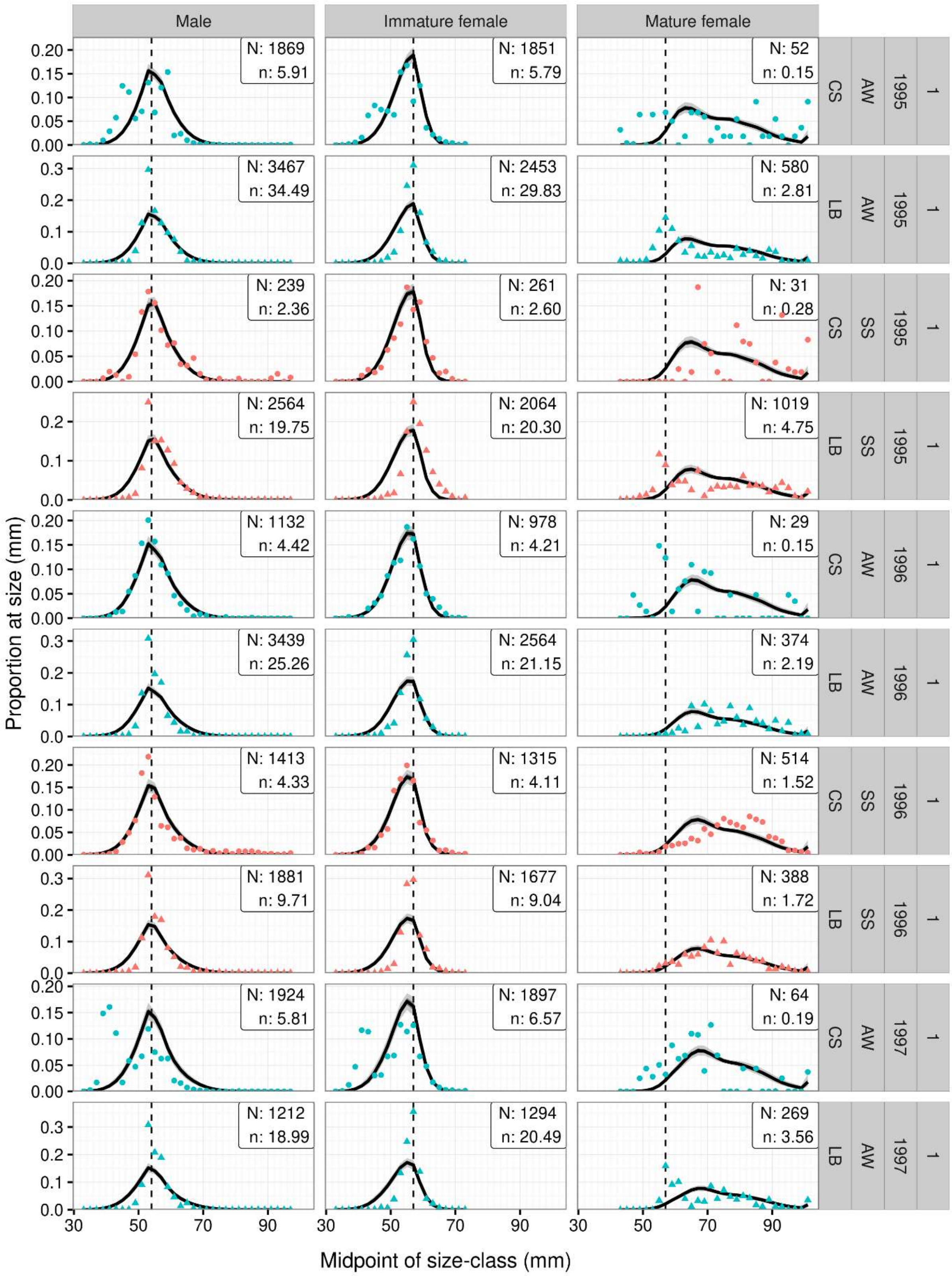
9. APPENDIX II: MCMC LENGTH FREQUENCY FITS

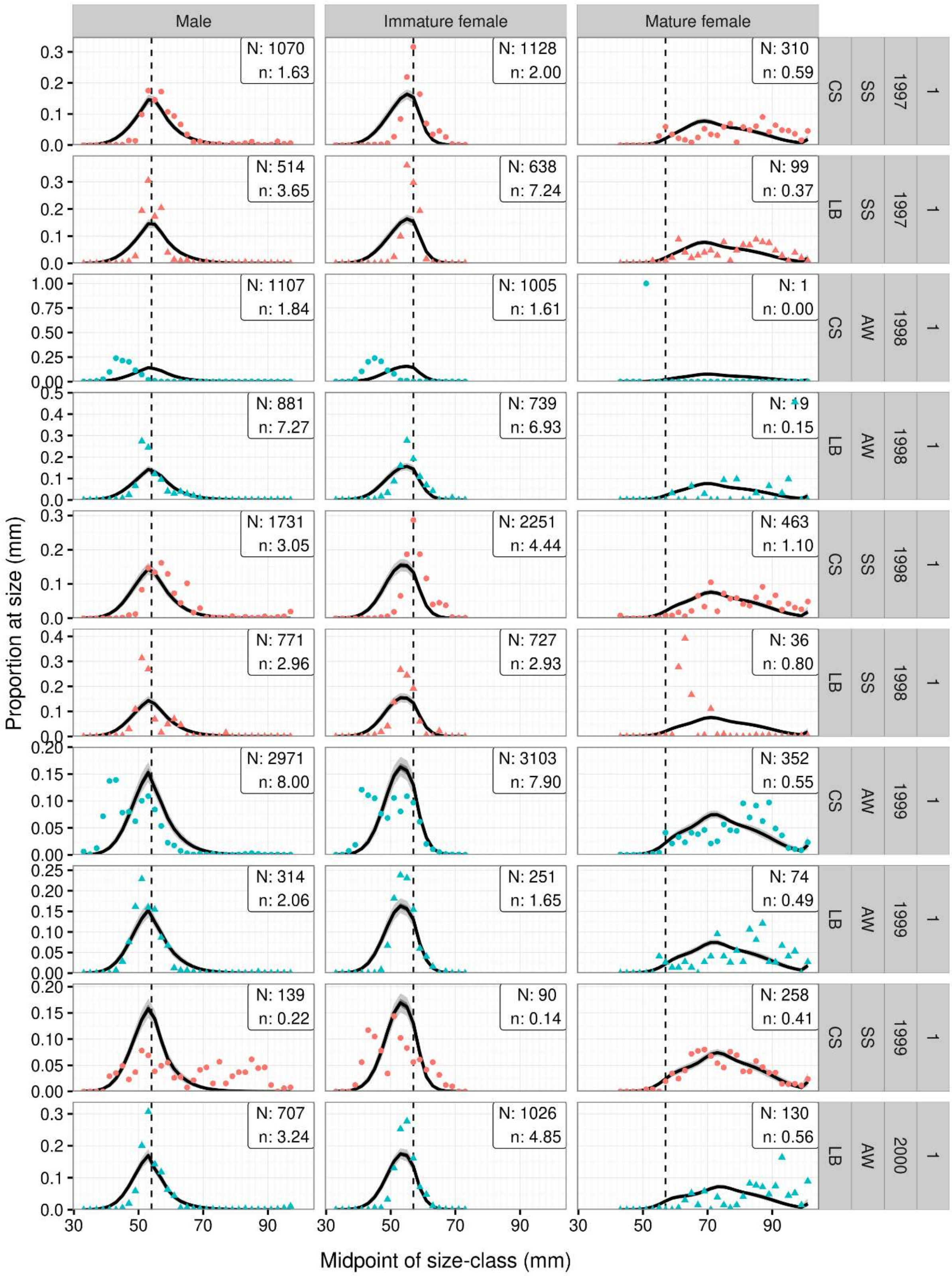
The figures below present the posterior distribution of the LFs compared with the observed LFs by region (1 = region 1, 2 = region 2), fishing year, season (AW = autumn/winter, SS = spring/summer), data source (CS = catch sampling, LB = logbook), and sex in the base case model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. In each panel the value for 'N' is the number of lobsters in the sample, and 'n' is the effective sample size. Data cover 1987–2018 for region 1 and 1989–2020 for region 2.

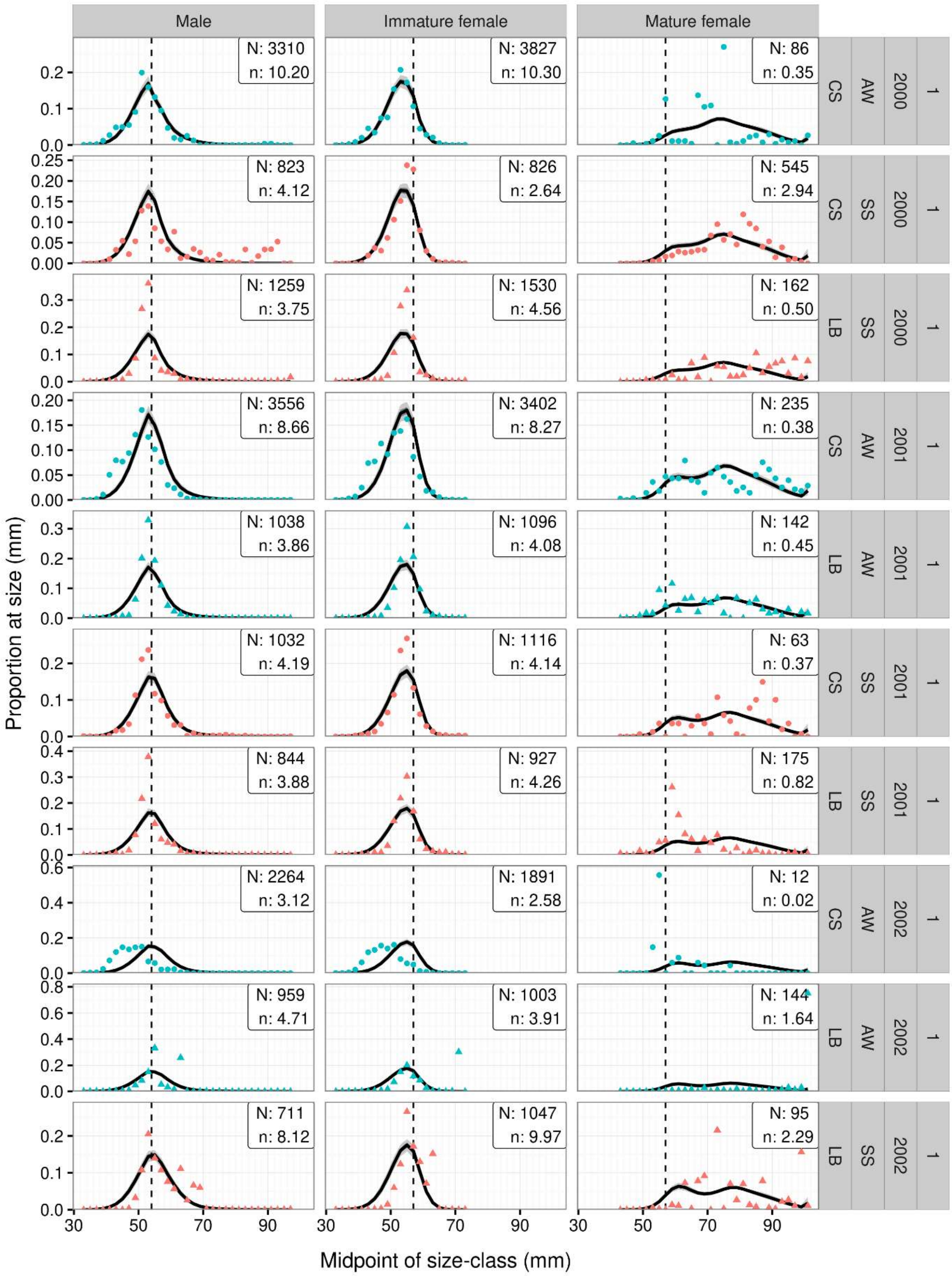


Male
Immature female
Mature female
N: 238
n: 1.70
N: 252
n: 1.80
N: 10
n: 0.07
CS AW 1987 1
N: 484
n: 1.42
N: 568
n: 1.67
N: 304
n: 0.89
CS SS 1987 1
N: 902
n: 4.19
N: 1090
n: 4.67
N: 5
n: 0.02
CS AW 1988 1
N: 789
n: 4.63
N: 985
n: 5.21
N: 58
n: 0.13
CS SS 1988 1
N: 450
n: 2.93
N: 628
n: 4.05
N: 36
n: 0.30
CS AW 1989 1
N: 589
n: 2.38
N: 797
n: 3.25
N: 64
n: 0.32
CS SS 1989 1
N: 1383
n: 4.29
N: 1387
n: 4.21
N: 27
n: 0.11
CS AW 1990 1
N: 1125
n: 2.86
N: 1442
n: 3.33
N: 463
n: 0.79
CS SS 1990 1
N: 2033
n: 4.34
N: 2081
n: 4.67
N: 106
n: 0.15
CS AW 1991 1
N: 1129
n: 1.64
N: 1130
n: 1.65
N: 75
n: 0.11
CS SS 1991 1
Proportion at size (mm)
Midpoint of size-class (mm)

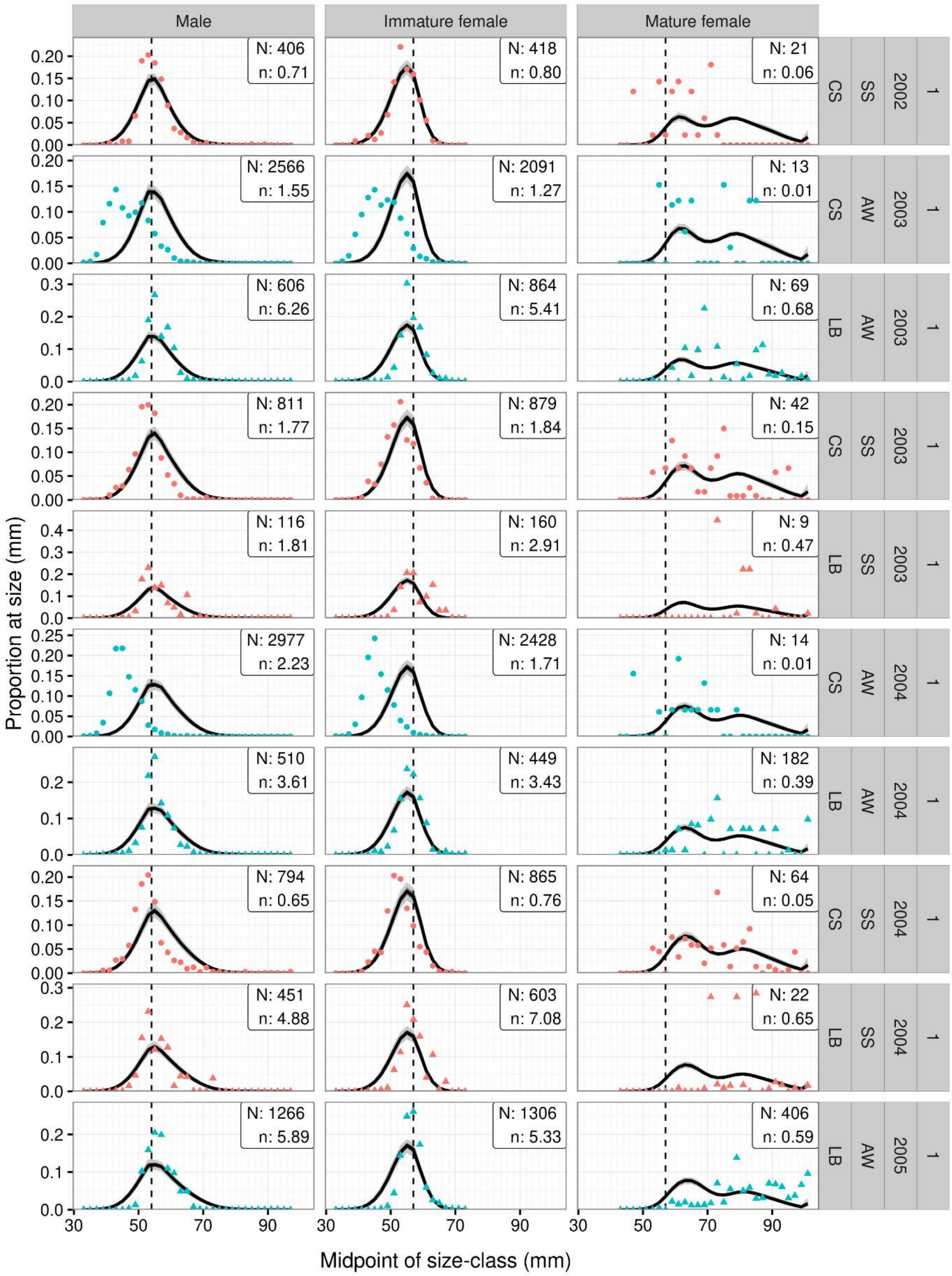

Male
Immature female
Mature female
Proportion at size (mm)
Midpoint of size-class (mm)
N: 2321
n: 5.90
N: 1703
n: 5.00
N: 41
n: 0.18
CS AW 1992 1
N: 607
n: 1.77
N: 662
n: 2.12
N: 65
n: 0.11
CS SS 1992 1
N: 1209
n: 5.12
N: 1365
n: 6.63
N: 20
n: 0.11
CS AW 1993 1
N: 4099
n: 37.45
N: 3959
n: 34.68
N: 397
n: 1.98
LB AW 1993 1
N: 372
n: 0.24
N: 484
n: 0.31
N: 1
n: 0.00
CS SS 1993 1
N: 1655
n: 23.23
N: 1590
n: 21.99
N: 471
n: 2.49
LB SS 1993 1
N: 2523
n: 5.38
N: 2365
n: 6.06
N: 43
n: 0.17
CS AW 1994 1
N: 3182
n: 37.98
N: 2013
n: 23.98
N: 803
n: 13.05
LB AW 1994 1
N: 755
n: 3.00
N: 931
n: 4.06
N: 54
n: 0.21
CS SS 1994 1
N: 2181
n: 34.41
N: 1486
n: 23.75
N: 804
n: 11.92
LB SS 1994 1

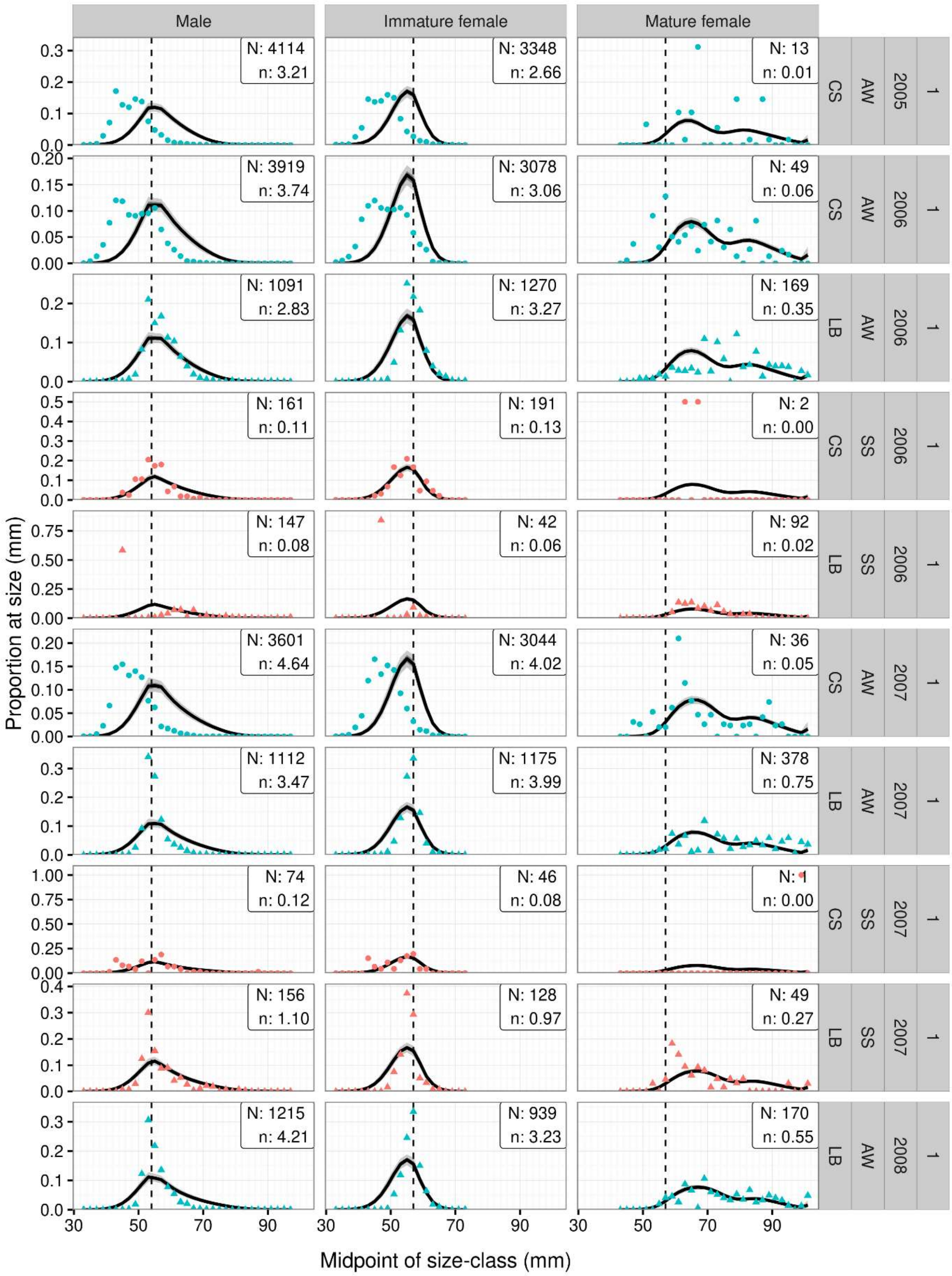

Male
Immature female
Mature female
N: 1869
n: 5.91
N: 1851
n: 5.79
N: 52
n: 0.15
CS AW 1995 1
N: 3467
n: 34.49
N: 2453
n: 29.83
N: 580
n: 2.81
LB AW 1995 1
N: 239
n: 2.36
N: 261
n: 2.60
N: 31
n: 0.28
CS SS 1995 1
N: 2564
n: 19.75
N: 2064
n: 20.30
N: 1019
n: 4.75
LB SS 1995 1
N: 1132
n: 4.42
N: 978
n: 4.21
N: 29
n: 0.15
CS AW 1996 1
N: 3439
n: 25.26
N: 2564
n: 21.15
N: 374
n: 2.19
LB AW 1996 1
N: 1413
n: 4.33
N: 1315
n: 4.11
N: 514
n: 1.52
CS SS 1996 1
N: 1881
n: 9.71
N: 1677
n: 9.04
N: 388
n: 1.72
LB SS 1996 1
N: 1924
n: 5.81
N: 1897
n: 6.57
N: 64
n: 0.19
CS AW 1997 1
N: 1212
n: 18.99
N: 1294
n: 20.49
N: 269
n: 3.56
LB AW 1997 1
Proportion at size (mm)
Midpoint of size-class (mm)


Male
Immature female
Mature female
N: 1070
n: 1.63
N: 1128
n: 2.00
N: 310
n: 0.59
CS SS 1997 1
N: 514
n: 3.65
N: 638
n: 7.24
N: 99
n: 0.37
LB SS 1997 1
N: 1107
n: 1.84
N: 1005
n: 1.61
N: 1
n: 0.00
CS AW 1998 1
N: 881
n: 7.27
N: 739
n: 6.93
N: 19
n: 0.15
LB AW 1998 1
N: 1731
n: 3.05
N: 2251
n: 4.44
N: 463
n: 1.10
CS SS 1998 1
N: 771
n: 2.96
N: 727
n: 2.93
N: 36
n: 0.80
LB SS 1998 1
N: 2971
n: 8.00
N: 3103
n: 7.90
N: 352
n: 0.55
CS AW 1999 1
N: 314
n: 2.06
N: 251
n: 1.65
N: 74
n: 0.49
LB AW 1999 1
N: 139
n: 0.22
N: 90
n: 0.14
N: 258
n: 0.41
CS SS 1999 1
N: 707
n: 3.24
N: 1026
n: 4.85
N: 130
n: 0.56
LB AW 2000 1
Proportion at size (mm)
Midpoint of size-class (mm)

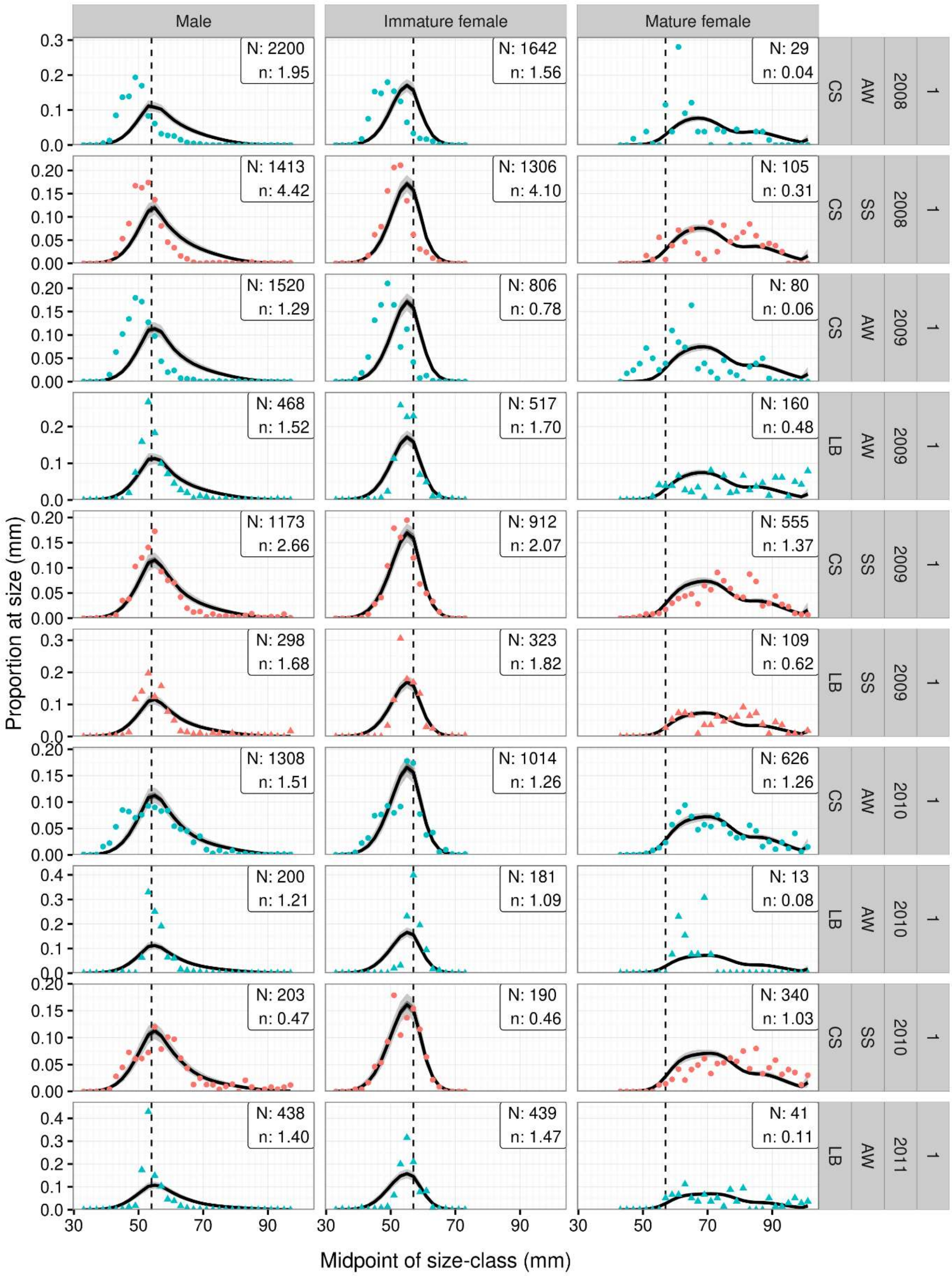


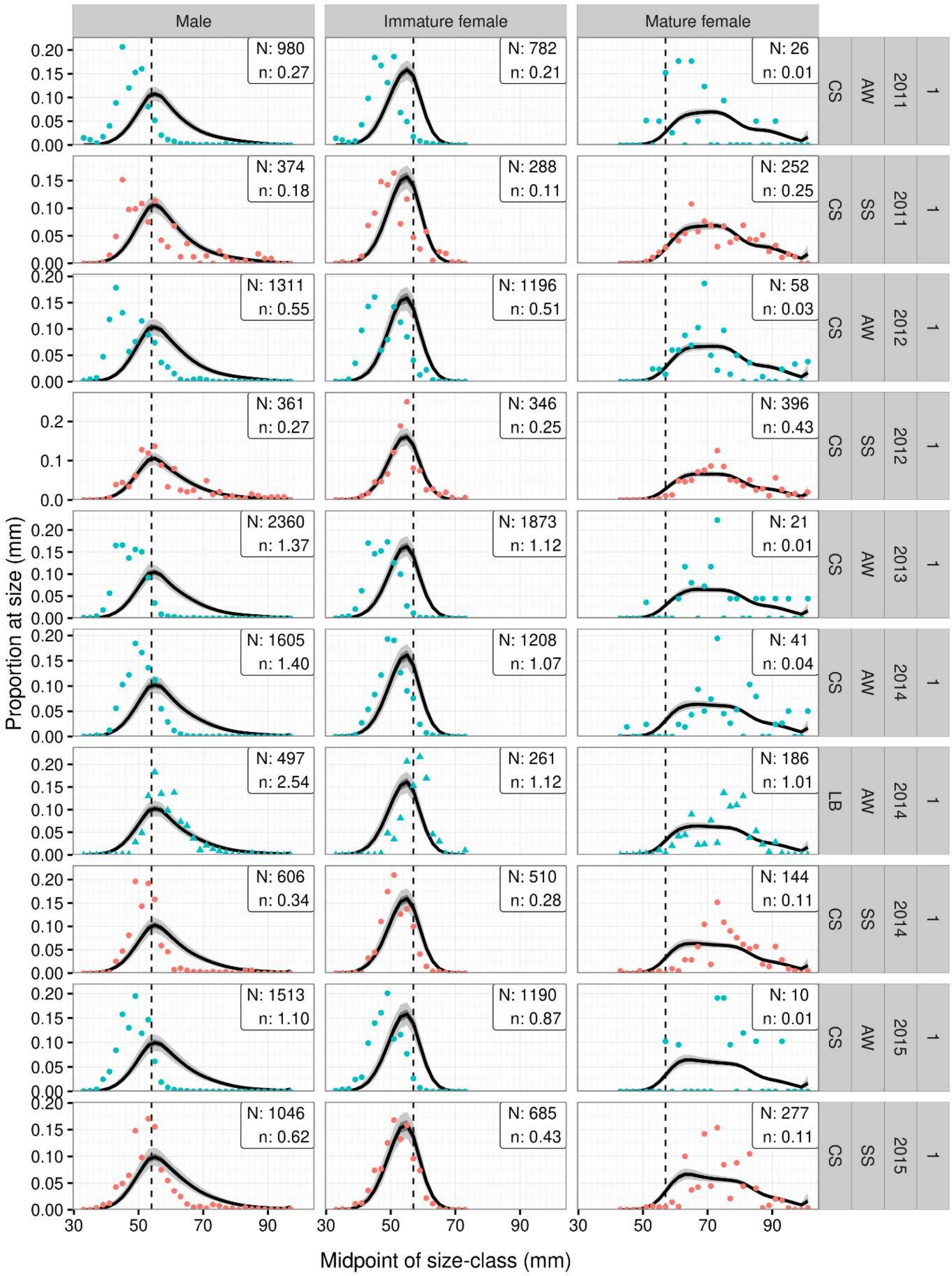
Male
Immature female
Mature female
N: 3310 n: 10.20
N: 3827 n: 10.30
N: 86 n: 0.35
CS AW 2000 1
N: 823 n: 4.12
N: 826 n: 2.64
N: 545 n: 2.94
CS SS 2000 1
N: 1259 n: 3.75
N: 1530 n: 4.56
N: 162 n: 0.50
LB SS 2000 1
N: 3556 n: 8.66
N: 3402 n: 8.27
N: 235 n: 0.38
CS AW 2001 1
N: 1038 n: 3.86
N: 1096 n: 4.08
N: 142 n: 0.45
LB AW 2001 1
N: 1032 n: 4.19
N: 1116 n: 4.14
N: 63 n: 0.37
CS SS 2001 1
N: 844 n: 3.88
N: 927 n: 4.26
N: 175 n: 0.82
LB SS 2001 1
N: 2264 n: 3.12
N: 1891 n: 2.58
N: 12 n: 0.02
CS AW 2002 1
N: 959 n: 4.71
N: 1003 n: 3.91
N: 144 n: 1.64
LB AW 2002 1
N: 711 n: 8.12
N: 1047 n: 9.97
N: 95 n: 2.29
LB SS 2002 1
Proportion at size (mm)
Midpoint of size-class (mm)

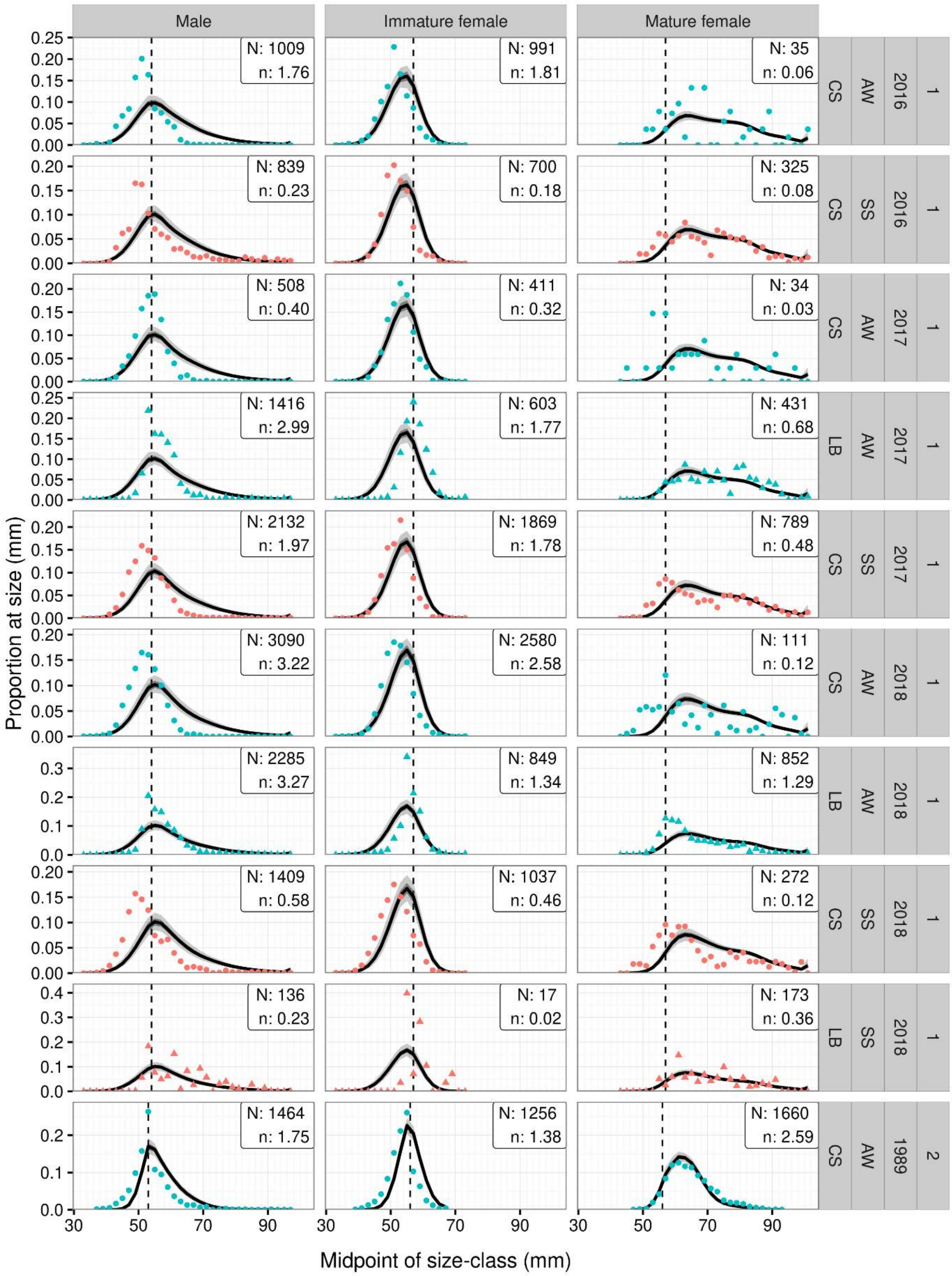

Male
Immature female
Mature female
N: 406
n: 0.71
N: 418
n: 0.80
N: 21
n: 0.06
CS SS 2002 1
N: 2566
n: 1.55
N: 2091
n: 1.27
N: 13
n: 0.01
CS AW 2003 1
N: 606
n: 6.26
N: 864
n: 5.41
N: 69
n: 0.68
LB AW 2003 1
N: 811
n: 1.77
N: 879
n: 1.84
N: 42
n: 0.15
CS SS 2003 1
N: 116
n: 1.81
N: 160
n: 2.91
N: 9
n: 0.47
LB SS 2003 1
N: 2977
n: 2.23
N: 2428
n: 1.71
N: 14
n: 0.01
CS AW 2004 1
N: 510
n: 3.61
N: 449
n: 3.43
N: 182
n: 0.39
LB AW 2004 1
N: 794
n: 0.65
N: 865
n: 0.76
N: 64
n: 0.05
CS SS 2004 1
N: 451
n: 4.88
N: 603
n: 7.08
N: 22
n: 0.65
LB SS 2004 1
N: 1266
n: 5.89
N: 1306
n: 5.33
N: 406
n: 0.59
LB AW 2005 1
Proportion at size (mm)
Midpoint of size-class (mm)



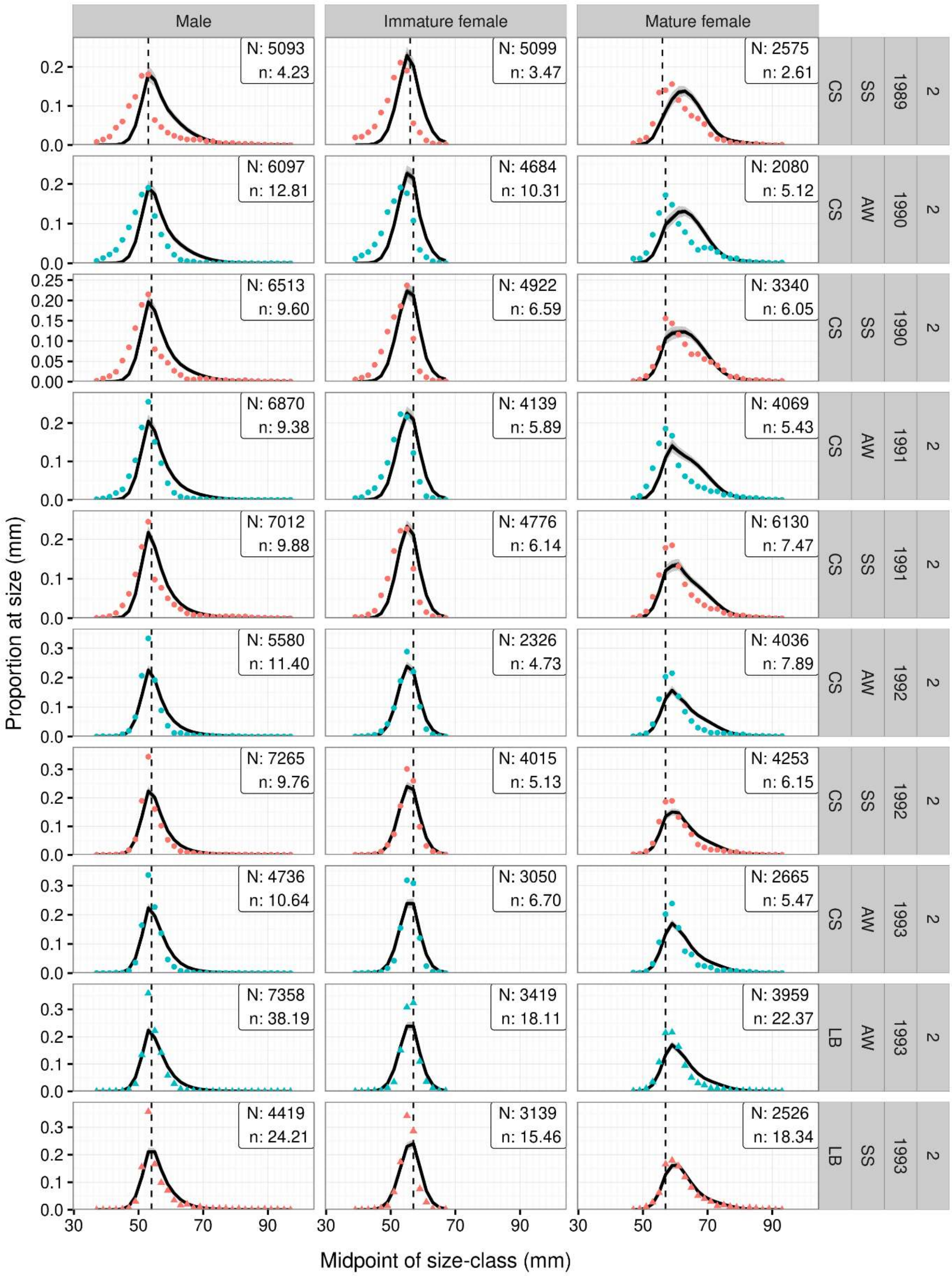
Male
Immature female
Mature female
N: 4114
n: 3.21
N: 3348
n: 2.66
N: 13
n: 0.01
CS AW 2005 1
N: 3919
n: 3.74
N: 3078
n: 3.06
N: 49
n: 0.06
CS AW 2006 1
N: 1091
n: 2.83
N: 1270
n: 3.27
N: 169
n: 0.35
LB AW 2006 1
N: 161
n: 0.11
N: 191
n: 0.13
N: 2
n: 0.00
CS SS 2006 1
N: 147
n: 0.08
N: 42
n: 0.06
N: 92
n: 0.02
LB SS 2006 1
N: 3601
n: 4.64
N: 3044
n: 4.02
N: 36
n: 0.05
CS AW 2007 1
N: 1112
n: 3.47
N: 1175
n: 3.99
N: 378
n: 0.75
LB AW 2007 1
N: 74
n: 0.12
N: 46
n: 0.08
N: 1
n: 0.00
CS SS 2007 1
N: 156
n: 1.10
N: 128
n: 0.97
N: 49
n: 0.27
LB SS 2007 1
N: 1215
n: 4.21
N: 939
n: 3.23
N: 170
n: 0.55
LB AW 2008 1
Proportion at size (mm)
Midpoint of size-class (mm)

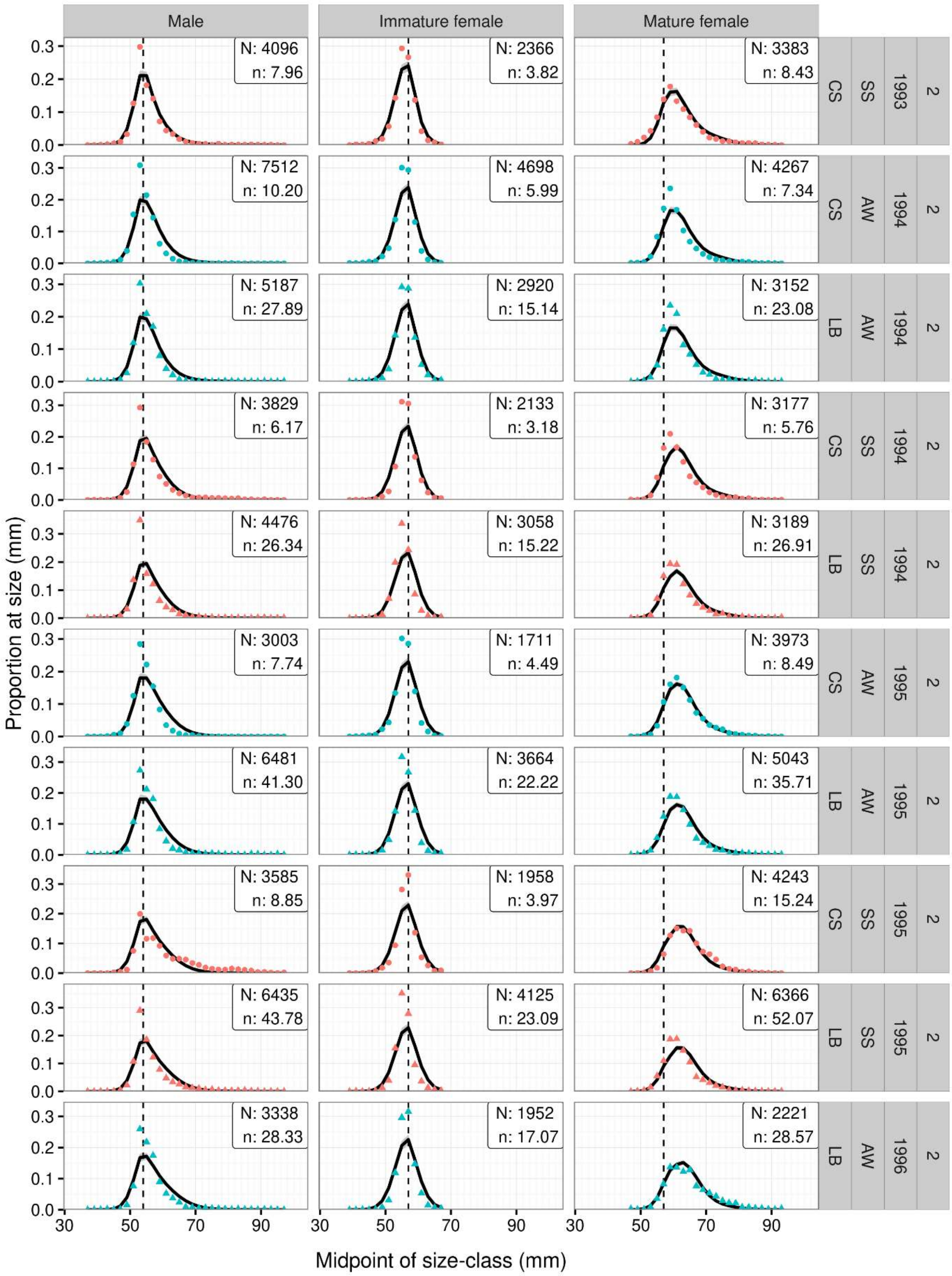

Male
Immature female
Mature female
Proportion at size (mm)
Midpoint of size-class (mm)
N: 2200
n: 1.95
N: 1642
n: 1.56
N: 29
n: 0.04
CS AW 2008 1
N: 1413
n: 4.42
N: 1306
n: 4.10
N: 105
n: 0.31
CS SS 2008 1
N: 1520
n: 1.29
N: 806
n: 0.78
N: 80
n: 0.06
CS AW 2009 1
N: 468
n: 1.52
N: 517
n: 1.70
N: 160
n: 0.48
LB AW 2009 1
N: 1173
n: 2.66
N: 912
n: 2.07
N: 555
n: 1.37
CS SS 2009 1
N: 298
n: 1.68
N: 323
n: 1.82
N: 109
n: 0.62
LB SS 2009 1
N: 1308
n: 1.51
N: 1014
n: 1.26
N: 626
n: 1.26
CS AW 2010 1
N: 200
n: 1.21
N: 181
n: 1.09
N: 13
n: 0.08
LB AW 2010 1
N: 203
n: 0.47
N: 190
n: 0.46
N: 340
n: 1.03
CS SS 2010 1
N: 438
n: 1.40
N: 439
n: 1.47
N: 41
n: 0.11
LB AW 2011 1

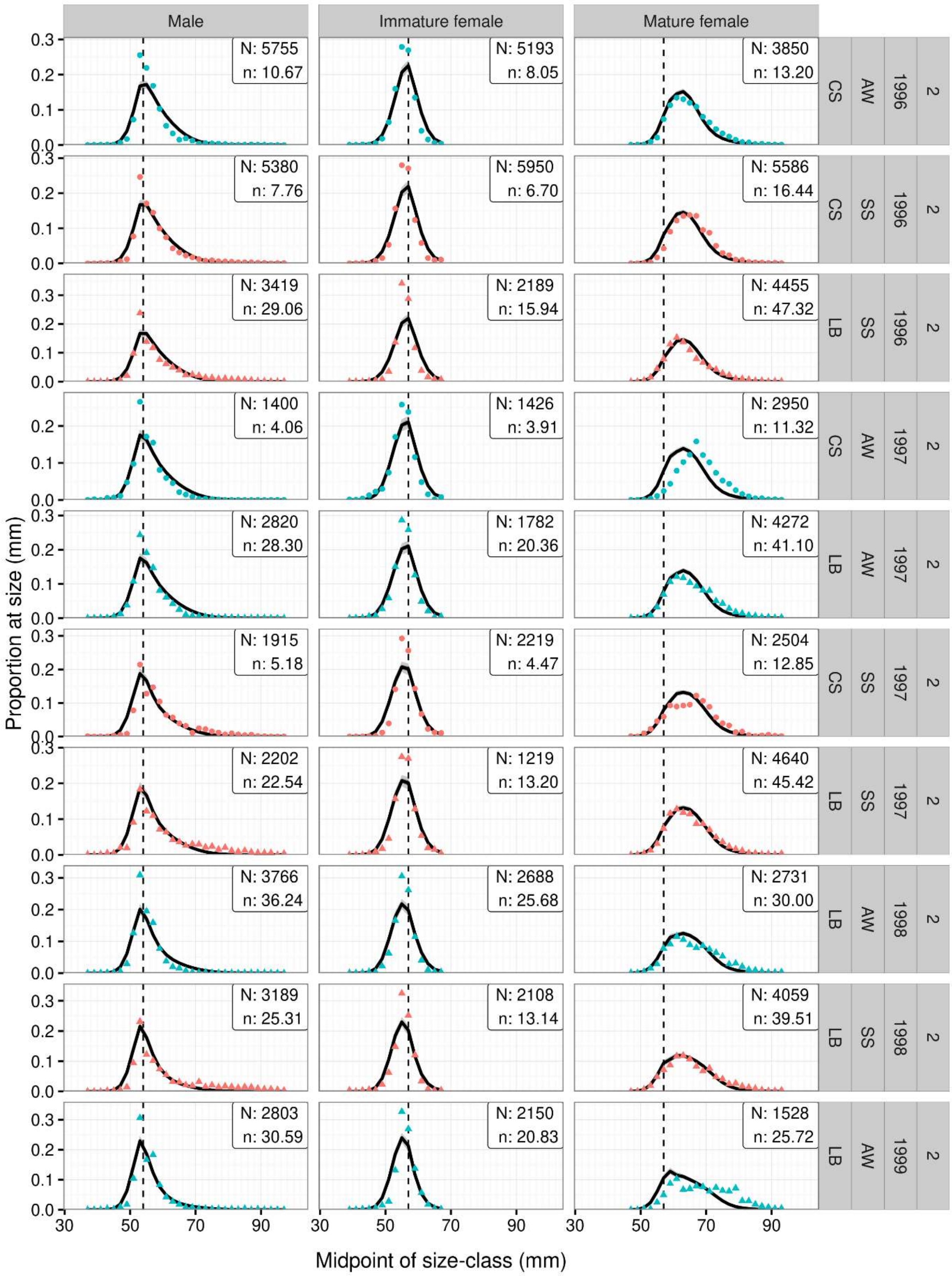

Male
Immature female
Mature female
N: 980
n: 0.27
N: 782
n: 0.21
N: 26
n: 0.01
CS
AW
2011
1
N: 374
n: 0.18
N: 288
n: 0.11
N: 252
n: 0.25
CS
SS
2011
1
N: 1311
n: 0.55
N: 1196
n: 0.51
N: 58
n: 0.03
CS
AW
2012
1
N: 361
n: 0.27
N: 346
n: 0.25
N: 396
n: 0.43
CS
SS
2012
1
N: 2360
n: 1.37
N: 1873
n: 1.12
N: 21
n: 0.01
CS
AW
2013
1
N: 1605
n: 1.40
N: 1208
n: 1.07
N: 41
n: 0.04
CS
AW
2014
1
N: 497
n: 2.54
N: 261
n: 1.12
N: 186
n: 1.01
LB
AW
2014
1
N: 606
n: 0.34
N: 510
n: 0.28
N: 144
n: 0.11
CS
SS
2014
1
N: 1513
n: 1.10
N: 1190
n: 0.87
N: 10
n: 0.01
CS
AW
2015
1
N: 1046
n: 0.62
N: 685
n: 0.43
N: 277
n: 0.11
CS
SS
2015
1
Proportion at size (mm)
Midpoint of size-class (mm)

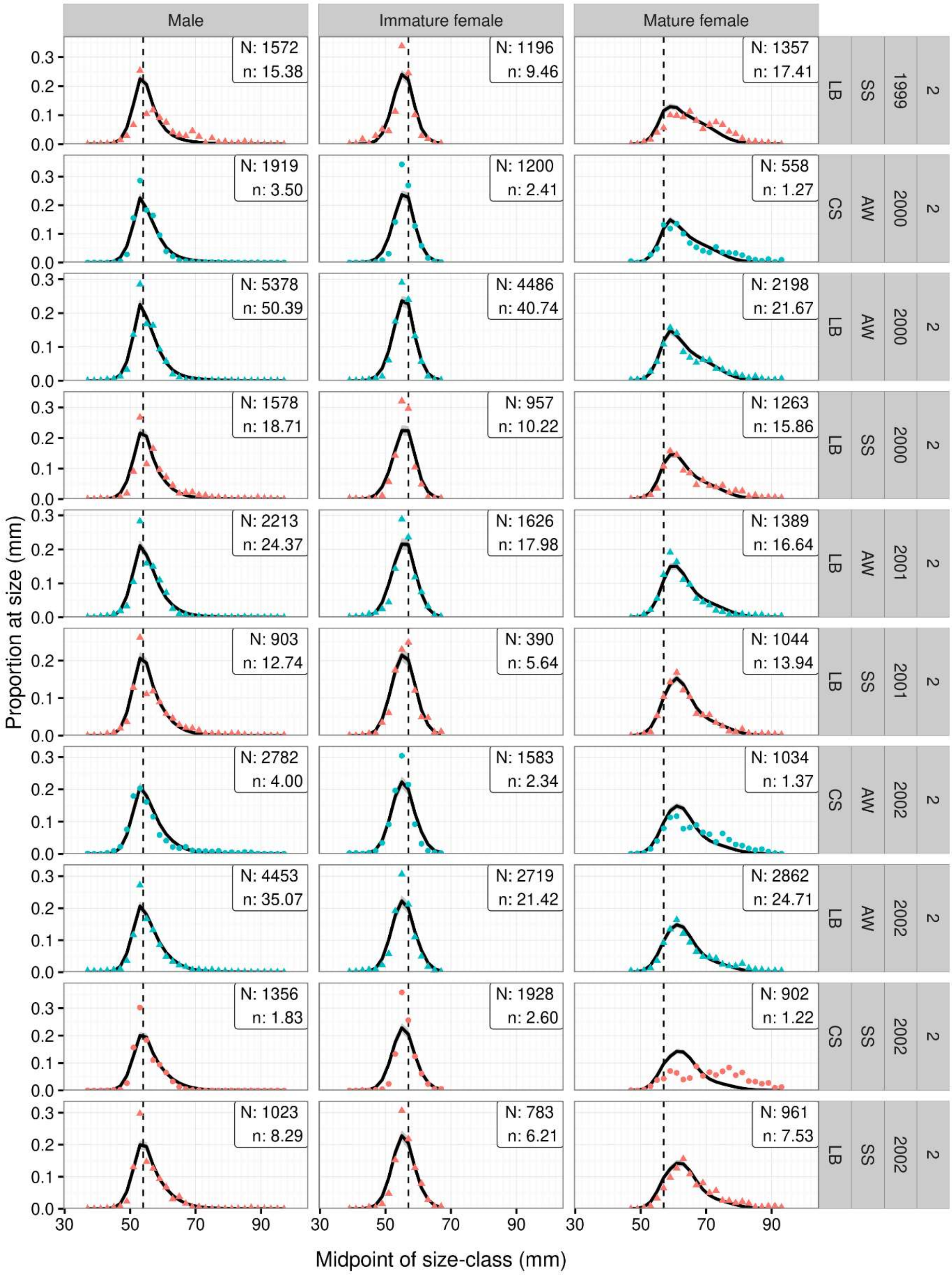


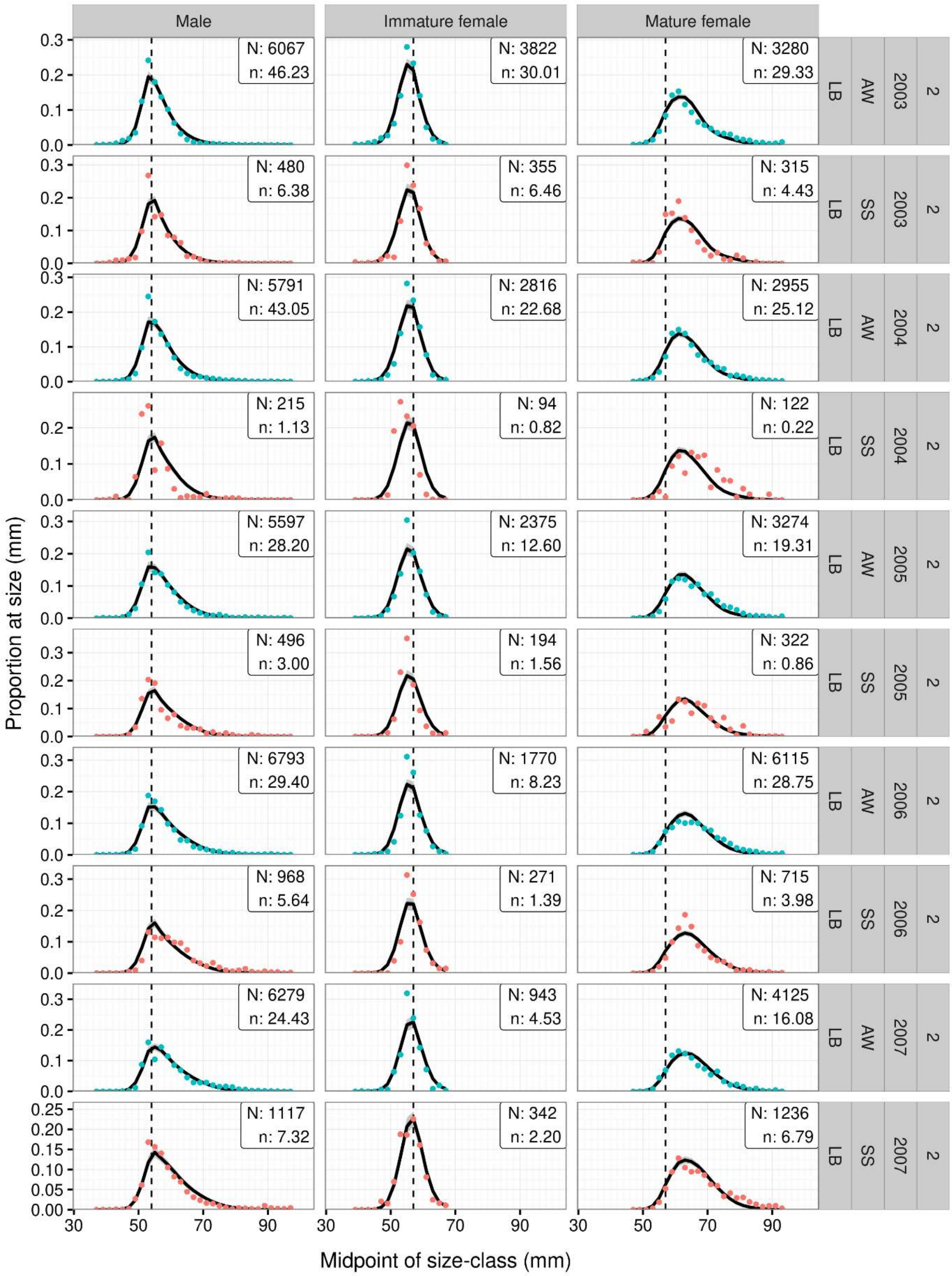
Male
Immature female
Mature female
Proportion at size (mm)
Midpoint of size-class (mm)
N: 1009 n: 1.76
N: 991 n: 1.81
N: 35 n: 0.06
CS AW 2016 1
N: 839 n: 0.23
N: 700 n: 0.18
N: 325 n: 0.08
CS SS 2016 1
N: 508 n: 0.40
N: 411 n: 0.32
N: 34 n: 0.03
CS AW 2017 1
N: 1416 n: 2.99
N: 603 n: 1.77
N: 431 n: 0.68
LB AW 2017 1
N: 2132 n: 1.97
N: 1869 n: 1.78
N: 789 n: 0.48
CS SS 2017 1
N: 3090 n: 3.22
N: 2580 n: 2.58
N: 111 n: 0.12
CS AW 2018 1
N: 2285 n: 3.27
N: 849 n: 1.34
N: 852 n: 1.29
LB AW 2018 1
N: 1409 n: 0.58
N: 1037 n: 0.46
N: 272 n: 0.12
CS SS 2018 1
N: 136 n: 0.23
N: 17 n: 0.02
N: 173 n: 0.36
LB SS 2018 1
N: 1464 n: 1.75
N: 1256 n: 1.38
N: 1660 n: 2.59
CS AW 1989 2

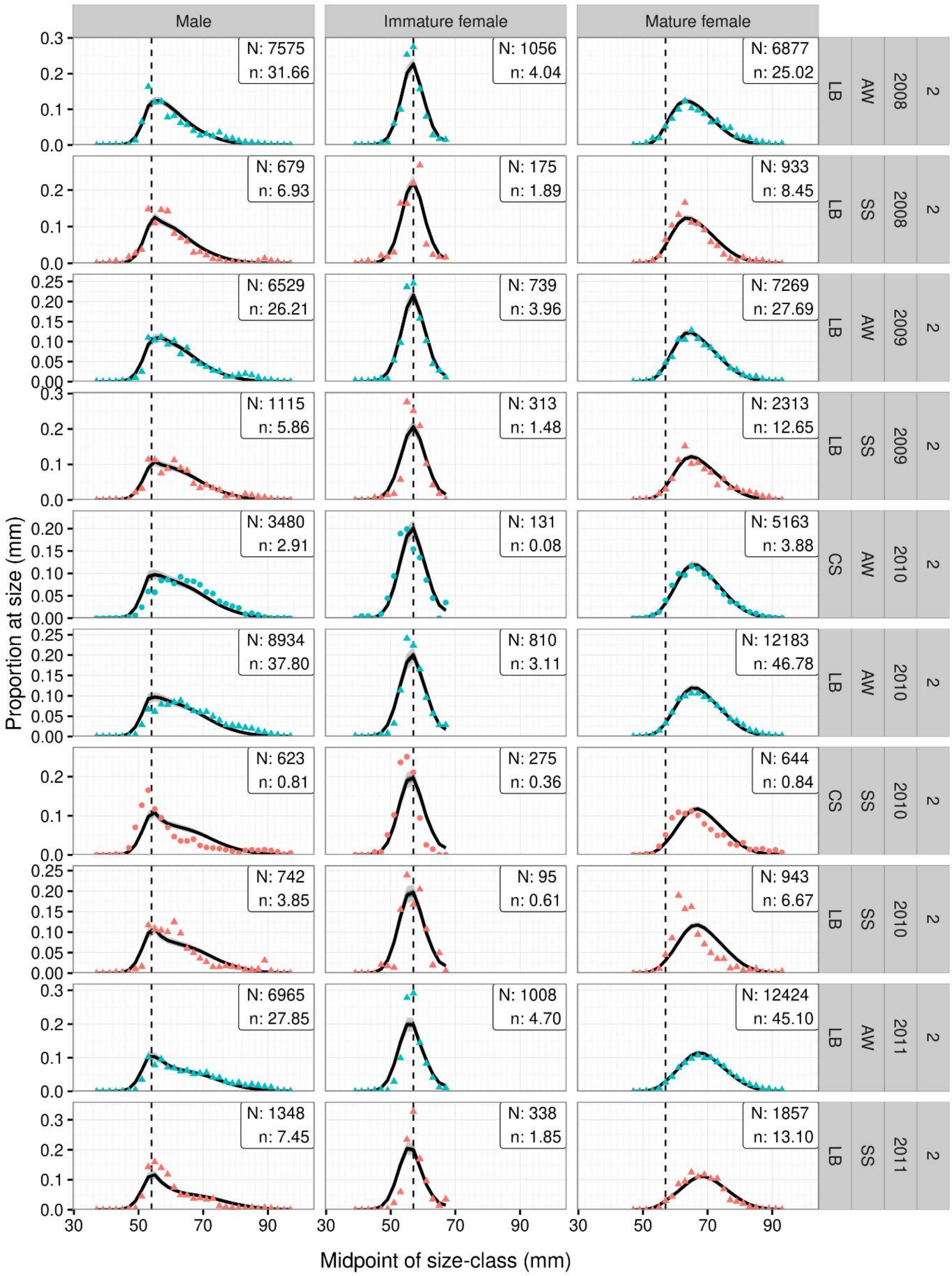

Male
Immature female
Mature female
N: 5093
n: 4.23
N: 5099
n: 3.47
N: 2575
n: 2.61
CS SS 1989 2
N: 6097
n: 12.81
N: 4684
n: 10.31
N: 2080
n: 5.12
CS AW 1990 2
N: 6513
n: 9.60
N: 4922
n: 6.59
N: 3340
n: 6.05
CS SS 1990 2
N: 6870
n: 9.38
N: 4139
n: 5.89
N: 4069
n: 5.43
CS AW 1991 2
N: 7012
n: 9.88
N: 4776
n: 6.14
N: 6130
n: 7.47
CS SS 1991 2
N: 5580
n: 11.40
N: 2326
n: 4.73
N: 4036
n: 7.89
CS AW 1992 2
N: 7265
n: 9.76
N: 4015
n: 5.13
N: 4253
n: 6.15
CS SS 1992 2
N: 4736
n: 10.64
N: 3050
n: 6.70
N: 2665
n: 5.47
CS AW 1993 2
N: 7358
n: 38.19
N: 3419
n: 18.11
N: 3959
n: 22.37
LB AW 1993 2
N: 4419
n: 24.21
N: 3139
n: 15.46
N: 2526
n: 18.34
LB SS 1993 2
Proportion at size (mm)
Midpoint of size-class (mm)


Male
Immature female
Mature female
Proportion at size (mm)
Midpoint of size-class (mm)
N: 4096 n: 7.96
N: 2366 n: 3.82
N: 3383 n: 8.43
CS SS 1993 2
N: 7512 n: 10.20
N: 4698 n: 5.99
N: 4267 n: 7.34
CS AW 1994 2
N: 5187 n: 27.89
N: 2920 n: 15.14
N: 3152 n: 23.08
LB AW 1994 2
N: 3829 n: 6.17
N: 2133 n: 3.18
N: 3177 n: 5.76
CS SS 1994 2
N: 4476 n: 26.34
N: 3058 n: 15.22
N: 3189 n: 26.91
LB SS 1994 2
N: 3003 n: 7.74
N: 1711 n: 4.49
N: 3973 n: 8.49
CS AW 1995 2
N: 6481 n: 41.30
N: 3664 n: 22.22
N: 5043 n: 35.71
LB AW 1995 2
N: 3585 n: 8.85
N: 1958 n: 3.97
N: 4243 n: 15.24
CS SS 1995 2
N: 6435 n: 43.78
N: 4125 n: 23.09
N: 6366 n: 52.07
LB SS 1995 2
N: 3338 n: 28.33
N: 1952 n: 17.07
N: 2221 n: 28.57
LB AW 1996 2

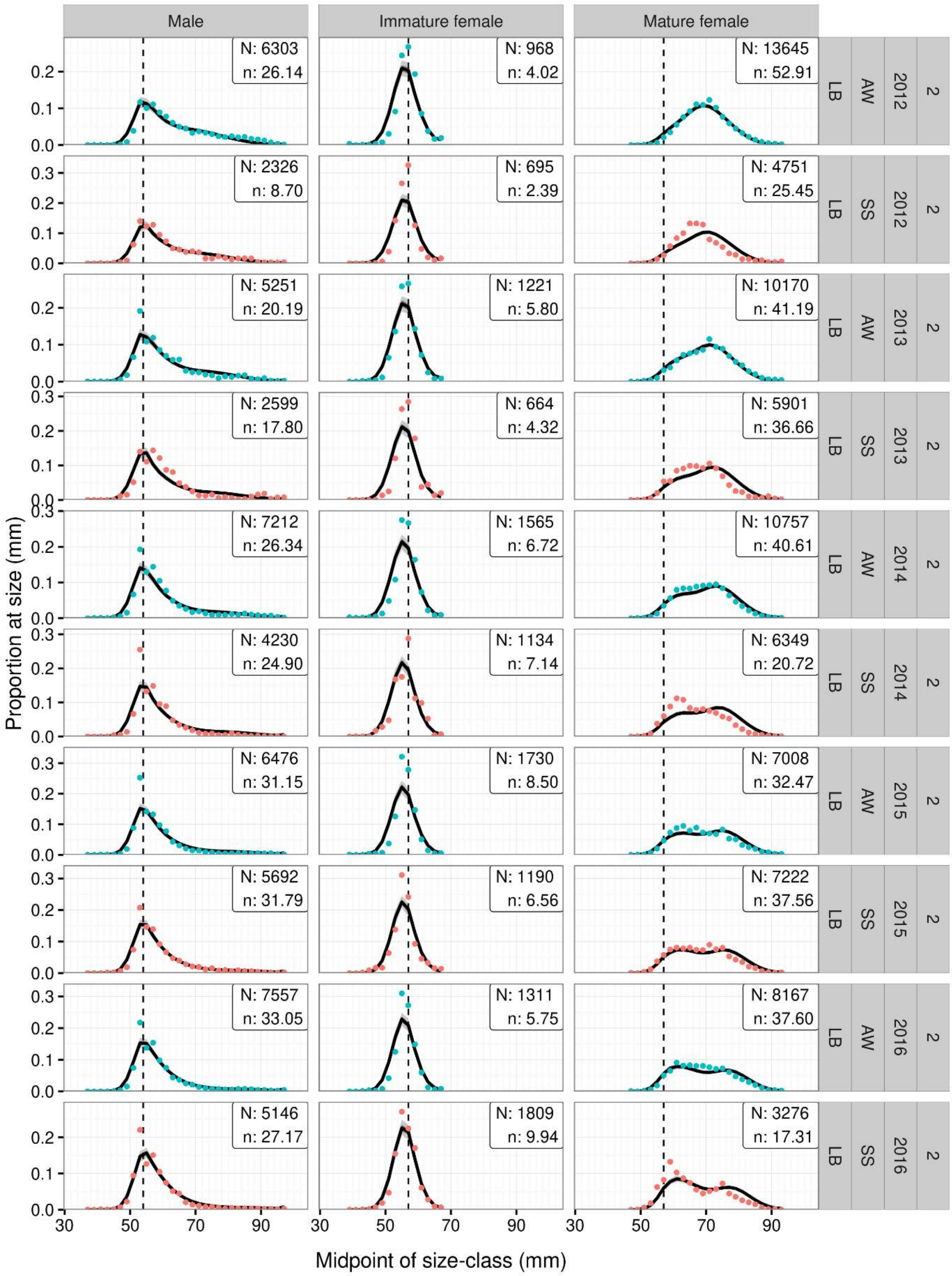

Male
Immature female
Mature female
N: 5755
n: 10.67
N: 5193
n: 8.05
N: 3850
n: 13.20
CS AW 1996 2
N: 5380
n: 7.76
N: 5950
n: 6.70
N: 5586
n: 16.44
CS SS 1996 2
N: 3419
n: 29.06
N: 2189
n: 15.94
N: 4455
n: 47.32
LB SS 1996 2
N: 1400
n: 4.06
N: 1426
n: 3.91
N: 2950
n: 11.32
CS AW 1997 2
N: 2820
n: 28.30
N: 1782
n: 20.36
N: 4272
n: 41.10
LB AW 1997 2
N: 1915
n: 5.18
N: 2219
n: 4.47
N: 2504
n: 12.85
CS SS 1997 2
N: 2202
n: 22.54
N: 1219
n: 13.20
N: 4640
n: 45.42
LB SS 1997 2
N: 3766
n: 36.24
N: 2688
n: 25.68
N: 2731
n: 30.00
LB AW 1998 2
N: 3189
n: 25.31
N: 2108
n: 13.14
N: 4059
n: 39.51
LB SS 1998 2
N: 2803
n: 30.59
N: 2150
n: 20.83
N: 1528
n: 25.72
LB AW 1999 2
Proportion at size (mm)
Midpoint of size-class (mm)

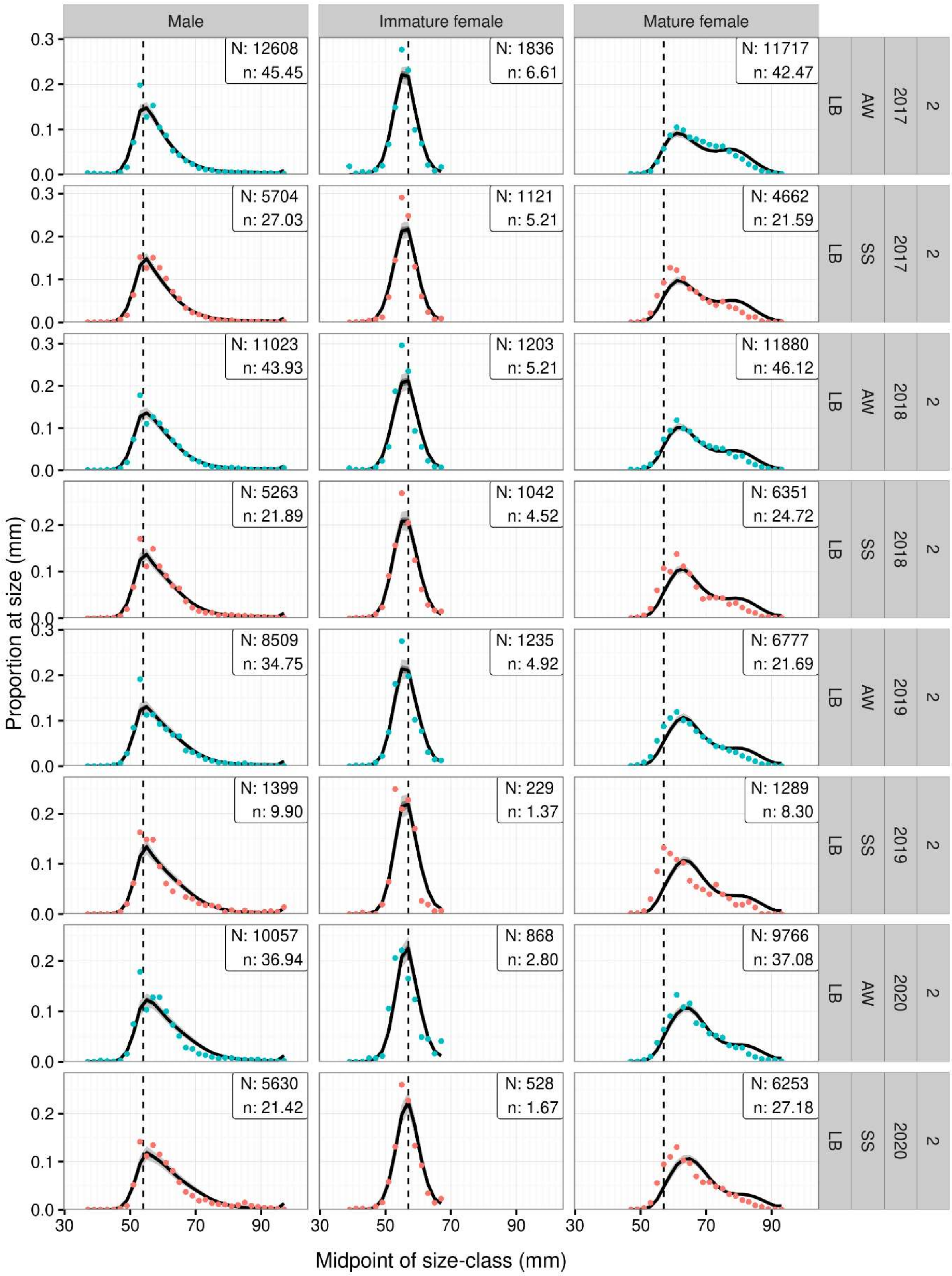

Male
Immature female
Mature female
N: 1572
n: 15.38
N: 1196
n: 9.46
N: 1357
n: 17.41
LB SS 1999 2
N: 1919
n: 3.50
N: 1200
n: 2.41
N: 558
n: 1.27
CS AW 2000 2
N: 5378
n: 50.39
N: 4486
n: 40.74
N: 2198
n: 21.67
LB AW 2000 2
N: 1578
n: 18.71
N: 957
n: 10.22
N: 1263
n: 15.86
LB SS 2000 2
N: 2213
n: 24.37
N: 1626
n: 17.98
N: 1389
n: 16.64
LB AW 2001 2
N: 903
n: 12.74
N: 390
n: 5.64
N: 1044
n: 13.94
LB SS 2001 2
N: 2782
n: 4.00
N: 1583
n: 2.34
N: 1034
n: 1.37
CS AW 2002 2
N: 4453
n: 35.07
N: 2719
n: 21.42
N: 2862
n: 24.71
LB AW 2002 2
N: 1356
n: 1.83
N: 1928
n: 2.60
N: 902
n: 1.22
CS SS 2002 2
N: 1023
n: 8.29
N: 783
n: 6.21
N: 961
n: 7.53
LB SS 2002 2
Proportion at size (mm)
Midpoint of size-class (mm)


Male
Immature female
Mature female
Proportion at size (mm)
Midpoint of size-class (mm)
LB AW 2003 2
LB SS 2003 2
LB AW 2004 2
LB SS 2004 2
LB AW 2005 2
LB SS 2005 2
LB AW 2006 2
LB SS 2006 2
LB AW 2007 2
LB SS 2007 2
N: 6067 n: 46.23
N: 3822 n: 30.01
N: 3280 n: 29.33
N: 480 n: 6.38
N: 355 n: 6.46
N: 315 n: 4.43
N: 5791 n: 43.05
N: 2816 n: 22.68
N: 2955 n: 25.12
N: 215 n: 1.13
N: 94 n: 0.82
N: 122 n: 0.22
N: 5597 n: 28.20
N: 2375 n: 12.60
N: 3274 n: 19.31
N: 496 n: 3.00
N: 194 n: 1.56
N: 322 n: 0.86
N: 6793 n: 29.40
N: 1770 n: 8.23
N: 6115 n: 28.75
N: 968 n: 5.64
N: 271 n: 1.39
N: 715 n: 3.98
N: 6279 n: 24.43
N: 943 n: 4.53
N: 4125 n: 16.08
N: 1117 n: 7.32
N: 342 n: 2.20
N: 1236 n: 6.79



Male
Immature female
Mature female
N: 7575
n: 31.66
N: 1056
n: 4.04
N: 6877
n: 25.02
LB
AW
2008
2
N: 679
n: 6.93
N: 175
n: 1.89
N: 933
n: 8.45
LB
SS
2008
2
N: 6529
n: 26.21
N: 739
n: 3.96
N: 7269
n: 27.69
LB
AW
2009
2
N: 1115
n: 5.86
N: 313
n: 1.48
N: 2313
n: 12.65
LB
SS
2009
2
N: 3480
n: 2.91
N: 131
n: 0.08
N: 5163
n: 3.88
CS
AW
2010
2
N: 8934
n: 37.80
N: 810
n: 3.11
N: 12183
n: 46.78
LB
AW
2010
2
N: 623
n: 0.81
N: 275
n: 0.36
N: 644
n: 0.84
CS
SS
2010
2
N: 742
n: 3.85
N: 95
n: 0.61
N: 943
n: 6.67
LB
SS
2010
2
N: 6965
n: 27.85
N: 1008
n: 4.70
N: 12424
n: 45.10
LB
AW
2011
2
N: 1348
n: 7.45
N: 338
n: 1.85
N: 1857
n: 13.10
LB
SS
2011
2
Proportion at size (mm)
Midpoint of size-class (mm)


Male
Immature female
Mature female
N: 6303
n: 26.14
N: 968
n: 4.02
N: 13645
n: 52.91
LB
AW
2012
2
N: 2326
n: 8.70
N: 695
n: 2.39
N: 4751
n: 25.45
LB
SS
2012
2
N: 5251
n: 20.19
N: 1221
n: 5.80
N: 10170
n: 41.19
LB
AW
2013
2
N: 2599
n: 17.80
N: 664
n: 4.32
N: 5901
n: 36.66
LB
SS
2013
2
N: 7212
n: 26.34
N: 1565
n: 6.72
N: 10757
n: 40.61
LB
AW
2014
2
N: 4230
n: 24.90
N: 1134
n: 7.14
N: 6349
n: 20.72
LB
SS
2014
2
N: 6476
n: 31.15
N: 1730
n: 8.50
N: 7008
n: 32.47
LB
AW
2015
2
N: 5692
n: 31.79
N: 1190
n: 6.56
N: 7222
n: 37.56
LB
SS
2015
2
N: 7557
n: 33.05
N: 1311
n: 5.75
N: 8167
n: 37.60
LB
AW
2016
2
N: 5146
n: 27.17
N: 1809
n: 9.94
N: 3276
n: 17.31
LB
SS
2016
2
Proportion at size (mm)
Midpoint of size-class (mm)
30
50
70
90



Male
Immature female
Mature female
N: 12608
n: 45.45
N: 1836
n: 6.61
N: 11717
n: 42.47
LB AW 2017 2
N: 5704
n: 27.03
N: 1121
n: 5.21
N: 4662
n: 21.59
LB SS 2017 2
N: 11023
n: 43.93
N: 1203
n: 5.21
N: 11880
n: 46.12
LB AW 2018 2
N: 5263
n: 21.89
N: 1042
n: 4.52
N: 6351
n: 24.72
LB SS 2018 2
N: 8509
n: 34.75
N: 1235
n: 4.92
N: 6777
n: 21.69
LB AW 2019 2
N: 1399
n: 9.90
N: 229
n: 1.37
N: 1289
n: 8.30
LB SS 2019 2
N: 10057
n: 36.94
N: 868
n: 2.80
N: 9766
n: 37.08
LB AW 2020 2
N: 5630
n: 21.42
N: 528
n: 1.67
N: 6253
n: 27.18
LB SS 2020 2
Proportion at size (mm)
Midpoint of size-class (mm)