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The 2024 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 3

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PLAIN LANGUAGE SUMMARY

The red rock lobster (*Jasus edwardsii*) supports the most valuable inshore commercial fishery in New Zealand. This fishery has been managed with catch quotas in nine Quota Management Areas (QMAs), which are usually treated as independent populations or stocks.

This document describes a stock assessment of red rock lobster in CRA 3 up to the 2023–24 fishing year. This stock assessment suggests that CRA 3 has experienced a period of steep decline in biomass over the past 10–15 years. Declining catch rates over this period corroborates this decline. However, projections suggest that the stock may increase slightly over the next five years.

More concerning is the decline in the number of females in CRA 3 since the early 2000s, evidenced by the depressed catch rate of females in recent years, which now account for less than 25% of the landed catch in terms of numbers of lobsters.

EXECUTIVE SUMMARY

Roberts, J. [1]**; Webber, D.N.**[2]**; Rudd, M.B.**[3]**; Starr, P.J.**[4]**; Pons, M.**[5] **(2025). The 2024 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 3.** ***New Zealand Fisheries Assessment Report 2025/34*****. 213 p.**

This document describes the 2024 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 3. Covariates and data included catch estimates for all sectors of the CRA 3 fishery, catch-per-unit-effort (CPUE) series, length frequency (LF) distributions and sex ratios, proportions of mature females that were in berry (egg-bearing), and tag-recapture growth increment data. The stock assessment used the lobster stock dynamics (LSD) model to evaluate the current status of the CRA 3 stock by fitting to these data. Data inputs and technical decisions were discussed and agreed upon by the Rock Lobster Working Group, who oversaw this work.

The reconstruction of the catch in this stock assessment began in 1945 because this was the first year with usable catch data. This stock assessment assumed a two-region model defined by component statistical areas (region 1 = Statistical Areas 909+910, region 2 = Statistical Area 911). This decision was based on an analysis of LF data specific to each region which showed a consistent difference between the two regions, with larger lobsters caught in Statistical Area 911 than in Statistical Areas 909+910, for most of the available year/season/sex comparisons. Additionally, the standardised Catch Effort Landing Return CPUE trends for the two regions diverged after 2012, with Statistical Area 911 remaining flat or increasing slightly while Statistical Areas 909+910 were decreasing. Another major difference between regions concerned the observed contribution of females in the catch by weight, which has been consistently below 20% in region 1 since the mid-1990s, while the percentage of females in the catch by weight was closer to 40% in region 2 over the same period.

An exploration of sex-specific CPUE determined that the abundance of females in CRA 3 region 1 was likely to have declined relative to that of the males, which is consistent with the declining proportion of females in the catch of region 1. The declining trend in female abundance experienced by the fishery was corroborated by a similar trend seen in fishery-independent survey data collected inside and outside of Te Tapuwae o Rongokako marine reserve since around 2010. The reasons for this trend are poorly understood, although candidate causes include warming sea surface temperatures and/or density dependent effects on growth. High fishery exploitation rates targeted towards females seems unlikely given the strong male-bias in the commercial fishery and given that the same pattern is observed both inside and outside the reserve. The updated CRA 3 assessment represented this sex ratio trend by estimating a time- and sex-specific M by region, which eliminated the strong trend in the region 1 sex ratio residuals and resulted in a more pessimistic prediction of current and projected spawning stock biomass (SSB) status for CRA 3.

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 the assessment was based on maximum *a posteriori* fits and subsequent Markov chain Monte Carlo (MCMC) simulations. The stock assessment estimated that the region 1 vulnerable biomass declined to a low level around 1970 and then increased to a level well above the initial equilibrium biomass around 1980, while the region 2 vulnerable biomass descended steadily from its initial equilibrium level to less than half of the reference level by the early 1990s. The region 1 vulnerable biomass dropped from its 1980 peak to a level below the reference level by the early 1990s, reflecting the intense fishery operating at that time. Both regions reached a low point in the abundance series around 1992, at which time active

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management intervention was undertaken by the then Ministry of Agriculture and Fisheries. Vulnerable biomass recovered in both regions from this low level, due to good recruitment in the early- to mid-1990s, coupled with a reduction in the estimated exploitation rate in both regions from 1995–2000. There was another cycle of reduced abundance in both regions followed by a recovery, which peaked in the early to mid-2010s. This peak appeared to be more pronounced in region 2 than in region 1. Both regions then experienced another period of decline in vulnerable biomass up to the early 2020s. SSB, particularly in region 1 but also in region 2, showed a steep continuous decline after 2010 and was near to or below the soft limit of 20% SSB_0 in both regions at the end of 2024.

1. INTRODUCTION

The National Rock Lobster Management Group (NRLMG) and Fisheries New Zealand directed that stock assessments for the CRA 3 and CRA 4 red rock lobster (*Jasus edwardsii*, CRA) Quota Management Areas (QMAs) would be done in 2024. The CRA 3 assessment was completed during May–November 2024, in fulfilment of Objective 6 of Fisheries New Zealand contract CRA2022-01. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Working Group (RLWG). The assessment of this stock was initially presented to the Fisheries New Zealand mid-year Plenary on 7 August 2024 but was rejected because the assessment failed to fit the available data credibly. Further analyses were commissioned, and a revised stock assessment was presented and approved by the Fisheries New Zealand mid-year Plenary on 6 November 2024 (Fisheries New Zealand 2024).

The CRA 3 QMA for red rock lobster extends from East Cape south to the Wairoa River in northern Hawke Bay and is comprised of three Statistical Areas (909, 910, and 911) (Figure 1). The RLWG agreed that CRA 3 was best evaluated by separating the QMA into two regions defined by component statistical areas (region 1 = Statistical Areas 909+910, region 2 = Statistical Area 911), as was also done for the 2019 assessment for CRA 3 (Starr et al. 2020). This decision was based on an analysis of length frequency (LF) data specific to each region which showed a consistent difference between the two regions, with larger lobsters caught in Statistical Area 911 than Statistical Areas 909+910 for most of the available year/season/sex comparisons. Additionally, the standardised CELR CPUE trends for the two regions diverged after 2012, with Statistical Area 911 remaining flat or increasing slightly and Statistical Areas 909+910 decreasing. Also, the observed proportion of females in the catch of region 1 was consistently below 0.2 from the mid-1990s, while this proportion was closer to 0.4 in region 2, over the same period.

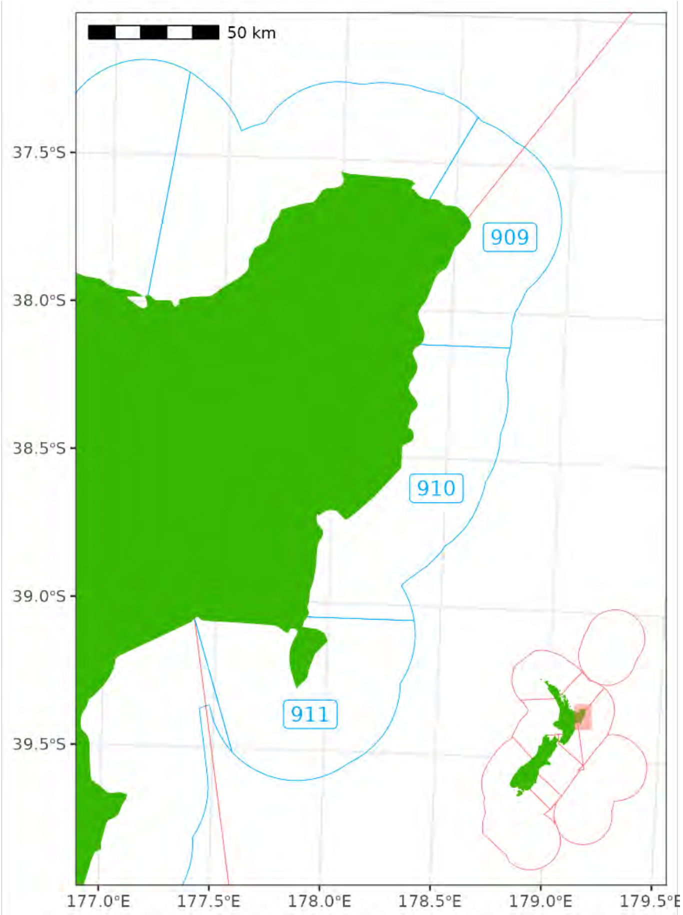


Figure 1: The CRA 3 Quota Management Area (QMA) boundaries (solid red lines) and statistical area boundaries (solid blue lines). In the two-region CRA 3 stock assessment, region 1 includes Statistical Areas 909 and 910, and region 2 is Statistical Area 911.

Potting and hand-gathering are the preferred methods for recreational fishers in CRA 3. Most of the recreational catch is taken during the summer months, consistent with all New Zealand rock lobster recreational fisheries. The region also supports several charter boat operators that cater to recreational fishers that are predominantly diving during the summer months. Lobsters are important to Māori in this area, and the customary allowance allows lobsters to be taken under permit.

The CRA 3 commercial fishery is by regulation a trap or pot fishery, fished by small boats on primarily day trips and in relatively shallow waters. There are two processing plants in Gisborne and product is also shipped to Wellington, Tauranga, and Auckland for processing and export. CRA 3 rock lobsters are packed for live export from three locations in Auckland. The number of commercial vessels operating in CRA 3 has declined through time, with a high of 86 vessels counted catching at least 1 tonne/year in 1984–85 and a low of 20 vessels in 2022–23 (Starr 2025). A fixed annual Total Allowable Commercial Catch (TACC) was set for CRA 3 at 195 tonnes (t) in 2021–22 but was reduced to 156 t in 2024–25. Allowances of 8 t for recreational catch, 60 t for 'other fishing mortality', and 20 t for customary catch were implemented by the Minister of Oceans and Fisheries to produce a Total Allowable Catch (TAC) of 244 t for 2024–25. From 1 April 2024, 20 tonnes of commercial catch was voluntarily shelved given concerns about the effects of February 2023 cyclones Gabrielle and Hale on the productivity of the stock.

The current minimum legal size (MLS) for red rock lobsters in the CRA 3 recreational fishery is 54 mm tail width (TW) for males and 60 mm TW for females. The current MLS for the commercial fishery in region 1 is 52 mm TW for males during the winter months of June, July, and August, 54 mm for males during the remaining months of the year, and 60 mm for females in all months. For region 2, the current voluntary MLS for the commercial fishery is 54 mm TW for males and 60 mm for females in all months of the year. Fishers in region 1 implemented a voluntary closure from 1 September to 15 January beginning in 2007 while region 2 fishes year-round. In the recreational and commercial fisheries, there is a general prohibition on the taking of berried females and soft-shelled individuals.

The 2019 stock assessment of CRA 3, documented by Webber et al. (2020), was an integrated length-based model fitted to length frequency data, sex ratio data, tag-recapture growth increment data, and standardised catch-per-unit-effort (CPUE) indices. The 2019 assessment depicted a stock that had declined rapidly between 1960 and 1970, followed by a plateau until about 1980, and then oscillated over roughly a 10-year cycle, with the stock increasing slightly after 1980 and then steadily declining until 1992. From that low point, it increased until 1998, declined until 2004, and then increased again to 2013. Since 2013, the stock declined and was projected in 2019 to further decline at the levels of catch at the time. However, at no point was the spawning stock biomass (SSB) predicted to fall below the soft limit (the default of 20% SSB_0). This was thought to be mainly due to the small size at maturity ogive estimated for CRA 3, which predicted that nearly all females greater than 50 mm TW were mature.

This document presents a new stock assessment for CRA 3, which includes a new CPUE series based on logbook data, updates to the length frequency and sex ratio standardisation procedures, and the estimation of the proportion of mature females in berry by season up to the end of the 2023[6] fishing year. The CRA 3 stock was assessed using a two-region model (region 1 consisted of Statistical Areas 909+910 and region 2 included Statistical Area 911) using the lobster stock dynamics (LSD) model (Webber et al. 2023). This document summarises the updated stock assessment for CRA 3 and the generation of the stock assessment inputs (a change from recent rock lobster assessments which reported the data inputs and covariates in a separate FAR from the stock assessment outputs, e.g., Rudd et al. 2024; Webber et al. 2024).

The covariates and data used in this stock assessment are summarised in Section 2.1 and Section 2.2, below. The stock assessment model settings are described in Section 3.1, model parameters and priors are defined in Section 3.2, and the stock assessment outputs, including stock status indicators, are defined in Section 3.3. The stock assessment results are presented in Section 3.4 to Section 3.7. As part of this assessment, a meta-analysis was done to understand the unusual catch composition of region 1 of CRA 3 in the context of patterns observed across New Zealand stocks. Also, a sex-specific CPUE meta-analysis was done to understand changes in the sex ratio over time, which influenced the selection of the base case model structure with major implications for estimates of SSB and stock status. These meta-analyses are documented in Appendices to this report and are referred to at relevant points in the main text.

2. DATA AND COVARIATES

2.1 Data

The data sets fitted to in this stock assessment included commercial fishery CPUE time series, length frequencies (LFs) and sex ratios (SRs) of the commercial catch, and tag-recapture data collected by commercial and recreational fishers. Each of these data sets have different temporal extents (Figure 2).

[6] The 2023–24 fishing year is referred to in this document with the first year (2023) of the pair of years.

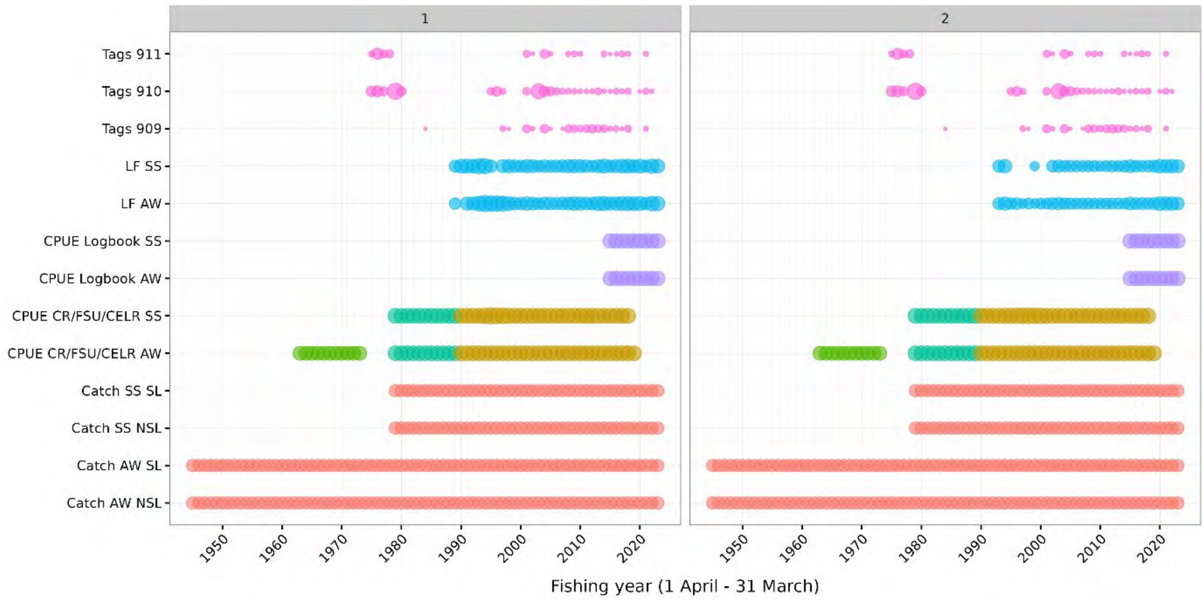


Figure 2: Data extent by region and fishing year used in the CRA 3 stock assessment. The size of the bubbles represents the relative number of recaptured tags by statistical area, the effective sample size for length frequency distributions, the standard deviation for CPUE, or a fixed size for catch. Bubble colours vary for the different data sets (CPUE colours: CR = green, FSU = teal, CELR = gold, LB = purple). See Section 2.1.1 for a detailed description of these data.

2.1.1 Catch per unit effort (CPUE)

Four separate CPUE series were generated and used in this stock assessment, which are summarised below (all series) and in Table 1 (for the model-based series):

- The **catch rate (CR)** series, which is an annual arithmetic daily catch rate from 1966 to 1973. This series is documented in Bentley et al. (2005).
- The **Fisheries Statistics Unit (FSU)** series, which is a seasonal standardised index from autumn/winter (AW) 1979 to AW 1989. The standardisation model was fitted to catch rate data by weight, aggregated by vessel, month and statistical area. Explanatory variables included fishing year, month, statistical area, and vessel. The FSU CPUE standardisation included all vessels. Data originated from the FSU database, a static copy of which is held by the rock lobster stock assessment team (Bentley et al. 2005). The FSU CPUE series used in this stock assessment differed from the equivalent series used in the 2019 CRA 3 stock assessment (Starr et al. 2020) through the inclusion of a vessel explanatory variable, which was not used in 2019.
- The **Catch Effort Landing Return (CELR)** series, which is a seasonal standardised series extending from spring/summer (SS) 1989 to AW 2019. The standardisation model was fitted to catch data by weight aggregated by vessel, month and statistical area and included year, month, statistical area, and vessel explanatory variables. The CELR CPUE standardisation data set only included vessels that had fished for at least five years in CRA 3. This CPUE series was unchanged from the equivalent series used in the 2019 CRA 3 stock assessment (Starr et al. 2020), except for the addition of the 2019 AW indices for both region 1 and region 2.
- The **logbook (LB)** series, which is a seasonal standardised series from AW 2015 to SS 2023 (the reported proportion of pots with zero catch was highly variable prior to this, along with questionable representativeness; Table B.1) based on data collected by CRA 3 fishers within a voluntary self-sampling programme. The standardisation model was fitted to pot-based catch data in terms of numbers of lobster caught per potlift and included period (season/year combination), month, statistical area, and vessel explanatory variables. The logbook CPUE

standardisation model included all vessels that reported logbook data in CRA 3 and all live lobsters above the MLS. This was because, when the catch in a pot exceeded the pot measuring limit of 25 lobsters, excess lobsters were enumerated as being above or below the MLS, with no accounting for berried females. The data used in this analysis were obtained from Fishserve (John Olver, pers. comm.) in October 2024.

Table 1: Summary table of standardised CPUE models developed for this assessment. Note that a CPUE model was not used to derive the catch rate (CR) series from 1963 to 1973, which was calculated as the annual kg of legal lobsters per day of fishing (Annala & King 1983).

Series	Response unit	Data aggregation	Model structure	Assumed statistical distribution	Period
Fisheries statistics unit	Kg per pot of legal lobsters	By month	CPUE ~ period + (1 | month) + (1 | vessel) + area + (1 | period:area)	Lognormal	1979 AW – 1989 AW
Catch effort landing return	Kg per pot of legal lobsters	By month	CPUE ~ period + (1 | month) + (1 | vessel) + area + (1 | period:area)	Lognormal	1989 SS – 2019 AW
Logbook	Number above the MLS	By pot	lobsters ~ period + (1 | month) + (1 | vessel) + area + (1 | period:area) zi ~ (1 | vessel)	Zero-inflated negative binomial	2015 AW – 2023 SS

An apparent change in reporting behaviour associated with the change in commercial catch and effort data collection from paper forms to electronic monitoring prevented the extension of the CELR CPUE abundance series beyond the AW of the 2019 fishing year (see appendix B in Starr 2025 for the evidence supporting this decision). Note that a catch sampling (CS) series, based on numbers of lobsters and all live lobsters per pot, was also developed and used by early model runs. However, this series was not used in any of the final model runs due to concerns from the RLWG about the representativeness of this series caused by the relatively low number of trips sampled per annum and the ability of samplers to skip pots, so this series is not described any further.

The FSU series was updated from the series described in Starr et al. (2020) by adding the catching vessel as an explanatory variable. However, this series was nearly identical to the series used in the 2019 stock assessment and it was used without further testing. No formal model comparison was done for the CELR CPUE series, which included only one additional season of new data (AW 2019) compared with the series used by the 2019 assessment. Instead, a generic CELR standardisation model structure was used which had been selected by CPUE model comparisons for all recent assessments (e.g., Roberts et al. 2023; Webber et al. 2024). However, the LB series, based on pot-level data, was new for this assessment and two alternative model structures were developed and compared for accounting for the large proportion of pots with zero catch: one that used the same model structure as the CELR series and another that also included a vessel-based zero-inflation term.

Diagnostic plots and other outputs for the CELR and LB CPUE models are provided in Appendix A and Appendix B, respectively (note that outputs for region 1 are labelled ‘910’, although this included both Statistical Areas 909 and 910; ‘911’ is the region 2 series). For the CELR CPUE model: there was good data overlap through time with respect to different statistical areas, months, and vessels (Figure A.1, Figure A.2, Figure A.3); acceptable model convergence was achieved (Figure A.4); there was a good agreement with the assumed statistical distribution (Figure A.5); and the coefficient distribution influence (CDI) plots indicated a minimal correction effect on the resulting CPUE series with respect to vessel, month, and statistical area, particularly in the most recent years (Figure A.6, Figure A.7, and

Figure A.8). The predicted catch rate was also shown with respect to statistical area and month (Figure A.9 and Figure A.10), noting that the month effect was very similar comparing the CELR, FSU, and LB models. The predicted CPUE series was shown by statistical area, which indicated very similar trends occurring in the two regions of CRA 3 up to 2012 (Figure A.11). However, the CPUE series for region 1 has a declining trend since then, compared with a more stable CPUE trend in region 2.

Compared with the CELR series, the logbook catch-effort data still had reasonable overlap over time with respect to different statistical areas, months, and vessels (Figure B.1, Figure B.2, Figure B.3), despite comprising fewer vessels, trips, and pots sampled over time, including the overlapping years (compare Table A.1 and Table A.2 with Table B.1 and Table B.2).

Two alternative models were run using the same LB data, one assuming a negative binomial error distribution (*fit_lb_nb*) and another which included a vessel-based zero-inflation term (*fit_lb_zinb*). Of these, the latter resulted in the superior fit to the data in terms of expected log predictive density (δ-ELPD) (Table B.3) and was used to develop all subsequent model outputs. The resulting LB model had an acceptable level of convergence (Figure B.4) and agreement with the assumed statistical distribution (Figure B.5). As for the CELR model, the coefficient distribution influence (CDI) plots of for the LB model indicated a minimal correction effect on the resulting CPUE series with respect to vessel, month, and statistical area (Figure B.6, Figure B.7, and Figure B.8). The CPUE index trends were also similar when comparing across the CRA 3 regions (Figure B.9).

The two overlapping CPUE series used by this assessment (CELR and LB) showed similar trends across the respective overlapping years (Figure 3), with a consistent declining trend in region 1 from 2012 and a more stable trend in region 2 from 2012 until around 2020. This is followed by a declining trend in the LB series. While not shown and not currently accepted for use in the assessment, an exploratory CPUE series fitted to data collected using electronic monitoring data and another using catch-at-sea sampling data also showed similar decreasing trends since 2019.

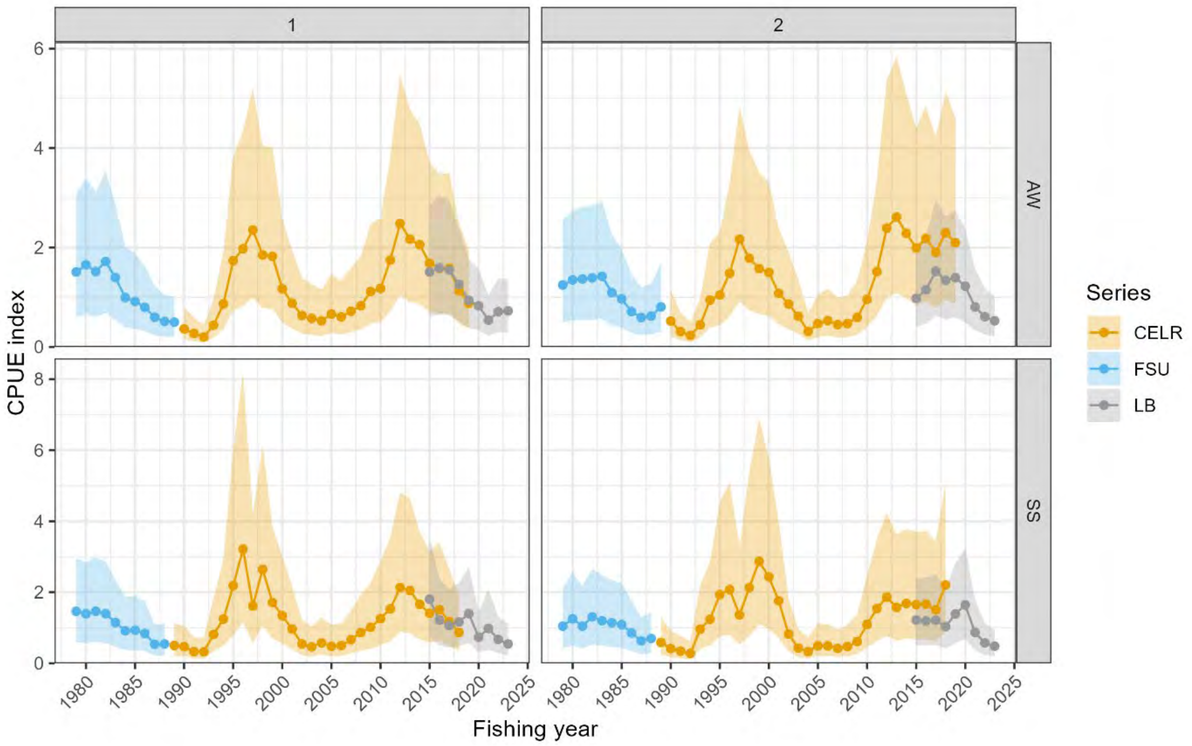


Figure 3: Comparison plot by region and season from 1979 to 2023 showing the three CPUE series used in the CRA 3 stock assessment. 'FSU' = Fisheries Statistics Unit; 'CELR' = Catch Effort Landing [paper] Returns; and 'LB' = logbook.

2.1.2 Length frequency and sex ratio data

The catch must be stratified by sex category (males, immature females, mature females) and length bin before it can be correctly removed from the modelled stock. Splitting the catch in this way was informed by the sex ratio data, the length frequency data, and the proportion of mature females in berry covariate. These inputs were derived from available observer catch sampling (CS)[7] and the voluntary logbook (LB)[8] data sets and standardisation models were developed for all three types of data/covariates using the procedure developed by Webber (2022). The resulting standardised LF distributions were scaled by the monthly commercial catches in each statistical area for each year[9].

The designs of the observer CS and LB programmes are summarised by Webber et al. (2024). The CRA 3 CS programme has sampled at least 5000 lobsters in region 1 and 1000 lobsters in region 2 in each fishing year since 1989 (Table C.1, Table C.2). The 1986 sample in region 1 was deemed by the RLWG to be too small to be representative and was excluded.

The CRA 3 LB programme started in 1993 with eight participants in region 1 and six participants in region 2 (Table C.1, Table C.2). Except for 1999–2002 in region 1 and 2002–2009 in region 2 there has been some LB coverage in both regions in all years since then. While the number of lobsters sampled by the LB programme was smaller than for the CS programme, the number of trips and days of sampling was much greater for the LB programme, e.g., greater than 50 trips sampled in region 1 by the LB programme in all years since 2007, compared with fewer than 25 trips sampled each year by the CS programme over the same period (Table C.1, Table C.2). This reflects the difference in the design of these two programmes, with the LB programme asking fishers to sample the same three to five pots every fishing day while the CS programme puts trained samplers on fishing vessels and attempts to sample the entire daily catch from a limited number of days fishing. Because of the generally superior coverage of fishing trips by the LB programme (Table C.1, Table C.2), it is considered likely to be more spatially and temporally representative of the catch in CRA 3.

Towards the end of this stock assessment, an error was identified in the CS data in the *rlcs* database, affecting measurements made since July 2020. A calliper adjustment had erroneously not been applied to the most recent TW measurements, causing the affected CS measurements to be approximately 2 mm TW smaller than they should have been. Also, for the LB data, the reported statistical area for the respective TW measurements were updated using fisher-reported latitude and longitude data, affecting the attributed statistical area for some biological samples. Thus, the SR and LF models were run using two versions of the data: once using corrected TW data and attributed statistical areas and again using uncorrected values. Only model runs using the corrected measurements and statistical areas are described here, although the model structures, model diagnostics, and outputs were very similar for the two runs, except that lobsters using the uncorrected data were slightly smaller after 2020 relative to the model run using the corrected data.

2.1.2.1 Sex ratio (SR) of the catch

Following the approach of Webber (2022), a model was constructed where the predictor term for each sex category estimated the SR for each fishing year, month, region, and fishing vessel. The explanatory variables included: fishing year, month, region, vessel, a fishing year by month interaction term, and a fishing year by region interaction term. The fishing year, month, and region terms were treated as population-level effects and the vessel and interaction terms were treated as group-level (random) effects.

For a given fishing year, month, region, vessel, data source (LB or CS), and trip, counts of the number of lobsters measured by sex category were generated and arranged as vectors by sex category (i.e., data

[7] obtained from MPI *rlcs* database in September 2024 (replog 16129).
[8] obtained from Fishserve (John Olver, pers. comm.) in October 2024
[9] commercial catch data were obtained from the MPI EDW database in May 2024 (replog 15830).

source and trips were replicates). These counts of lobsters by sex category were fitted using a multinomial distribution and the default *brms* priors were used. MCMC mixing was excellent (Figure C.1). This model was then used to simulate the SR by year, month, and region from the posterior distribution. This model-based approach also predicted the SR if there was catch in a stratum but no catch sampling from either data source and combined the available SR data from both (CS and LB) data sources if both were present in the respective stratum.

The catch (tonnes) in each fishing year, month, and region was calculated from the catch and effort data[9]. The simulated SRs were scaled by the monthly catch in each region and aggregated by posterior sample, fishing year, season, and sex category then converted to proportions (i.e., month and statistical area were rolled up). The mean and SD (i.e., uncertainty) by fishing year, season, and sex category were calculated from this distribution of sex ratios. Finally, the SR data set weight for each fishing year and season was calculated from the posterior SD (see Webber 2022).

For region 1, the standardisation and the catch scaling did not alter the time series of raw sex ratios by fishing year and season (Figure 4). However, for region 2, there was a major standardisation effect for the period beginning in 2013, with the predicted proportion of males in the catch being greater than from the raw data, particularly in SS. Model exploration (not shown here) identified that this standardisation effect occurred with the addition of the vessel term to the model.

Based on the model predictions (and the raw data), the proportion of immature females in the catch of both regions was close to zero in all years (Figure 4). Furthermore, the proportion of *mature* females in the catch was low, particularly in region 1 (close to or lower than 0.1 in nearly all years since the mid-1990s), and has declined since the mid-2000s in both regions.

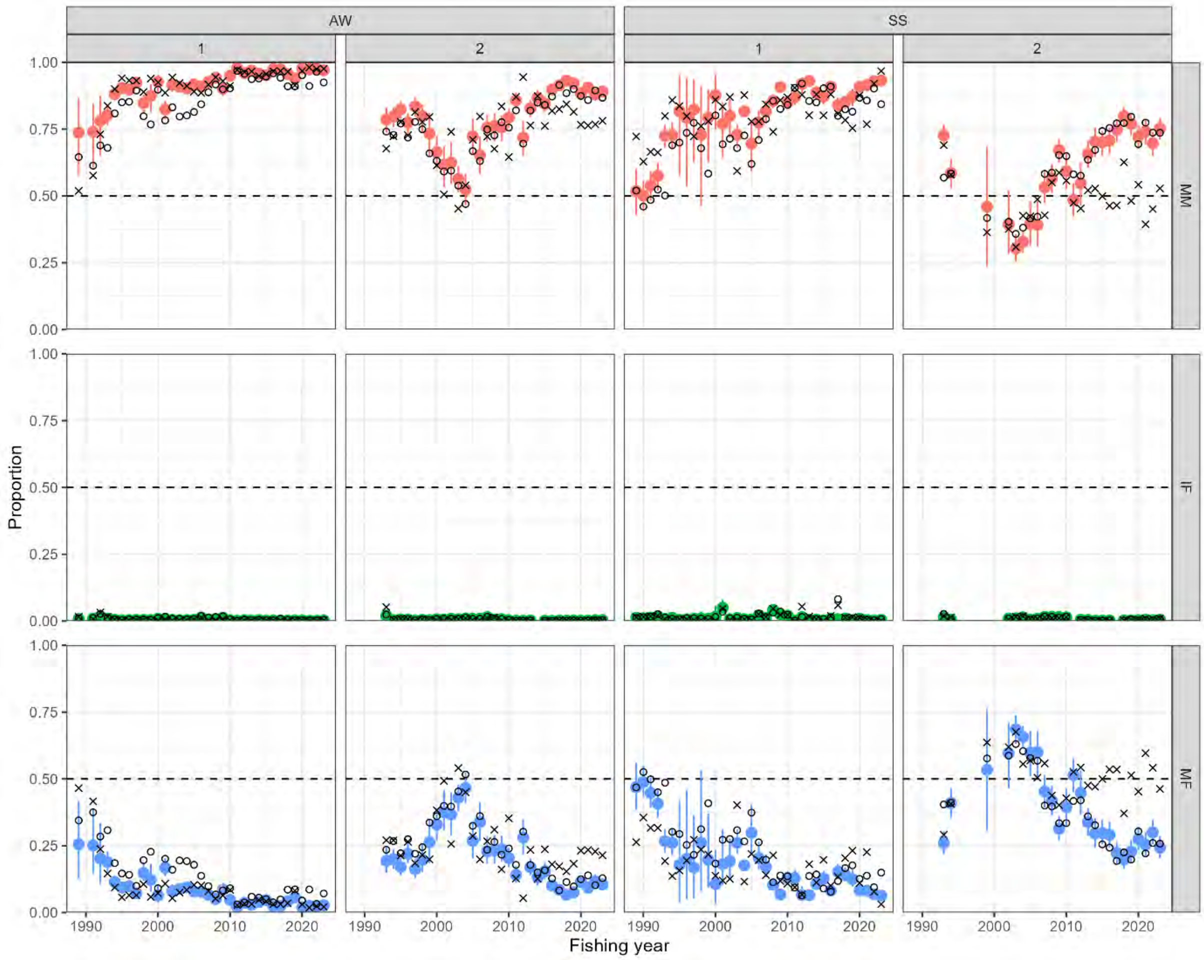


Figure 4. Sex ratio (SR) of males (MM), immature females (IF), and mature females (MF) by fishing year, season (AW = autumn/winter, SS = spring/summer), and region (1 = 909+910, 2 = 911), showing raw SRs (black crosses), predicted SRs (open black circles), and scaled SRs (closed circles with error bars representing 95% credible intervals).

2.1.2.2 Length frequency of the catch

Following the approach of Webber (2022), a model was constructed that estimated proportions at length for each sex category (i.e., male, immature female, and mature female) in the catch for each fishing year, month, and region. The explanatory variables included: fishing year, month, region, vessel, and a fishing year by region interaction term. All terms were treated as group-level (random) effects.

For a given sex category, fishing year, month, region, vessel, data source (LB or CS), and trip, counts of the number of lobsters measured by tail width (TW) bin were generated and arranged as vectors by sex category (i.e., data source and trips were replicates). These counts of lobsters by size category were fitted separately for each sex category using a Poisson decomposed multinomial distribution and the default *brms* priors. MCMC mixing was acceptable for each sex category (Figure C.2, Figure C.3, Figure C.4).

The fitted LF models were used to simulate the predicted LF by sex category, fishing year, month, and region from the posterior distribution. This model-based approach also predicted the LF if there was catch in a stratum but no catch sampling from either data source and combined the available LF data from both data sources if both (LB and CS) data sources were present in the stratum. The catch (tonnes) in each fishing year, month, and region was calculated from the commercial catch and effort data[9]. The simulated LFs were scaled, first by the sex ratio model, then by the monthly catch in each region and aggregated by posterior sample, region, fishing year, season, sex category, and length bin then converted to proportions. The mean and SD by region, fishing year, season, sex category, and length bin were calculated from the posterior distribution. Finally, the data set weight for each region, fishing year, season, and sex category was calculated from the posterior SD.

In most years, the sample sizes were reasonably high and the standardised LFs (i.e., the scaled, predicted LFs) were very similar to the LFs produced from the raw data (Figure C.5 to Figure C.20), but at lower sample sizes (e.g., mature females in region 1 in AW of 2022) (Figure C.12) the procedure adjusted the LFs considerably. Scaling the LFs by the catch generally did very little to alter the predicted LFs. This was because the CS programme is adjusted in each year so that the samples are approximately proportional to the catch by statistical area, while the LB programme design attempts to mimic fishing patterns, resulting in a data set that is essentially self-weighting.

The standardised LFs in region 1 were quite narrow and changed little through time, with a very small proportion of lobsters of either sex being smaller than 40 mm TW or larger than 60 mm TW for males or larger than 65 mm TW for females (Figure 5). By comparison, the males and mature females in region 2 were generally 5–10 mm TW larger than in region 1 and exhibited greater variation in size distribution over time. However, the standardised CRA 3 LFs were generally similar when comparing adjacent years, with periods of slightly larger male and female lobsters in the late-1990s and the 2010s in region 2 (Figure 5). Accordingly, the mean tail width of males and mature females was greatest in the late-1990s and the 2010s in both the CS and LB data sets (Figure 6). Notably, since the early 2000s there has been a consistent declining trend in the mean TW of immature females over time in the AW period that is not apparent in the SS period, although the proportion of the overall sample comprised of immature females was small (Figure 4).

The standardised LFs were similar when using the uncorrected CS data, except that the resulting TW distributions were slightly smaller since 2020 (compare Figure 5 with Figure C.21).

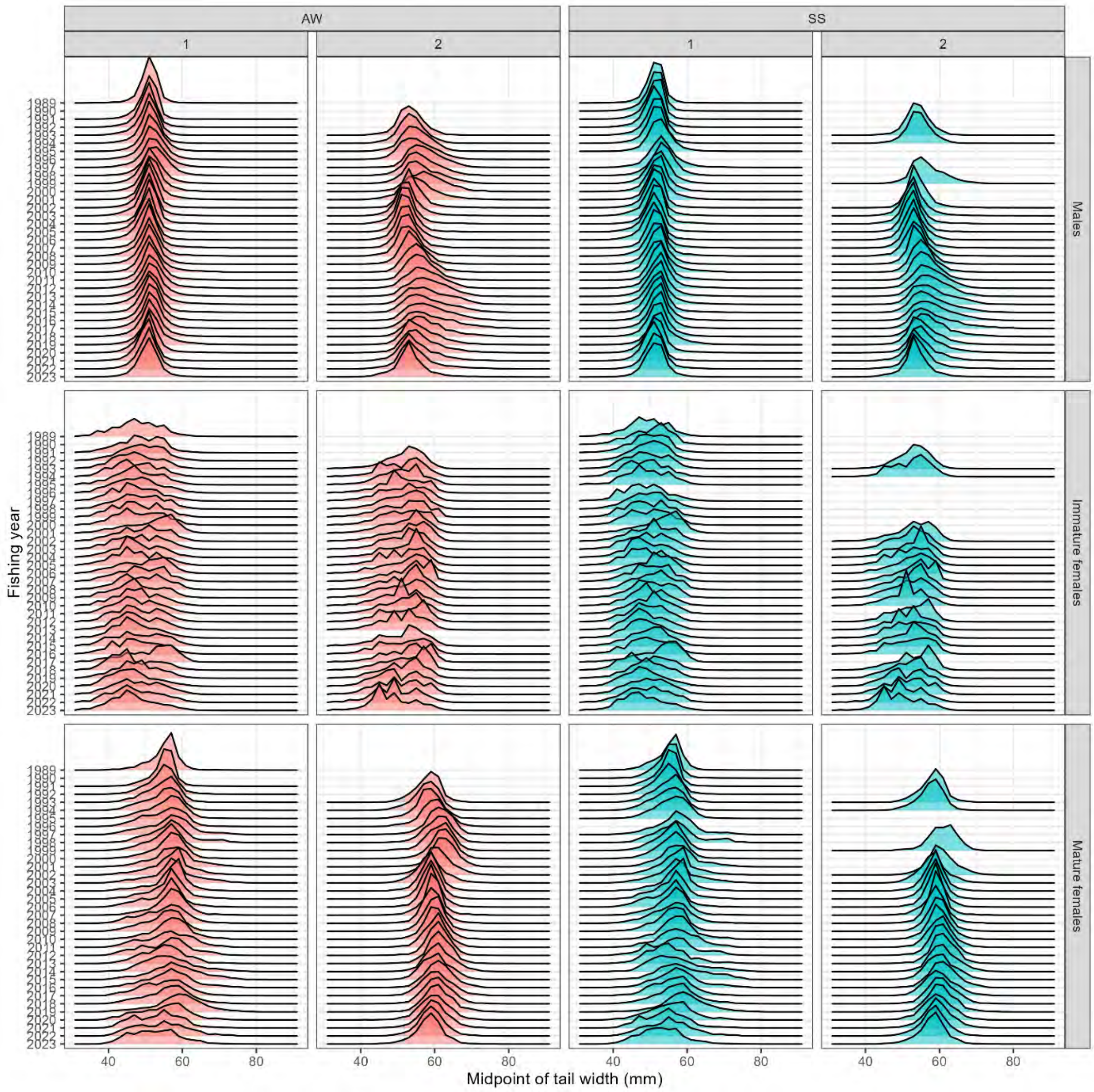


Figure 5. Predicted standardised LFs by fishing year (from 1989 to 2023), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex. See Figure C.5 to Figure C.20 for a comparison of raw and standardised LF distributions by year, season and sex.

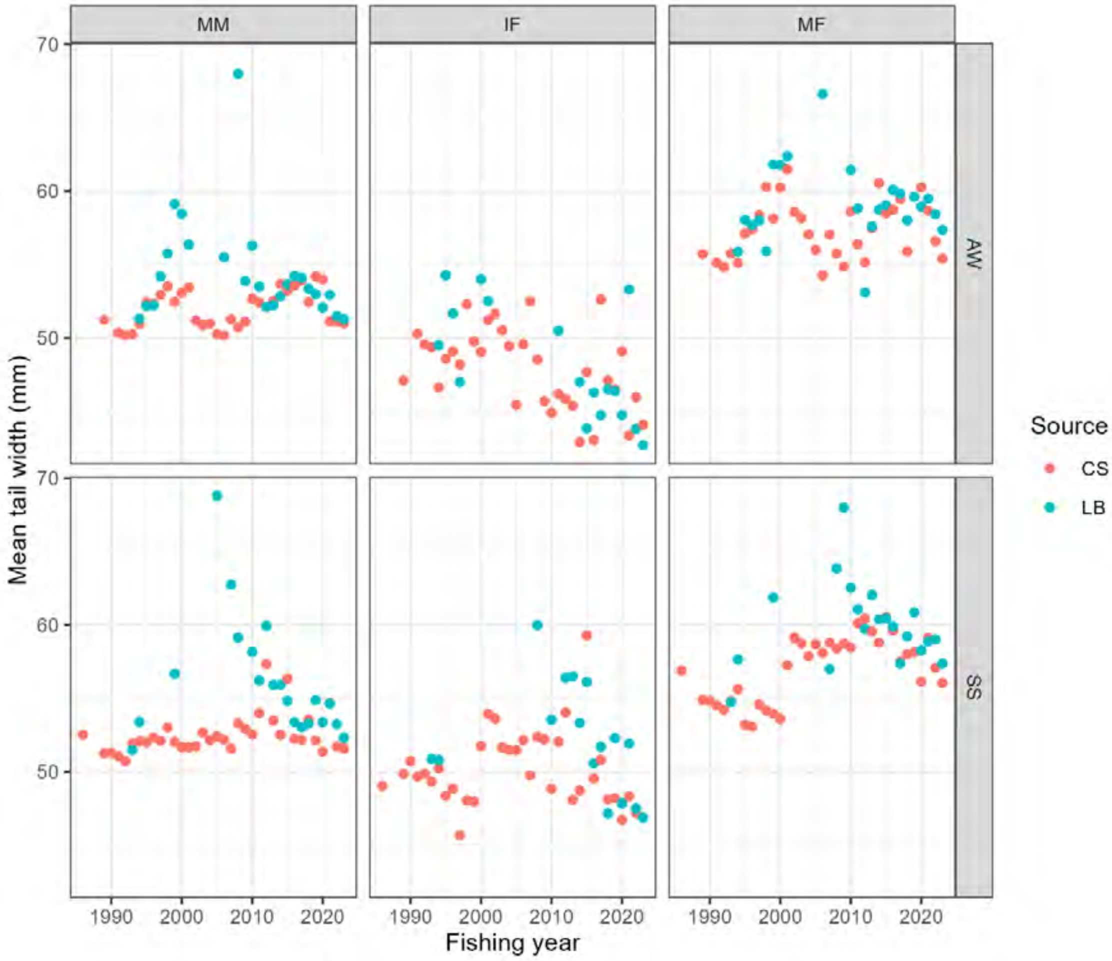


Figure 6. Mean tail width (mm) by fishing year, sex category (MM = males, IF = immature females, MF = mature females), season (AW = autumn/winter, SS = spring/summer), and data source (CS = observer catch sampling, LB = voluntary logbook).

2.1.3 Tag-recapture data

This section describes tag-recapture data that were used to inform growth in the stock assessment of rock lobster stocks. These data were also useful for informing decisions about stock structure and movement. Tag data for all QMAs were obtained in May 2024 from Fisheries New Zealand (replog 15841).

2.1.3.1 Data processing

Before the tag data were used to inform growth in stock assessments, they were processed (i.e., obvious errors were corrected and records that cannot be used were removed). This required that every release-recapture event for a tag was linked to create a single record, while all tags with no recaptures were discarded. Processing, linking, and formatting were done using purpose-built software written in the *R* statistical computing language (see section 5.1 in Starr et al. 2020 for a description of these preparatory steps).

A comparison was done to ensure that the new data extract was not missing records that were available in previous years and to see how many new data records were available (Table D.1, Table D.2). This comparison showed an overall increase in the number of usable recoveries of 117 tags for all New Zealand compared to the same total from last year, with nearly all the new usable recaptures coming from recaptures made in 2022 and 2023.

2.1.3.2 Tag data summary

Recovery rates (tags returned relative to numbers released) varied by QMA, with the highest rate occurring in CRA 8 (30.3%) and the lowest rate in CRA 9 (2.0%) (Table D.3). There were 36 007 complete release/recovery record pairs (i.e., not missing a key piece of information such as sex, QMA or statistical area, initial size, recapture size, or time at liberty) available in the New Zealand rock lobster tagging data set, of which 22 148 were males and the remaining 13 859 were females (Table D.4). The QMA with most recovered tags was CRA 8, and the fewest recaptured tags came from CRA 6 and CRA 9, which had 270 recoveries and 129 recoveries respectively (Table D.4). Tagged lobsters were primarily recaptured in the statistical area of release, but there was evidence that some individuals moved much greater distances (Table D.5).

The updated CRA 3 assessment used paired individual tag-recapture observations from initial tag releases (i.e., not from re-released lobsters) in all three CRA 3 Statistical Areas (909, 910, and 911). A large proportion of the tagging effort in CRA 3 took place from 1975–1980, with nearly all the remaining tag recaptures coming from releases from 1995–2022 (Table D.6). Tagging effort in CRA 3 was distributed across all three statistical areas, with Statistical Area 910 having about 60% of the recoveries and the others having around 20% each. Across all CRA 3, there was a total of 5801 recaptures of which 4436 were males and 1365 were females (Table D.6).

The monthly distribution of tag releases resulting in recaptures is shown in Table D.7. As noted by the 2019 assessment of CRA 3, the distribution of tag releases was highly seasonal with a large proportion of tag releases in July. Very few recaptures were made outside of the statistical area of release (Table D.8). Times at liberty in the processed tag data varied from 1 day to slightly more than 2650 days (~7 years) for females and 2200 days for males (~6 years) (Table D.9). The median periods at liberty were 193 days for females and 181 days for males (Table D.9). A few males were re-released four to seven times, and up to three times for females (Table D.10), which is lower than the corresponding number of recaptures for CRA 4, which exceeded 10 recaptures for some males (Rudd et al. 2025). Only 14% of male recoveries came from re-releases while the equivalent percentage for females was 12%, which again was low relative to the respective proportions for CRA 4 (Rudd et al. 2025). Growth increments (mm) ranged from -18 to +20 mm TW for males and from -25 to +29 mm TW for females (Table D.11).

Following the approach used for the CRA 4 assessment (Rudd et al. 2025), the RLWG agreed to exclude tagged lobsters that had been at liberty for less than six months, based on an analysis that showed a decreasing proportion of lobsters in the zero-growth increment bin as the number of months at liberty increased (not presented). The zero-growth increment bin was interpreted as lobsters which had failed to moult after tagging. Given that moulting is not explicitly accounted for by the growth model used (see Webber et al. 2023), there was concern that the inclusion of short time at liberty observations in the growth model, in conjunction with the highly seasonal tagging effort, would negatively bias any estimates of growth. While the analysis concluded that nearly all zero-growth lobsters had disappeared by the time they had been at liberty for eight months, the RLWG agreed that a six-month exclusion was a reasonable compromise without excluding too much data (Table D.12).

2.2 Covariates

The covariates used in this stock assessment included the catch, assumed handling mortality rates associated with the commercial and recreational catch, the sequence of MLS regulations, estimates of the proportion of mature females in berry (i.e., egg bearing), and other fixed quantities (Table 2).

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 in order to maintain a high-quality product for live export. Handling mortality was applied to undersized lobsters of each sex taken in either season by the size-limited (SL) fishery as well as to mature berried females returned to the water by both the AW and SS SL fisheries. It was assumed that there were no discards in the non-size-limited (NSL) fishery. Destination code X discards were included in the commercial catches, thus assuming 100% mortality.

Table 2: Fixed quantities used in the CRA 3 base case stock assessment model.

Quantity	Value	Quantity	Value
Growth		**Catch and handling**	
length at *Galpha*	30	handling mortality, 1945–1989	0.1
length at *Gbeta*	80	handling mortality, 1990–2023	0.05
Gmin	0.2	projected SL commercial catch	135 t
Gdd	0	projected SL commercial catch	156 t
Length-weight		Projected NSL illegal catch	32.6 t
male *a*	4.16e-6	Projected NSL customary catch	10 t
male *b*	2.935	**Recruitment**	
female *a*	1.3e-5	*sigmaR*	0.4
female *b*	2.545	last year of estimated *Rdevs*	2020
Maturation		*Rdev* years for 5-year projections	2011–2020
mat50 (mm) R1	40	*Rdevs* ‘data years’ for reference level	1989–2020
mat50 (mm) R2	45	years for estimating autocorrelation	1989–2020
mat95 (mm)	10	recruitment autocorrelation R1	0.127
proportion MF in berry (AW) R1	0.721	recruitment autocorrelation R2	0.003
proportion MF in berry (SS) R1	0.005	recruitment size mean	32 mm
proportion MF in berry (AW) R2	0.790	recruitment size SD	2 mm
proportion MF in berry (SS) R2	0.005	**Tail compression**	
		male bins	4 to 23
		immature female bins	4 to 17
		mature female bins	4 to 24
		male bins	4 to 23

2.2.1 Minimum legal size (MLS)

Prior to 1949, there was no MLS for red rock lobster in New Zealand. MLS restrictions were initially implemented for New Zealand red rock lobster as measurements of tail length in inches. This measurement standard was subject to some abuse because tails could be stretched, but it was required because a significant fraction of the national catch came from Fiordland, where it was permissible to tail lobsters at sea. The MLS was changed to a width measurement (in mm) across the spines of the second abdominal segment (called the tail width or TW) in 1988 for all New Zealand red rock lobsters, requiring the conversion of the pre-1988 regulations into equivalent TW measurements for use in the stock assessment model (Breen et al. 1988). MLS regulations in CRA 3 were set at 54 mm for males and 60 mm for females in 1992 (Table 3). However, in 1993, the male MLS in CRA 3 was changed to 52 mm for the winter months of June, July, and August whilst closing the fishery for females in the same months. These regulations were applied for the entire AW season in the stock assessment model because seasonality is defined in 6-month seasons (Table 3). The restriction on the take of females was lifted in 2004 and fishers in region 2 agreed to voluntarily return to the 54 mm TW regulation for males beginning with 2007 (Table 3).

Table 3: The tail-width (mm) minimum legal size (MLS) limits for males and females over time in CRA 3 as applied in the 2024 CRA 3 stock assessment model. Note that MLS before 1987 was expressed in terms of tail-length and has been converted to tail-width using the procedure described by Breen et al. (1988).

region 1 (909+910)			region 2 (911)		
Period	Males	Females	Period	Males	Females
1945–1949	None	None	1945–1949 AW	None	None
			1945–1978 SS	None	None
1950–1951	47	49	1950–1951 AW	47	49
1952–1958	51	53	1952–1958 AW	51	53
			1959–1987 AW		
1959–1987	53	58	1979–1987 SS	53	58
1988–1991	54	58	1988–1991	54	58
			1992 AW		
1992 AW, 1992+ SS	54	60	1992 + SS	54	60
1993-2004 AW	52	100	1993–2004 AW	52	100
2005+ AW	52	60	2005–2006 AW	52	60
			2007+ AW	54	60

2.2.2 Proportion of mature females in berry

The proportion of mature females in berry is a covariate that excludes berried females from the catch in the SL fishery (legal commercial and recreational catch). Previous New Zealand rock lobster stock assessments treated this process as binary, assuming all females were in berry during the AW season and none during the SS season.

Following the approach used in the 2023 CRA 6 stock assessment (Webber et al. 2024), biological data from both the LB[7] and CS[8] sampling programmes were used to derive standardised proportions of berried females during the AW and SS seasons for CRA 3. This analysis also estimated the proportions in berry for the other assessed QMAs/stock regions, which are shown here for completeness.

Previous standardisations of the proportion of mature females in berry, including the latest CRA 4 assessment (Rudd et al. 2025), were based entirely on the LB biological data while this analysis, which covered all CRA QMAs, also included maturity stage information from the CS programme. After excluding records which lacked statistical area information, a total sample of 1 458 895 mature females, of which 40% were from the CS programme was available. This represented a substantial increase in the sample size for some QMAs/regions, including both regions of CRA 3, where more mature females were sampled by the CS programme than by the LB programme.

For the LB sample, berried females were defined as having sex code = 4 (‘berried female’) only. This corrected an error in the analysis used by the CRA 4 assessment, which included sex code = 5 (‘spent female’) in the definition of berried females (Rudd et al. 2025), primarily affecting the predicted proportions in berry in region 2 of CRA 3 (not shown here). For the CS sample, berried females were defined as sex code = 4 (‘berried female’) or sex code = 5 (‘berried female, eyed eggs’). Using these definitions over all CRA QMAs and for both programmes, 643 900 of the sample of mature females were determined to be berried and 814 995 were not.

Following the approach of Webber et al. (2024), there were two stages to the analysis that generated the proportion in berry estimates:

1. a *brms* model-based standardisation was used to produce predictions of the proportion of mature females that were berried/not berried by statistical area or region, fishing year, and month; then
2. using the reported catch in each (area/fishing year/month) stratum, catch-weighted values of the proportion of mature females in berry were produced for each stock-region and season and (as required) fishing year. The catch weighting used the ‘F0_L algorithm’, i.e., excluding

destination code ‘X’ (legal discards).

A binomial distribution was assumed, and models were fitted to the total number of mature females that were in berry (‘successes’), given the total number of mature females sampled (‘trials’) within each respective fishing month – statistical area stratum. The model structure was the identical to the optimal model (*fit10*) of Webber et al. (2024):

<u>*n_berried*</u> | *trials* ~ (1 | *fmonth*) + (1 | *area*) + (1 | *fyear*) + (1 | *fmonth:area*) + (1 | *fyear:area*)

where *n_berried* is the number of mature females in each stratum that were berried, *trials* is the total number of lobsters sampled by the respective stratum, *fmonth* is the fishing month, *fyear* is the fishing year, and *area* is the statistical area or region. Interaction terms were specified between month fished and stock assessment region or statistical area, as well as between fishing year and stock assessment region or statistical area, to allow the month and year effects to vary in space. All parameters were specified as group level parameters (analogous to random effects in frequentist statistics).

The MCMC for model *fit10* mixed acceptably (Figure E.1) with no divergent transitions. The model fits to the data were excellent (Figure E.2). The posteriors of the estimated parameters of model *fit10* were summarised in Table E.3.

The predicted proportions for each QMA/stock assessment region are shown for each season in Table E.4 and Figure E.3, noting that differences when comparing assessment regions reflected contrast in the monthly catch distribution as well as the reproductive cycle of females. The mean estimates (across all fishing years) were used by the CRA 3 stock assessment. Note that the mean values used by the CRA 3 assessment (0.721 in AW and 0.005 in SS for region 1 and 0.790 in AW and 0.005 in SS for region 2) are marginally different from those shown in Table E.4, which were estimated using a more complete extract of the *rlcs* database. Although not used by this assessment, the model was used to predict the seasonal proportions in berry by QMA/region and by fishing year. There were long-term trends for the proportion in berry in some QMAs (e.g., a possible declining trend in both CRA 1 and CRA 2) and evidence for an abrupt drop in this proportion in both regions of CRA 3 around 2012 (Figure E.4), although the proportion in berry in region 1 appeared to have returned to previous levels by the late 2010s.

2.2.3 Catch

2.2.3.1 Commercial catch

The fishing year and calendar year were the same before 1979 for all New Zealand rock lobster QMAs. Since 1979, the fishing year changed to 1 April through 31 March. Reported annual commercial catches from 1945 through to 1978, summarised by calendar year, are held in the CRACE database, with sources documented by Bentley et al. (2005). From 1 January 1979 to 31 March 1986, catches were taken from monthly data summarised by fishing year from data collected by the Fisheries Statistics Unit (FSU), a version of which is documented and held in CRACE (Bentley et al. 2005). The three months of catch from January to March 1979 were added to the 1978 annual total to ensure that no catch was lost when switching from calendar year to fishing year collation.

Beginning 1 January 1979, fisheries data were allocated to each region based on the reported statistical area. This applied to all data types: catch, observer, and logbook catch sampling, and tag-based growth data. However, assigning catch to a region before 1979 was more difficult because spatial catch data were only available from 1963 to 1973, and the area definitions used for these data differed from those used in the post-1978 data period (Annala & King 1983). Only annual estimates by CRA QMA were available for the periods 1974–1978 and 1945–1962 (Bentley et al. 2005). The Annala & King (1983) areas were resolved into regions consistent with the modern statistical area definitions, noting that a) A & K Area 5 almost perfectly overlapped with the combined Statistical Areas 909+910; and b) A & K Area 6 encompassed post-1978 Statistical Areas 911 and 912. Therefore, catches were assigned to Statistical Area 911 by applying a constant proportion of 0.544[10] to the A & K Area 6 annual catches (Starr et al. 2020). Over the period 1974 to 1978, catches by CRA 3 region were assigned by interpolation. Pre-1963 catches were assigned using the mean regional proportion observed from 1963–1967 (Starr et al. 2020).

2.2.3.2 Recreational catch

Seven annual recreational survey catch estimates are available for CRA 3 (Table 4). The estimates from the two Kingett Mitchell national telephone diary surveys in 1999–2000 and 2000–01 (Boyd et al. 2004, Boyd & Reilly 2004) were not accepted by the RLWG for the 2014 CRA 3 stock assessment (Starr et al. 2015), because these survey estimates were considered implausibly high for CRA 3. The earlier regional 1994 and national 1996 telephone-diary surveys, conducted by researchers at the University of Otago, were assessed as being biased, in a review of the available recreational surveys (unpublished minutes: Recreational Technical Working Group [Auckland NIWA, 10–11 June 2004]), because the interview questions possibly underestimated fisher participation rates by allowing for an easy exit from the interview ('soft refusal' bias). The RLWG agreed that these two early surveys should not be used by the 2024 stock assessment. Both the Kingett Mitchell and the Otago surveys were potentially biased high because recreational logbook participants were not closely supervised and may not have accurately recorded their fishing activity. The much larger harvest estimates of the Kingett Mitchell surveys were a result of higher claimed participation in saltwater fishing over the previous 12 months in the initial screening survey.

Table 4: Information available to estimate recreational catch for CRA 3.

Survey	Numbers	Mean weight (kg)	Catch weight (t)	Assumed CV
1994 (Otago: Bradford 1997)	8 000	0.534[1]	4.27	not used
1996 (Otago: Bradford 1998)	27 000	0.534[1]	14.42	not used
2000 (Boyd & Reilly 2004)	270 000	–	146.61	not used
2001 (Boyd et al. 2004)	215 000	–	116.75	not used
2011–12 (NPS: Wynne-Jones et al. 2014)	13 912	0.58	8.07	0.33
2017–18 (NPS: Wynne-Jones et al. 2019)	22 515	0.54	12.21	0.26
2022–23 (NPS: Heinemann & Gray 2024)	9 257	0.62	5.74	0.51
Section 111 reported landings				
Maximum reported landings (t) (in 2016–17)			**3.047**	

[1] SS (spring-summer) mean weight (kg) calculated from commercial sampling data from 1994 to 1996 assuming recreational minimum legal sizes (Starr et al. 2003).

Three large-scale population-based diary/interview surveys (National Panel Survey or NPS) have been conducted by National Research Bureau (NRB) under contract to Fisheries New Zealand from 1 October 2011–30 September 2012 (Wynne-Jones et al. 2014), from 1 October 2017 to 30 September 2018 (Wynne-Jones et al. 2019) and from 1 October 2022 to 30 September 2023 (Heinemann & Gray 2024). These surveys were designed to estimate FMA- and QMA-specific annual catches for all major finfish and non-finfish species (Heinemann et al. 2015), based on an initial screening survey of the resident population of New Zealand, which was sampled from 'mesh block' dwelling cluster strata that had been enumerated by Statistics New Zealand during the most recent national census. A door-to-door survey of households drawn from randomly selected mesh block strata was used to select one putative fisher panellist from any household that claimed to contain at least one marine fisher, who was invited to report their catch for an entire year. Each panellist was contacted at least once a month to see if they had been fishing, and those that claimed to have done so were interviewed using a structured and carefully designed Computer Assisted Telephone Interview (CATI) method to record trip effort and harvest data for any trips that had been reported since the previous reporting period. The survey results were thought to be plausible for CRA 3, with 26 (2011–12), 30 (2017–18), and 10 (2022–23) fishers providing details from 47, 90, and 25 trips where rock lobster were caught for the respective survey years (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019, Heinemann & Gray 2024). These estimates have relatively high CVs (0.33 in 2011–12, 0.26 in 2017–18, 0.51 in 2022–23, Table 4). The surveys provided estimates of

[10] Mean proportion 911/(911 + 912) from 1979–1983 (see table 7 in Starr et al. 2020).

the distribution of fishing platforms used to take lobsters in CRA 3, with boat-based fishing accounting for the majority of the catch (Table 5). Over the three surveys, catch has been roughly even between diving and potting (Table 5). NPS survey results from logbook participants were in terms of numbers of fish. The mean individual weights of the most important finfish and non-finfish species QMAs captured by recreational fishers were estimated in parallel projects (Hartill & Davey 2015, Davey et al. 2019, Davey et al. 2024).

Table 5: Fishing platform and capture method categories for CRA 3 estimated by the national NPS recreational surveys (Wynne-Jones et al. 2014; 2019, Heinemann & Gray 2024).

Category	2011–12			2017–18			2022–23		
	Catch (t)	CV	% of total	Catch (t)	CV	% of total	Catch (t)	CV	% of total
Capture method									
Hand gather by diving	3.92	0.50	48.6	3.78	0.39	31.0	2.86	0.61	49.8
Pot	3.86	0.41	47.9	8.43	0.32	69.0	2.88	0.72	50.2
Other	0.28	0.73	3.5	–	–	-	–	–	–
Platform									
Trailer boat	4.16	0.37	51.5	7.48	0.31	61.3	5.07	0.56	88.3
Larger motor boat or launch	0.31	1.05	3.8	1.29	0.69	10.6	-	-	-
Off land	1.91	0.37	23.7	3.18	0.43	26.0	0.67	0.61	11.7
Other	1.69	0.84	20.9	0.26	0.65	2.1	–	–	–

A recreational catch vector was developed by assuming that recreational catch had been proportional to the CRA 3 spring/summer (SS) abundance, as reflected in the standardised SS CPUE for all CRA 3. The standardised SS CPUE vector was calculated first by region using the FSU series from 1979–1988, CELR series from 1989–2013, and the average of the CELR, catch sampling, and logbook CPUE series from 2014–2023. The SS CPUE for all of CRA 3 was calculated by taking the average of the resulting series across regions. By agreement in the RLWG, the recreational catch vector was based on the first two NPS survey estimates (in tonnes), using the catch values and CVs shown in Table 4. The 2022 NPS survey estimate was not used in this calculation because it was felt that it might be biased by the Cyclone Gabrielle event in January 2023. Because of the loss of the CRA 3 CPUE abundance series in 2019 with the introduction of the ERS, CPUE series were developed from the data available from the CELR, catch sampling and logbook programmes (see below). The SS CPUE estimates from the available series were averaged during overlapping years from 2014 to create a composite CPUE series for use in Eq. 1. A scalar quantity *q* was estimated by obtaining the best fit to these survey estimates when minimising a lognormal distribution using the CVs for each survey (Table 4).

Eq. 1:

$$W_t = w_t N_t$$
$$\widehat{W}_t = \hat{q}_t$$
$$CPUE_t = \sum_{t=1}^{t=3} \frac{\left(log(W_t) - log(\widehat{W}_t)\right)^2}{2\sigma_t^2}$$

where *t* subscripts represent the three recreational surveys estimates (Table 4: 1 = 2011–12 NPS; 2 = 2017–18 NPS; the 2022–23 NPS was not used); $w_t$is the mean SS weight >= MLS for sampled lobster in year/survey *t* for CRA 3; N_t is the mean number of lobsters in year/survey *t* for CRA 3; $CPUE_t$is the CRA 3 SS standardised CPUE in year *t*; and $\widehat{W}_t$ is the CRA 3 estimated recreational catch (tonnes) for year *t*.

Eq. 2:

$$\boldsymbol{\widehat{W}_{1945} = 0.2\widehat{W}_{1979}}$$
$$\widehat{W}_y = \hat{q}CPUE_y \text{if y} \geq 1979$$
$$\widehat{W}_y = \widehat{W}_{y-1} + \frac{\widehat{W}_{1979} - \widehat{W}_{1945}}{1979 - 1945} \quad \text{if y} > 1945 \text{ \& y} < 1979$$

The estimated recreational catch trajectory was constructed in the following manner:

a. CRA 3 SS CPUE was used to scale recreational catch, using the *q* estimated in Eq. 1 (Eq. 2, Figure 7 left);

b. recreational catch in 1945 was assumed to be 20% of recreational catch in 1979 and was scaled linearly between 1945 and 1979;

c. when available, Section 111 destination code ‘F’ annual catches were added; the maximum value over the CELR period (= 3.05 t observed in the 2016–17 fishing year; Table 2) was used in years when Section 111 destination code ‘F’ catch was not available;

d. charter boat estimates in the years available were added, based on ACV-ACR reporting data; and

e. estimated recreational catch values in NPS Years (2011, 2017, and 2022) were replaced with the sum of the NPS survey catches, the estimated charter vessel catches and the declared S.111 catches. Charter boat catches reported by panellists were excluded when calculating NPS estimates, to avoid any double counting of charter boat catches (Figure 7 right).

The annual recreational catch estimates were split assuming 10% was caught in AW and 90% was caught in SS. Those seasonal recreational catches were then split by region assuming the same proportion as observed commercial catch in the same fishing year (Figure 8). The commercial catch split was 62.9% from region 1 and 37.1% from region 2 on average across years.

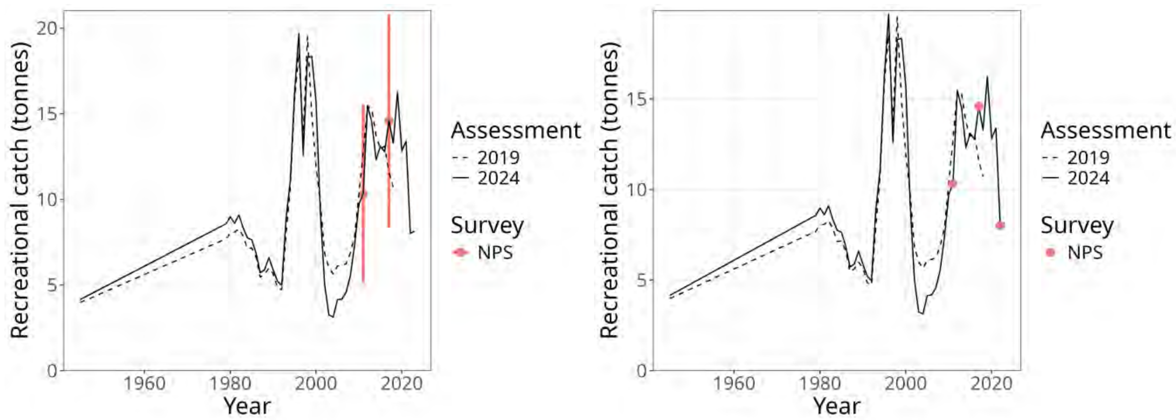


Figure 7: [left panel] CRA 3 recreational catch trajectory (tonnes) (Eq.2) from 1979 based on the standardised SS seasonal CRA 3 CPUE series fitted to two recreational catch surveys (Eq. 1 and Table 4). Error bars are ±2 SE, assuming a lognormal distribution. [right panel] CRA 3 recreational series showing all three of the NPS survey estimates.

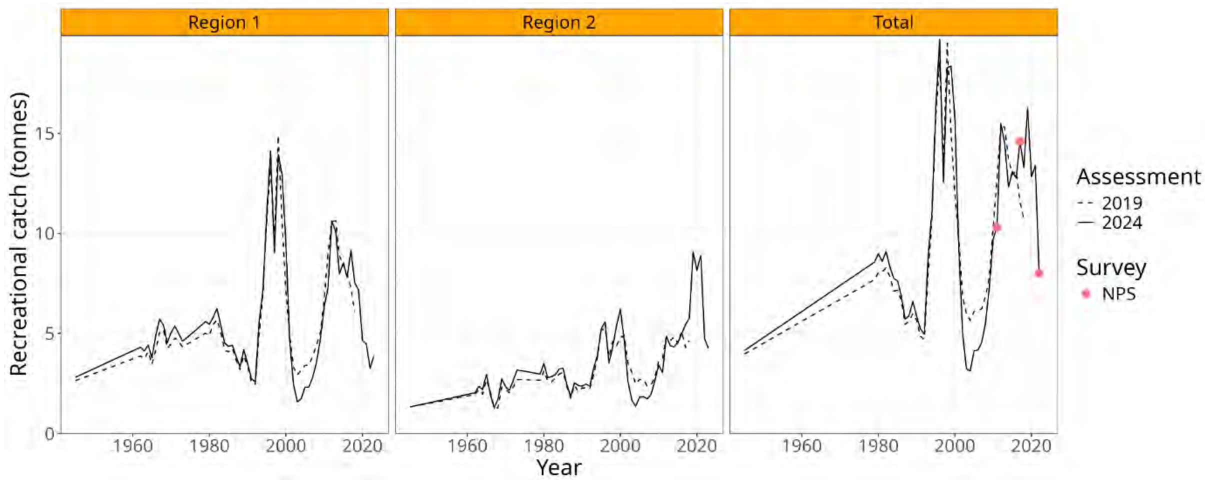


Figure 8: CRA 3 regional and total recreational catch trajectory (tonnes). Also shown is the equivalent recreational catch series used in the 2019 CRA 3 stock assessment.

2.2.3.3 Customary catch

Fisheries New Zealand were asked to provide estimates of current and historical customary catches, and an appreciation of their uncertainty. Fisheries New Zealand advised that a constant customary catch of 10 t should be assumed. This was split between seasons with 90% assumed taken in the SS. The customary catch estimates for each region by year and season were based on the observed commercial catch regional distribution in the same fishing year and season.

2.2.3.4 Illegal catch

For the 2024 stock assessment, the RLWG continued to reject the use of the estimates of illegal catch from MPI Compliance Services, as well as to discontinue the use of the early export discrepancies. Instead, the RLWG agreed to use fixed percentages of the total commercial catch from 1945 to 2023, assuming 20% of the pre-1990 catches and 15% of the commercial catches from 1990 onwards. This represented a change from the 2019 stock assessment, which used alternative fixed percentages of the catch (10% and 20%) over the period 1981–2018. Note that the 2019 stock assessment used the export discrepancy estimates for the pre-1981 illegal catches, a procedure that was discontinued for 2024. As done by the 2019 stock assessment, the RLWG did not agree to scale the resulting catch total proportionately to the annual standardised CPUE index because this approach led to very large catches in the years with high CPUE. Instead, a constant average level of illegal catch was assumed to be 20% of the total commercial catch from 1945–1990 and 15% of total commercial catch from 1991 onwards (Figure 9, solid line). When these annual catch estimates were used in the stock assessment model as seasonal catches, they were assumed to be distributed between seasons in the same proportion as the commercial catch for each year. The commercial catch regional splits were also used to create regional catch estimates (Figure 9). The proportion of commercial catch across seasons and regions was 36.7% in region 1 AW, 23.3% region 1 SS, 18.8% region 2 AW, and 21.2% region 2 SS on average across years.

The estimated illegal catch vector used in the stock assessment accounted for 1536 t of historical catch from 1945 to 1978 and for 1604 t from 1979 to 2023.

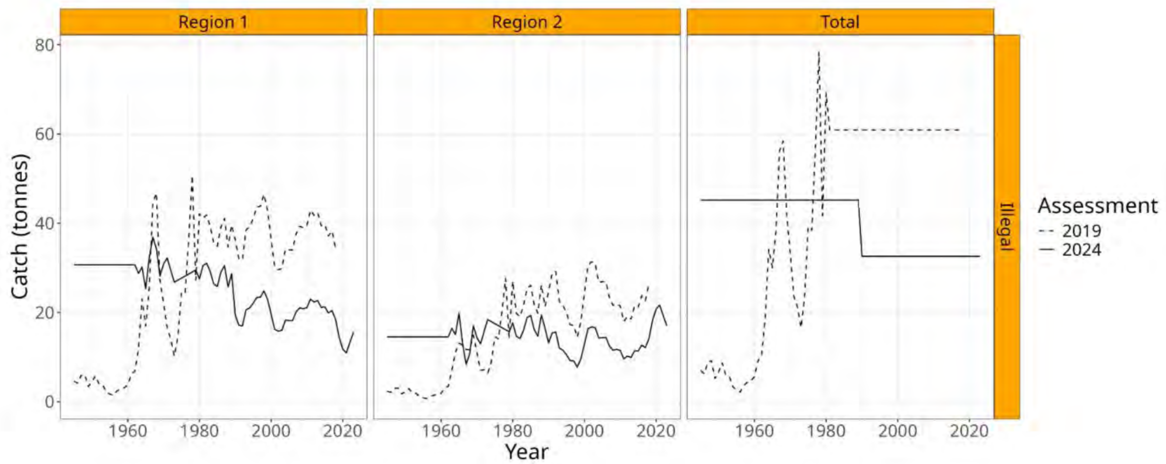


Figure 9: CRA 3 illegal catch trajectories split by region and total CRA 3 for the 2024 stock assessment. The commercial catch regional proportions by year were used to assign the illegal catches by region. The 2024 illegal catch series is compared with the export discrepancy series (1945–1980) followed by the 20% illegal catch series from 1981–2018 that was used by the 2019 stock assessment.

3. STOCK ASSESSMENT

This section describes a stock assessment for CRA 3 done in 2024, using the length-based lobster stock dynamics (LSD) model (Webber et al. 2023). The LSD model was coded in Stan (Stan Development Team 2016, 2017) and has been used as the main assessment software for all currently assessed rock lobster stocks in New Zealand, including CRA 1 (2019), CRA 2 (2017, 2022), CRA 3 (2019, 2024), CRA 4 (2020, 2024), CRA 5 (2020), CRA 6 (2018, 2023), and CRA 7&8 (2021).

Maximum *a posteriori* (MAP) estimation and Markov chain Monte Carlo (MCMC) simulation were used to make inferences about the stock. MAP inference involved identifying the set of parameter values that represented the mode of the density specified by the model. This set of parameter values may be used as parameter estimates or as an approximation of a Bayesian posterior. MAP inference was used for exploring alternative modelling choices without committing the computing time required for Bayesian inference (using MCMC) while Bayesian inference was used to characterise parameter uncertainty. The LSD model uses the Stan software to run MCMC simulations using the Hamiltonian Monte Carlo (HMC) algorithm.

MAP runs were used to develop a base case model and then a series of MAP model runs were used to explore the sensitivity of model outputs to changes in model structure and inputs. Full Bayesian inference using MCMC was completed for the base case model run and a subset of the sensitivity model runs. The posterior distribution of the base case model run was used to derive the CRA 3 reference level following the methods described in Rudd et al. (2021). Finally, the posterior distribution from the base case was used to project forward five years for providing management advice.

3.1 Model

The lobster stock dynamics (LSD) model (Webber et al. 2023) tracks the numbers of individual lobsters in three sex categories (immature females, mature females, and males) for each of 31 two-mm TW bins (from 30 mm to 90+ mm), by year and season. The first model year was set to 1945. The last year in the reconstruction of the stock was 2023, but this was extended to 2028 for the projections. The model used two six-month seasons within a model year: AW (April to September) and SS (October to March). The 2024 stock assessment split CRA 3 into two regions, as was done in the previous assessment for this stock in 2019 (Webber et al. 2020). The RLWG agreed that CRA 3 was best evaluated by separating the QMA into two regions defined by component statistical areas (region 1 = Statistical Areas 909+910; region 2 = Statistical Area 911). This decision was based on an analysis of length frequency (LF) data specific to each region which showed a consistent difference between the two regions, with larger lobsters caught in Statistical Area 911 than in Statistical Areas 909+910 for most of the available year/season/sex comparisons (Starr et al. 2020). Additionally, the standardised CELR CPUE trends for the two regions diverged after 2012, with Statistical Area 911 remaining flat or increasing slightly and with combined Statistical Areas 909+910 decreasing. Also, the observed proportion of females in the catch of region 1 was consistently below 0.2 since the mid-1990s, while this proportion was closer to 0.4 in region 2, over the same period.

Within each region, new recruits to the model were added equally for each sex during each season. The size at recruitment was assumed to be normally distributed with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm) (Table 2). Recruitment in a specific year was determined by the mean recruitment parameter (R_0) and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero and standard deviation of 0.4. Recruitment deviations were estimated for 1945–2020. Stock assessments for other QMAs typically estimated recruitment deviates up to two years before the final model year. This was adjusted for the 2022 CRA 2 stock assessment due to an estimated recruitment spike in 2019 when that recruitment deviate was estimated. While this could be caused by an observation of small individuals recruited in recent years or model weighting to fit increasing CPUE, the Plenary was uncomfortable with including this recruitment spike and wanted to wait until more years of data were available to inform it. This practice was continued for the 2024 CRA 3 and CRA 4 stock assessments, so the most recent estimated recruitment deviate was 2020 in this stock assessment. The 2021 to 2023 recruitment deviations were fixed to be the same as the 2020 recruitment deviation during the model fitting phase.

For each sex category within each region, a growth transition matrix specified the probability of an individual remaining in the same size class or transitioning to another size class. Separate growth models were assumed for each region and sex (males and females). The 2024 CRA 3 stock assessment fixed the four *Galpha* parameters (one for each combination of region and sex) to their MAP values due to convergence issues. The *Gobs* parameters by region describing the standard deviation of observation error for tag-recaptures were also fixed to 1.0.

The proportion of immature females becoming mature each time step (maturation) was specified using a two-parameter logistic curve, with separate curves for each region. The 2024 CRA 3 stock assessment fixed both the length at 50% maturation at 40 mm and 45 mm for regions 1 and 2 respectively, and 10 mm difference between length at 95% and 50% maturation for both regions.

A logistic selectivity ogive was assumed to define the size composition of the catch, which was assumed to be size class, region, and sex specific and the same for both immature and mature females. Selectivity was assumed to be the same during the AW and SS seasons. Separate selectivities were estimated for females in region 1 for two time periods, prior to 1993 and from 1993 onwards. The functional form of these selectivity ogives differed from that used in the 2019 assessment (Webber et al. 2020), which assumed a double normal ogive with a large, fixed value specifying the right-hand limb while the 2024 selectivity ogive was logistic. Other than the structure of the selectivity function itself, the assumptions about selectivity by size, region, sex, year, and season were the same as the 2019 assessment. Vulnerability parameters defined the relative scaling (i.e., the height) of the selectivity curves by sex, region, and season, with immature and mature females sharing the same vulnerability parameters. Vulnerability parameters were estimated relatively, with the vulnerability for males fixed to one in each season and the remaining female vulnerability parameters estimated to be between zero and two. All previous red rock lobster assessments using LSD have chosen a single vulnerability parameter to fix to one (usually males during the AW) and then estimated the other vulnerability parameters relatively but assumed they must be between zero and one. The 2024 CRA 3 stock assessment is the first rock lobster stock assessment to allow estimated vulnerability parameters to be higher than the vulnerabilities fixed at one (generally the males). The 2019 CRA 3 assessment fixed the maximum male vulnerability in the AW season to one, and estimated males in SS by region and females by season and region between zero and one.

To account for retention and discarding, retention was defined as the probability of retaining an individual lobster by year, season, sex, and size class. For CRA 3, this included legal status rules (MLS and the proportion of mature females in berry) but did not include any other forms of retention, such as high-grading. Discarding of large lobsters appeared to be infrequent in CRA 3, given the low use of destination code ‘X’ in this QMA; it is not known if this reflected a lack of discarding or a failure to record discards, but discarding of large lobsters was not modelled in this stock assessment.

Following recent best practices in rock lobster stock assessment models (Punt 2024) and recent work on size-based natural mortality (Lorenzen 2022, Lorenzen et al. 2022), natural mortality (*M*) was assumed to be size-specific:

$$log(M_l) = M_{60} + clog(\ell_l)$$

where ℓ_l is the midpoint of the TW for size class l, M_l is the natural mortality for size class l, the estimated parameter M_{60} is the natural mortality at 60 mm TW, and $c = -1$ was assumed. Furthermore, the M_{60} parameter was assumed to be different for females and males, and female M_{60} varied through time with two time blocks: prior to 2010 and 2010–2023.

Natural, fishing, and handling mortalities were applied to each sex category in each size class. Exploitation rates were determined from observed catch and model biomass, modified by sex-specific MLS, proportions of mature females in berry, sex/season specific vulnerabilities, and sex-specific selectivity. Exploitation rates for each fishery were calculated from the catch, model biomass, and natural mortality. The LSD model removed catch from the population using discrete exploitation rates, a change from the 2019 CRA 3 assessment which used instantaneous fishing mortality. The combination of selectivity, vulnerability, and retention was used to define exploitation rates (U) for the SL fishery, while only selectivity and vulnerability were needed to define exploitation rates for the NSL fishery.

3.2 Parameters and priors

Model parameters that could be estimated included productivity parameters (i.e., average recruitment, natural mortality, and growth), maturation parameters, and fishery parameters (i.e., catchability, selectivity, and vulnerability) (see Table 6). Four vulnerability parameters (i.e., *vuln1*, …, *vuln4*) were estimated including females by region and season. The 2024 CRA 3 stock assessment fixed some key parameters to address convergence and model fit issues: six natural mortality at 60 mm TW (M_{60}) parameters (males by region, and two time blocks for females, by region), four *Galpha* parameters (males and females by region), *Gobs* by region, and all four maturation parameters (length at 50% and 95% maturation by region).

Uninformative priors with wide parameter bounds were specified for most model parameters (Table 7). Wide uniform priors were specified for the catchability coefficient (q) for each of the CPUE series (Table 7). Beta distributions, with both shape parameters set to one, were used for priors for all parameters bounded between zero and one, including the growth parameter *Gdiff* and initial exploitation rate (U_0). An informative lognormal prior was specified for natural mortality (M_{60}, prior to the decision to fix these parameters); and informative normal priors were specified for the growth parameters *Galpha* (prior to the decision to fix this parameter), *Gshape*, *GCV*, and *Gobs* (prior to the decision to fix this parameter), based on an unpublished meta-analysis (Table 7). Uninformative normal prior distributions were specified for all other model parameters (Table 7). 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.

Table 6: Definitions of parameters discussed in the text.

Parameter	Definition
R_0	initial numbers recruiting
Rdevs	annual recruitment deviations
sigmaR	standard deviation of *Rdevs*
U_0	initial exploitation rate (the first model year is in equilibrium using this estimate)
M_{60}	instantaneous rate of natural mortality at 60 mm TW
qCR	catchability coefficient (relationship between the vulnerable biomass and CR series)
qFSU	catchability coefficient (relationship between the vulnerable biomass and FSU CPUE series)
qCELR	catchability coefficient (relationship between the vulnerable biomass and CELR CPUE series)
qLB	catchability coefficient (relationship between the number of lobsters above the MLS including berried females and LB CPUE series)
qdrift	additive change in catchability coefficient each year
mat50	TW at which 50% of immature females become mature
mat95	difference between *mat50* and the TW at which 95% of immature females become mature
Galpha	annual growth increment at 50 mm TW
Gbeta	annual growth increment at 80 mm TW
Gdiff	the ratio of *Gbeta* to *Galpha* (*Gbeta* = *Gdiff* × *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

Table 7: Specifications for estimated parameters in the CRA 3 models including the upper and lower bounds, prior type, and prior parameters.

Sex	Parameter	Lower bound	Upper bound	Prior type	Prior parameter 1	Prior parameter 2
	R_0	exp(1)	exp(25)	normal	1e6	1e7
	M_{60}	0.01	0.95	lognormal	0.3	0.4
	Rdevs	-2.3	2.3	uniform	–	–
	qCR	exp(-25)	1	uniform	–	–
	qFSU	exp(-25)	1	uniform	–	–
	qCELR	exp(-25)	1	uniform	–	–
	qLB	exp(-25)	1	uniform	–	–
	mat50	10	50	normal	50	10
	mat95	1	60	normal	10	10
male	*Galpha*	1	20	normal	5	3
male	*Gshape*	0.1	15	normal	4.81	1
male	*GCV*	0.01	3	normal	0.59	1
female	*Galpha*	1	20	normal	5	3
female	*Gshape*	0.1	15	normal	4.51	1
female	*GCV*	0.01	3	normal	0.82	1
	Gdiff	0.001	0.99	beta	1	1
	Gobs	0.0001	5	normal	1.48	0.074
	selL	1	50	normal	10	5
	selM	30	90	normal	55	50
	vuln	0	2	normal	0.5	5
	U_0	0.00	0.99	beta	1	1

3.3 Assessment indicators

This assessment used the same indicators that were used in the 2022 CRA 2 assessment (Webber et al. 2023), using a discrete exploitation rate in place of the instantaneous fishing mortality rate that was used in previous rock lobster stock assessments (Table 8, Table 9). The exploitation rate associated with the reference level (U_R, see Section 3.6) was updated to be defined as the fixed exploitation rate associated with a median vulnerable biomass equal to B_R at equilibrium. The main indicators were related to the relative estimates of adjusted vulnerable biomass[11], SSB, and total biomass, including the probabilities that each of the biomass indicators would fall below current levels, after projecting the current catch forward for five years (see Section 3.7). Probabilities were calculated over all samples of the posterior distribution.

In the past, vulnerable biomass was defined as start-of-season AW biomass, which did not include any mature females because they were all assumed to be in berry and were thus excluded from harvest. However, in this assessment, a small proportion of mature females (about 0.28 in region 1 and 0.21 in region 2, which is the proportion not in berry – see the AW proportion in berry estimates given in Table 2) was included in the AW vulnerable biomass. Vulnerable biomass accounts for the MLS, selectivity, and sex/seasonal vulnerability, and was the estimated biomass available to be caught by the fishery at the beginning of the AW season. Adjusted vulnerable biomass was calculated by applying the MLS and selectivity from the final model year to all previous years, including those years when earlier regulations were enforced.

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

The value H_{2023} is the model estimate of the amount of handling mortality (in tonnes) in the final fishing year (2023).

Table 8: Reference points for the CRA 3 stock assessment.

Type	Description
B_0	Equilibrium AW adjusted vulnerable biomass before fishing
SSB_0	Equilibrium female spawning stock biomass before fishing
T_0	Equilibrium total biomass before fishing
B_{0now}	Equilibrium adjusted vulnerable biomass using mean of 2011–2020 recruitment
SSB_{0now}	Equilibrium female spawning stock biomass using mean 2011–2020 recruitment
T_{0now}	Equilibrium total biomass using mean of 2011–2020 recruitment
B_{MIN}	The lowest beginning AW adjusted vulnerable biomass in the series
B_{2024}	Beginning of season AW adjusted vulnerable biomass for 2024
B_{2028}	Beginning of season AW adjusted vulnerable biomass for 2028
SSB_{2024}	Female spawning stock biomass at beginning of 2024 AW season
SSB_{2028}	Female spawning stock biomass at beginning of 2028 AW season
T_{2024}	Beginning of season AW total biomass for 2024
T_{2028}	Beginning of season AW total biomass for 2028
H_{2023}	Total handling mortality for 2023 (tonnes)
H_{2028}	Total handling mortality for 2028 (tonnes)
B_R	Average AW vulnerable biomass between projected fixed catch and fixed *U* rules that maximise catch while meeting constraints
U_R	Annual exploitation rate associated with B_R at equilibrium, weighted across seasons by seasonal vulnerable biomass
U_{2024}	weighted average exploitation rate between the 2024 AW and SS exploitation rates based on seasonal vulnerable biomass

[11] 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.

Type	Description
U_{2028}	weighted average exploitation rate between the 2028 AW and SS exploitation rates based on seasonal vulnerable biomass

Table 9: Performance indicators and stock status probabilities for the CRA 3 stock assessment.

Type	Description
Performance indicators	
B_{2024} / B_0	Ratio of B_{2024} to B_0
B_{2028} / B_0	Ratio of B_{2028} to B_0
B_{2024} / B_{0now}	Ratio of B_{2024} to B_{0now}
B_{2028} / B_{0now}	Ratio of B_{2028} to B_{0now}
B_{2028} / B_{2024}	Ratio of B_{2028} to B_{2024}
SSB_{2024} / SSB_0	Ratio of SSB_{2024} to SSB_0
SSB_{2028} / SSB_0	Ratio of SSB_{2028} to SSB_0
SSB_{2024} / SSB_{0now}	Ratio of SSB_{2024} to SSB_{0now}
SSB_{2028} / SSB_{0now}	Ratio of SSB_{2028} to SSB_{0now}
SSB_{2028} / SSB_{2024}	Ratio of SSB_{2028} to SSB_{2024}
T_{2024} / T_0	Ratio of T_{2024} to T_0
T_{2024} / T_{0NOW}	Ratio of T_{2024} to T_{0NOW}
T_{2028} / T_0	Ratio of T_{2028} to T_0
T_{2028} / T_{0NOW}	Ratio of T_{2028} to T_{0NOW}
T_{2028} / T_{2024}	Ratio of T_{2028} to T_{2024}
T_{male} / T_{female}	Ratio of the total male to total female biomass in the final model year (2023)
B_{2024} / B_R	Ratio of B_{2024} to B_R
B_{2028} / B_R	Ratio of B_{2028} to B_R
U_{2024} / U_R	Ratio of U_{2024} to U_R
U_{2028} / U_R	Ratio of U_{2028} to U_R
U_{2028} / U_{2024}	Ratio of U_{2028} to U_{2024}
Probabilities	
P($B_{2024} > B_{MIN}$)	Probability B_{2024} is greater than B_{MIN}
P($SSB_{2024} > 20\%SSB_0$)	Probability SSB_{2024} is greater than 20% SSB_0
P($SSB_{2024} > 10\%SSB_0$)	Probability SSB_{2024} is greater than 10% SSB_0
P($SSB_{2024} > 20\%SSB_{0now}$)	Probability SSB_{2024} is greater than 20% SSB_{0NOW}
P($SSB_{2024} > 10\%SSB_{0now}$)	Probability SSB_{2024} is greater than 10% SSB_{0NOW}
P($SSB_{2028} > 20\%SSB_0$)	Probability SSB_{2028} is greater than 20% SSB_0
P($SSB_{2028} > 10\%SSB_0$)	Probability SSB_{2028} is greater than 10% SSB_0
P($SSB_{2028} > 20\%SSB_{0now}$)	Probability SSB_{2028} is greater than 20% SSB_{0NOW}
P($SSB_{2028} > 10\%SSB_{0now}$)	Probability SSB_{2028} is greater than 10% SSB_{0NOW}
P($B_{2028} > B_{2024}$)	Probability B_{2028} is greater than B_{2024}
P($SSB_{2028} > SSB_{2024}$)	Probability SSB_{2028} is greater than SSB_{2024}
P($T_{2028} > T_{2024}$)	Probability T_{2028} is greater than T_{2024}
P($U_{2028} > U_{2024}$)	Probability U_{2028} is greater than U_{2024}
P($B_{2024} > B_R$)	Probability B_{2024} is greater than B_R
P($B_{2028} > B_R$)	Probability B_{2028} is greater than B_R
P($U_{2024} > U_R$)	Probability U_{2024} is greater than U_R
P($U_{2028} > U_R$)	Probability U_{2028} is greater than U_R

3.4 Developing a base case

3.4.1 Matching the previous assessment model

In every year since its initial development, the LSD model code and the preparation of the input data have been improved to ensure that these procedures are consistent with current best practices in stock assessment. Because this is an ongoing process that can occur multiple times in the interval between full stock assessments for any CRA QMA, it is necessary to track how these improvements may have affected the results obtained by the previous base case stock assessment. Key LSD model updates since the 2019 CRA 3 stock assessment included:

1. Calculate discrete exploitation rates instead of instantaneous fishing mortality rates.
2. Develop standardised length frequency and sex ratio inputs.
3. Develop logbook and catch sampling CPUE series, including updated likelihood functions, to replace the loss of the CPUE series based on the statutory catch and effort data.
4. Develop an updated model for predicting TW from CL, primarily used to convert older tag data into TW.
5. Estimate proportion of mature females in berry by season rather than using a binary process.
6. Updated assumptions about illegal, recreational, and customary catches.
7. Allow vulnerability parameters for immature and mature females to exceed one.
8. The potential for *M* to vary by region, sex, year, and length.
9. Improved the catch penalty to be differentially smooth (the catch penalty prevents the exploitation rate from going too high to sustain population for all sex and length classes individually).

Starting with the 2023 rapid update, which had the same model structure as the 2019 stock assessment but with data updated to include 2023, subsequent model runs added new features in small steps so as to identify where changes occurred. Updating the structure of LF and sex ratio inputs and changes to LF weighting (*v2_r1qdrift*[12]) resulted in identical selectivity estimates (Figure 10). Recent biomass trajectories matched but there were some differences in population magnitude in the early years, most likely due to changes in magnitude of recruitment spikes (Figure 11, Figure 12, Figure 13). Updates to the CPUE likelihood and removal of arbitrary process error had negligible impacts (not shown).

Calculating exploitation rates (*U*) instead of fishing mortality rates (*F*) led to some changes in estimated parameters and identified issues with differentiability. Initial runs estimated a slightly left shifted selectivity for females (Figure 10), higher R_0, higher natural mortality, and higher standard deviation of observation error for tag-recapture data (*Gobs*) leading to changes in estimated recruitment and population biomass (Figure 11, Figure 12, Figure 13). This was similar to CRA 4, which was impacted by the change from *F* to exploitation rates, but dissimilar to CRA 2 and CRA 6, which had no change when switching to removing catch using exploitation rates. There were similar impacts when updating both 2019 CRA 3 base models with the updated model code (see *r1_qdrift* and *r2_qdrift,* Figure 14). Note that the impact of this update to exploitation rate removals differed among the two 2019 base runs, with the base run that discarded the tags at liberty for less than one year ('r1') showing a greater degree of shift in biomass compared to the base run which retained all tags, regardless of the time at liberty ('r2'), which showed a relatively small amount of biomass shift. As updated data sources were introduced (e.g. updated catch data), issues with differentiability due to high exploitation rates emerged for some sex and length bins. This led to the development of an improved penalty function such that the fifth and all lower derivatives were rendered continuous and applied to all sex and length classes individually.

[12] Note that there were two base case runs for the 2019 CRA 3 stock assessment: one (designated as 'r1' in the discussion that follows) discarded all tag recovery information that had been at liberty for less than 365 days; the other 2019 base run (designated as 'r2') retained all the tag recovery data, regardless of the length of time at liberty. Most of the MAP comparisons that follow in this discussion were made with the 'r1' base run. Only one (Figure 14) includes the 'r2' base run.

Due to time constraints while developing the improved penalty, we compared the 2023 rapid update with each updated data source while still calculating *Fs*. There were changes in female selectivity in region 1, recruitment, and estimates of spawning biomass in the early years when updating the tag data extract and removing tags from the Te Tapuwae o Rongokako marine reserve, which had been used in the 2019 assessment but were not authorised for use at the initial stages of the 2024 stock assessment (Figure 15, Figure 16, Figure 17). Including updated catch series had negligible impact on selectivity for both sexes but shifted the recruitment and biomass trajectories (Figure 18, Figure 19, Figure 20, Figure 21). Updated length frequency and sex ratio inputs shifted female selectivity in both regions (but with no impact on male selectivity), with some impacts on recruitment particularly during higher recruitment periods in region 1. Updated CPUE series had some impact on the shape of female selectivity curves and some impact on recruitment, particularly the scale of recruitment in early years, which led to magnitude shifts in population biomass but no significant changes in the pattern of population biomass trajectory.

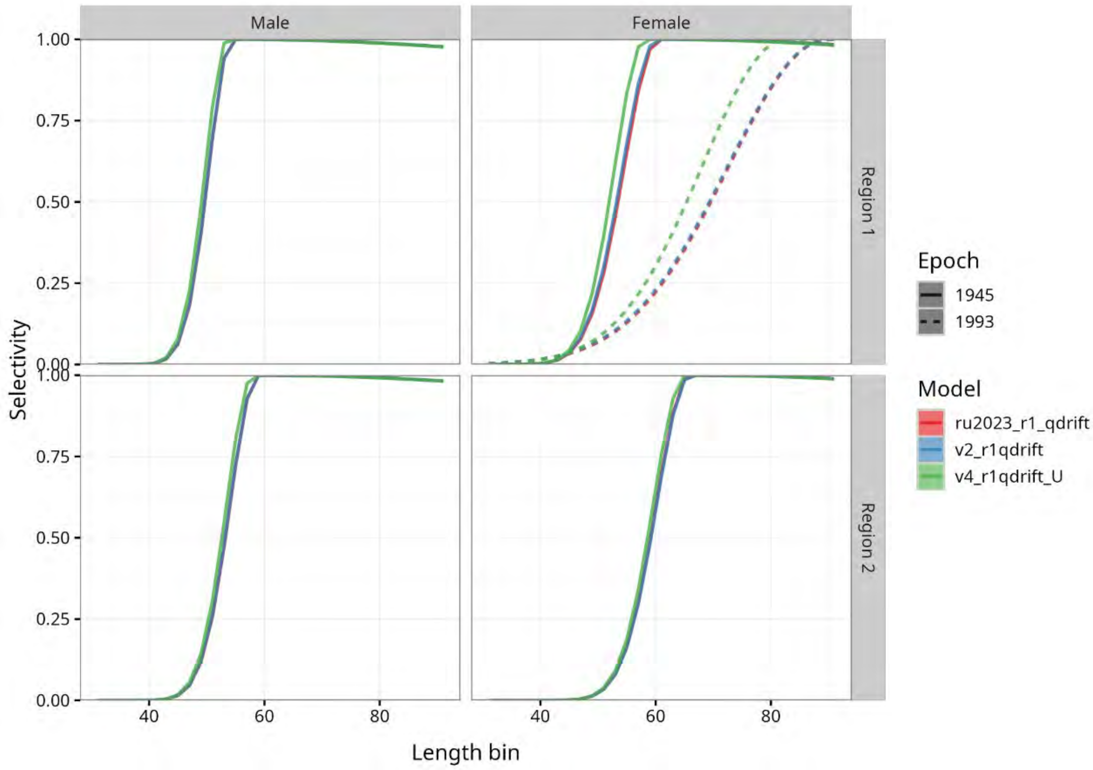


Figure 10: MAP of selectivity for initial models by region building up from the 2023 rapid update (*ru2023_r1_qdrift*): updates to LF and sex ratio inputs (*v2_r1qdrift)* and calculating exploitation rates instead of fishing mortality rates (*v4_r1qrift_U*). This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

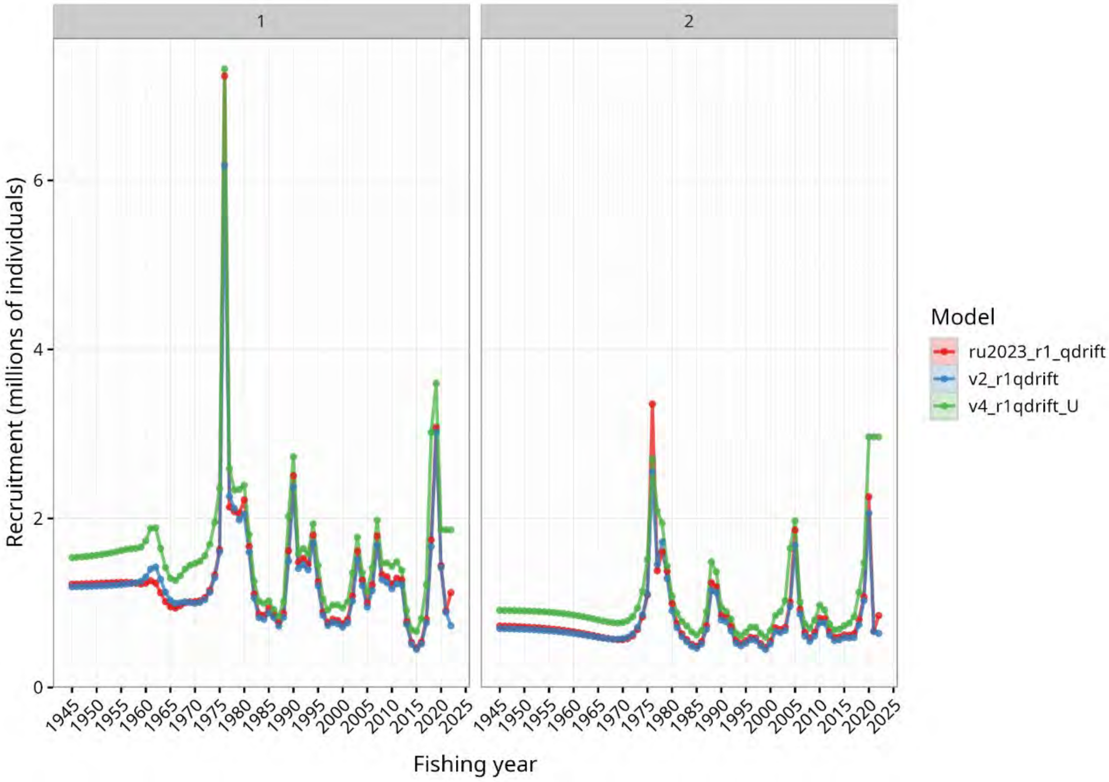


Figure 11: **MAP of recruitment for region 1 and 2 initial models, building up from the 2023 rapid update (*ru2023_r1_qdrift*): updates to LF and sex ratio inputs (*v2_r1qdrift)* and calculating exploitation rates instead of fishing mortality rates (*v4_r1qrift_U*). This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').**

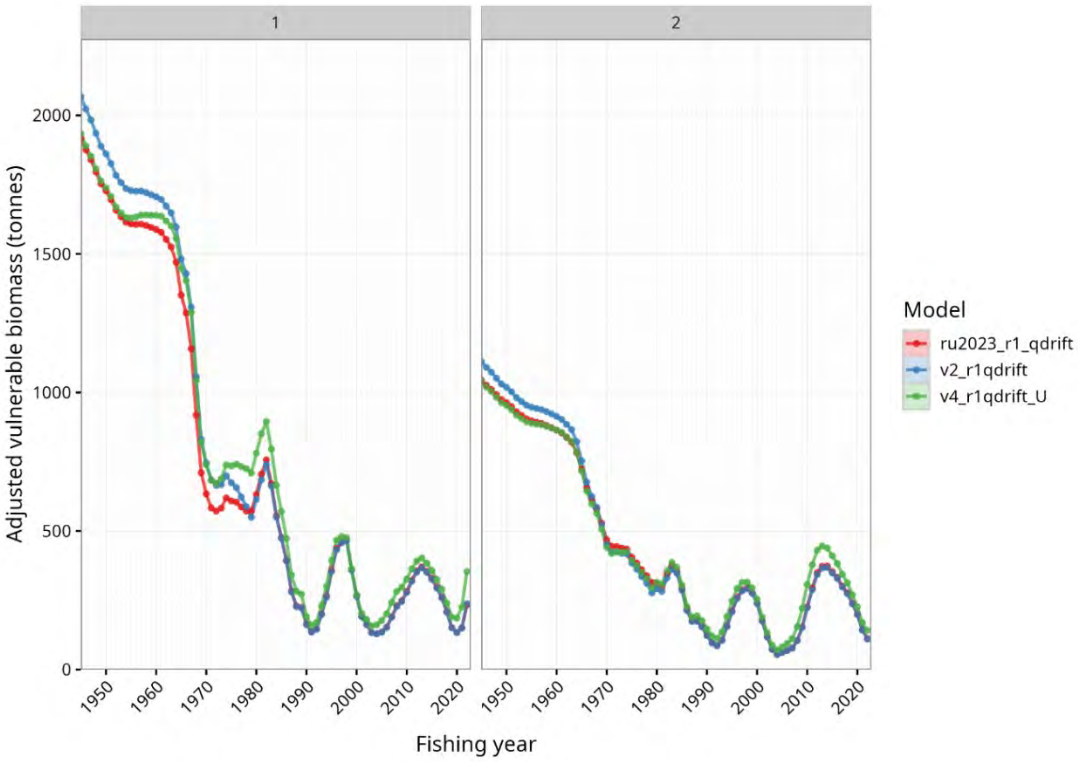


Figure 12: **MAP of adjusted vulnerable biomass for region 1 and 2 initial models, building up from the 2023 rapid update (*ru2023_r1_qdrift*): updates to LF and sex ratio inputs (*v2_r1qdrift)* and calculating exploitation rates instead of fishing mortality rates (*v4_r1qrift_U*). This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').**

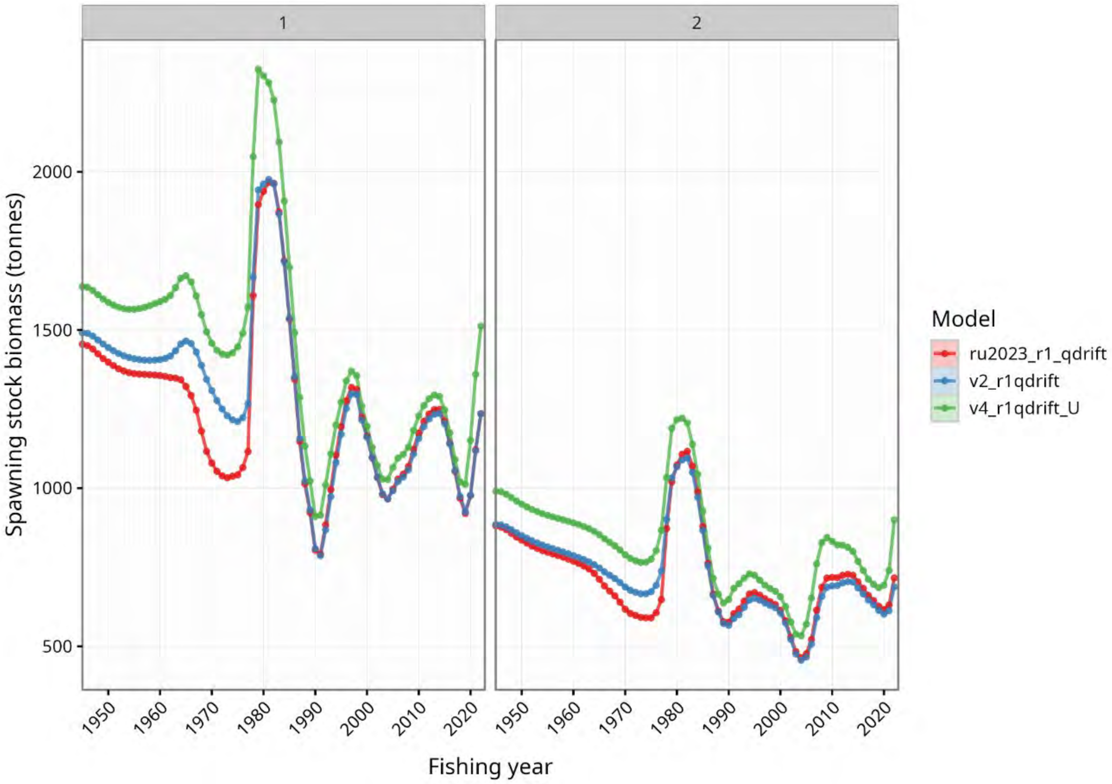


Figure 13: **MAP of spawning stock biomass for region 1 and 2 initial models building up from the 2023 rapid update (*ru2023_r1_qdrift*): updates to LF and sex ratio inputs (*v2_r1qdrift)* and calculating exploitation rates instead of fishing mortality rates (*v4_r1qrift_U*). This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1')..**

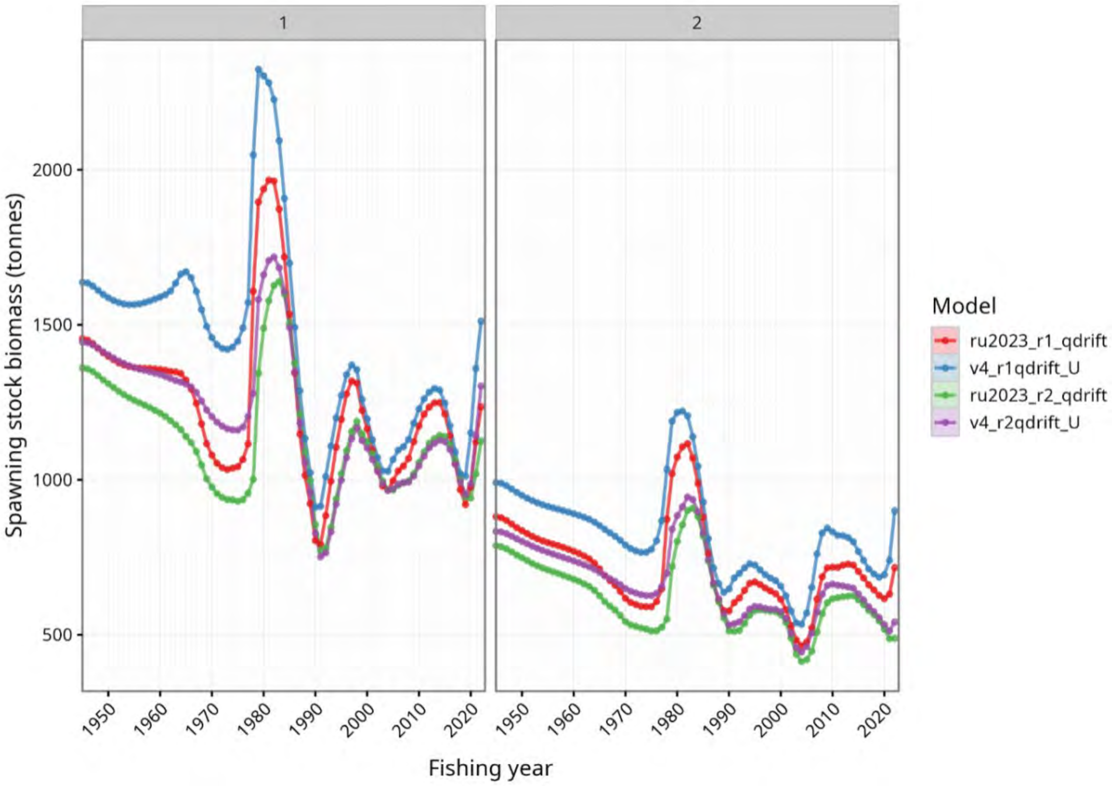


Figure 14: **MAP of spawning stock biomass comparing the impact of calculating exploitation rates for both 2019 region 1 and 2 base run models (*r1_qdrift, r2_qdrift*), building up from the 2023 rapid update and showing the impact of switching fishing mortality from an instantaneous F to an exploitation rate U.**

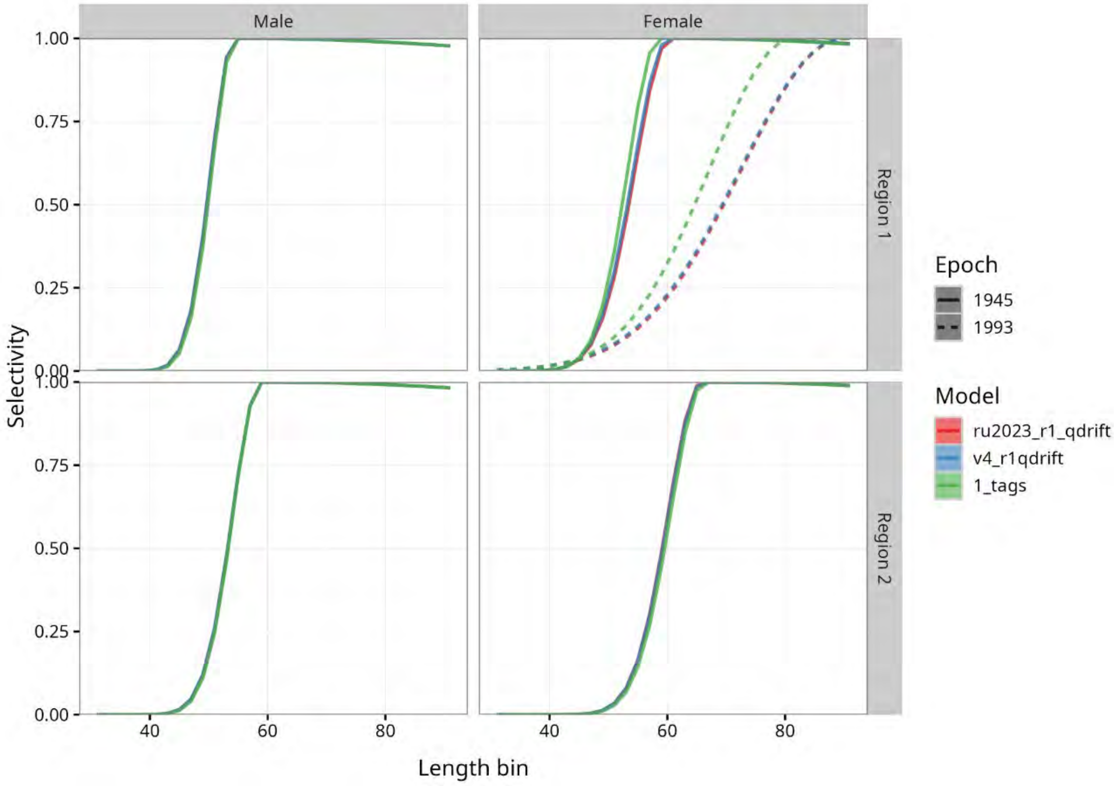


Figure 15: MAP of selectivity for initial models by region, building up from the 2023 rapid update (*ru2023_r1_qdrift*): model updates while still calculating *F*s (*v4_r1qdrift*) and updated tag data extract with marine reserve tags removed (*1_tags*). This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

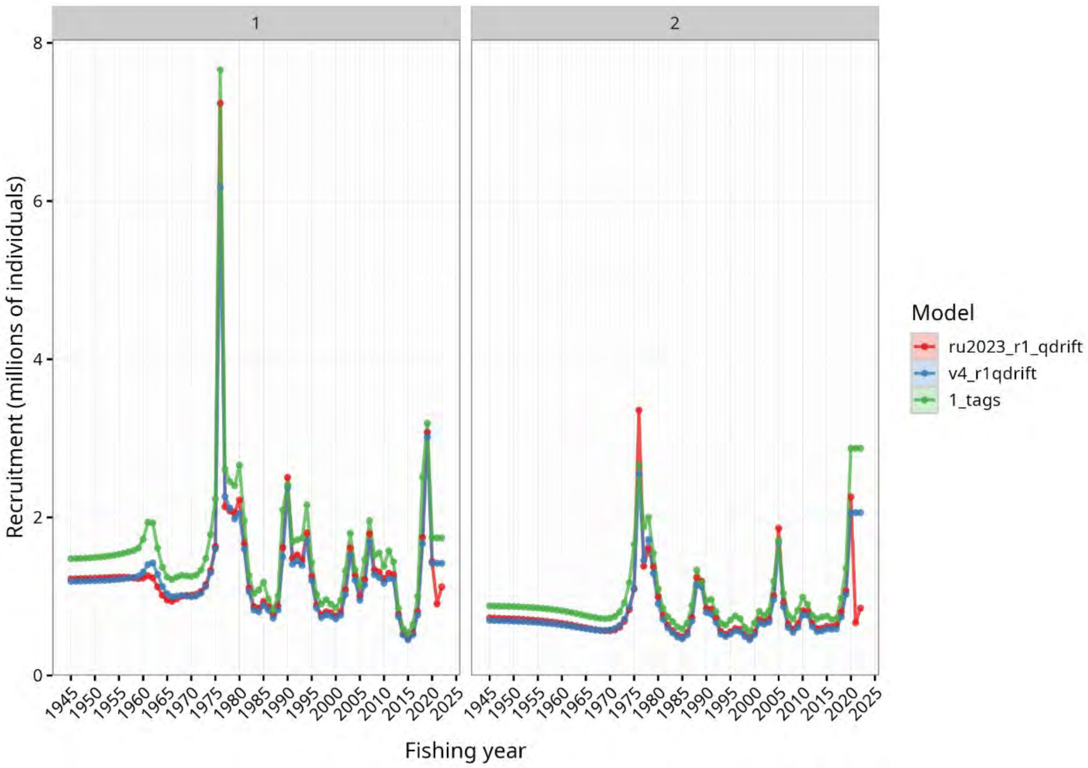


Figure 16: MAP of recruitment for initial region 1 and 2 models, building up from the 2023 rapid update (*ru2023_r1_qdrift*): model updates while still calculating *F*s (*v4_r1qdrift*) and updated tag data extract with marine reserve tags removed (*1_tags*). This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

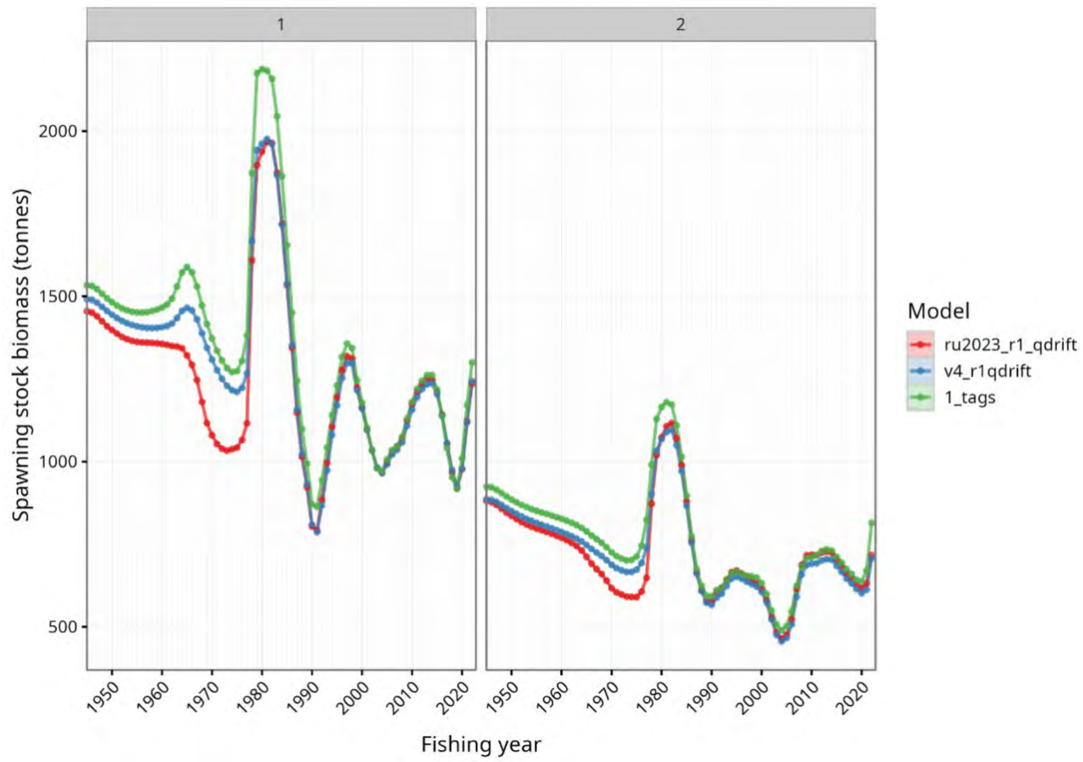


Figure 17: MAP of spawning biomass for initial region 1 and 2 models, building up from the 2023 rapid update (*ru2023_r1_qdrift*): model updates while still calculating *F*s (*v4_r1qdrift*) and updated tag data extract with marine reserve tags removed (*1_tags*). This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

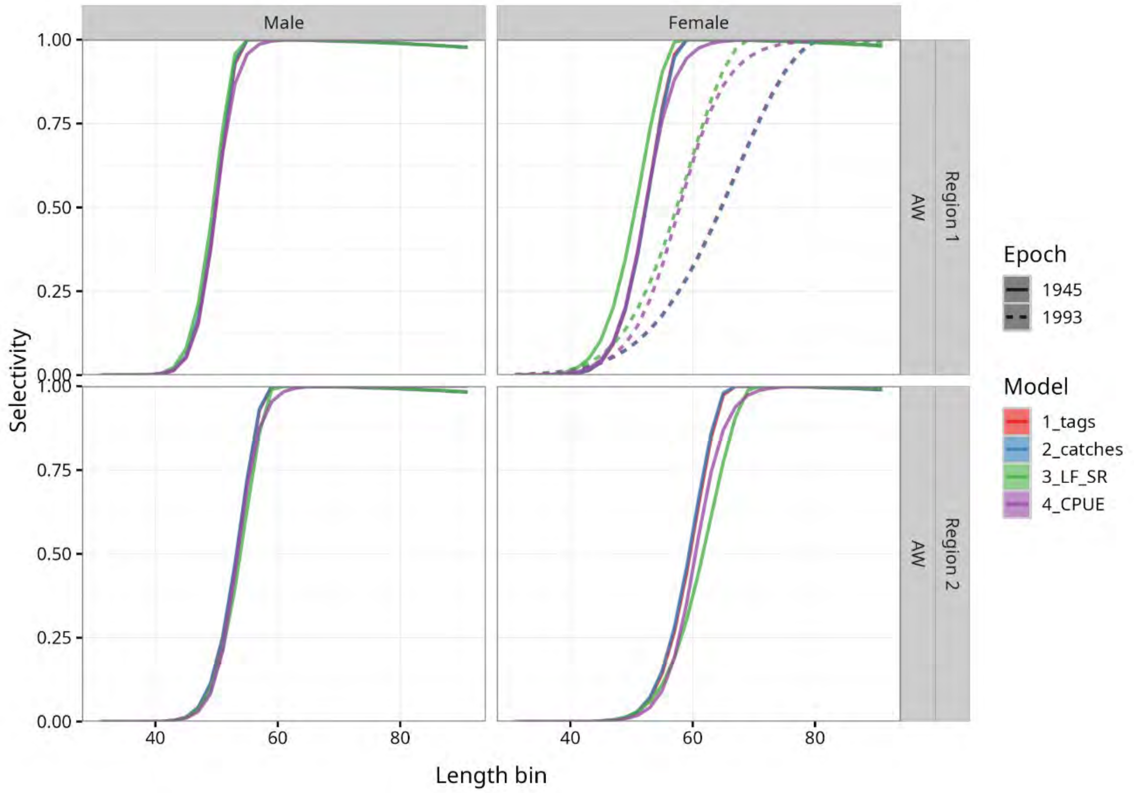


Figure 18: MAP of selectivity for initial region 1 and 2 models bringing in updated data inputs: tag extract without marine reserve data *(1_tags*), updated catch series (*2_catches*), updated length frequency and sex ratio inputs (*3_LF_SR*), and updated CPUE series *(4_CPUE)*. This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

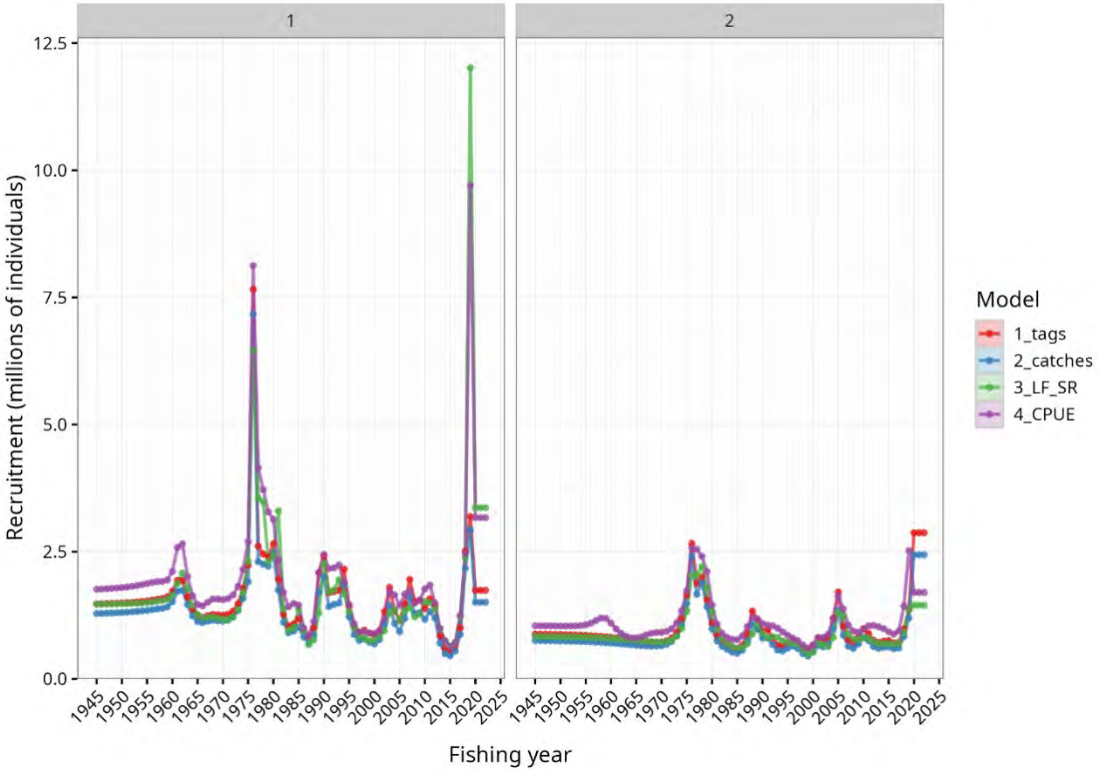


Figure 19: MAP of recruitment for initial region 1 and 2 models bringing in updated data inputs: tag extract without marine reserve data *(1_tags*), updated catch series (*2_catches*), updated length frequency and sex ratio inputs (*3_LF_SR*), and updated CPUE series *(4_CPUE)*. This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

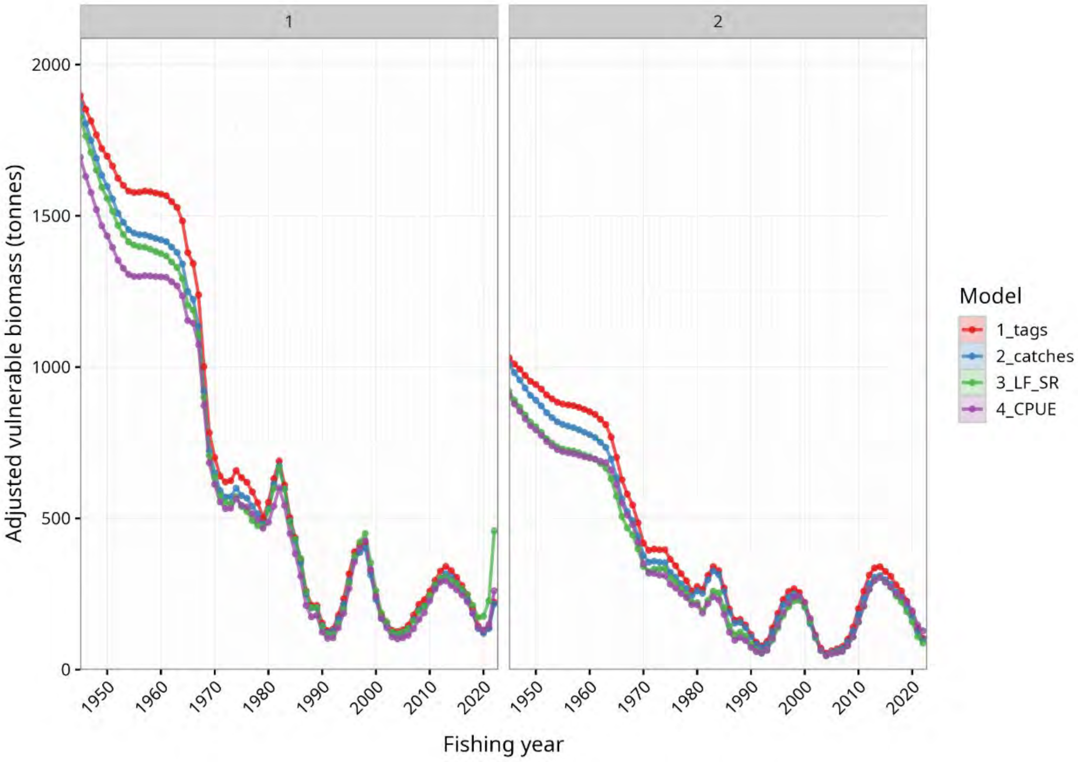


Figure 20: MAP of adjusted vulnerable biomass for initial region 1 and 2 models bringing in updated data inputs: tag extract without marine reserve data *(1_tags*), updated catch series (*2_catches*), updated length frequency and sex ratio inputs (*3_LF_SR*), and updated CPUE series *(4_CPUE)*. This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

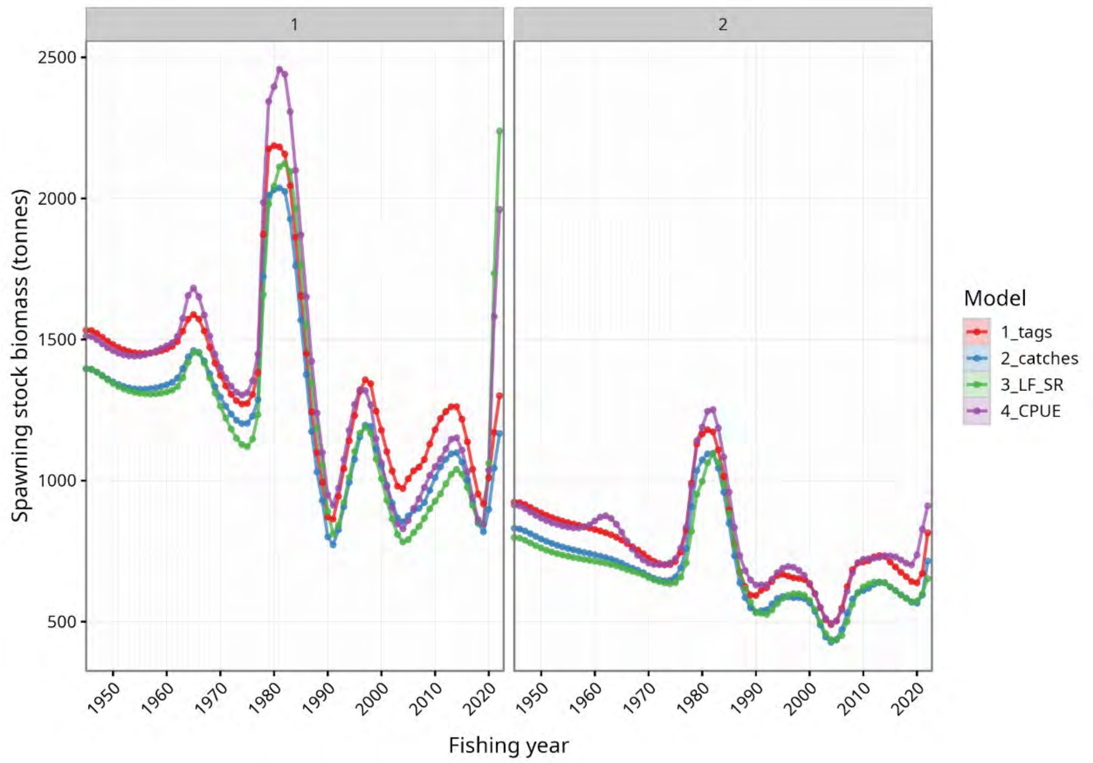


Figure 21: MAP of spawning biomass for initial region 1 and 2 models bringing in updated data inputs: tag extract without marine reserve data *(1_tags)*, updated catch series (*2_catches*), updated length frequency and sex ratio inputs (*3_LF_SR*), and updated CPUE series *(4_CPUE)*. This comparison is for the 2019 base run that discarded all tags at liberty <1 year ('r1').

3.4.2 Searching for a new base case

Exploratory model runs were done to develop a new base case stock assessment model. The following is an abbreviated sequence of steps that led to the CRA 3 base case as data were updated and model changes were implemented:

1. Calculation of discrete exploitation rates instead of instantaneous fishing mortality rates: running iterative Newton-Raphson algorithm to calculate fishing mortality rates was no longer required, which improved speed of model runs. There were some differences in model results associated with calculating exploitation rates vs. fishing mortality rates that were not observed for CRA 2 or CRA 6, including higher estimated M, higher R_0, and change in the CR series q.
2. Updated tag data extract. Initial model runs were not authorised to include Te Tapuwae o Rongokako marine reserve tag data in region 1, but the eventual base model included these data.
3. Updated assumptions about illegal and recreational catches as described in Section 2.2.3.
4. Added standardised length frequencies (using a Bayesian Poisson-decomposed multinomial GLMM model) and sex ratios (using a Bayesian multinomial GLMM model), replacing the approach used by the 2019 assessment which kept catch sampling and logbook data separate and used ad-hoc weightings; the updated approach implemented standardised LF and sex ratios, resulting in a single series for each year, season, and sex category.
5. Developed and included logbook and catch sampling CPUE series: updated model code so that the newly developed logbook CPUE series (from 2011–2023) could be fitted with units in numbers per potlift above the MLS and the catch sampling CPUE series (from 2004–2023) with units in terms of total numbers per potlift both above and below the MLS. The FSU series (1979–1989) and the CELR series (1990–2019 AW) were maintained with units of kg/potlift. CPUE weights were halved for the years of CELR, logbook, or catch sampling series overlap (i.e., 2004–2023). Note that the CS CPUE series and the scaling of overlapping CPUE weights were dropped in the final version of the CRA 3 stock assessment.

6. Estimated recruitment deviates through to 2020 (three years prior to final model year) rather than 2021 (other rock lobster stock assessments have typically used two years prior to final model year). This approach was adopted during the 2022 CRA 2 assessment with concern over whether recent data could adequately inform recent recruitment deviates.
7. Used average proportion of mature females in berry covariate estimated using catch sampling and logbook data to update the 2019 binary assumption of 100% berried in AW and 0% berried in SS. The 2024 stock assessment used an average over years by season. This update was expected to model the SSB and vulnerable biomass more accurately. The CRA 3 proportion of berried females for the 2024 assessment was assumed to be 0.721 region 1 AW, 0.005 region 1 SS, 0.790 region 2 AW, and 0.005 SS (see Appendix E).

At this point, there were concerns with the previous model structure during the development of a base model. Early model runs prior to August 2024 resulted in poor fits to the CELR CPUE series, particularly missing recent estimates of CPUE (Figure 22) and very poor fits to sex ratios, among other potential issues pointed out by the reviewers. For these models, natural mortality could vary by region but was fixed across sex, time, and length. The best model runs that attempted to address these issues included many selectivity and vulnerability time blocks (*v1/6_sel93vuln*) and assumed growth varied by region (*v1/12_grow2r*, Figure 22, Figure 23, Figure 24). However, the CRA 3 assessment in this form was not accepted by the August Plenary. More work was done from August through to November 2024 to address reviewer concerns and achieve better fits to CPUE and sex ratios.

Several meta-analyses were done to better understand the underlying causes of two primary concerns raised by the August Plenary review:

- The general lack of females in the catch of region 1; and
- An increasing male bias in sex ratio in both regions, which was most pronounced in region 1.

With respect to the first of these, a meta-analysis of variation in numerical density and individual growth around New Zealand (Appendix F) determined that the generally low proportion of females in the catch of region 1 was most likely to be caused by density-dependent effects on the growth of individual lobsters in region 1, particularly of females. Therefore, the generally low estimated proportion of females in the catch of region 1 (i.e., across all model years) was not in itself a cause for concern for this assessment.

A second meta-analysis (Appendix G) determined that the mean size at maturation of females in region 1 of CRA 3 was likely to be the lowest of all the assessed QMAs/regions. This additional analysis also provided recommended maturation parameter values for the base case and sensitivity runs to use, given issues experienced with estimating these parameters within the assessment model.

A third meta-analysis (Appendix H) developed exploratory sex-specific CPUE series based on CS and LB catch sampling data. This confirmed that the increasingly male bias in catches in region 1 of CRA 3 may have been caused by a decline in female CPUE over time, which is not so apparent for males. Furthermore, it had been determined that the preponderance of males in the catch was also observed for lobsters captured by a potting survey inside Te Tapuwae o Rongokako marine reserve located to the north of Gisborne (inside region 1 of CRA 3) (J. Roberts et al., in prep.). These additional analyses justified the use of time and sex-specific M, so that an apparent increase in female M over time relative to males could be modelled in each region.

The updates eventually included in the accepted CRA 3 base model included:

8. Fixed increasing trend in catchability coefficient (*qdrift*) at 1% for all CPUE series.
9. Changed model code to allow vulnerability parameters for immature and mature females to be above 1.0. Vulnerability was assumed to vary by region and season (four vulnerabilities, as immature and mature females were shared and male vulnerabilities were fixed to 1.0).

10. Changed natural mortality code so it could vary by region, sex, year, and length. The 2024 base model assumed natural mortality varied by region, sex (male/female), length, and with two female time blocks from 1945–2009 and 2010–2023 for females. Key sensitivity trials explored simpler assumptions about *M* (e.g. time-invariant *M, 4_Mtime,* as shown in Figure 22, Figure 23, and Figure 24).
11. Selectivity was assumed to vary by sex and region with two region 1 time blocks from 1945–1992 and from 1993–2023, defining five selectivities).
12. Fixed the length at 50% and 95% maturation parameters for both regions (40 mm and 10 mm in region 1, 45 mm and 10 mm in region 2, for *mat50* and *mat95,* respectively).
13. Growth parameters were assumed to vary by region and sex.
14. Growth, maturation, and natural mortality all vary by region. These assumptions rendered region 1 and region 2 fully independent assessment models.
15. Initial model runs down weighted CPUE series with overlapping years (i.e. CELR and logbook), but this approach was discarded by the base model because it was causing issues with model fits.
16. The catch sampling CPUE series, were dropped due to data conflict.
17. Initial model runs were not authorized to use region 1 marine reserve tags, but they were brought back in for the base model.

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

- **Years**: 1945 to 2023[13], estimating an initial exploitation rate.
- **Seasons**: two six-month seasons AW (April-September) and SS (October-March) during each fishing year.
- **Sex categories**: males, immature females, and mature females.
- **Tail width bins**: 31 two-mm wide bins with midpoints from 31 mm to 91 mm tail width (last bin was a ‘plus group’ or accumulator bin).
- **Regions**: two regions where region 1 includes Statistical Areas 909 and 910 and region 2 is 911.
- **Recruitment**: recruitment deviations (*Rdev*s) estimated from the first model year through to 2020. The final three model years were set to the 2020 estimate, given no real information in data for these recruitments and no puerulus settlement index. No stock recruitment relationship was assumed. Size at recruitment was assumed to have a mean of 32 mm and standard deviation 2 mm, based on a study of juvenile growth (Table 2, Roberts & Webber 2022).
- **Growth**: regional and sex-specific using the Schnute-Francis growth model. No density-dependent growth. Excluded recaptures at liberty less than six months.
- **Maturation**: female only logistic ogive by region, with *mat50* region 1 = 40 mm, region 2 = 45 mm, and *mat95* fixed at 10 mm for both regions.
- **Natural mortality**: region and sex-specific (male/female) time varying M_{60} (i.e., size-based M), with two time-blocks for female M_{60} from 1945–2009 and 2010–2023.
- **Selectivity**: logistic, region and sex-specific (male/female) selectivity with two time-blocks for females in region 1 from 1945–1992 and 1993–2023.
- **Vulnerability**: male vulnerability was fixed to 1 each region and season, then four separate vulnerabilities by region and season were estimated for females (combined immature and mature).
- **Handling mortality**: two periods: 1945 to 1989 fixed at 0.1, and 1990 to 2028 fixed at 0.05.
- **Catch**: from 1945 to 2023 using updated assumptions on illegal, recreational, and customary (see Section 2.2.3). Recreational and commercial catch combined to form a size-limited (SL) fishery and illegal/customary catch combined to form a non-size limited (NSL) fishery. Catch removed using discrete exploitation rates.
- **Abundance indices**: four CPUE series (CR, FSU, CELR, and LB), each with a separate catchability coefficient (*q*) for each region and season resulting in 14 *q* parameters. Fixed *qdrift* at 1% per year for all series.
- **Likelihoods**:

[13] April-March fishing years from 1979–80 to 2023–24

- o Lognormal for all CPUE series (CR, FSU, CELR, and LB);
- o Robust normal for tags;
- o Multinomial for LFs, fitted to standardised proportions at length for males, immature females, and mature females, with each sex category normalised separately;
- o Multinomial for sex ratios.

- **Data weighting**: determined iteratively and simultaneously for all data types. The LFs were weighted following the TA1.8 weighting method of Francis (2011) and the other data types were weighted aiming for a standard deviation of the normalised residual (SDNR) of one. No re-weighting of tag data because they are self-weighting through the estimation of an observation error parameter.

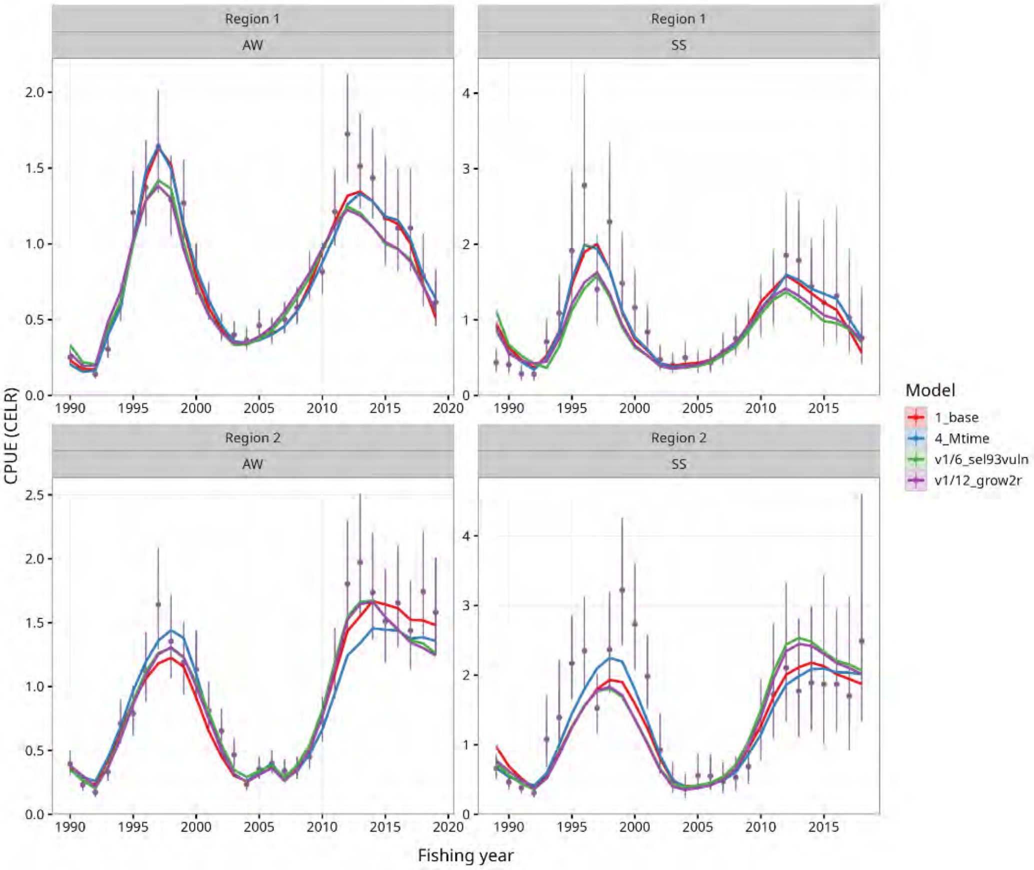


Figure 22: MAP fits to the CELR CPUE series by season and region for the MAP version of the *base* model run (*1_base*) compared with a key sensitivity (*4_Mtime*) and the early versions of the 2024 CRA 3 assessment (*v1/6_sel93vuln*, *v1/12_grow2r*).

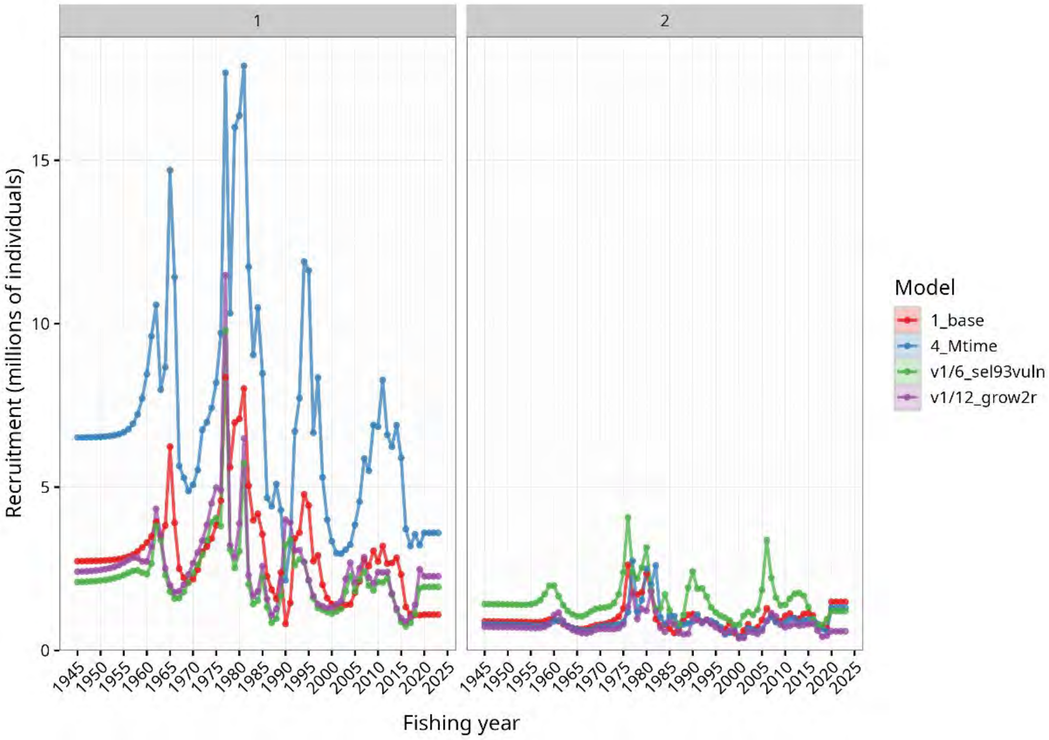


Figure 23: MAP recruitment for the MAP version of the *base* mode run (*1_base*) compared with a key sensitivity (*4_Mtime*) and the early versions of the 2024 CRA 3 assessment (*v1/6_sel93vuln*, *v1/12_grow2r*).

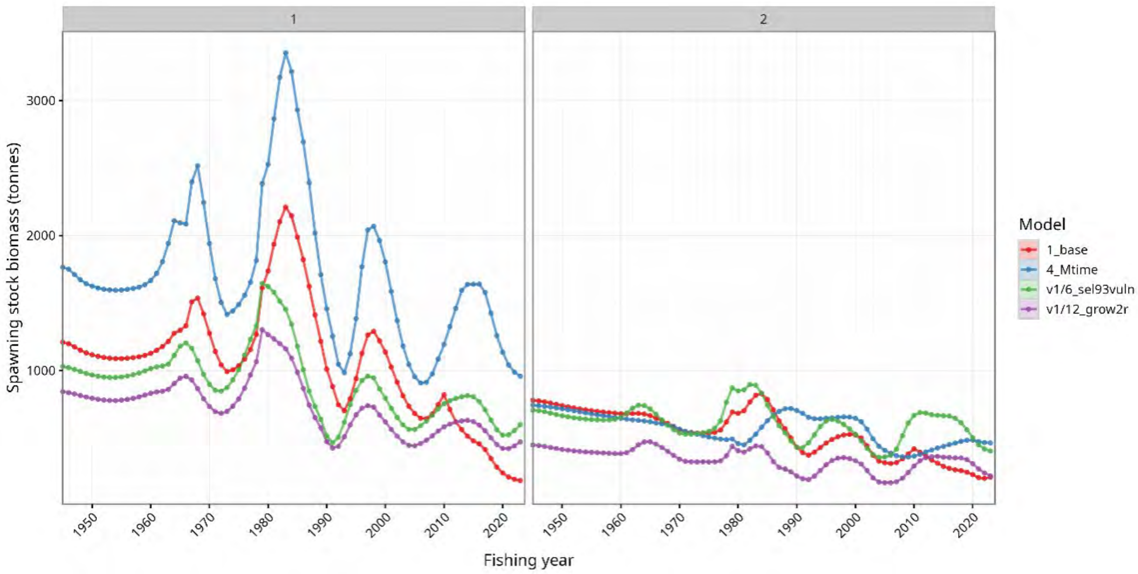


Figure 24: MAP spawning biomass for the MAP version of the *base* case (*1_base*) compared with a key sensitivity (*4_Mtime*) and the early versions of the 2024 CRA 3 assessment (*v1/6_sel93vuln*, *v1/12_grow2r*).

3.4.3 MCMC base case

MCMC was used to obtain samples from the posterior distribution of the *base* case model (referred to as *1_base_fix_M_Galpha* in MCMC figures). The base model was developed as an MAP and examined against other MAP sensitivity trials (see Section 3.5.1). Under MCMC inference, the chosen base model and other sensitivity trials would not converge without fixing key parameters. Models tested prior to the implementation of time and length-varying *M*, for example, were rejected by the Plenary as they did not adequately fit the CPUE and sex ratio data. However, the base model was chosen because it adequately fitted the CPUE and sex ratio data in the MAP run and addressed several of the Plenary reviewers' concerns. At this point in the assessment workshop, time had run out to overcome the convergence issue. Therefore, the MCMC base case fixed M_{60} and *Galpha* parameters at their MAP values and *Gobs* at 1.0, in addition to other parameters fixed in the MAP (e.g. maturation, *qdrift*).

MCMC trace plots indicated that MCMC chains were well-mixed (Figure I.1, Figure I.2, Figure I.3, and Figure I.4) and almost all Rhat statistics were less than the accepted 1.01 threshold level (see Table 11). The traces for the key estimated biological parameters, such as growth parameters 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 I.5, Figure I.6, Figure I.7). Likelihoods, the standard deviation of the normalised residual (SDNR), and parameter estimates were inspected (Table 10), as were the derived parameters and probabilities, including projections, for the base case (Table 11).

Table 10: Summary of the posterior distributions for the model likelihoods and standard deviation of the normalised residual (SDNR) for the *base* model showing the mean, standard deviation (SD) of the mean, median, and 90% credible interval (i.e., 5% and 95%).

	Region	Season	Mean	SD	5%	Median	95%
Likelihoods							
Total			33 787	10	33 771	33 787	33 803
Prior			29	8	16	29	41
Penalty							
Tags			5 031	6	5 022	5 031	5 042
Sex ratio			5 031	3	5 026	5 031	5 037
LFs			23 617	9	23 603	23 617	23 634
CPUE [CR]	909+910		50	1	48	50	53
CPUE [CR]	911		56	1	54	56	58
CPUE [FSU]	909+910	AW	-19	2	-21	-19	-16
CPUE [FSU]	909+910	SS	-13	1	-15	-14	-11
CPUE [FSU]	911	AW	-13	2	-16	-13	-9
CPUE [FSU]	911	SS	-8	2	-10	-8	-4
CPUE [CELR]	909+910	AW	-23	2	-25	-23	-19
CPUE [CELR]	909+910	SS	3	3	-2	3	9
CPUE [CELR]	911	AW	-15	2	-17	-15	-12
CPUE [CELR]	911	SS	14	3	10	14	18
CPUE [LB]	909+910	AW	5	1	4	5	7
CPUE [LB]	909+910	SS	10	2	7	9	13
CPUE [LB]	911	AW	13	1	12	13	15
CPUE [LB]	911	SS	17	1	15	17	19
SDNR							
Tags			1.707	0.018	1.678	1.706	1.738
Sex ratio	909+910		1.032	0.029	0.985	1.029	1.083
Sex ratio	911		1.025	0.033	0.975	1.024	1.081
LFs			0.463	0.088	0.396	0.437	0.612
CPUE [CR]	909+910		0.697	0.166	0.445	0.687	0.980
CPUE [FSU]	909+910		1.045	0.096	0.896	1.040	1.213
CPUE [CELR]	909+910		0.888	0.121	0.701	0.884	1.093
CPUE [LB]	909+910		1.200	0.086	1.070	1.192	1.353
CPUE [CR]	911		1.099	0.063	0.998	1.099	1.202
CPUE [FSU]	911		1.088	0.049	1.010	1.087	1.172
CPUE [CELR]	911		1.149	0.111	0.989	1.139	1.353
CPUE [LB]	911		1.073	0.080	0.952	1.069	1.204

Table 11: Summary of the posterior distribution for the model parameter estimates for the *base* model showing the mean, standard deviation (SD) of the mean, median, 90% credible interval (i.e., 5% and 95%), effective number of samples, and Rhat statistic are reported. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. '–': not applicable. Gray shading denotes a fixed value.

Parameter	Region	Season	Mean	SD	5%	Median	95%	Effective N	Rhat
R_0	909+910		3 190 703	202 113	2 867 990	3 178 880	3 524 450	902	1.002
R_0	911		973 273	57 935	880 013	969 944	1 071 770	577	1.013
M_{60} [M]	909+910		0.465						
M_{60} [F] < 2010			0.293						
M_{60} [F] ≥ 2010			0.480						
M_{60} [M]	911		0.265						
M_{60} [F] < 2010			0.192						
M_{60} [F] ≥ 2010			0.314						
qCR	909+910		0.439	0.070	0.331	0.436	0.563	1032	0.999
	911		0.344	0.060	0.252	0.339	0.456	474	0.999
qFSU	909+910	AW	0.001	0.000	0.001	0.001	0.001	911	1.009
		SS	0.001	0.000	0.001	0.001	0.002	983	1.002
	911	AW	0.003	0.000	0.002	0.003	0.003	940	1.000
		SS	0.002	0.000	0.002	0.002	0.003	926	1.000
qCELR	909+910	AW	0.002	0.000	0.002	0.002	0.003	789	0.999
		SS	0.004	0.000	0.004	0.004	0.005	903	1.000
	911	AW	0.004	0.000	0.004	0.004	0.005	936	0.999
		SS	0.005	0.000	0.004	0.005	0.005	992	0.999
qLB	909+910	AW	4.908E-06	5.334E-07	4.085E-06	4.910E-06	5.778E-06	956	0.999
		SS	7.163E-06	8.845E-07	5.827E-06	7.098E-06	8.756E-06	945	0.999
	911	AW	1.345E-05	1.150E-06	1.169E-05	1.339E-05	1.545E-05	936	1.002
		SS	1.222E-05	1.075E-06	1.062E-05	1.214E-05	1.402E-05	969	0.999
mat50	909+910		40.000						
			45.000						
mat95	911		10.000						
			10.000						
Galpha [M]	909+910		14.020						
Galpha [F]			7.140						
Galpha [M]	911		7.580						
Galpha [F]			6.270						
Gdiff [M]	909+910		0.049	0.009	0.034	0.049	0.063	927	0.999
Gdiff [F]			0.086	0.013	0.064	0.087	0.108	929	1.000
Gdiff [M]	911		0.318	0.049	0.236	0.316	0.400	893	1.000
Gdiff [F]			0.080	0.012	0.062	0.079	0.101	948	1.009
Gshape [M]	909+910		7.681	0.172	7.408	7.680	7.967	891	1.000
Gshape [F]			6.157	0.211	5.824	6.152	6.515	1025	1.001
Gshape [M]	911		2.392	0.296	1.947	2.362	2.897	857	1.000
Gshape [F]			3.328	0.134	3.100	3.327	3.561	890	1.000
GCV [M]	909+910		0.653	0.011	0.636	0.653	0.671	867	1.000
GCV [F]			1.645	0.058	1.555	1.642	1.742	835	0.999
GCV [M]	911		0.539	0.031	0.488	0.539	0.590	1004	1.000
GCV [F]			0.994	0.078	0.876	0.990	1.131	803	1.017
Gobs	909+910		1.000						
	911		1.000						
vuln [F]	909+910	AW	0.246	0.045	0.179	0.242	0.326	828	1.001
		SS	0.666	0.113	0.494	0.658	0.864	864	1.000
	911	AW	0.419	0.029	0.374	0.418	0.467	969	1.000
		SS	1.100	0.059	1.005	1.098	1.198	1081	1.002
selL [M]	909+910		5.602	0.201	5.270	5.596	5.964	939	1.000
selL [F] < 1993			8.706	0.799	7.460	8.641	10.071	936	1.003
selL [F] ≥ 1993			12.332	0.641	11.354	12.303	13.381	972	1.001
selL [M]	911		4.634	0.161	4.364	4.639	4.903	1027	1.000
selL [F]			6.453	0.167	6.177	6.454	6.727	521	1.028
selM [M]	909+910		48.161	0.170	47.880	48.161	48.454	1076	1.000
selM [F] < 1993			53.825	0.968	52.335	53.795	55.445	1042	0.999
selM [F] ≥ 1993			61.171	1.203	59.326	61.089	63.283	871	1.001
selM [M]	911		51.520	0.162	51.266	51.517	51.780	1086	0.999
selM [F]			58.719	0.210	58.373	58.720	59.068	877	1.030

Table 12: Summary of the posterior distribution for the derived quantities for the *base* model showing the mean, standard deviation (SD) of the mean, median, and 90% credible interval (i.e., 5% and 95%) are reported. Biomass values and handling mortality (*H*) are reported in tonnes.

	Region	Mean	SD	5%	50%	95%
Vulnerable biomass						
B_0	909+910	759	45	686	757	834
	911	957	55	870	955	1054
	Total	1716	72	1603	1711	1841
B_{0now}	909+910	557	22	522	557	595
	911	1083	51	1003	1080	1171
	Total	1640	56	1549	1640	1735
B_{MIN}	909+910	133	10	116	133	151
	911	40	3	36	40	46
	Total	174	11	156	174	191
B_R	909+910	222	–	–	–	–
	911	150	–	–	–	–
	Total	372	–	–	–	–
B_R / B_0	909+910	0.294	0.017	0.266	0.293	0.323
	911	0.157	0.009	0.142	0.157	0.172
	Total	0.217	0.009	0.202	0.217	0.232
B_R / B_{0now}	909+910	0.399	0.016	0.373	0.399	0.425
	911	0.139	0.007	0.128	0.139	0.15
	Total	0.227	0.008	0.214	0.227	0.24
B_{2024}	909+910	209	56	131	203	312
	911	111	17	83	110	140
	Total	320	58	241	312	427
B_{2028}	909+910	232	79	117	223	382
	911	214	80	98	205	358
	Total	446	110	271	440	636
B_{2024} / B_0	909+910	0.276	0.074	0.172	0.269	0.413
	911	0.116	0.019	0.086	0.115	0.150
	Total	0.187	0.035	0.139	0.183	0.250
B_{2028} / B_0	909+910	0.307	0.106	0.155	0.295	0.500
	911	0.224	0.085	0.102	0.213	0.375
	Total	0.260	0.066	0.160	0.254	0.378
B_{2024} / B_{0now}	909+910	0.375	0.098	0.238	0.364	0.560
	911	0.102	0.014	0.079	0.101	0.126
	Total	0.195	0.035	0.148	0.190	0.260
B_{2028} / B_{0now}	909+910	0.416	0.139	0.209	0.404	0.672
	911	0.197	0.072	0.093	0.190	0.329
	Total	0.271	0.066	0.170	0.268	0.386
B_{2028} / B_{2024}	909+910	1.153	0.423	0.585	1.096	1.947
	911	1.931	0.653	0.960	1.872	3.088
	Total	1.417	0.358	0.874	1.391	2.068
B_{2024} / B_R	909+910	0.942	0.252	0.589	0.913	1.406
	911	0.737	0.115	0.555	0.733	0.930
	Total	0.859	0.157	0.647	0.838	1.149
B_{2028} / B_R	909+910	1.045	0.356	0.526	1.006	1.723
	911	1.424	0.533	0.654	1.364	2.387
	Total	1.198	0.296	0.730	1.183	1.709
Exploitation						
U_R	909+910	0.349	–	–	–	–
	911	0.385	–	–	–	–
U_{2024}	909+910	0.341	0.095	0.213	0.326	0.515
	911	0.338	0.055	0.260	0.332	0.441
U_{2028}	909+910	0.376	0.148	0.205	0.342	0.677
	911	0.261	0.100	0.148	0.239	0.445
U_{2028} / U_{2024}	909+910	1.128	0.378	0.642	1.065	1.864
	911	0.765	0.229	0.488	0.714	1.207

	Region	Mean	SD	5%	50%	95%
U_{2024} / U_R	909+910	0.976	0.272	0.610	0.934	1.477
	911	0.878	0.143	0.676	0.861	1.146
U_{2028} / U_R	909+910	1.076	0.425	0.587	0.980	1.941
	911	0.677	0.259	0.385	0.621	1.156
Spawning stock biomass						
SSB_0	909+910	1205	76	1088	1203	1332
	911	772	44	701	770	846
	Total	1977	88	1837	1974	2124
SSB_{0now}	909+910	304	15	281	303	329
	911	261	12	242	261	283
	Total	565	20	533	564	601
SSB_{2024}	909+910	236	45	173	230	317
	911	213	23	179	212	255
	Total	449	51	376	445	537
SSB_{2028}	909+910	262	53	183	256	361
	911	230	38	177	227	293
	Total	492	64	394	488	602
SSB_{2024} / SSB_0	909+910	0.196	0.038	0.142	0.192	0.262
	911	0.277	0.031	0.232	0.275	0.332
	Total	0.228	0.027	0.190	0.225	0.277
SSB_{2028} / SSB_0	909+910	0.218	0.046	0.154	0.213	0.302
	911	0.298	0.050	0.226	0.294	0.386
	Total	0.249	0.034	0.198	0.246	0.309
SSB_{2024} / SSB_{0now}	909+910	0.776	0.144	0.578	0.756	1.054
	911	0.816	0.069	0.717	0.809	0.939
	Total	0.795	0.084	0.677	0.787	0.949
SSB_{2028} / SSB_{0now}	909+910	0.863	0.169	0.616	0.850	1.159
	911	0.879	0.134	0.680	0.867	1.110
	Total	0.870	0.108	0.708	0.862	1.053
SSB_{2028} / SSB_{2024}	909+910	1.137	0.254	0.766	1.117	1.589
	911	1.077	0.137	0.874	1.065	1.303
	Total	1.102	0.141	0.888	1.097	1.343
Total biomass						
T_0	909+910	3291	204	2974	3279	3622
	911	2418	135	2203	2413	2646
	Total	5708	247	5322	5697	6136
T_{0now}	909+910	1743	77	1619	1739	1866
	911	2059	90	1918	2055	2210
	Total	3802	122	3608	3796	4005
T_{2024}	909+910	1217	304	797	1170	1806
	911	1076	176	827	1052	1389
	Total	2292	355	1804	2252	2927
T_{2028}	909+910	1271	309	822	1237	1831
	911	1157	218	844	1139	1532
	Total	2428	375	1842	2399	3112
T_{2024} / T_0	909+910	0.371	0.093	0.238	0.356	0.543
	911	0.446	0.076	0.342	0.437	0.578
	Total	0.402	0.064	0.312	0.394	0.518
T_{2028} / T_0	909+910	0.388	0.097	0.248	0.376	0.564
	911	0.480	0.092	0.350	0.472	0.648
	Total	0.426	0.068	0.320	0.418	0.550
T_{2024} / T_{0now}	909+910	0.698	0.172	0.466	0.673	1.021
	911	0.522	0.079	0.407	0.512	0.666
	Total	0.603	0.090	0.474	0.592	0.773
T_{2028} / T_{0now}	909+910	0.729	0.173	0.480	0.712	1.039
	911	0.562	0.101	0.415	0.551	0.735
	Total	0.639	0.095	0.492	0.631	0.809

	Region	Mean	SD	5%	50%	95%
T_{2028} / T_{2024}	909+910	1.092	0.333	0.643	1.041	1.706
	911	1.085	0.176	0.843	1.060	1.429
	Total	1.075	0.189	0.791	1.049	1.436
$T_{2024}^{male} / T_{2024}^{female}$	909+910	1.561	0.066	1.454	1.562	1.671
	911	1.448	0.038	1.386	1.448	1.509
Other quantities						
Rmean	909+910	2124288	98097	1967790	2119770	2278600
	911	1044685	48642	967290	1042540	1127910
Rrho	909+910	0.127	0.023	0.087	0.129	0.160
	911	0.003	0.019	-0.031	0.005	0.031
H_{2023}	909+910	4.133	0.231	3.777	4.126	4.496
	911	2.975	0.243	2.605	2.960	3.386
	Total	7.108	0.342	6.582	7.100	7.696
H_{2028}	909+910	6.402	1.386	4.489	6.227	9.050
	911	1.837	0.532	1.219	1.744	2.782
	Total	8.239	1.475	6.140	8.069	10.872

Table 13: Summary of the posterior distribution for the derived quantities for the base model.

Indicator	Region	Probability	Indicator	Region	Probability
$P(B_{2024} > B_{MIN})$	909+910	0.970	$P(SSB_{2024} < 20\% SSB_0)$	909+910	0.596
	911	1.000		911	0.004
	Total	1.000		Total	0.143
$P(B_{2024} > B_R)$	909+910	0.353	$P(SSB_{2024} < 10\% SSB_0)$	909+910	0.000
	911	0.017		911	0.000
	Total	0.168		Total	0.000
$P(B_{2028} > B_R)$	909+910	0.506	$P(SSB_{2028} < 20\% SSB_0)$	909+910	0.383
	911	0.789		911	0.011
	Total	0.741		Total	0.056
$P(B_{2028} > B_{2024})$	909+910	0.604	$P(SSB_{2028} < 10\% SSB_0)$	909+910	0.001
	911	0.943		911	0.000
	Total	0.886		Total	0.000
$P(T_{2028} > T_{2024})$	909+910	0.558	$P(SSB_{2024} < 20\% SSB_{0now})$	909+910	0.000
	911	0.645		911	0.000
	Total	0.622		Total	0.000
$P(U_{2024} > U_R)$	909+910	0.389	$P(SSB_{2024} < 10\% SSB_{0now})$	909+910	0.000
	911	0.172		911	0.000
$P(U_{2028} > U_R)$	909+910	0.471		Total	0.000
	911	0.092	$P(SSB_{2028} < 20\% SSB_{0now})$	909+910	0.000
$P(U_{2028} > U_{2024})$	909+910	0.573		911	0.000
	911	0.120		Total	0.000
			$P(SSB_{2028} < 10\% SSB_{0now})$	909+910	0.000
				911	0.000
				Total	0.000
			$P(SSB_{2028} < SSB_{2024})$	909+910	0.695
				911	0.695
				Total	0.753

Effort creep (*qdrift*) was fixed at 1%/year for all of the CPUE series. The model fits to the four CPUE series were good (Figure 25), with the exception of a small number of years when the standardised residuals were outside of the ±2 range (Figure I.8).

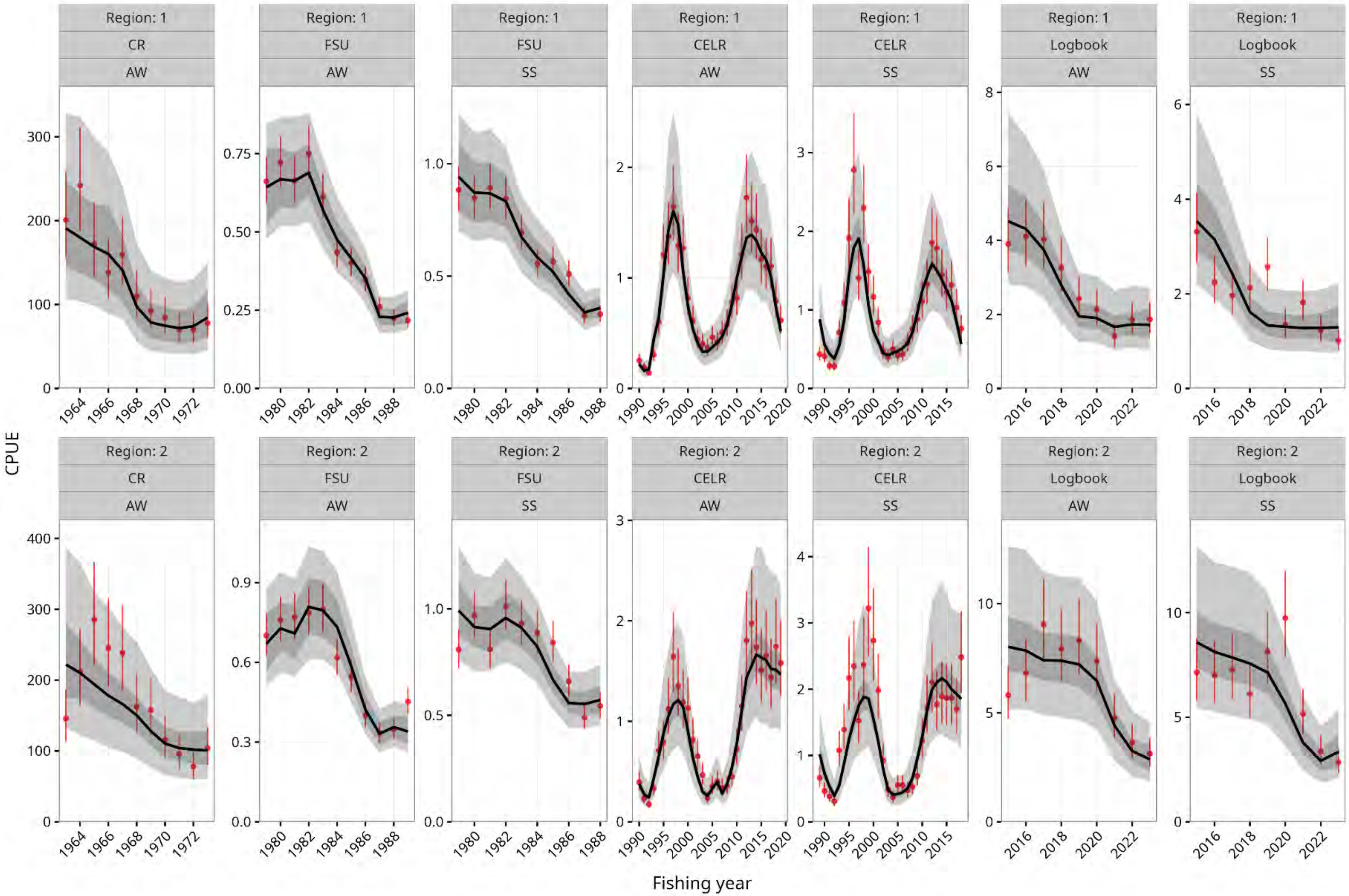


Figure 25: Posterior predicted CPUE for the CR, FSU, CELR, and LB series by fishing year, season, and region in the base model run. The solid line indicates the posterior median and grey shading with variable intensity indicates 90% credible intervals for the posterior distribution and the posterior predictive distribution. Error bars are +/- one standard deviation.

With the exception of a few years, the base case model fit to the sex ratio data was reasonably good (Figure 26), with no pronounced pattern in the one step ahead residuals by region, year, or season (Figure I.9).

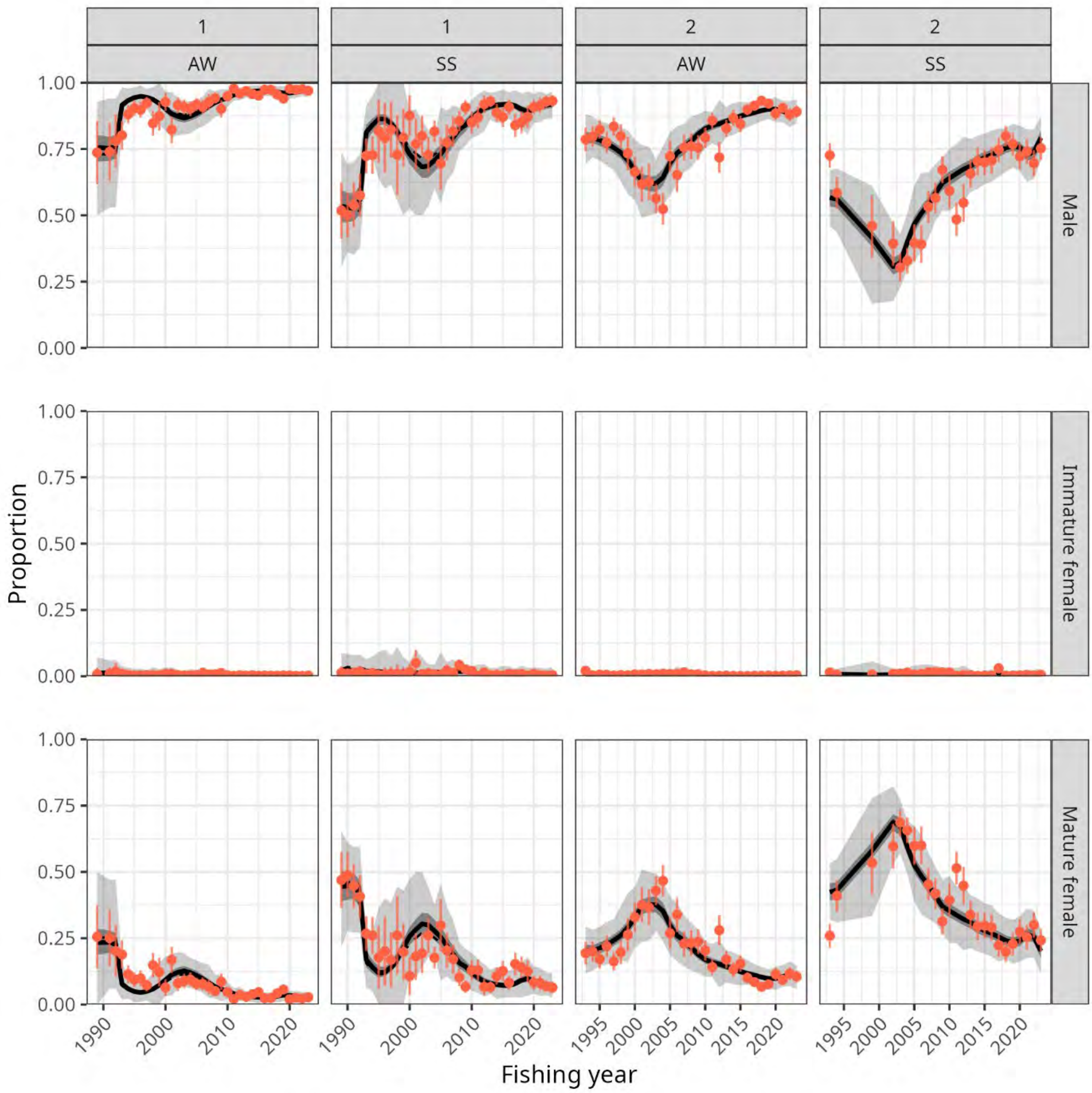


Figure 26: Posterior distribution of the sex ratios compared to the observed sex ratios by region, fishing year, season (AW = autumn/winter, SS = spring/summer), and sex, in the base model run. The solid line indicates the posterior median and grey shading indicates the 90% credible intervals or the posterior and posterior predictive distributions. Error bars are +/- one standard deviation.

Model fits to the LF data were generally acceptable (Figure I.10) for males and mature females while the apparent poor fits to the immature female LF distributions reflected the small amount of data in this sex category. One-step-ahead standardised residuals were outside the ±2 range for only a few size classes (even for the immature females, Figure I.11) and only in the tails of the residual distributions in some of the years (Figure I.12). Generally, the fits to the male and mature female LFs in the centre of the length distributions were acceptable, with some bias around the respective MLS for both males and females.

The most notable feature of the tagging data used to estimate growth was the extreme variability in the observed individual growth increments, through which the model finds an average (Figure 27). This variation could be attributed to measurement error, individual variability in growth, spatial-temporal variability, or the short time period many lobsters spend at liberty. It is important to note that this model uses a continuous growth function to model growth, while lobster growth is a discrete process (i.e., growth can only occur after moulting). Attempts were made in the early 2000s to model growth more realistically, but these were unsuccessful because there was no reliable visual indicator that an observer could use to determine whether an individual lobster had recently moulted. However, while the residuals in this growth model are large, there is little evidence for any systematic bias with respect to the predicted growth increment by year of release (Figure I.13) or by statistical area of release (Figure I.14) for either sex.

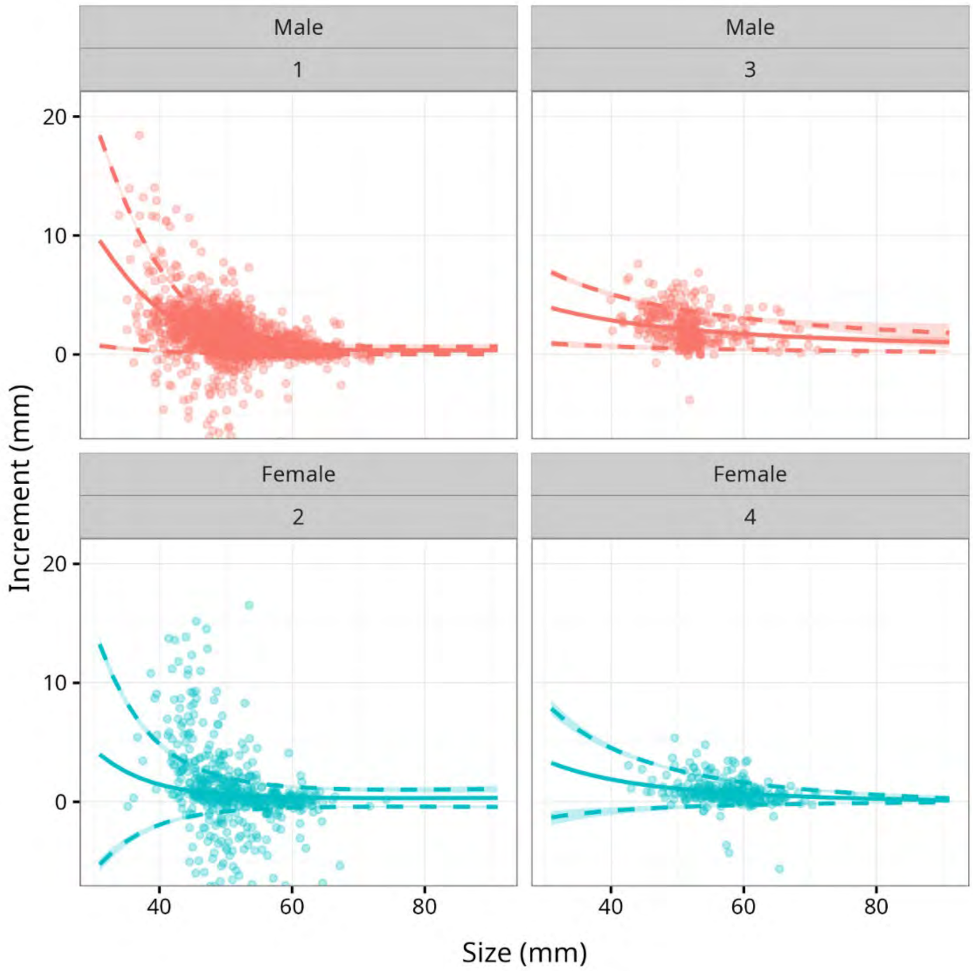
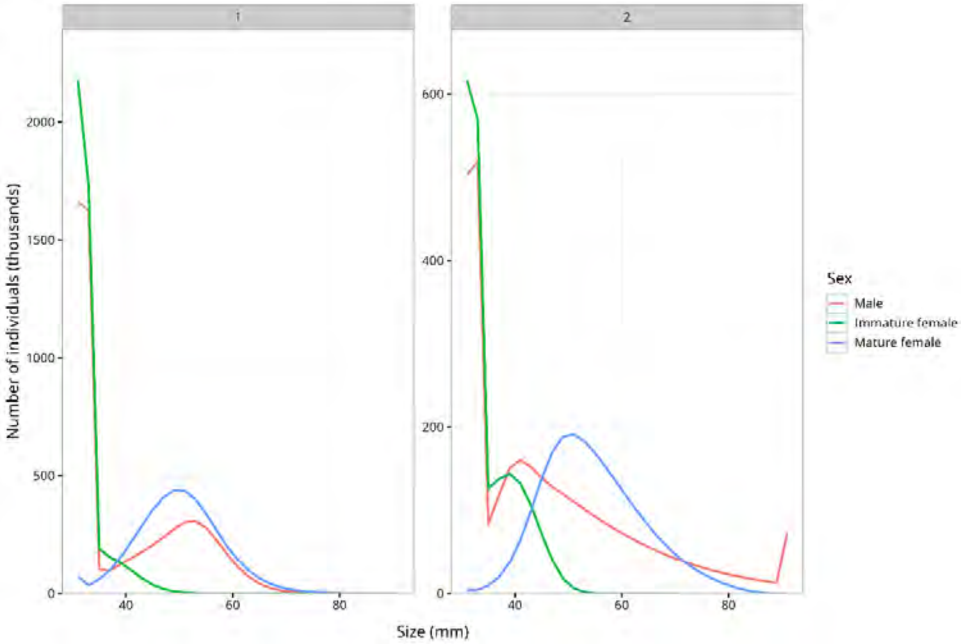


Figure 27: Posterior distribution of predicted six-monthly growth increment by size (mm), region (left column is region 1; right column is region 2), and sex in the base model run showing the mean (solid line), ±1 standard deviation (dashed line). Shading shows 90% credible interval.

The estimated size distribution of the unfished population compared to the size distribution in the final model year (Figure 28) further highlights the reduction in the abundance of mature females and also the reduction in the number of larger lobsters.

1945



2023

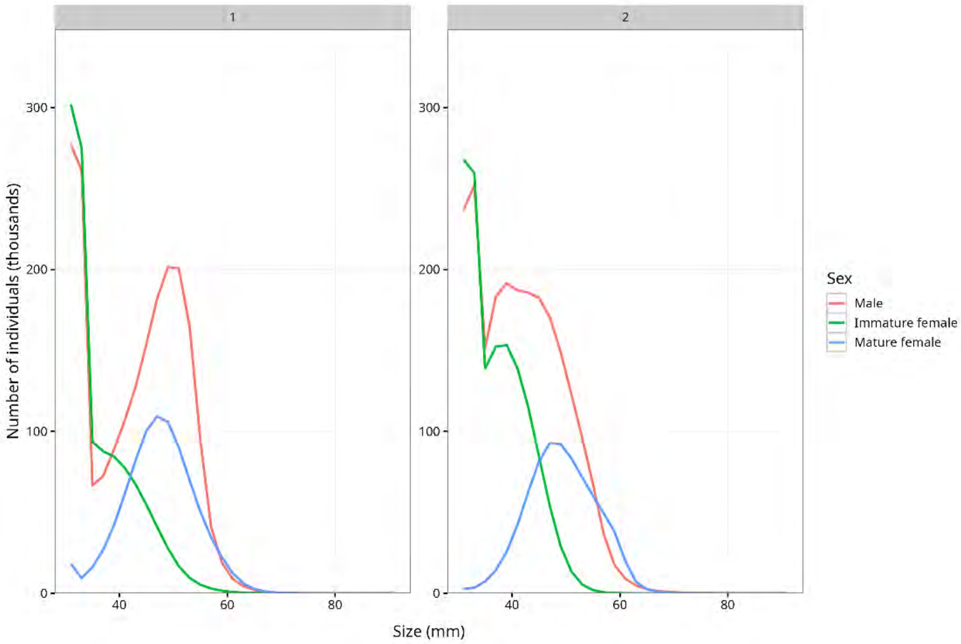


Figure 28: Median number of individuals by region, size and sex category that were estimated by the *base* model for the first and final no projected model years.

The selectivity functions were simplified from previous assessments that fixed the right limb at nearly logistic selectivity by assuming logistic selectivity. Selectivity multiplied by vulnerability provided an improved visualisation of the relative probabilities of each sex being captured by the gear in the fishery (Figure 29). The selectivity posterior plot for the *base* model showed little uncertainty in these parameters, indicating that selectivity was well defined by the data (see the tight posterior density plots for selectivity in Figure I.7). There was more uncertainty in vulnerability parameters than in the selectivity parameters (demonstrated by the wide posteriors for the vulnerability parameters in Figure I.7) by season (Figure 29). Note that some of the uncertainty in the female vulnerabilities probably incorporate some uncertainty from the male vulnerabilities which were fixed at one as part of the estimation procedure.

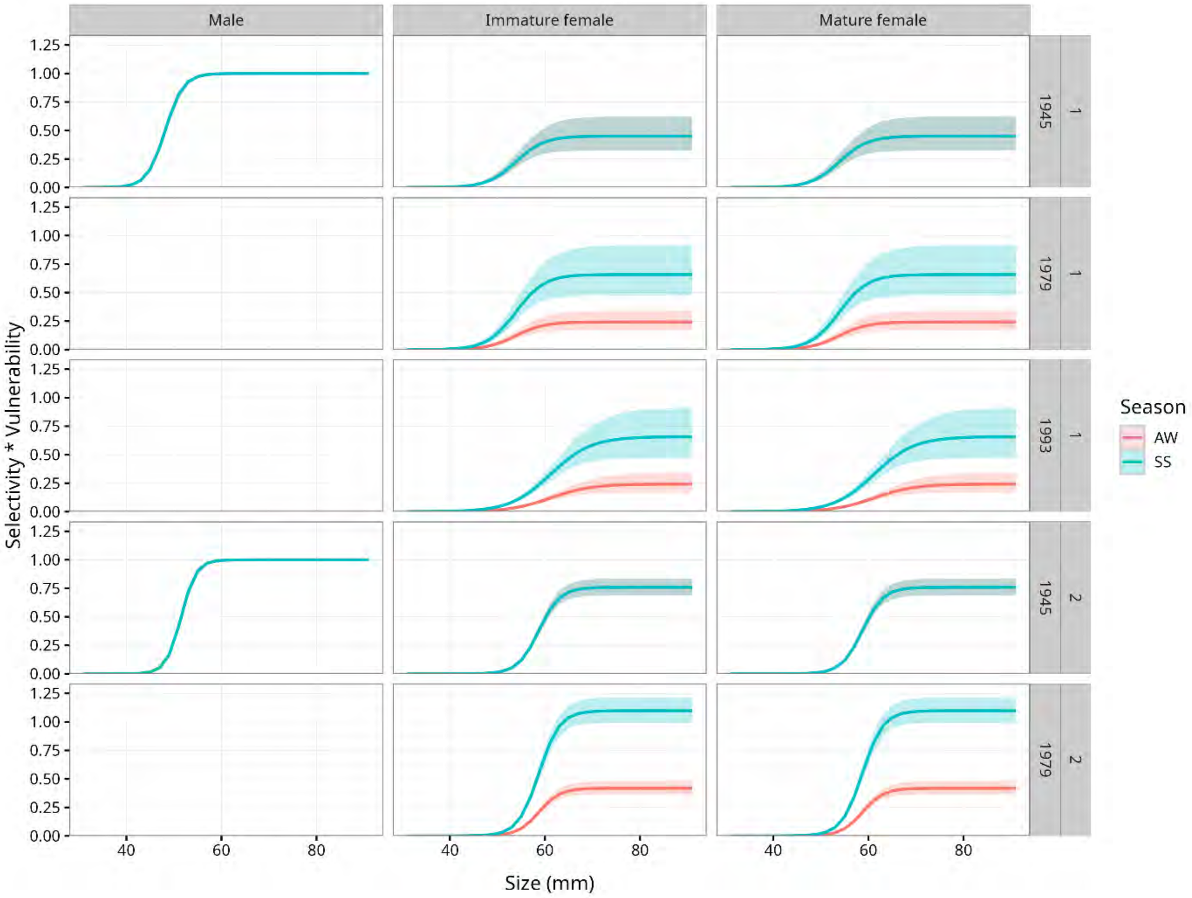


Figure 29: Posterior distribution of selectivity by size (mm) multiplied by vulnerability by region, sex, and season in the *base* model run. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

The size at 50% of female maturation was not estimated within this model. Instead, the *mat50* parameters were fixed to 40 mm and 45 mm TW for region 1 and 2 respectively, while the *mat95* parameters were fixed to 10 mm in both regions (Figure 30, but see also Appendix G). This CRA 3 maturity was considerably smaller than the equivalent maturity estimated for CRA 7&8, where 50% maturity was estimated to be near 60 mm TW (Webber et al. 2022). With a female MLS of 60 mm TW, many immature females would be selected to the gear in CRA 7&8, unlike for CRA 3 where only a few immature females were vulnerable to the fishery (Figure 28 given Figure H.3). However, female vulnerability was generally relatively low compared to other QMAs. In region 1, the median female vulnerability was 0.242 in AW and 0.658 in SS. In region 2, the median female vulnerability in AW was 0.418. Alternatively, female vulnerability was relatively high in region 2 SS. This was the first stock assessment using the LSD model where vulnerability was able to be estimated above one (i.e. high relative to males fixed to one in each region and season). When the maximum value for vulnerability was one (i.e. just as vulnerable as males), the region 2 female SS vulnerability was initially estimated to be close to the bound, causing problems during MCMC. Once the upper bound of the prior was updated to allow vulnerability to be estimated greater than one, the region 2 female SS vulnerability was estimated to have most of its posterior distribution exceeding one (Table 11).

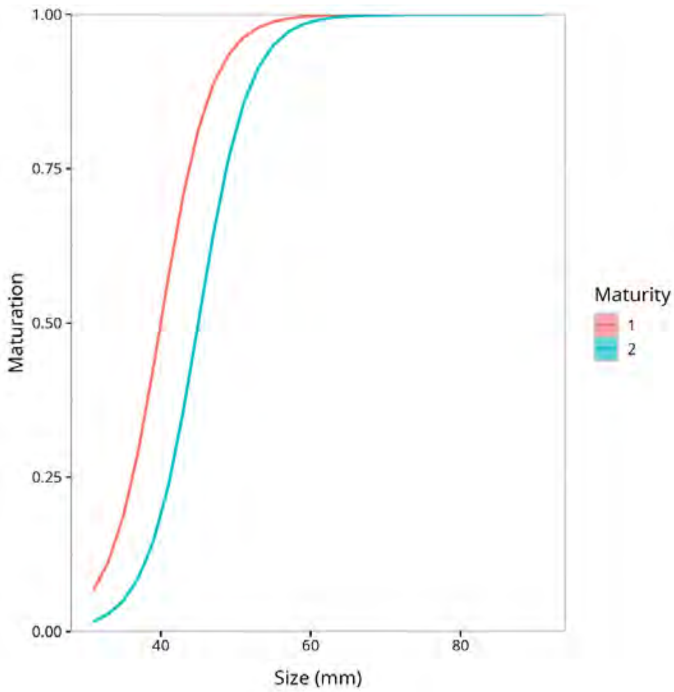


Figure 30: The assumed female maturation curve by region (region 1 = red, region 2 = blue) and size in the *base* model run. Note that the *mat50* and *mat95* parameters were fixed at 40 mm and 10 mm, respectively.

In both regions, the NSL exploitation rates were very low compared with the SL exploitation rates, reflecting the small amount of assumed NSL catch relative to SL catch (Figure 31). Exploitation rates in region 1 were very high, close to 1.0, until around 1990 when exploitation rates decreased and levelled off in response to the management interventions that started in 1993. Region 2 SL exploitation rates increased steadily until 1990, although the peak was lower than in region 1. Since the early 1990s, exploitation rates have been lower with some higher peaks during the 2000s and in recent years (Figure 31). These exploitation rates were reflected in the catch; region 1 catches increased to a peak in the 1980s and have decreased since then. Region 2 catches generally increased until the 1980s and then began to decline, with some higher periods of both size-limited and non-size-limited catches in the 2000s and again in recent years (Figure 32).

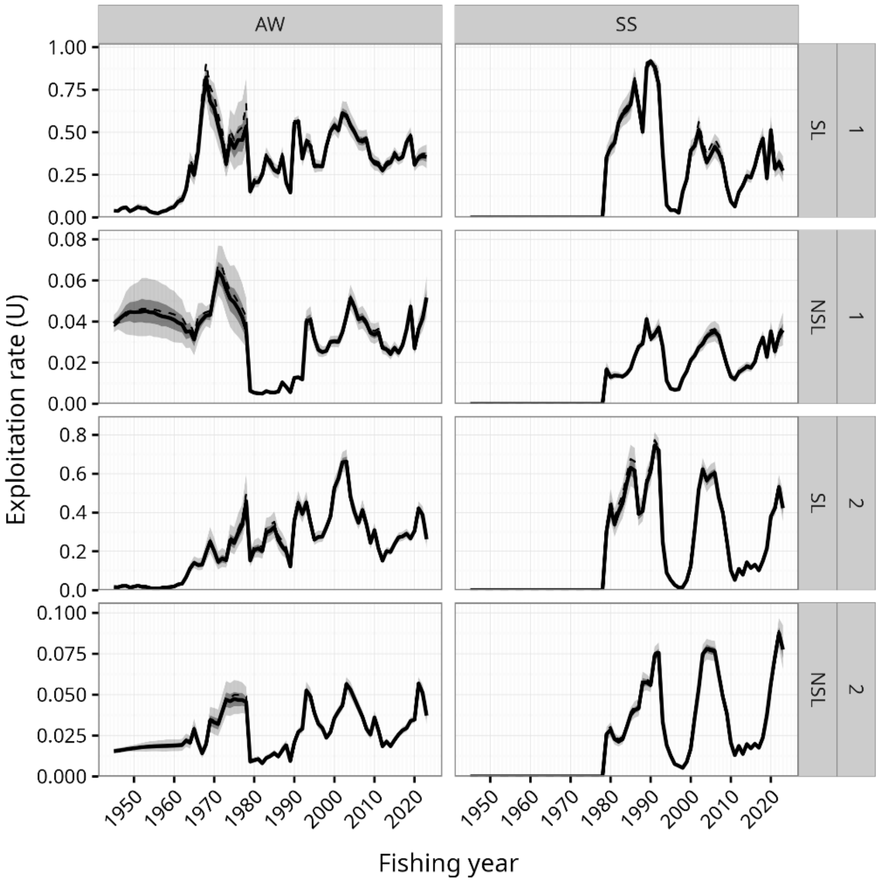


Figure 31: Posterior distribution of exploitation rate (*U*) by region, fishing year, season, and fishery (SL = size-limited; NSL = non-size-limited) for the *base* model run. The solid black line indicates the median of the posterior and variable shading intensity indicating the 50% and 90% credible intervals. The dashed black line is the MAP.

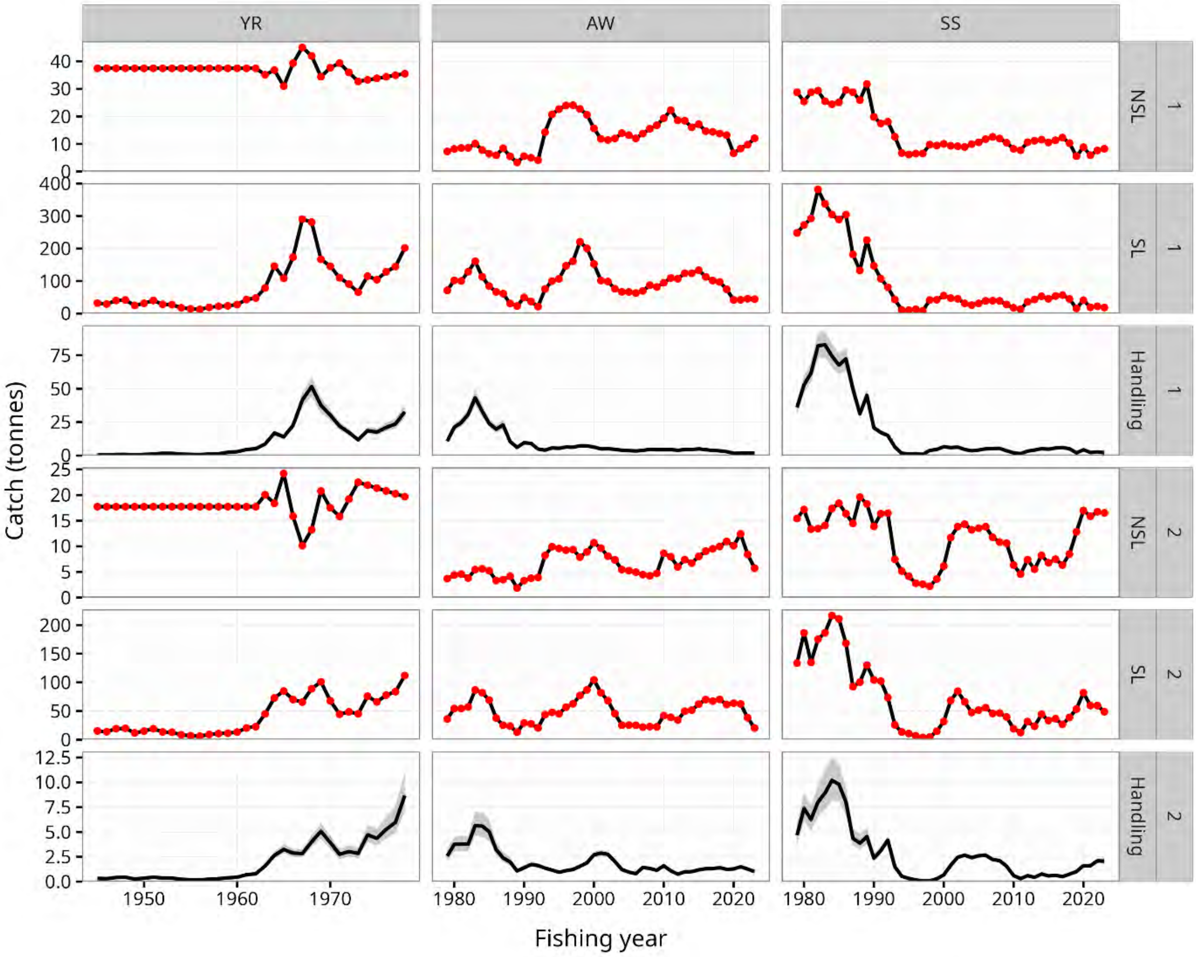


Figure 32: Posterior distribution of the catch and handling mortality (*H*) by region, fishing year, season, and fishery (SL = size-limited; NSL = non-size-limited) for the *base* model run. The solid black line indicates the median of the posterior and shading indicates the 90% credible interval; the red dots represent the observed catch.

Three strong recruitment pulses were estimated in CRA 3 region 1, one in the mid-1960s, one in the late 1970s and early 1980s, and the third in the mid-1990s. Region 2 has had one recruitment pulse in the late 1970s and early 1980s. Median recruitment was estimated around R_0 in both regions in the late 2000s and early 2010s and has dropped below R_0 in recent years. Region 2 has had an estimated high recruitment year in the final estimated year of 2020 (Figure 33).

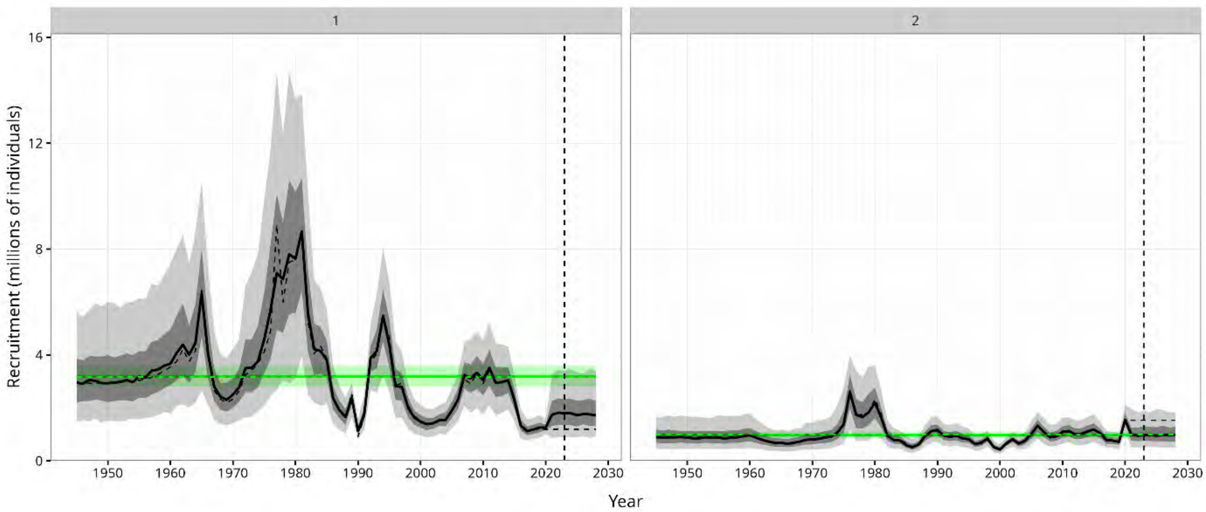


Figure 33: Posterior distribution of recruitment by region for the *base* model run. The horizontal green line is R_0 and the vertical dashed line is the final year of the reconstruction period after which the projected recruitment is shown. The solid black line indicates the median of the posterior and variable shading intensity indicates the 50% and 90% credible intervals. The dashed lines indicate the MAP.

The AW adjusted vulnerable biomass in CRA 3 region 1 fluctuated through time with peaks in the early 1960s, early 1980s, mid 1990s, and early 2010s and troughs in the early 1970s, early 1990s, early 2000s, and in recent years (since around 2018). Since 2021, the AW adjusted biomass was predicted to be increasing, most likely due to a lower TACC (Figure 34). Median estimated vulnerable biomass in region 1 at the beginning of 2024 was 26.9% B_0 (90% credible interval: 17.2%–41.3%) and 91.3% B_R (90% credible interval: 58.9%–141%) (Table 12). There was a probability of 0.353 that B_{2024} was greater than B_R (Table 13). The AW adjusted vulnerable biomass in CRA 3 region 2 declined from the first model year in 1945 until the early 1990s, but has fluctuated since then, with peaks in the late 1990s and mid-2010s and troughs in the early 1990s, mid-2000s, and in recent years (since 2020). However, region 2 AW vulnerable biomass was projected to increase, most likely due to an estimated recent recruitment spike and lower TACC (Figure 34). Median estimated vulnerable biomass in region 2 at the beginning of 2024 was 11.5% B_0 (90% credible interval: 8.6%–15.0%) and 73.3% B_R (90% credible interval: 55.5%–93.0%) (Table 12). There was a probability of 0.017 that B_{2024} was greater than B_R (Table 13).

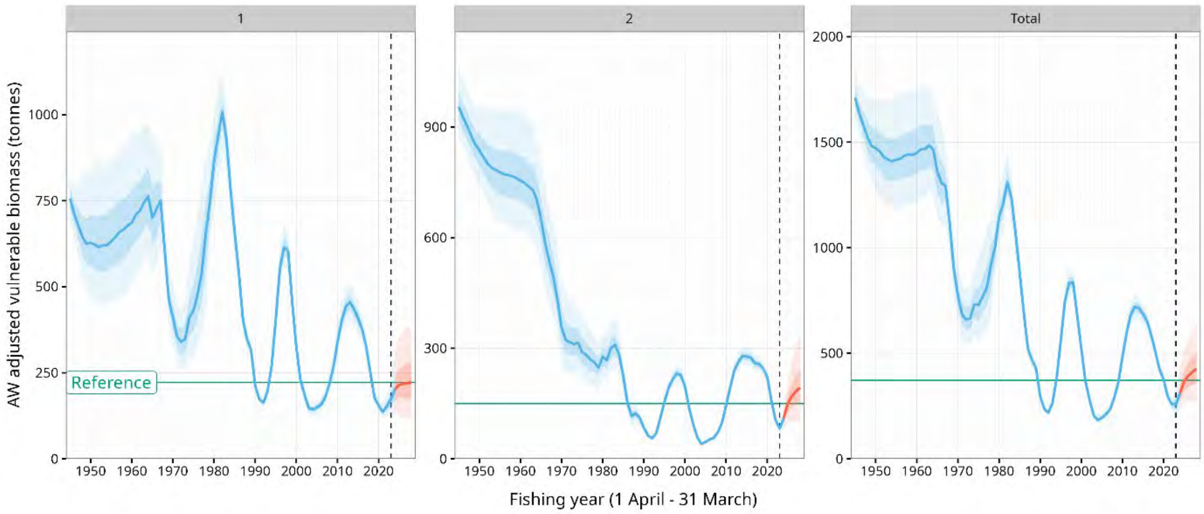


Figure 34: Posterior distribution of the AW adjusted vulnerable biomass (tonnes) by region and fishing year for the *base* model run compared with the reference level. The dashed vertical line shows the final model year (2023), the blue line shows the model years and first projection year as the current year for which commercial catches were known (2024) and the red line shows projection years for which catches are assumed.

Like vulnerable biomass, the SSB trend was heavily influenced by the pattern in recruitment. Although there have been oscillations in SSB over time associated with recruitment spikes, the general trend has been declining with a sharp decline in both regions since 2010 (Figure 35). The early 2010s correspond with the highest recruitment in recent years, which was near R_0 in the early 2010s (Figure 33). However, both regions estimate low female M_{60} values prior to 2010 and high female M_{60} from 2010 onwards (Table 11), which contributed to the declining trend in female SSB (Figure 35). This hypothesis is supported by the mature female component of the total biomass, which drops off much faster since 2010 than the other sex categories (Figure 36). Median estimated SSB at the beginning of 2024 was 19.2% of SSB_0 in region 1, 27.5% in region 2, and 22.5% overall (Table 12). The stock assessment estimated a probability of 0.596 of being below 20% SSB_0 in region 1, which is below the soft limit (Table 13). However, there was a 0.004 probability of being below 20% SSB_0 in region 2 and 0.143 probability of being below 20% SSB_0 overall in CRA 3 (Table 13).

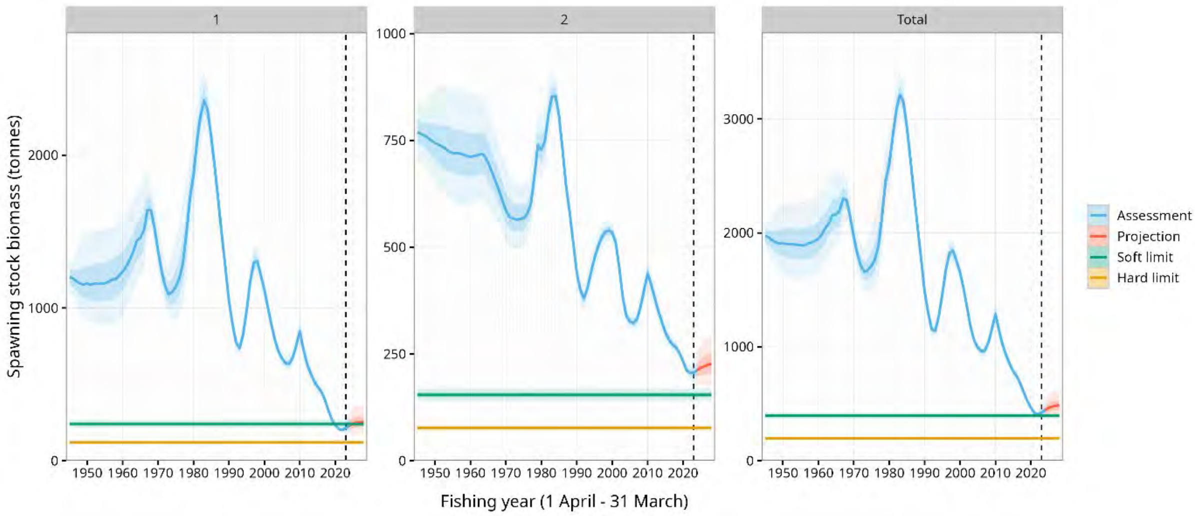


Figure 35: Posterior distribution of beginning year spawning stock biomass (tonnes) by region and fishing year for the base model. The associated soft (20% SSB_0) and hard limits (10% SSB_0) are also shown. The dashed vertical line shows the final model year (2023), the blue line shows the model years and first projection year as the current year for which commercial catches were known (2024) and the red line shows projection years for which catches are assumed.

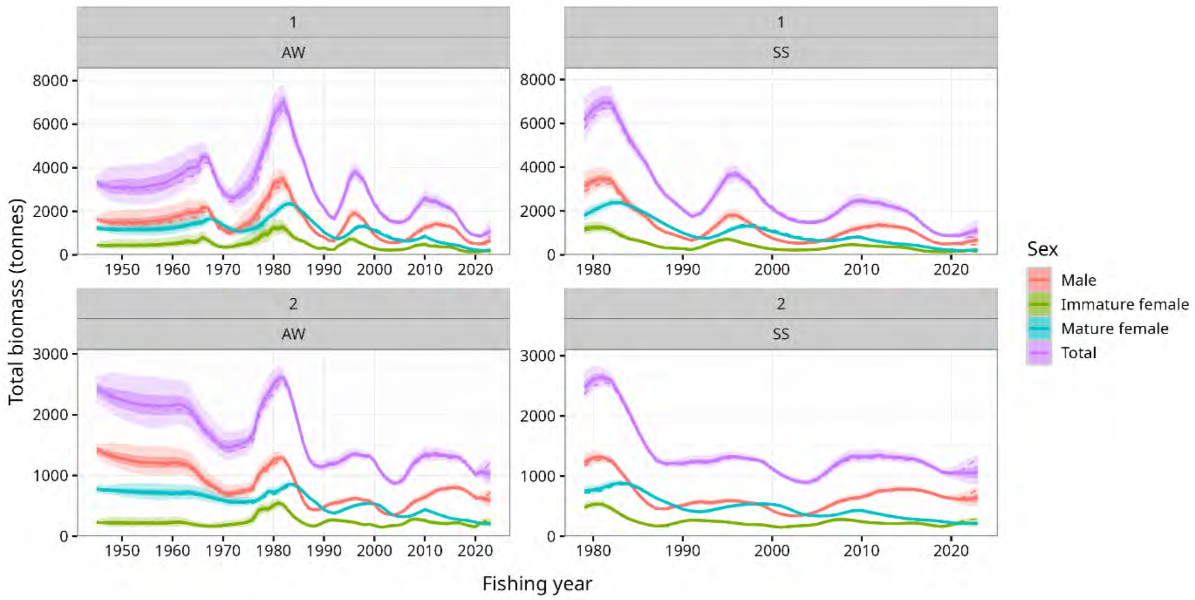


Figure 36: Posterior distribution of the beginning year total biomass by region, sex category, season, and fishing year for the *base* model run. Variable shading intensity indicates the 50% and 90% credible intervals.

The 2024 stock assessment estimated both region 1 and region 2 to have been theoretically overfished (B below B_R) and undergoing overfishing (U above U_R) in the years since the last full assessment in 2019. The phase plot shows that the *base* model run estimated region 1 to be overfished and undergoing overfishing (B below B_R and U above U_R) in 2020, with a decline in U in 2021 and 2022 such that region 1 was very close to no longer undergoing overfishing in those years (Figure 37). The *base* run estimated U in 2023 and 2024 to fall below U_R, with B_{2024} just below B_R (Figure 37). The region 2 phase plot shows that the *base* model estimated recent years (2022, 2023) to be both overfished and undergoing overfishing, but B in 2024 was just under B_R (overfished) but U was under U_R (no longer undergoing overfishing; Figure 37).

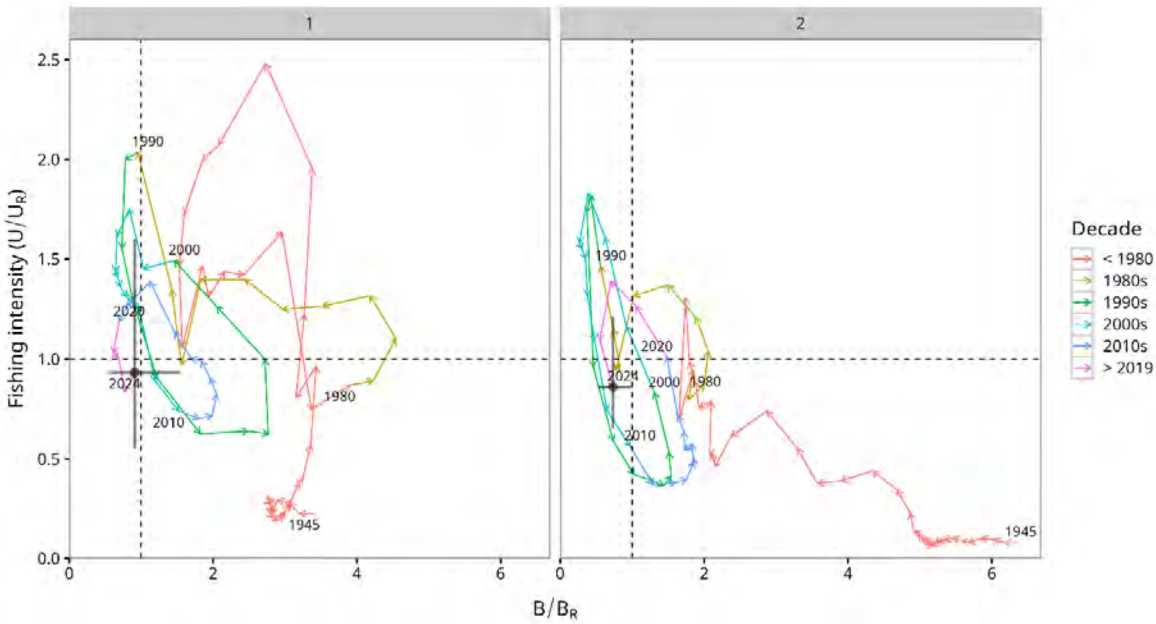


Figure 37: Phase plot for the CRA 3 *base* model by region. The figure shows the median of the posterior distribution of the AW vulnerable biomass as a proportion of the vulnerable biomass reference level in each year against the fishing intensity (exploitation rate relative to the overfishing threshold, the exploitation rate associated with the reference level). The 95th percentiles are shown for the final year.

The 2024 CRA 3 stock assessment included several model updates, including likelihood and data inputs (see Section 3.4.1) and structural changes that aimed to improve model fits compared to those obtained in 2019. These model updates also avoided the need to agree to two base runs by re-examining many of the underlying assumptions made by the 2019 stock assessment. The estimated recruitment in region 1 and region 2 followed similar patterns to the 2019 base models, which is not surprising given that most of the LF data that are used to inform recruitment are the same. However, the 2024 assessment estimated a much higher level of recruitment in region 1 than was estimated in 2019, most likely due to the assumption of differential growth and estimates for *M*. The 2024 *base* model estimated similar recruitment in region 2 to that estimated by the 2019 assessment, but with possibly slightly higher recruitment in recent years. (Figure 38).

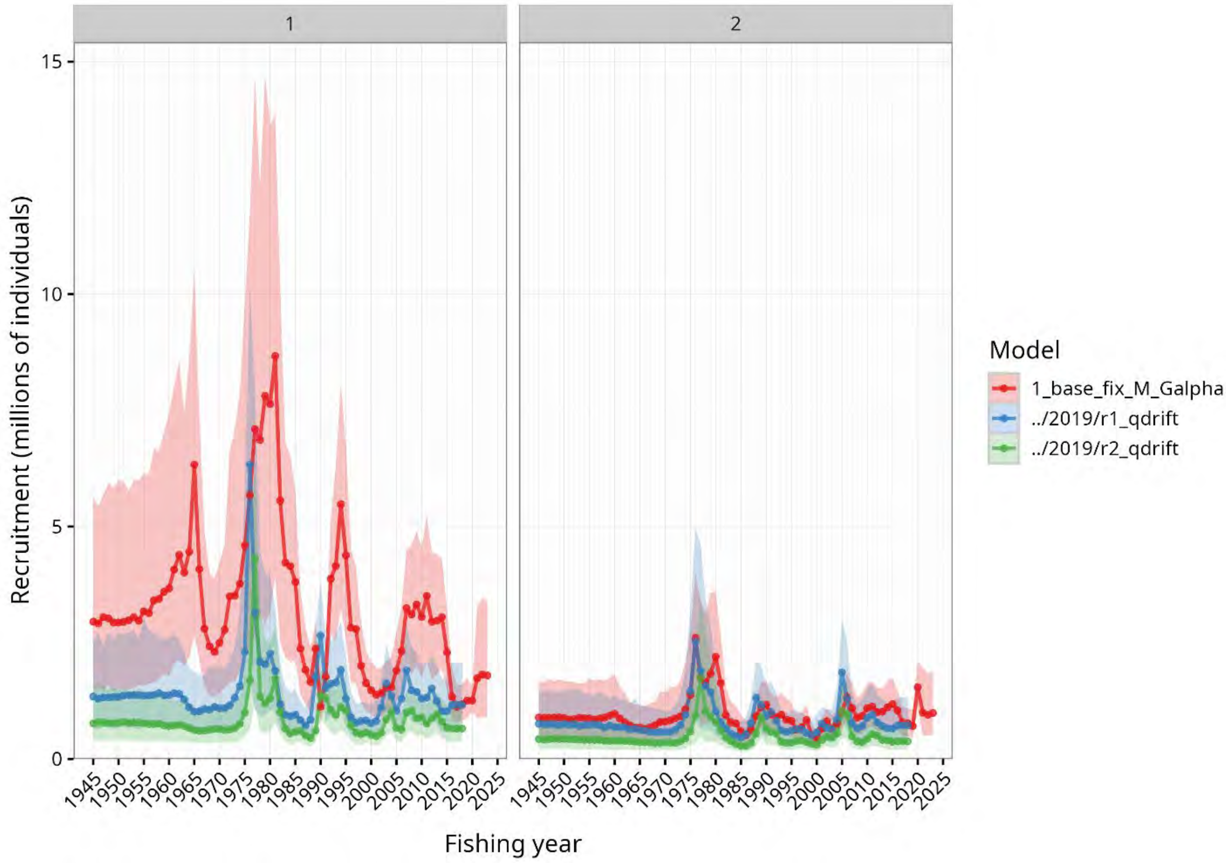


Figure 38: Posterior distribution of recruitment for the 2024 (*base*) and the two 2019 base case stock assessment model runs[12] (*r1_qdrift, r2_qdrift*).

Vulnerable biomass estimated in the 2019 base models and the 2024 *base* case were quite similar for most of the time series, except that the 2019 assessment estimated vulnerable biomass in region 1 to be much higher in the early years than the 2024 assessment (Figure 39). This means that the 2024 stock assessment reports higher relative vulnerable biomass (B/B_0) in recent years than the 2019 assessment, because there was a lower estimated B_0 to build back up to. The very key difference between the 2019 and 2024 assessments of CRA 3 is the steep decline in spawning stock biomass since 2010 in region 1 in the 2024 assessment (Figure 40), The 2019 base models estimated an oscillating but stable spawning biomass well above the soft limit. However, the 2024 CRA 3 assessment had much better fits to sex ratio and CPUE data, largely due to model structure and parameter changes with time, length, sex, and region-varying *M*. A higher *M* for mature females since 2010, combined with relatively low recruitments, led to a sharp decline in recent spawning biomass that was not estimated by either of the two 2019 stock assessment base runs.

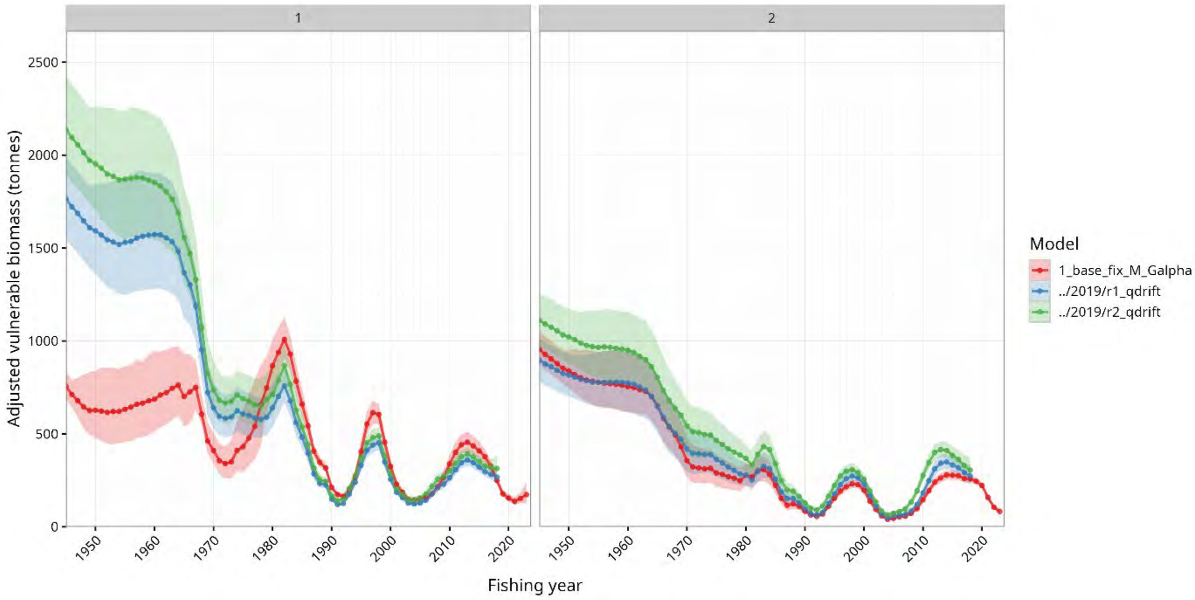


Figure 39: Posterior distribution of adjusted vulnerable biomass for the 2024 *base* (labelled *1_base_fix_M_Galpha*) and 2019 base case stock assessment model runs (*r1_qdrift*, *r2_qdrift*).

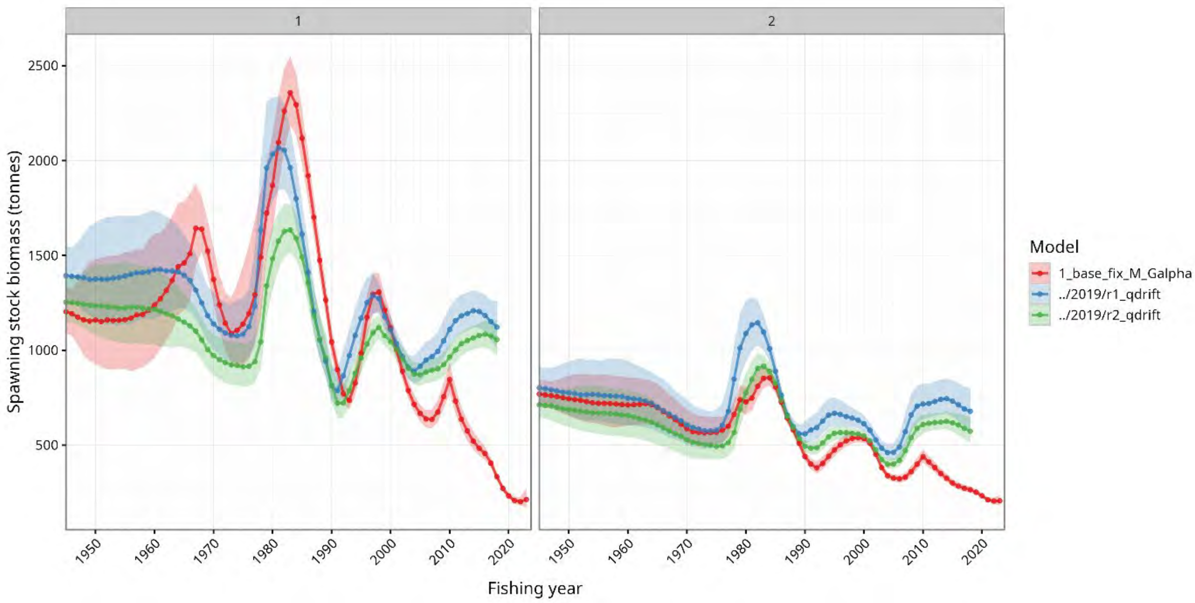


Figure 40: Posterior distribution of spawning biomass for the 2024 *base* (labelled *1_base_fix_M_Galpha*) and 2019 base case stock assessment model runs (*r1_qdrift*, *r2_qdrift*).

3.5 Model sensitivity

The 2024 CRA 3 stock assessment took longer that had been anticipated for a number of reasons, including the initial rejection of the assessment at the August 2024 Plenary (due to model fit issues) and the consequent need to overhaul the model code to address the August Plenary comments. There were also convergence issues with the resulting model MCMC runs. Some of these issues arose because of an error that was discovered with recent catch sampling data. Furthermore, permission to include the tag recapture data from within the marine reserve was very late in arriving.

The only converged model run that was achieved by the end of this process was the *1_base_fix_M_Galpha* model, for which the key M_{60} and growth *Galpha* and *Gobs parameters* were fixed. All other sensitivity runs assessed using MCMC inference did not converge. The improvement in model fit and other problematic aspects of the initial August 2024 CRA 3 assessment led to the updated CRA 3 stock assessment being accepted at the November 2024 Plenary, but there was insufficient time to work through convergence issues for the MCMC sensitivity runs.

MAP sensitivity trials were used to test some of the base case model assumptions. The RLWG decided on seven sensitivity trials as single variants relative to the *base* case (Table 14). These included sensitivity trials testing assumptions related to natural mortality (*3_Mlength*, *4_Mtime, 5_Msex, 6_Mregion*), sex ratios (*7_sexr*), and maturation (*8_matLo, 9_matHi*). These sensitivity runs were not presented to the 6 November 2024 Plenary meeting.

Table 14: List of maximum *a posteriori* (MAP) sensitivity trials. Each model run below the *base* model run implements a single change to the *base* model run.

Model name	Model description	MCMC
base	Named *1_base_fix_M_Galpha* in figures. *M* varies by length, sex, and region, with two time periods for females in region 1 split in 2010, sex ratios include vessel effect, fixed maturation where *mat50/mat95* = 40/10 mm in region 1 and 45/10 mm in region 2	Yes
3_Mlength	Length invariant *M*	No
4_Mtime	Time invariant *M*	No
5_Msex	*M* is not sex-specific	No
6_Mregion	*M* is not region-specific	No
7_sexr	Alternative sex ratio sensitivity (no vessel effect)	No
8_matLo	Lower fixed *mat50* parameter: 35 mm region 1 and 40 mm region 2	No
9_matHi	Higher fixed *mat50* parameter: 45 mm region 1 and 50 mm region 2	No

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the nine sensitivity trials are compared with each other and with the base (*base*) case Table 15.

Making natural mortality length invariant (*3_Mlength*) led to higher estimates of *M* in region 1 for both males and females (Table 15, e.g., male *M* = 0.557 in the *3_Mlength* model run compared with 0.465 in *base*) but lower estimates of *M* in region 2 for both sexes. The fits of both of these models to CPUE were almost indistinguishable (Figure 41, Figure 42), selectivity for females in region 1 changed only slightly (Figure 43), recruitment was slightly lower on average in region 1 but slightly higher in region 2 (comparing R_0 estimates in Table 15 and see Figure 44), and all measures of biomass were very similar (Figure 45, Figure 46, Figure 47).

Setting *M* to be time invariant (*4_Mtime*) had a much greater impact on model fits in region 2 for the CELR CPUE series (Figure 41) and both regions for the LB series (Figure 42). Again, selectivity for females in region 1 changed only slightly (Figure 43), but average recruitment increased substantially in region 1 (Table 15, Figure 44). The vulnerable biomass was similar between *base* and the *4_Mtime* model run (Figure 45), but the SSB was different both in terms of scale (Figure 46) and trend, especially since 2010 (Figure 47).

Sharing *M* between males and females (*5_Msex*) had little impact on model fits to CPUE (Figure 41, Figure 42). Again, selectivity for females in region 1 changed only slightly (Figure 43). This model run had the lowest average recruitment in region 1 compared to the other natural mortality sensitivity trials (Table 15, Figure 44). However, this model predicted the highest initial vulnerable biomass of the set (Figure 45). In region 1, there were two groups of similar SSB trajectories: 1) high SSB maintained in recent years (time-invariant *M* and *M* shared across both regions) and 2) a drop in SSB below the soft limit (*base*, length-invariant *M*, *M* shared by sex, Figure 46, Figure 47).

Sharing *M* between regions (*6_Mregion*) resulted in some minor difference in the fits to CPUE (Figure 41, Figure 42), selectivity for females in region 1 (Figure 43), and recruitment (Figure 44). However, all measures of biomass were different (Figure 45, Figure 46, Figure 47).

Table 15: CRA 3 maximum *a posteriori* (MAP) outputs showing likelihoods, standard deviation of normalised residuals (SDNRs), likelihood weights, parameter estimates, and derived quantities. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. '–': not applicable. Fixed values are indicated in grey. SDNRs 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)

	Region	Sex	Time	*base*	*3_Mlength*	*4_Mtime*	*5_Msex*	*6_Mregion*	*7_sexr*	*8_matLo*	*9_matHi*
Likelihoods											
Total				33 703	33 705	33 886	33 815	33 904	39 587	33 720	33 724
Penalty				0.239	0.213	0.114	0.339	0.250	0.369	0.240	0.324
Prior				2.711	3.263	2.639	1.137	-10.266	-18.652	0.907	1.174
tag				4 985	4 981	5 011	4 985	4 983	4 988	4 980	4 992
Sex ratio				5 033	5 037	5 170	5 098	5 199	10 887	5 032	5 050
LF				23 628	23 627	23 650	23 651	23 667	23 654	23 650	23 622
CPUE				54.958	55.233	51.790	79.141	64.533	76.664	56.545	58.458
Standard deviation of normalised residual (SDNR)											
Sex ratio	1			1.034	1.064	1.582	1.145	1.591	1.391	1.017	1.070
	2			1.005	1.031	1.886	1.544	1.885	1.561	1.040	1.028
CR CPUE				0.497	0.557	0.433	0.509	0.625	0.456	0.499	0.554
FSU CPUE				1.011	1.026	1.005	1.113	1.025	1.039	1.030	1.015
CELR CPUE	1			0.710	0.701	0.688	0.735	0.763	0.740	0.706	0.729
CELR CPUE	2			1.064	1.095	1.172	1.255	1.037	1.162	1.081	1.161
LB CPUE	1			1.045	1.023	0.947	1.210	1.024	1.219	1.042	1.077
LB CPUE	2			1.014	1.033	0.883	1.122	1.030	1.064	1.036	0.989
CR CPUE				1.047	1.022	1.309	1.053	1.237	1.330	1.054	1.065
FSU CPUE				1.017	1.011	1.167	1.042	1.277	0.935	1.003	1.009
Likelihood weights											
Sex ratio	1			1.453	1.453	1.453	1.453	1.453	1.453	1.453	1.453
	2			2.951	2.951	2.951	2.951	2.951	2.951	2.951	2.951
LF	1			0.463	0.463	0.463	0.463	0.463	0.463	0.463	0.463
	2			0.872	0.872	0.872	0.872	0.872	0.872	0.872	0.872
CR CPUE				1.550	1.550	1.550	1.550	1.550	1.550	1.550	1.550
FSU CPUE				3.800	3.800	3.800	3.800	3.800	3.800	3.800	3.800
CELR CPUE	1			2.110	2.110	2.110	2.110	2.110	2.110	2.110	2.110
CELR CPUE	2			1.810	1.810	1.810	1.810	1.810	1.810	1.810	1.810
LB CPUE	1			1.870	1.870	1.870	1.870	1.870	1.870	1.870	1.870
LB CPUE	2			2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000

	Region	Sex	Time	*base*	*3_Mlength*	*4_Mtime*	*5_Msex*	*6_Mregion*	*7_sexr*	*8_matLo*	*9_matHi*
Parameters											
R_0	1			2 956 250	2 296 420	7 279 040	1 248 030	1 741 490	816 044	297 5610	2 403 140
	2			979 398	488 963	850 484	403 364	377 792	605 901	707 724	920 476
M_{60}	1	M		0.465	0.557	0.694	–	–	0.161	0.465	0.415
	1	F	< 2010	0.293	0.342	–	–	–	0.205	0.302	0.257
	1	F	≥ 2010	0.480	0.564	–	–	–	0.339	0.492	0.433
	1	F		–	–	0.387	–	–	–	–	–
	1		< 2010	–	–	–	0.209	–	–	–	–
	1		≥ 2010	–	–	–	0.423	–	–	–	–
	1			–	–	–	–	0.432	–	–	–
	2	M		0.265	0.221	0.291	–	–	0.224	0.233	0.257
	2	F	< 2010	0.192	0.174	–	–	–	0.161	0.181	0.170
	2	F	≥ 2010	0.314	0.312	–	–	–	0.206	0.309	0.279
	2	F		–	–	0.116	–	–	–	–	–
	2		< 2010	–	–	–	0.156	–	–	–	–
	2		≥ 2010	–	–	–	0.240	–	–	–	–
	2			–	–	–	–	0.183	–	–	–
Galpha	1	M		14.023	14.117	13.528	14.441	14.096	14.557	14.016	14.167
	1	F		7.138	7.146	7.227	6.800	8.153	7.290	7.297	6.534
	2	M		7.585	7.905	11.239	10.188	9.897	9.286	8.739	7.565
	2	F		6.267	6.481	1.644	6.650	8.006	8.522	8.447	5.392
Gbeta	1	M		0.509	0.519	0.374	0.632	0.608	0.785	0.506	0.544
	1	F		0.007	0.007	0.008	0.007	0.009	0.008	0.008	0.007
	2	M		2.429	2.540	2.952	2.393	2.738	2.478	2.495	2.437
	2	F		0.488	0.510	0.252	0.503	0.667	0.647	0.638	0.531
Gshape	1	M		7.404	7.474	6.872	7.895	7.673	8.299	7.396	7.569
	1	F		5.435	5.228	5.353	5.514	5.226	5.585	5.366	5.517
	2	M		2.290	2.602	4.117	3.396	3.516	3.189	2.932	2.317
	2	F		3.337	3.379	0.808	3.468	5.125	4.972	4.723	3.223
GCV	1	M		0.687	0.691	0.694	0.673	0.700	0.675	0.687	0.684
	1	F		1.938	1.944	1.788	2.146	1.674	2.136	1.866	2.236
	2	M		0.562	0.567	0.547	0.561	0.557	0.560	0.562	0.562
	2	F		1.042	1.017	1.957	0.996	1.184	1.067	1.016	1.064
Gobs	1			0.700	0.677	0.677	0.743	0.677	0.758	0.696	0.713
	2			0.137	0.136	0.117	0.138	0.137	0.138	0.143	0.136
vuln	1	F	AW	0.232	0.330	0.288	0.181	0.330	0.090	0.230	0.233
	1	F	SS	0.624	0.878	0.776	0.491	0.888	0.300	0.620	0.626
	2	F	AW	0.415	0.415	0.371	0.426	0.353	0.396	0.405	0.424
	2	F	SS	1.085	1.087	0.984	1.024	0.919	1.147	1.071	1.115
selL	1	M		5.507	5.574	5.320	5.581	5.596	5.634	5.508	5.545
	1	F	< 1993	9.946	10.491	10.027	9.326	9.697	8.731	9.852	10.340
	1	F	≥ 1993	15.066	15.407	14.533	15.239	16.309	13.232	14.938	15.787
	2	M		4.609	4.692	4.787	4.772	4.795	4.703	4.679	4.615
	2	F		6.540	6.758	5.538	6.740	7.440	7.494	7.131	6.933
selM	1	M		47.983	48.062	48.665	47.278	47.701	46.603	47.985	47.792
	1	F	< 1993	53.632	55.241	56.072	51.016	53.077	48.469	53.250	54.149
	1	F	≥ 1993	64.037	66.572	68.646	61.496	66.276	53.243	63.594	64.818
	2	M		51.482	51.322	51.357	51.189	51.169	51.236	51.335	51.467
	2	F		58.788	58.781	58.362	58.558	59.612	59.314	59.352	59.075

Derived parameters: adjusted vulnerable biomass										
B_0	1		740	750	612	1 862	925	2 139	743	800
	2		998	1 051	944	2 016	1 337	1 145	1 152	1 029
	1+2		1 738	1 801	1 556	3 878	2 262	3 284	1 895	1 829
B_{0now}	1		541	504	511	580	593	1 303	542	573
	2		1 088	1 083	1 018	1 207	1 403	1 137	1 259	1 133
	1+2		1 629	1 587	1 528	1 787	1 996	2 440	1 801	1 706
B_{MIN}	1		124	131	155	119	135	102	124	117
	2		39	38	40	40	39	36	38	39
	1+2		163	168	194	159	174	138	162	156
B_{2024}	1		123	129	238	118	181	132	125	116
	2		110	110	168	134	183	79	104	109
	1+2		234	239	406	252	364	211	229	225
B_{2024} / B_0	1		0.167	0.172	0.389	0.063	0.195	0.062	0.168	0.145
	2		0.111	0.105	0.178	0.067	0.137	0.069	0.091	0.106
	1+2		0.135	0.133	0.261	0.065	0.161	0.064	0.121	0.123
Derived parameters: spawning stock biomass										
SSB_0	1	MF	1210	1280	1704	936	714	686	1234	1125
	2	MF	780	721	728	529	529	824	813	722
	1+2	MF	1990	2001	2432	1465	1243	1509	2047	1846
SSB_{0now}	1	MF	311	356	1236	324	430	184	330	257
	2	MF	257	247	730	338	531	469	289	207
	1+2	MF	568	603	1966	662	961	653	619	465
SSB_{2024}	1	MF	180	206	892	186	297	126	191	152
	2	MF	233	222	457	260	439	301	268	162
	1+2	MF	413	427	1348	447	735	428	458	315
SSB_{2024} / SSB_0	1	MF	0.149	0.161	0.523	0.199	0.415	0.184	0.155	0.136
	2	MF	0.298	0.307	0.627	0.492	0.829	0.366	0.329	0.225
	1+2	MF	0.207	0.214	0.554	0.305	0.591	0.283	0.224	0.171
Derived parameters: total biomass										
T_0	1		3150	3168	4690	3551	2591	3364	3114	3063
	2		2464	2248	2357	2884	2235	2406	2427	2527
	1+2		5614	5416	7046	6435	4826	5770	5541	5590
T_{0now}	1		1640	1641	3505	1584	1673	1849	1628	1554
	2		2031	1831	2438	2040	2335	2043	2047	2084
	1+2		3671	3472	5943	3624	4008	3892	3676	3639
T_{2024}	1		741	762	2355	672	918	501	736	668
	2		1308	1072	1558	1096	1377	869	1016	1325
	1+2		2049	1834	3913	1769	2295	1370	1752	1993
Derived parameters: other										
H_{2023}	1		4.139	4.094	3.519	4.271	3.549	4.057	4.134	4.171
	2		3.080	3.117	2.708	3.045	2.888	3.412	3.064	3.124
	1+2		7.219	7.211	6.227	7.316	6.437	7.469	7.198	7.295
$T0_{male} / T0_{female}$	1		0.949	0.940	0.782	2.161	1.694	3.172	0.981	0.961
	2		1.437	1.609	1.235	3.578	2.570	1.508	1.632	1.379
T_{male} / T_{female}	1		1.360	1.265	0.692	1.231	1.133	1.705	1.407	1.310
	2		1.429	1.402	0.729	1.189	0.975	0.856	1.376	1.364

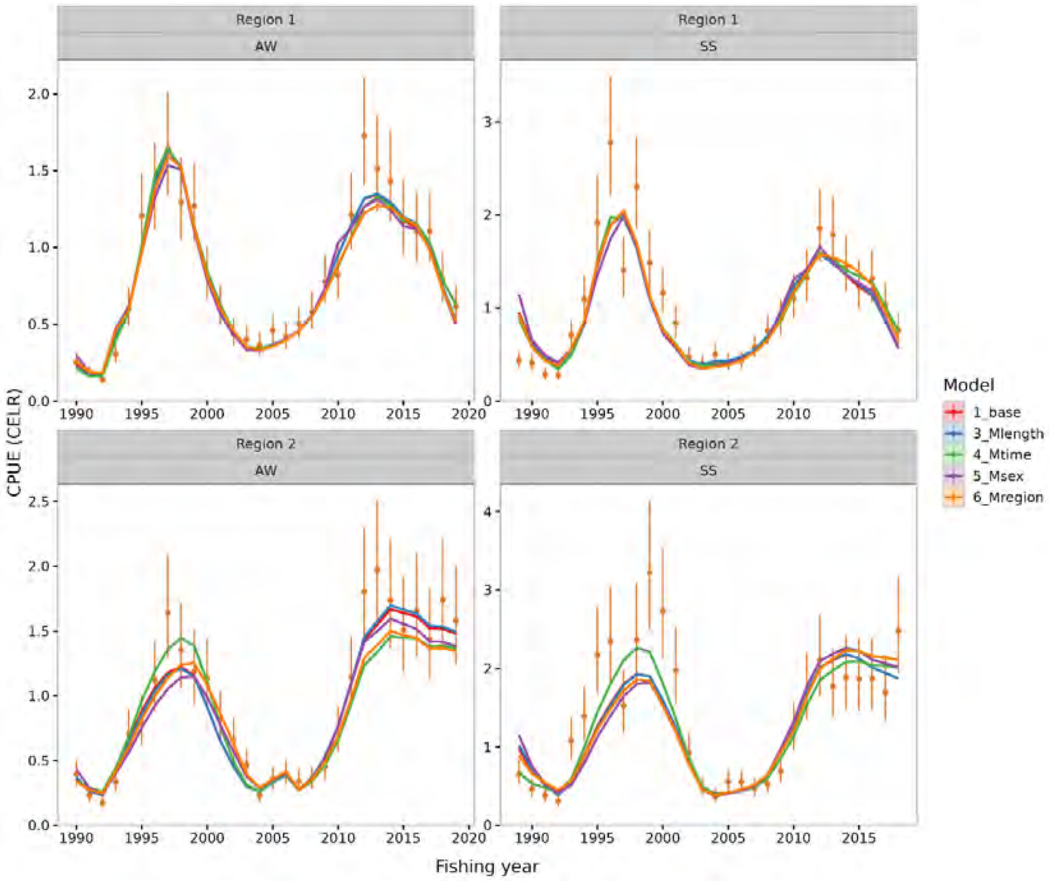


Figure 41: MAP comparison of CELR CPUE fits by region, season, and year for the *base case* with 4 key sensitivity trials relating to *M* assumptions.

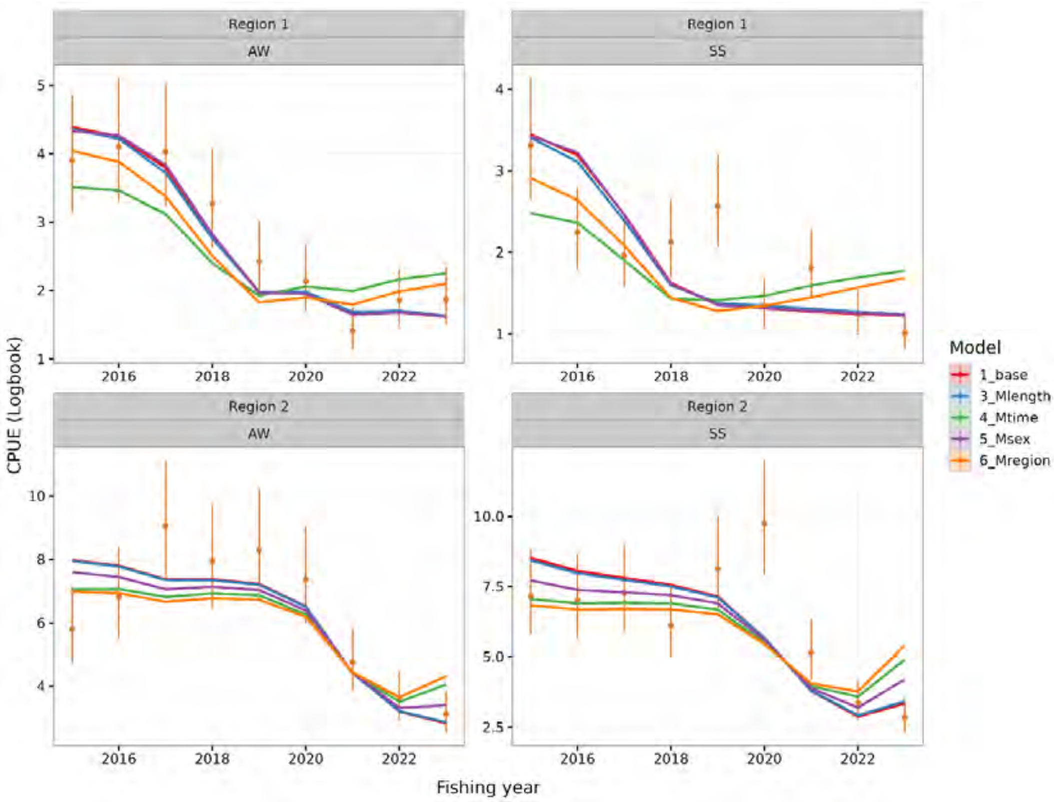


Figure 42: MAP comparison of logbook CPUE fits by region, season, and year for the *base case* with four key sensitivity trials relating to *M* assumptions.

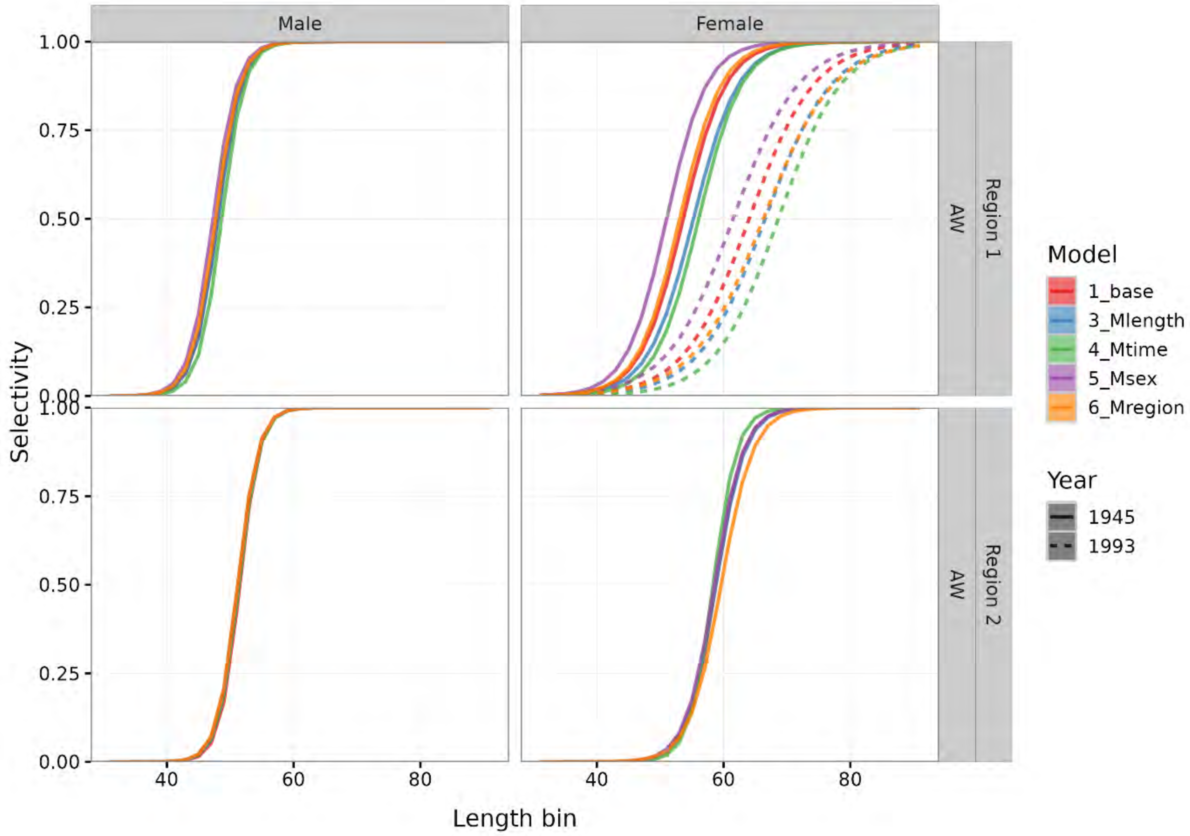


Figure 43: MAP comparison of selectivity by region, sex and season, time block, and size for the *base case* with four key sensitivity trials relating to *M* assumptions.

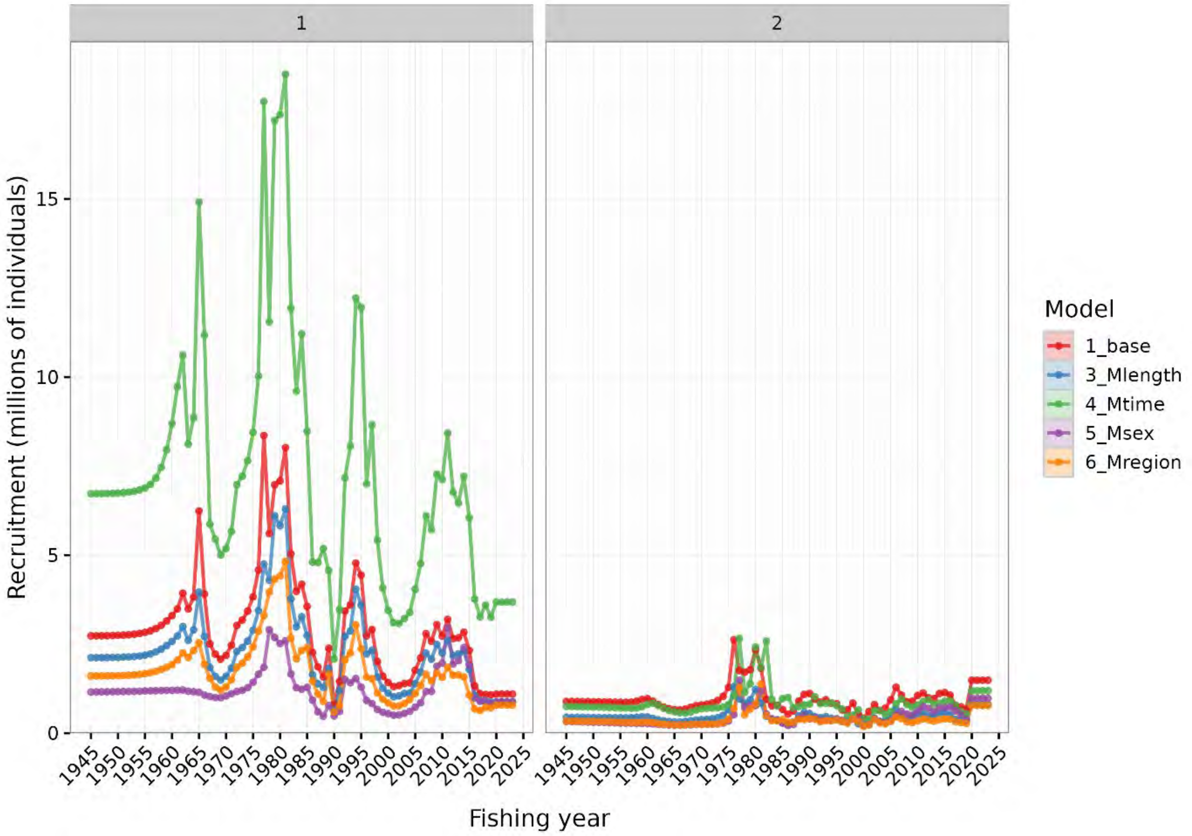


Figure 44: MAP comparison of recruitment by region and year for the ***base case*** with four key sensitivity trials relating to ***M*** assumptions.

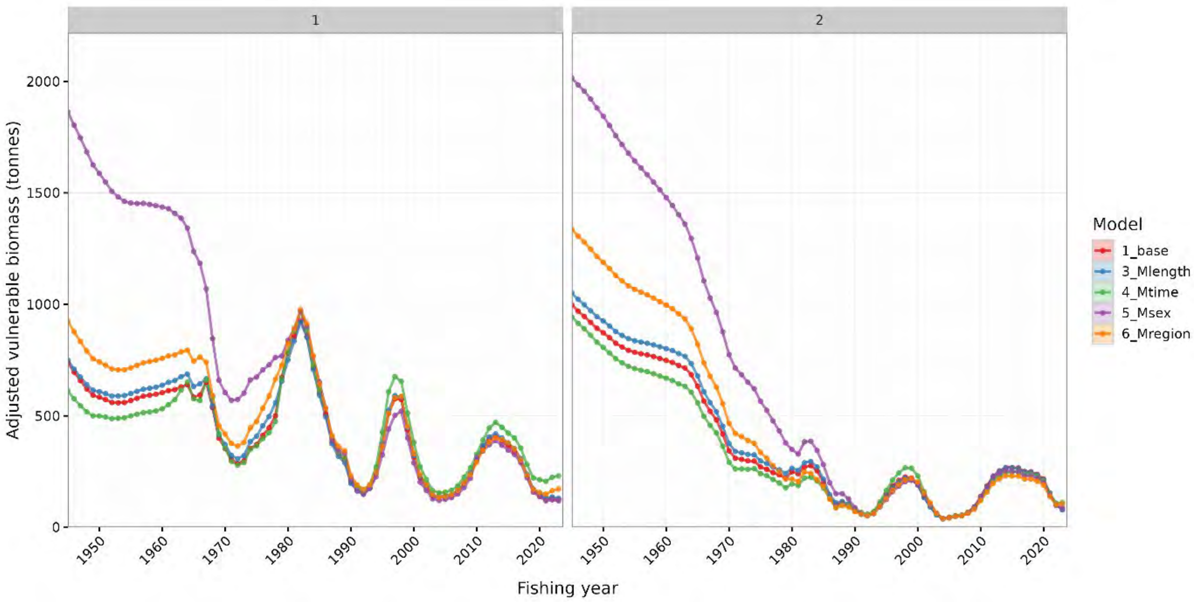


Figure 45: MAP comparison of adjusted vulnerable biomass by region and year for the ***base case*** with four key sensitivity trials relating to ***M*** assumptions.

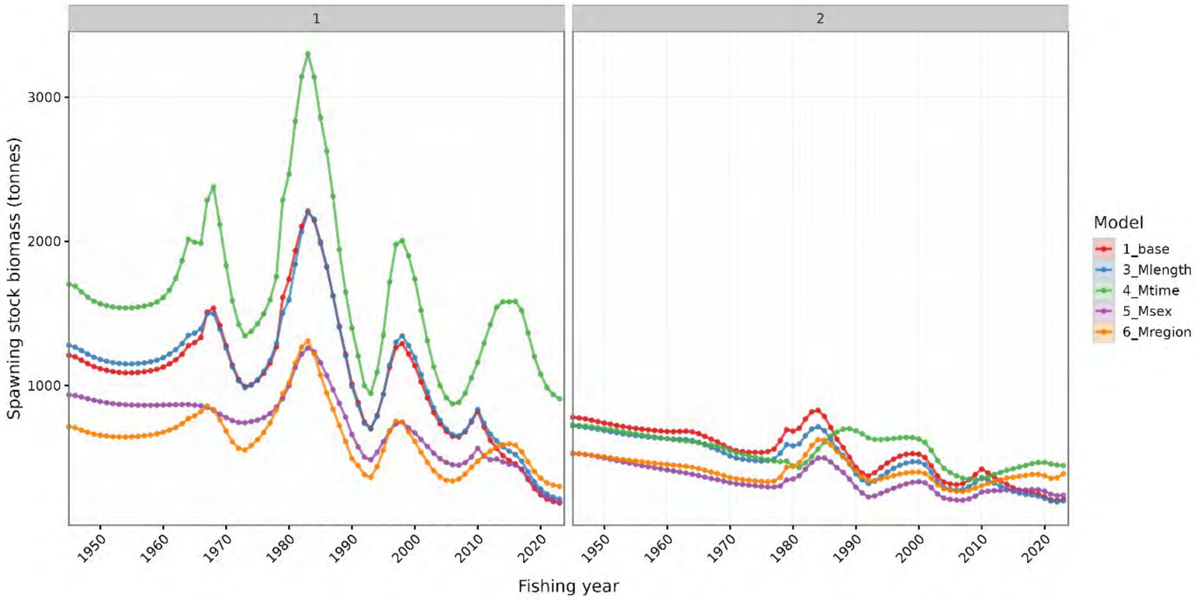


Figure 46: MAP comparison of spawning stock biomass by region and year for the *base case* with four key sensitivity trials relating to *M* assumptions.

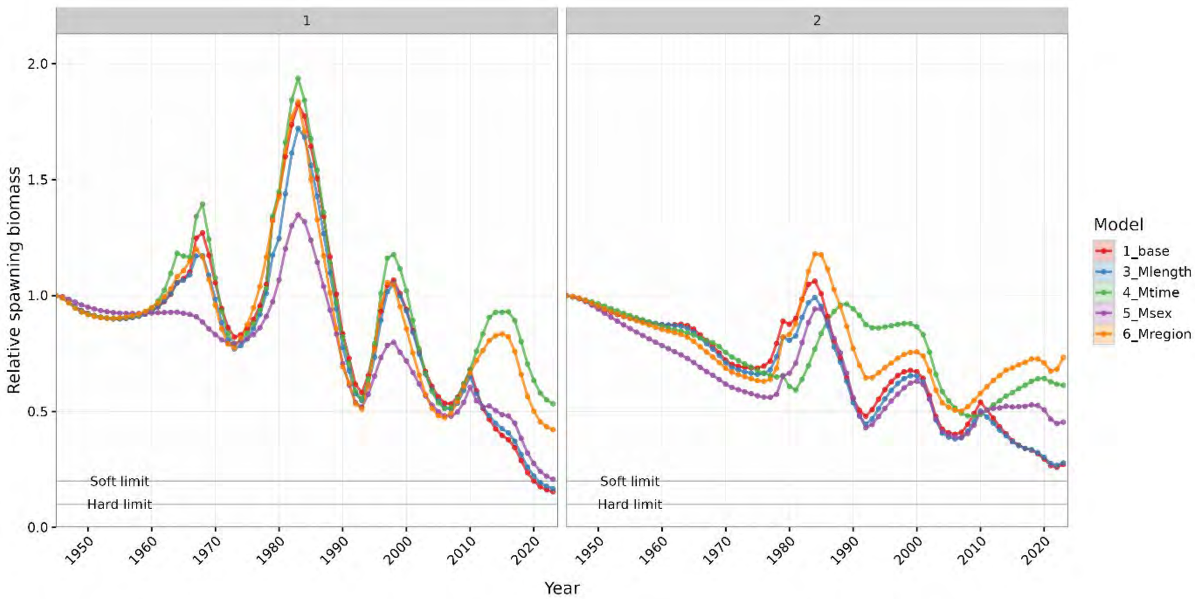


Figure 47: MAP comparison of relative spawning stock biomass by region and year for the *base case* with four key sensitivity trials relating to *M* assumptions.

There were negligible differences in model results among base and the sensitivity runs that explored higher and lower fixed values for the length at 50% maturation (Table 15, Figure 48, Figure 49, Figure 50, Figure 51, Figure 52, Figure 53, Figure 54). However, the model run that fitted to the alternative sex ratio series (i.e., the sex ratio model that did not include vessel as an explanatory variable) was somewhat different with minor differences in the fits to CPUE (Figure 48, Figure 49), moderate differences in selectivity in region 1 (Figure 50), and more pronounced differences in recruitment in both regions (Figure 51) and therefore in how this model run interpreted biomass through time (Figure 52, Figure 53, Figure 54).

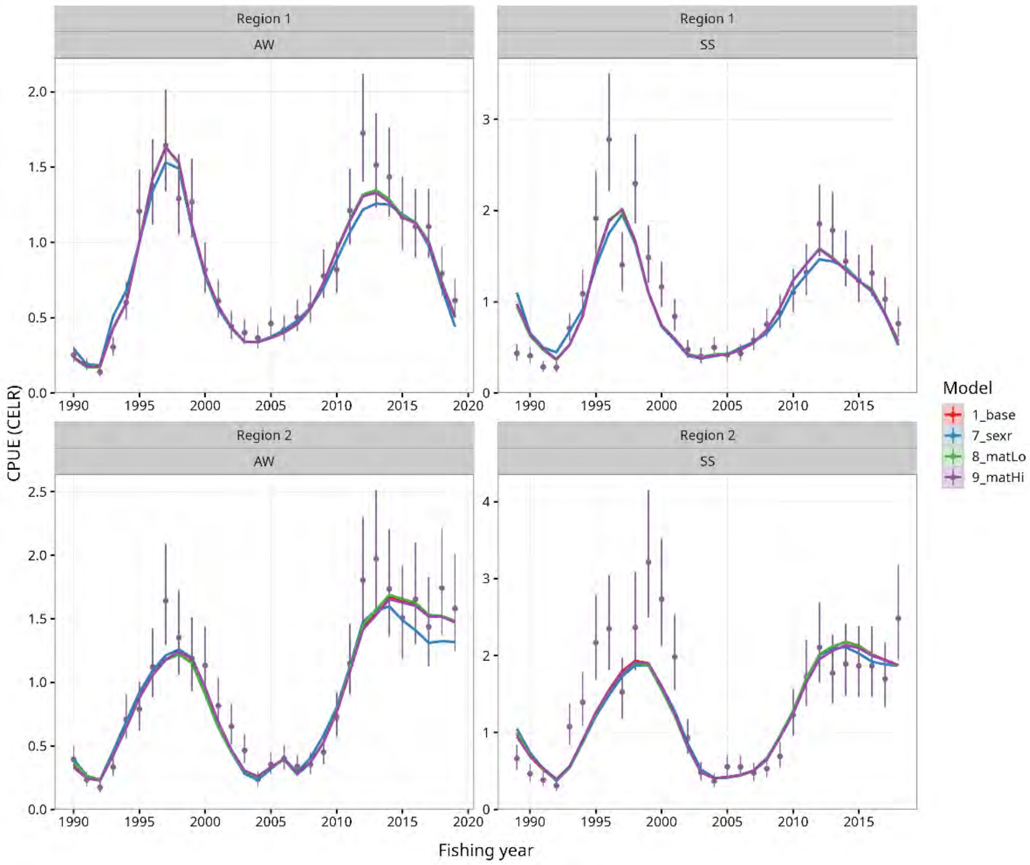


Figure 48: MAP comparison of CELR CPUE fits by region, season, and year for the *base case* with three key sensitivity trials regarding sex ratio and maturation assumptions.

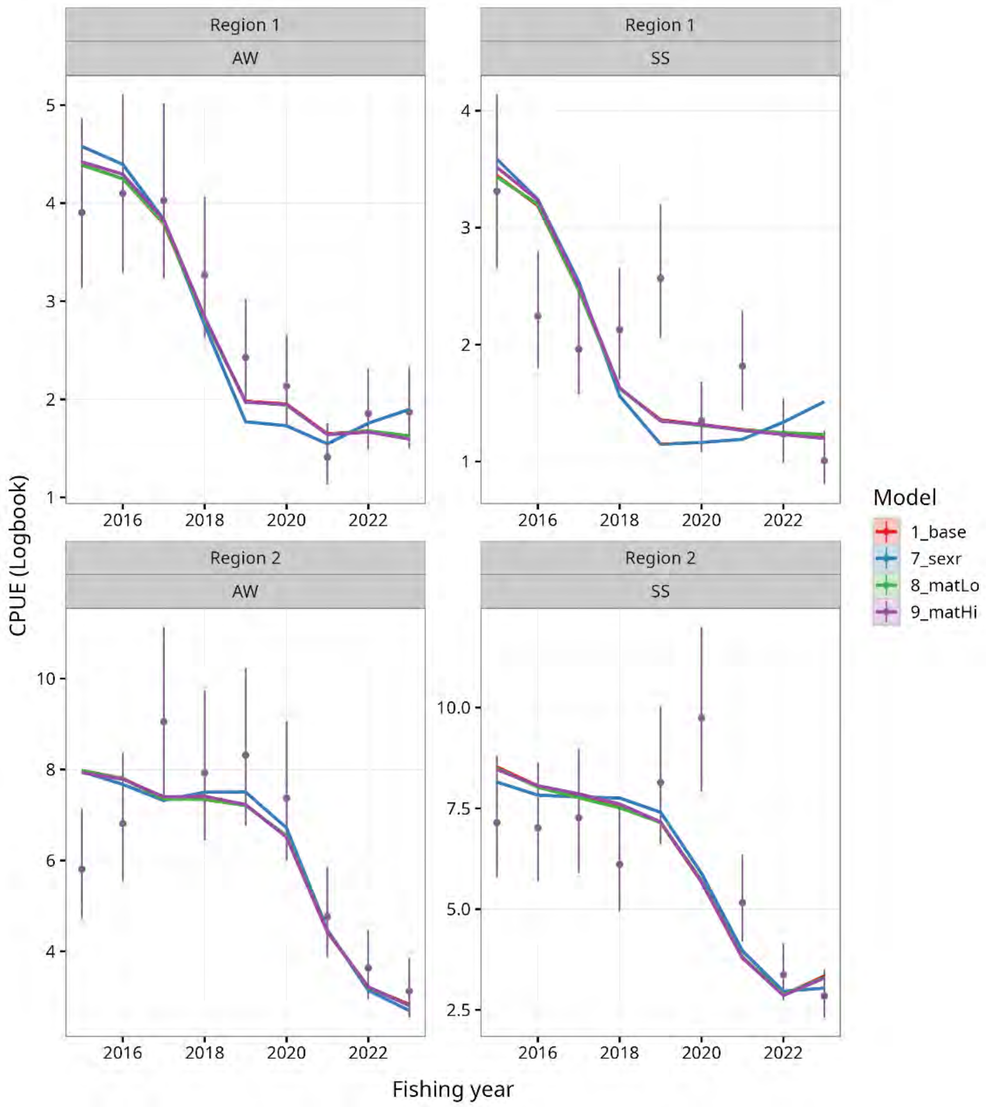


Figure 49: MAP comparison of logbook CPUE fits by region, season, and year for the *base case* with three key sensitivity trials regarding sex ratio and maturation assumptions.

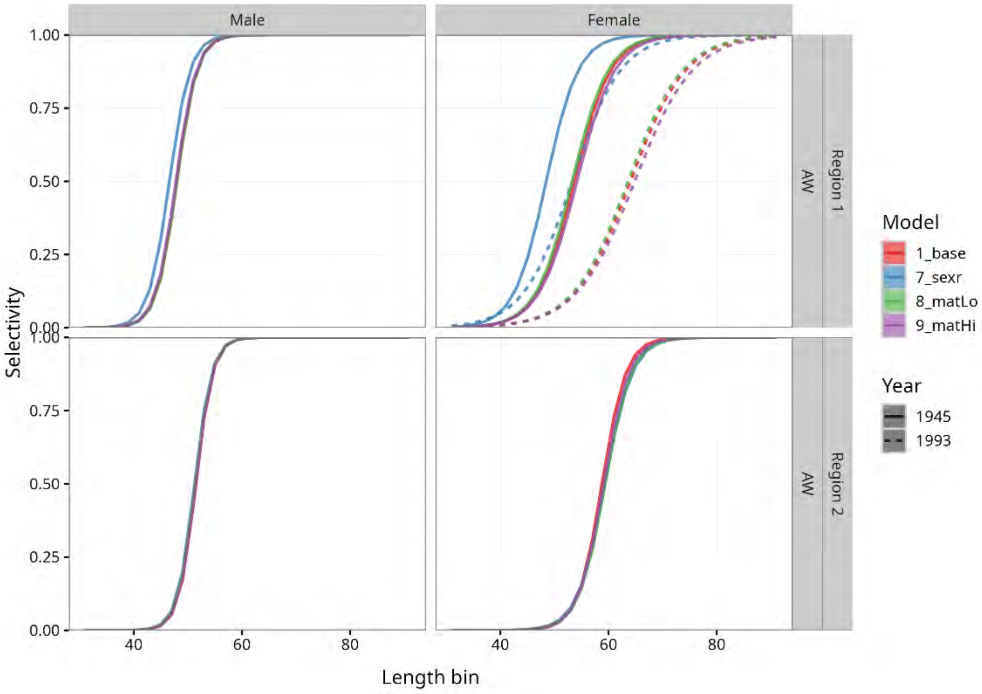


Figure 50: MAP comparison of selectivity by region, sex and season, time block, and size for the *base case* with three key sensitivity trials regarding sex ratio and maturation assumptions.

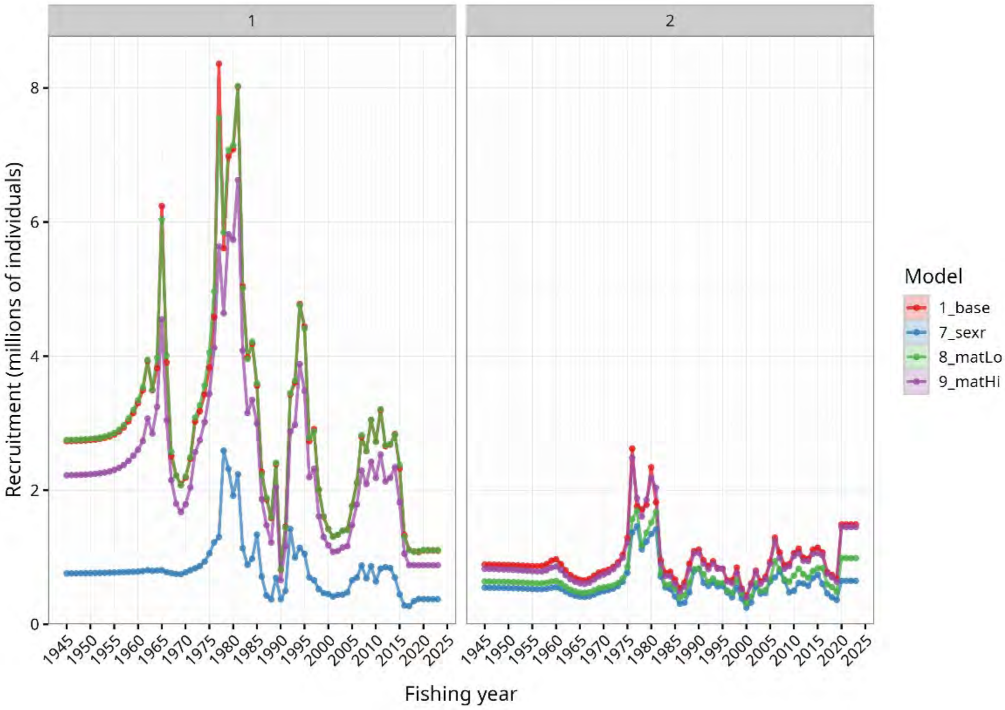


Figure 51: MAP comparison of recruitment by region and year for the *base case* with three key sensitivity trials regarding sex ratio and maturation assumptions.

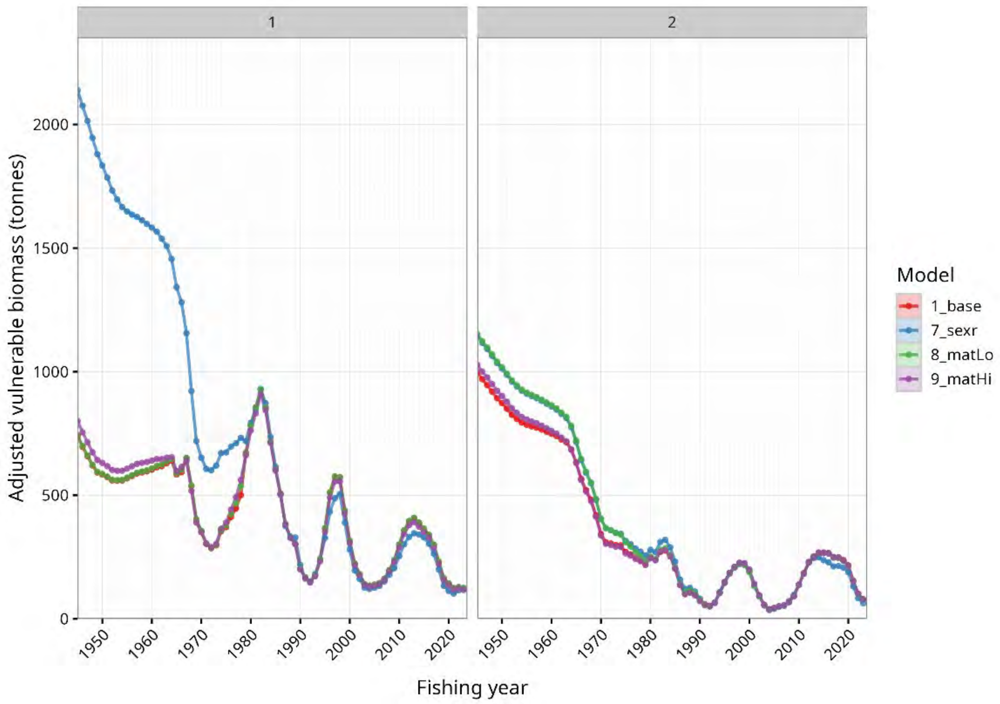


Figure 52: **MAP comparison of adjusted vulnerable biomass by region and year for the *base case* with three key sensitivity trials regarding sex ratio and maturation assumptions.**

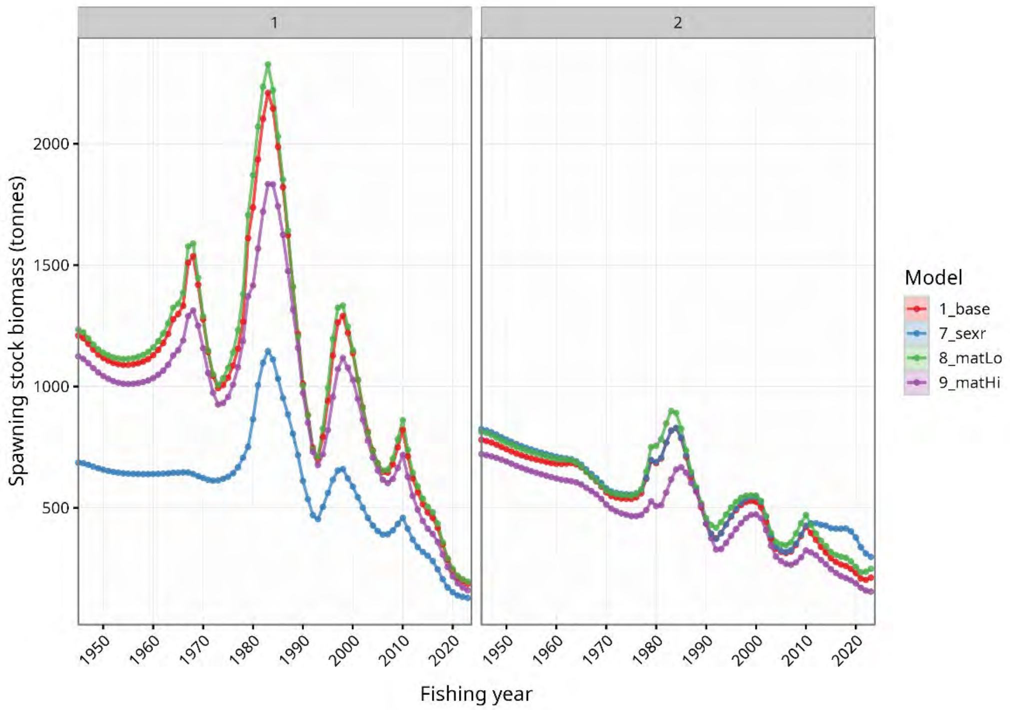


Figure 53: **MAP comparison of spawning stock biomass by region and year for the *base case* with three key sensitivity trials regarding sex ratio and maturation assumptions.**

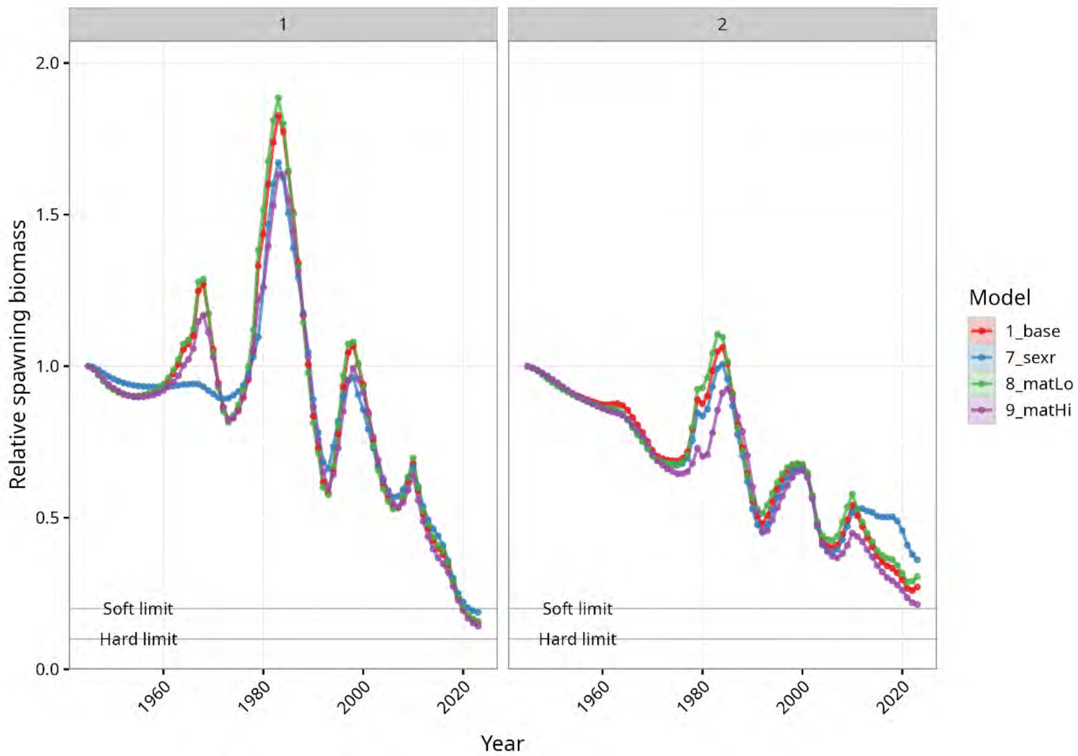


Figure 54: MAP comparison of relative spawning stock biomass by region and year for the *base case* with three key sensitivity trials regarding sex ratio and maturation assumptions.

3.6 Reference level

Model-based reference levels for red rock lobster stocks have been calculated in rock lobster stock assessments since 2018 (see more detailed discussion in Rudd et al. 2021). An interim target reference level for the CRA 3 population vulnerable to fishing (B_R) was developed using the *base* stock assessment model described in Section 3.4.3 to project the vulnerable biomass forward using simulation. Starting with the CRA 3 base case model (*base*), projections were done across a range of fixed catch and fixed *U* levels. These simulations were run for 100 years across the 1000 MCMC posterior samples. Each simulation replicate drew random recruitment deviates from a normal distribution based on the mean, standard deviation, and the autocorrelation of model-estimated recruitment deviates across a defined 'data period'. The 'data period' was defined as the period of years starting in the first year with a reasonable amount of length data and ending three years before the final model year. For CRA 3, the data period included 31 years from 1989 to 2020 (Table 2). This is also the period used for basing the estimate of SSB_0 (SSB_0^{data}).

Only the size-limited (SL) catches changed in these projections, with the non-size-limited (NSL) catch (sum of illegal and customary catch) being held constant at the 2023 level. Rules that dropped below 20% SSB_0^{data} more than 5% of the time for the final 20 simulation years were rejected. The constant catch rules were further constrained by the requirement that at least 99% of the expected catch had to be taken from at least 95% of years in the final 20 simulation years. The vulnerable biomass associated with the fixed catch and fixed *U* levels that maximised the catch for each harvest strategy, while satisfying the constraints over the final 20 simulation years, were then averaged to obtain the interim target reference level for CRA 3 (see Rudd et al. 2021).

To provide an exploitation rate indicator (U_R), the exploitation rate associated with B_R was calculated, which was defined as the *U* that resulted in a median equilibrium biomass equal to the B_R. U_R was identified by finding the fixed *U* resulting in a median vulnerable biomass of B_R over the final 20 simulation years of the 100-year projections described above. The fixed input *U* is distributed within the model by fleet and season, resulting in separate *U* by season (AW and SS) that result in the reference level at equilibrium. The seasonal Us were then weighted based on the vulnerable biomass each season to obtain U_R as an annual rate.

At the beginning of 2024 AW, the stock in CRA 3 region 1 was predicted to be just below B_R and just below U_R (not undergoing overfishing but technically overfished, Table 12). The probability of B_{2024} being above B_R in region 1 was 0.353 (Table 13). In region 2, the CRA 3 stock was also predicted to be below B_R but below U_R (not undergoing overfishing but technically overfished; Figure 37). The probability of B_{2024} being above B_R in region 2 was 0.017 (Table 13).

3.7 Projections

A five-year projection, for the fishing years 2024 to 2028, was done for the *base* model only. This projection was repeated for each sample from the posterior distribution. The non-size-limited (illegal and customary) catches were assumed to be the same as in the final model year (2023) and were set to be constant when projecting forward (Table 16). The projected commercial catch in 2024 was set to 135 tonnes and in 2025–2028 was set to the current CRA 3 TACC of 156 tonnes. Each year the commercial catch was split into the two regions and seasons based on the 2023 commercial catch distribution (Table 16). Projected recreational catch was based on the average exploitation rate of the recreational fishing sector over the last five years (2019–2023), applied to the projected vulnerable biomass. Therefore, this approach added uncertainty to the projected recreational catches by accounting for a larger range of potential recreational catches.

Projected recruitment deviates were simulated from a normal distribution with mean calculated from the mean of the 2011–2020 recruitment deviates, the standard deviation set to *sigmaR* (Table 2), and recruitment autocorrelation derived from the 1989–2020 recruitment deviates (i.e., the years for which LFs were available). Projected recruitment deviates replaced the 2021, 2022, and 2023 deviates because recruitment was not estimated in the reconstruction model for these years (Figure 33).

Table 16: Catch (tonnes) in the final model year (grey shading) and the projection years by season and fishing sector. The median is shown for projected recreational catches; because they are based on the average exploitation rate for the recreational sector over the last five years, there is uncertainty in projected recreational catch due to uncertainty in the vulnerable biomass.

Fishing year	Region	Commercial		Recreational		Customary		Illegal	
		AW	SS	AW	SS	AW	SS	AW	SS
2024–25	909+910	54.791	21.668	0.613	5.970	0.477	4.293	11.574	3.963
	911	39.539	19.002	0.502	5.110	0.523	4.706	5.219	11.813
2025–26	909+910	63.313	25.039	0.649	6.020	0.477	4.293	11.574	3.963
	911	45.689	21.958	0.673	6.220	0.523	4.706	5.219	11.813
2026–27	909+910	63.313	25.039	0.653	6.020	0.477	4.293	11.574	3.963
	911	45.689	21.958	0.762	6.860	0.523	4.706	5.219	11.813
2027–28	909+910	63.313	25.039	0.665	6.210	0.477	4.293	11.574	3.963
	911	45.689	21.958	0.823	7.350	0.523	4.706	5.219	11.813
2028–29	909+910	63.313	25.039	0.679	6.380	0.477	4.293	11.574	3.963
	911	45.689	21.958	0.872	7.870	0.523	4.706	5.219	11.813

The projection suggested an increase in the adjusted vulnerable biomass (Figure 34) and the SSB (Figure 35) over the next five years. The adjusted total vulnerable biomass at the beginning of 2024 was estimated to be 18% of B_0 (median B_{2024} / B_0 = 0.183) and was projected to increase to 25% of B_0 by 2028, at the specified levels of catch (median B_{2028} / B_0 = 0.254) (Table 12). The projection predicted that the CRA 3 stock will increase from 84% of B_R (median B_{2024} / B_R = 0.838) to 118% of B_R (median B_{2028} / B_R = 1.183) by the beginning of 2028 (Table 12). The SSB at the beginning of 2024 was estimated to be 23% of SSB_0 (median SSB_{2024} / SSB_0 = 0.225) and was projected to increase to 25% of SSB_0 (median SSB_{2028} / SSB_0 0.246) by the beginning of 2028 (Table 12).

4. DISCUSSION

The 2024 CRA 3 stock assessment made many improvements over the previous stock assessment of CRA 3 (Webber et al. 2020), including fitting to a new logbook CPUE index series of relative abundance from 2015 to 2023, generating plausible hypotheses to explain the lack of females in the region 1 population and developing growth models that eliminated the need to put forward two base runs as was done in 2019. The preparation of the composition data was substantially improved, with model-based standardisation of the length frequencies and sex ratio data replacing the ad-hoc procedures previously used. These model-based procedures also provided more defensible data weightings for these observation types as well as combining the two sources of compositional data into a single frequency distribution. The assessment also moved away from the binary assumption that 100% of mature females are in berry in the AW and 0% in the SS to using estimated values for these proportions by season. Also, eliminating tag recaptures for lobsters spending less than six months at liberty was seen as a good compromise for eliminating potential bias relating to the seasonality of tagging while retaining a good proportion of the data, negating the requirement for a bifurcated base case. This assessment also revised the assumptions underlying the setting of recreational and illegal catches. These improvements resulted in defensible changes to model outputs, with likely improvements in the accuracy of model estimates of SSB and vulnerable biomass.

The *base* model for CRA 3 fitted the tag recapture growth data reasonably well, but it is worth noting the small sample of tag recapture data from Statistical Areas 909 and 911 in CRA 3 (Figure I.14). The model fit to the other data sources was good (Figure 25, Figure 26, Figure 27, Figure I.10) and generated parameter estimates that were considered plausible by the RLWG and Plenary reviewers. As such, the *base* run was accepted as a good representation of stock status at the beginning of the 2024–25 fishing year by the RLWG and the stock assessment Plenary.

The 2024 CRA 3 assessment estimated a high *M* relative to the previous assessment which estimated *M* to be between 0.179 and 0.242 (Webber et al. 2020). An exploration of sex-specific CPUE determined that the status of females in CRA 3 (and possibly in some statistical areas of CRA 4 as well as other QMAs in recent years) was likely to have declined relative to that of the males. The updated CRA 3 assessment represented this by estimating a time and sex-specific *M*, which effectively eliminated a strong trend in the sex ratio residuals and resulted in a more pessimistic prediction of current and projected SSB status for CRA 3. Because this was the first time that alternative parameterisations of natural mortality (*M*) were explored, several sensitivity runs were developed to test assumptions related to *M* (i.e., *3_Mlength*, *4_Mtime*, *5_Msex*, and *6_Mregion*). Setting *M* to be length invariant (*3_Mlength*) resulted in subtle changes to the model fits and estimates of biomass. However, setting *M* to be time invariant (*4_Mtime*), the same for both sexes (*5_Msex*), or the same for both regions (*6_Mregion*) resulted in significant changes, highlighting the importance of *M* in this stock assessment. Note that the previous 2019 CRA 3 stock assessment made all three of those assumptions regarding *M*.

In the *base* case run, the vulnerable biomass was estimated to be below B_R at the beginning of 2024, but was expected to increase to be above the reference level by 2028 (Table 13, Figure 34) at the status quo future catch levels specified for the projection (Table 16). Of greater concern was the declining trend in estimated SSB in both regions over the last 40 years. Although the SSB was estimated to be just above the soft limit of 20% SSB_0 in CRA 3, the soft limit was estimated to have been breached at the beginning of 2024 in region 1 (Table 13, Figure 35). However, the SSB was predicted to increase above the soft limit by 2028 in both regions (Table 13, Figure 35).

5. POTENTIAL RESEARCH

The RLWG and Plenary identified several potentially useful avenues of research to evaluate or improve this assessment in the future. Potential improvements that are specific to CRA 3 include:

- Increase tagging effort in CRA 3, particularly targeting individuals in Statistical Area 911;

- Explore sensitivity to starting the stock assessment in model in 1979 and to different values for *q-drift*;
- Explore alternative model parameterisations for explaining changes in sex ratio;
- Explore the potential of ensemble models.

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

- Further explore sex-specific CPUE and, as required, consider options for specified sex-specific life history parameters for the affected stocks.
- Merge mature and immature females within the assessment model and estimate maturity outside of the assessment model.
- Explore an apparent change in reporting behaviour associated with the change to electronic monitoring, with the aim of extending the CELR CPUE abundance series beyond the AW of the 2019 fishing year or establish a reliable new CPUE series based on these data.
- Conduct additional morphometric work; for example, collect data and analyse relationships between tail width, carapace length, weight, sex, and somatic condition.
- Consider different time periods for resampling recruitment within projections for sensitivity analysis.
- Include random effects for certain LSD model parameters (e.g., selectivity parameters).
- Develop and evaluate alternative growth models, including consideration of options for representing apparent non-linear TW-based growth in males.
- Further explore evidence for density dependence and climate change effects within and across rock lobster stocks.
- Develop computer code to include the effects of density-dependent growth and environmental effects in the LSD model.
- Investigate potential fisheries-independent survey designs.
- Improve estimates of non-commercial catch.

6. FULFILMENT OF BROADER OUTCOMES

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

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

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Appendix A. CELR CPUE DIAGNOSTICS

Table A.1: Summary of CELR effort in region 1 of CRA 3 by fishing year and season ('AW' = autumn/winter, 'SS' = spring/summer) in terms of: the number of vessels and the number of pots sampled. The CELR data were prepared using the 'F2 LFX' algorithm (see appendix D of Starr 2021). This algorithm aggregates the weight (kg) of legal lobsters and number of pots lifted from each period, month, vessel, and statistical area.

	Vessels			Pots reported		
	SS	AW	Total	SS	AW	Total
1989	49	–	49	323 314	–	323 314
1990	32	35	41	254 488	151 074	405 562
1991	36	32	39	285 106	142 741	427 847
1992	27	31	32	220 289	102 538	322 827
1993	24	27	28	65 244	160 905	226 149
1994	4	25	25	4 330	95 874	100 204
1995	1	21	21	420	60 665	61 085
1996	2	19	19	135	57 043	57 178
1997	2	20	21	85	61 241	61 326
1998	9	20	20	11 209	112 671	123 880
1999	11	18	18	24 321	100 237	124 558
2000	14	22	22	48 242	128 063	176 305
2001	17	19	21	56 703	107 371	164 074
2002	20	22	25	85 462	120 706	206 168
2003	12	21	21	47 485	72 864	120 349
2004	9	20	21	43 625	81 149	124 774
2005	14	18	18	52 129	79 412	131 541
2006	16	18	19	77 800	90 255	168 055
2007	14	17	17	54 658	88 857	143 515
2008	12	15	16	32 661	80 645	113 306
2009	13	15	15	21 881	70 851	92 732
2010	8	17	17	9 631	76 348	85 979
2011	10	17	17	5 167	72 327	77 494
2012	14	14	16	16 282	46 981	63 263
2013	12	13	14	21 668	57 540	79 208
2014	13	15	15	32 616	71 096	103 712
2015	14	15	17	33 277	96 309	129 586
2016	15	14	16	36 512	88 561	125 073
2017	14	13	14	44 446	73 024	117 470
2018	13	13	13	41 163	77 779	118 942
2019	–	13	13	–	56 479	56 479

Table A.2: Summary of CELR effort in region 2 of CRA 3 by fishing year and season ('AW' = autumn/winter, 'SS' = spring/summer) in terms of: the number of vessels and the number of pots sampled. The CELR data were prepared using the 'F2 LFX' algorithm (see appendix D of Starr 2021). This algorithm aggregates the weight (kg) of legal lobsters and number of pots lifted from each period, month, vessel, and statistical area.

	Vessels			Pots reported		
	SS	AW	Total	SS	AW	Total
1989	24	–	24	121 514	–	121 514
1990	24	25	26	183 665	64 637	248 302
1991	33	31	37	209 970	97 018	306 988
1992	31	29	34	192 316	97 646	289 962
1993	16	22	22	22 977	109 692	132 669
1994	7	15	15	7 560	53 777	61 337
1995	6	11	11	1 481	43 008	44 489
1996	4	12	12	580	33 538	34 118
1997	4	10	10	488	26 356	26 844
1998	2	8	8	190	30 852	31 042
1999	3	8	8	1 850	46 061	47 911
2000	4	10	11	3 290	56 440	59 730
2001	11	10	12	27 109	61 505	88 614
2002	9	8	9	49 390	50 935	100 325
2003	13	12	13	77 859	52 834	130 693
2004	13	12	13	73 371	47 671	121 042
2005	11	12	13	61 498	45 821	107 319
2006	12	13	13	77 878	45 425	123 303
2007	10	9	10	57 715	34 359	92 074
2008	9	8	9	68 772	40 690	109 462
2009	9	8	9	39 099	35 816	74 915
2010	9	9	9	13 995	43 398	57 393
2011	7	9	9	5 041	26 598	31 639
2012	7	7	8	11 207	12 868	24 075
2013	5	6	7	8 720	16 034	24 754
2014	10	12	12	18 746	24 143	42 889
2015	10	10	11	16 223	31 043	47 266
2016	13	9	13	15 068	37 167	52 235
2017	7	8	8	7 662	25 513	33 175
2018	6	7	8	6 971	21 777	28 748
2019	–	9	9	–	21 477	21 477

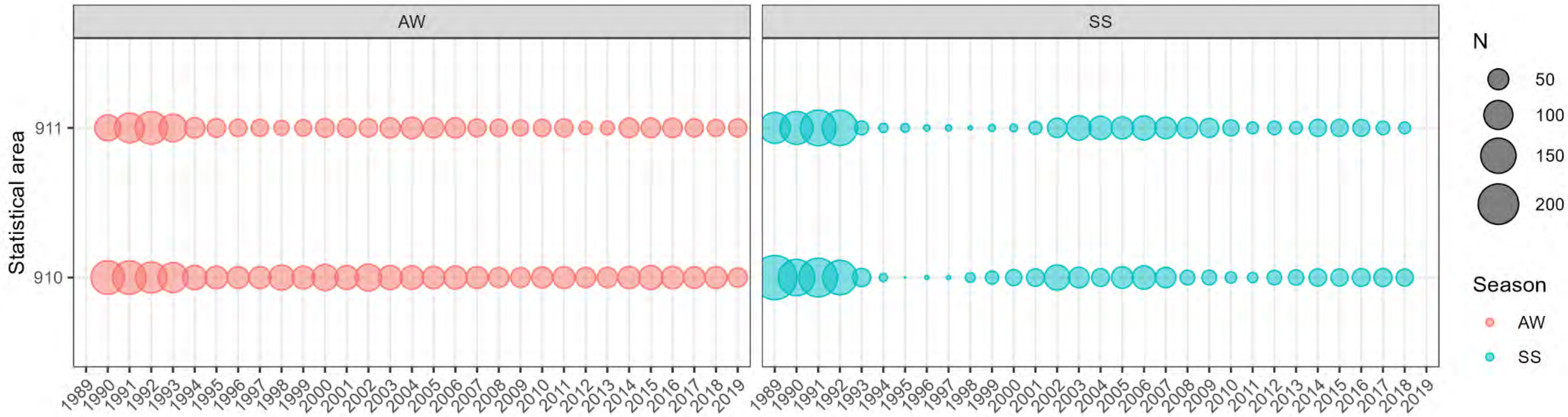


Figure A.1: Bubble plot of CELR effort by fishing year, season, and Statistical Area (where 909 and 910 are combined into 910).

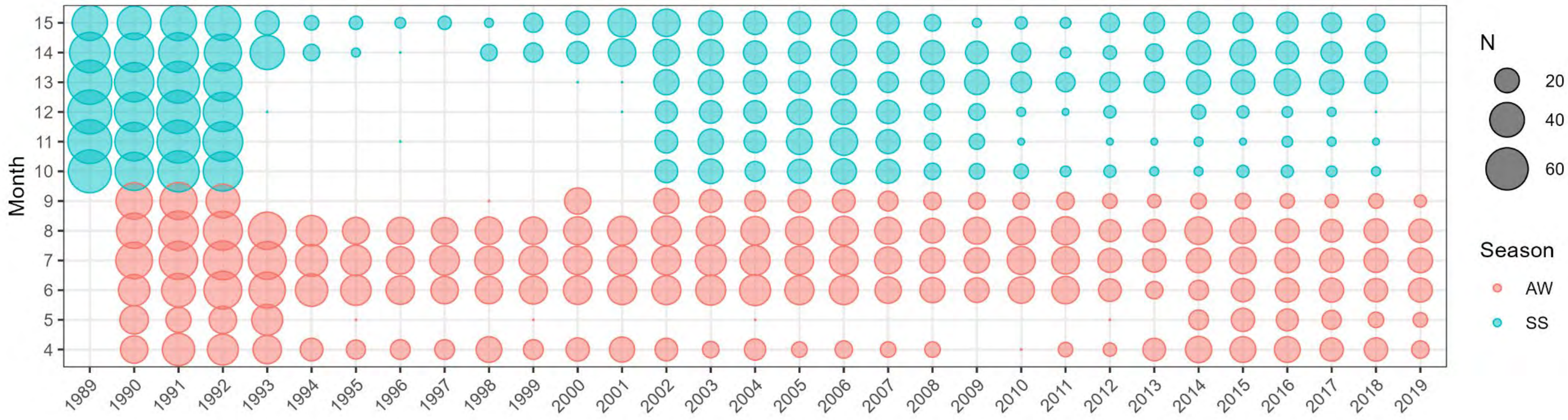


Figure A.2: Bubble plot of CELR effort by fishing year and month (4 = April and 15 = March).

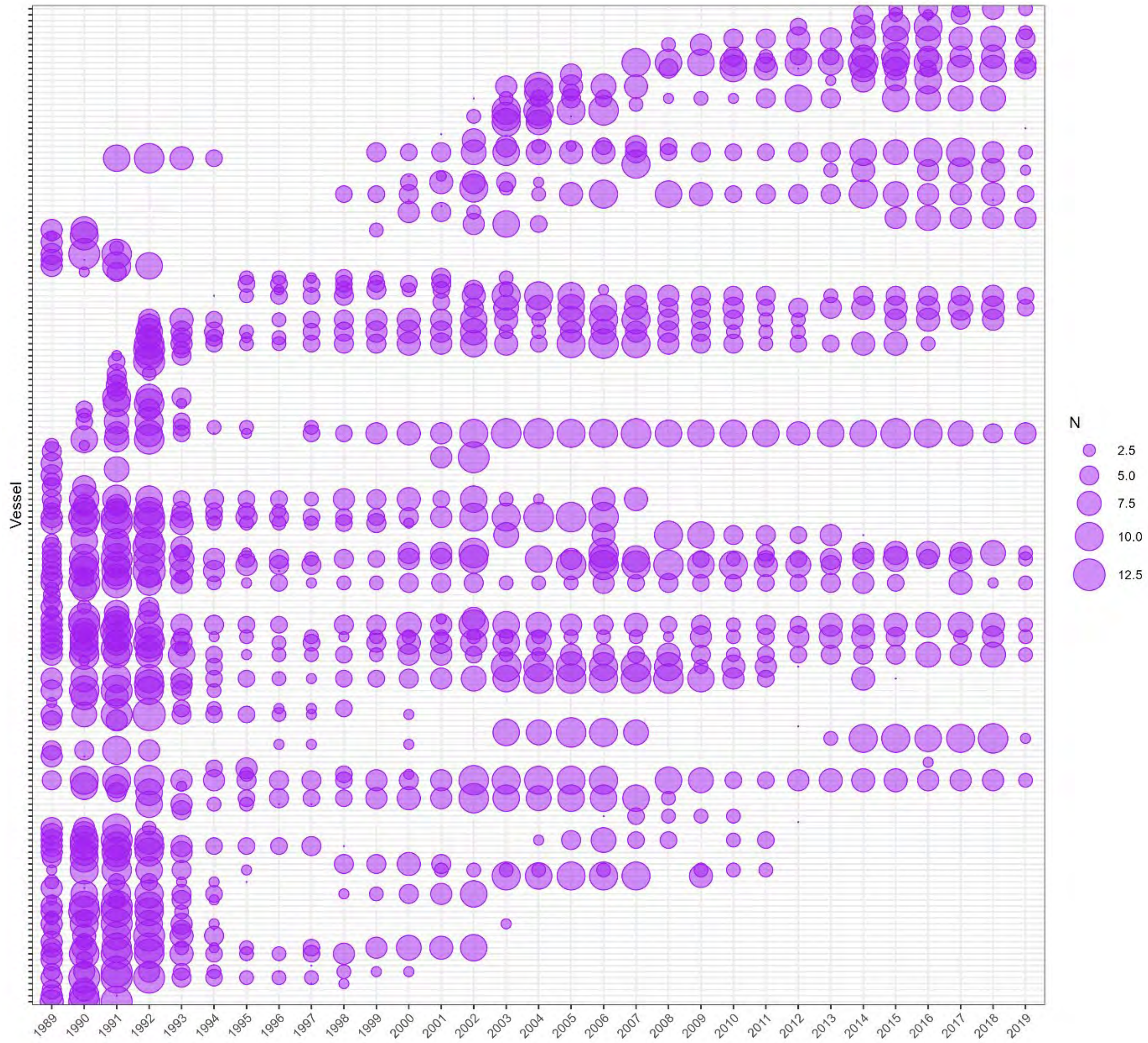


Figure A.3: Bubble plot of CELR effort by fishing year and vessel (the vessel codes are omitted).

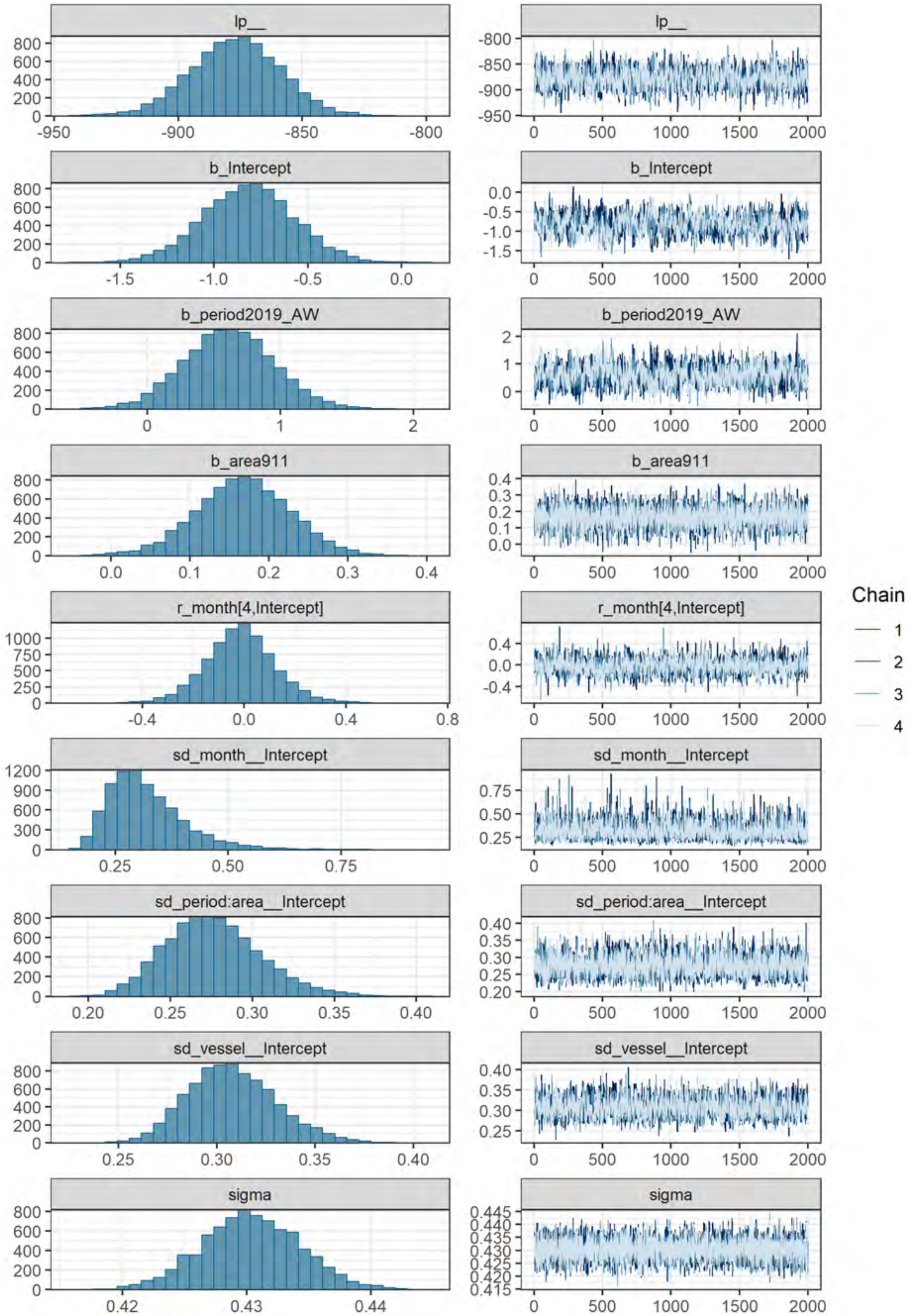


Figure A.4: Posterior densities (left) and MCMC trace plots (right) for a subset of model parameters from the CELR CPUE model.

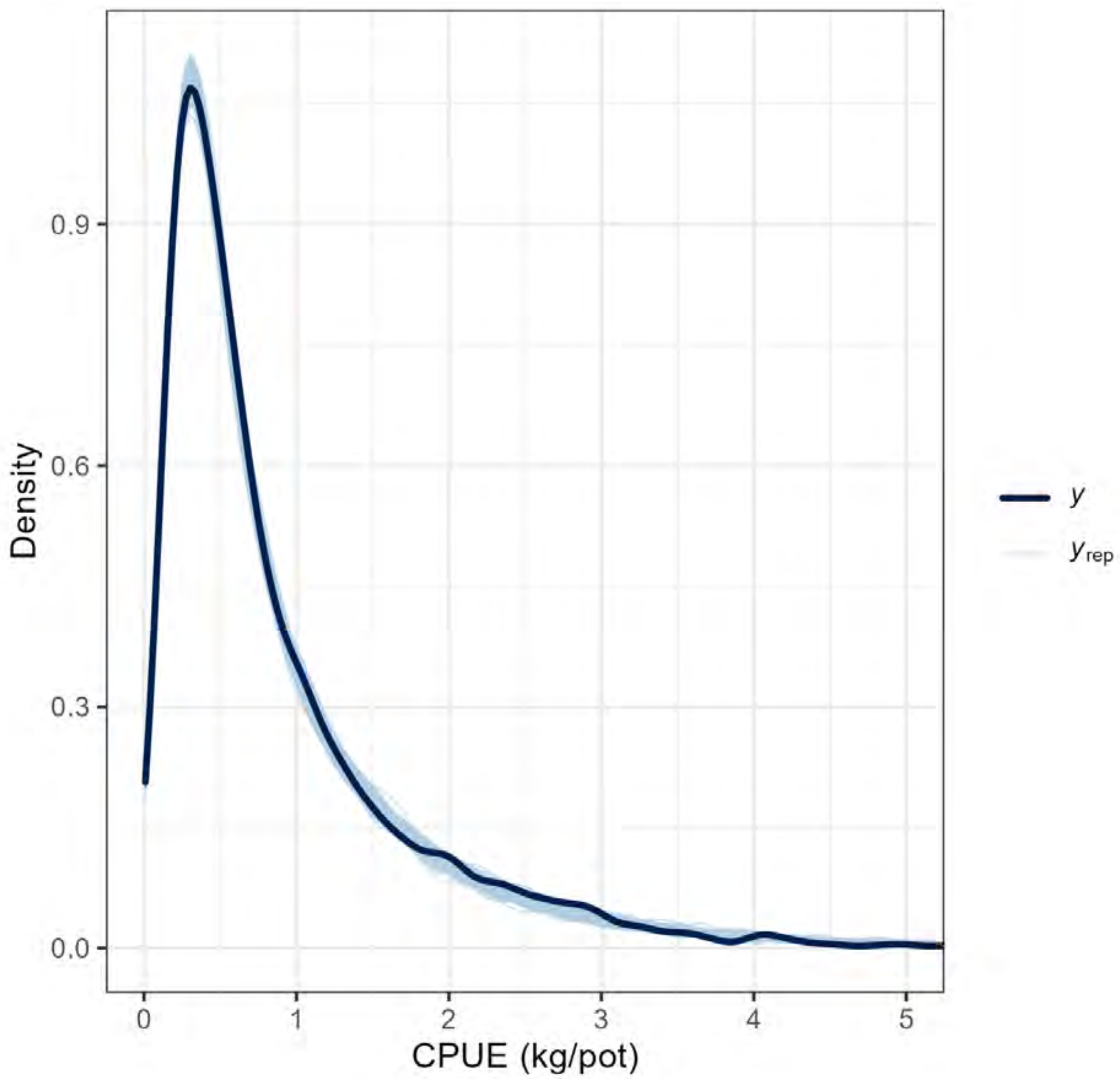


Figure A.5: Model posterior predictive density overlay for the CELR CPUE model. In this plot, *y* is the density of the data (solid blue line) and *yrep* is the density of 100 draws of data from the posterior predictive distribution.

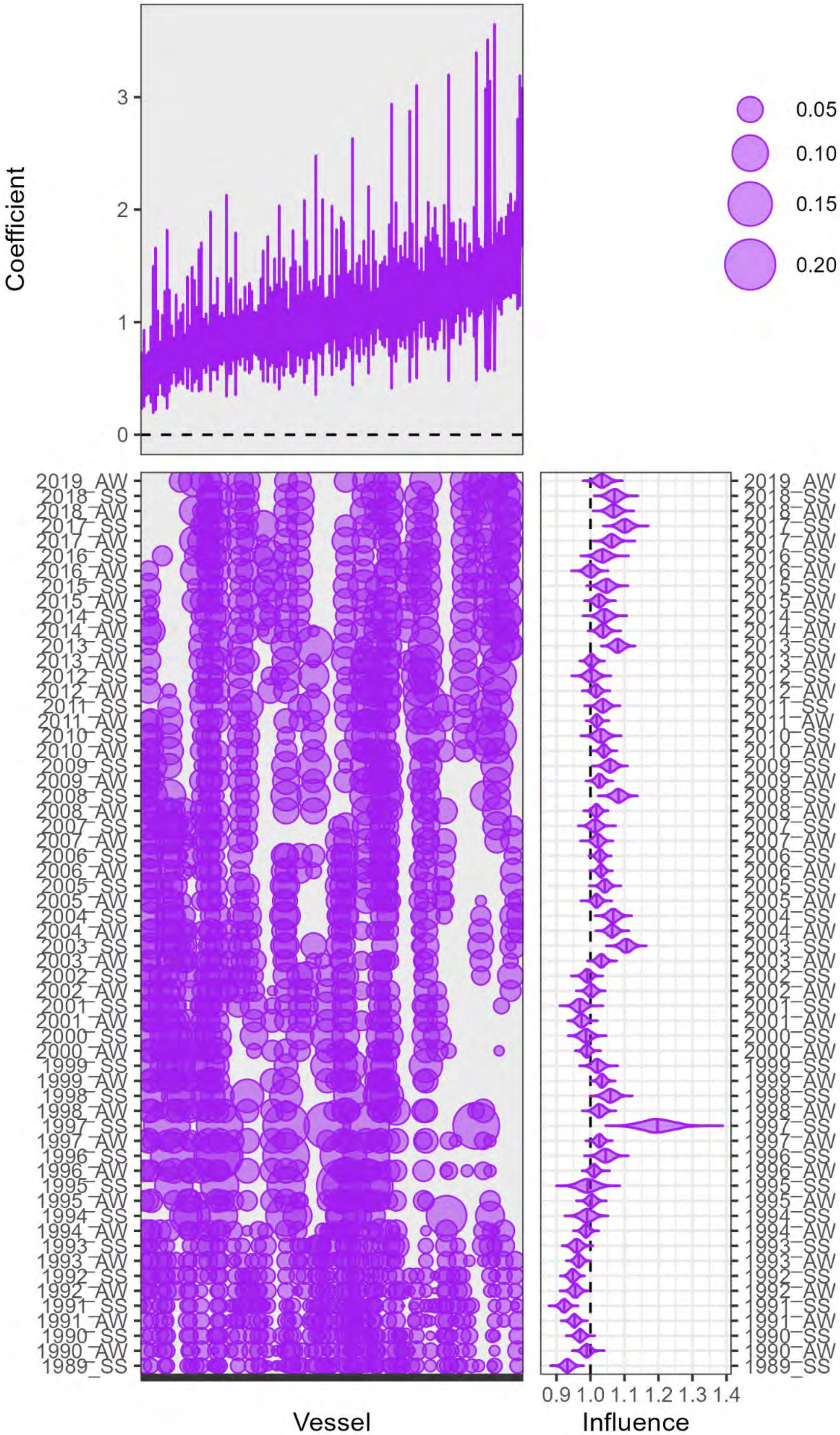


Figure A.6: Coefficient distribution influence plot for the explanatory variable vessel for the CELR CPUE model.

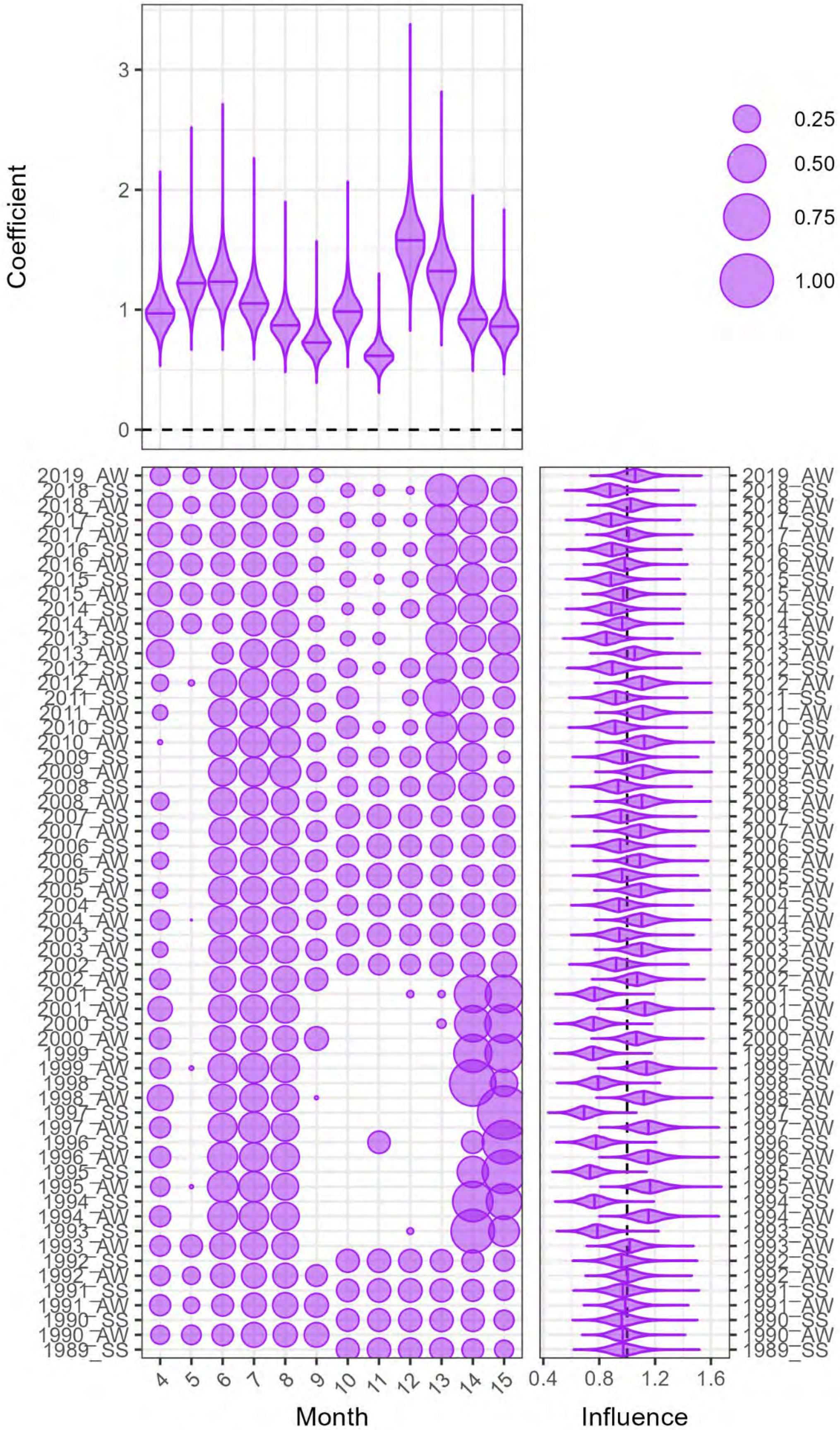


Figure A.7: Coefficient distribution influence plot for the explanatory variable month for the CELR CPUE model.

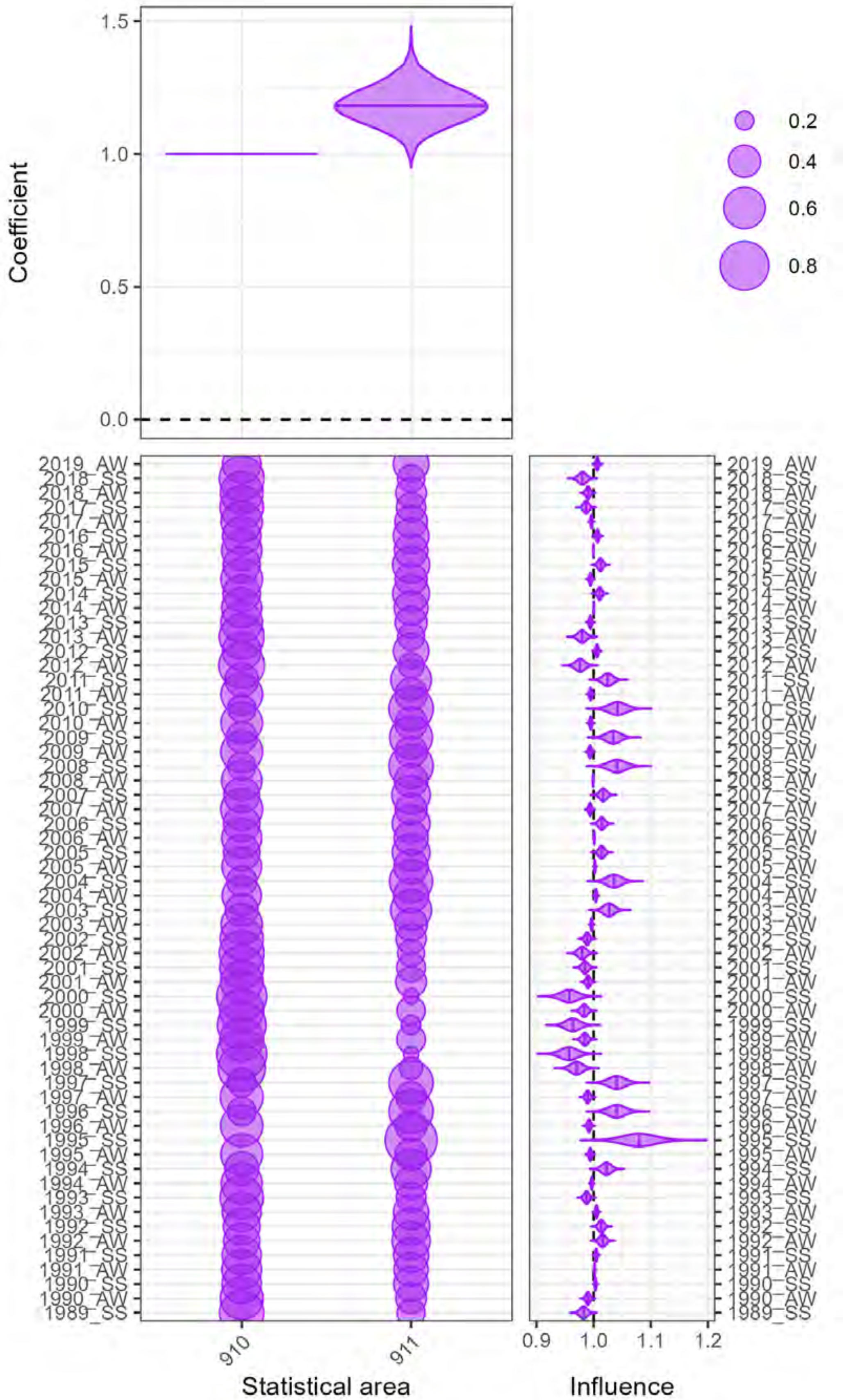


Figure A.8: Coefficient distribution influence plot for the explanatory variable region (910=region 1; 911=region 2) for the CELR CPUE model.

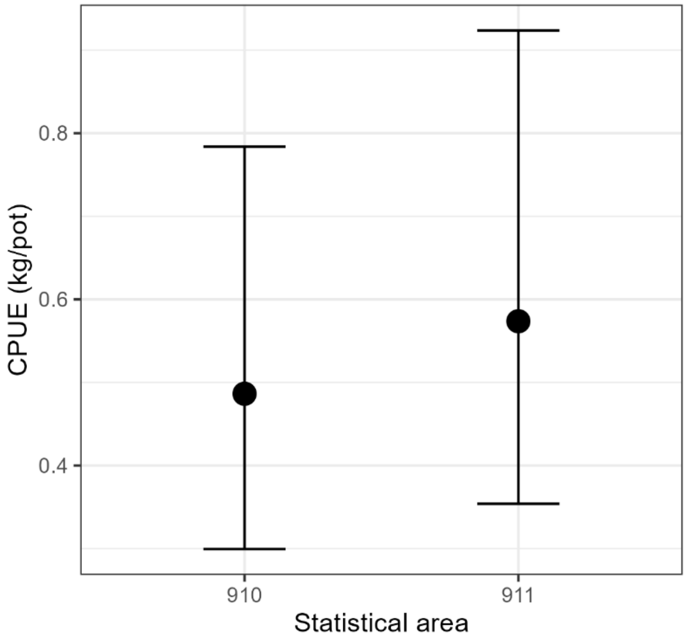


Figure A.9: Plot of the predicted CPUE of lobsters in response to region (910=region 1; 911=region 2). The prediction is represented by closed points and the 95% credible interval is represented by bars.

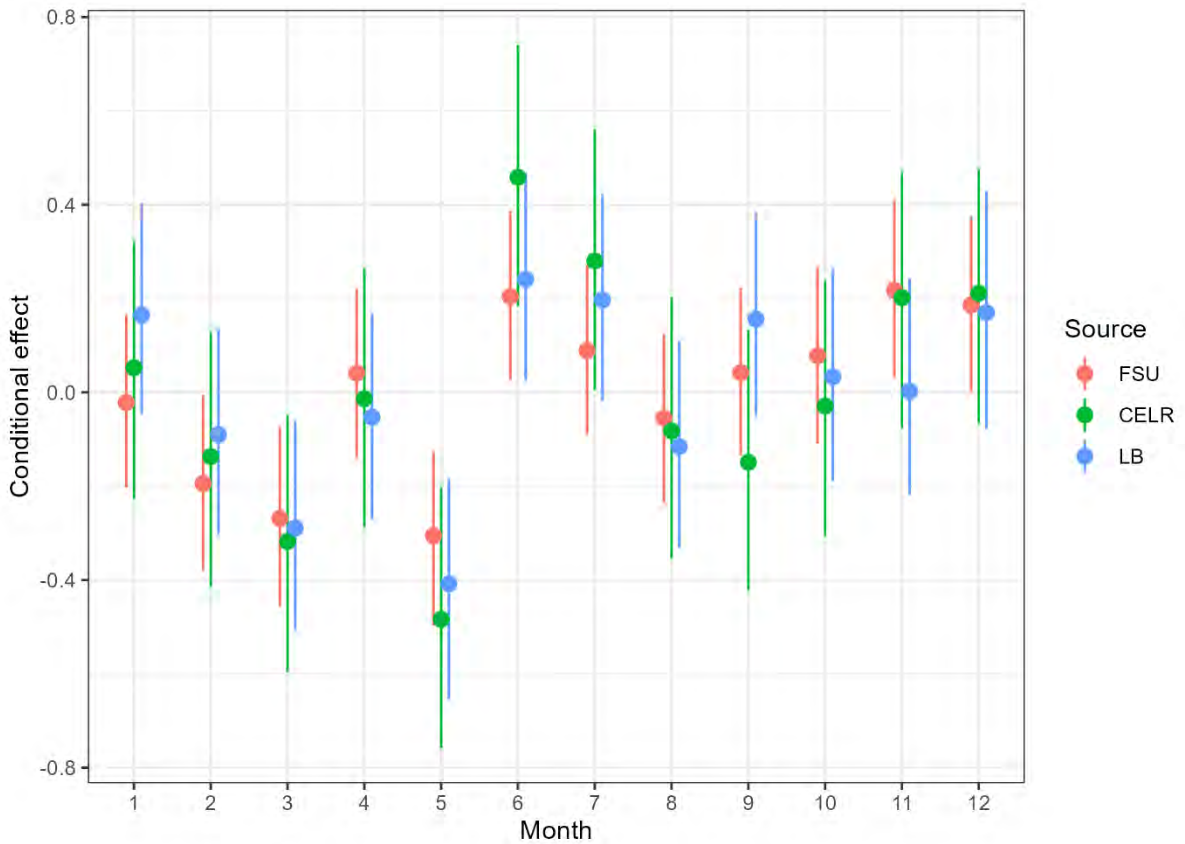


Figure A.10: The conditional effect of month comparing the FSU, CELR, and logbook (LB) CPUE models. The prediction is represented by closed points; the 95% credible interval is represented by bars.

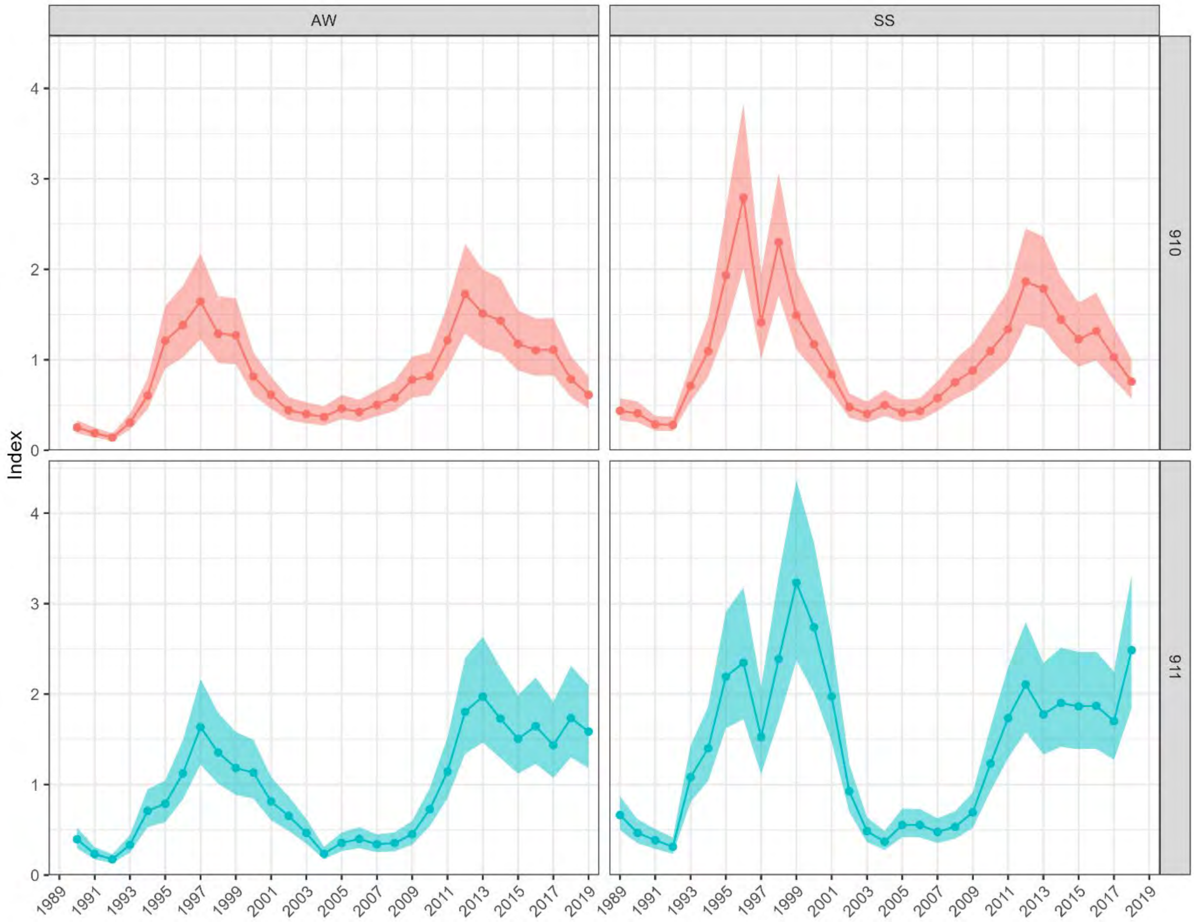


Figure A.11: Plot of the predicted CPUE index of the CELR CPUE model by region (910=region 1; 911=region 2) and season. The prediction is represented by closed points; the 95% credible interval is represented by the shaded area.

Appendix B. LOGBOOK CPUE DIAGNOSTICS

Table B.1: Summary of logbook (LB) sampling effort in region 1 of CRA 3 by fishing year and season ('AW' = autumn/winter, 'SS' = spring/summer) in terms of: the number of vessels, trips, pots, and lobsters sampled. Fishing years shaded grey were not included in the LB CPUE model.

	Vessels			Trips			Pots			Lobsters		
Fishing year	AW	SS	Total	AW	SS	Total	AW	SS	Total	AW	SS	Total
1993	8	–	8	135	–	135	520	–	520	703	–	703
1994	–	9	9	–	199	199	–	734	734	–	2 128	2 128
1995	–	9	9	–	128	128	–	495	495	–	3 024	3 024
1996	–	4	4	–	112	112	–	425	425	–	3 227	3 227
1997	–	1	1	–	17	17	–	65	65	–	836	836
1998	–	2	2	–	20	20	–	80	80	–	246	246
1999	1	–	1	19	–	19	31	–	31	60	–	60
2000	1	1	1	74	25	99	129	25	154	272	53	325
2001	1	–	1	12	–	12	30	0	30	48	–	48
2002	–	–	–	–	–	–	–	–	–	–	–	–
2003	1	1	2	1	1	2	1	2	3	3	3	6
2004	2	–	2	86	–	86	216	–	216	451	–	451
2005	1	2	2	13	46	59	13	80	93	24	171	195
2006	3	1	3	15	51	66	27	86	113	115	146	261
2007	2	1	2	54	47	101	158	129	287	831	450	1 281
2008	1	3	4	15	79	94	37	296	333	48	1 067	1 115
2009	1	2	2	55	69	124	191	188	379	633	781	1 414
2010	2	6	6	93	125	218	293	427	720	620	2 155	2 775
2011	3	5	5	88	149	237	367	526	893	738	2 288	3 026
2012	3	3	3	40	108	148	154	398	552	625	1 881	2 506
2013	6	4	7	97	81	178	290	293	583	763	1 570	2 333
2014	4	8	8	88	168	256	308	540	848	755	2 839	3 594
2015	3	5	5	55	124	179	198	451	649	547	2 088	2 635
2016	6	6	6	93	200	293	342	710	1 052	1 191	2 522	3 713
2017	7	6	7	157	163	320	561	589	1 150	893	1 822	2 715
2018	1	5	6	29	65	94	56	232	288	99	461	560
2019	5	4	5	169	113	282	730	420	1 150	1 229	1 220	2 449
2020	2	4	4	30	106	136	115	403	518	122	1 111	1 233
2021	3	7	8	67	210	277	190	754	944	626	2 704	3 330
2022	8	7	8	256	202	458	1 037	668	1 705	1 980	1 992	3 972
2023	5	7	7	148	222	370	513	804	1 317	1 001	2 249	3 250

Table B.2: Summary of logbook (LB) sampling effort in region 2 of CRA 3 by fishing year and season (‘AW’ = autumn/winter, ‘SS’ = spring/summer) in terms of: the number of vessels, trips, pots, and lobsters sampled. Fishing years shaded grey were not included in the LB CPUE model.

	Vessels			Trips			Pots			Lobsters		
Fishing year	AW	SS	Total	AW	SS	Total	AW	SS	Total	AW	SS	Total
1993	6	–	6	73	–	73	270	–	270	528	–	528
1994	2	7	8	25	138	163	90	479	569	185	716	901
1995	–	3	3	–	83	83	–	303	303	–	468	468
1996	–	2	2	–	52	52	–	196	196	–	364	364
1997	–	2	2	–	24	24	–	87	87	–	250	250
1998	–	2	2	–	31	31	–	112	112	–	365	365
1999	1	1	1	2	28	30	7	109	116	61	381	442
2000	–	1	1	–	39	39	–	153	153	–	601	601
2001	–	1	1	–	24	24	–	86	86	–	267	267
2002	–	–	–	–	–	–	–	–	–	–	–	–
2003	–	–	–	–	–	–	–	–	–	–	–	–
2004	–	–	–	–	–	–	–	–	–	–	–	–
2005	–	–	–	–	–	–	–	–	–	–	–	–
2006	–	–	–	–	–	–	–	–	–	–	–	–
2007	–	–	–	–	–	–	–	–	–	–	–	–
2008	–	–	–	–	–	–	–	–	–	–	–	–
2009	–	–	–	–	–	–	–	–	–	–	–	–
2010	1	1	1	6	5	11	24	16	40	59	39	98
2011	1	2	2	9	29	38	32	92	124	108	287	395
2012	–	1	1	–	12	12	–	38	38	–	148	148
2013	–	1	1	–	1	1	–	1	1	–	5	5
2014	2	2	2	64	33	97	219	117	336	846	123	969
2015	2	2	2	57	79	136	184	253	437	992	1 185	2 177
2016	2	2	2	24	82	106	90	278	368	509	1 494	2 003
2017	2	3	3	21	83	104	63	280	343	421	2 240	2 661
2018	3	2	3	18	72	90	50	250	300	241	1 507	1 748
2019	3	3	3	31	53	84	89	184	273	590	1 230	1 820
2020	2	2	2	68	54	122	254	188	442	1 933	1 144	3 077
2021	2	3	3	38	151	189	134	522	656	527	2 243	2 770
2022	3	3	3	87	89	176	307	248	555	751	772	1 523
2023	3	3	3	118	116	234	398	401	799	879	1 138	2 017

Table B.3: Comparison of logbook CPUE models. Models are compared using the difference in the expected log predictive density (δ-ELPD) and the standard error of this difference (SE δ-ELPD).

Model label	Model structure	δ-ELPD	SE δ-ELPD
fit_lb_zinb	lobsters ~ period + (1|month) + (1|vessel) + area + (1|period:area), zi ~ (1|vessel)	0.0	0.0
fit_lb _nb	lobsters ~ period + (1|month) + (1|vessel) + area + (1|period:area)	-39.2	9.6

Figure B.1: Bubble plot of logbook (LB) effort by fishing year, season, and region (910=region 1 which includes 909; 911=region 2), including only the fishing years included in the LB CPUE model.

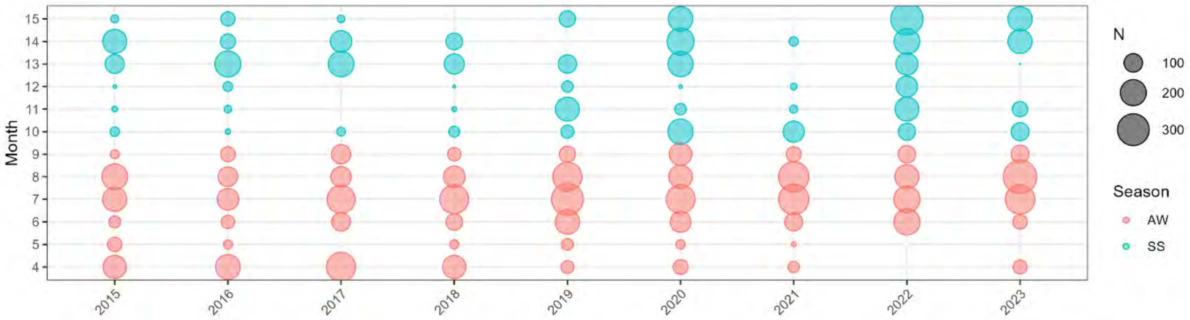


Figure B.2: Bubble plot of logbook (LB) effort by fishing year, season, and month (4 = April, 15 = March), including only the fishing years included in the LB CPUE model.

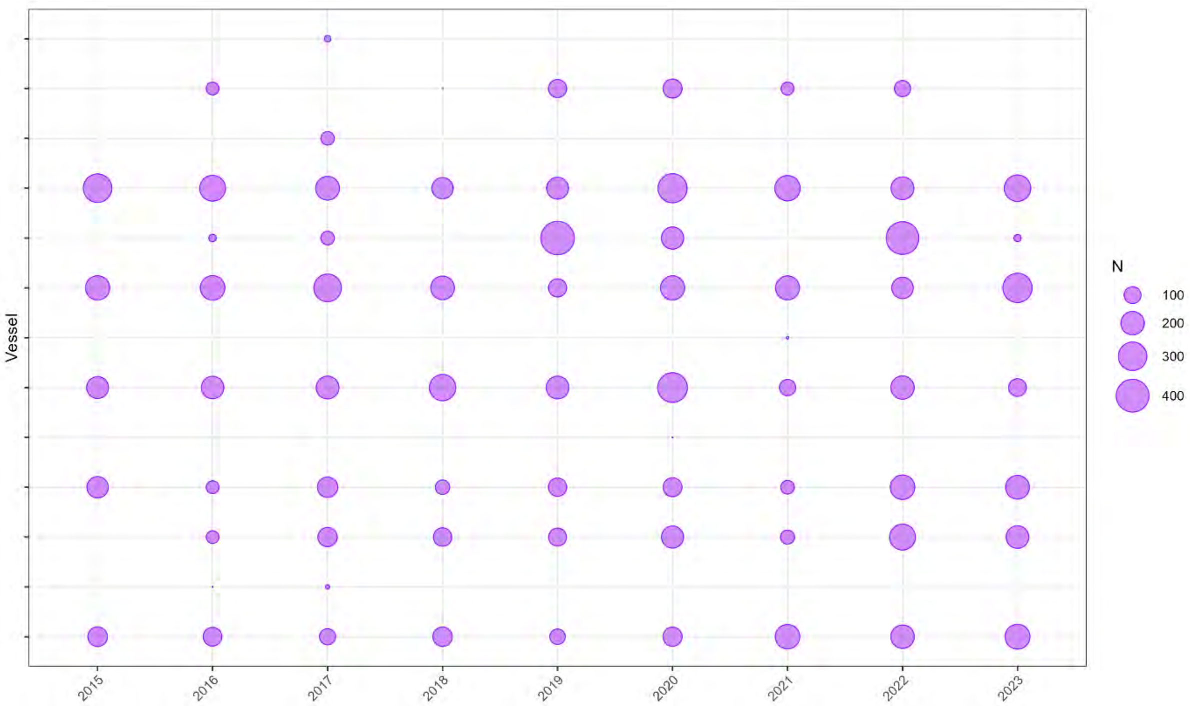


Figure B.3: Bubble plot of logbook (LB) effort by fishing year, season, and vessel (vessel codes omitted), including only the fishing years included in the LB CPUE model.

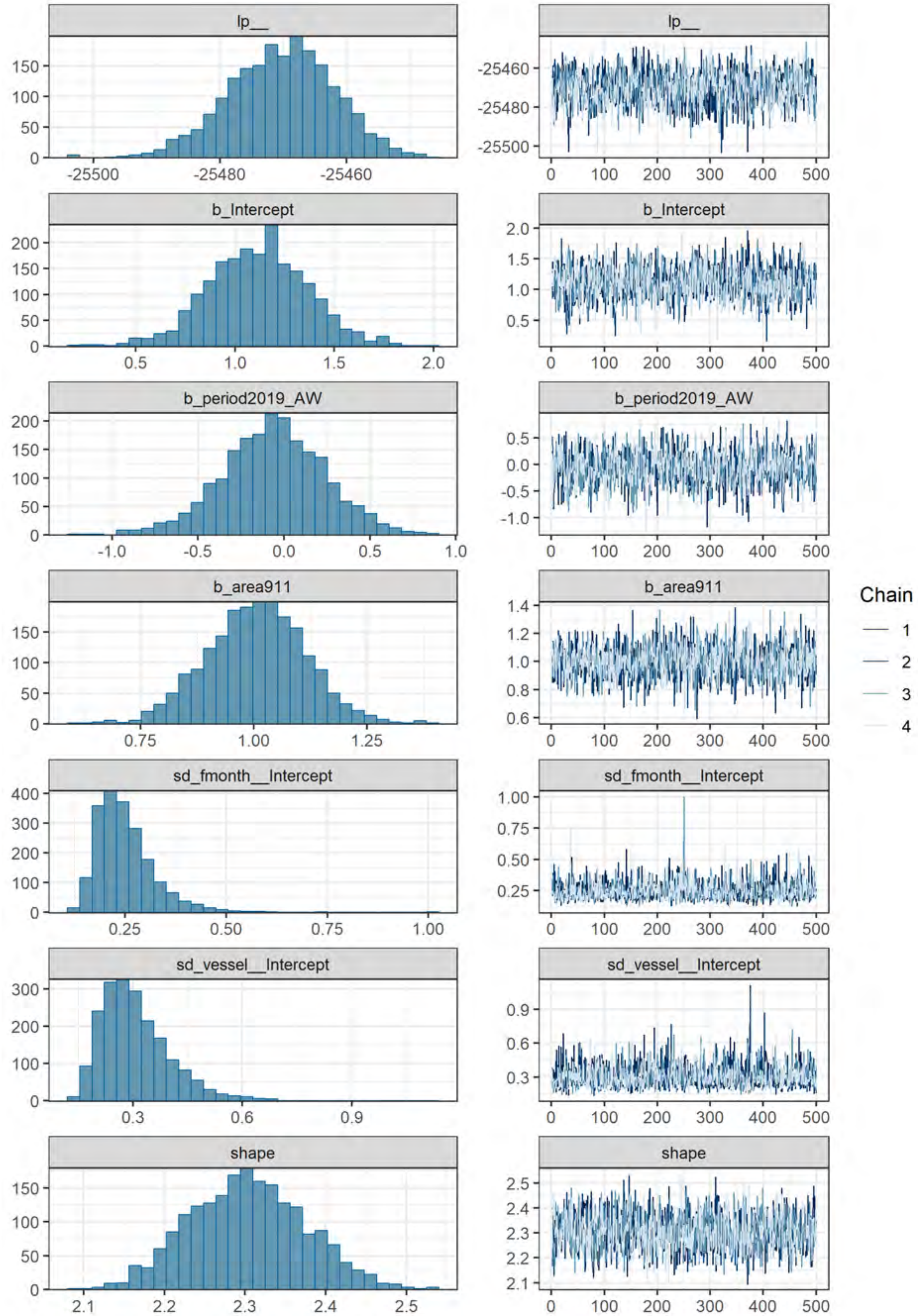


Figure B.4: Posterior densities (left) and MCMC trace plots (right) for a subset of model parameters from the final logbook CPUE model (*fit_lb_zinb*).

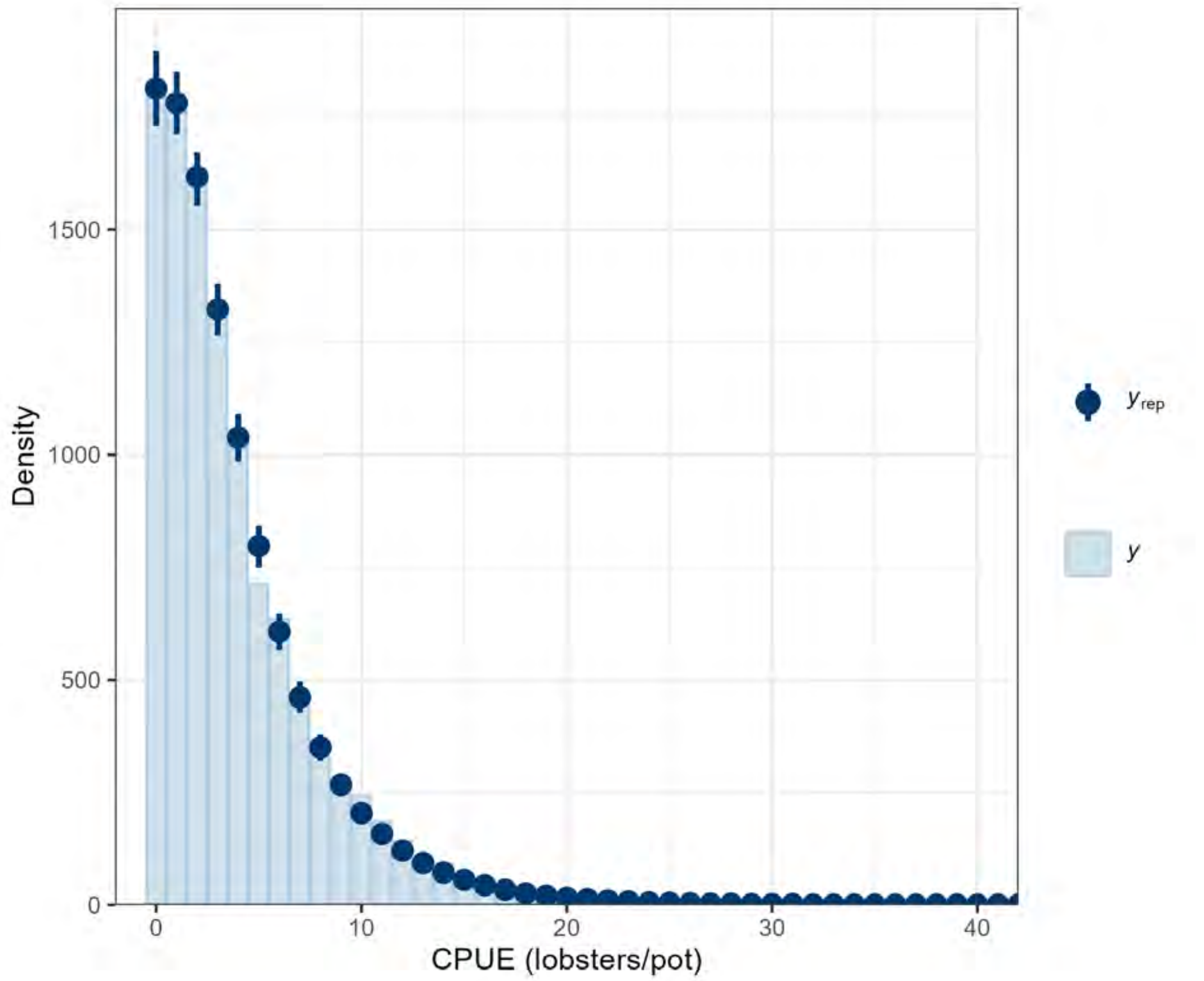


Figure B.5: Posterior predictive density overlay for the final logbook CPUE model run (*fit_lb_zinb*). In this plot, *y* is the density of the data (solid blue line) and *yrep* is the density of 100 draws of data from the posterior predictive distribution (points are medians and bars are the 50th percentiles).

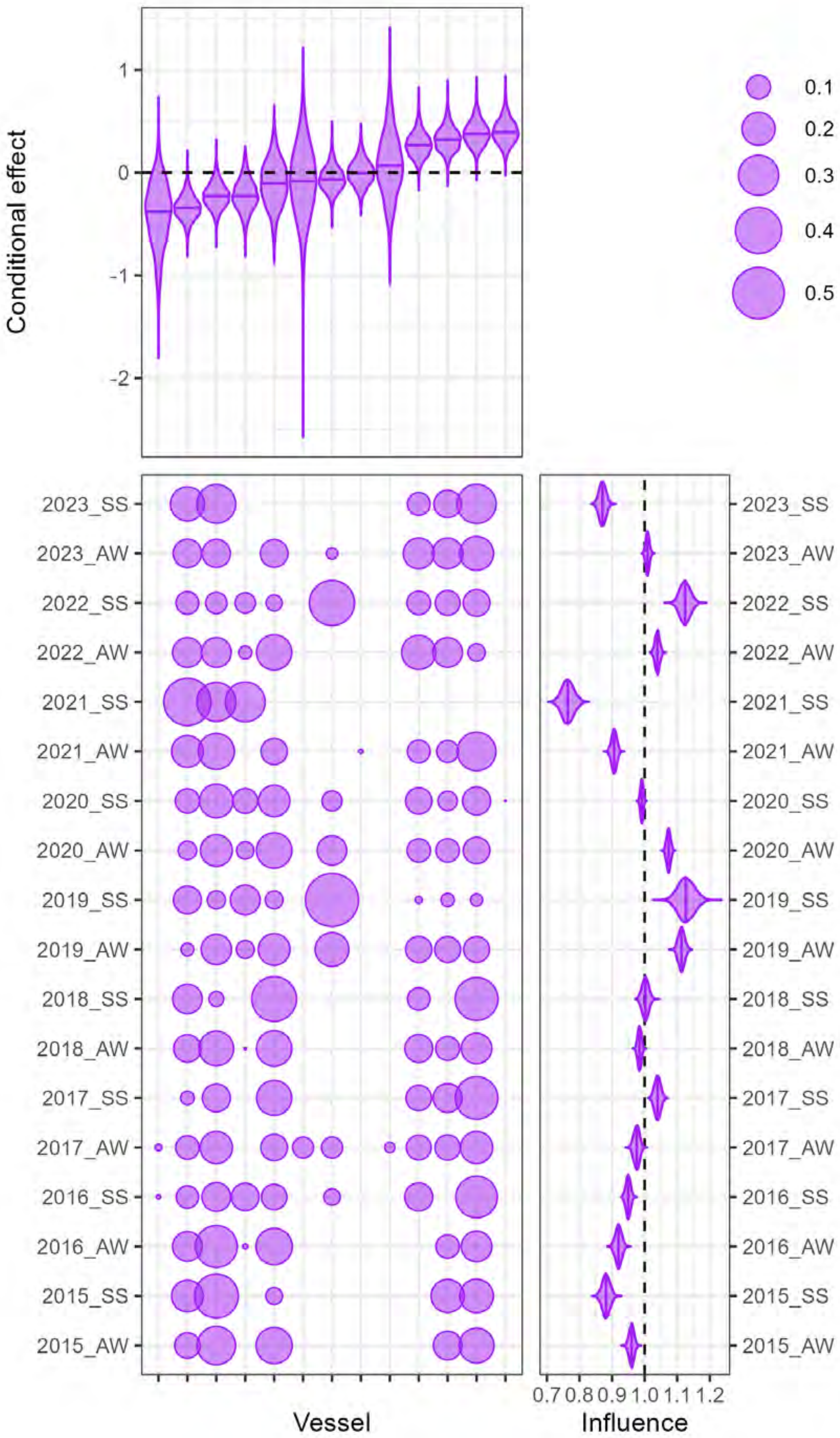


Figure B.6: Coefficient distribution influence plot for the explanatory variable vessel for the final logbook CPUE model (*fit_lb_zinb*).

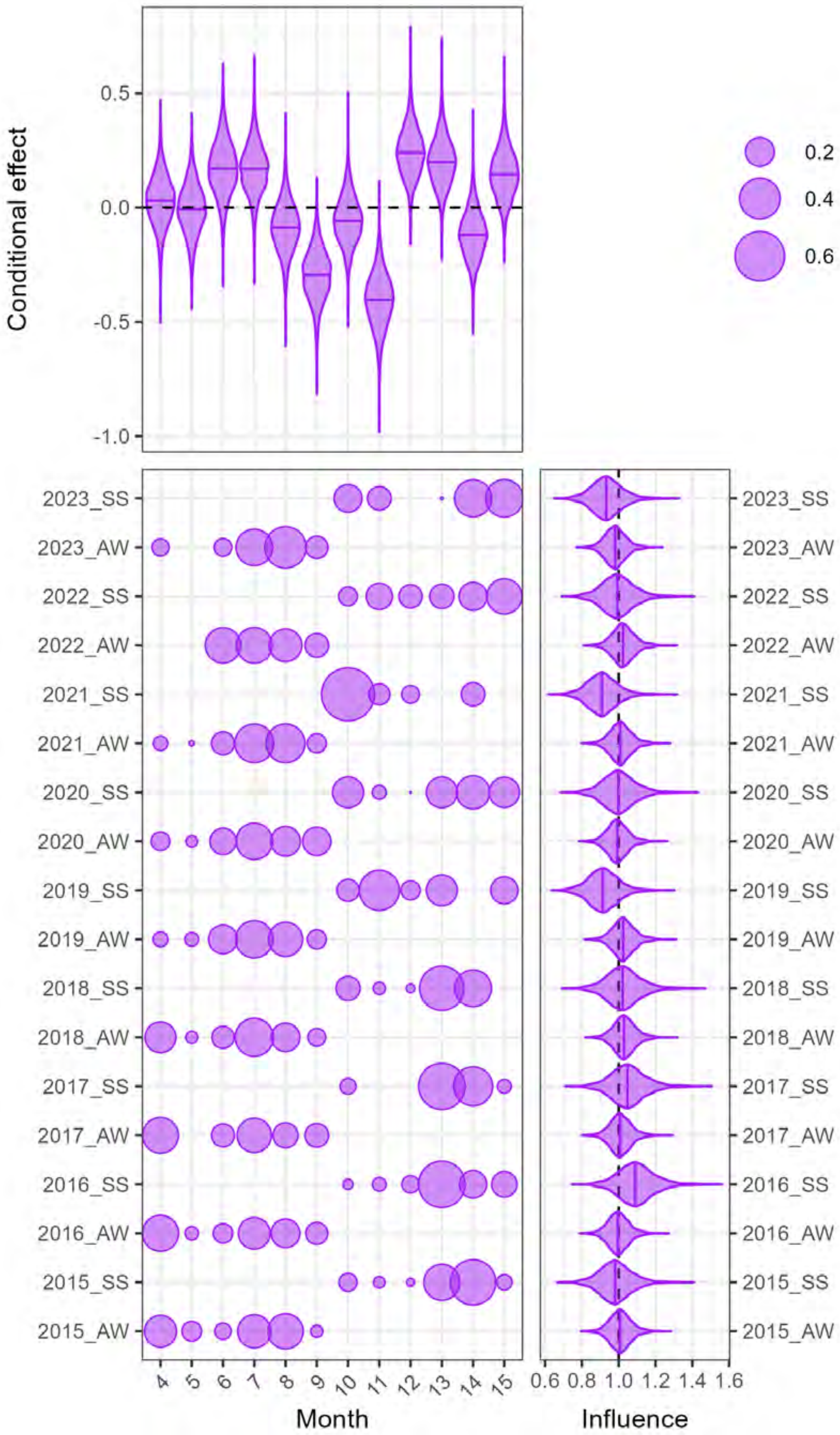


Figure B.7: Coefficient distribution influence plot for the explanatory variable month for the final logbook CPUE model (*fit_lb_zinb*).

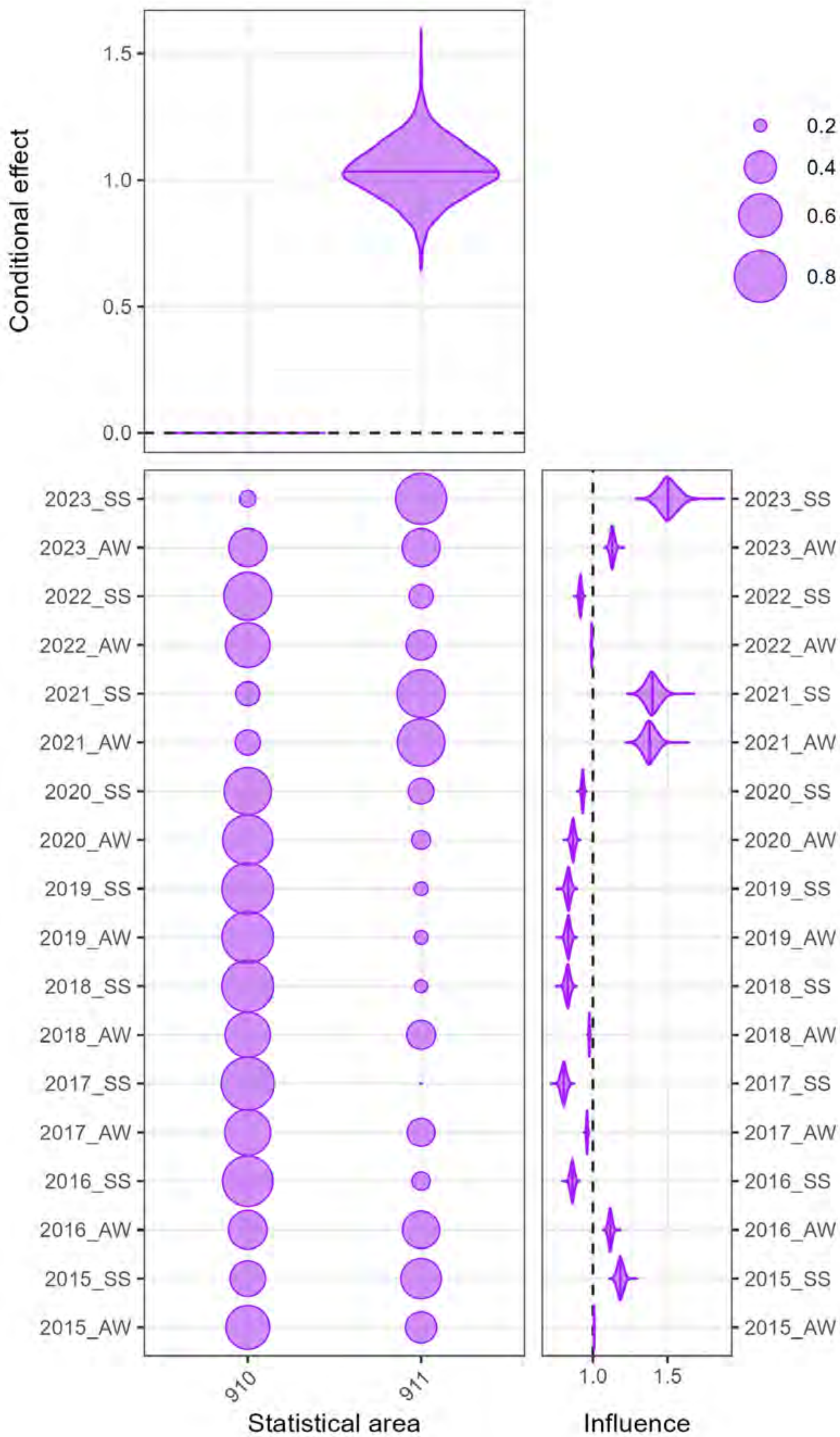


Figure B.8: Coefficient distribution influence plot for the explanatory variable statistical area for the final logbook CPUE model (*fit_lb_zinb*). 910 = region 1; 911 = region 2.

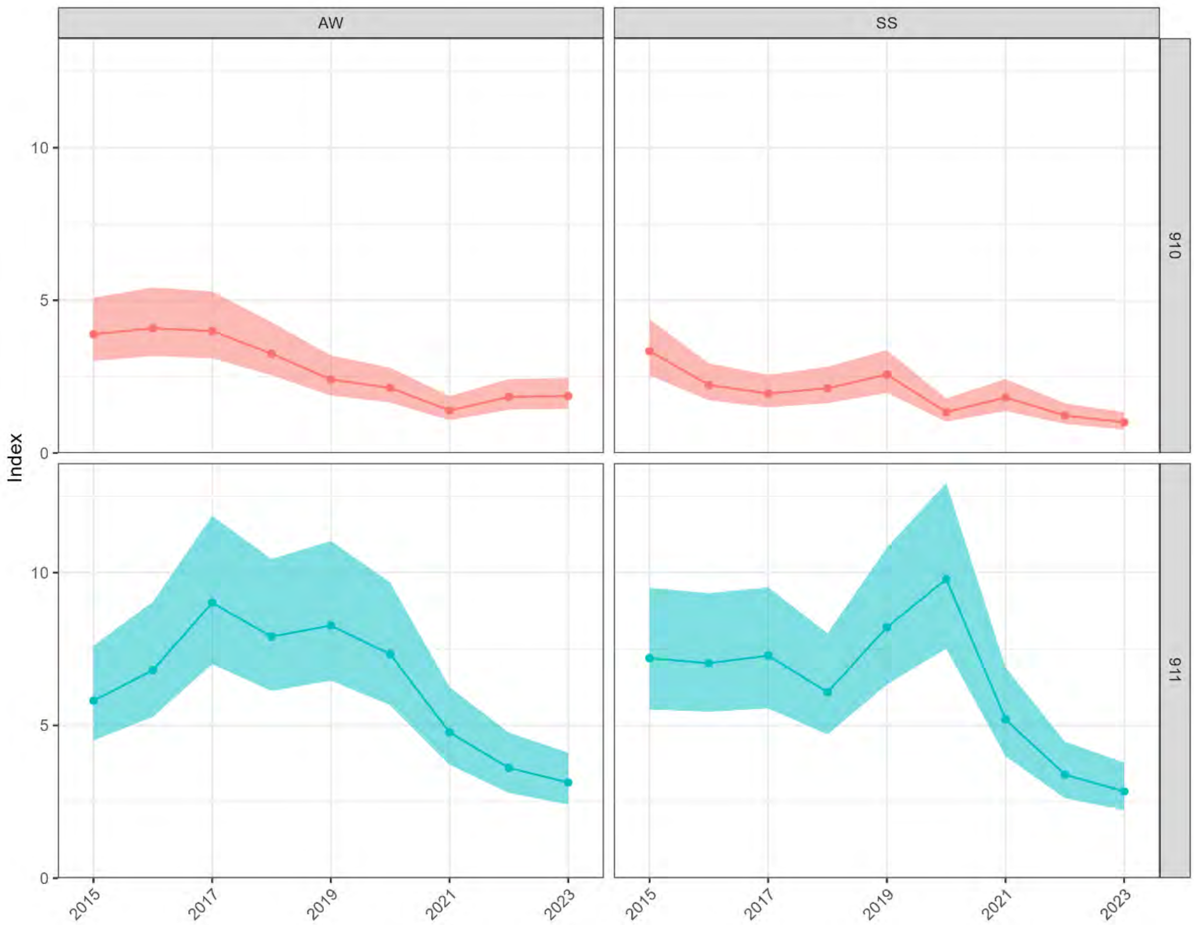


Figure B.9: Plot of the predicted CPUE index by region ('910' is the region 1 series, including Statistical Areas 909 and 910, '911' is the region 2 series) and season from the final logbook CPUE model (*fit_lb_zinb*). The prediction is represented by closed points; the 95% credible interval is represented by the shaded area.

Appendix C. CATCH COMPOSITION ANALYSIS

Table C.1: Catch sampling summary for region 1 of CRA 3, including: number of vessels, days, trips, pots, and lobsters sampled by the observer catch sampling (CS) and voluntary logbook (LB) programmes each fishing year. The fishing years indicated in grey were not included in the LF and SR models.

Fishing	Observer catch sampling					Voluntary logbook				
year	Vessels	Days	Trips	Pots	Lobsters	Vessels	Days	Trips	Pots	Lobsters
1986	1	1	1	45	191	–	–	–	–	–
1987	–	–	–	–	–	–	–	–	–	–
1988	–	–	–	–	–	–	–	–	–	–
1989	7	10	10	626	5 177	–	–	–	–	–
1990	4	17	17	1 299	13 493	–	–	–	–	–
1991	5	21	21	1 404	14 386	–	–	–	–	–
1992	6	23	23	1 522	13 157	–	–	–	–	–
1993	11	36	38	2 228	23 102	8	43	135	489	5 191
1994	10	33	33	3 184	34 971	9	71	199	681	6 075
1995	9	29	29	2 193	28 038	9	52	128	461	6 153
1996	8	24	24	1 844	25 533	4	49	112	403	6 199
1997	6	24	24	1 841	28 737	1	17	17	65	1 190
1998	6	19	24	1 568	19 549	2	20	20	74	477
1999	4	14	17	1 150	13 823	–	–	–	–	–
2000	4	13	16	1 078	10 854	–	–	–	–	–
2001	8	18	25	1 935	18 911	–	–	–	–	–
2002	7	15	19	1 336	13 184	–	–	–	–	–
2003	6	10	13	817	7 323	1	17	17	19	74
2004	6	12	14	1 080	9 477	1	87	87	128	552
2005	7	15	16	1 369	8 860	1	12	12	25	85
2006	7	14	15	1 382	9 663	2	2	2	3	13
2007	9	11	14	923	8 261	1	79	79	176	694
2008	9	14	14	1 230	11 021	2	52	52	75	310
2009	9	16	19	1 625	15 044	3	54	54	79	458
2010	7	15	20	1 492	12 202	2	98	98	256	1 902
2011	6	17	20	1 311	11 883	4	57	91	283	2 063
2012	5	15	19	729	9 533	2	107	119	311	2 628
2014	8	16	20	1 340	15 013	6	163	216	632	5 479
2015	7	18	18	1 421	14 843	5	138	230	772	6 126
2016	5	11	11	825	8 657	3	97	148	509	5 517
2017	6	15	15	883	9 846	6	113	168	524	5 281
2018	6	17	18	1 118	10 498	8	107	250	779	8 418
2019	7	19	21	1 336	13 083	4	101	178	609	6 198
2020	5	10	10	581	6 064	6	140	290	999	7 855
2021	5	18	20	1 176	11 134	7	174	317	1 068	8 408
2022	3	6	10	671	7 530	6	58	88	262	2 198
2023	4	18	23	1 700	18 352	5	165	281	1 059	7 586

Table C.2: Catch sampling summary for region 2 of CRA 3, including: number of vessels, days, trips, pots, and lobsters sampled by the observer catch sampling (CS) and voluntary logbook (LB) programmes each fishing year. The fishing years indicated in grey were not included in the LF and SR models.

Fishing	Observer catch sampling					Voluntary logbook				
year	Vessels	Days	Trips	Pots	Lobsters	Vessels	Days	Trips	Pots	Lobsters
1986	1	1	1	42	292	–	–	–	–	–
1987	–	–	–	–	–	–	–	–	–	–
1988	–	–	–	–	–	–	–	–	–	–
1989	–	–	–	–	–	–	–	–	–	–
1990	–	–	–	–	–	–	–	–	–	–
1991	–	–	–	–	–	–	–	–	–	–
1992	–	–	–	–	–	–	–	–	–	–
1993	6	18	18	1 311	5 542	6	25	72	212	983
1994	8	18	18	1 449	8 499	8	93	161	444	2 482
1995	5	8	8	713	4 273	3	52	83	213	655
1996	4	8	8	768	5 113	2	42	52	154	511
1997	2	4	4	407	1 727	2	24	24	76	281
1998	5	7	8	439	3 171	2	31	31	96	417
1999	4	2	4	240	1 178	1	29	30	101	517
2000	3	2	4	385	2 761	1	39	39	132	769
2001	1	4	4	460	2 938	1	24	24	69	348
2002	5	9	10	829	5 482	–	–	–	–	–
2003	4	13	15	1 163	6 288	–	–	–	–	–
2004	5	14	15	939	3 910	–	–	–	–	–
2005	4	13	13	927	4 317	–	–	–	–	–
2006	3	13	13	930	3 596	–	–	–	–	–
2007	3	14	14	958	3 275	–	–	–	–	–
2008	3	14	14	991	3 469	–	–	–	–	–
2009	3	10	10	879	3 395	–	–	–	–	–
2010	2	7	7	601	2 660	1	11	11	34	126
2011	2	9	9	689	3 598	2	36	37	108	543
2012	2	9	9	553	4 217	1	12	12	36	165
2014	3	8	8	476	3 722	1	1	1	1	13
2015	2	7	7	426	3 816	2	80	92	272	1 673
2016	2	12	12	693	6 197	2	116	135	402	3 572
2017	3	7	7	456	3 793	2	83	105	344	2 873
2018	2	6	6	271	2 372	3	84	104	328	3 839
2019	3	7	8	430	3 355	3	65	90	285	2 557
2020	3	8	8	362	3 374	3	77	83	266	3 080
2021	3	10	16	886	8 112	2	105	122	436	6 023
2022	2	13	13	868	6 468	3	124	186	595	5 095
2023	2	12	14	998	8 121	3	121	168	483	3 226

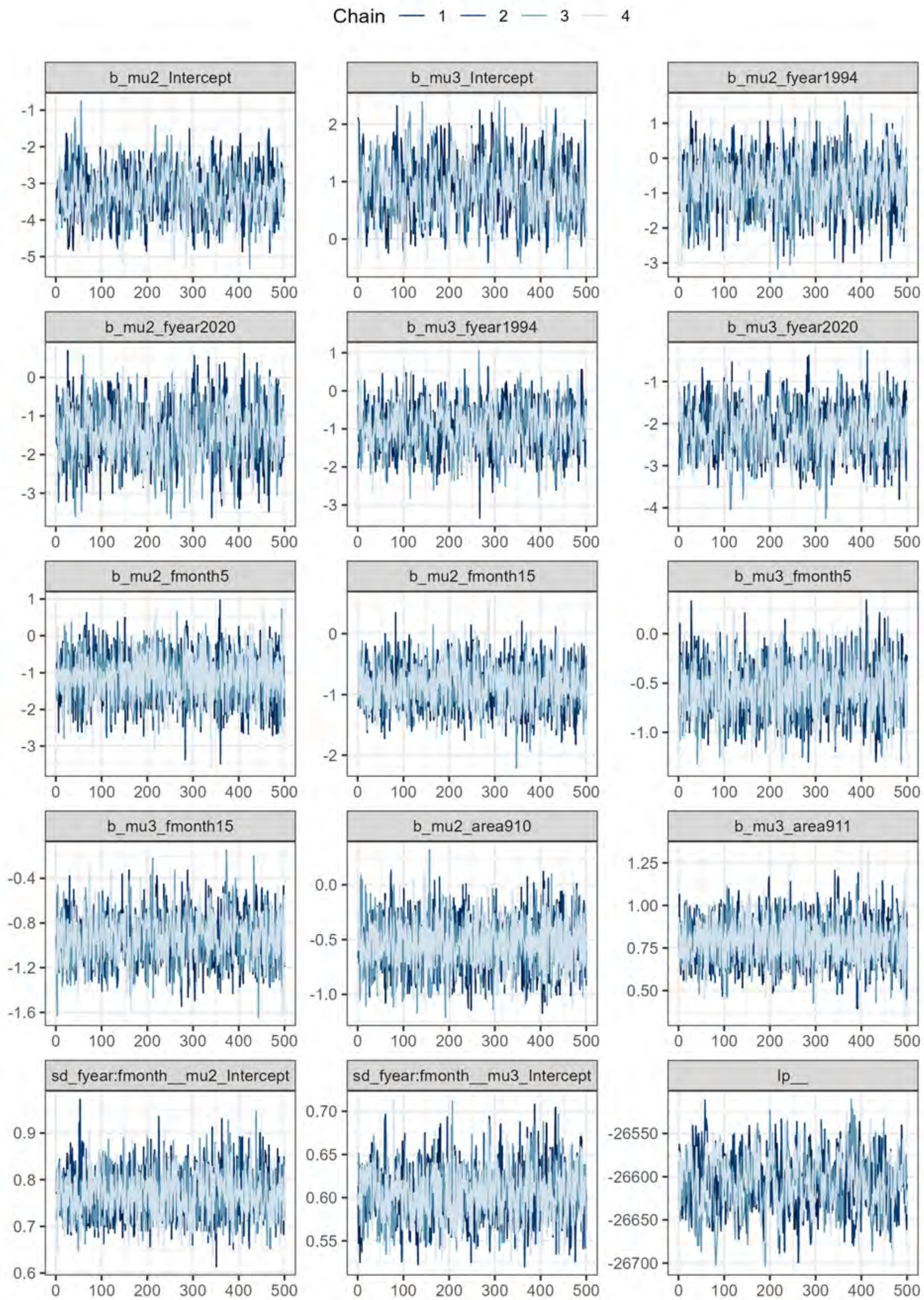


Figure C.1: MCMC trace plots for a subset of model parameters from the sex ratio model.

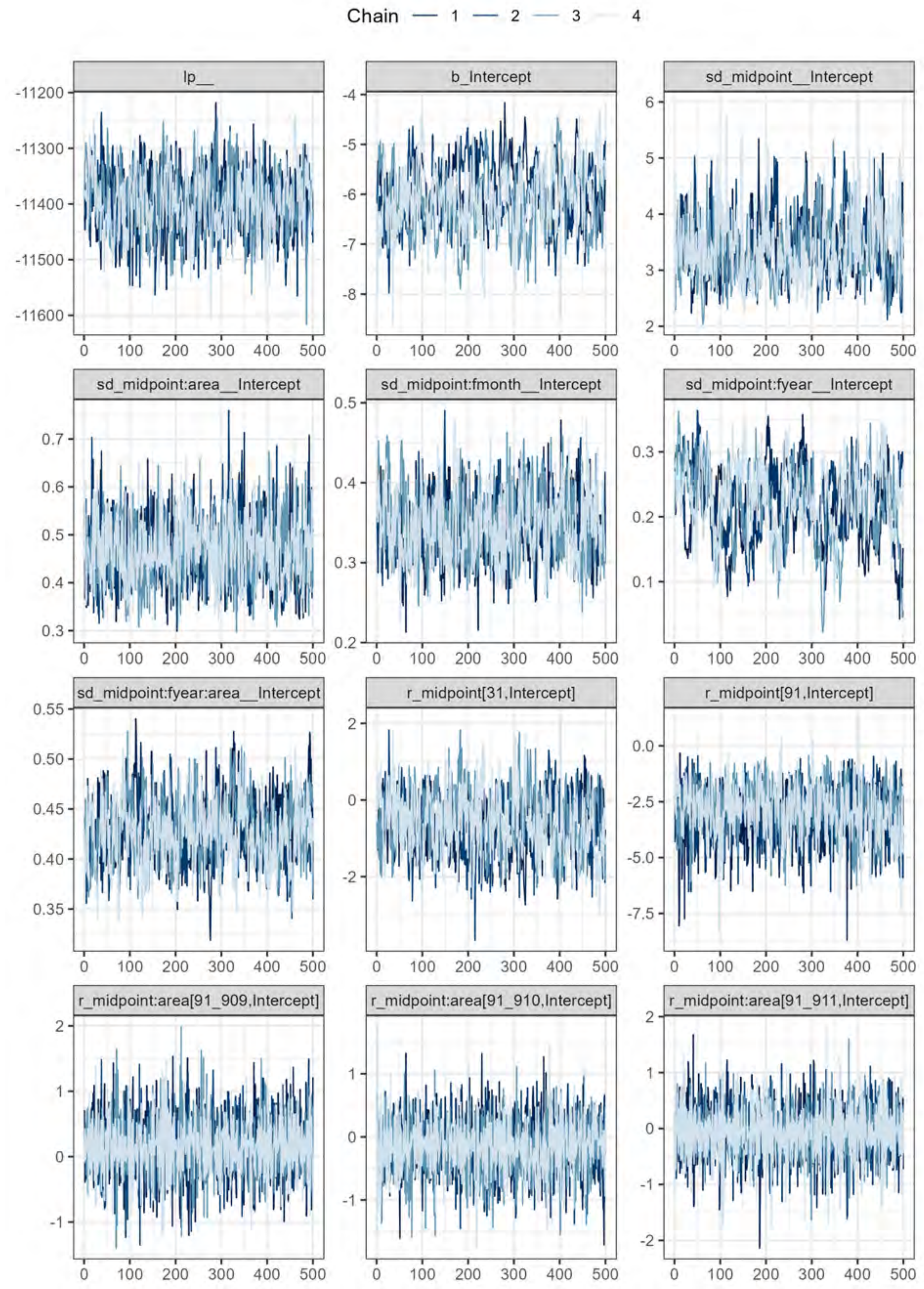


Figure C.2: MCMC trace plots for a subset of model parameters from the immature female LF model.

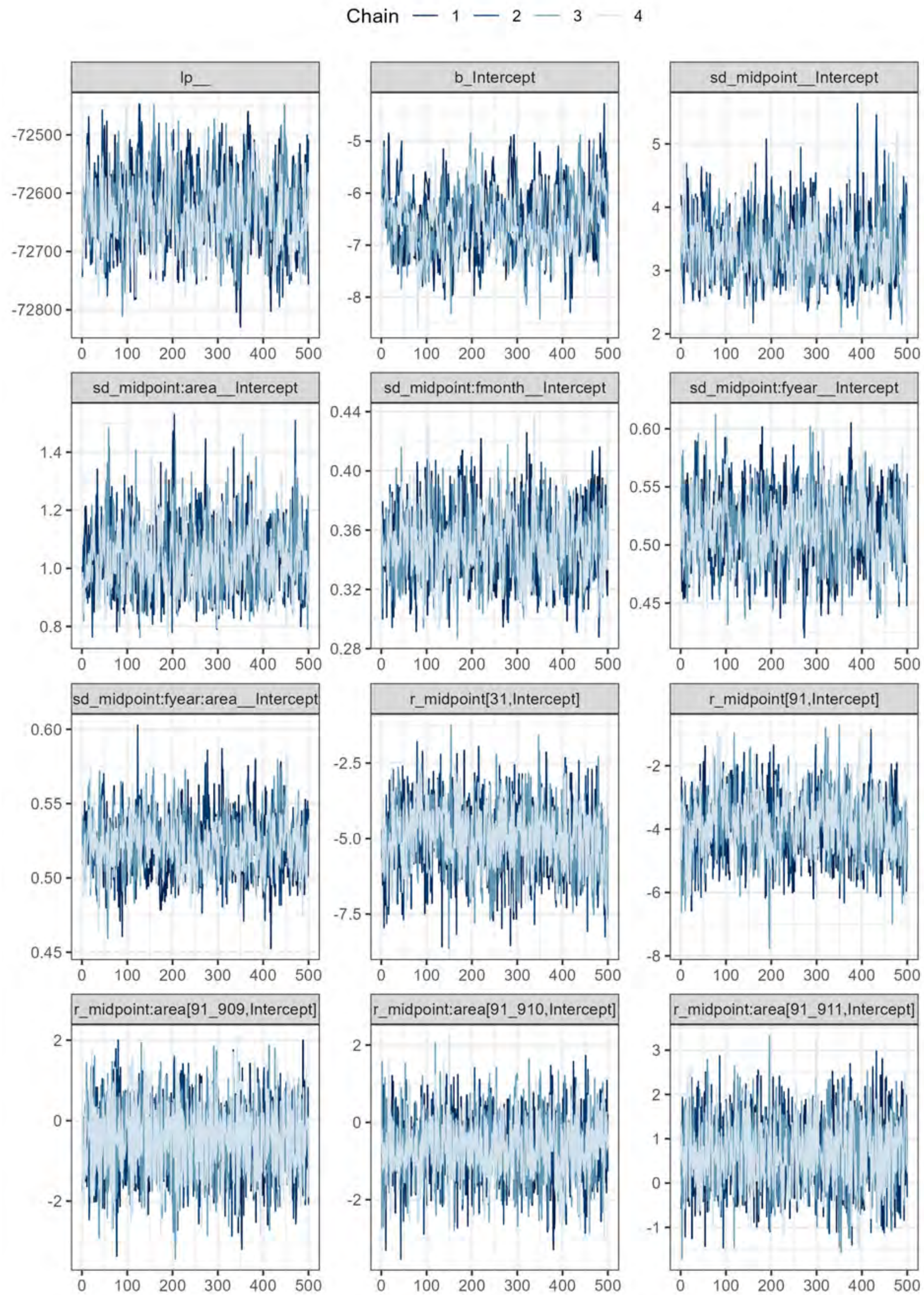


Figure C.3: MCMC trace plots for a subset of model parameters from the mature female LF model.

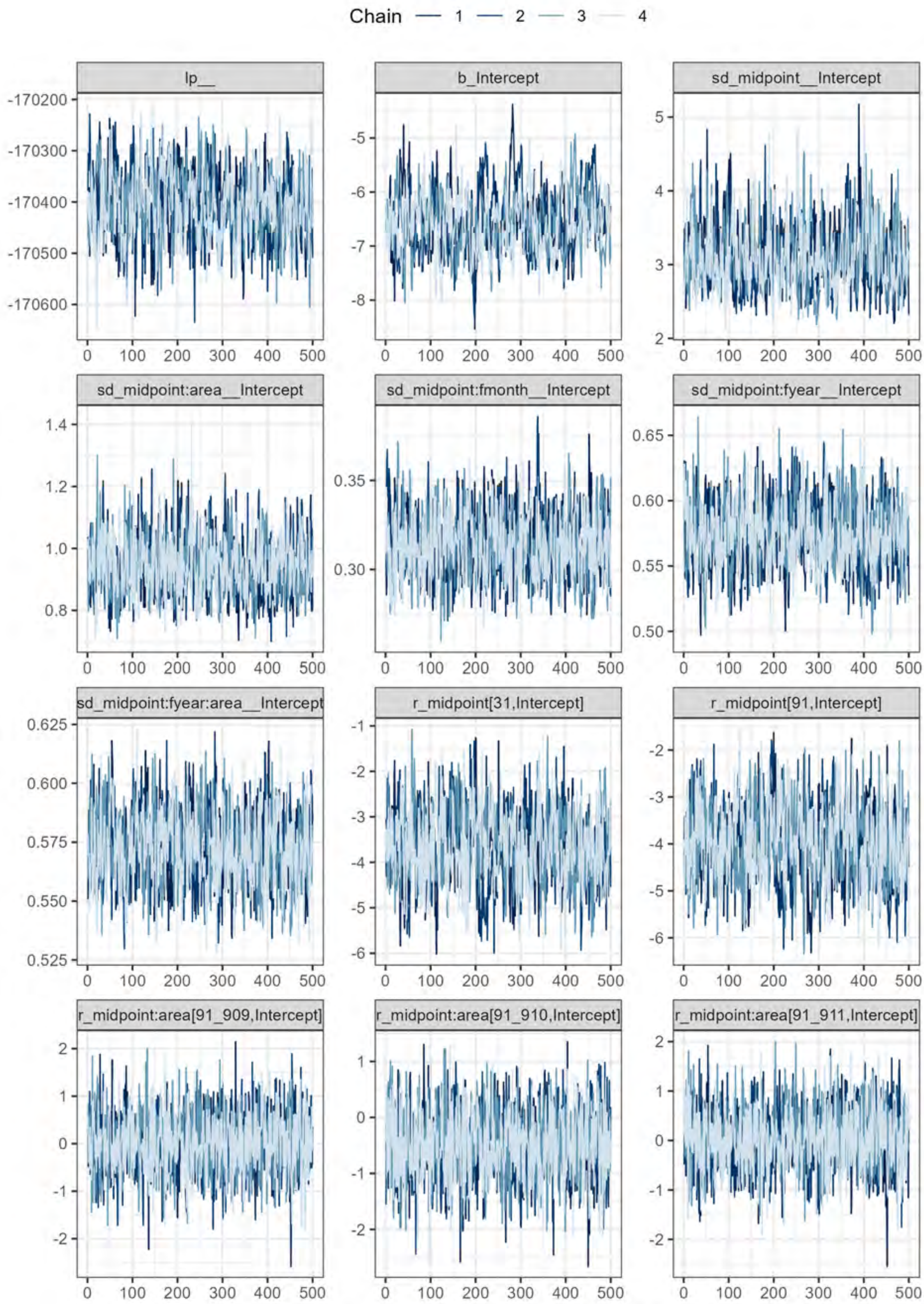


Figure C.4: MCMC trace plots for a subset of model parameters from the male LF model.

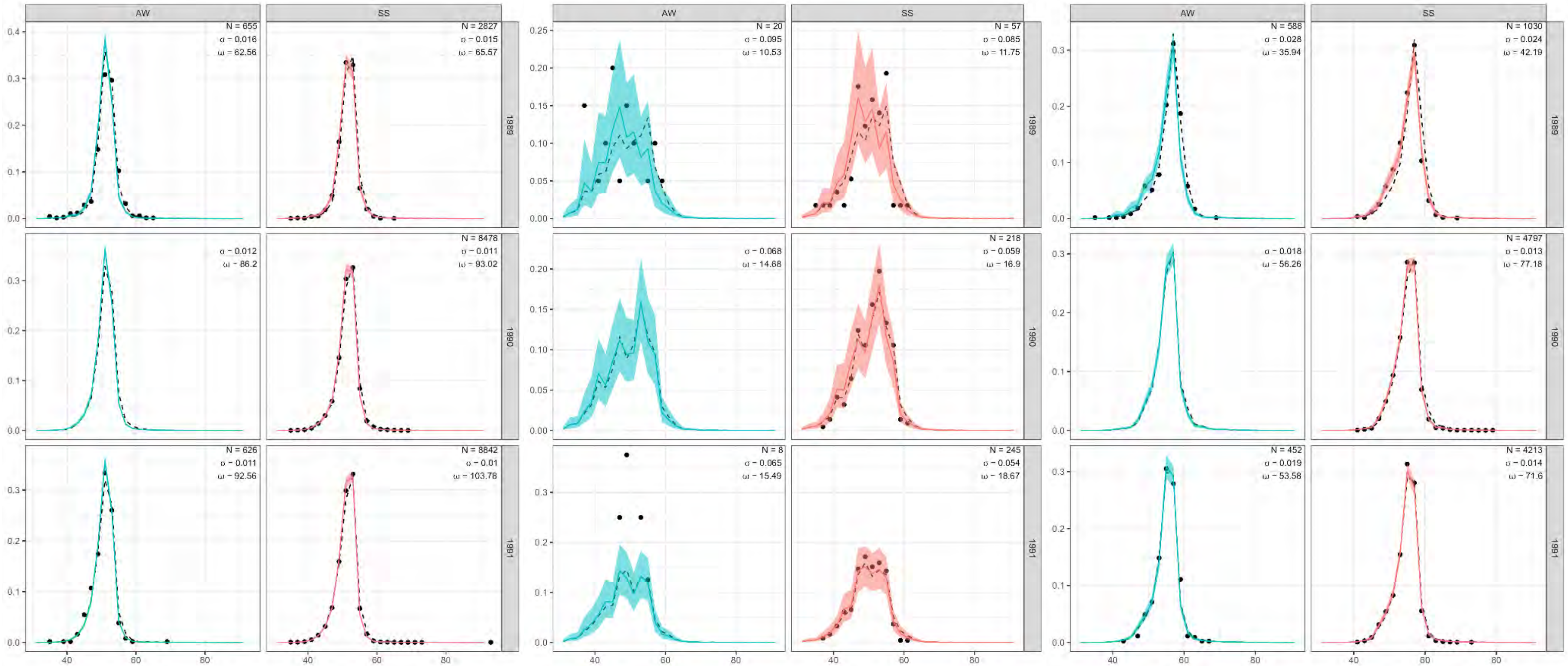


Figure C.5: CRA 3 <u>region 1</u> LFs by fishing year (from 1989 to 1991), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (Ϭ); and the data set weight for each stratum (ω).

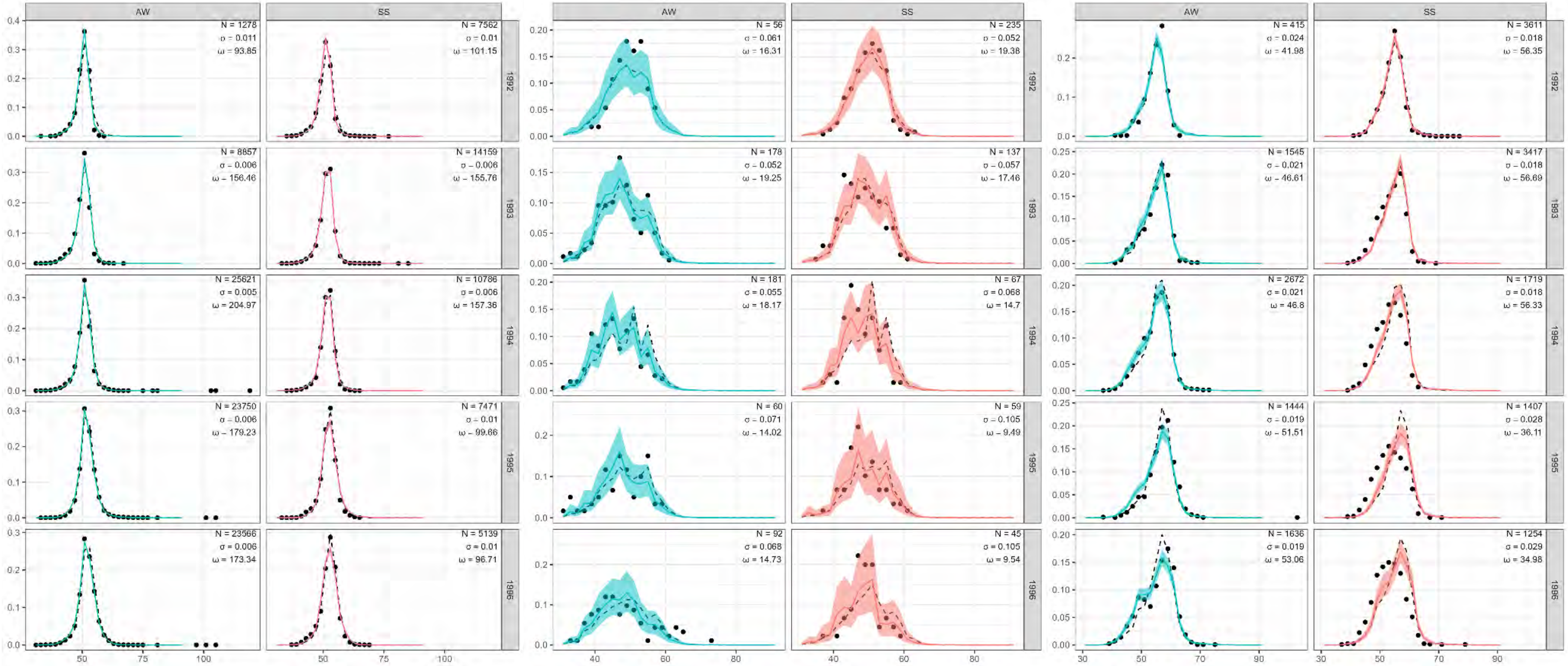


Figure C.6: CRA 3 <u>region 1</u> LFs by fishing year (from 1992 to 1996), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (Ϭ); and the data set weight for each stratum (ω).

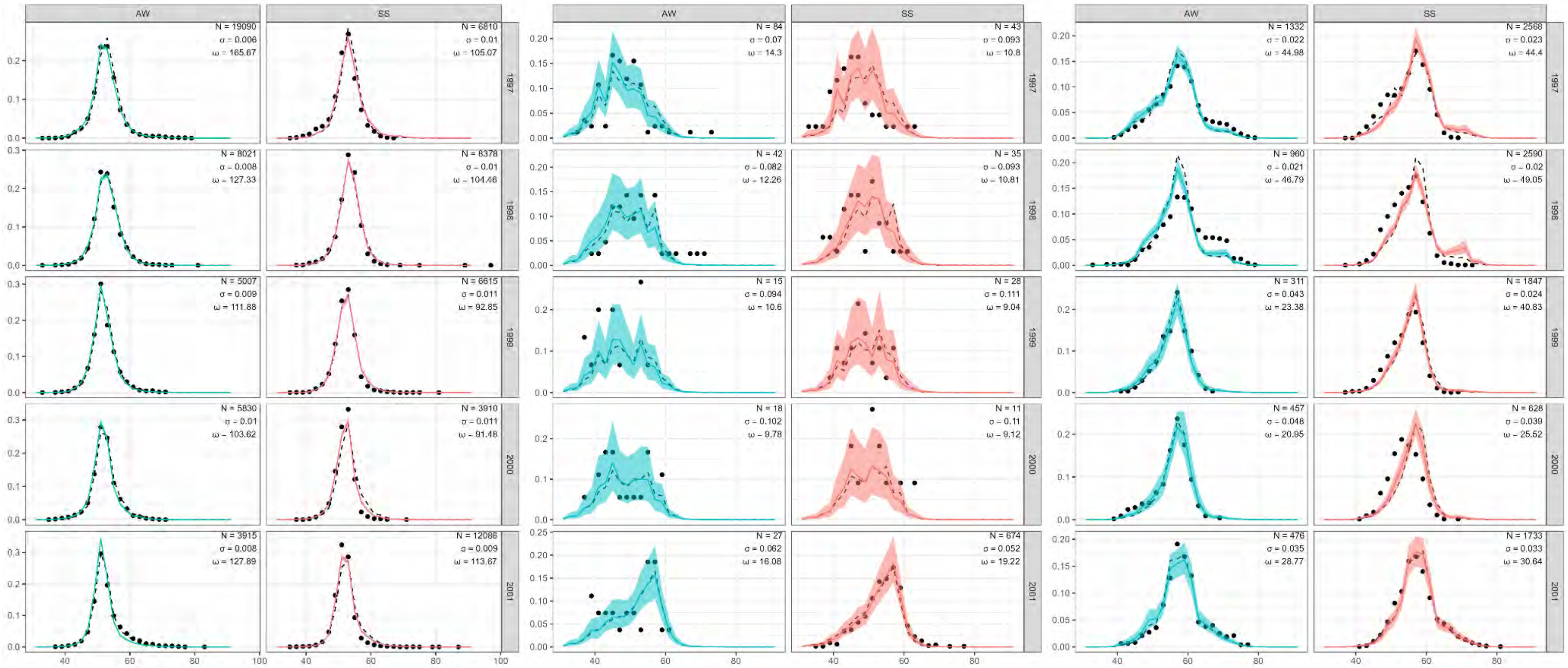


Figure C.7: CRA 3 <u>region 1</u> LFs by fishing year (from 1997 to 2001), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (Ϭ); and the data set weight for each stratum (ω).

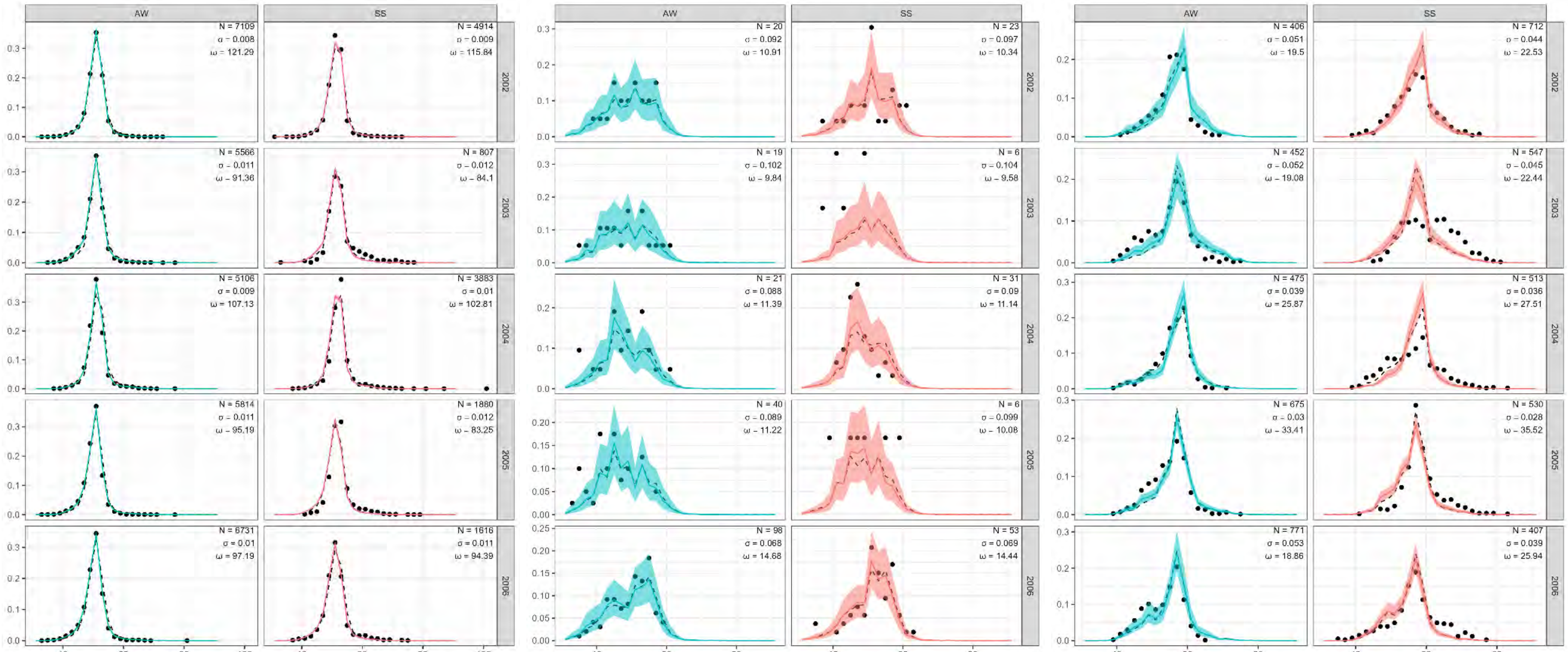


Figure C.8: CRA 3 region 1 LFs by fishing year (from 2002 to 2006), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

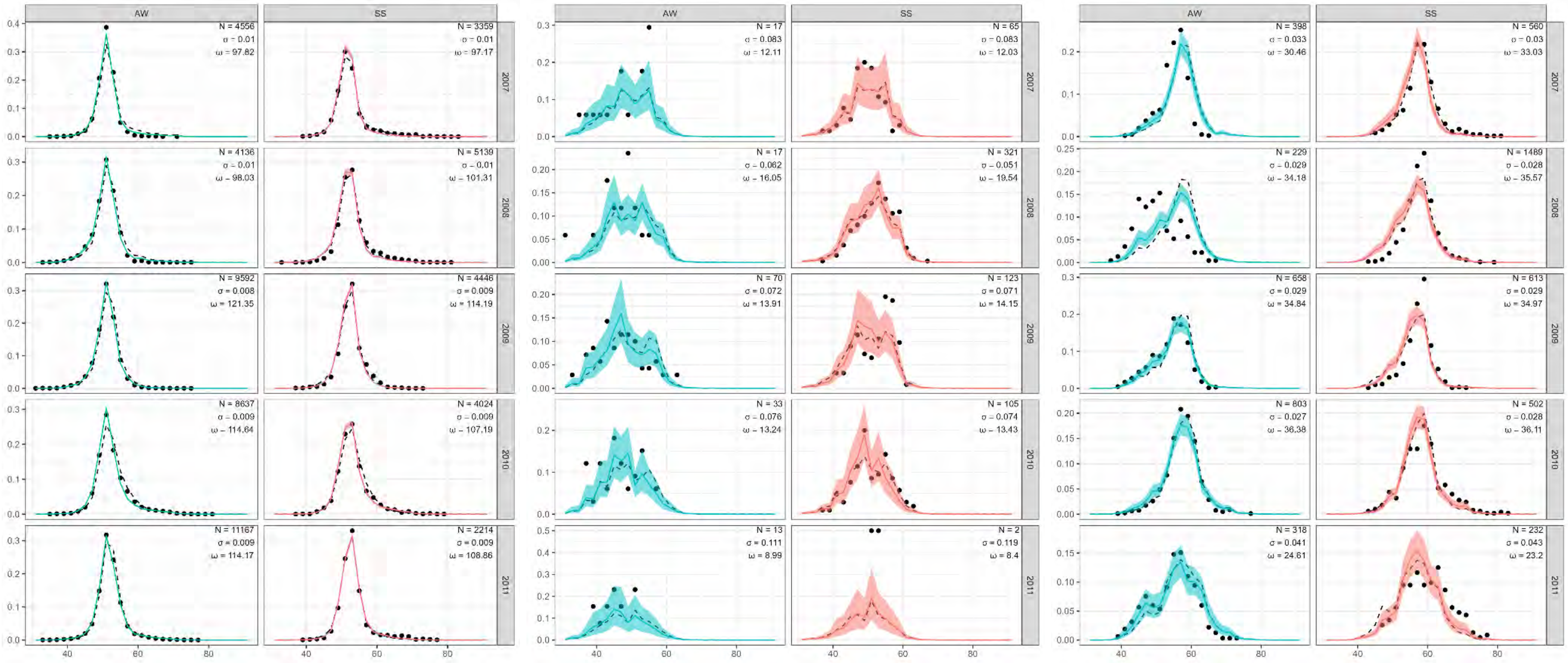


Figure C.9: CRA 3 region 1 LFs by fishing year (from 2007 to 2011), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

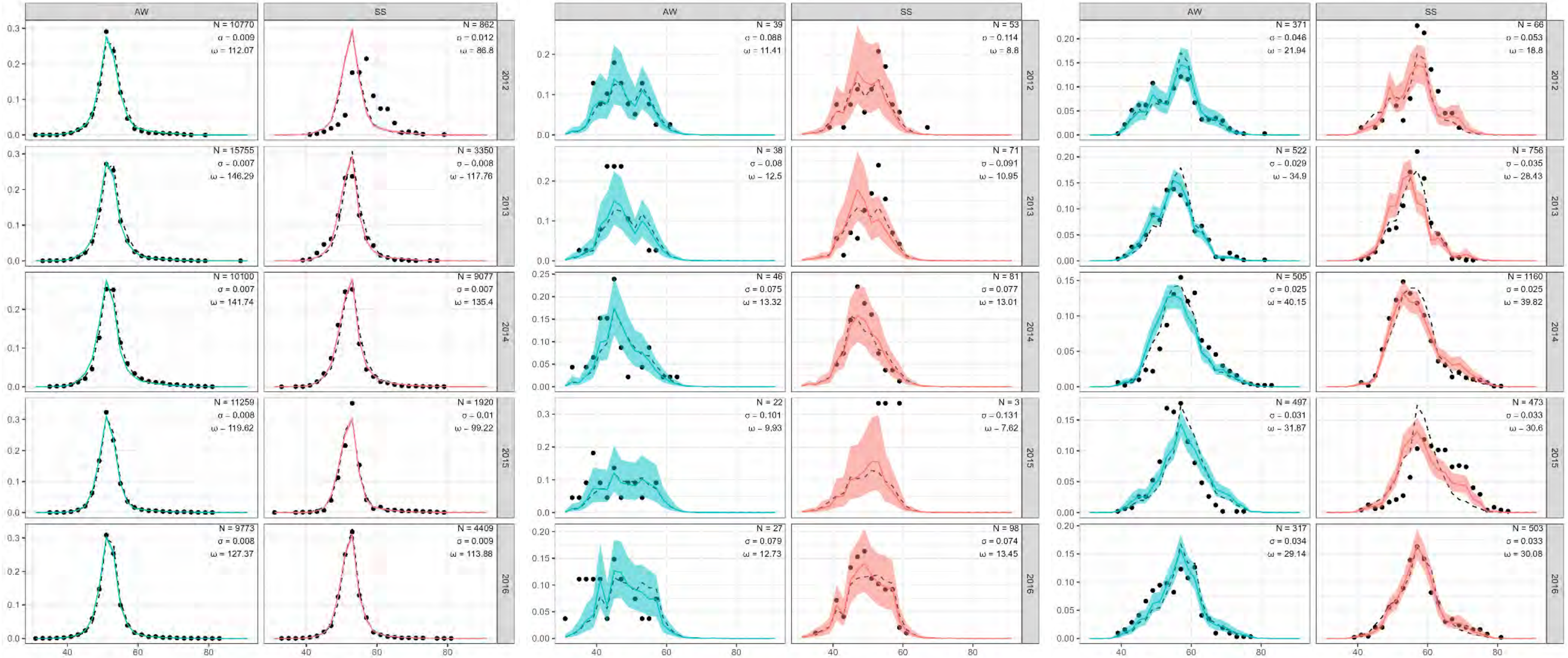


Figure C.10: CRA 3 <u>region 1</u> LFs by fishing year (from 2012 to 2016), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum(σ); and the data set weight for each stratum (ω).

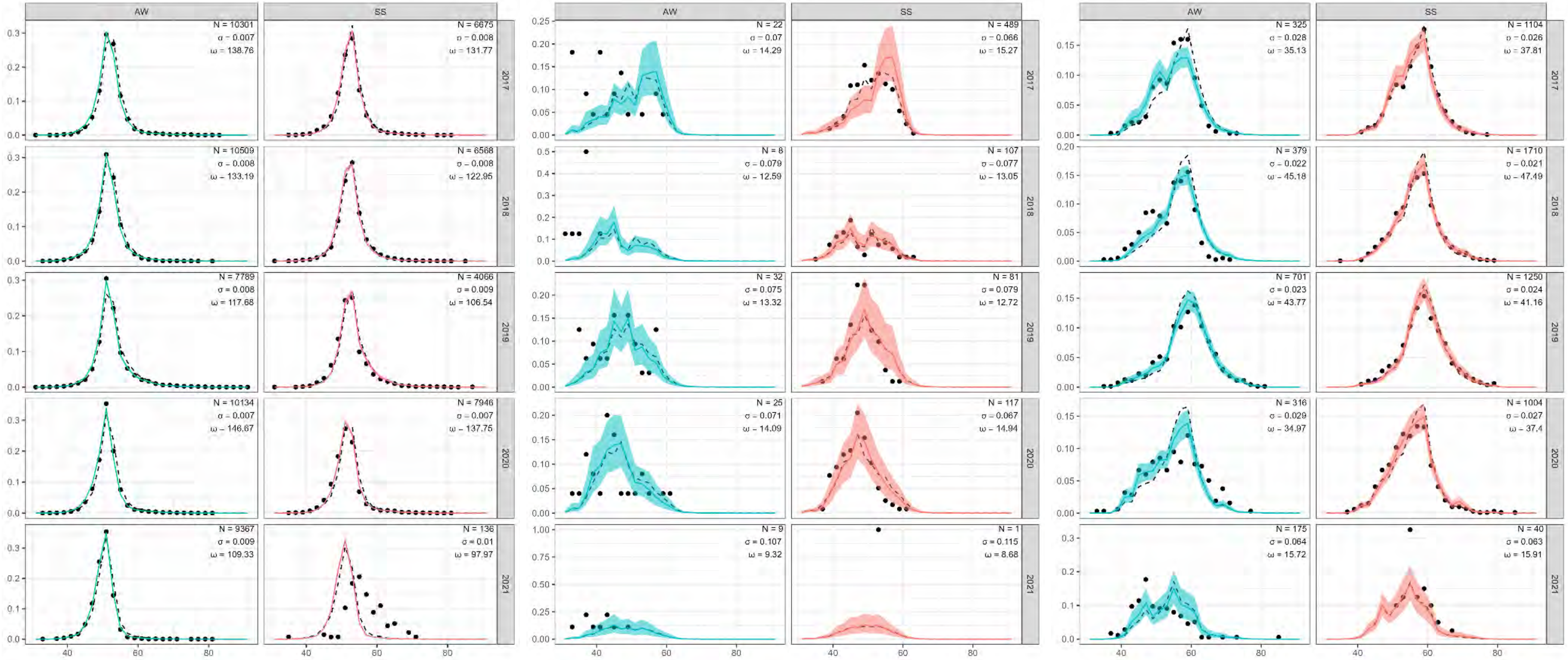


Figure C.11: CRA 3 <u>region 1</u> LFs by fishing year (from 2017 to 2021), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

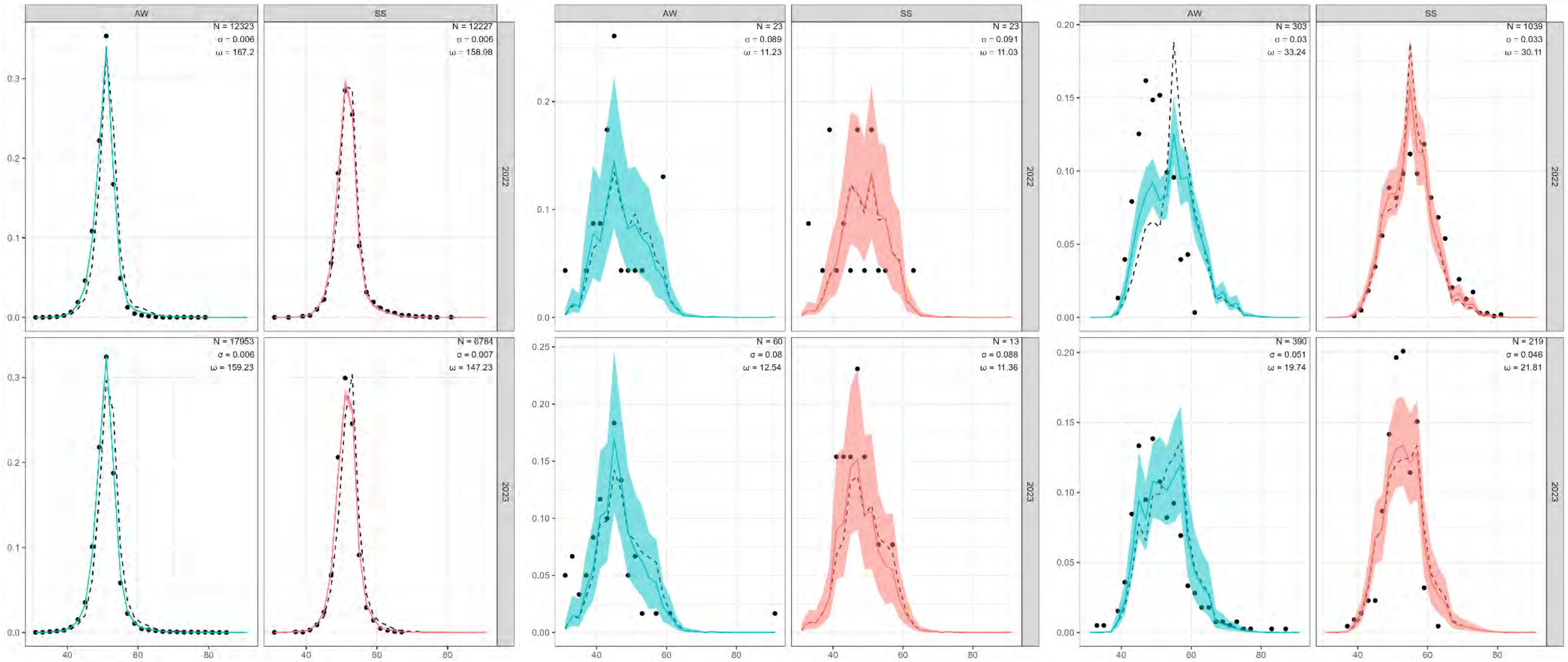


Figure C.12: CRA 3 <u>region 1</u> LFs by fishing year (from 2022 to 2023), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

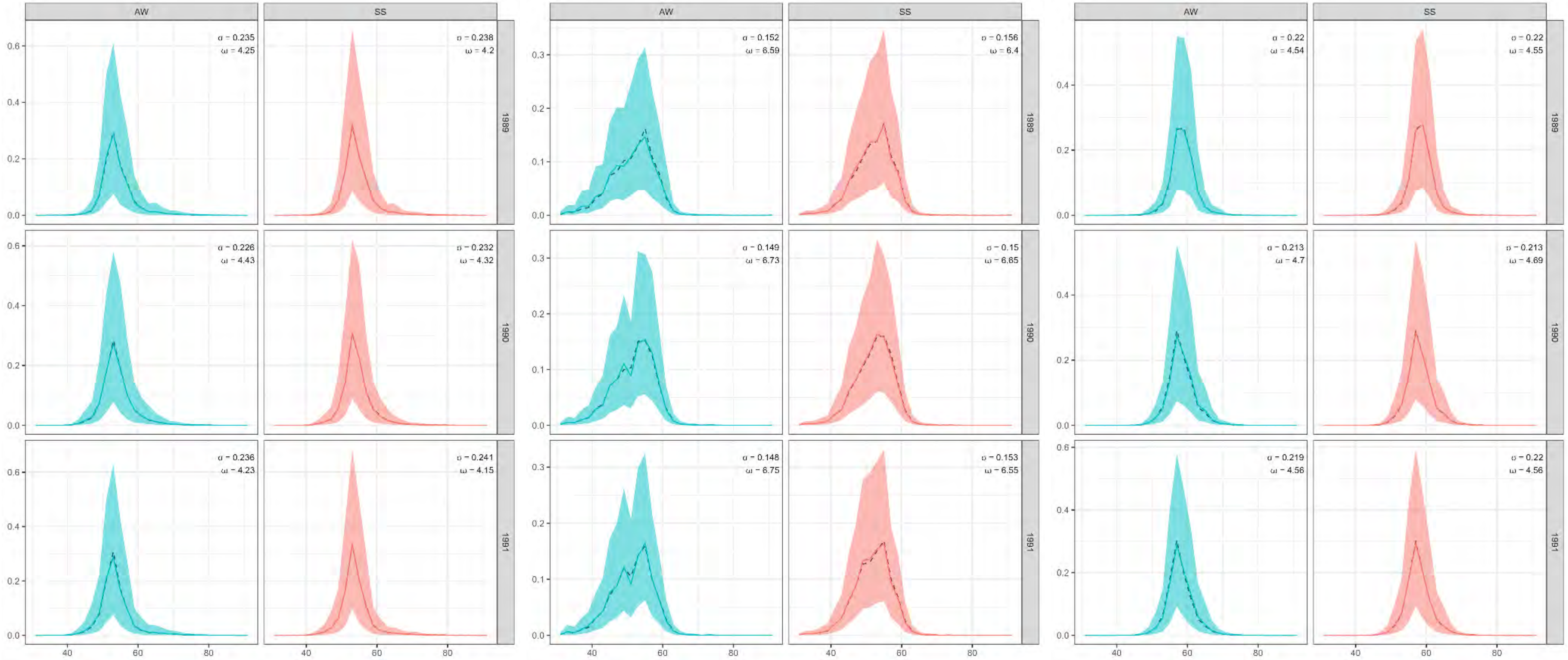


Figure C.13: CRA 3 <u>region 2</u> LFs by fishing year (from 1989 to 1991), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (Ϭ); and the data set weight for each stratum (ω).

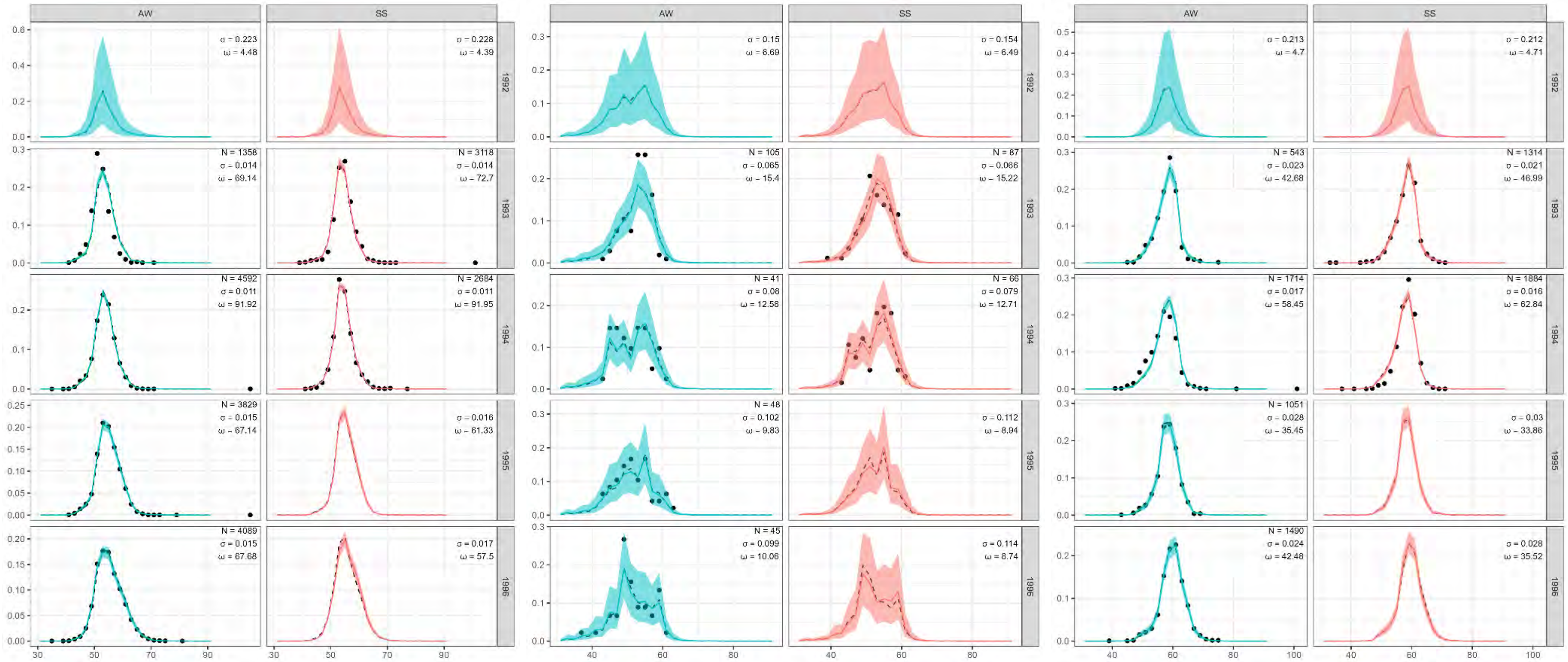


Figure C.14: CRA 3 region 2 LFs by fishing year (from 1992 to 1996), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (Ϭ); and the data set weight for each stratum (ω).

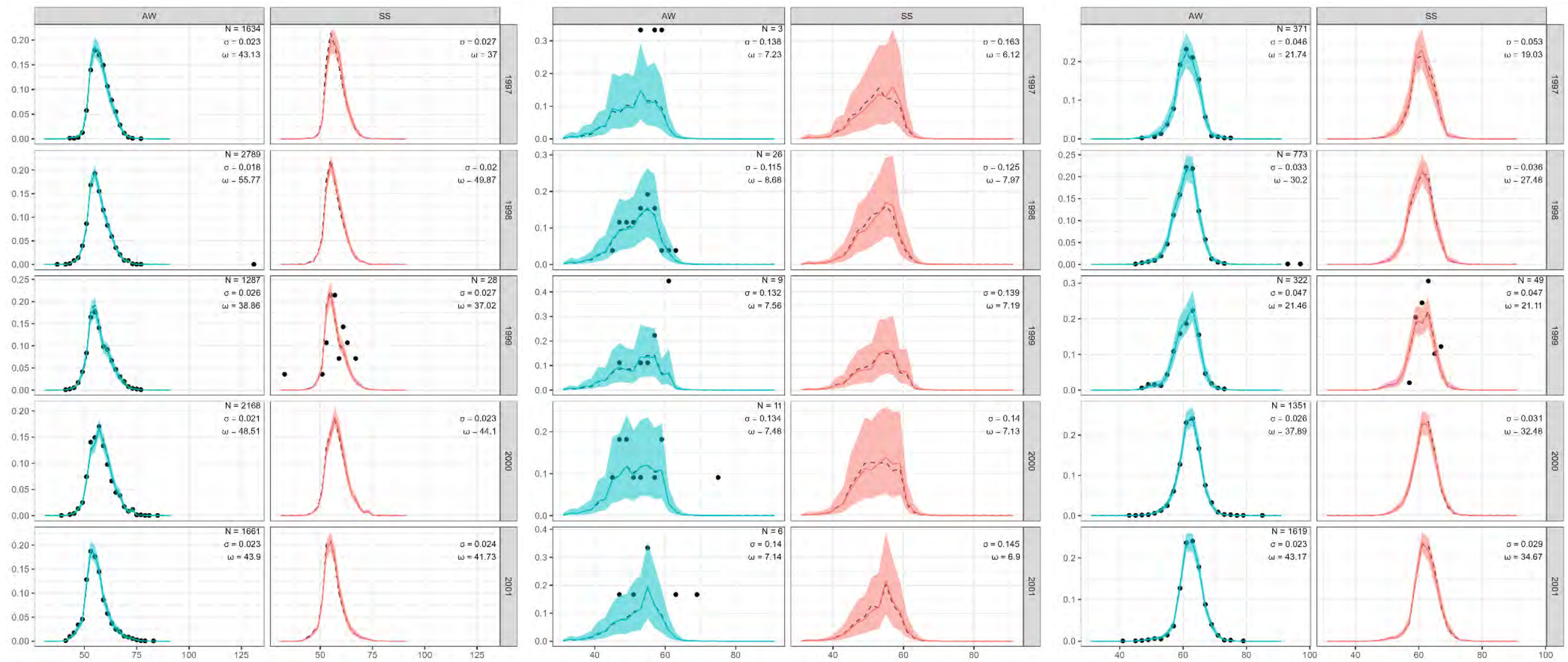


Figure C.15: CRA 3 <u>region 2</u> LFs by fishing year (from 1997 to 2001), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum(Ϭ); and the data set weight for each stratum (ω).

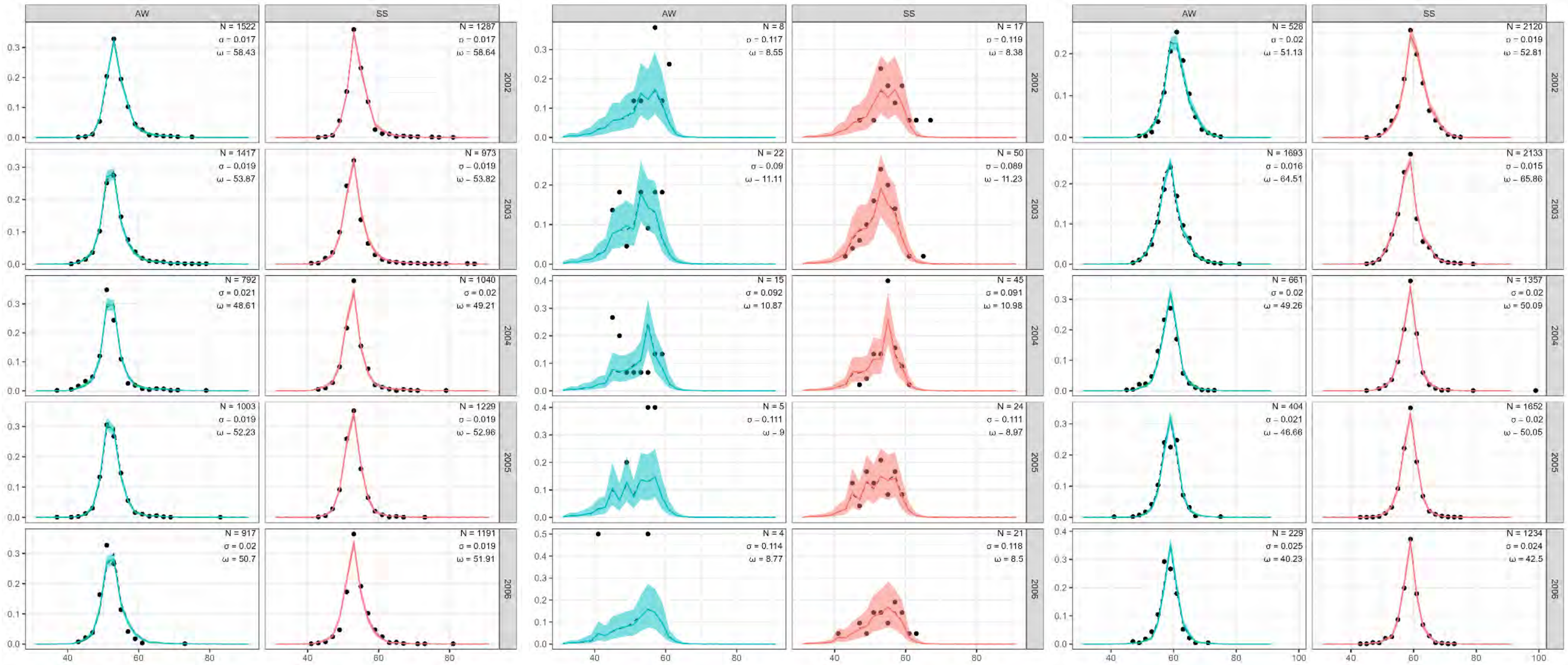


Figure C.16: CRA 3 <u>region 2</u> LFs by fishing year (from 2002 to 2006), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

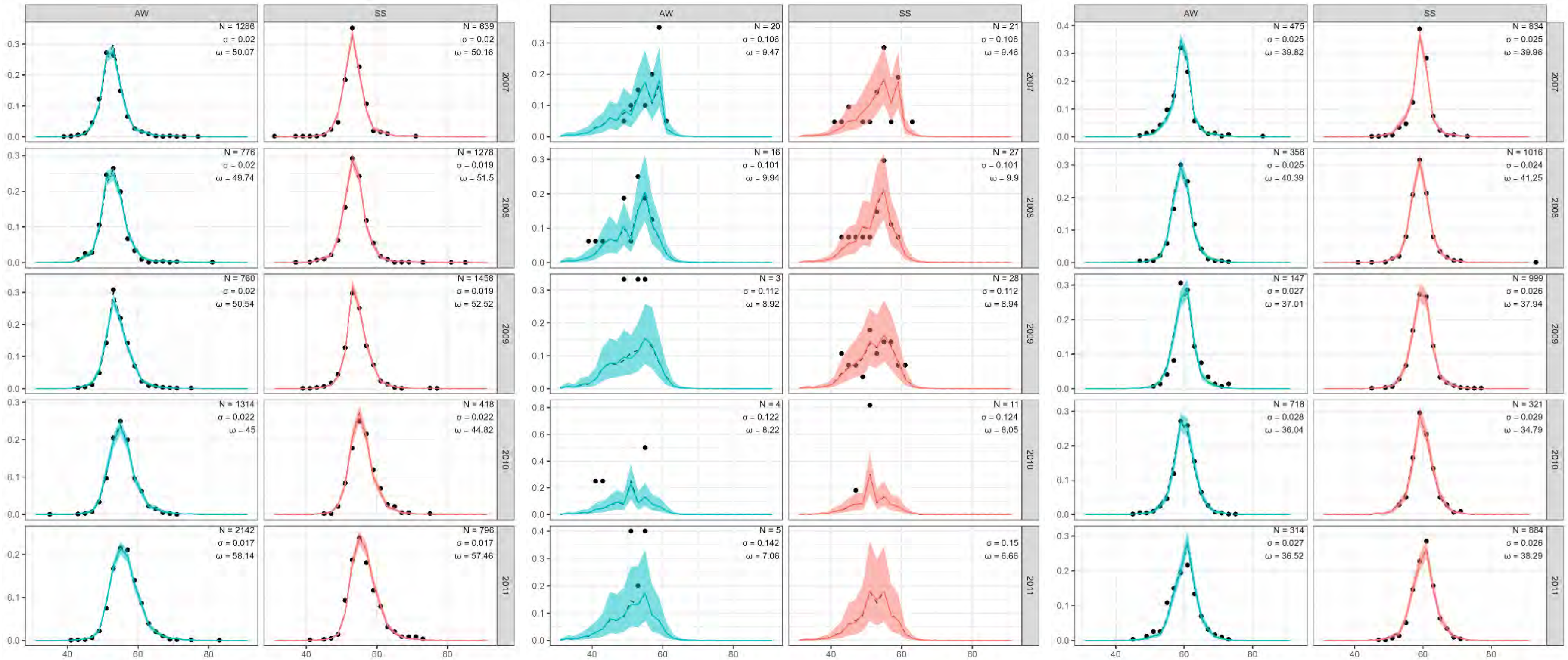


Figure C.17: CRA 3 <u>region 2</u> LFs by fishing year (from 2007 to 2011), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (Ϭ); and the data set weight for each stratum (ω) .

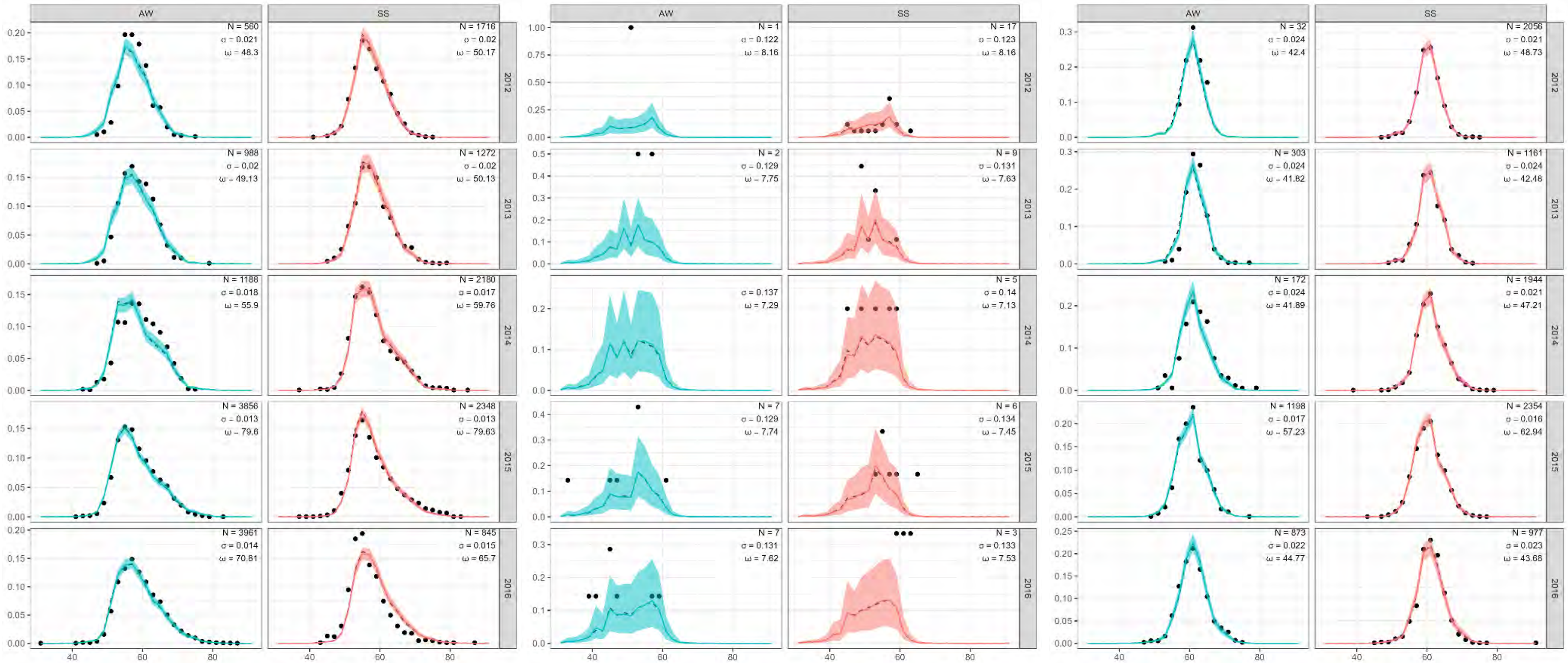


Figure C.18: CRA 3 <u>region 2</u> LFs by fishing year (from 2012 to 2016), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

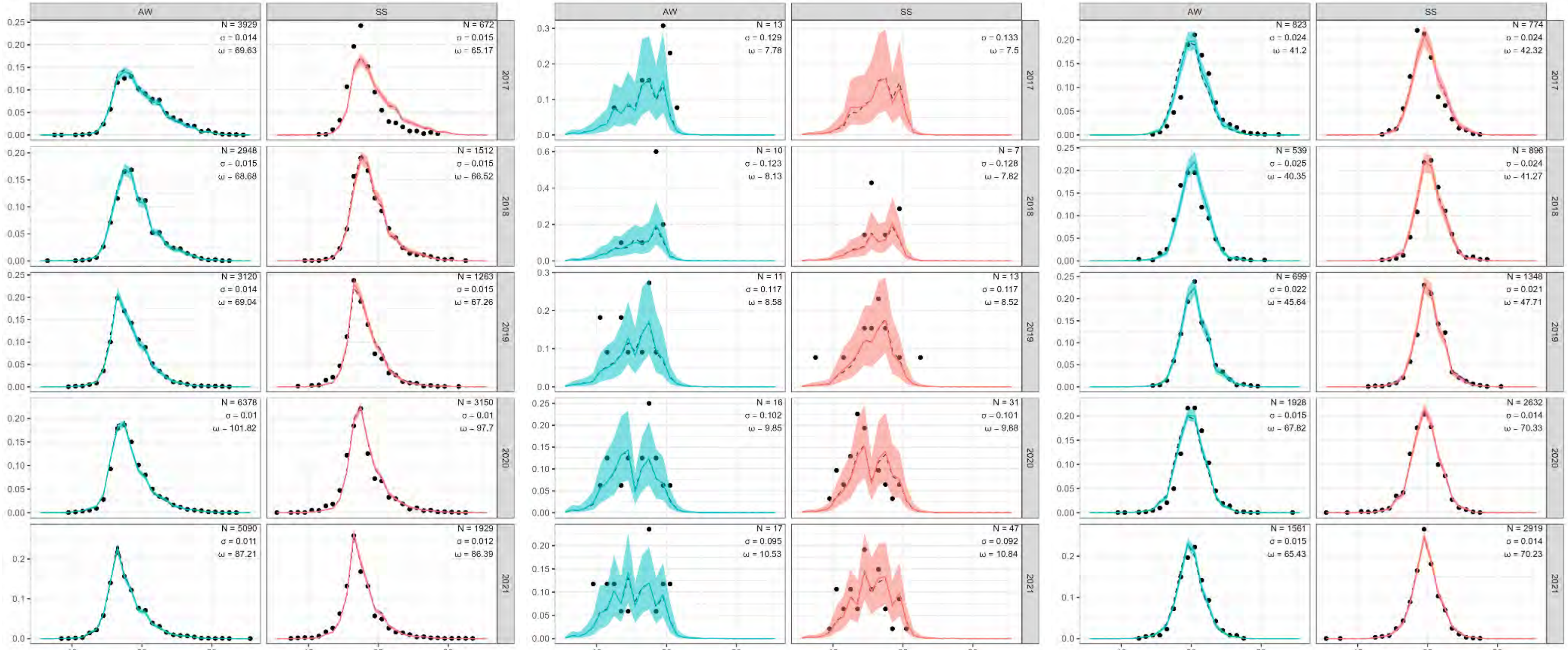


Figure C.19: CRA 3 <u>region 2</u> LFs by fishing year (from 2017 to 2021), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

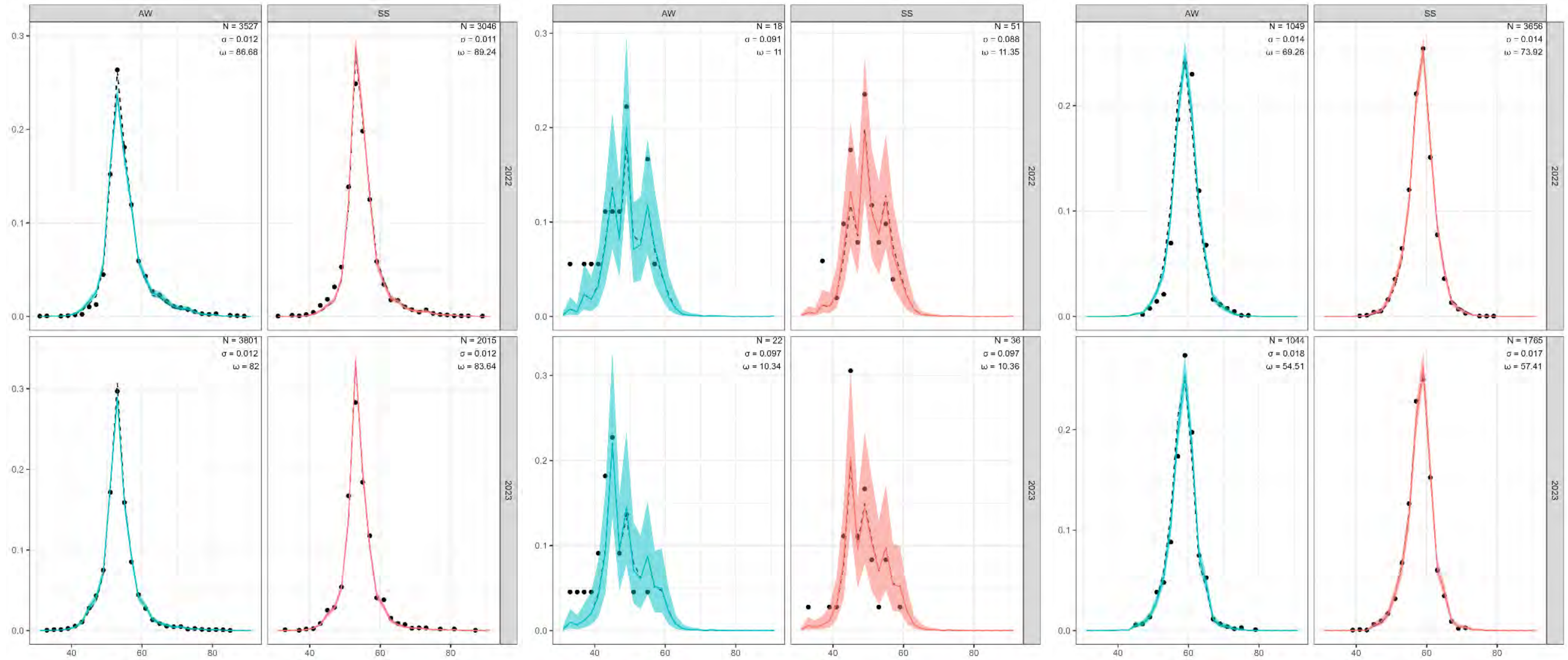


Figure C.20: CRA 3 <u>region 2</u> LFs by fishing year (from 2022 to 2023), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured (N); the SD of the predicted LF for each stratum (σ); and the data set weight for each stratum (ω).

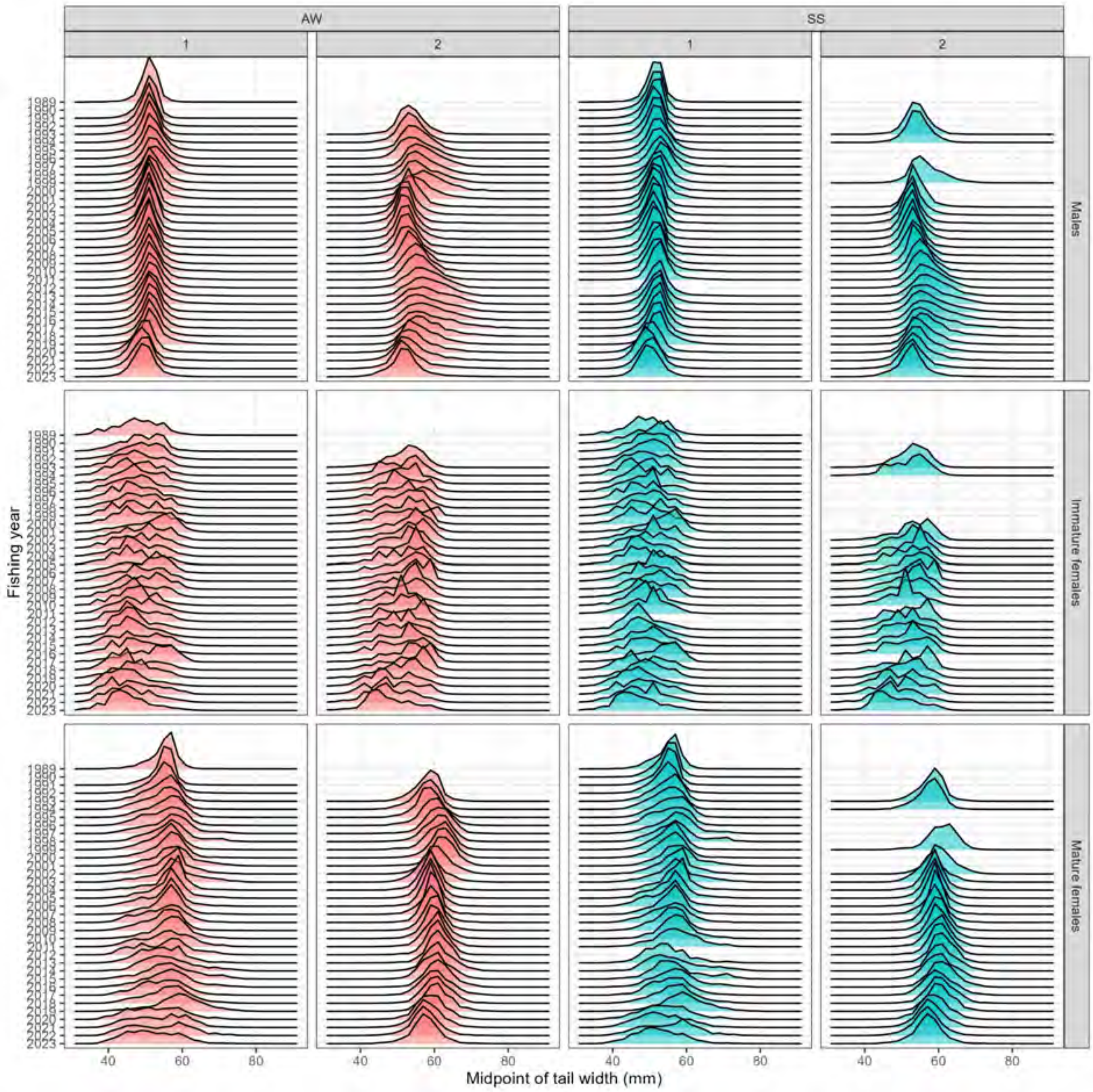


Figure C.21: Expected standardised LFs using the <u>uncorrected</u> TW data, by fishing year (from 1989 to 2023), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex. See Figure 5 for comparable standardised LFs derived from the corrected TW data.

Appendix D. TAG RECAPTURE DATA

Table D.1: Comparison of the number of records by Project ID in the new (2024) tag data extract with the number of records in the extract made for the 2023 CRA 6 assessment (Webber et al. 2024), i.e., the next most recent red rock lobster stock assessment.

Project ID	Previous	Current	Difference
CRA_Akaroa	227	227	–
CRA_CCampb	44	44	–
CRA_Gis70s	2 240	2 240	–
CRA_Gisb	48	48	–
CRA_ReefPt	573	573	–
CRA_StewIs	1 614	1 614	–
CRA01Gisb	1 179	1 179	–
CRA1_TAG	1 647	1 694	47
CRA2_EBOP	5	5	–
CRA2_TAG	4 776	4 840	64
CRA2_WBOP	268	268	–
CRA3_TAG	2 190	2 184	-6
CRA4_TAG	3 138	3 137	-1
CRA4_Wair	10	10	–
CRA5_Kaik	1 176	1 176	–
CRA5_TAG	6 107	6 107	–
CRA6_TAG	250	270	20
CRA7_TAG	703	722	19
CRA7rs	202	202	–
CRA8_Fiord	1 714	1 714	–
CRA8_TAG	7 419	7 393	-26
CRA8rs	233	233	–
CRA9_TAG	127	127	–
Total	35 890	36 007	117

Table D.2: Comparison of the number of records by recapture year in the new (2024) tag data extract with the number of records in the extract for the 2023 CRA 6 stock assessment (Webber et al. 2024).

Calendar year	Previous	Current	Difference
1966	53	53	–
1967	28	28	–
1968	7	7	–
1969	2	2	–
1971	1	1	–
1975	115	115	–
1976	1 268	1 268	–
1977	2 091	2 091	–
1978	886	886	–
1979	1 081	1 081	–
1980	1 112	1 112	–
1981	593	593	–
1982	332	332	–
1983	273	273	–
1984	1 071	1 071	–
1985	394	394	–
1986	76	76	–
1987	18	18	–
1988	4	4	–
1989	2	2	–
1991	1	1	–
1992	1	1	–
1994	39	39	–
1995	72	72	–
1996	423	423	–
1997	2 558	2 558	–
1998	2 944	2 944	–

Calendar year	Previous	Current	Difference
1999	2 486	2 486	–
2000	1 585	1 585	–
2001	1 377	1 377	–
2002	1 571	1 571	–
2003	1 121	1 121	–
2004	2 079	2 079	–
2005	2 386	2 386	–
2006	975	975	–
2007	482	481	-1
2008	366	366	–
2009	304	304	–
2010	237	237	–
2011	548	548	–
2012	425	425	–
2013	510	510	–
2014	778	778	–
2015	875	875	–
2016	525	525	–
2017	565	565	–
2018	363	363	–
2019	203	203	–
2020	271	275	4
2021	254	225	-29
2022	140	240	100
2023	19	60	41
2024	–	2	2
Total	35 890	36 007	117

Table D.3: Number of tags released, including tags that were never recaptured, compared with the number and proportion recaptured, by QMA.

QMA	Number released	Number recaptured	Number not recaptured	Percent recaptured
CRA 1	19 742	2 257	17 485	11.4%
CRA 2	29 103	4 973	24 130	17.1%
CRA 3	43 858	5 801	38 057	13.2%
CRA 4	42 610	3 147	39 463	7.4%
CRA 5	44 640	7 554	37 086	16.9%
CRA 6	10 803	270	10 533	2.5%
CRA 7	12 996	910	12 086	7.0%
CRA 8	36 191	10 966	25 225	30.3%
CRA 9	6 575	129	6 446	2.0%

Table D.4: Number of complete tagging release/recovery records by sex and QMA. Note that the row totals are not always consistent with other tables because some records could not be assigned to a sex category.

QMA	Male	Female	Total
CRA 1	973	1 284	2 257
CRA 2	2 494	2 479	4 973
CRA 3	4 440	1 361	5 801
CRA 4	2 427	720	3 147
CRA 5	5 233	2 321	7 554
CRA 6	63	207	270
CRA 7	443	467	910
CRA 8	6 041	4 925	10 966
CRA 9	34	95	129
Total	22 148	13 859	36 007

Table D.5: Number of tags released by QMA (rows) and recaptured by QMA (columns). Note that the row totals are not always the same as in previous tables because some records could not be assigned to a QMA.

Releas	Recovery QMA									
e QMA	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9	Total
CRA 1	2 227	–	30	–	–	–	–	–	–	2 257
CRA 2	1	4 962	10	–	–	–	–	–	–	4 973
CRA 3	–	14	5 726	8	1	–	–	52	–	5 801
CRA 4	–	–	–	3 140	7	–	–	–	–	3 147
CRA 5	–	–	–	2	7 546	–	6	–	–	7 554
CRA 6	–	–	–	–	–	270	–	–	–	270
CRA 7	–	–	6	–	–	–	858	46	–	910
CRA 8	–	1	121	–	–	–	1	10 840	3	10 966
CRA 9	–	–	–	–	–	–	–	–	129	129
Total	2 228	4 977	5 893	3 150	7 554	270	865	10 938	132	35 890

Table D.6: Number of tag recaptures by calendar year of release and sex for each statistical area in CRA 3. Tags were classified to statistical area based on the reported location and then the reported statistical area of release. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

	Statistical Area			Sex		
Release year	909	910	911	Female	Male	Total
1975	–	386	27	60	353	413
1976	–	591	390	261	720	981
1977	–	479	172	154	497	651
1978	–	–	242	81	161	242
1979	–	845	–	428	417	845
1980	–	350	2	145	207	352
1984	4	–	–	–	4	4
1995	–	93	–	6	87	93
1996	–	152	–	22	130	152
1997	21	37	–	5	53	58
1998	2	–	–	1	1	2
1999	–	1	–	–	1	1
2000	–	–	–	–	–	–
2001	79	122	53	36	218	254
2002	9	1	7	1	16	17
2003	–	1	1	1	1	2
2004	126	146	155	54	373	427
2005	18	9	39	5	74	79
2006	–	–	2	–	2	2
2007	1	–	1	1	1	2
2008	66	9	34	19	90	109
2009	63	–	54	7	110	117
2010	38	13	18	7	62	69
2011	71	6	4	–	81	81
2012	98	16	–	7	107	114
2013	70	48	–	25	93	118
2014	149	14	25	16	172	188
2015	34	8	1	3	40	43
2016	75	26	9	8	102	110
2017	24	23	39	9	77	86
2018	51	36	16	1	102	103
2019	6	–	–	–	6	6
2020	2	11	1	–	14	14
2021	11	36	12	2	57	59
2022	2	5	–	–	7	7
2023	–	–	–	–	–	–
Total	1 020	3 464	1 304	1 365	4 436	5 801

Table D.7: Number of tag releases by sex, release month, and release statistical area for CRA 3.

Release month	Statistical Area				Sex		
	Unknown	909	910	911	Females	Males	Total
Jan	1	82	45	61	26	163	189
Feb	2	25	178	85	57	233	290
Mar	2	35	409	5	51	400	451
Apr	–	29	153	19	36	165	201
May	–	–	361	4	207	158	365
Jun	–	138	137	56	63	268	331
Jul	–	418	1098	501	396	1 621	2 017
Aug	2	253	84	59	32	366	398
Sep	–	1	119	63	55	128	183
Oct	1	–	335	397	320	413	733
Nov	3	8	422	50	67	416	483
Dec	2	31	123	4	55	105	160
Total	13	1 020	3 464	1 304	1 365	4 436	5 801

Table D.8: Number of tag recaptures by release (rows) and recovery (columns) statistical areas for CRA 3 releases, summed across all years. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

	Unknown	908	909	911	912	916	924	Total
Unknown	11	–	2	–	–	–	–	13
909	4	–	1 014	1	–	1	–	1 020
910	45	1	–	3 365	–	1	1	3 464
911	4	–	1	6	1 286	6	–	1 304
Total	64	1	1 015	3 374	1 286	8	1	5 801

Table D.9: Days-at-liberty statistics for recaptures of CRA 3 releases. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

Statistical area of release	Sex	N	Minimum	5%	Median	95%	Maximum
Unknown	Males	13	9	11.4	143	408.4	499
	Females	–	–	–	–	–	–
909	Males	995	1	8	319	721.3	2 201
	Females	25	5	15	318	1 050.4	2 654
910	Males	2 677	1	3	145	564	2 053
	Females	787	1	4	193	619.3	2 128
911	Males	751	1	14.5	179	632	1 991
	Females	553	1	15	202	858	1 831
CRA 3	Males	4 436	1	5	181	606	2 201
	Females	1 365	1	10.2	193	813.6	2 654

Table D.10: Number of tag re-releases in CRA 3, by sex and statistical area of release. Re-release event code = 0 means the first release-recapture event.

Re-release event	909		910		911		Unknown		CRA 3	
	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop
Males										
0	719	0.723	2 302	0.860	660	0.879	0	0.000	3 681	0.830
1	189	0.913	220	0.942	55	0.952	10	0.769	474	0.937
2	53	0.966	138	0.994	33	0.996	3	1.000	227	0.988
3	19	0.985	14	0.999	3	1.000	0	1.000	36	0.996
4	9	0.994	2	1.000	0	1.000	0	1.000	11	0.998
5	3	0.997	1	1.000	0	1.000	0	1.000	4	0.999
6	2	0.999	0	1.000	0	1.000	0	1.000	2	1.000
7	1	1.000	0	1.000	0	1.000	0	1.000	1	1.000
Females										
0	22	0.880	707	0.898	506	0.915	0	–	1 235	0.905
1	3	1.000	71	0.989	21	0.953	0	–	95	0.974
2	0	1.000	8	0.999	26	1.000	0	–	34	0.999
3	0	1.000	1	1.000	0	1.000	0	–	1	1.000
3	22	0.880	707	0.898	506	0.915	0	–	1 235	0.905

Table D.11: Statistics for tail width growth increments (mm) for recaptures of CRA 3. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

Statistical Area of release	Sex	N	Minimum	5%	Median	95%	Maximum
Unknown	Males	13	-4	-1.6	0	4.4	5
	Females	–	–	–	–	–	–
909	Males	995	-2.6	0	1.7	6.73	20.4
	Females	25	-10.7	-1.66	0.3	4.62	7.7
910	Males	2 677	-18.21	-1.16	1	7.1	19.68
	Females	787	-24.57	-7.95	0.35	9.49	28.86
911	Males	751	-20	-0.1	2.68	9	20.97
	Females	553	-11.9	-0.59	0.3	5.92	15.47
CRA 3	Males	2 677	-18.21	-1.16	1	7.1	19.68
	Females	787	-24.57	-7.95	0.35	9.49	28.86

Table D.12: The number and proportion of recaptured tag releases by period at liberty category and by QMA.

QMA of release	Number of tags spending period at liberty			Proportion of tags spending period at liberty	
	< 6 months	6-12 months	12+ months	> 6 months	> 12 months
CRA 1	631	761	867	0.721	0.384
CRA 2	1 782	1 506	1 745	0.646	0.347
CRA 3	2 779	1 855	1 167	0.521	0.201
CRA 4	1 447	1 105	607	0.542	0.192
CRA 5	2 903	2 647	2 063	0.619	0.271
CRA 6	113	44	112	0.580	0.416
CRA 7	385	240	288	0.578	0.315
CRA 8	3 794	3 428	3 806	0.656	0.345
CRA 9	30	58	41	0.767	0.318

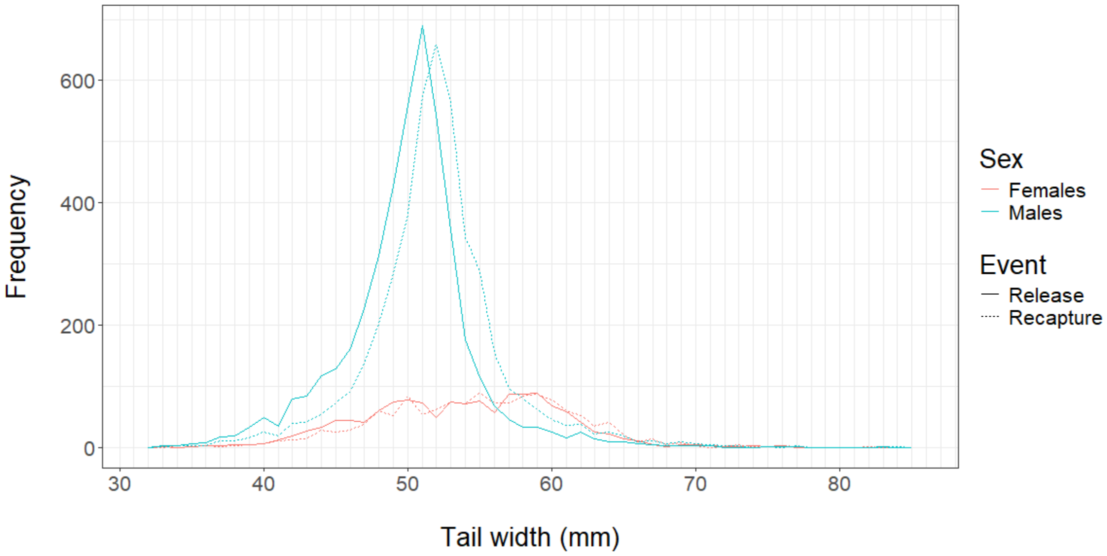


Figure D.1: CRA 3 size at release (solid lines) and recapture (dashed lines) distributions by sex. A bin width of 1 mm was used.

Appendix E. PROPORTION IN BERRY ANALYSIS

Table E.1: Sample size of mature females by month and QMA/stock assessment region from CS data.

QMA/stock assessment region	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
CRA 1	2 314	875	381	9 868	7 359	8 438	17 730	7 754	460	77	65	614	55 935
CRA 2	175	0	75	2 593	4 838	4 389	10 114	4 543	1 896	1 047	1 032	204	30 906
CRA 3_R1	**236**	**138**	**5 372**	**6 390**	**5 012**	**1 474**	**4 233**	**23 575**	**5 357**	**5 611**	**4 783**	**1 051**	63 232
CRA 3_R2	**79**	**509**	**5 523**	**5 260**	**3 259**	**4 104**	**5 735**	**6 745**	**3 731**	**5 971**	**7 884**	**668**	49 468
CRA 4	482	14 835	27 504	16 698	12 001	28 015	47 602	37 852	29 349	18 640	9 417	1 395	243 790
CRA 5 R1	–	1 451	1 881	667	102	133	6 920	6 128	5 291	2 367	–	–	24 940
CRA 5 R2	–	3 612	2 258	–	1 029	1 583	2 437	–	–	–	–	–	10 919
CRA 6	–	–	867	1 918	1 384	1 426	4 829	250	942	1 795	1 003	–	14 414
CRA 7&8 Fiordland	–	550	2 227	1 050	14 770	17 857	15 411	14 895	–	5 797	816	–	73 373
CRA 7&8 Southland	–	–	14	641	889	1 976	2 402	4 225	1 254	132	156	–	11 689
CRA 9	–	–	–	–	–	71	–	–	–	–	–	–	71

Table E.2: Sample size of mature females by month and QMA/stock assessment region from LB data.

QMA/stock assessment region	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
CRA 1	709	311	202	680	1 462	3 037	3 724	1 928	539	468	182	294	13 536
CRA 2	1 470	999	2 900	16 948	17 316	19 960	26 081	12 476	6 808	6 950	3 082	1 402	116 392
CRA 3_R1	**278**	**26**	**1 069**	**1 547**	**1 045**	**92**	**169**	**550**	**426**	**1 341**	**1 855**	**603**	9 001
CRA 3_R2	**491**	**549**	**905**	**1 199**	**954**	**1 652**	**2 790**	**607**	**423**	**1 385**	**1 933**	**629**	13 517
CRA 4	82	1 380	3 414	3 720	2 799	4 621	5 782	4 718	3 982	5 759	1 859	236	38 352
CRA 5 R1	18 062	36 873	21 335	11 453	10 113	16 023	18 050	17 713	13 990	13 314	595	338	177 859
CRA 5 R2	6 880	19 707	20 328	13 030	10 464	16 095	14 697	8 882	5 613	13 205	1 105	108	130 114
CRA 6	–	129	342	561	571	1 310	3 688	3 245	2 126	1 975	1 051	45	15 043
CRA 7&8 Fiordland	11 820	41 232	34 291	28 976	39 060	68 850	26 595	16 934	6 337	31 081	15 219	9 380	329 775
CRA 7&8 Southland	261	1 797	1 196	962	1 936	3 099	2 146	521	128	141	139	32	12 358
CRA 9	528	332	1 734	4 369	4 702	5 672	4 264	1 328	139	171	435	537	24 211

Table E.3: Summary of parameter estimates of final model for predicting the proportion of mature females in berry (*fit10*). This tables excludes parameters relating to interaction terms.

Parameter label	Mean	SD	2.50%	Median	97.50%
b_Intercept	-1.285	1.020	-3.258	-1.285	0.766
sd_area__Intercept	1.042	0.166	0.758	1.042	1.382
sd_fmonth__Intercept	3.669	0.829	2.478	3.669	5.559
sd_fmonth:area__Intercept	1.542	0.071	1.415	1.542	1.684
sd_fyear__Intercept	0.316	0.064	0.205	0.316	0.451
sd_fyear:area__Intercept	1.061	0.031	1.001	1.061	1.122
Intercept	-1.285	1.020	-3.258	-1.285	0.766
r_area[901,Intercept]	-1.030	0.515	-1.999	-1.030	-0.043
r_area[902,Intercept]	-0.522	0.570	-1.641	-0.522	0.536
r_area[903,Intercept]	0.951	0.548	-0.125	0.951	2.113

Parameter label	Mean	SD	2.50%	Median	97.50%
r_area[904,Intercept]	-0.481	0.553	-1.534	-0.481	0.584
r_area[905,Intercept]	-0.414	0.497	-1.429	-0.414	0.591
r_area[906,Intercept]	-0.637	0.488	-1.595	-0.637	0.316
r_area[907,Intercept]	-0.874	0.482	-1.816	-0.874	0.016
r_area[908,Intercept]	-0.905	0.505	-1.869	-0.905	0.038
r_area[909,Intercept]	-1.392	0.500	-2.386	-1.392	-0.427
r_area[910,Intercept]	-1.300	0.478	-2.285	-1.300	-0.434
r_area[911,Intercept]	-1.847	0.520	-2.859	-1.847	-0.788
r_area[912,Intercept]	-1.294	0.519	-2.317	-1.294	-0.253
r_area[913,Intercept]	-0.493	0.461	-1.358	-0.493	0.408
r_area[914,Intercept]	-0.484	0.492	-1.437	-0.484	0.469
r_area[915,Intercept]	-0.281	0.497	-1.233	-0.281	0.719
r_area[916,Intercept]	0.619	0.492	-0.406	0.619	1.516
r_area[917,Intercept]	1.441	0.471	0.524	1.441	2.349
r_area[920,Intercept]	-0.436	0.529	-1.468	-0.436	0.611
r_area[921,Intercept]	0.436	0.546	-0.610	0.436	1.527
r_area[923,Intercept]	0.843	0.638	-0.425	0.843	2.115
r_area[924,Intercept]	1.425	0.483	0.474	1.425	2.365
r_area[925,Intercept]	1.537	0.712	0.175	1.537	2.976
r_area[926,Intercept]	0.627	0.449	-0.228	0.627	1.470
r_area[927,Intercept]	-0.065	0.448	-0.908	-0.065	0.799
r_area[928,Intercept]	0.170	0.452	-0.765	0.170	1.057
r_area[929,Intercept]	0.632	0.941	-1.228	0.632	2.634
r_area[930,Intercept]	-0.374	0.678	-1.711	-0.374	0.948
r_area[933,Intercept]	0.106	0.485	-0.849	0.106	1.069
r_area[934,Intercept]	0.295	0.654	-1.037	0.295	1.557
r_area[939,Intercept]	-1.273	0.514	-2.257	-1.273	-0.216
r_area[940,Intercept]	0.088	0.515	-0.883	0.088	1.129
r_area[941,Intercept]	0.521	0.487	-0.408	0.521	1.482
r_area[942,Intercept]	-0.344	0.524	-1.372	-0.344	0.631
r_area[943,Intercept]	-0.726	0.569	-1.836	-0.726	0.361
r_area[918,Intercept]	0.994	0.512	0.026	0.994	2.018
r_area[922,Intercept]	0.476	0.725	-0.916	0.476	1.907
r_area[931,Intercept]	1.101	0.520	0.087	1.101	2.070
r_area[932,Intercept]	0.383	1.006	-1.517	0.383	2.499
r_area[935,Intercept]	0.858	0.541	-0.153	0.858	1.995
r_area[936,Intercept]	0.839	0.546	-0.229	0.839	1.921
r_area[937,Intercept]	0.021	0.883	-1.678	0.021	1.807
r_fmonth[10,Intercept]	-0.209	1.027	-2.135	-0.209	1.726
r_fmonth[11,Intercept]	-2.028	1.042	-4.062	-2.028	0.034
r_fmonth[12,Intercept]	-3.317	1.053	-5.436	-3.317	-1.342
r_fmonth[13,Intercept]	-4.060	1.045	-6.122	-4.060	-2.108
r_fmonth[14,Intercept]	-4.240	1.053	-6.261	-4.240	-2.212
r_fmonth[15,Intercept]	-4.346	1.079	-6.395	-4.346	-2.304
r_fmonth[4,Intercept]	-1.833	1.080	-3.905	-1.833	0.170
r_fmonth[5,Intercept]	1.698	1.056	-0.360	1.698	3.775

Parameter label	Mean	SD	2.50%	Median	97.50%
r_fmonth[6,Intercept]	4.682	1.039	2.682	4.682	6.598
r_fmonth[7,Intercept]	5.009	1.048	2.989	5.009	7.089
r_fmonth[8,Intercept]	3.747	1.046	1.695	3.747	5.752
r_fmonth[9,Intercept]	1.705	1.029	-0.317	1.705	3.656
r_fyear[1989,Intercept]	-0.449	0.234	-0.954	-0.436	-0.032
r_fyear[1990,Intercept]	-0.088	0.235	-0.534	-0.086	0.368
r_fyear[1991,Intercept]	0.337	0.228	-0.068	0.325	0.804
r_fyear[1992,Intercept]	0.558	0.266	0.049	0.558	1.100
r_fyear[1993,Intercept]	-0.105	0.198	-0.487	-0.115	0.287
r_fyear[1994,Intercept]	0.197	0.194	-0.177	0.202	0.556
r_fyear[1995,Intercept]	0.236	0.198	-0.144	0.228	0.632
r_fyear[1996,Intercept]	0.119	0.182	-0.214	0.117	0.483
r_fyear[1997,Intercept]	0.067	0.181	-0.284	0.064	0.408
r_fyear[1998,Intercept]	-0.284	0.192	-0.666	-0.286	0.065
r_fyear[1999,Intercept]	-0.354	0.190	-0.726	-0.350	0.001
r_fyear[2000,Intercept]	-0.008	0.174	-0.368	-0.008	0.330
r_fyear[2001,Intercept]	-0.350	0.181	-0.712	-0.349	-0.005
r_fyear[2002,Intercept]	0.277	0.177	-0.064	0.276	0.639
r_fyear[2003,Intercept]	-0.176	0.179	-0.533	-0.178	0.173
r_fyear[2004,Intercept]	0.446	0.183	0.106	0.441	0.813
r_fyear[2005,Intercept]	-0.107	0.181	-0.467	-0.113	0.244
r_fyear[2006,Intercept]	-0.077	0.176	-0.429	-0.082	0.259
r_fyear[2007,Intercept]	0.287	0.173	-0.047	0.284	0.625
r_fyear[2008,Intercept]	0.219	0.173	-0.105	0.211	0.594
r_fyear[2009,Intercept]	0.339	0.176	-0.002	0.340	0.699
r_fyear[2010,Intercept]	-0.063	0.178	-0.422	-0.059	0.266
r_fyear[2011,Intercept]	-0.033	0.173	-0.370	-0.039	0.316
r_fyear[2012,Intercept]	-0.067	0.184	-0.418	-0.068	0.292
r_fyear[2013,Intercept]	-0.080	0.184	-0.439	-0.081	0.262
r_fyear[2014,Intercept]	-0.048	0.169	-0.384	-0.040	0.270
r_fyear[2015,Intercept]	0.414	0.173	0.086	0.413	0.749
r_fyear[2016,Intercept]	-0.231	0.175	-0.570	-0.231	0.111
r_fyear[2017,Intercept]	-0.208	0.179	-0.562	-0.212	0.146
r_fyear[2018,Intercept]	-0.068	0.172	-0.413	-0.071	0.244
r_fyear[2019,Intercept]	0.046	0.174	-0.287	0.042	0.389
r_fyear[2020,Intercept]	-0.213	0.176	-0.571	-0.206	0.116
r_fyear[2021,Intercept]	-0.221	0.178	-0.565	-0.218	0.125
r_fyear[2022,Intercept]	-0.307	0.172	-0.656	-0.304	0.029
r_fyear[2023,Intercept]	-0.002	0.172	-0.340	-0.007	0.327

Table E.4: Summary of posteriors of predicted proportion of mature females in berry by stock assessment QMA/Region and season (*fit10*).

Season	QMA/Region	Mean	SD	2.5%	Median	97.5%
AW	CRA 1	0.631	0.107	0.460	0.628	0.828
	CRA 2	0.717	0.093	0.448	0.728	0.860
	CRA 3_R1	0.818	0.124	0.510	0.866	0.954
	CRA 3_R2	0.712	0.146	0.347	0.736	0.933
	CRA 4	0.797	0.071	0.633	0.802	0.917
	CRA 5_R1	0.924	0.037	0.849	0.937	0.977
	CRA 5_R2	0.856	0.068	0.688	0.868	0.968
	CRA 6	0.828	0.074	0.654	0.826	0.951
	CRA 7&8 Fiordland	0.692	0.122	0.396	0.711	0.878
	CRA 7&8 Southland	0.749	0.117	0.474	0.761	0.965
	CRA 9	0.847	0.077	0.648	0.854	0.954
SS	CRA 1	0.080	0.046	0.022	0.069	0.205
	CRA 2	0.052	0.030	0.017	0.044	0.129
	CRA 3_R1	0.005	0.005	0.000	0.002	0.018
	CRA 3_R2	0.003	0.005	0.000	0.001	0.014
	CRA 4	0.022	0.019	0.003	0.016	0.076
	CRA 5_R1	0.146	0.067	0.045	0.138	0.303
	CRA 5_R2	0.056	0.038	0.011	0.043	0.181
	CRA 6	0.052	0.026	0.014	0.049	0.115
	CRA 7&8_Fiordland	0.103	0.068	0.018	0.086	0.277
	CRA 7&8_Southland	0.345	0.154	0.119	0.318	0.676
	CRA 9	0.190	0.114	0.034	0.174	0.429

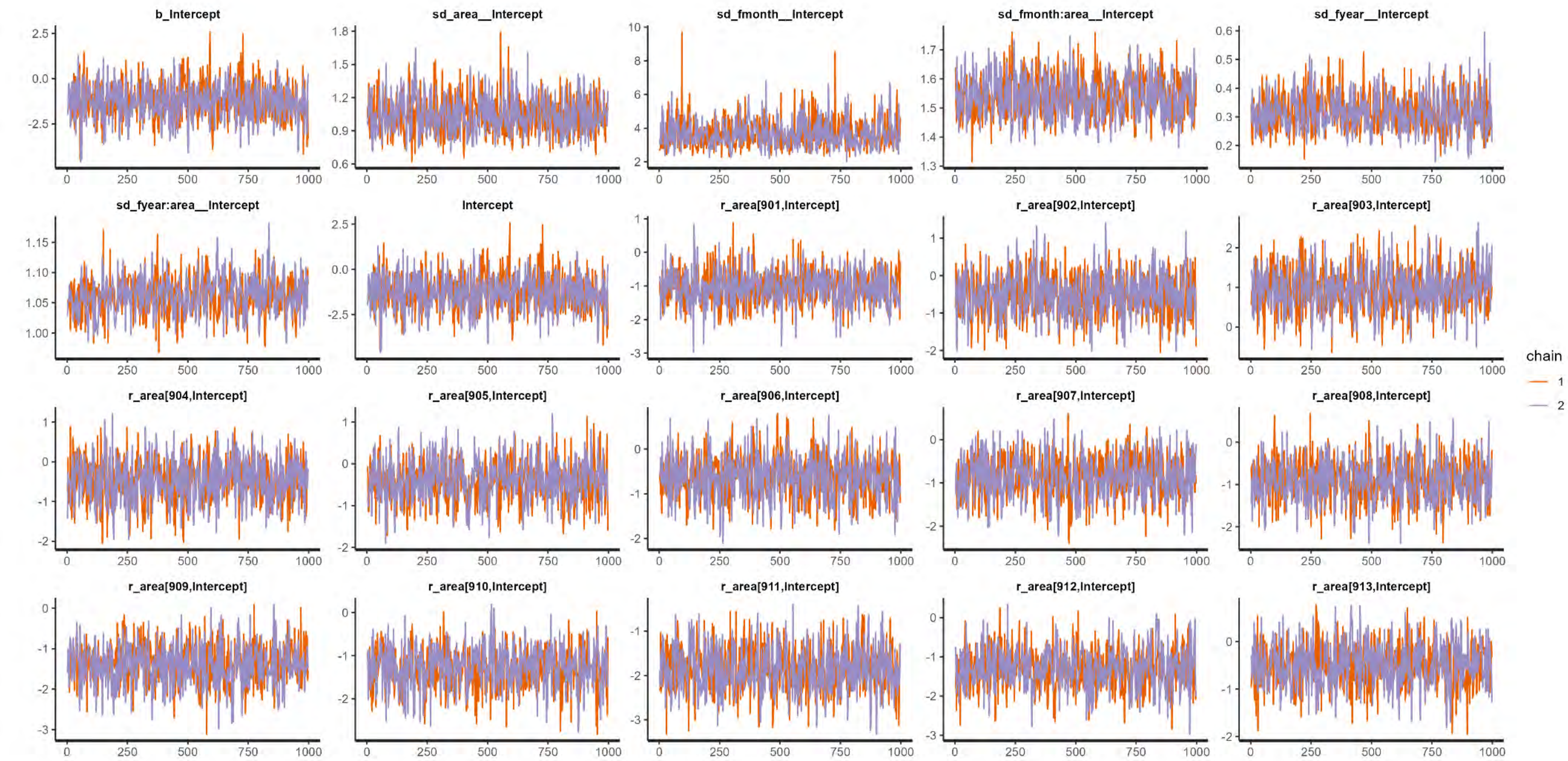


Figure E.1: MCMC traces of a sample of estimated parameters of the final model used to predict the proportion of mature females in berry (*fit10*).

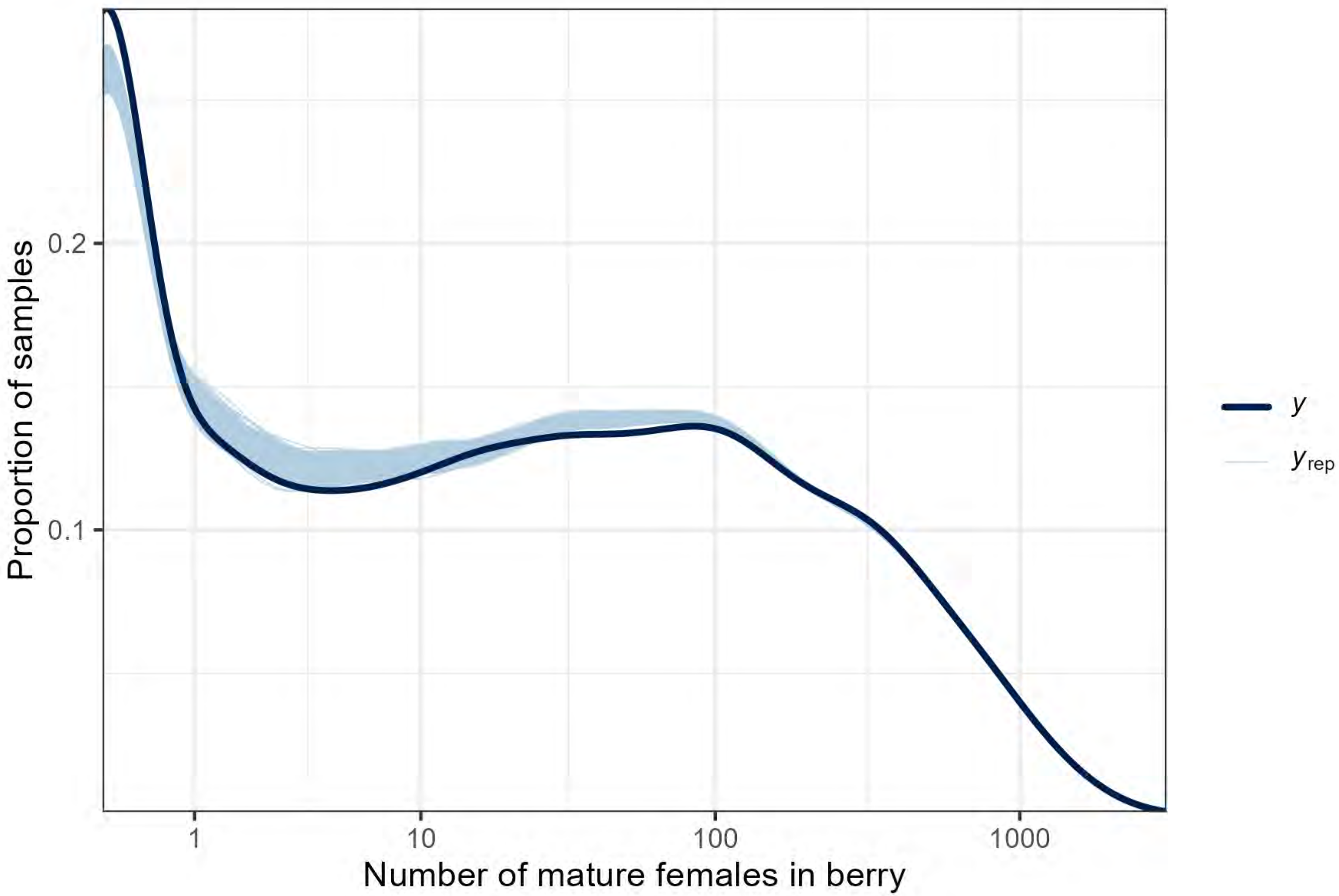


Figure E.2: Comparison of observed (dark blue line) versus predicted (light blue lines) density of the number of mature females in berry from the posterior predictive distribution of the final model used to predict the proportion of mature females in berry (*fit10*).

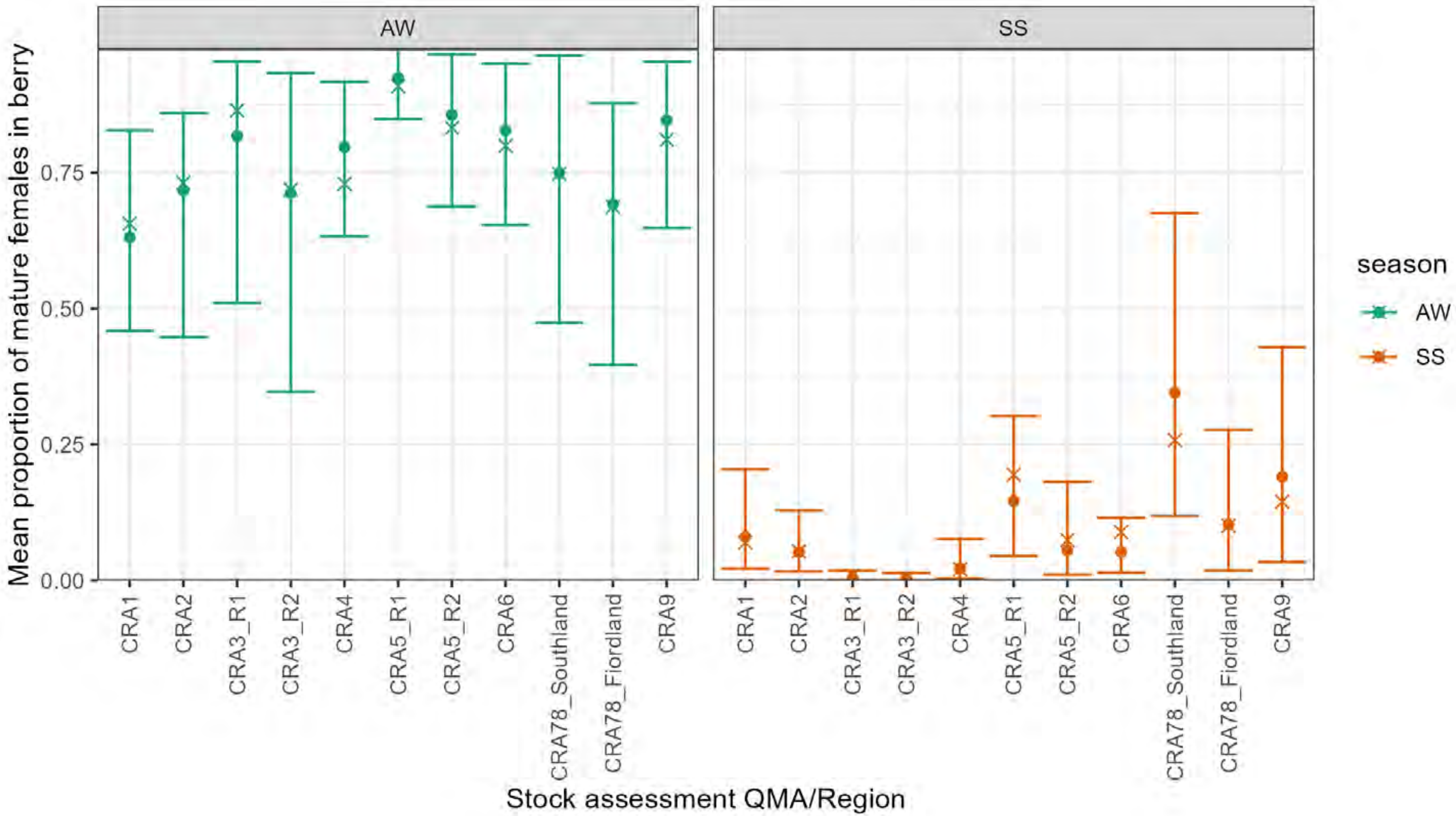


Figure E.3: Catch-weighted posterior of the proportion of mature females in berry by stock assessment QMA/region and season from the final model (*fit10*). Closed points are mean values; bars are the 95% credible intervals; and the non-catch-weighted proportions are represented by crosses.

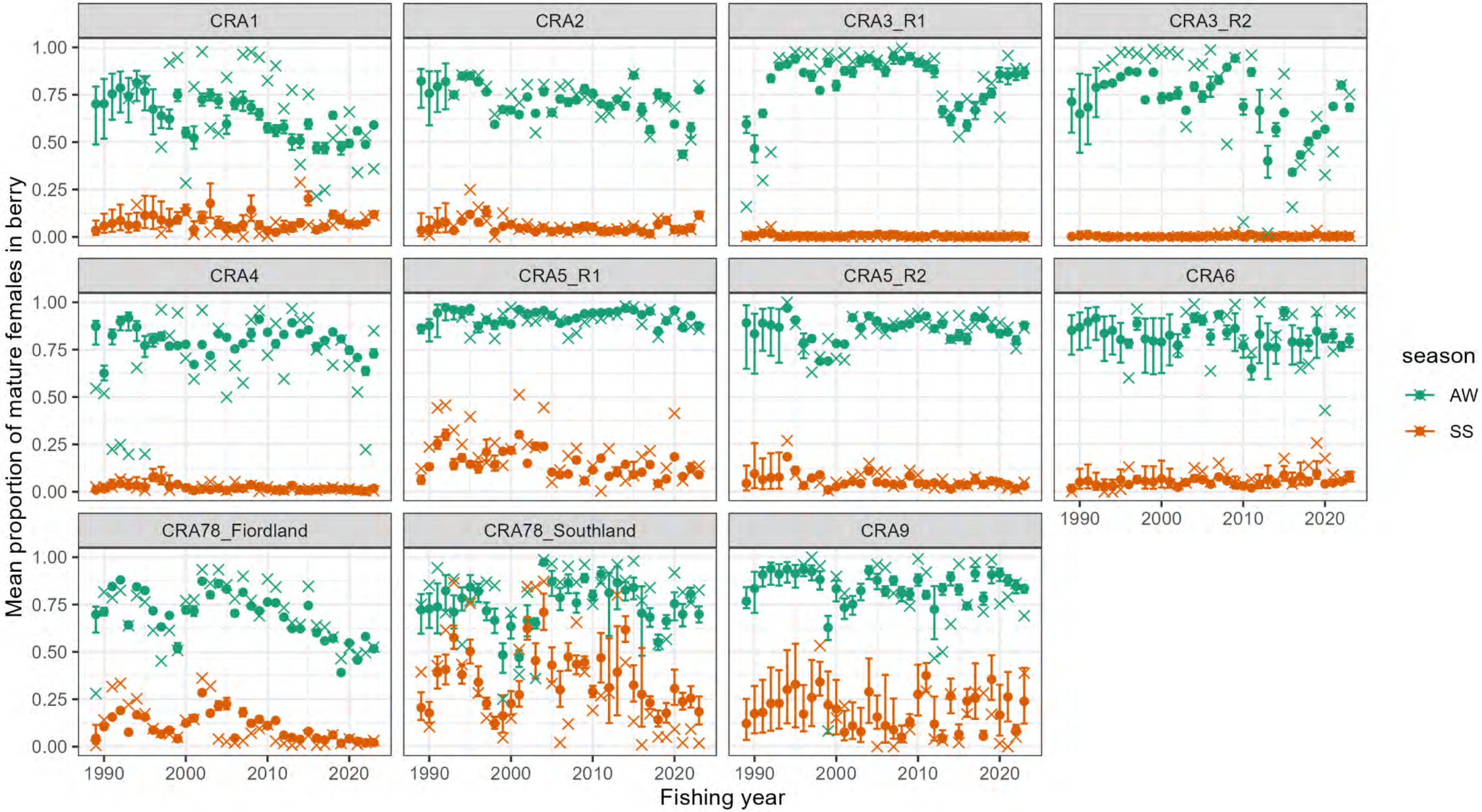


Figure E.4: Catch-weighted posterior of the proportion of mature females in berry by stock assessment QMA/region, season, and fishing year from the final model (*fit10*). Closed points are mean values; bars are the 95% credible intervals; and the non-catch-weighted proportions are represented by crosses.

Appendix F. EXPLORATION OF DENSITY EFFECTS ON GROWTH AND CATCH COMPOSITION

G.1 Background

The commercial catch of region 1 of CRA 3 (Statistical Areas 909 and 910) has been dominated by males since the beginning of consistent catch sampling in the late-1980s (Figure 4). The very low percentage (~10%) of females in the catch here is highly unusual relative to the other assessed stocks/regions of New Zealand. By comparison, at least 25% of the catch was comprised of females in each of the other statistical areas and most are close to an equal sex ratio (Figure F.1).

The first Plenary review of CRA 3 in August 2024 was concerned that the low proportion of females in region 1 might have been caused by the commercial fishery. However, a potting survey inside Te Tapuwae o Rongokako marine reserve located to the north of Gisborne (inside region 1 of CRA 3) caught a similarly low proportion of females when using commercial pots with a standard mesh size, despite the cessation of commercial fishing there in 1999 (J. Roberts et al., in prep.). Furthermore, sex ratios closer to 50:50 were obtained when the survey used fine-mesh pots both inside the reserve and in adjacent reference areas – the inference being that relatively few of the females were too large to escape from standard-mesh commercial pots (J. Roberts et al., in prep.). Similarly, approximately 50:50 sex ratios were obtained by diver survey sampling inside the same reserve (Freeman 2008), because the diver surveys were also able to sample smaller lobsters than did the standard-mesh commercial pots.

It appears therefore, that females in region 1 of CRA 3 are smaller than in other parts of New Zealand. Research fishing in the south-west of Tasmania caught small females comparable to those in CRA 3 (Frusher 1997), and which, like the females in region 1 of CRA 3 (Appendix G), appeared to mature at much smaller sizes than in other fished areas (Frusher 1997) (note the almost total lack of immature females in the catch of region 1; Figure F.1). A meta-analysis determined that the mean size of *J. edwardsii* and the size at maturation both decrease consistently moving from the north of Tasmania to the south, where very few captured lobsters were above the MLS (Frusher 1997; Gardner et al. 2006). The spatial variation in individual growth rate around Tasmania appears to be more pronounced in females than in males, based on previous analyses of size composition data (Frusher 1997) and tag-based growth increment data (Punt et al. 1997). Furthermore, as noted by Gardner et al. (2006), smaller size distributions of *J. edwardsii* were typically caught in areas where the numerical catch rate from research surveys using fine-mesh pots was high. This observation of the small size of lobsters in the south of Tasmania was therefore believed to be the consequence of density-dependent effects on the growth rate and reproductive development of lobsters.

The north to south latitudinal gradient in both female size and the size at maturation around Tasmania differed from that observed in New Zealand, with the Tasmanian gradient being positively correlated with sea surface temperature (i.e., smaller and earlier maturing where the water is relatively cold), rather than *negatively* correlated as it is around New Zealand (smaller and earlier maturing where the water is warm) (Annala et al. 1980; Gardner et al. 2006). Therefore, it does not seem likely that regional variation in *J. edwardsii* size is primarily driven by gradients in sea temperature, although it could be a second order effect related to density effects.

This Appendix describes a brief meta-analysis of the numerical catch rate and individual growth of *J. edwardsii* in fished areas of New Zealand. Density and growth are then related to assess the support for the hypothesis that regions of slow growth (where the catch size distribution is small and the catch sex ratio is biased, e.g., as in region 1 of CRA 3) are primarily density mediated.

G.2 Spatial variation in density

Numerical catch rate information is available from the observer at-sea catch sampling (CS) and the voluntary logbook (LB) programmes, which have previously been used to generate CPUE series fitted in rock lobster stock assessment models (e.g., Rudd et al. 2024) and are used to characterise the size composition of the catch. Here, a simple CPUE analysis was undertaken using catch rate data from the CS and LB programmes (the same data used in the generation of assessment CPUE indices; see Section 2.1.1), with the aim of describing variation in numerical catch rate (a proxy for density) with respect to statistical area. The spatial scope of this analysis included all New Zealand statistical areas for which there were sufficient CS or LB data.

Because of the way the data were processed for use by CPUE analysis, the two sources of CPUE data differ in terms of the size of lobsters they represent:

- CS data included vulnerable lobsters of all recorded sizes, whereas
- LB data catch rate included vulnerable lobsters above the minimum landing size (MLS) for the respective QMAs.

Therefore, CPUE indices generated using the CS data will tell us about the relative density of lobsters vulnerable to the fishery (regardless of size), whereas the LB data tell us about the density of legal lobsters, noting that the MLS values used for each sex are stock-specific.

The methods generating the CS and LB catch rate data used by this analysis were the same as those producing the respective CPUE data prepared for the CRA 3 assessment (see Section 2.1.1). However, note that only the LB CPUE series was ultimately used in the CRA 3 assessment. The CS data were subset to exclude records from fishing years prior to 1990 and both the CS and LB data were then aggregated up to the trip level for the purposes of this analysis. Statistical areas with fewer than a total of ten CS trips were excluded from the CS analysis. Likewise, statistical areas with fewer than 100 trips were excluded from the LB analysis (LB trips comprise fewer pots per trip than CS trips). A summary of the data used by this analysis of CS and LB CPUE data is given in Table F.3, Table F.4, and Table F.5.

Generalised Additive Models (GAMs) (Wood 2011) were fitted separately to the CS and LB CPUE data, using the same simple model structure:

number of lobsters ~ log(pots) + statistical area + month

Although vessel ID is known to explain much of the variation in catch rate in CRA fisheries, this was excluded from these models because vessel and area effects across QMA boundaries would have been strongly confounded, due to vessels primarily fishing in QMAs for which they have quota. Hence this simple model structure was preferred for the purposes of this exploratory analysis. Both models assumed a negative binomial error distribution, with the dispersion parameter estimated during model fitting (‘family = nb()’).

The CS CPUE model explained 61.4% of the null model deviance and had a reasonably good fit by statistical area and month, although it was likely to be slightly under-dispersed, based on the shape of the distributions of Pearson residuals (Figure F.2, Figure F.3). The same was true of the LB CPUE model (Figure F.4, Figure F.5), which explained 34.1% of the null model deviance. However, rootograms produced for the CS and LB models using the *gratia R* package (Simpson 2024) did not indicate a critical lack of fit to the data (Figure F.6).

The conditional effects of the number of pots, statistical area, and month are shown for the CS and LB models in Figure F.7 and Figure F.8, respectively. These show the expected linear increase in lobsters caught with increasing numbers of pots per trip.

The CS and LB models were used to predict the number of lobsters per pot by statistical area, using the same month (July) to facilitate the comparison of catch rate from the two sources. The resulting area-based predictions are shown for the CS and LB models in Figure F.9 and Figure F.10. The model predictions were close to the raw average catch rate values for the respective areas.

Based on the CS CPUE model, which represented vulnerable lobsters of all sizes (above and below the MLS), Statistical Area 910 (region 1 of CRA 3) and Statistical Area 916 (in region 2 of CRA 5) were the only areas to have an average catch rate greater than 10 lobsters per pot (Figure F.9). Intermediate catch rates (defined as 3–10 lobsters per pot) were predicted for Statistical Areas 909 (region 1 of CRA 3) and 911 (region 2 of CRA 3). The predicted catch rates were low (< 3 lobsters per pot) in all statistical areas of CRA 2, indicative of comparatively low lobster densities in this QMA.

As expected, the predicted catch rate was lower for each area based on the LB CPUE model, which represented only vulnerable lobsters that were above the MLS (Figure F.10). As with the CS CPUE model, Statistical Area 916 (in region 2 of CRA 5) had the greatest predicted number of lobsters per pot. The catch rate of legal-sized lobsters in all statistical areas of CRA 3 was between 3–4 lobsters per pot which was approximately the average across all New Zealand statistical areas. Based on the comparison with the CS model predictions, the comparatively high numerical density of lobsters in region 1 of CRA 3 therefore appears to be primarily composed of sub-legal lobsters.

G.3 Spatial variation in growth

In the previous subsection it was established that the numerical density of sub-legal lobsters in region 1 of CRA 3 was high relative to other assessed QMAs/regions. Here, we assess the relative growth rate of male and female lobsters by statistical area, to explore the hypothesis that lobsters (of both sexes, but primarily of females) in region 1 of CRA 3 are slow-growing relative to other areas, causing the male-biased sex ratio of lobsters in the commercial catch.

This analysis used the same tag data that was developed for the current CRA 3 assessment and used the tag data for all assessed QMAs/regions (see Section 2.1.3 for additional summaries of these data). In addition to the standard methods used to process these data (described in Section 2.1.3.1), tag recaptures of lobsters that had spent less than 1 year at liberty were excluded. This was found to remove a large proportion of tag records with zero or negative growth increments and resulted in a sample size of 8482 tag records. The remaining tag records with zero or negative growth increments were also excluded from the '1 year at liberty' data set to help with model fitting, yielding a final sample of 8024 records. The tag sample used by this analysis is summarised by sex, fishing year and statistical area of release in Table F.1 and Table F.2, showing representation in all assessed QMAs/regions.

A single GAM model assuming a normal error distribution was fitted to square root-transformed TW growth increment data, using the following model structure:

sqrt(tw_inc) ~ s(tw_rel, by = sex) + s(tw_rel, by = stock_region) + area:sex + s(liberty, k = 4)

where 'tw_inc' is the observed growth increment in terms of mm TW, 'tw_rel' is the observed TW at release, which was included in two splines that allowed the growth increment with respect to TW at release to vary by sex and by QMA/region, 'area:sex' is an interaction term that allowed the difference in male and female growth rate to vary by sex, and 'liberty' was the number of days at liberty, allowing a non-linear increase in the growth increment with increasing days at liberty (this relationship was constrained from having an unrealistically wiggly shape by specifying a basis dimension value (k) = 4). Other model structures were trialled for this exploratory analysis but were inferior in terms of model AIC and are not described here.

This model structure explained 56.5% of the null model deviance and fitted well to the data, based on the distribution of the Pearson residuals, which are plotted by TW at release, month, and decade of release (Figure F.11, Figure F.12, and Figure F.13).

The growth increment with respect to days at liberty predicted by this model is shown in Figure F.14, which plots the expected asymptote in growth rate with increasing period at liberty. The model was used to predict the annual growth increment by TW, sex and statistical area (Figure F.15). This indicated that the growth rate at smaller sizes (< 60 mm TW) varied considerably by statistical area, with particularly slow growth in the areas (909 and 910) which comprise region 1 of CRA 3 and also in region 2 as well as in some statistical areas of CRA 4. There was almost no data for this region to inform the predictions at > 60 mm TW, which are highly uncertain. Generally, growth was predicted to be faster for males than for females and while the rate of decay in growth rate with increasing size was consistent for females, the male growth curves had a pronounced hump between 50- and 60-mm TW. The predicted annual growth increments are also displayed at 40, 50, and 60 mm TW at the time of release (Figure F.16), which highlights the relatively slow growth of both male and (particularly) female lobsters in region 1 of CRA 3 at 40 mm TW.

G.4 Relating density and growth

The predicted catch rates of lobsters by statistical area from the CS and LB CPUE models were compared with the predicted growth increments of male and female lobsters also by statistical area. When using the CS CPUE predictions, which included lobsters above and below the MLS, there was a strong negative correlation between lobster density and growth rate (Figure F.17). For both sexes, this negative correlation was statistically significant when using the CS CPUE data, based on Spearman's rank correlation coefficient (males – ρ = -0.664, p-value < 0.001, d.f. = 20; females – ρ = -0.662, p-value = 0.001, d.f. = 20). However, this relationship was very weak for either sex when using the LB CPUE predictions for each area, which only represent lobsters above the MLS (Figure F.18) (males – ρ = -0.205, p-value 0.358, d.f. = 20; females – ρ = -0.213, p-value = 0.340, d.f. = 20).

G.5 Conclusions for stock assessment

This analysis indicates that the growth rate of lobsters in region 1 of CRA 3 is comparatively slow relative to all other assessed QMAs/regions of New Zealand (also quite slow in region 2 and in some parts of CRA 4) and that this is most pronounced for females. This is a strong candidate reason for the relative lack of females in the catch in region 1 of CRA 3. The cause of this very slow growth rate is not known, although, given the correlations shown here, it is plausibly related to the relatively high numerical density of lobsters, particularly of sub-legal sized individuals. Slow growth in region 1 of CRA 3 is consistent with females appearing to mature at smaller sizes here compared with all other New Zealand stocks/regions (see Appendix G).

A negative relationship was observed between the growth rate and density of lobsters by statistical area, but only when including sub-legal lobsters in the model predicting densities. This is consistent with regional patterns in growth rate of New Zealand red rock lobsters being largely governed by density-dependent processes, as also appears to be true for *J. edwardsii* around Tasmania, noting that other unassessed processes (e.g., sea temperature, habitat type, and food availability) are also likely to be influential for growth. Thus, growth rate is likely to vary not just in space, but also through time in response to temporal changes in the density of lobsters.

The approach used here to model growth allowed a more flexible shape to the change in growth rate with increasing lobster size than is allowed by recent stock assessment models. Doing so resulted in more non-linear growth curves for males, with a prominent hump between 50–60 mm TW. This should be compared with the strongly non-linear shape of carapace length – tail width relationship for males in some QMAs (see figure D.8 of Webber et al. 2024) and with humps around the MLS in the LF distributions of numerous CRA stocks to see if these patterns could be caused by non-linear TW growth. Also, consideration should be given to more flexible growth models, where this is TW-based.

Table F.1: Number of male tag growth increment observations used by the tag growth model, by year and statistical area of release.

	CRA 1		CRA 2				CRA 3 R1		CRA 3 R2	CRA 4				CRA 5 R2		CRA 5 R1	CRA 7&8 R1			CRA 7&8 R2		
Year	939	901	905	906	907	908	909	910	911	912	913	914	915	933	916	917	920	923	924	926	927	928
1965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	9	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
1984	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1996	0	0	2	135	56	21	0	12	0	0	0	0	0	0	83	0	0	0	0	0	0	2
1997	0	0	0	67	20	27	18	4	0	0	0	0	0	50	18	52	0	17	105	30	102	3
1998	0	0	0	28	3	5	0	0	0	28	21	25	0	5	2	1	0	1	5	87	90	16
1999	0	0	0	8	3	3	0	0	0	0	4	25	5	7	1	14	0	1	24	10	35	14
2000	27	31	0	0	0	0	0	0	0	0	3	2	2	4	166	12	0	0	4	2	12	0
2001	4	0	0	1	0	1	27	23	15	0	0	0	0	17	123	69	0	0	0	0	2	0
2002	13	5	0	26	0	1	0	0	0	0	0	0	0	1	27	5	0	0	0	0	4	0
2003	38	0	1	39	15	4	0	0	0	0	0	0	0	0	3	3	0	1	0	152	216	20
2004	1	0	0	1	0	0	33	64	32	0	0	0	0	5	145	23	0	0	0	12	62	6
2005	0	0	0	1	0	0	1	1	1	0	1	10	3	1	12	1	0	0	0	3	31	1
2006	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	1	0	0	0	0	22	1
2007	0	0	0	0	0	0	0	0	0	3	3	11	9	0	2	0	15	0	0	0	12	0
2008	0	0	1	5	3	8	22	1	1	0	0	0	0	0	0	0	0	0	0	0	3	1
2009	3	0	0	1	0	0	50	0	12	8	0	13	0	0	0	0	0	0	0	0	3	0
2010	6	3	0	0	0	0	8	2	0	4	22	1	1	0	0	0	0	0	0	0	3	0
2011	1	0	0	0	0	0	22	4	0	0	1	1	0	0	0	0	0	0	0	0	0	0
2012	33	0	3	0	0	0	14	11	0	0	0	0	0	16	7	17	23	0	0	0	0	0
2013	14	3	0	0	0	0	18	9	0	0	0	0	0	4	0	2	3	0	0	0	0	0
2014	2	0	2	3	12	5	15	1	7	0	12	62	0	2	0	2	0	0	0	0	0	0
2015	0	0	0	0	2	4	1	1	1	0	15	2	1	0	0	1	0	0	0	0	0	0
2016	0	0	0	1	2	3	10	16	1	0	3	0	0	0	1	4	1	0	0	0	0	0
2017	1	0	0	2	1	0	0	1	15	0	4	1	0	0	0	1	24	0	0	0	0	0
2018	0	0	0	0	1	0	7	18	7	0	0	0	0	0	2	1	10	0	0	0	0	0
2019	3	0	0	0	17	9	0	0	0	0	0	0	0	0	0	0	12	8	0	13	0	0
2020	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	5	10	0
2021	2	0	0	1	3	1	8	11	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2022	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table F.2: Number of female tag growth increment observations used by the tag growth model, by year and statistical area of release.

	CRA 1		CRA 2				CRA 3 R1		CRA 3 R2	CRA 4				CRA 5 R2		CRA 5 R1	CRA 7&8 R1			CRA 7&8 R2		
Year	939	901	905	906	907	908	909	910	911	912	913	914	915	933	916	917	920	923	924	926	927	928
1965	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1977	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
1984	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
1996	0	0	1	147	85	18	0	8	0	0	0	0	0	0	58	0	0	0	0	0	0	7
1997	0	0	1	23	13	27	3	1	0	0	0	0	0	23	4	90	0	44	160	95	388	30
1998	0	0	2	22	3	3	0	0	0	4	15	34	0	3	0	12	0	0	8	88	123	14
1999	0	0	1	6	3	2	0	0	0	1	10	28	14	8	3	97	0	3	25	13	71	6
2000	94	57	0	1	0	0	0	0	0	0	0	1	24	2	16	27	0	0	2	1	37	0
2001	19	3	0	4	0	0	0	1	10	0	0	1	0	44	12	37	0	0	1	0	16	0
2002	61	25	13	92	9	6	0	0	0	0	0	0	0	4	1	5	0	0	1	0	13	0
2003	66	4	22	111	62	30	0	0	0	0	0	0	1	4	0	5	0	0	0	1	14	0
2004	9	0	1	3	6	0	0	0	20	0	0	0	0	20	5	103	0	0	0	1	8	0
2005	6	0	0	0	1	0	0	0	0	0	1	3	11	0	0	5	0	0	0	0	5	0
2006	1	0	0	1	1	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	2	0
2007	1	0	0	0	0	0	0	0	0	0	0	1	3	0	0	1	18	0	0	0	1	0
2008	0	0	3	21	10	19	0	0	8	0	0	0	1	0	0	1	1	0	0	0	4	0
2009	17	0	0	1	0	2	0	0	0	5	0	3	0	0	0	0	0	0	0	0	0	0
2010	14	18	0	1	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
2011	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
2012	27	5	6	0	0	0	2	0	0	0	0	0	0	51	0	21	20	0	0	0	0	0
2013	18	33	0	0	0	0	0	14	0	0	0	0	0	1	0	2	4	0	0	0	0	0
2014	0	0	9	9	22	24	0	0	7	0	0	5	8	2	0	1	0	0	0	0	0	0
2015	3	0	0	1	14	11	0	0	0	0	7	1	0	0	0	0	0	0	0	0	0	0
2016	1	0	3	14	6	5	0	3	0	0	0	2	3	0	0	5	1	0	0	0	0	0
2017	4	0	1	4	0	0	1	0	3	0	0	0	0	1	0	3	4	0	0	0	0	0
2018	1	0	0	0	2	0	0	0	1	0	0	1	0	0	0	6	0	0	0	0	0	0
2019	16	0	0	0	26	13	0	0	0	0	0	0	0	0	0	0	0	4	0	3	0	0
2020	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
2021	2	0	0	3	3	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table F.3: Number of trips included in the CS CPUE model by fishing year and statistical area.

	CRA 1					CRA 2				CRA 3 R1		CRA 3 R2	CRA 4					CRA 5 R2		CRA 5 R1	CRA 6				CRA 7&8 R1					CRA 7&8 R2		
Fishing year	939	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	934	933	916	917	940	941	942	943	920	921	923	924	925	926	927	928
1990	–	–	–	–	–	–	–	–	–	17	33	–	49	34	–	51	–	–	–	68	–	–	–	–	23	–	–	55	–	107	131	136
1991	–	–	–	–	–	–	–	–	–	12	38	–	62	25	–	–	–	–	–	44	–	–	–	–	17	–	–	42	–	80	69	126
1992	–	–	–	–	–	–	–	–	–	12	40	–	61	29	–	–	–	–	–	79	–	–	–	–	23	–	–	29	–	98	91	112
1993	–	–	–	–	–	–	–	–	–	10	81	66	39	39	–	–	–	–	–	75	20	3	18	11	9	10	–	9	–	78	107	70
1994	–	–	–	–	–	–	–	–	–	–	60	61	13	27	–	–	–	–	–	75	22	10	19	15	20	16	–	16	7	81	72	101
1995	–	–	–	–	–	–	–	–	–	7	25	26	30	26	–	–	–	–	–	77	64	29	57	65	22	14	2	28	–	79	90	83
1996	–	–	–	–	–	–	–	–	–	3	11	31	9	8	3	–	–	–	–	55	–	3	4	3	31	36	–	69	6	112	93	115
1997	20	–	7	–	–	–	–	–	–	8	12	14	38	25	54	–	–	–	–	51	24	25	7	12	15	23	13	8	–	28	1	8
1998	15	40	–	–	3	–	–	–	–	5	47	16	30	18	41	–	–	7	14	31	–	–	–	–	15	10	5	29	–	–	–	–
1999	42	49	–	8	1	8	5	12	15	14	44	11	14	19	4	34	–	51	11	14	–	–	–	–	29	7	–	30	–	–	–	–
2000	14	40	14	–	3	–	5	6	–	6	27	16	30	19	26	4	–	51	7	8	–	–	–	–	15	12	–	46	–	7	11	4
2001	14	52	–	–	11	14	13	5	5	–	40	2	28	23	45	18	–	–	–	–	–	–	–	–	18	6	–	87	–	–	–	–
2002	15	–	–	–	–	–	–	4	–	2	28	34	23	24	53	11	–	–	–	–	–	–	–	–	18	14	–	–	–	72	–	–
2003	–	69	–	–	–	–	–	5	–	–	26	26	21	28	51	18	–	–	–	–	–	–	–	–	16	21	–	–	–	–	–	–
2004	–	47	–	–	–	4	6	–	8	4	11	30	17	37	57	9	–	–	–	–	–	–	–	–	22	15	–	–	–	–	–	–
2005	13	44	8	–	–	–	5	14	3	6	18	15	32	40	73	24	–	–	–	–	–	–	–	–	25	7	–	–	–	–	–	–
2006	10	29	11	3	–	13	7	5	6	–	20	7	12	24	98	43	–	–	–	–	–	–	–	–	11	20	–	–	–	–	–	–
2007	–	32	3	–	–	–	17	–	5	–	22	35	10	30	83	42	2	–	–	–	–	–	–	–	17	13	–	–	–	–	–	–
2008	–	37	–	–	–	–	–	5	4	6	5	30	19	8	46	67	–	14	–	14	–	–	–	–	13	11	–	–	–	–	–	–
2009	5	39	4	–	7	–	–	–	10	8	12	25	30	25	67	20	2	3	3	11	–	–	–	–	16	8	–	–	–	–	–	–
2010	–	42	3	–	–	–	10	7	15	4	36	31	20	30	52	43	3	3	4	14	–	–	–	–	12	16	–	10	–	22	25	38
2011	9	65	–	–	4	13	20	10	9	6	37	35	25	33	83	25	–	–	–	–	–	–	–	–	14	18	–	–	–	–	–	–
2012	5	80	3	–	–	10	–	4	–	5	34	18	20	53	73	15	–	–	–	–	–	–	–	–	25	13	–	–	–	–	–	–
2013	3	51	–	–	–	6	4	–	–	2	37	31	19	53	78	15	3	–	–	–	–	–	–	–	26	1	–	–	–	–	–	–
2014	5	9	–	–	–	–	4	–	–	–	44	8	18	26	76	10	–	–	–	–	–	–	–	–	30	–	–	–	–	–	–	–
2015	9	–	11	–	–	–	4	–	–	–	8	25	10	20	87	21	4	–	–	–	–	–	–	–	29	8	–	–	–	–	–	–
2016	12	38	17	–	–	–	–	–	3	–	18	21	10	29	69	31	1	–	–	–	–	–	–	–	37	13	–	–	–	–	–	–
2017	15	11	–	3	–	–	12	–	5	5	29	20	21	24	75	26	7	–	–	–	–	–	–	–	32	21	–	–	–	–	–	–
2018	19	44	19	–	–	–	–	–	3	8	17	22	34	40	58	19	–	–	–	6	–	–	–	–	37	15	–	–	–	–	–	–
2019	11	51	3	–	–	–	–	–	–	5	14	25	27	29	47	21	–	–	–	–	–	–	–	–	33	24	–	–	–	–	–	–
2020	–	45	–	–	–	–	5	–	10	–	16	31	24	28	77	24	6	–	–	–	3	4	10	–	27	25	–	–	–	–	–	–
2021	10	–	2	–	–	–	56	–	5	6	20	24	16	20	102	19	–	–	–	–	–	–	–	–	21	26	–	–	–	–	–	–
2022	–	41	12	4	–	–	11	–	–	–	34	38	19	33	73	15	–	–	–	–	26	9	36	18	34	20	–	–	–	–	–	–
2023	11	35	–	6	–	–	–	–	4	11	41	28	4	42	63	28	–	–	–	–	24	18	18	17	21	15	–	–	–	–	–	–

Table F.4: Number of trips included in the LB CPUE model by fishing year and statistical area: CRA 1–5.

	CRA 1				CRA 2				CRA 3 R1		CRA 3 R2	CRA 4					CRA 5 R2		CRA 5 R1	
Fishing year	939	901	902	903	905	906	907	908	909	910	911	912	913	914	915	934	933	916	917	918
1993	–	34	–	–	87	1 283	221	492	26	109	73	–	–	–	–	–	–	–	–	–
1994	48	–	–	18	287	837	267	287	29	170	163	–	–	–	–	–	91	138	741	–
1995	43	–	–	–	43	657	195	177	39	89	83	–	–	–	–	–	167	28	328	–
1996	–	–	–	–	44	562	155	169	38	74	52	–	–	–	–	–	193	21	407	–
1997	–	–	–	–	21	441	182	135	17	–	24	–	–	60	–	–	147	38	280	–
1998	–	–	–	–	105	459	67	165	–	20	31	–	–	50	–	–	121	51	117	–
1999	–	–	–	–	92	507	230	144	–	–	30	–	–	33	–	–	185	113	230	23
2000	–	–	–	–	65	538	203	180	–	–	39	–	–	–	7	–	415	128	355	107
2001	–	–	–	–	76	396	173	137	–	–	24	–	–	–	–	–	408	144	520	59
2002	–	–	–	–	102	796	208	224	–	–	–	–	–	–	51	–	426	259	543	34
2003	–	–	–	–	104	589	161	159	–	–	–	–	–	–	95	–	352	320	296	40
2004	–	–	–	–	136	838	35	211	6	–	–	–	–	–	73	–	335	211	388	30
2005	–	–	–	–	76	920	244	285	11	–	–	–	–	–	99	–	367	299	397	27
2006	–	–	–	–	75	579	191	255	1	–	–	–	–	–	95	–	327	331	469	23
2007	–	–	–	–	13	514	185	351	81	–	–	–	–	–	71	–	396	275	454	25
2008	–	–	–	–	57	611	144	482	48	–	–	–	–	–	39	–	312	178	315	9
2009	–	–	–	–	51	582	203	398	40	–	–	–	–	1	36	–	406	220	379	46
2010	–	–	–	–	105	783	200	417	95	–	11	–	54	22	123	36	217	219	324	43
2011	21	–	–	–	71	870	200	343	74	19	37	2	80	102	9	–	316	171	249	40
2012	16	–	–	–	81	746	232	461	124	–	11	1	53	87	60	26	262	161	194	149
2013	15	–	–	–	76	816	343	413	163	52	–	–	38	44	70	7	393	71	165	112
2014	12	–	–	24	86	814	346	331	170	64	97	17	90	119	86	4	420	151	239	35
2015	120	37	–	44	221	674	252	486	69	79	136	29	155	178	150	29	413	158	214	61
2016	99	51	75	10	170	321	281	231	108	68	106	25	151	362	141	16	455	76	283	106
2017	77	19	99	24	172	390	253	291	110	141	100	31	92	250	93	20	294	108	306	53
2018	73	60	105	22	77	175	147	88	105	73	90	–	145	313	133	21	201	175	324	40
2019	13	71	102	16	44	163	135	109	123	169	73	17	40	215	102	13	291	125	408	67
2020	51	78	48	9	46	218	144	101	159	160	122	52	122	157	57	–	274	76	369	64
2021	104	54	77	3	58	169	177	130	36	34	189	27	69	103	96	–	318	112	339	78
2022	103	54	69	53	16	183	140	102	86	196	176	39	65	107	76	4	335	111	462	73
2023	88	42	102	18	74	243	123	118	28	114	234	5	19	80	68	2	251	155	493	110
2024	39	40	16	9	27	167	104	58	34	72	36	48	1	38	1	–	80	12	132	61

Table F.5: Number of trips included in the LB CPUE model by fishing year and statistical area: CRA 6–9.

Fishing year	CRA 6				CRA 7&8 R1					CRA 7&8 R2			CRA 9			
	940	941	942	943	920	921	922	923	924	926	927	928	930	931	935	936
1993	–	–	–	–	–	–	48	18	362	299	460	406	–	–	–	–
1994	–	–	–	–	–	–	66	109	379	422	663	226	–	–	–	–
1995	–	–	–	–	–	–	105	118	454	769	565	897	–	–	–	–
1996	–	–	–	–	–	–	91	–	405	512	619	506	–	–	37	–
1997	–	–	–	–	–	–	30	15	164	406	671	729	–	–	38	–
1998	–	–	–	–	–	–	–	31	135	391	576	559	25	43	19	–
1999	–	–	–	–	–	–	–	–	31	176	357	225	–	42	–	–
2000	–	–	–	–	–	–	–	–	171	251	588	287	48	–	–	79
2001	36	–	–	24	139	47	–	–	167	93	268	246	61	–	117	–
2002	61	4	48	48	71	–	–	12	130	171	368	195	–	–	–	–
2003	122	28	35	92	43	–	–	24	70	245	232	164	–	–	–	–
2004	136	38	44	–	–	–	–	11	54	259	224	140	–	–	–	–
2005	90	264	110	–	–	–	–	9	89	156	281	117	–	55	69	1
2006	150	149	101	–	–	–	–	–	94	129	393	149	–	49	86	2
2007	128	158	90	52	–	–	–	6	108	106	238	108	–	78	151	1
2008	182	70	92	27	–	–	–	1	92	96	224	142	–	86	128	–
2009	75	67	–	–	–	–	–	–	46	76	219	163	–	116	169	–
2010	71	29	34	33	–	–	–	1	21	136	350	280	–	62	56	–
2011	95	121	34	46	–	–	–	–	46	132	357	224	19	75	77	2
2012	68	54	–	–	–	–	–	–	–	181	327	252	–	60	37	5
2013	–	–	–	–	–	–	–	2	8	66	310	273	–	72	–	–
2014	36	112	6	30	–	–	–	6	18	136	342	297	–	73	–	–
2015	37	52	13	18	–	–	–	1	–	293	327	225	–	60	110	5
2016	47	19	35	–	–	–	–	–	9	261	376	182	18	66	88	8
2017	58	51	25	–	–	–	–	3	52	325	365	242	–	69	110	–
2018	68	72	72	–	–	–	–	1	81	352	396	268	–	78	89	1
2019	30	36	7	22	–	–	–	–	77	92	237	112	–	31	91	–
2020	76	85	68	5	–	–	–	3	67	287	355	230	–	38	35	–
2021	87	62	42	4	–	–	–	1	85	242	286	250	–	28	38	–
2022	76	53	32	37	–	–	–	3	86	236	290	360	–	40	88	1
2023	87	81	26	32	–	43	–	–	70	184	305	337	–	45	32	1
2024	35	23	18	18	51	130	5	2	59	134	155	153	–	42	13	–

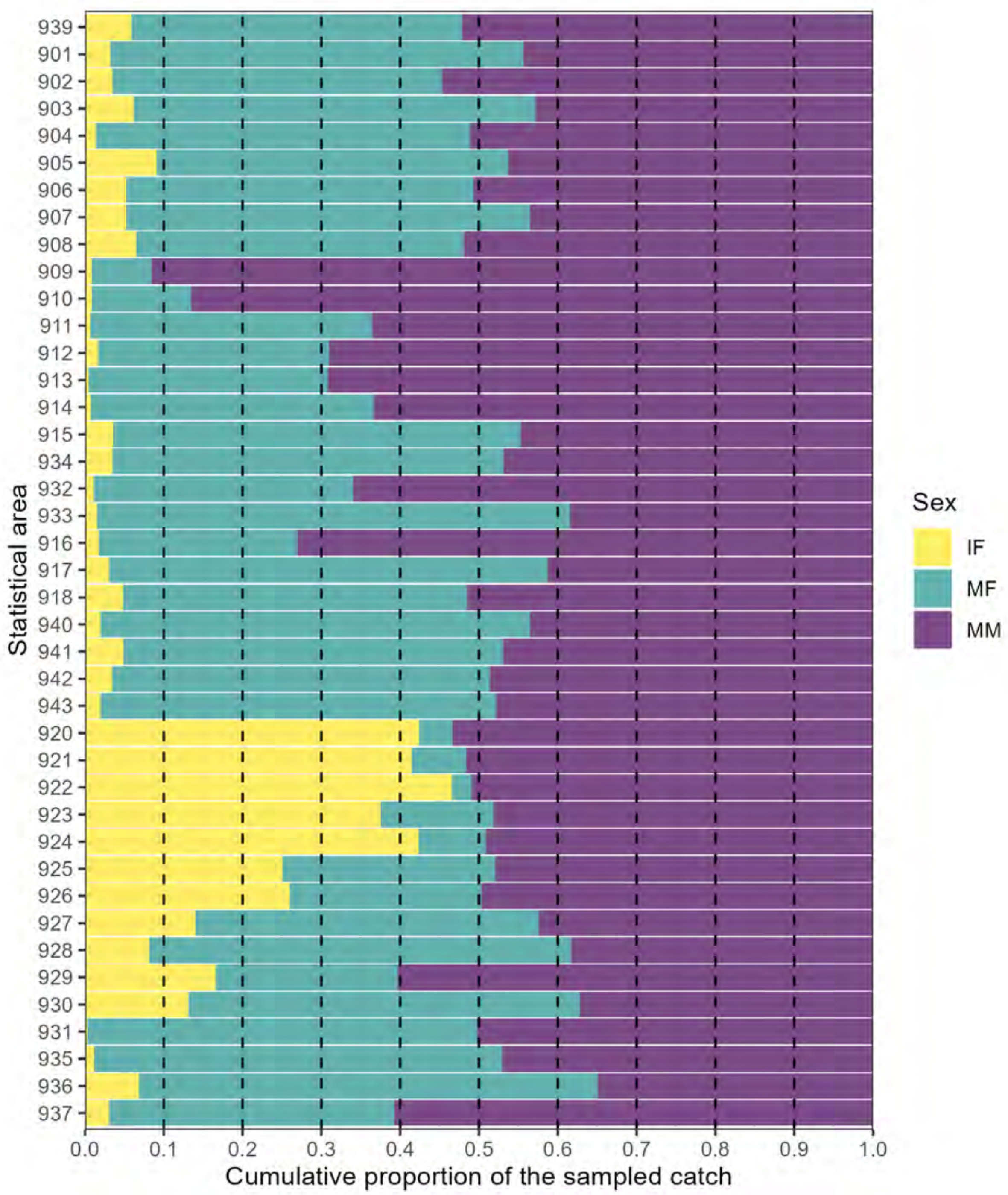


Figure F.1: The raw (unstandardised) numerical proportions of lobsters sampled by the voluntary logbook (LB) and catch-at-sea sampling (CS) programmes that were immature female ('IF'), or mature female ('MF'), or male ('MM'). A spatial correction was applied to the fisher-reported statistical areas for the LB portion of sampling based on fisher-reported latitude and longitude data. Region 1 of CRA 3 is comprised of Statistical Areas 909 and 910; region 2 is comprised of Statistical Area 911.

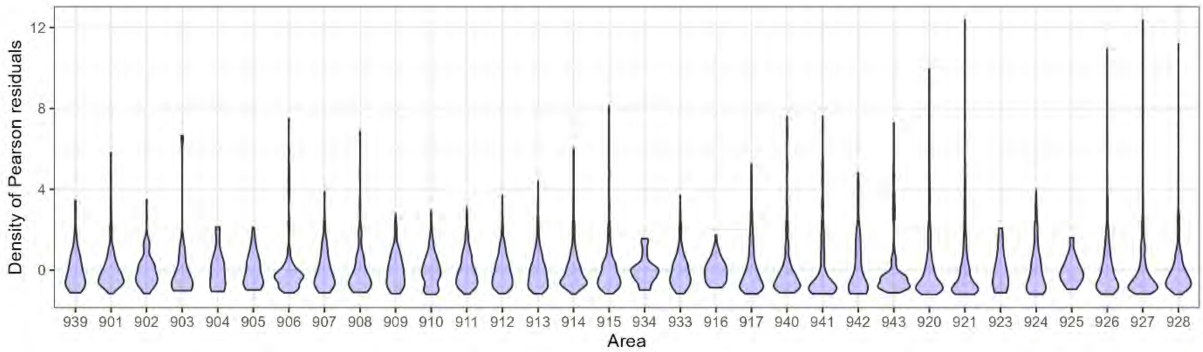


Figure F.2: Distribution of Pearson residuals from the CPUE model fitted to <u>observer catch-at-sea sampling (CS)</u> CPUE data, by statistical area.

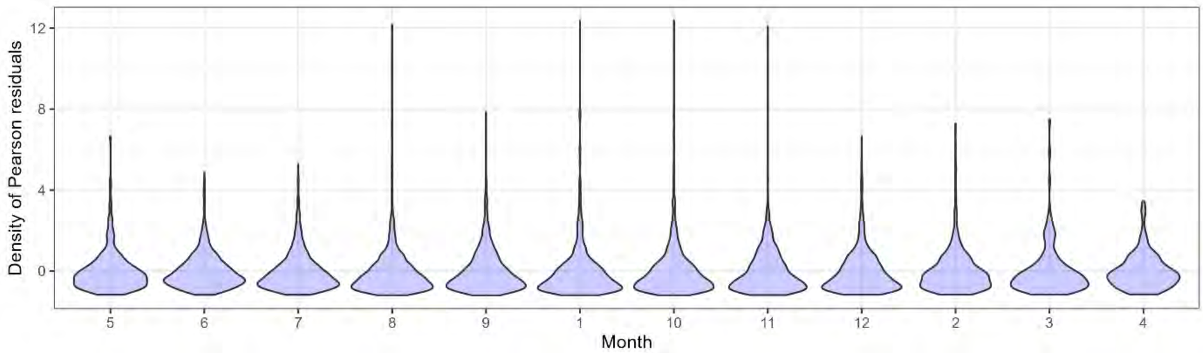


Figure F.3: Distribution of Pearson residuals from the CPUE model fitted to <u>observer catch-at-sea sampling (CS)</u> CPUE data, by month.

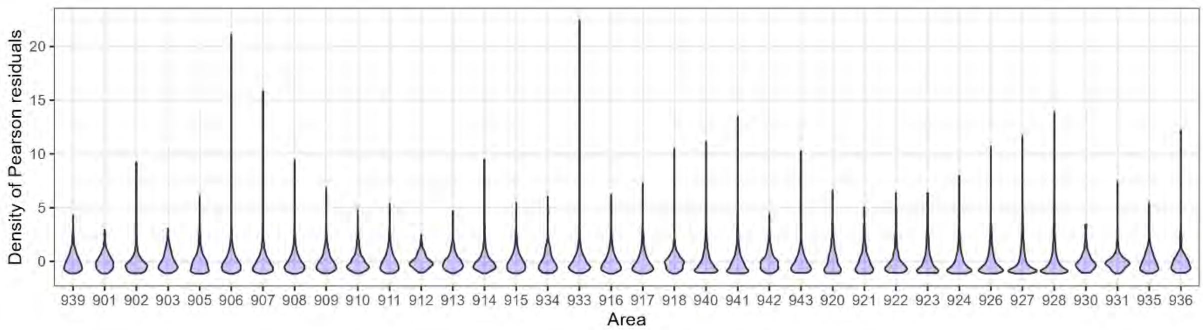


Figure F.4: Distribution of Pearson residuals from the CPUE model fitted to <u>voluntary logbook (LB)</u> CPUE data, by statistical area.

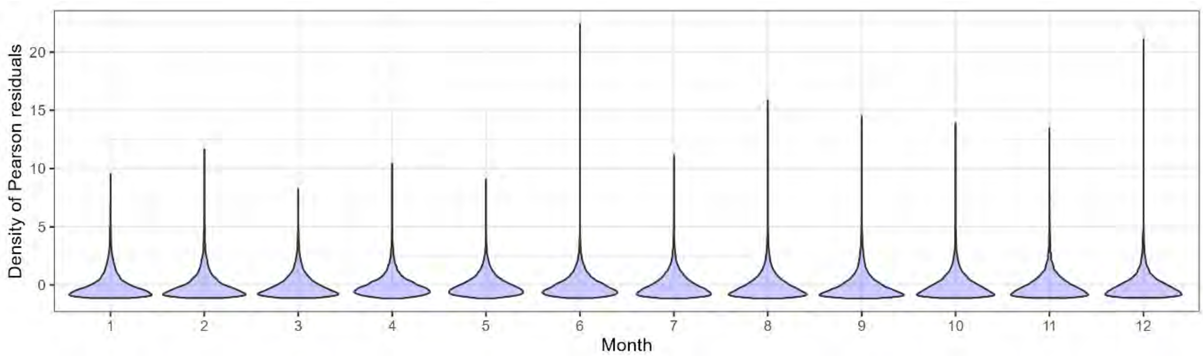


Figure F.5: Distribution of Pearson residuals from the CPUE model fitted to <u>voluntary logbook (LB)</u> CPUE data, by month.

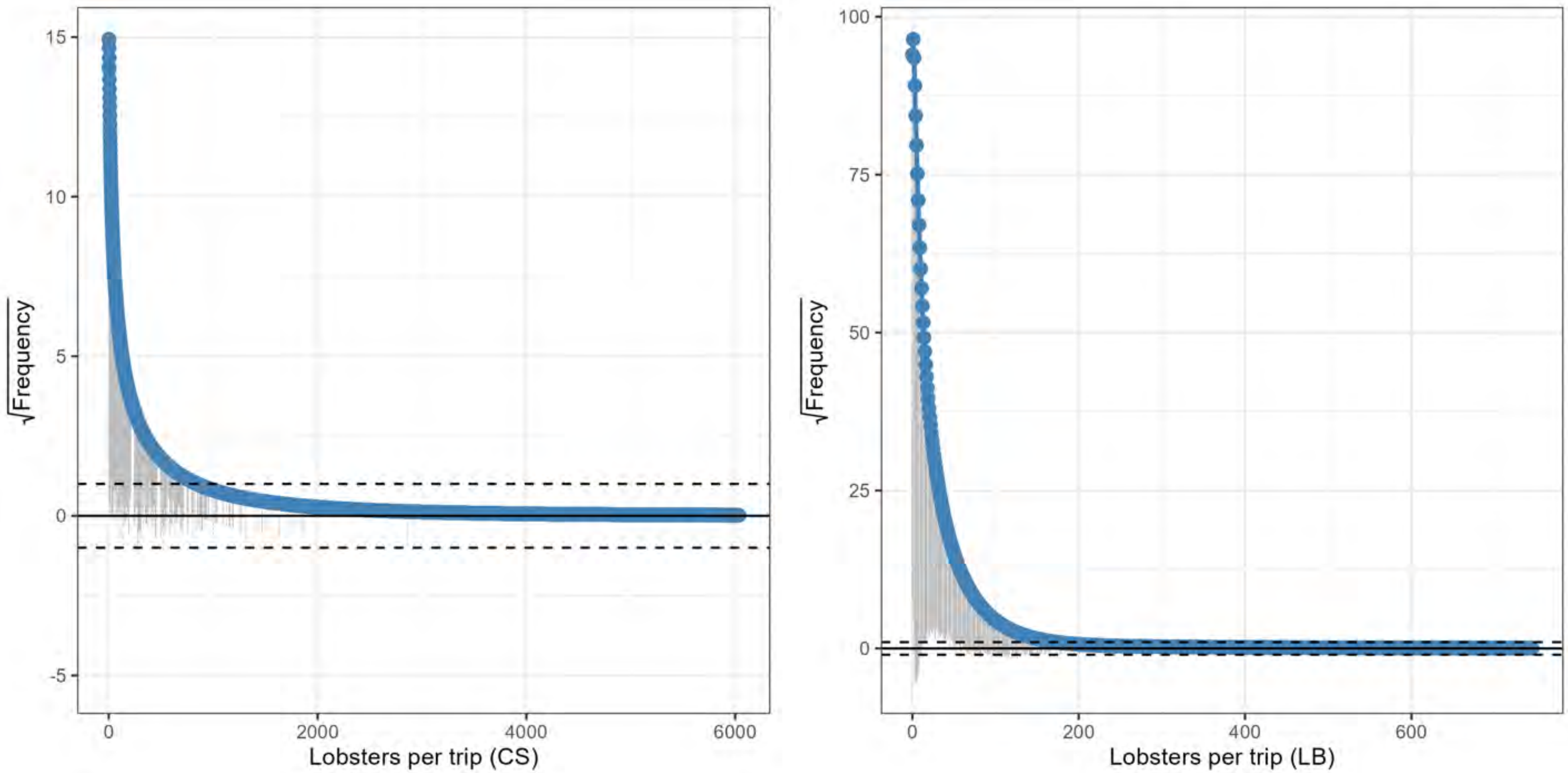


Figure F.6: Rootograms showing the goodness of fit of the CS (left) and LB (right) CPUE models to the assumed negative binomial distribution. The observed frequencies of lobsters per trip are compared with those expected from the fitted models. In this visualization a 'hanging' rootogram was used, so that discrepancies are assessed by comparison with the x-axis. Dashed lines represent the confidence interval around the zero-discrepancy line, with grey lines terminating in this zone being indicative of good fit.

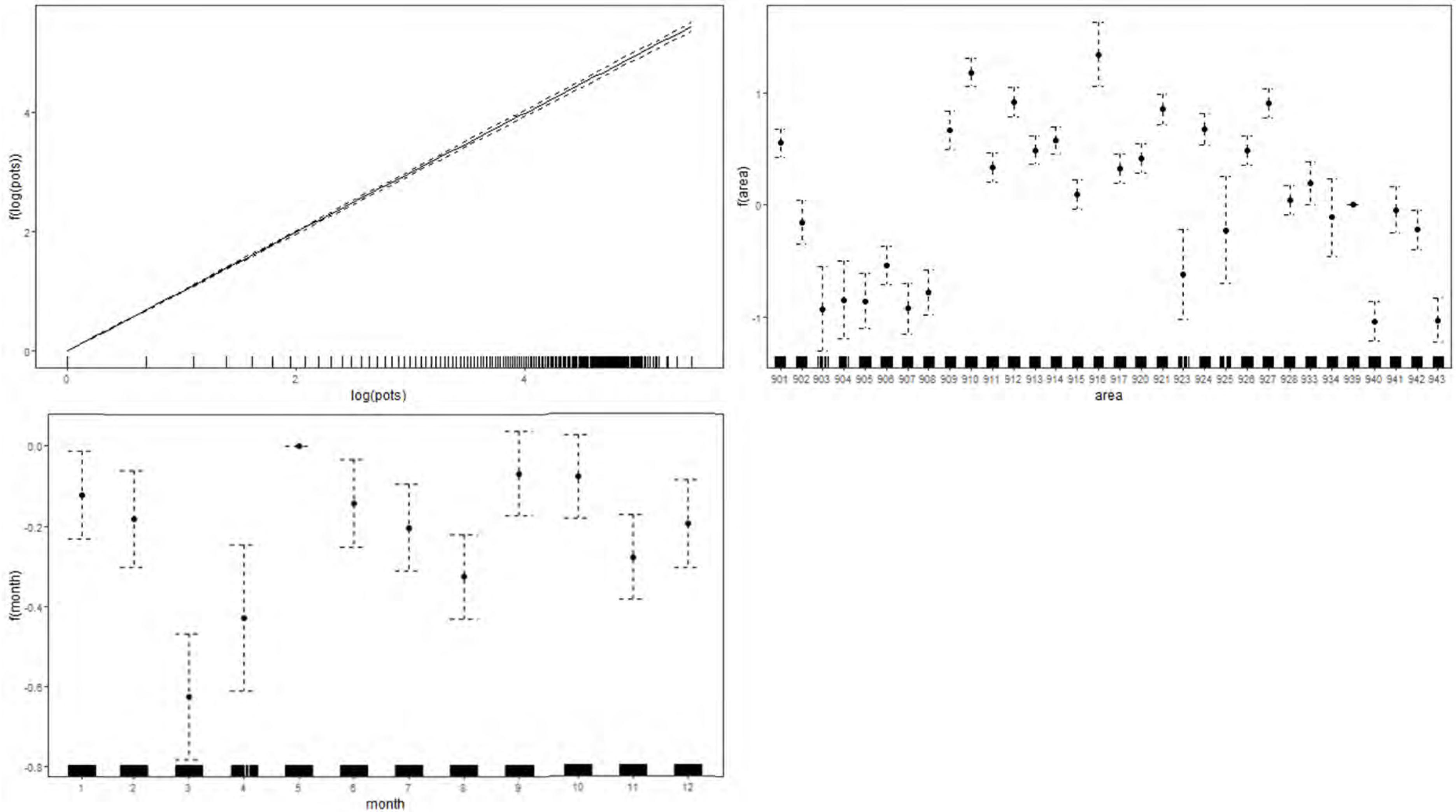


Figure F.7: Term plot for CPUE model fitted to <u>observer catch-at-sea sampling (CS)</u> CPUE data.

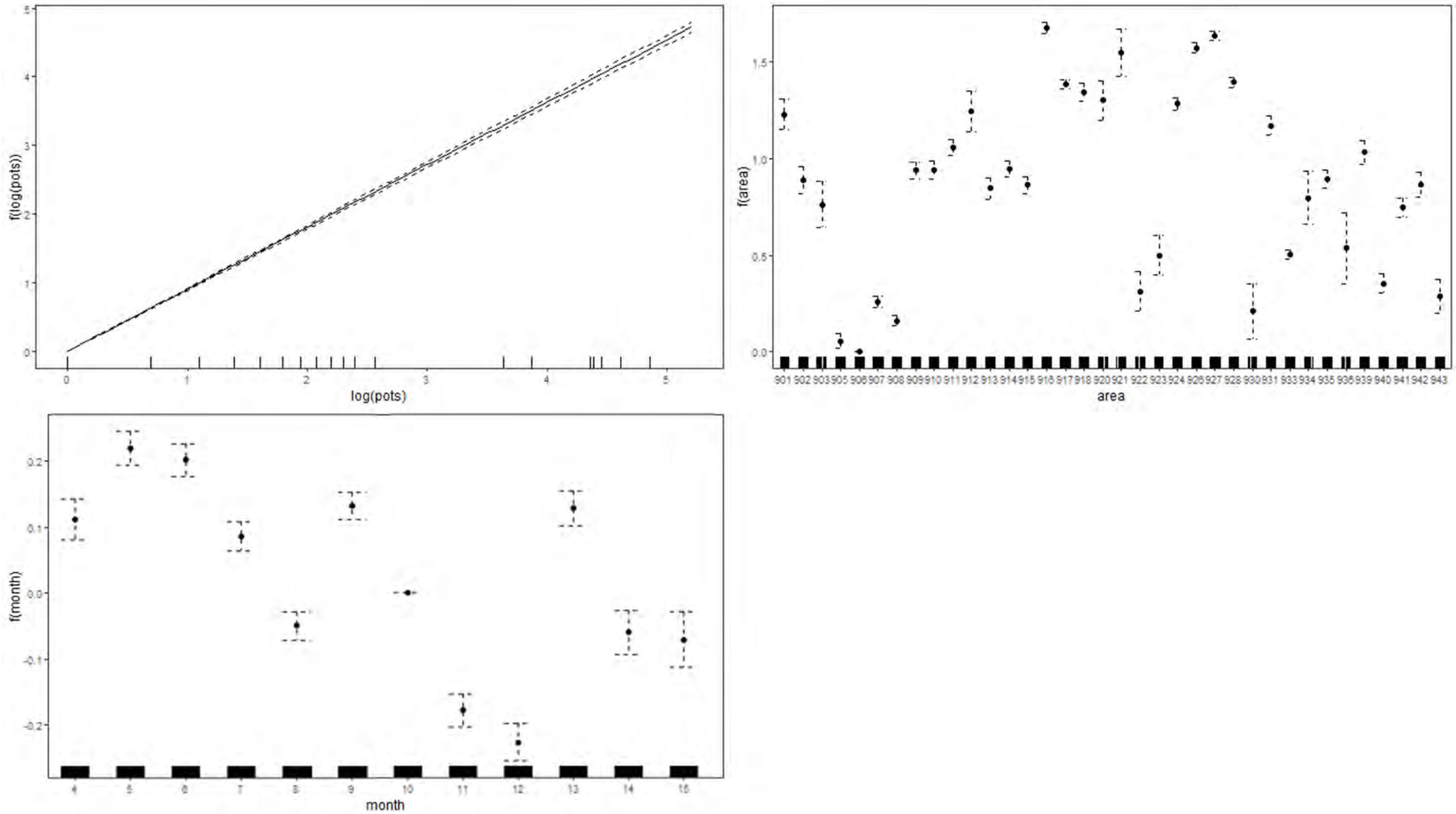


Figure F.8: Term plot for CPUE model fitted to <u>voluntary logbook (LB)</u> CPUE data.

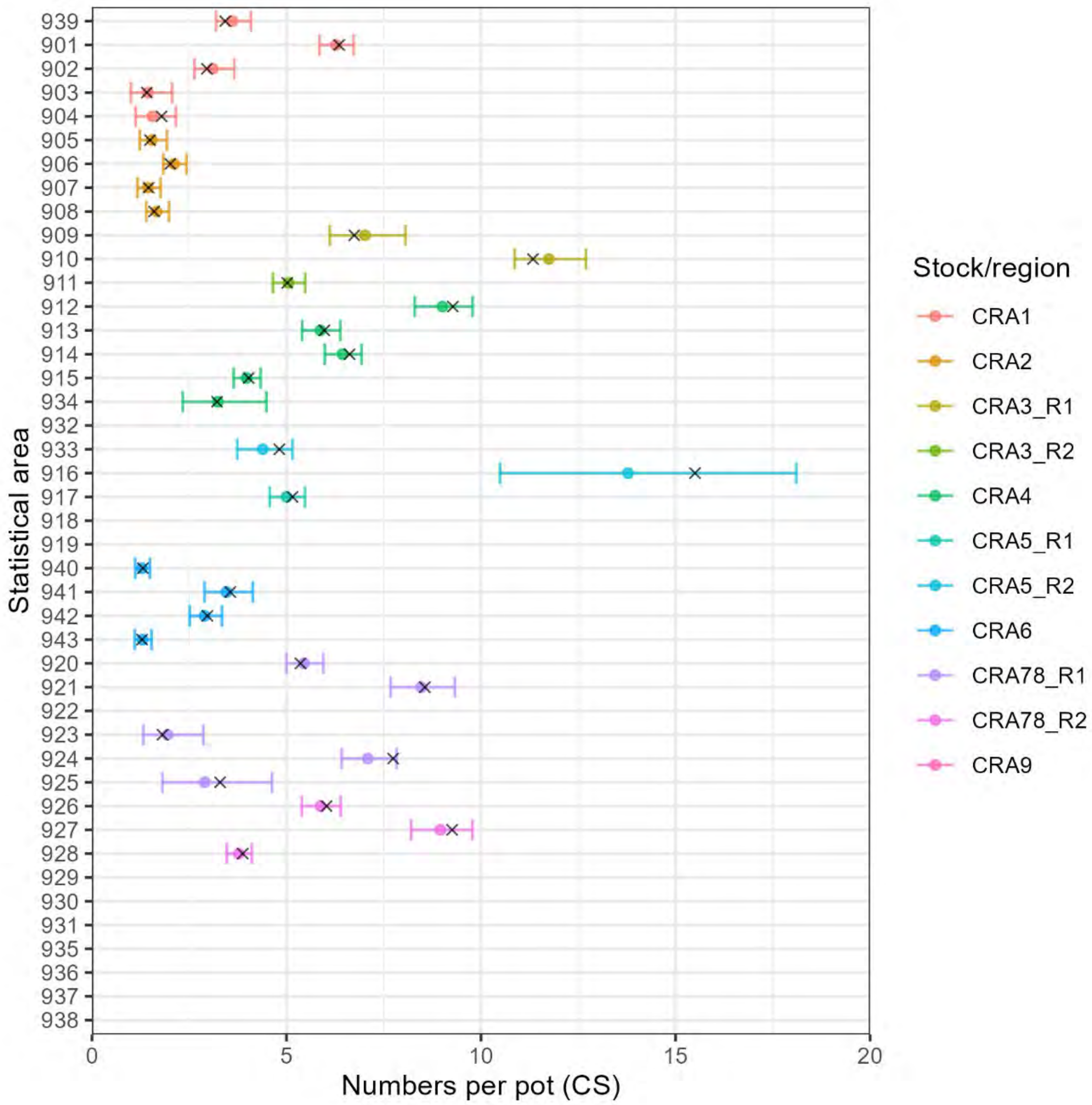


Figure F.9: Predicted numbers per pot by statistical area, based on the model fitted to <u>observer catch-at-sea sampling (CS)</u> CPUE data. The closed circles represent mean estimates, the whiskers represent 95% confidence intervals, and the crosses represent unstandardised averages.

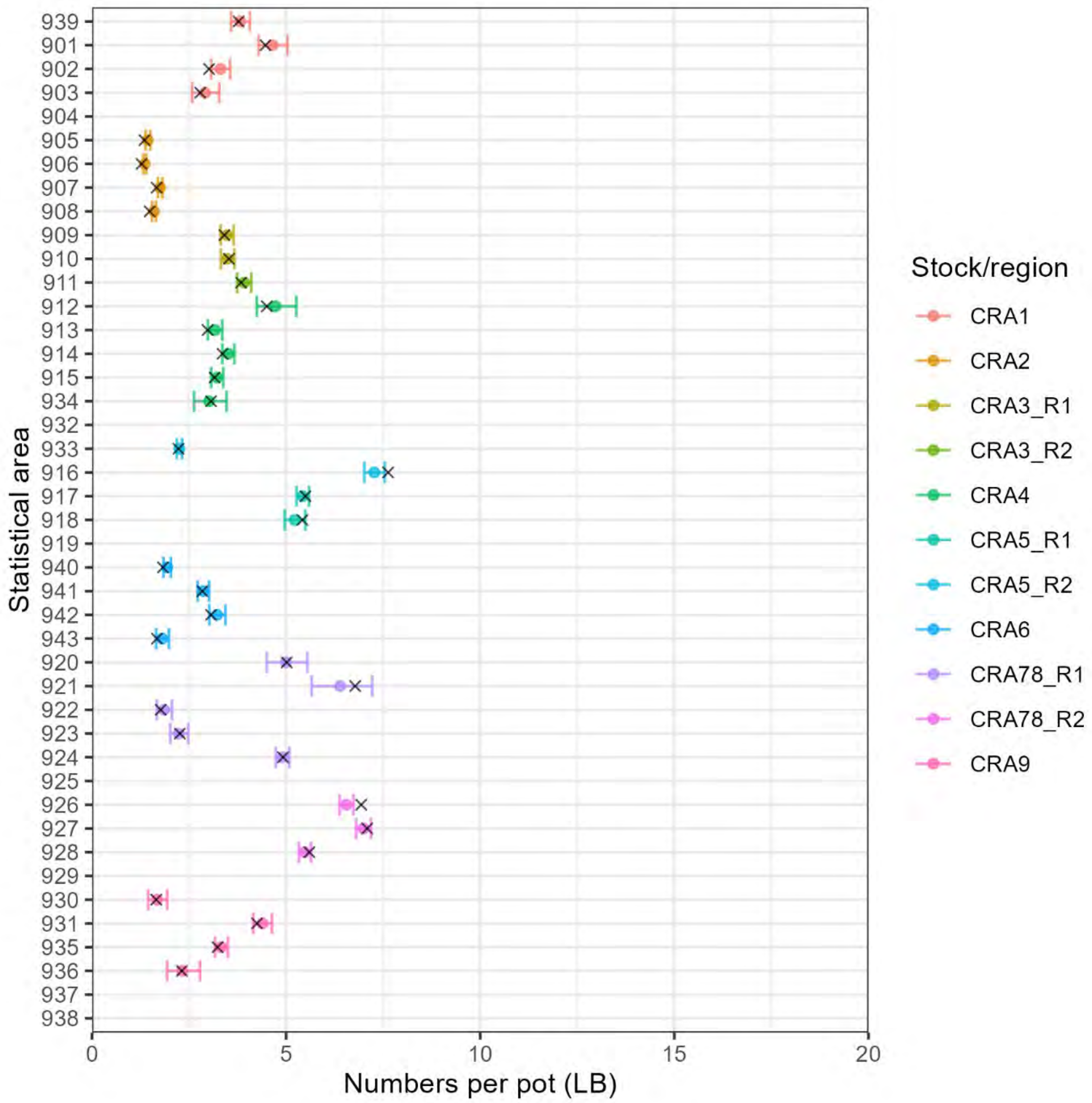


Figure F.10: Predicted numbers per pot by statistical area, based on the model fitted to voluntary logbook sampling (LB) CPUE data. The closed circles represent mean estimates, the whiskers represent 95% confidence intervals, and the crosses represent unstandardised averages.

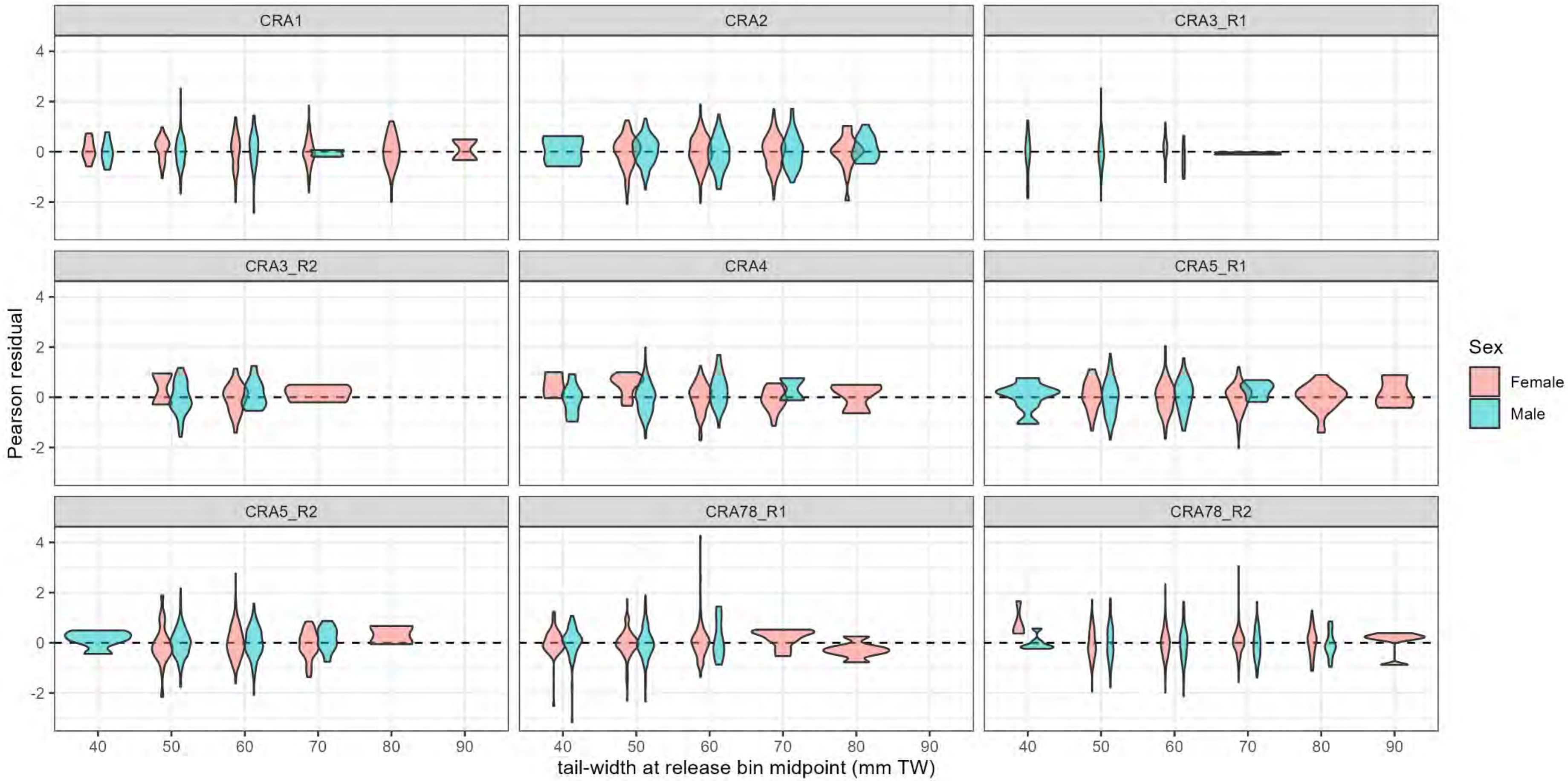


Figure F.11: Distribution of Pearson residuals from the growth model by 10 mm tail-width of release bin (mm TW), sex, and QMA/region.

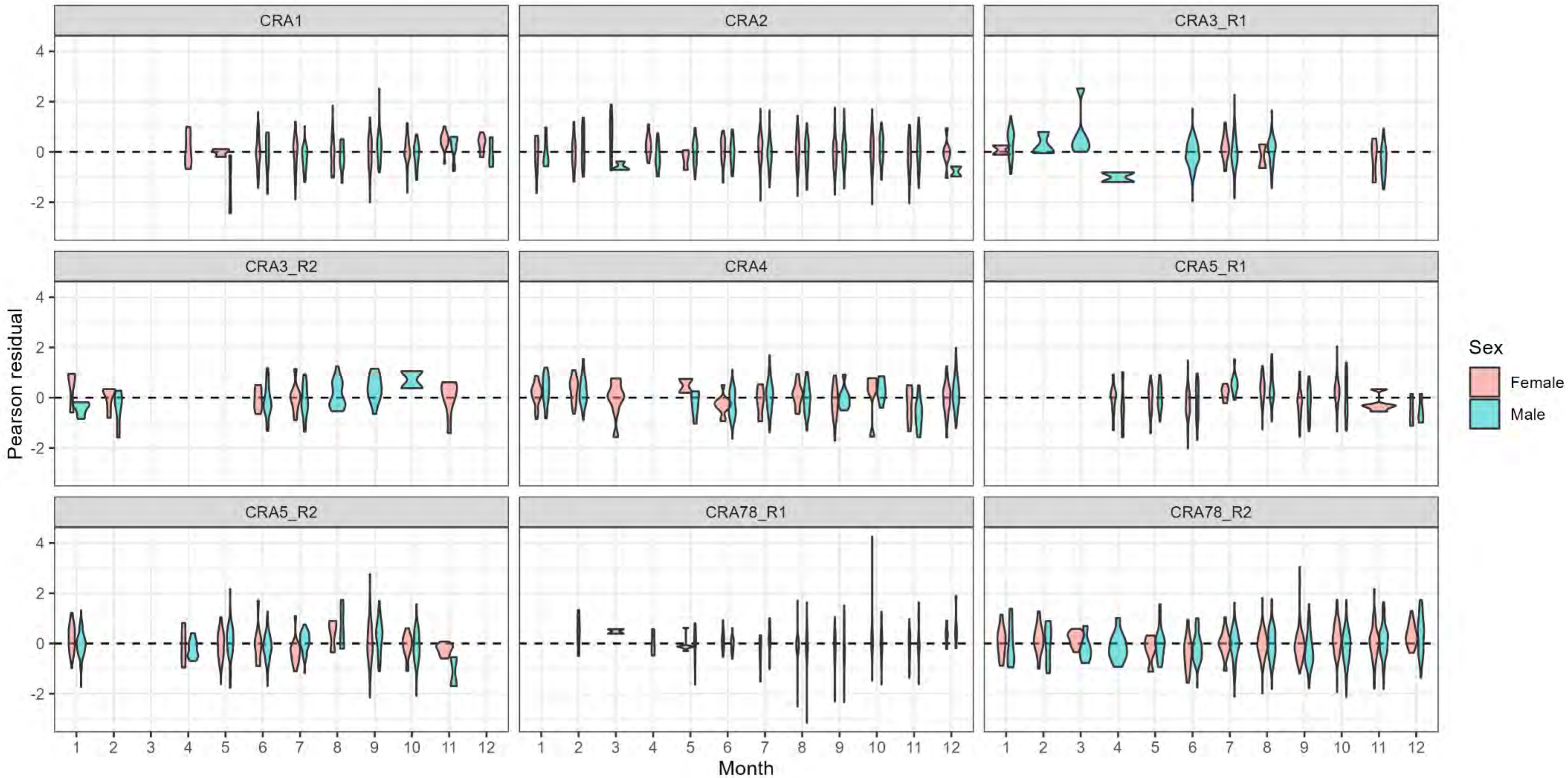


Figure F.12: Distribution of Pearson residuals from the growth model by month of release, sex, and QMA/region.

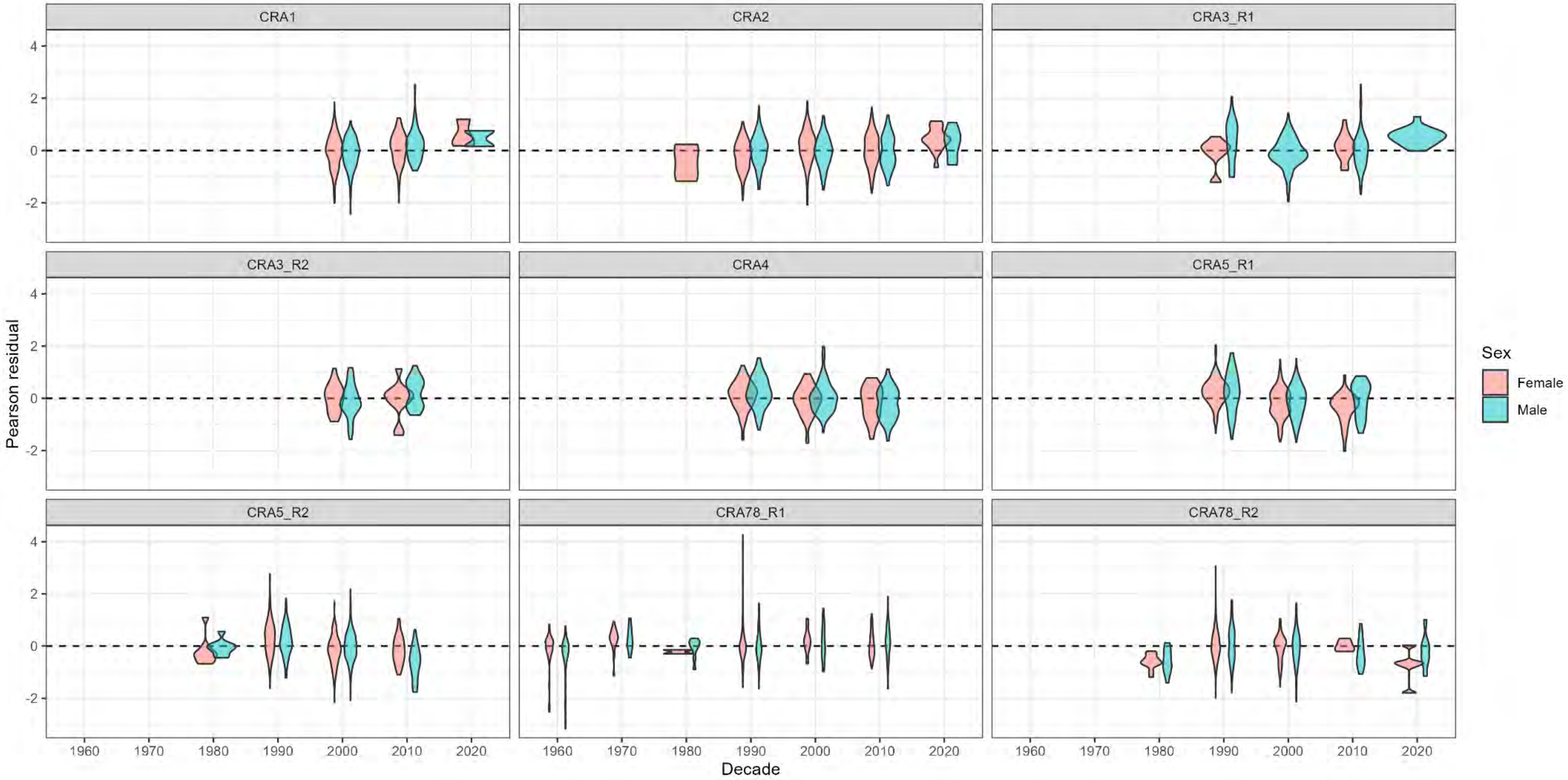


Figure F.13: Distribution of Pearson residuals from the growth model by decade of release, sex, and QMA/region.

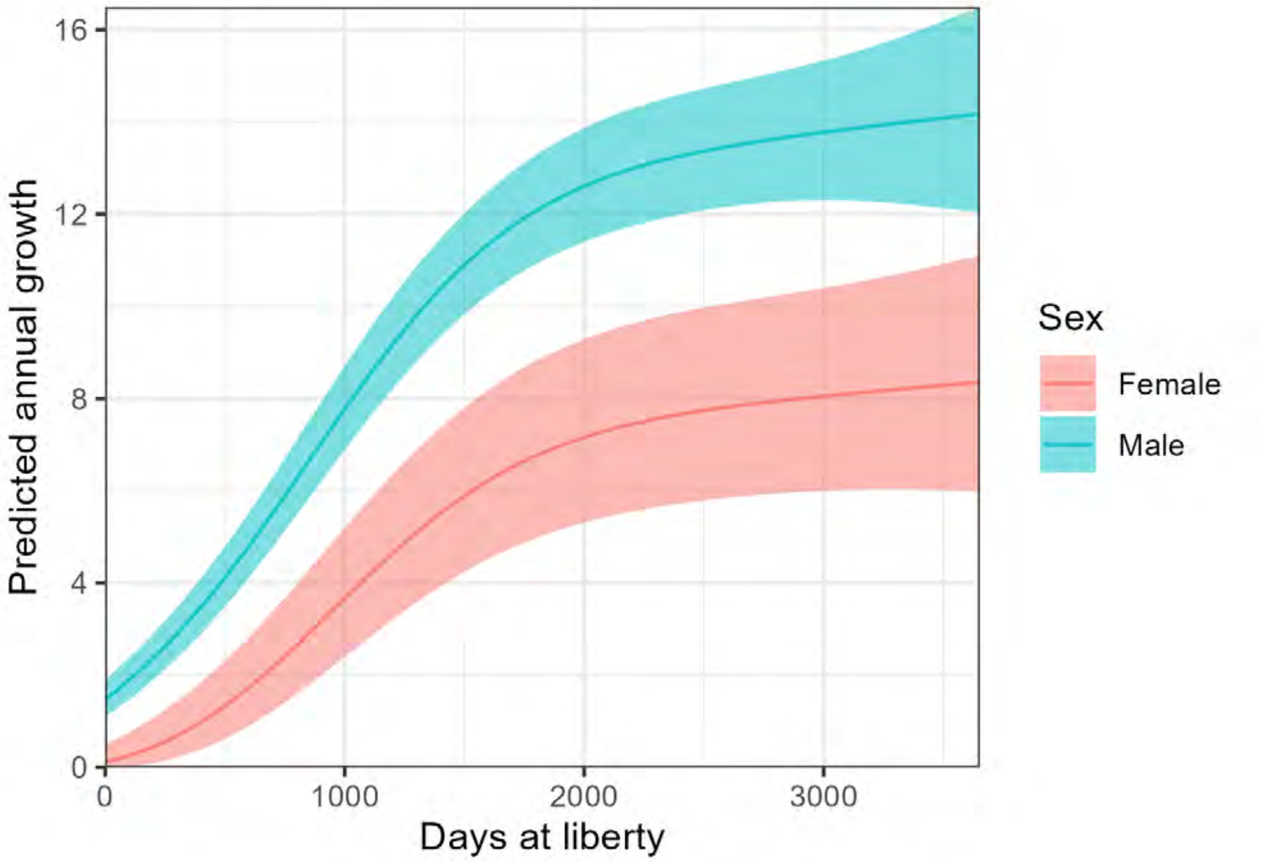


Figure F.14: Predicted growth increment of males and females in response to days at liberty.

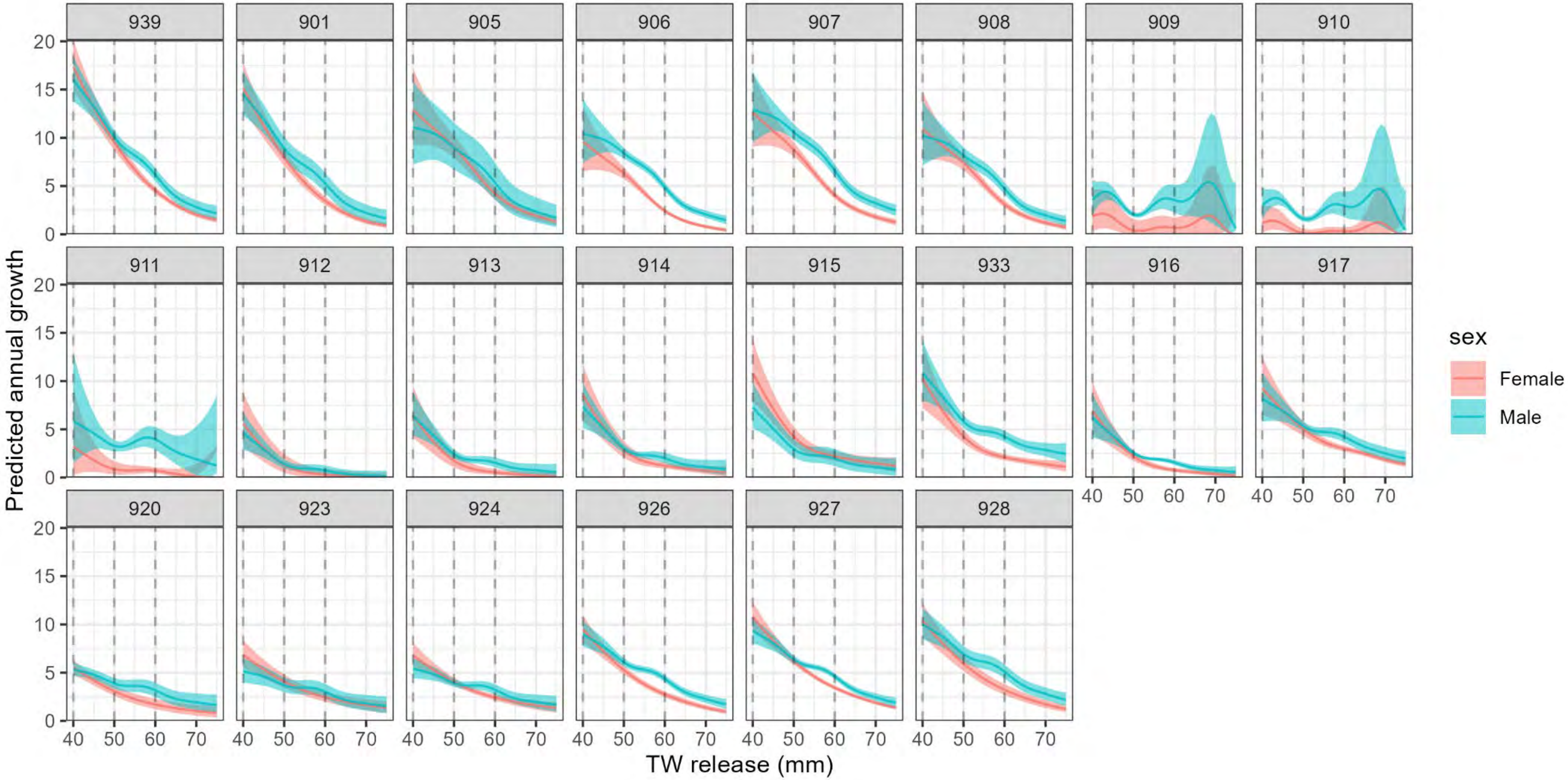


Figure F.15: Predicted annual growth increment of males and females by tail-width (TW) of release and statistical area. Lines represent mean estimates and shaded areas represent 95% confidence intervals. The dashed lines represent the TW values used to summarise predictions in Figure F.16.

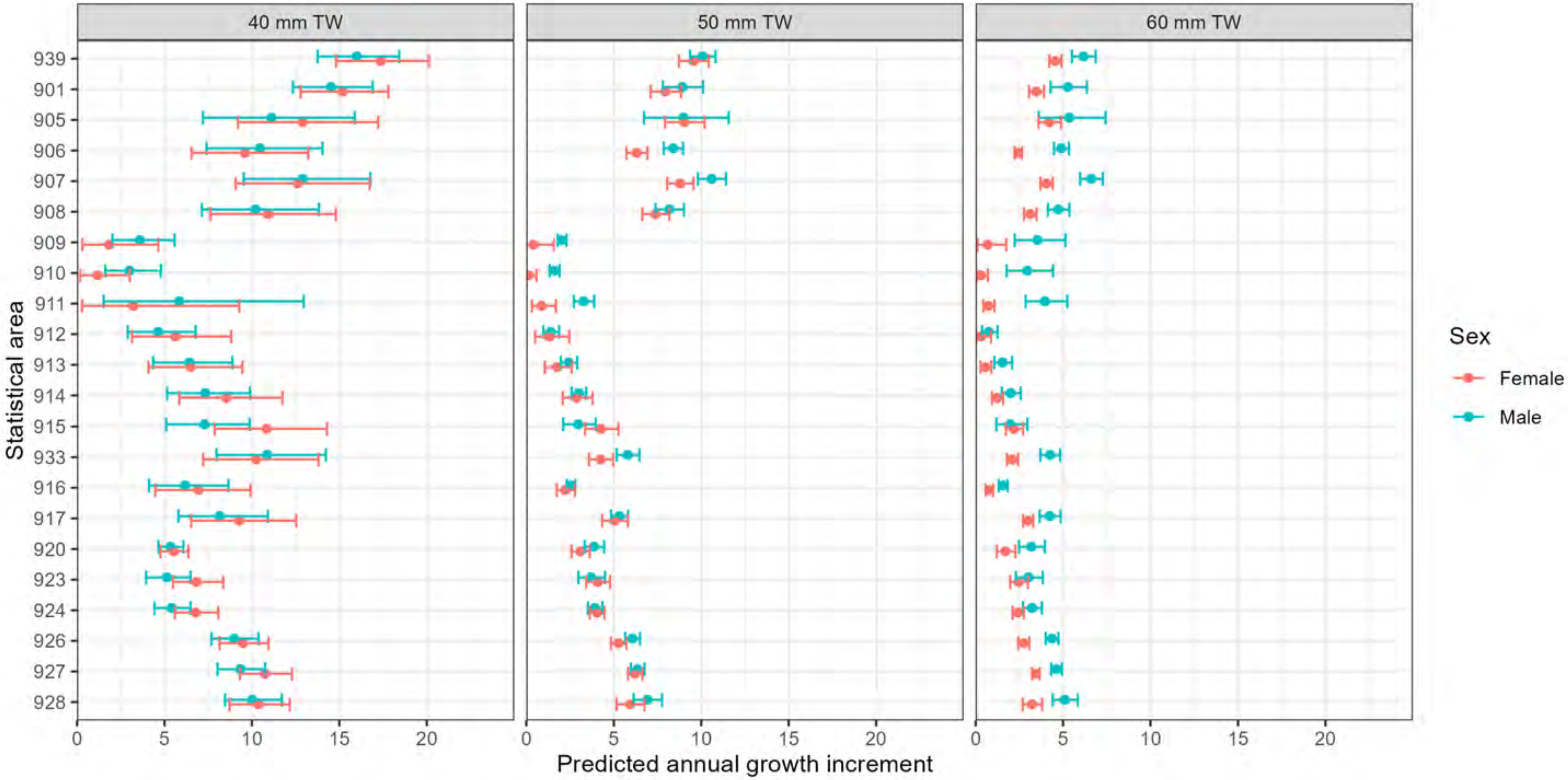


Figure F.16: Predicted annual growth increment of males and females by statistical area at selected values of tail-width of release. Points are mean estimates and whiskers represent 95% confidence intervals.

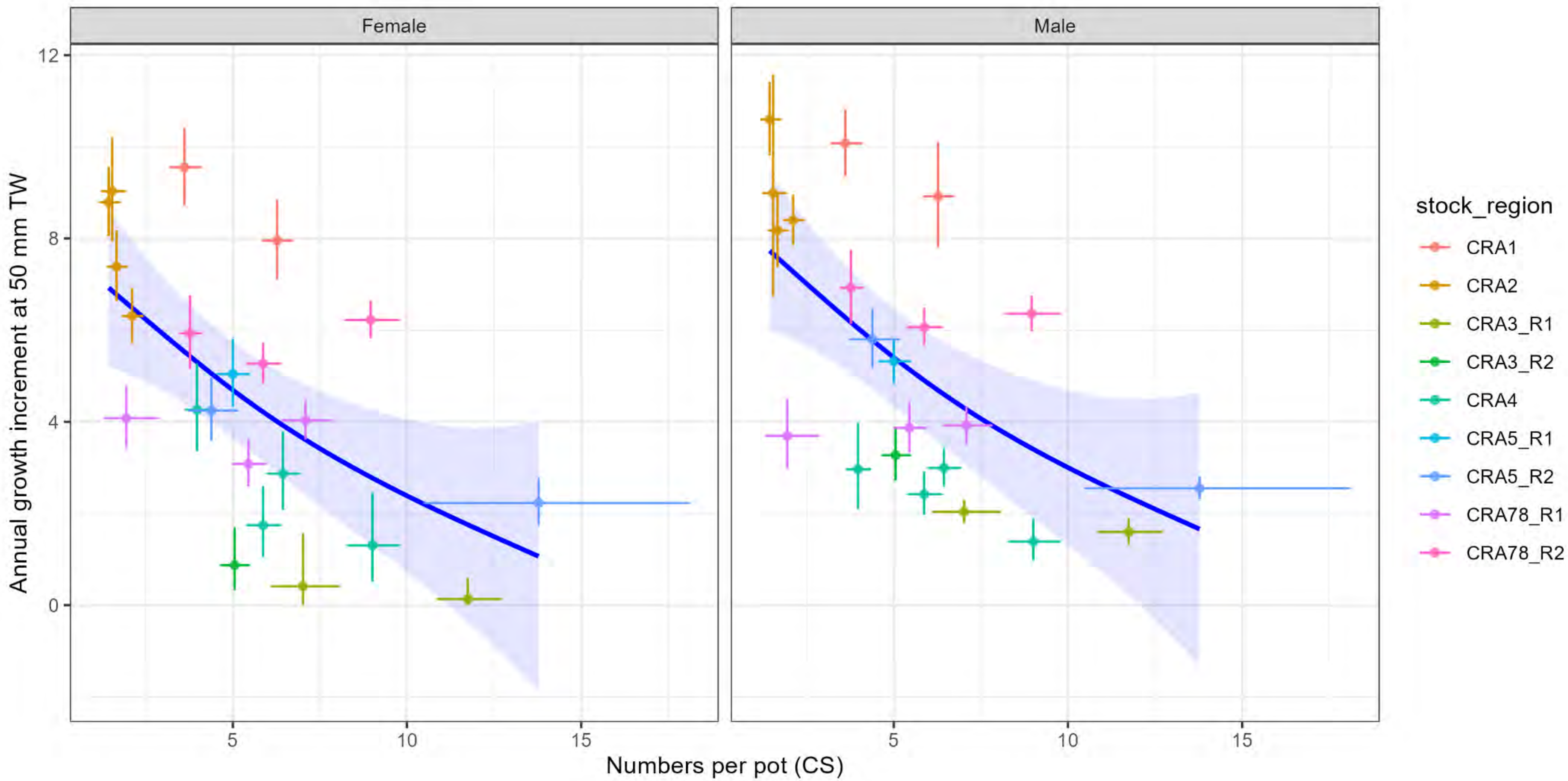


Figure F.17: The relationship between predicted numbers per pot from the <u>CS model (including lobsters above and below the MLS)</u> and the predicted annual growth increment at 50 mm TW by statistical area. Whiskers represent the 95% confidence intervals around model predictions. The blue line represents a GAM smooth using the points estimates of each prediction and the shaded area represents the 95% confidence interval of this relationship.

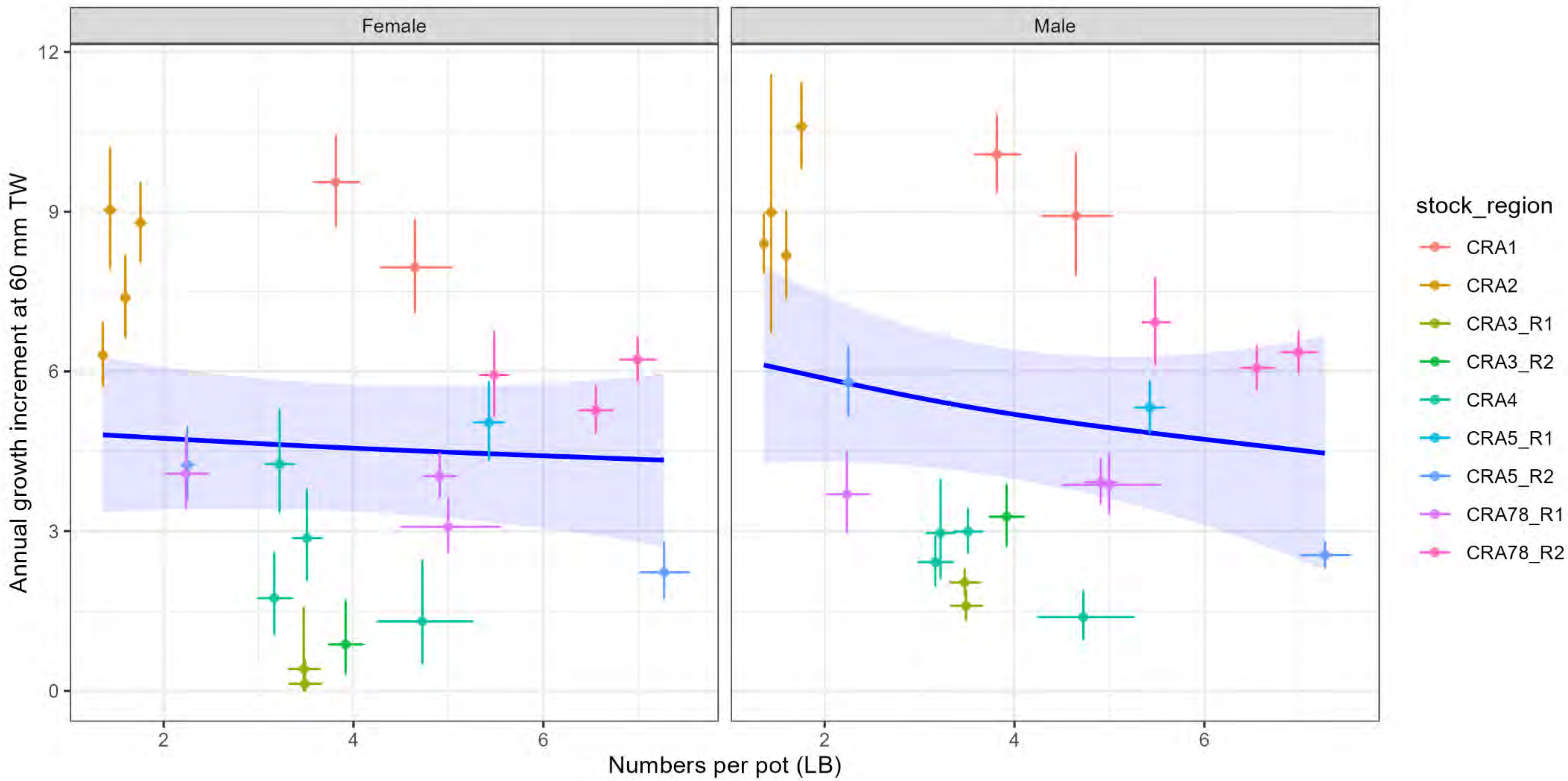


Figure F.18: The relationship between predicted numbers per pot from the <u>LB model (including lobsters above the MLS only)</u> and the predicted annual growth increment at 50 mm TW by statistical area. Whiskers represent the 95% confidence intervals around model predictions. The blue line represents a GAM smooth using the points estimates of each prediction and the shaded area represents the 95% confidence interval of this relationship.

Appendix G. MATURITY EXPLORATION

H.1 Background

The current stock assessment model for CRA 3 experienced difficulties with estimating maturation parameters, which are likely to be confounded with other model parameters, e.g., vulnerability by sex/maturity stage and season. Briefly, the lobster stock dynamics (LSD) model used to assess New Zealand red rock lobster stocks (Webber et al. 2023) uses a logistic maturation curve to specify the proportion of females that are mature by tail width bin (m_l)

Equation 1:

$$m_l = 1/1 + \exp\left(-\frac{\log(19)}{\kappa^m(\ell_l - \mu^m)}\right) \quad \text{where} \quad m_l \in [0, 1]$$

where ℓ_l is the mid-point of each tail-width based size-class and the parameters μ^m and κ^m define the curve's midpoint and steepness, respectively. In the CRA 3 stock assessment, the maturation parameters are respectively defined as *mat50* (the TW at which 50% of immature females become mature) and *mat95* (the difference between *mat50* and the TW at which 95% of immature females become mature).

In this Appendix, maturity stage information from the existing catch sampling data were used to determine probable region-specific values for the two maturation parameters for use by the CRA 3 stock assessment.

Also, comparison was made with the maturity stage information from the other assessed red rock lobster stocks. Given the relatively slow growth of female lobsters in region 1 of CRA 3 (Appendix F), we asked the question whether they also mature at smaller sizes which would be consistent with observations from Tasmanian stocks of *J. edwardsii* (Gardner et al. 2006).

H.2 Maturity stage data

There are two main sources of information for the size at maturity of red rock lobsters around New Zealand: the observer catch-as-sea sampling (CS) data, collected by trained technicians; and the voluntary logbook sampling (LB) data collected by commercial fishers. The CS data were provided by Fisheries New Zealand in September 2024 (rep log 16129) and the LB data were provided by Fishserve in October 2024.

Mature females were defined in the CS sample as being individuals with reported sex codes from 3–7, inclusive, and for the LB sample were individuals with reported sex codes from 3–5 (i.e., including females that were considered mature, berried, and spent, but not of unidentified maturity stage). The total sample size of mature females recorded by the CS and LB programmes is displayed by stock/region in Table G.1 and is summarised by QMA/region and fishing year and data source in Table G.2, Table G.3, and Figure G.1.

The proportion of females that were mature is shown by statistical area, 1 mm TW bin, and data source in Figure G.2. From these plots, there was very good agreement in the size-at-maturity information for some areas (e.g., Statistical Area 924 in CRA 7&8 Southland, and Statistical Area 927 in CRA 7&8 Fiordland), poor agreement in some areas (e.g., Statistical Area 907 in CRA 2), and moderate agreement in others.

Notably, the LB data for some areas include an implausibly high proportion of very small lobsters (i.e., < 40 mm TW) that were mature according to the data (e.g., Statistical Area 920 in CRA7&8 Southland). Hence, given probable issues in the reported maturity stages of females in the LB data for some areas, only the CS data were used in this maturity analysis, of which there was a good sample size for all QMA/regions apart from CRA 9 (Table G.1).

H.2 Maturity stage by tail-width

A GAM smoothing function was estimated for each statistical area using the *ggplot2 R* package (Wickham 2016; R Core Team 2024). This appeared to be a good representation of the CS maturity data based on a comparison with binned proportions (Table G.3), and had biologically plausible relationships in most areas except for a small number in which the proportion increased at very small sizes (e.g., areas 927 and 939), although this did not seem to appreciably affect the agreement of the area-based smoothing functions with the data at larger sizes.

Based on the CS data only, the size at 50% maturity was likely to vary considerably by QMA/region, ranging from about 40 mm TW in area 910 (CRA 3 region 1) and about 45 mm TW in area 911 (CRA 3 region 2) to 55–60 mm TW in areas 926–928 (CRA 7&8 Fiordland) (Figure G.3).

Analogous GAM smoothing functions were estimated for data aggregated by QMA/region (Figure G.4), which provided further confirmation of the size at 50% maturity being about 40 mm TW in region 1 of CRA 3, compared with about 45 mm TW in region 2 of CRA 3.

H.3 Conclusions for stock assessment

Based on this analysis, the size at 50% maturity was likely to be about 40 mm TW in region 1 of CRA 3 and about 45 mm TW in region 2. Note that the size at 50% maturity (this analysis) will occur at slightly smaller sizes than the size at 50% *maturation* (how this process is represented in the stock assessment models). However, sensitivity values for *mat50* set 5 mm TW below (i.e., 35 mm TW and 40 mm TW for region 1 and region 2, respectively) and above these proposed base case values (i.e., 45 mm TW and 50 mm TW for region 1 and region 2, respectively) were considered likely to encompass the true values of *mat50*.

The apparent maturation of females at smaller sizes in region 1 of CRA 3 compared with all other QMAs/regions is consistent with slow individual growth, potentially mediated by density dependent effects, given the high catch rate here of sub-legal lobsters (Appendix F).

H.4 Tables and Figures

Table G.1: Total number of mature females sampled by QMA/region and data source (CS: catch-at-sea observer sampling; LB: voluntary logbook sampling).

QMA/region	Mature females sampled by source	
	CS	LB
CRA 1	57 762	15 669
CRA 2	34 359	131 135
CRA 3_R1	67 883	9 914
CRA 3_R2	50 248	14 732
CRA 4	254 423	39 887
CRA 5_R1	29 178	188 870
CRA 5_R2	13 630	133 022
CRA 6	20 559	15 943
CRA 7&8_Fiordland	141 318	422 621
CRA 7&8_Southland	105 855	54 933
CRA 9	108	25 569

Table G.2: Total number of mature females sampled by the observer catch-at-sea sampling programme, by QMA/region and fishing year.

Fishing year	CRA 1	CRA 2	CRA 3 R1	CRA 3 R2	CRA 4	CRA 5 R1	CRA 5 R2	CRA 6	CRA 7&8 Southland	CRA7&8 Fiordland	CRA 9
1986	–	284	70	175	237	–	–	–	–	–	–
1987	–	151	–	–	1 047	–	–	–	2 565	–	–
1988	–	–	–	–	994	–	–	–	2 156	–	–
1989	–	–	1 726	–	3 818	2 051	–	936	1 542	10 697	–
1990	–	233	5 169	–	13 668	2 942	–	–	3 380	15 153	–
1991	–	406	5 005	–	7 715	2 622	–	–	3 449	19 246	–
1992	–	–	4 377	–	4 712	1 505	–	–	2 492	14 736	–
1993	–	–	4 534	1 731	5 492	3 844	–	609	1 884	11 578	–
1994	–	–	4 176	2 841	2 574	3 227	–	497	3 555	14 497	–
1995	–	–	2 626	1 016	3 418	2 621	–	1 515	2 215	12 077	–
1996	–	472	3 036	1 457	864	2 948	2 167	8 287	2 852	20 731	–
1997	1 155	–	4 030	348	9 898	1 976	377	1 630	3 413	9 157	–
1998	952	–	3 575	743	4 597	1 074	1 462	–	3 743	–	–
1999	3 034	1 873	2 226	291	6 727	1 191	3 871	–	3 803	–	–
2000	2 708	1 799	3 334	1 169	9 697	437	4 412	–	5 289	1 760	–
2001	1 349	1 746	3 697	1 506	9 266	–	–	–	4 823	–	108
2002	2 429	1 313	1 167	2 691	7 856	–	–	–	2 343	5 465	–
2003	3 078	1 109	1 024	3 921	8 047	–	–	–	3 026	–	–
2004	2 095	735	968	2 091	9 880	–	–	–	3 372	–	–
2005	2 626	993	1 248	2 092	12 481	–	–	–	3 361	–	–
2006	2 510	1 003	1 330	1 494	10 640	–	–	–	3 320	–	–
2007	1 221	1 046	876	1 362	8 433	–	–	–	3 128	–	–
2008	1 795	1 287	2 029	1 422	7 451	804	691	–	3 082	–	–
2009	2 357	1 654	1 420	1 177	8 467	468	243	–	2 353	–	–
2010	2 289	1 156	1 186	1 000	8 310	753	407	–	2 170	6 221	–
2011	2 176	1 207	463	1 073	6 126	–	–	–	1 361	–	–
2012	3 795	1 379	362	2 105	8 187	–	–	–	1 996	–	–
2013	2 261	1 690	560	1 475	6 264	–	–	–	1 930	–	–
2014	1 932	1 706	954	1 356	5 251	–	–	–	1 903	–	–
2015	561	844	337	2 152	5 972	–	–	–	2 163	–	–
2016	3 629	879	517	1 077	4 851	–	–	–	2 051	–	–
2017	919	1 134	1 200	607	9 095	–	–	–	3 103	–	–
2018	1 453	1 315	1 787	913	5 030	715	–	–	4 000	–	–
2019	1 955	–	673	1 148	5 727	–	–	–	3 059	–	–
2020	1 684	2 463	754	2 203	7 793	–	–	1 907	3 051	–	–
2021	2 001	1 840	148	2 970	9 339	–	–	–	3 097	–	–
2022	4 290	1 421	735	3 542	9 563	–	–	3 008	2 973	–	–
2023	1 508	1 221	564	1 100	4 936	–	–	2 170	1 852	–	–

Table G.3: Total number of mature females sampled by the voluntary logbook catch sampling programme, by QMA/region and fishing year.

Fishing year	CRA 1	CRA 2	CRA 3 R1	CRA 3 R2	CRA 4	CRA 5 R1	CRA 5 R2	CRA 6	CRA 7&8 Southland	CRA 7&8 Fiordland	CRA9
1986	–	–	–	–	–	–	–	–	–	–	–
1987	–	–	–	–	–	–	–	–	–	–	–
1988	–	–	–	–	–	–	–	–	–	–	–
1989	–	–	–	–	–	–	–	–	–	–	–
1990	–	–	–	–	–	–	–	–	–	–	–
1991	–	–	–	–	–	–	–	–	–	–	–
1992	–	–	–	–	–	–	–	–	–	–	–
1993	65	9 423	773	332	–	–	–	–	6 102	13 466	–
1994	267	9 184	511	892	–	5 490	2 656	–	4 276	12 855	–
1995	150	4 981	383	93	–	2 674	1 412	–	5 422	19 657	–
1996	–	5 204	441	85	–	4 797	1 587	–	5 003	11 253	76
1997	–	3 884	20	26	1 230	3 806	1 930	–	2 300	12 293	149
1998	–	4 360	68	64	1 147	2 267	2 519	–	1 521	11 642	283
1999	–	6 057	–	89	146	3 127	3 354	–	327	6 362	148
2000	–	5 399	–	198	101	5 788	6 943	–	2 945	9 008	759
2001	–	3 174	–	125		5 855	7 651	64	3 261	4 875	1 111
2002	–	4 787	–	–	294	7 235	8 761	276	2 789	8 008	–
2003	–	3 808	–	–	1 165	3 942	8 776	660	1 652	8 105	395
2004	–	3 774	73	–	752	5 256	8 484	500	1 361	6 606	263
2005	–	5 476	8	–	1 290	5 197	9 853	1 589	1 747	7 225	950
2006	–	4 003	4	–	759	6 337	9 192	1 009	1 578	10 158	1 356
2007	–	4 352	168	–	764	6 890	9 790	1 376	1 819	7 990	1 729
2008	–	4 965	29	–	158	4 254	6 280	1 159	1 137	10 302	2 092
2009	–	4 629	46	–	461	7 741	6 612	355	1 112	11 735	2 371
2010	–	5 618	258	58	1 321	8 559	4 416	509	278	15 812	530
2011	131	4 805	106	134	817	6 830	4 950	1 162	594	17 408	1 177
2012	206	5 130	167	1	1 561	8 691	4 666	350	9	21 348	850
2013	144	5 110	827	–	1 115	4 773	3 244	–	158	18 872	841
2014	289	4 587	838	942	2 684	7 933	4 523	645	577	20 449	729
2015	1 767	3 416	658	1 413	2 650	5 411	3 001	479	5	17 967	1 228
2016	1 614	1 893	428	787	4 443	6 811	2 854	246	156	14 626	1 770
2017	1 523	2 318	740	1 006	3 347	8 381	1 777	406	756	19 677	1 268
2018	1 570	2 036	418	542	3 086	8 889	1 036	703	1 239	21 579	1 571
2019	1 085	1 482	1 392	927	2 851	10 248	1 147	433	1 111	10 082	999
2020	1 131	2 336	708	2 406	2 803	8 566	1 234	1 155	1 317	18 375	467
2021	1 361	1 793	77	1 579	1 743	5 824	1 823	909	1 354	14 822	552
2022	2 405	1 516	653	1 245	2 022	8 781	1 525	1 139	1 533	19 649	985
2023	1 961	1 635	120	1 788	1 177	8 517	1 026	819	1 494	20 415	920

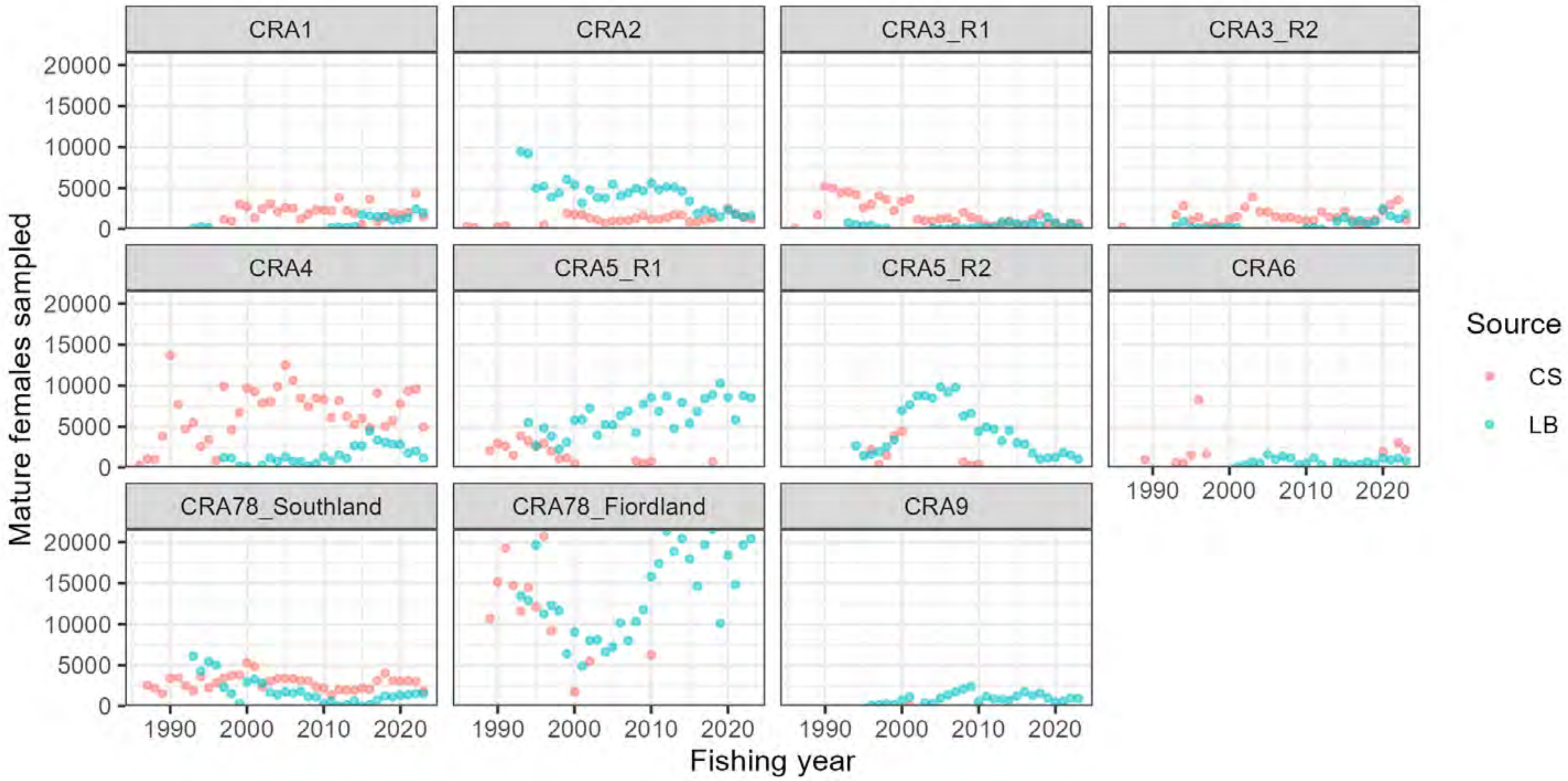


Figure G.1: Number of mature females sampled by stock/region, fishing year, and data source ('CS' = catch-at-sea observer sampling; 'LB' = voluntary logbook sampling).

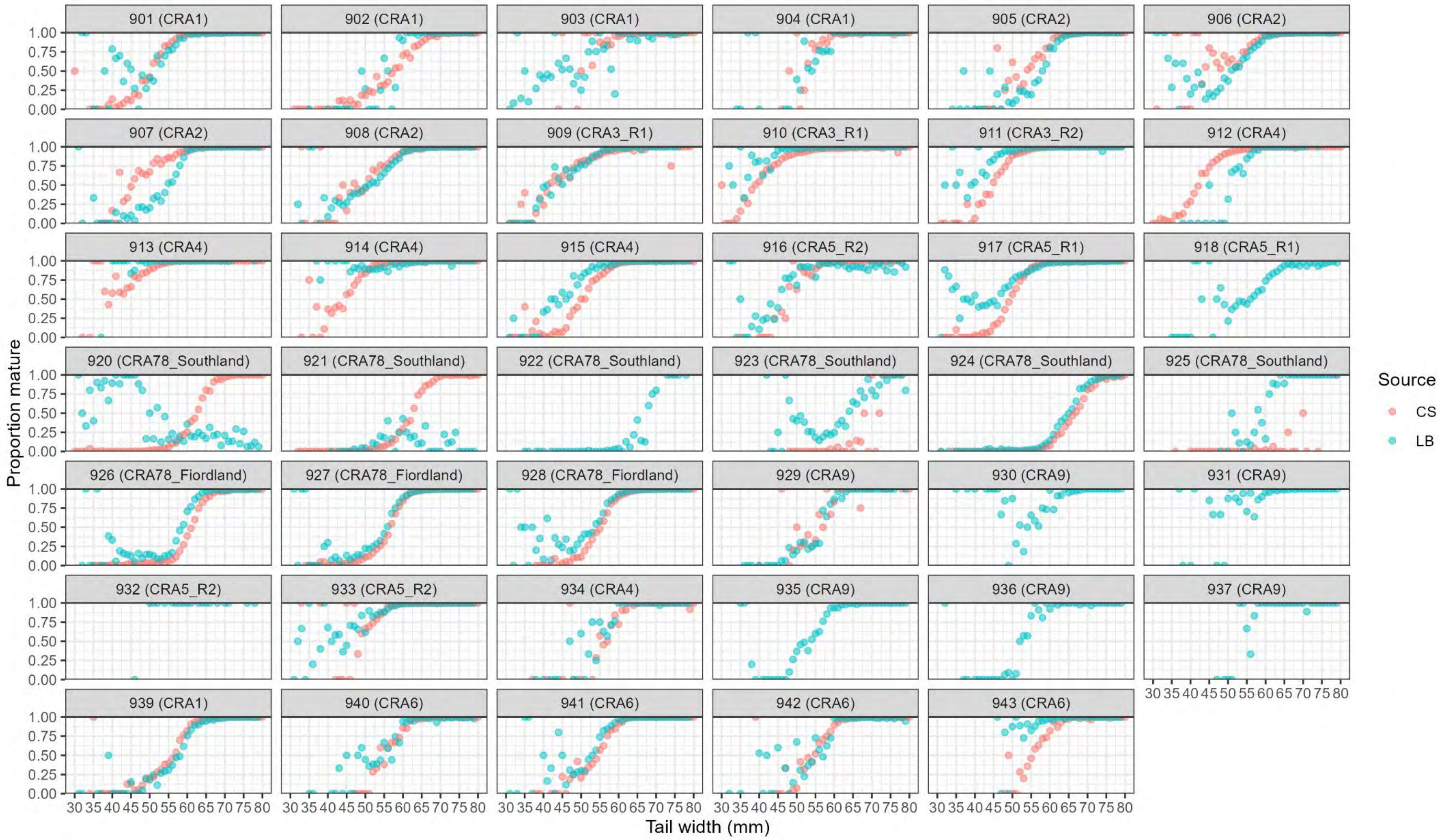


Figure G.2: Proportion of mature females that were mature by statistical area, tail width, and data source (‘CS’ = catch-at-sea observer sampling; ‘LB’ = voluntary logbook sampling).

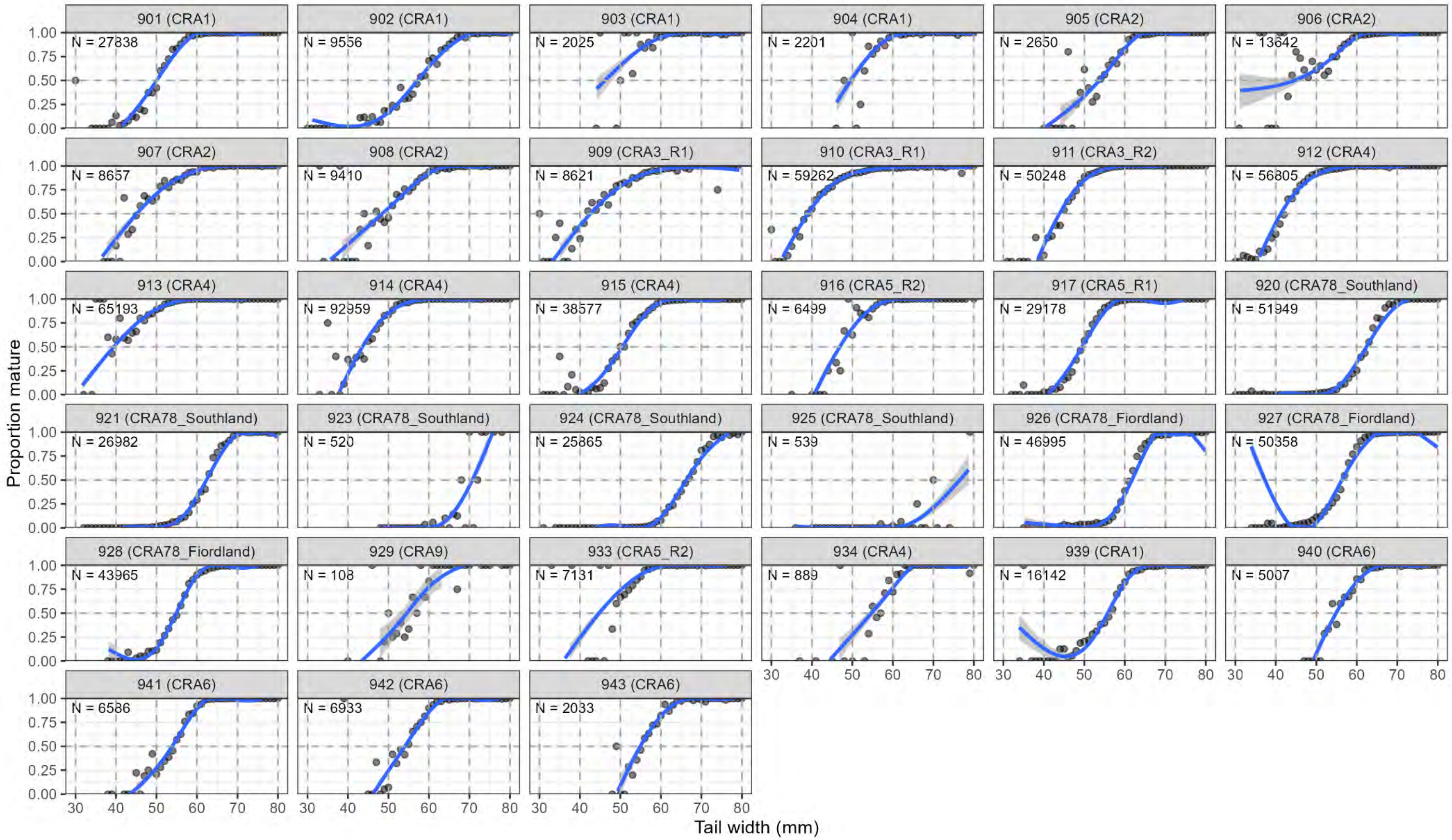


Figure G.3: Proportion of mature females that are mature by stock/region and tail-width (TW). Points show the mean proportion by 1 mm TW bin, the blue lines show the predictions of a GAM fitted to the raw (un-binned) TW values and the shaded areas are the 95% confidence interval of the prediction. Plots are annotated with the total sample size of mature females for each area (N).

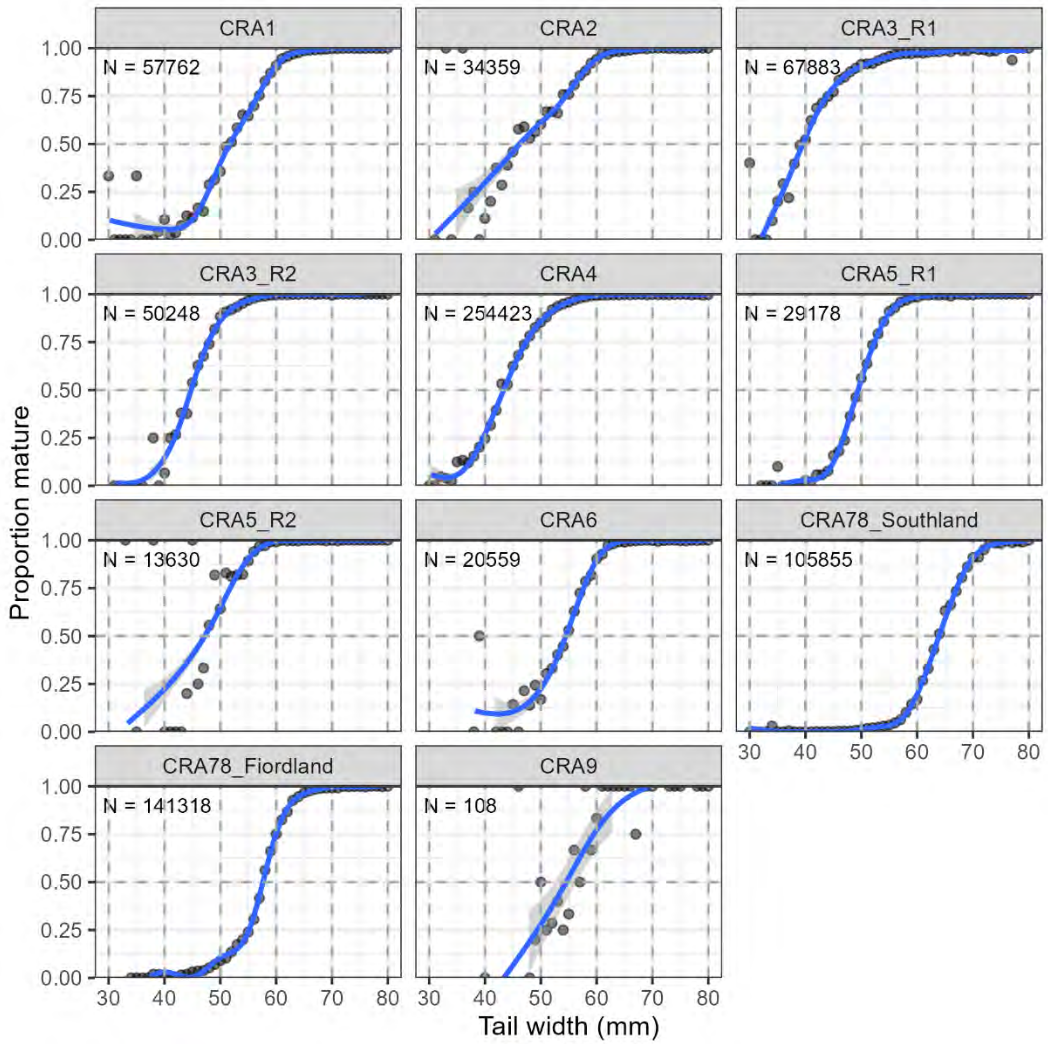


Figure G.4: Proportion of mature females that are mature by stock/region and tail-width (TW). Points show the mean proportion by 1 mm TW bin, the blue lines show the predictions of a GAM fitted to the raw (un-binned) TW values and the shaded areas are the 95% confidence interval of the prediction. Plots are annotated with the total sample size of mature females for each stock/region (N).

Appendix H. EXPLORATION OF SEX-SPECIFIC CPUE

I.1 Introduction and method

Introduction

All recent stock assessments of red rock lobsters have been fitted to three main data types from the commercial fishery: catch-per-unit-effort (CPUE), catch length frequencies (LFs), and catch sex ratios (SRs). Based on Appendix F, the proportion of females in the catch in region 1 of CRA 3 is anomalously low when compared with other assessed New Zealand stocks/regions and this may be primarily caused by density-dependent effects, which appear to affect female growth. However, as the August Plenary review of the CRA 3 assessment noted, the proportion of females in the catch in CRA 3 appears to have declined over time, particularly in region 1, and interim stock assessment runs (not shown here) did not fit well to the temporal trend in sex ratio.

Because the CPUE series combines this information from both males and females, it is not immediately clear whether the trend in sex ratio was caused by relatively good male status, poor female status, or a combination of these. To address this, the analysis in this Appendix used the sampling data from the observer catch-at-sea (CS) and voluntary logbook (LB) sampling programmes to explore the development of sex-specific CPUE series. The expectation was that the trending sex ratios in the catch data from CRA 3 would be caused by differential trends in males and female CPUE over time and that this would not be the case in other assessed stocks/regions of New Zealand. Hence, all fisheries statistical areas with ample data were assessed to facilitate comparison between CRA 3 and other assessed stocks.

Method

The CS and LB data extract used for this analysis were the same as was used for the preparation of LF and SR series used by the current CRA 3 stock assessment (see Section 2.1.2) and the data preparation method was essentially the same (including the statistical area correction for the LB data based on reported positional data), except that the numerical abundances of male and female captures were derived. This was done at the trip level and was achieved by multiplying the total reported number of captured lobsters of both sexes by the total number of *measured* males or females divided by the total number of *measured* lobsters of both sexes. This resulted in non-integer catch numbers by sex, which were rounded to the nearest integer to facilitate the use of count-based statistical model distributions.

It should be noted that the RLWG decided to exclude both region 1 and region 2 CS CPUE series from the CRA 3 stock assessment because they were thought to be unrepresentative of the fishery due to the small number of vessels used in the sampling. However, these data were retained for this exploratory analysis as they were believed to be the most informative data available to address this issue of comparative CPUE trends by sex over time in the two regions. Similarly, the stock assessment excluded all LB data from the CPUE series used in the CRA 3 stock assessment before 2014 due to concerns for likely non-representativeness. These data were retained for the purposes of this exploratory analysis but trends before 2015 should be interpreted with caution.

At-sea catch sampling programme observers are permitted to skip pots during periods of high catch rate that would otherwise impinge on fishing operations, such that we cannot determine the catch composition by sex of these pots. Pot skipping is known to be relatively frequent in region 1 of CRA 3 (Starr 2012), where the catch rate is generally high. No attempt was made in this analysis to address any potential bias in sex-specific catch rate due to pot-skipping behaviour. However, an initial exploration (not shown here) determined that, while pots containing fewer lobsters (and so were less likely to be skipped) generally included a slightly greater proportion of females, the rate of pot skipping in both regions of CRA 3 had not changed over time. Therefore, it was assumed for this exploratory analysis that, even if pot skipping might have biased the sex composition of the catch, any bias would be reasonably consistent over time for the purposes of estimating the relative catch rate of males or females by fishing year.

GAMs were fitted to numerical catch rate information from catch sampling data to generate sex-specific CPUE series for statistical areas with ample coverage. For the CS analysis, the areas deemed to have good coverage over time were Statistical Areas 910–915 and 920–921; among these eight area-fishing year strata, those with fewer than five fishing trips were excluded. For the LB analysis, the Statistical Areas deemed to have adequate coverage over time were areas 906–911, 916–917, 924, 926–928, and 933. For the LB analysis, only year-area strata with at least 50 fishing trips (larger than the cut-off used for CS data, because of the much smaller number of pots sampled per trip by the LB programme) and at least two vessels were used. It was assumed that the vessel-based cut-off was not required for the CS data, which were recorded by dedicated trained technicians and comprised a much larger number of pots per trip. As well, only one vessel would have been available for many of the area-year strata.

The derived number of lobsters per trip was modelled separately for each data source (LB or CS) and sex (i.e., four separate models) using the same GAM structure:

numbers caught by sex ~ log(pots) + fishing year + fishing year:statistical area + month + month:statistical area + s(vessel, bs = "re")

where ‘pots’ was the total number of pots per trip, the interaction terms between area and month as well as between area and year allowed temporal CPUE patterns (numbers per pot) to vary by area, and a vessel random effect was used. This model structure is broadly comparable with the CPUE model structure used for recent CRA stock assessments including the current CRA 3 assessment, except that CPUE was modelled by fishing year instead of by the respective six-month AW/SS periods for each fishing year. Because of the comparability with the approved CPUE model structure already used by recent stock assessments, no other model structures were trialled for this exploratory analysis. A negative binomial error structure was assumed with the dispersion parameter estimated during model fitting (‘family = nb()’).

I.2 Results

Catch sampling at-sea observer (CS) analysis

The trip-based dataset retained for the analysis of CS data is summarised by fishing year in Table H.1, Figure H.1, Figure H.2, Figure H.3. Briefly, this included data from CRA 3 (both regions), CRA 4, and CRA 7&8 (region 1 only), although with some temporal gaps in coverage in all areas.

The male CS CPUE model explained 82.3% of the null model deviance. This could not be calculated for the female model, due to there being two year-month-area strata for which there was no female catch (in areas 912 and 913), although the model fit with respect to fishing year and area was equally good for both sexes (Figure H.4, Figure H.5).

The number of males and females per pot for each fishing year was predicted from the CS model, using the most frequently occurring vessel and month in the CS data for the predictions. The resulting predictions are shown separately for each sex in Figure H.6 (as numbers per pot) and are shown on the same plot in Figure H.7 (rescaled to the geometric mean for each sex). For region 1 of CRA 3, the model predictions are consistent with male CPUE being relatively consistent over time, whereas female CPUE has a strong declining trend with the lowest estimates in the most recent three years with data (2021–2023). Sex differences in CPUE trend were not so apparent for region 2 of CRA 3 or in areas 920 and 921 (both region 1 of CRA 7&8), although there was evidence of this in Statistical Areas 913 and 914 (both in CRA 4).

The predicted monthly patterns in CPUE were different by sex, although these were similar when comparing the monthly predictions for different statistical areas within each sex (Figure H.8). The predicted numbers per pot are shown in Figure H.9 and showed the expected near-linear increasing trend in numbers caught with increasing pots per trip.

Voluntary logbook sampling (LB) analysis

The analogous (to the CS) data summary table and plots for the LB data are shown in Table H.2, Figure H.10, Figure H.11, and Figure H.12. Relative to the CS programme, there was much more consistent coverage over time for each statistical area (except for a gap in coverage in both regions of CRA 3) and the number of statistical areas with coverage was much greater than for the CS programme, with good representation in CRA 2 as well as all regions of CRA 3, CRA 5, and CRA 7&8.

The LB CPUE models explained 66.4% of the null model deviance for males and (as with the CS analysis) this statistic could not be calculated for females due to the zero catch of females in some model strata. The fits for both the male and female models indicated a degree of under-dispersion when assuming the negative binomial error structure, although this was consistent comparing years (Figure H.13, Figure H.14) and it was deemed unlikely to influence the model predictions for the purposes of this exploratory analysis.

The predicted CPUE series for each sex from the LB models is shown in Figure H.15 (numbers per pot) and in Figure H.16 (sexes overlaid and predictions rescaled to the geometric mean for each sex). For both regions of CRA 3, the model predictions are consistent with a relatively poor status of females over time, with the lowest estimates in region 1 again being in the most recent three years with data (as for the CS model). There were also signs of a relatively less optimistic CPUE trend for females in some statistical areas of CRA 2 (after 2018), in Statistical Area 916 (region 2 of CRA 5), and in Statistical Area 924 (region 1 of CRA 7&8) as well as at least some statistical areas in region 2 of CRA 7&8 (after 2020).

As with the CS model, the predicted monthly CPUE patterns from the LB models were different when comparing the sexes. However, while the monthly pattern for females was quite similar when comparing statistical areas, the seasonality of the predicted CPUE for males varied by statistical area (Figure H.17). As with the CS model, the predicted numbers per pot showed the expected near-linear increasing trend in numbers caught with increasing pots per trip (Figure H.18).

I.3 Conclusions for stock assessment

This exploratory CPUE analysis indicated that the CS and LB data were sufficiently informative to develop preliminary sex-specific CPUE series for many statistical areas. Some improvements in model fit could still be made for the LB model, although this was unlikely to have a major effect on the model predictions.

This analysis confirmed that the increasing relative predominance of males in the catches from region 1 of CRA 3 was likely to have been caused by a decline in female CPUE over time, which is not as apparent for males. For region 2 of CRA 3, the CS data analysis indicated that both male and female CPUE had varied over time with minimal differences when comparing the sexes, However, the LB data analysis possibly suggested a less optimistic status for females in CRA 3 region 2 for the most recent years. These CRA 3 region 1 and region 2 results should be viewed with some caution because the CS CPUE series were excluded from the CRA 3 stock assessment due to concerns about representativeness. The pre-2015 LB data were excluded for the same reason.

The apparently more adverse status of females in region 1 of CRA 3 (also possibly in region 2) could be represented in stock assessment models using:

- sex and time-varying natural mortality rates (*M*) (held constant across sexes and time in previous CRA stock assessments, e.g., Rudd et al. 2024); or

- sex-specific annual recruitment deviates (which might be more appropriate if a substantial proportion of the additional female mortality was occurring prior to recruitment to the fishery).

Either of these options would allow improved stock assessment model fits to trending sex ratio indices in CRA 3. Which of these options is likely to be more appropriate will depend on which sizes of females are potentially being affected by increasing mortality rate relative to males and may also be constrained by modelling practicalities.

This analysis is also consistent with the relatively less optimistic status of females in other QMAs (e.g., CRA 4), which may have implications for current spawning stock status and requires further exploration for the affected stocks.

I.4 Tables and Figures from Catch Sampling analysis

Table H.1: Number of fishing trips by fishing year and statistical area in the data used by the sex-specific catch sampling (CS) CPUE models. This dataset excluded fishing year-area combinations for which there was fewer than five fishing trips of CS sampling.

Fishing	CRA 3 R1	CRA 3 R2	CRA 4				CRA 7&8 R1	
year	910	911	912	913	914	915	920	921
1987	–	–	15	–	–	–	6	–
1988	–	–	15	–	–	–	10	–
1989	6	–	7	6	–	11	8	–
1990	10	–	14	10	–	13	9	–
1991	11	–	14	7	–	–	6	–
1992	11	–	13	6	–	–	9	–
1993	23	15	8	10	–	–	–	–
1994	20	18	–	7	–	–	8	–
1995	9	8	9	7	–	–	11	–
1996	–	8	–	–	–	–	16	12
1997	–	–	11	9	14	–	8	12
1998	14	5	8	9	9	–	9	5
1999	11	–	5	8	–	8	15	–
2000	9	–	9	8	6	–	9	6
2001	12	–	8	7	11	5	9	–
2002	9	9	10	8	13	–	9	6
2003	9	9	7	10	12	5	8	7
2004	–	9	7	11	14	–	10	5
2005	6	5	7	13	19	7	12	–
2006	7	–	–	7	24	12	7	8
2007	6	9	–	8	21	13	8	7
2008	–	7	6	–	11	20	10	5
2009	–	7	6	7	17	6	10	5
2010	10	5	–	8	15	13	8	7
2011	12	9	5	9	20	7	7	8
2012	11	5	–	13	21	–	11	–
2013	9	8	–	13	23	–	14	–
2014	12	–	–	9	21	–	15	–
2015	–	9	–	7	24	7	12	–
2016	–	–	–	9	19	8	11	–
2017	7	5	–	7	19	8	9	6
2018	–	6	8	9	18	7	12	–
2019	–	7	7	9	17	7	9	6
2020	–	11	7	8	23	8	8	7
2021	6	9	5	6	26	6	8	7
2022	11	11	6	10	22	10	10	5
2023	15	8	–	13	19	11	6	–

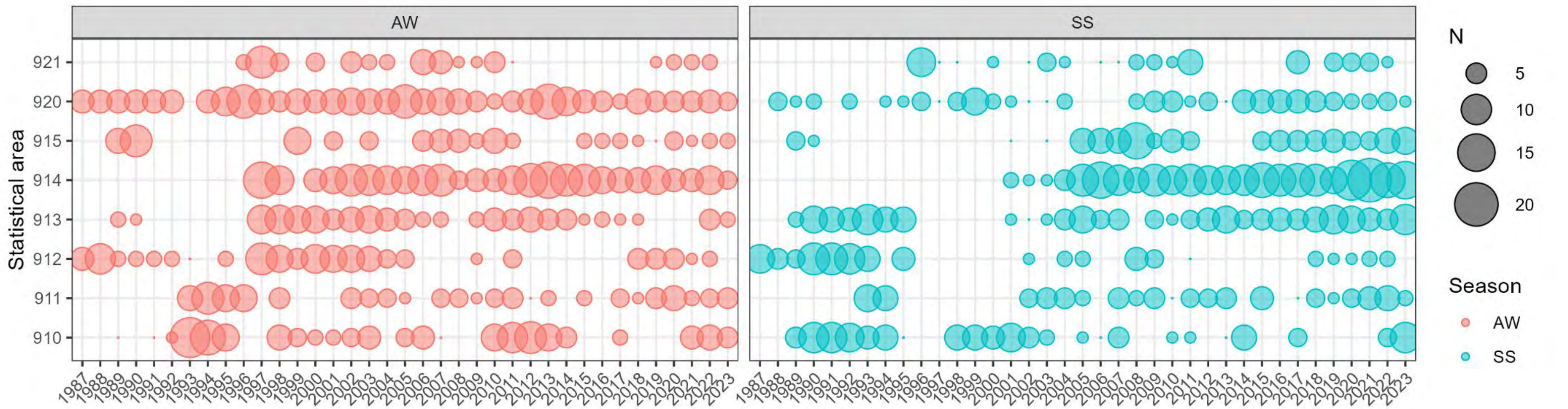


Figure H.1: Bubble plot of catch sampling (CS) effort by fishing year, season, and statistical area, including only the fishing years included in the CS CPUE model.

Figure H.2: Bubble plot of catch sampling (CS) effort by fishing year, season, and month, including only the fishing years included in the CS CPUE model.

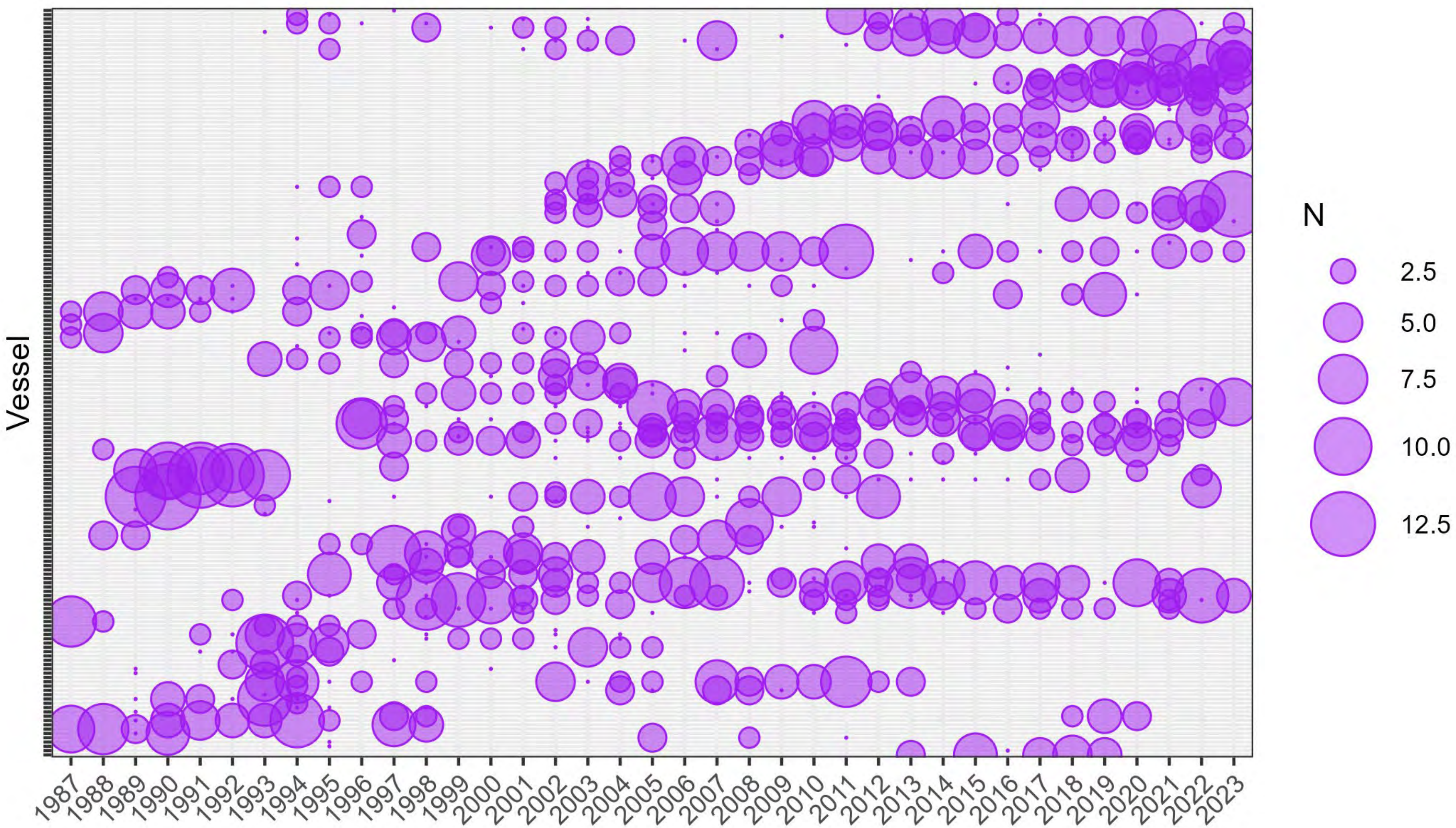


Figure H.3: Bubble plot of catch sampling (CS) effort by fishing year, season, and vessel, including only the fishing years included in the CS CPUE model.

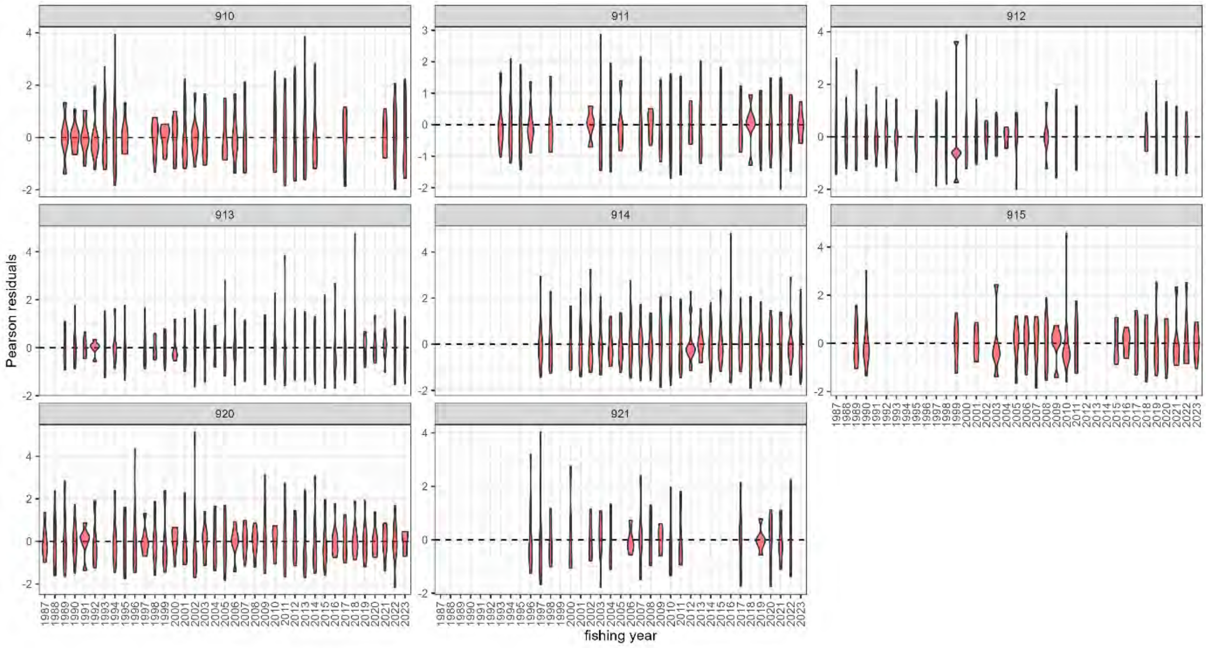


Figure H.4: Violin plot of Pearson residuals with respect to year and area for the <u>female</u> CS CPUE model.

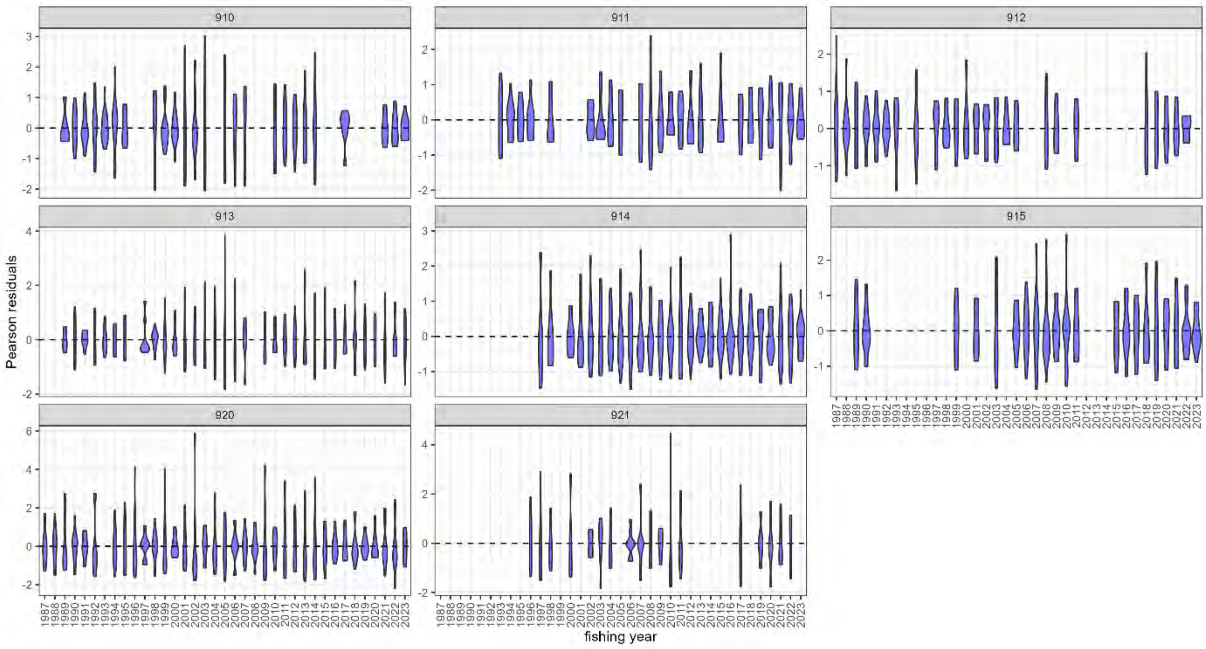


Figure H.5: Violin plot of Pearson residuals with respect to year and area for the <u>male</u> CS CPUE model.

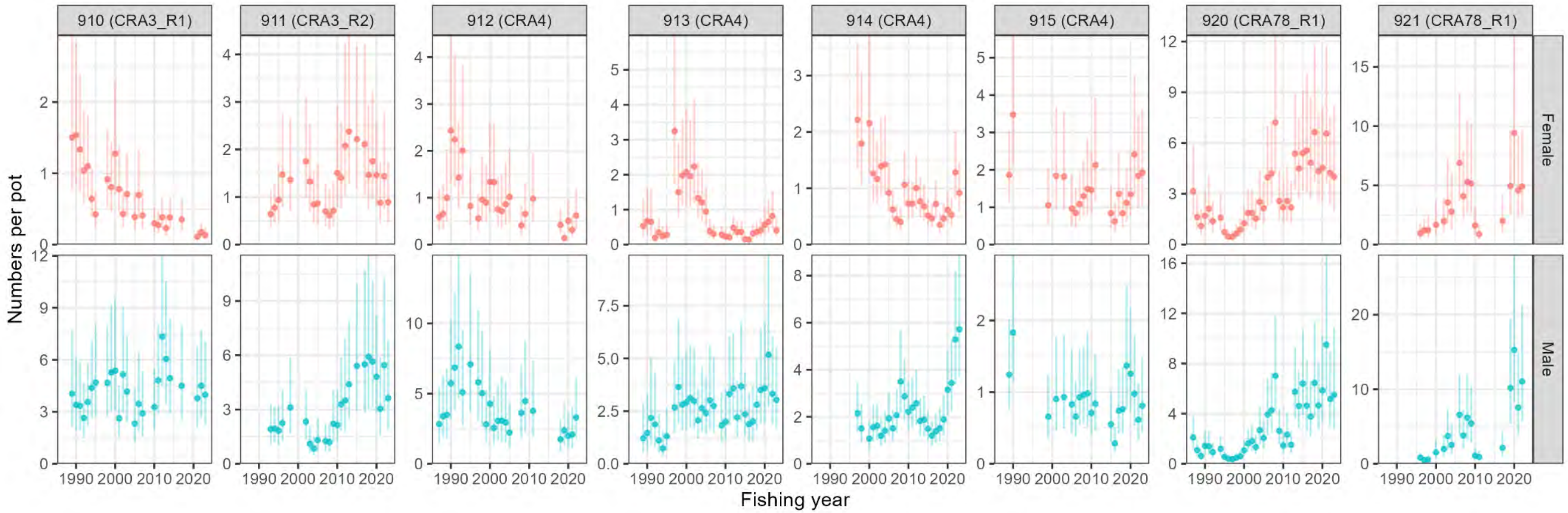


Figure H.6: Predicted number of females (top row) and males (bottom row) by statistical area and fishing year from the sex-specific CS CPUE models. Points and whiskers represent the mean and 95% confidence interval of the prediction, respectively. Note different y-axis scales used for each plot.

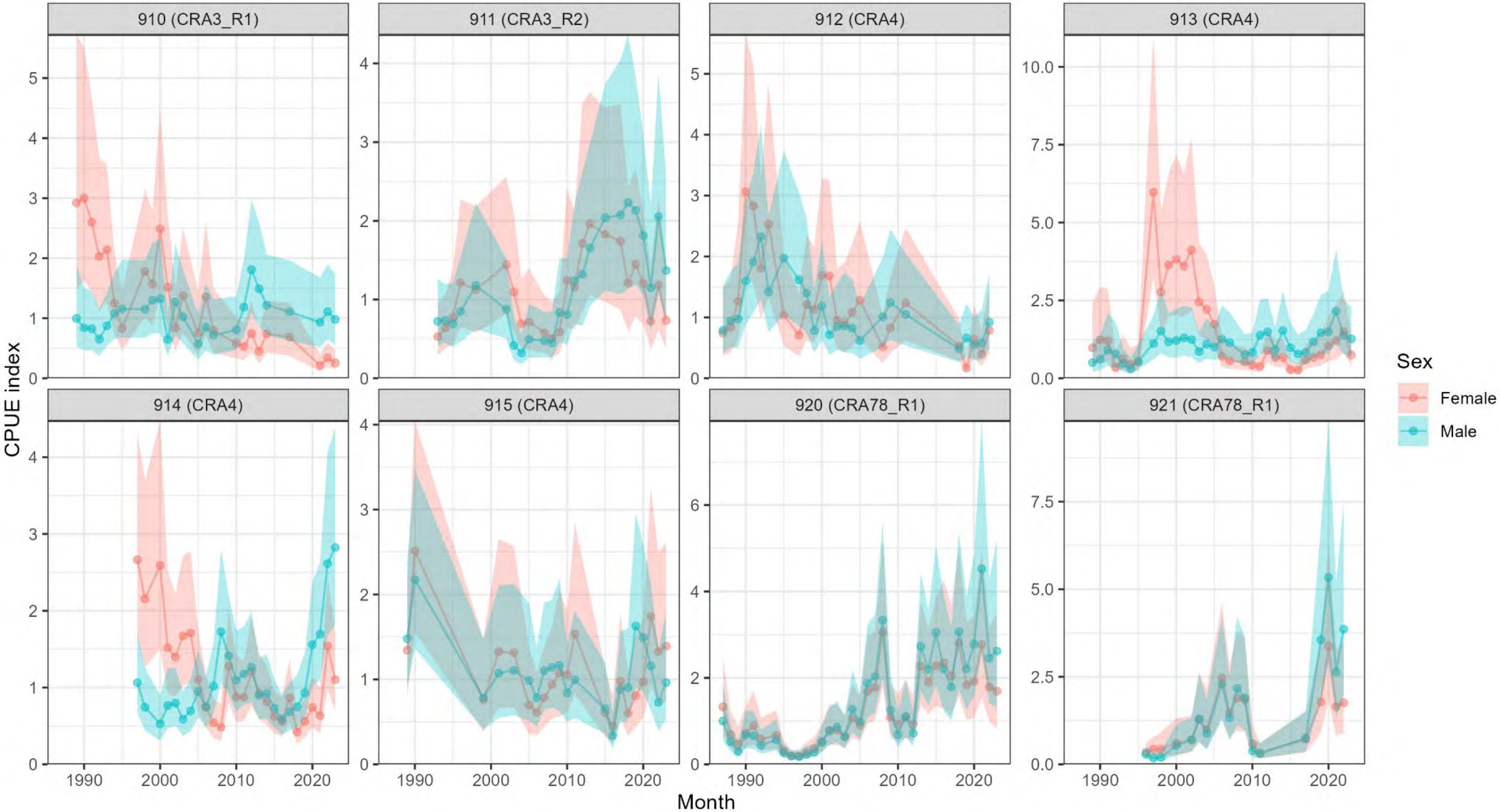


Figure H.7: Predicted number of females (red) and males (blue) by statistical area and fishing year from the sex-specific CS CPUE models, with the sexes overlayed. Points and whiskers represent the mean and 95% confidence interval of the prediction, respectively. Note different y-axis scales used for each plot.

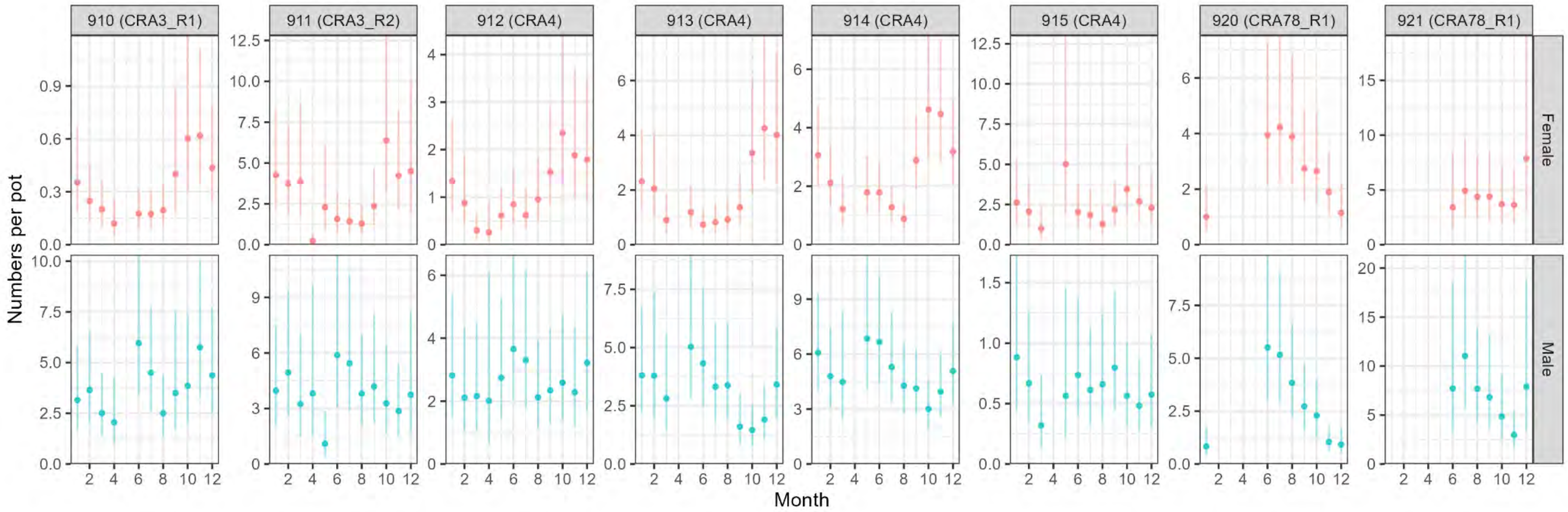


Figure H.8: Predicted number of females (top row) and males (bottom row) by statistical area and month from the sex-specific CS CPUE model for females. Points and whiskers represent the mean and 95% confidence interval of the prediction, respectively. Note different y-axis scales used for each plot.

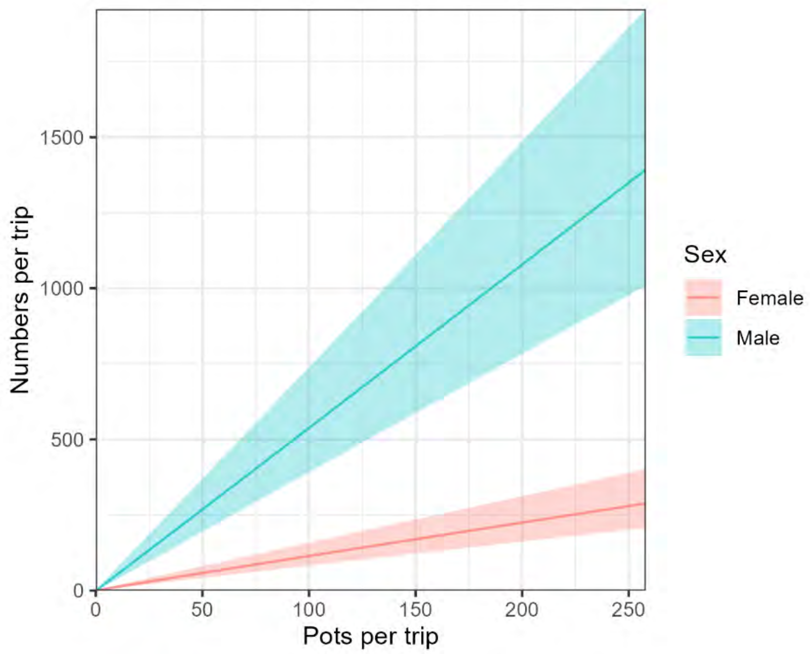


Figure H.9: Predicted number of females (red) and males (blue) per trip by the number of pots from the sex-specific CS CPUE model. Lines and shaded areas represent the mean and 95% confidence interval of the prediction, respectively.

I.5 Tables and Figures from Logbook Sampling analysis

Table H.2: Number of fishing trips by fishing year and statistical area in the data used by the sex-specific logbook (LB) CPUE models. This dataset excluded fishing year-area strata for which there were fewer than fifty fishing trips and two vessels of LB sampling.

	CRA 2			CRA 3 R1	CRA 3 R2	CRA 5 R2		CRA 5 R1	CRA 7&8 R1	CRA 7&8 R2		
	906	907	908	910	911	933	916	917	924	926	927	928
1993	1283	221	492	135	73	–	–	–	362	299	460	406
1994	837	267	287	199	138	0	126	700	379	422	663	226
1995	657	190	152	128	83	0	–	328	454	769	565	897
1996	541	155	145	112	52	172	–	407	405	512	619	506
1997	440	180	121	–	–	147	–	280	164	406	671	729
1998	459	67	126	–	–	121	–	109	135	391	576	559
1999	507	208	142	–	–	180	113	192	–	176	357	225
2000	538	163	154	–	–	395	128	355	171	251	588	287
2001	396	173	116	–	–	408	144	493	167	74	268	246
2002	796	208	224	–	–	382	257	543	130	156	368	195
2003	589	161	113	–	–	330	318	250	61	230	226	118
2004	838	–	211	–	–	335	196	388	–	253	211	139
2005	920	244	285	–	–	367	258	397	88	151	244	117
2006	579	191	255	–	–	327	331	469	75	119	345	149
2007	514	185	351	–	–	396	275	454	95	71	211	108
2008	611	144	482	–	–	312	146	315	91	84	208	136
2009	582	203	398	–	–	406	220	379	–	68	194	128
2010	783	200	417	50	–	217	183	284	–	109	332	271
2011	870	200	343	79	–	316	128	202	–	104	357	210
2012	746	232	461	69	–	262	161	162	–	157	327	231
2013	816	343	413	215	–	393	–	154	–	–	310	273
2014	814	346	331	234	64	420	151	239	–	93	342	297
2015	674	252	486	108	136	413	158	214	–	293	327	225
2016	321	281	184	176	82	455	–	283	–	261	376	141
2017	390	253	291	251	79	294	68	306	51	325	365	242
2018	175	147	82	178	72	201	175	324	79	352	396	219
2019	126	120	109	292	–	291	125	408	56	92	199	84
2020	218	109	88	319	122	274	54	369	53	261	355	230
2021	136	152	107	59	151	318	65	339	82	222	286	250
2022	183	105	53	282	176	335	80	462	50	201	290	360
2023	243	123	91	106	234	251	155	462	68	183	296	337

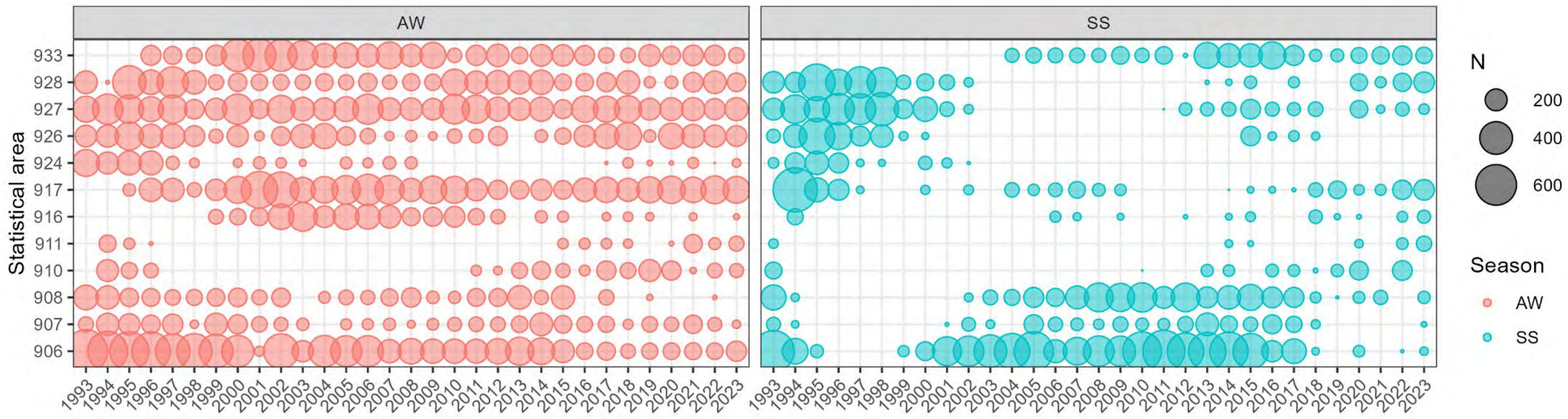


Figure H.10: Bubble plot of logbook (LB) effort by fishing year, season, and statistical area, including only the fishing years included in the LB CPUE model

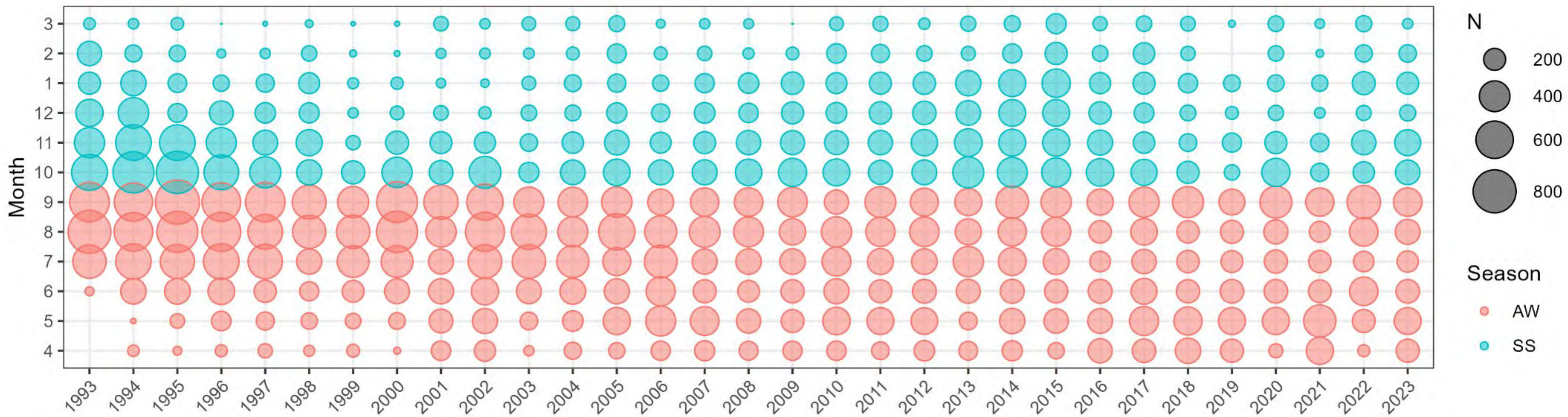


Figure H.11: Bubble plot of logbook (LB) effort by fishing year, season, and month, including only the fishing years included in the LB CPUE model.

Figure H.12: Bubble plot of logbook (LB) effort by fishing year, season, and vessel, including only the fishing years included in the LB CPUE model.

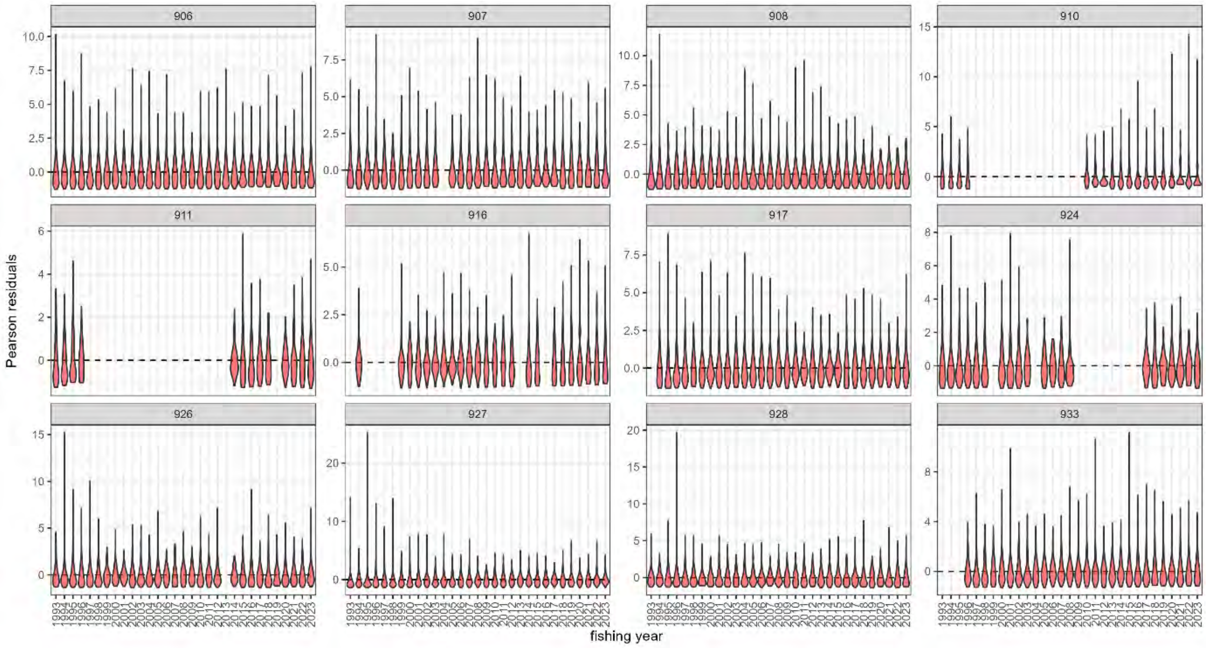


Figure H.13: Violin plot of Pearson residuals with respect to year and area for the <u>female</u> LB CPUE model.

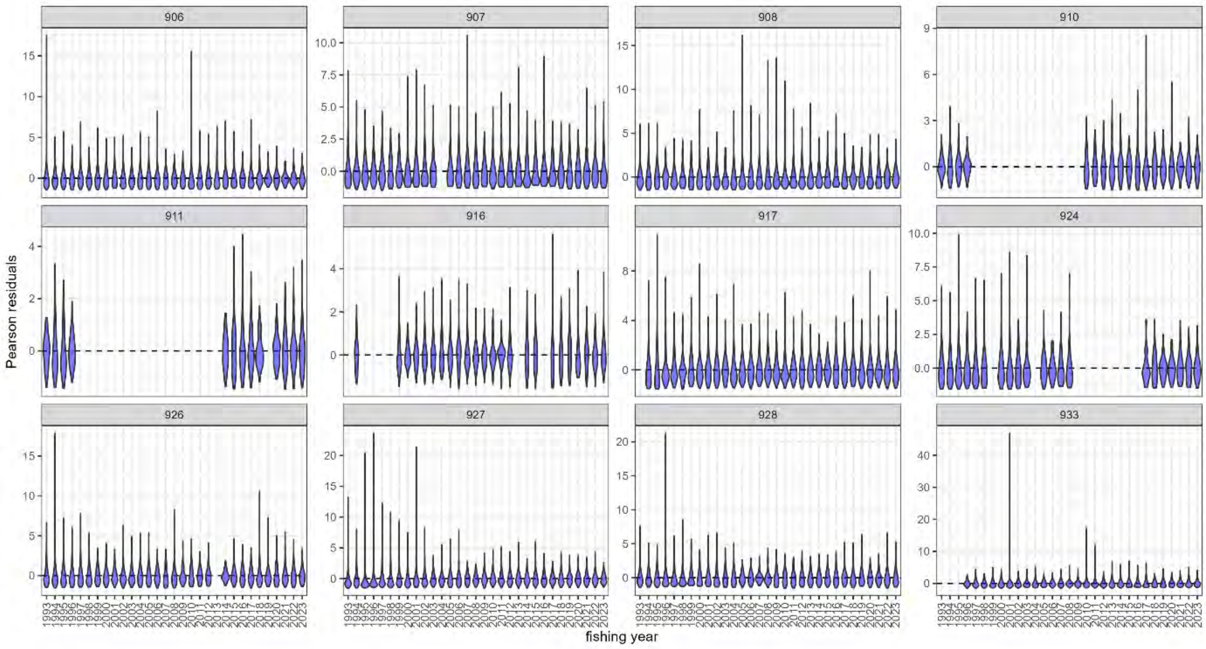


Figure H.14: Violin plot of Pearson residuals with respect to year and area for the <u>male</u> LB CPUE model.

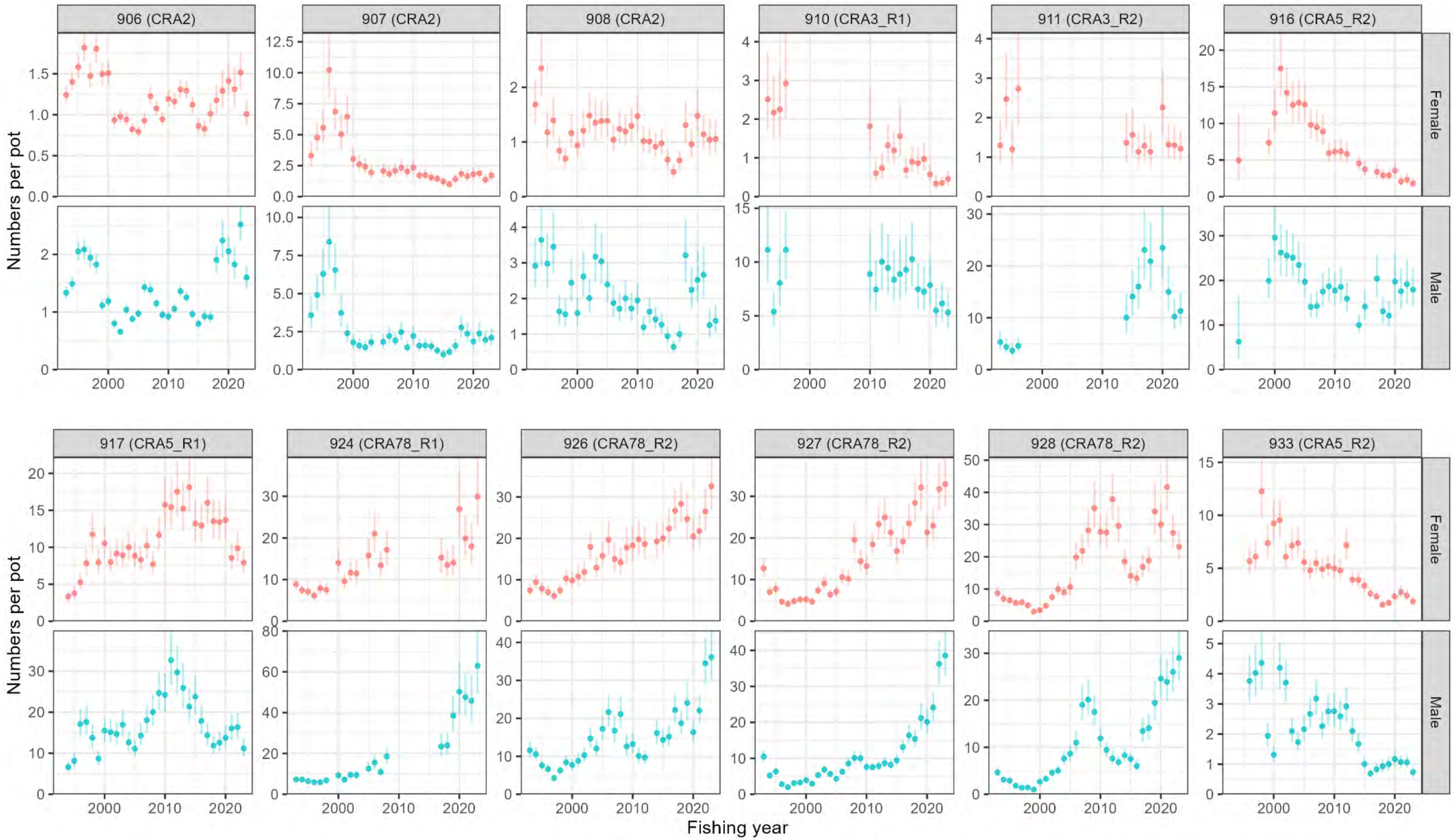


Figure H.15: Predicted number of females (red) and males (blue) by statistical area and fishing year from the sex-specific LB CPUE models. Points and whiskers represent the mean and 95% confidence interval of the prediction, respectively. Note different y-axis scales used for each plot.

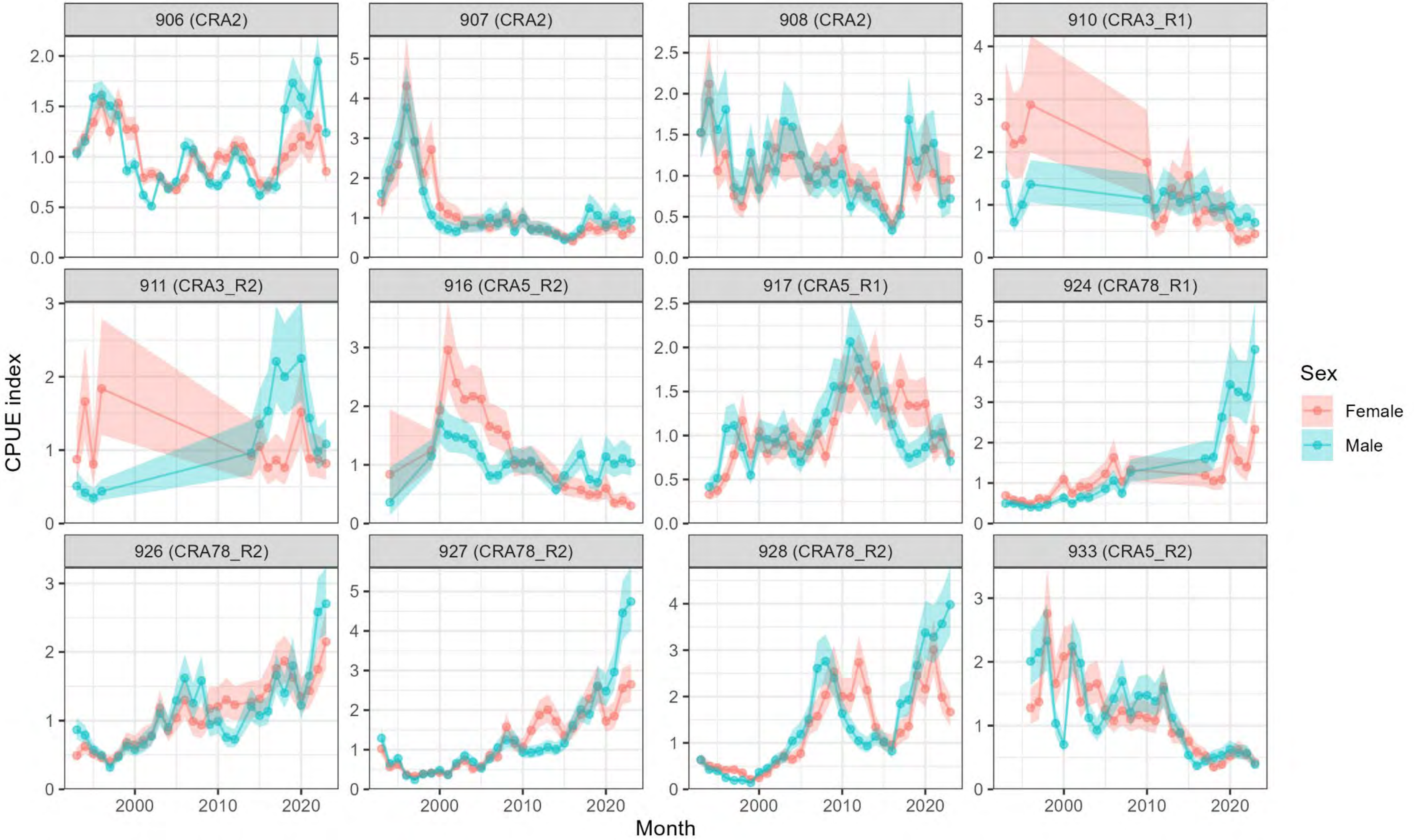


Figure H.16: Predicted number of females (red) and males (blue) by statistical area and fishing year from the sex-specific LB CPUE models, with the sexes overlayed. Points and whiskers represent the mean and 95% confidence interval of the prediction, respectively. Note different y-axis scales used for each plot.

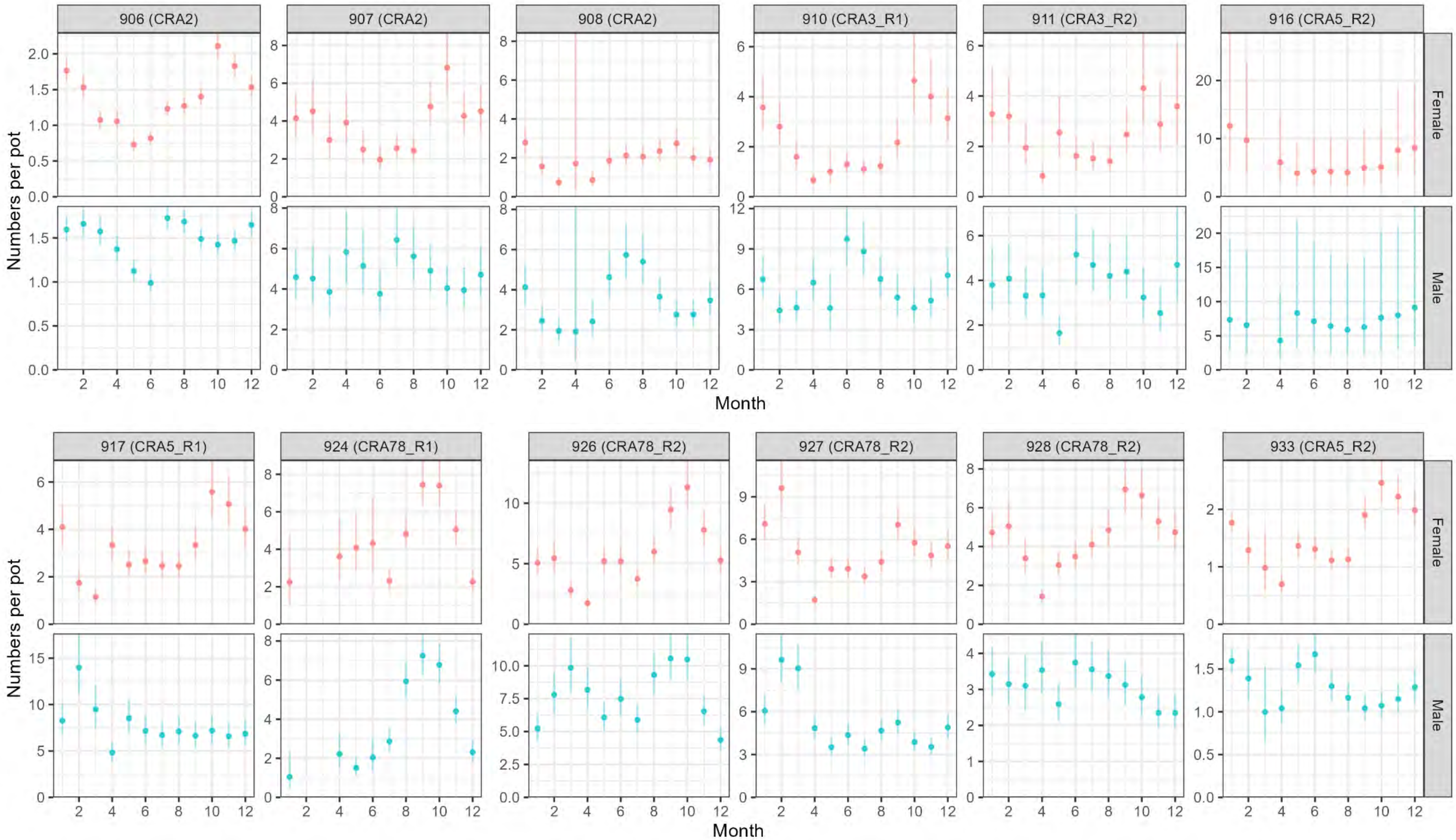


Figure H.17: Predicted number of females (red) and males (blue) by statistical area and month from the sex-specific LB CPUE model for females. Points and whiskers represent the mean and 95% confidence interval of the prediction, respectively. Note different y-axis scales used for each plot.

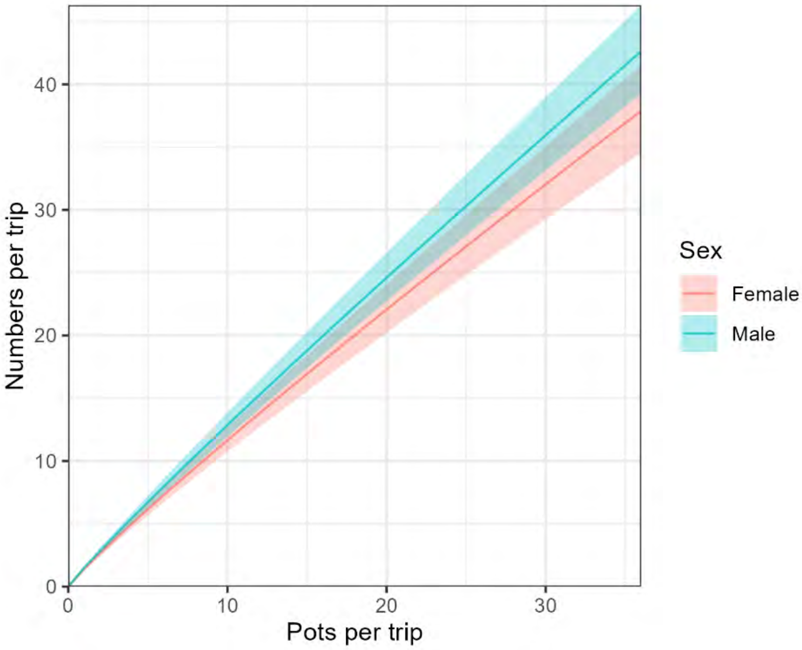


Figure H.18: Predicted number of females (red) and males (blue) per trip by the number of pots from the sex-specific LB CPUE model. Lines and shaded areas represent the mean and 95% confidence interval of the prediction, respectively.

Appendix I. BASE CASE MCMC DIAGNOSTICS

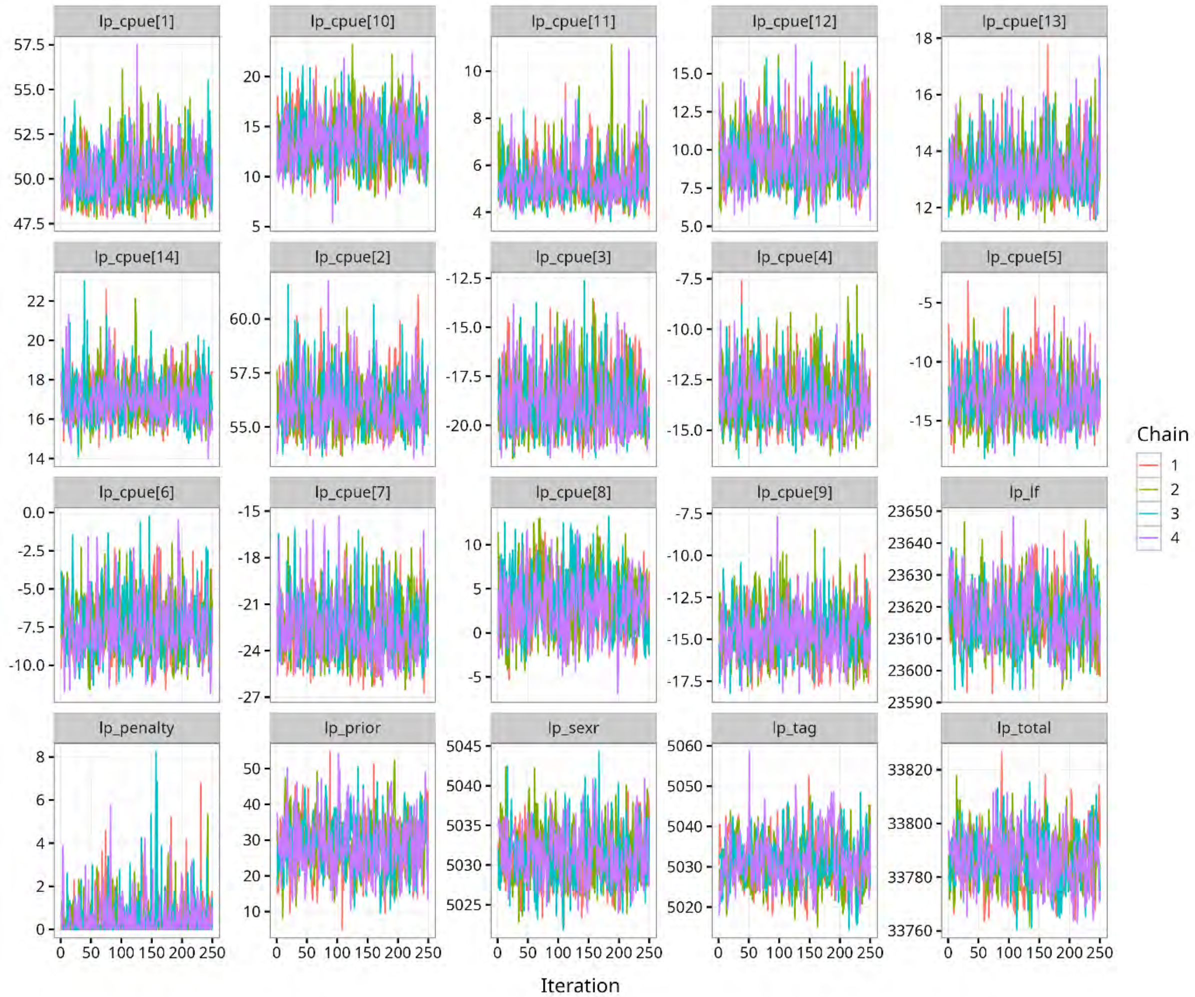


Figure I.1: MCMC trace plots by independent chain for likelihood components for the base model run.

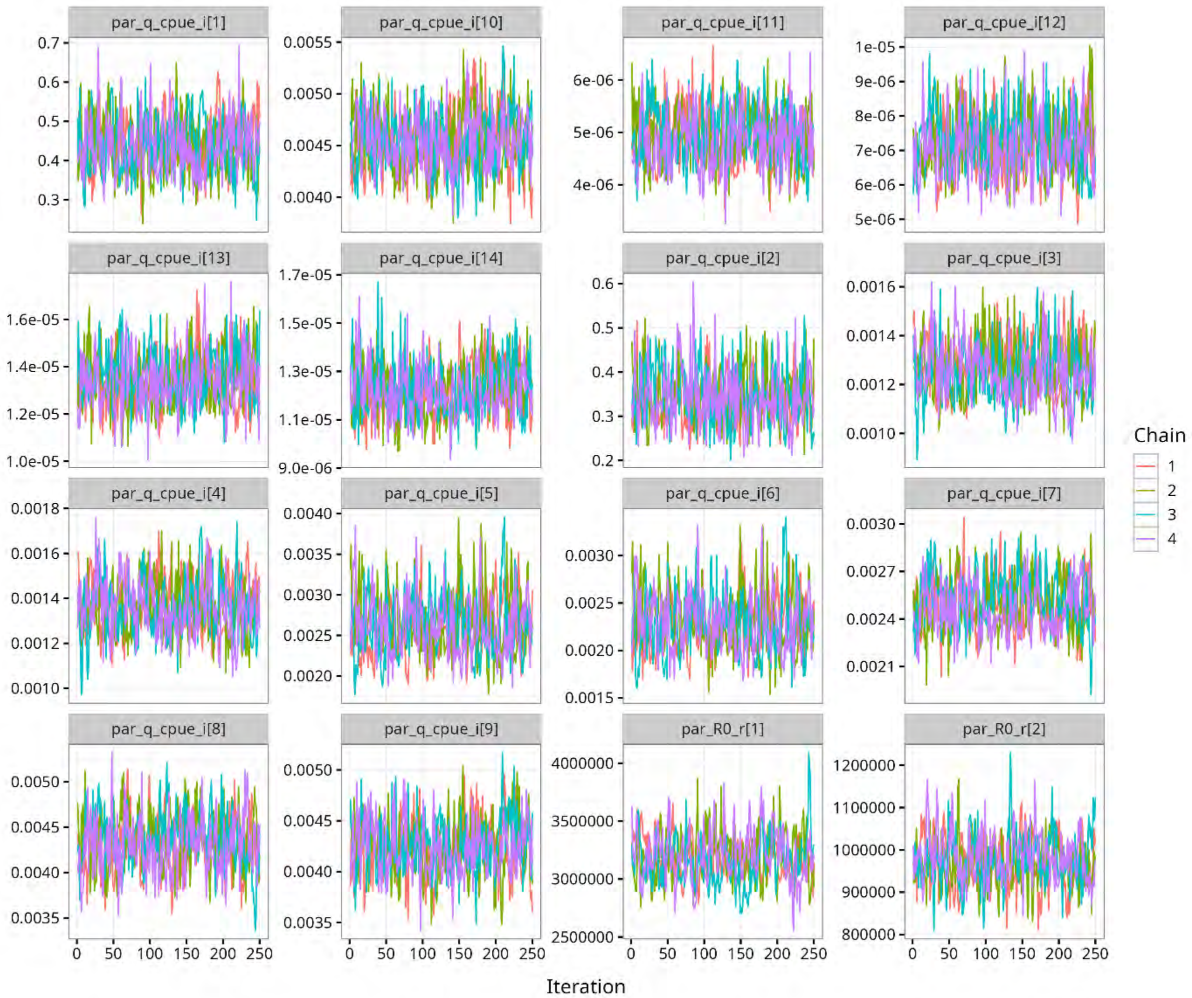


Figure I.2: **MCMC trace plots by independent chain for *M*, *R₀*, maturation, and CPUE parameters for the <u>base</u> model run.**

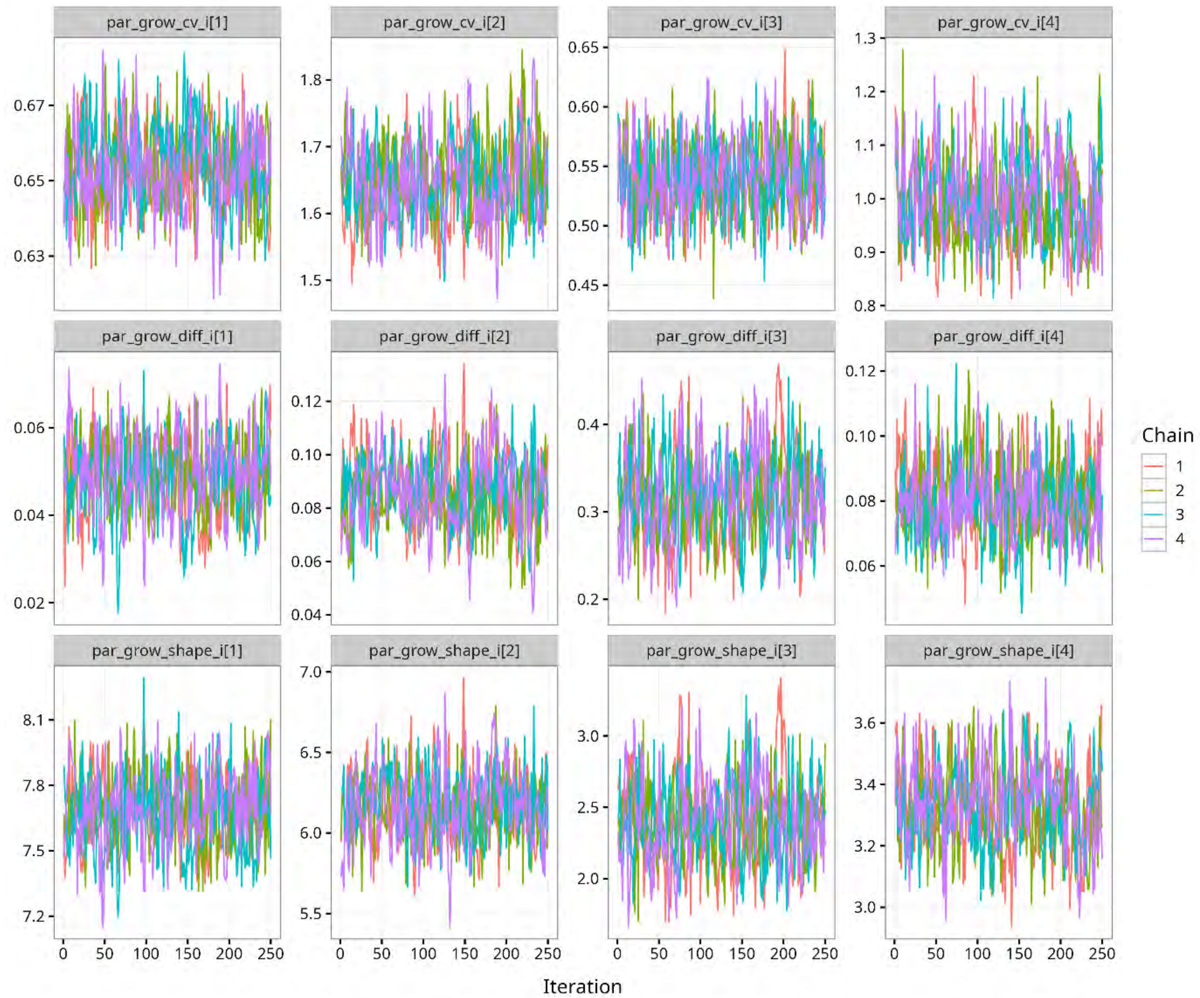


Figure I.3: MCMC trace plots by independent chain for growth parameters for the <u>base</u> model run.

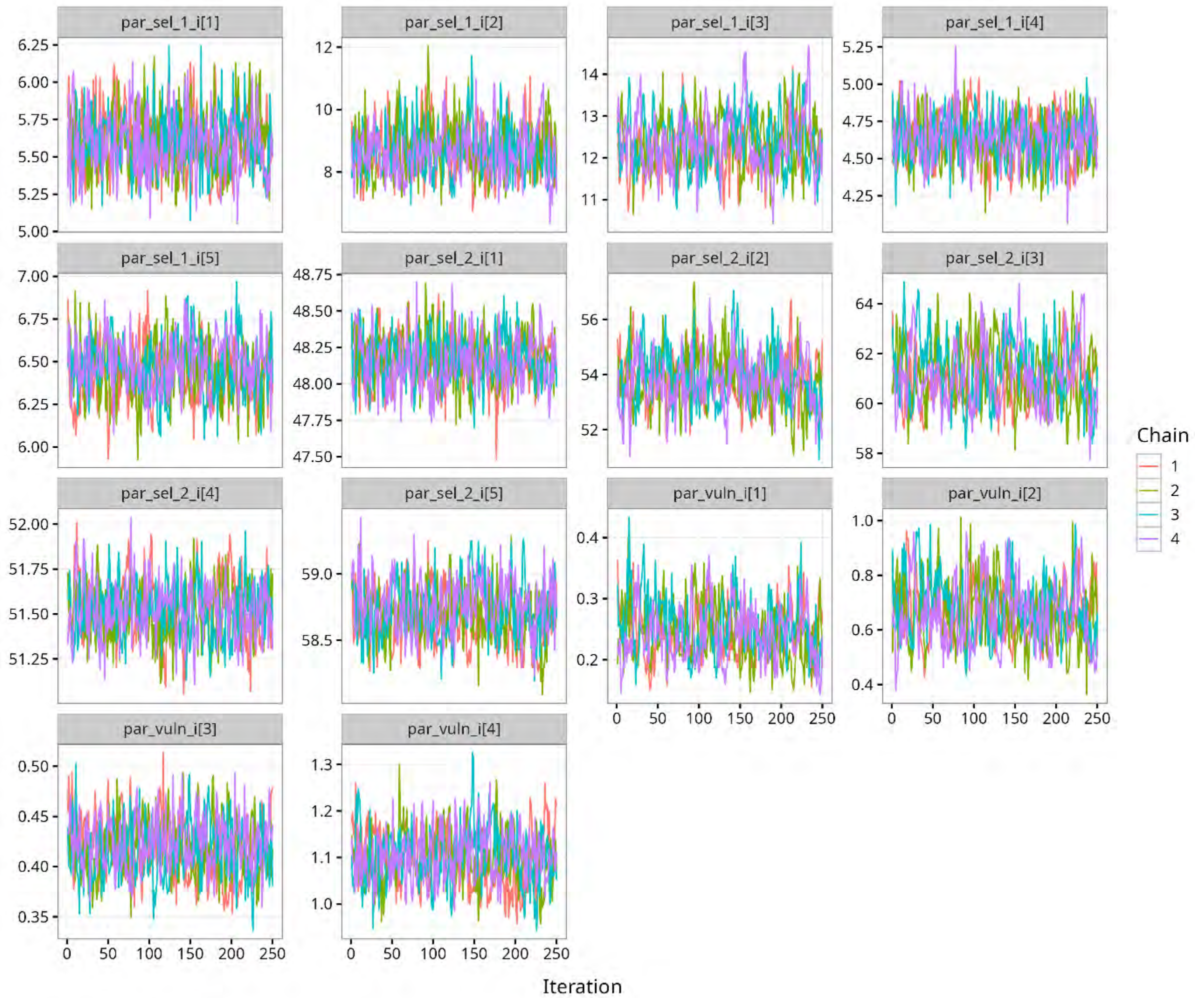


Figure I.4: MCMC trace plots by independent chain for selectivity and vulnerability parameters for the base model run.

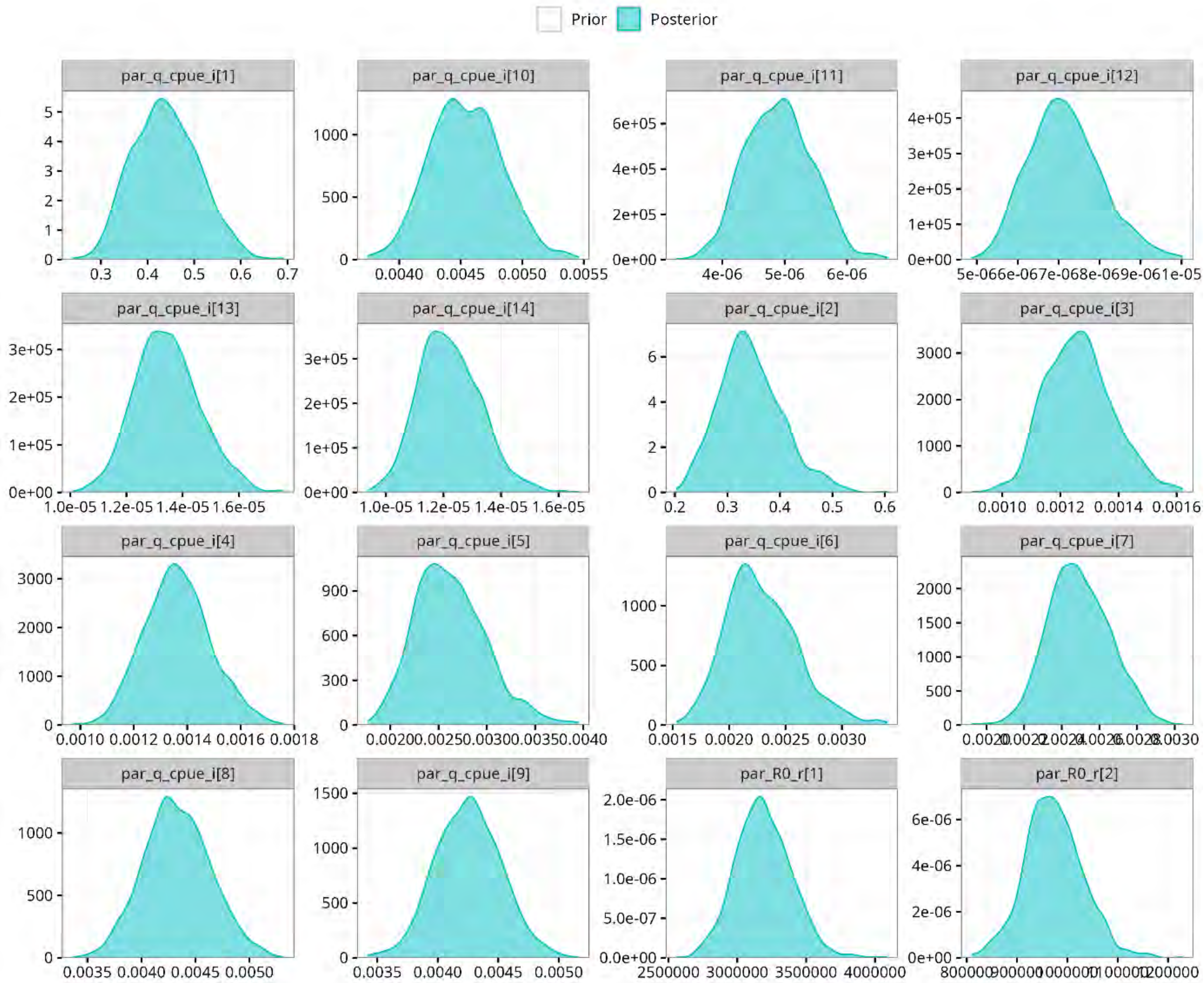


Figure I.5: Density plots showing posterior distributions (blue) for the *R*$_0$ parameter, maturation, and CPUE parameters for the base model run.

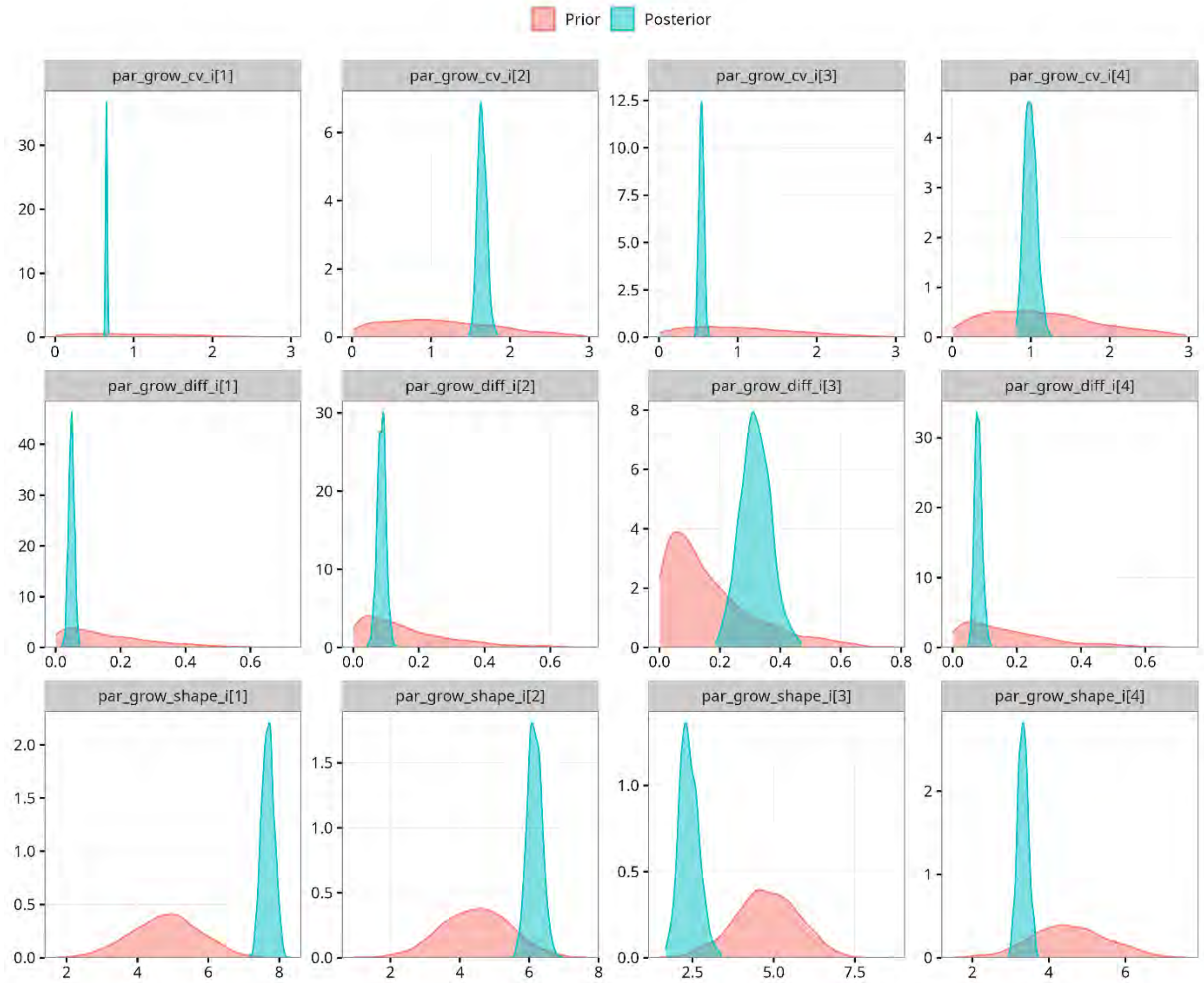


Figure I.6: Density plots showing prior (red) and posterior distributions (blue) for growth parameters for the base model run.

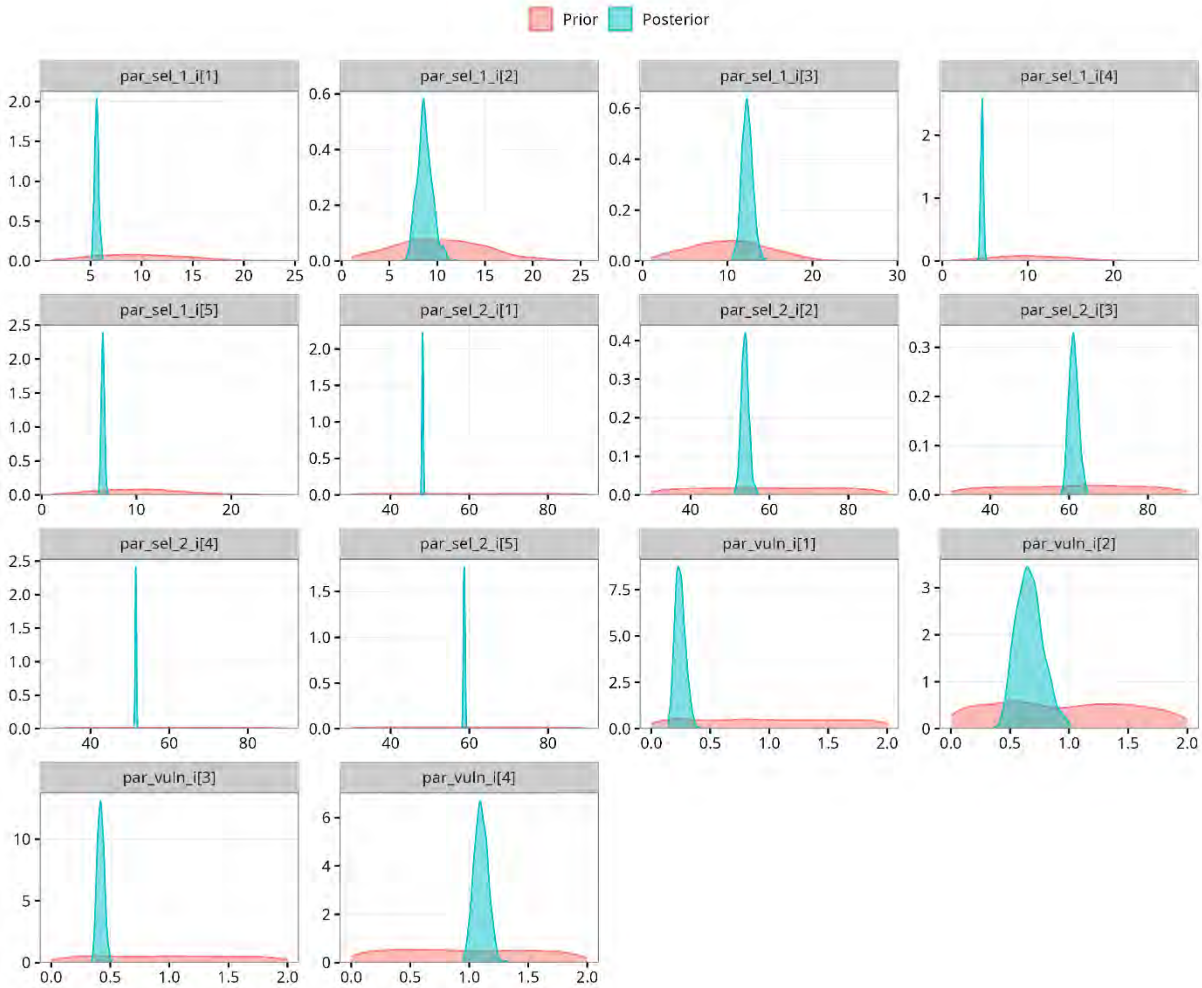


Figure I.7: Density plots showing prior (red) and posterior distributions (blue) for selectivity and vulnerability parameters for the <u>base</u> model run.

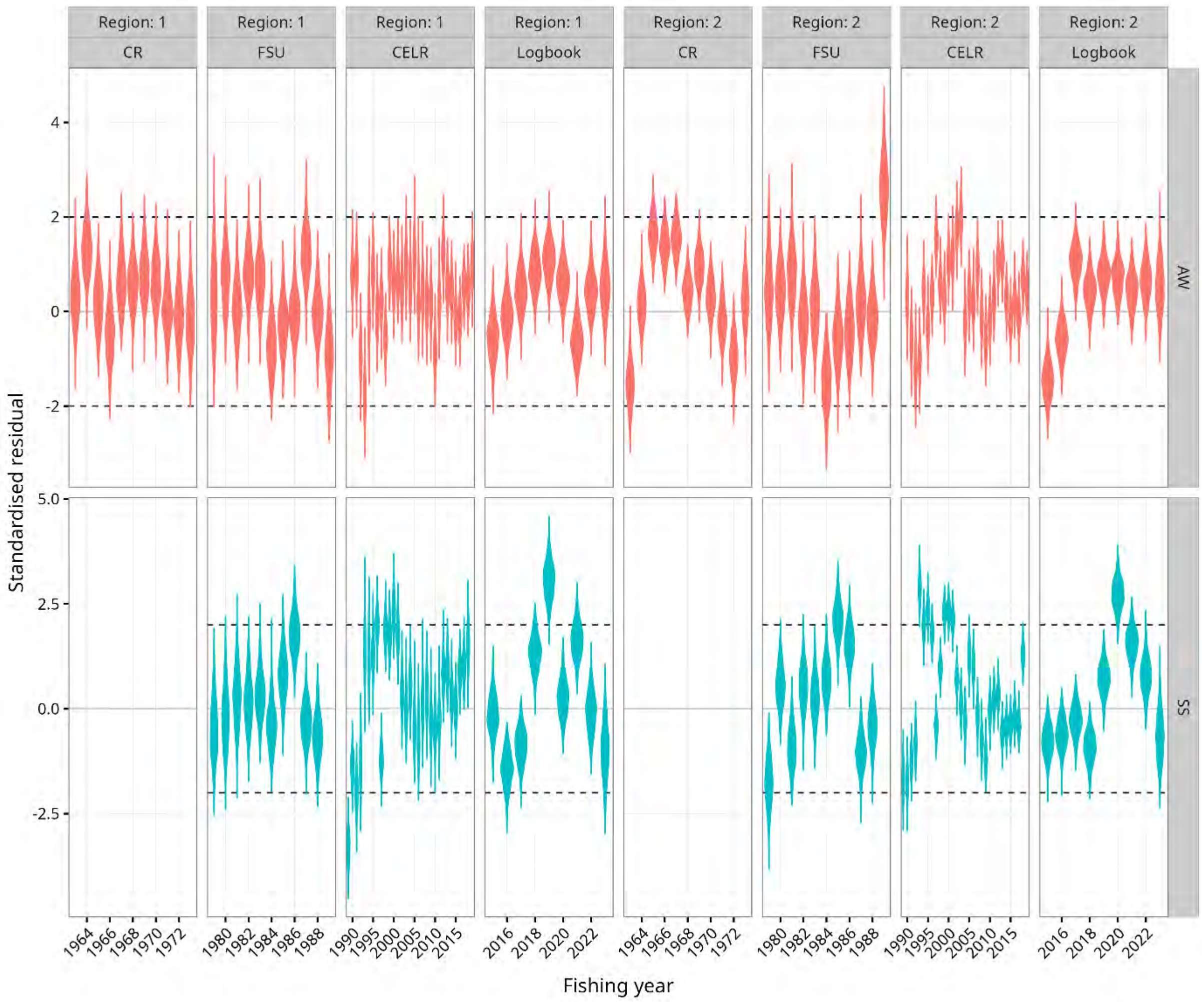


Figure I.8: CPUE residuals for the CR, FSU, CELR, and logbook series by fishing year, season, and region in the base model run.

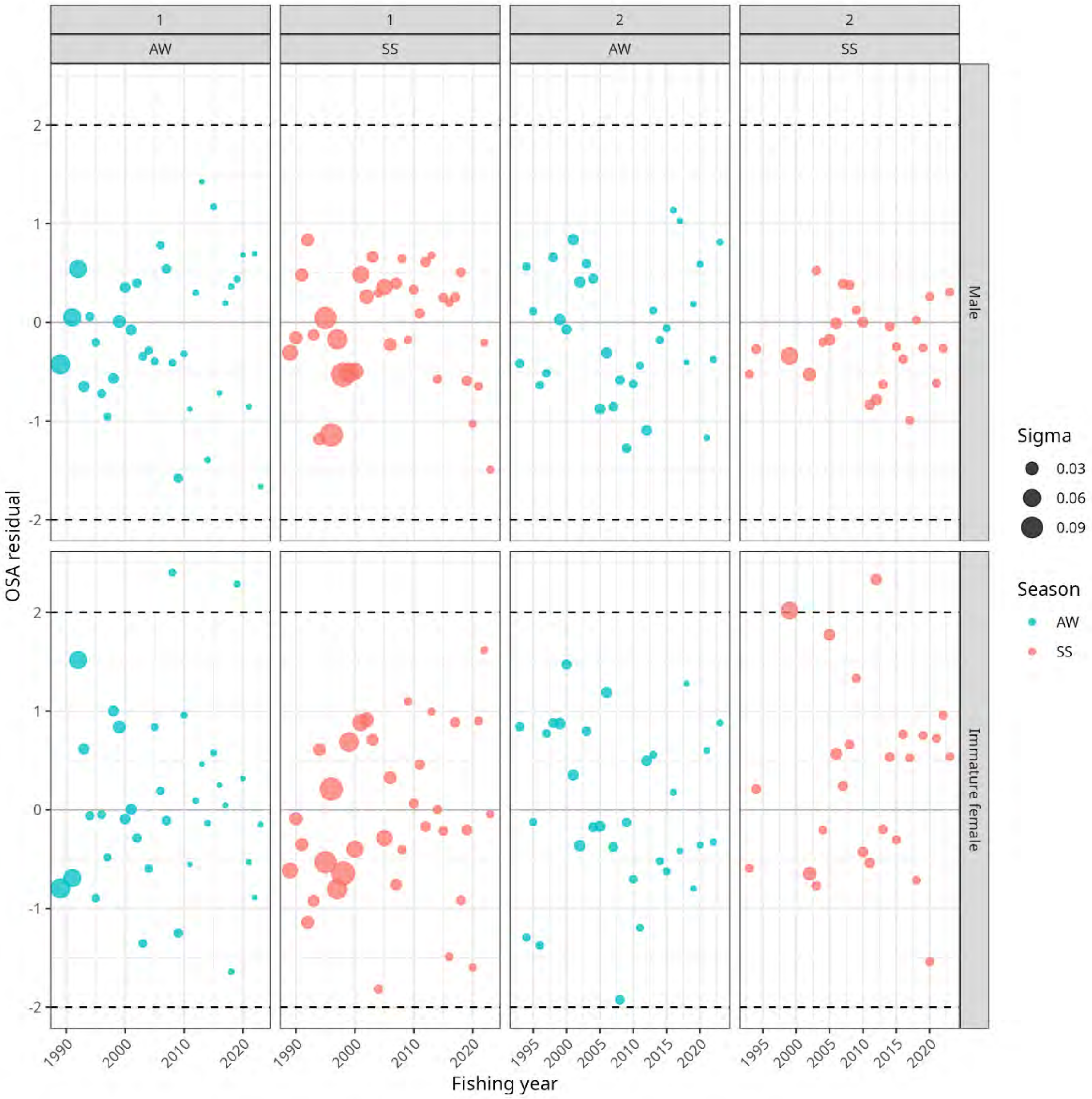


Figure I.9: Median of the OSA residuals of the sex ratios by region, fishing year, season (AW = autumn/winter, SS = spring/summer), and sex, in the base model run.

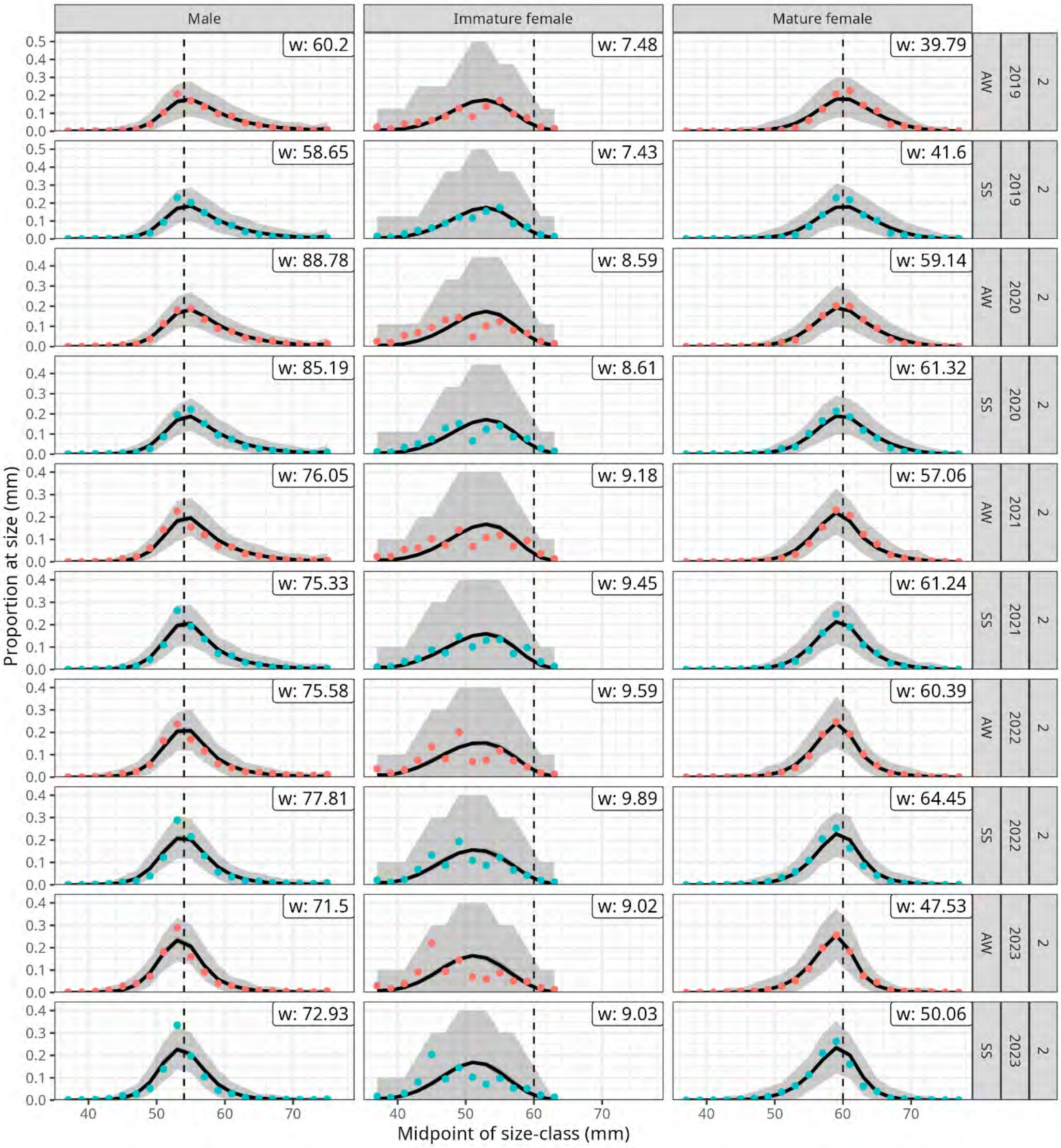


Figure I.10: Posterior distribution of the LFs compared with the observed LFs by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex category in the base model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. In each panel 'w' is the effective sample size.

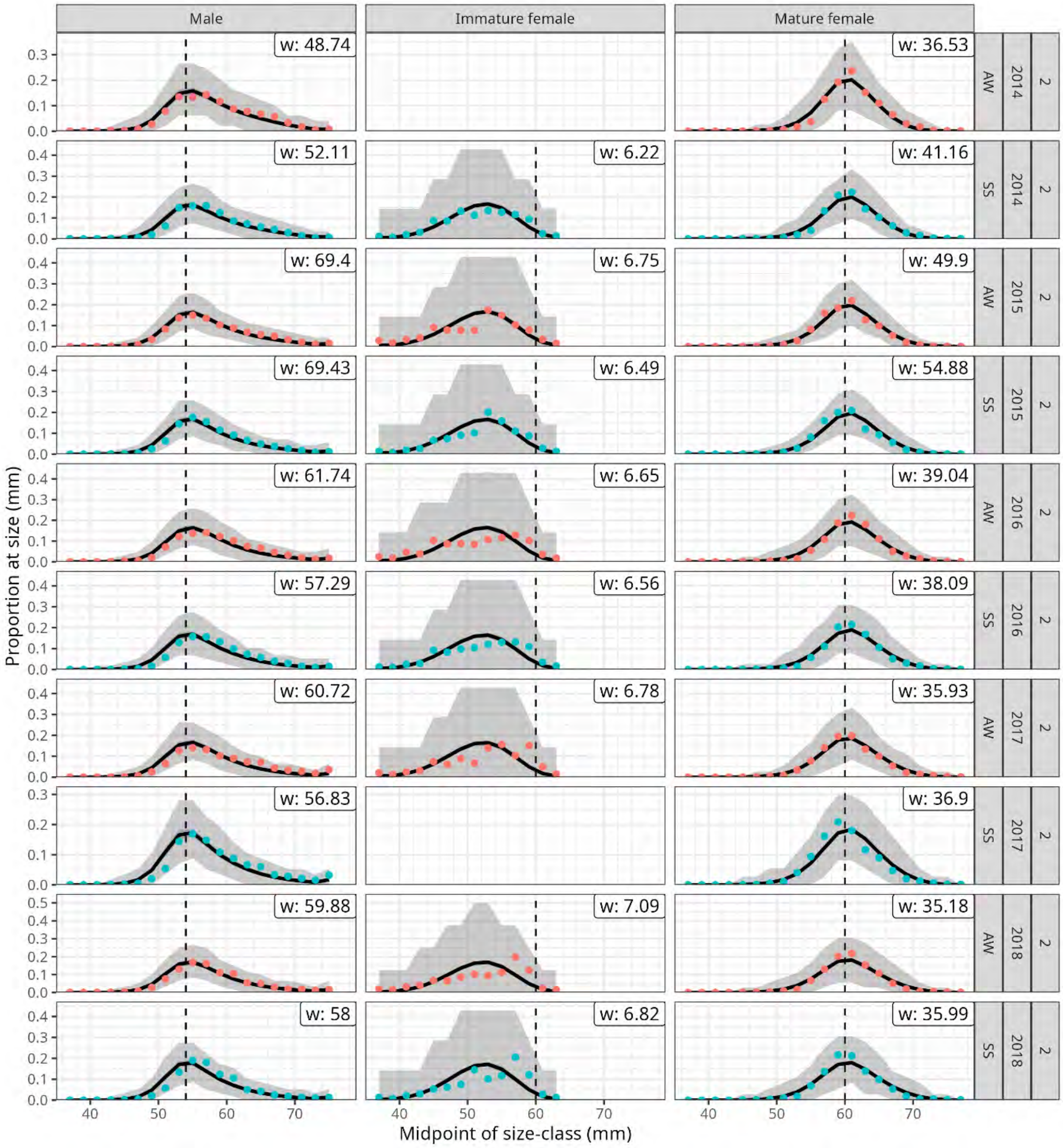


Figure I.10: (cont.):

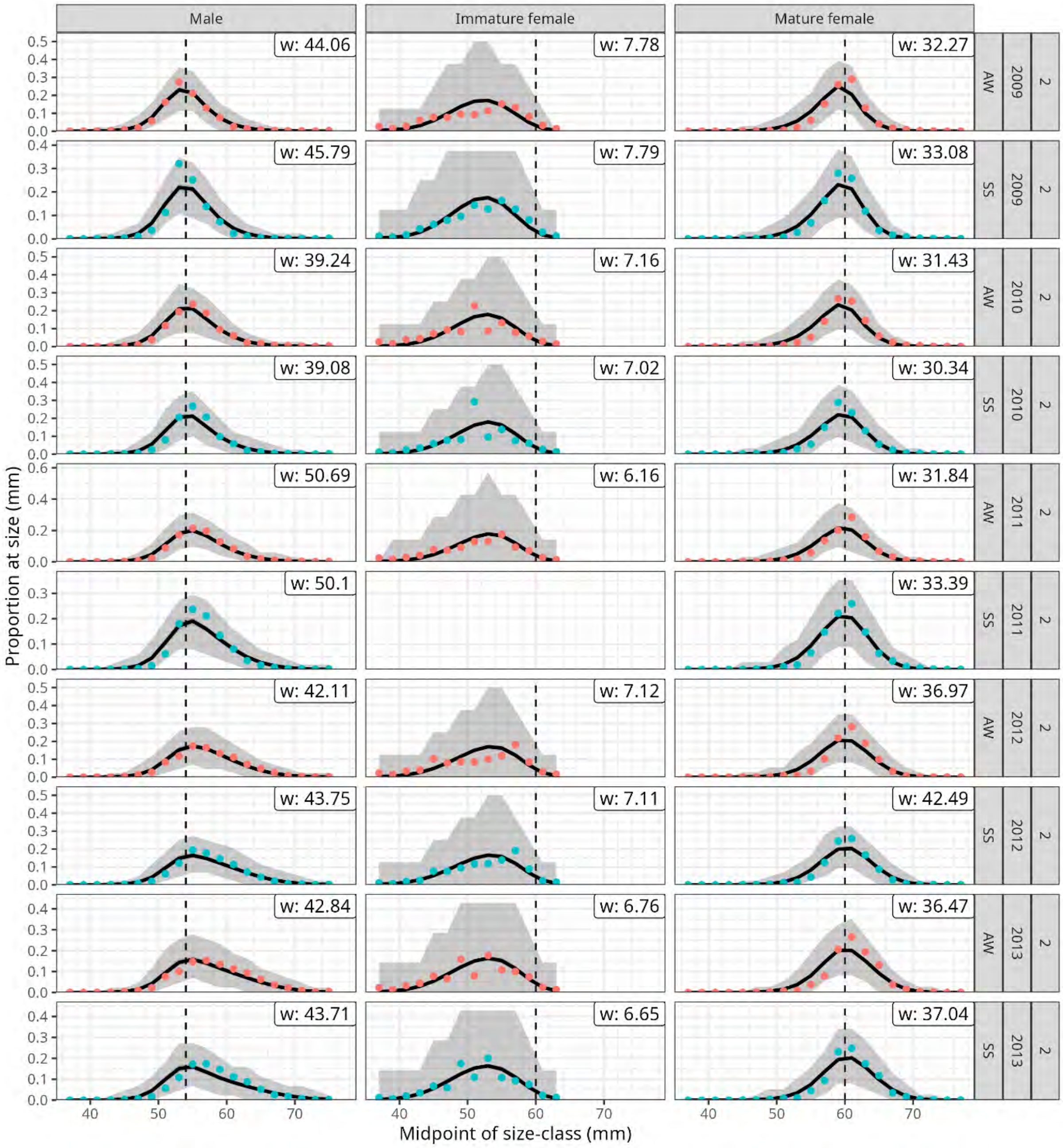
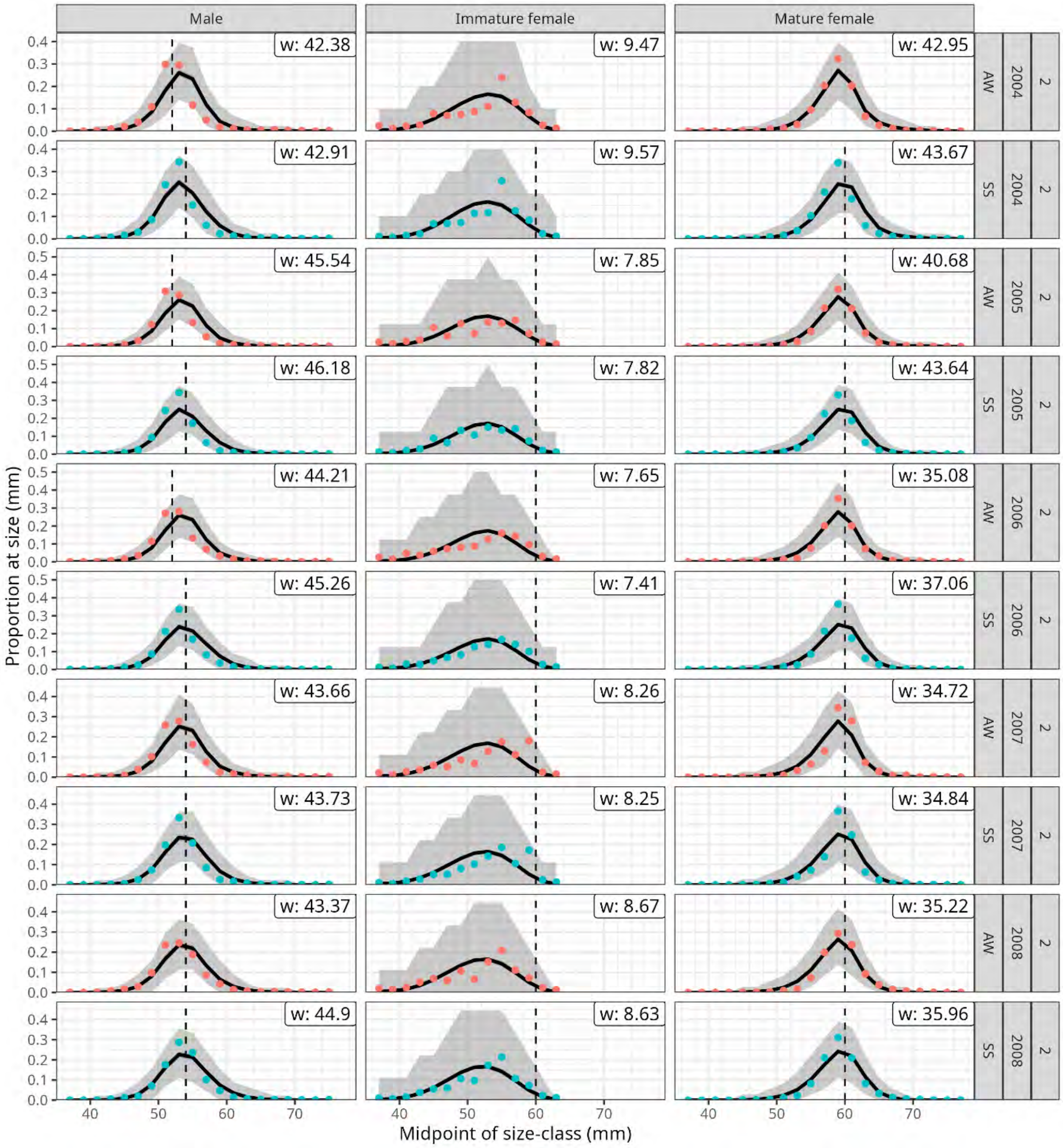


Figure I.10 (cont.)



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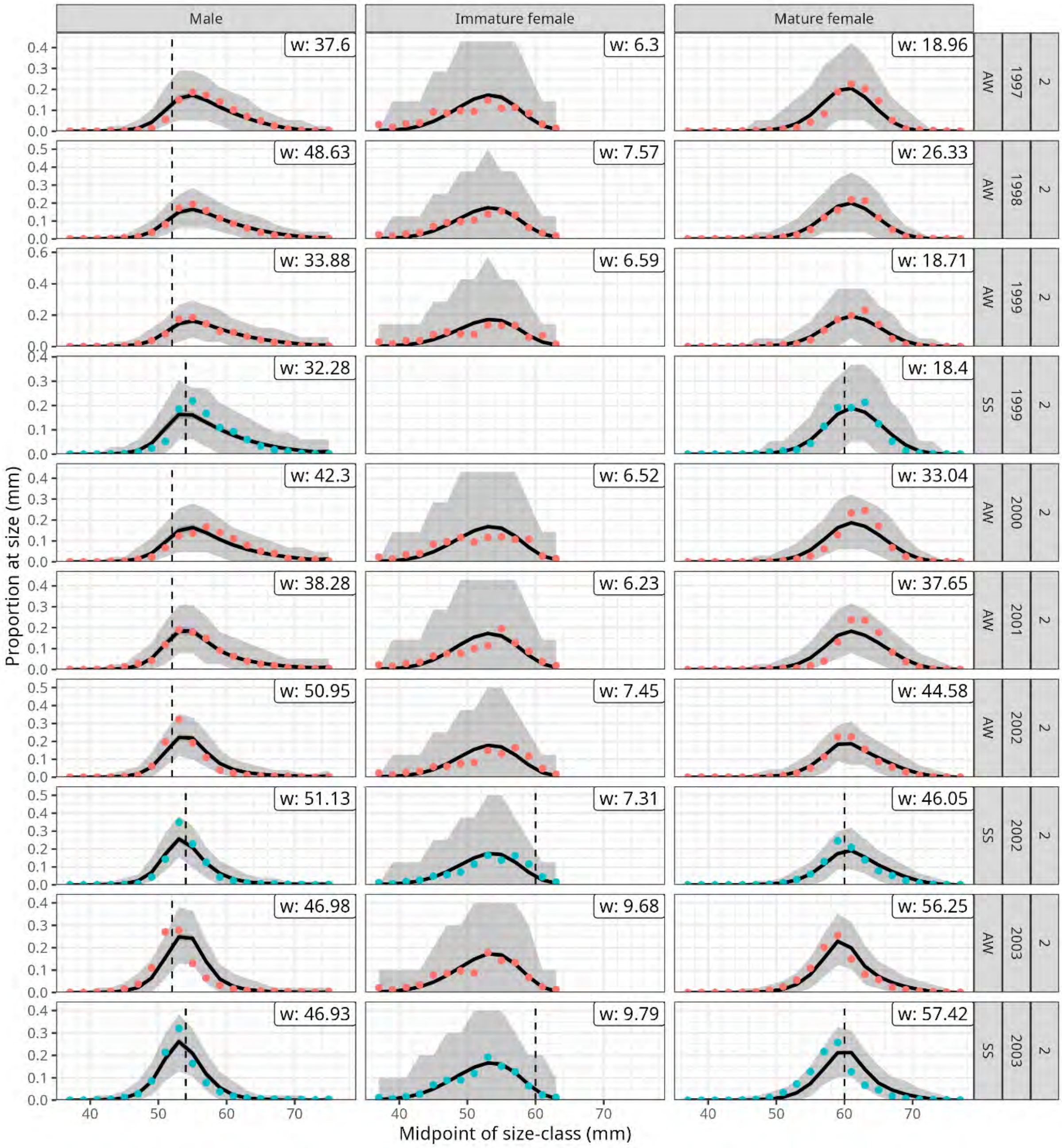

Figure I.10 (cont.)

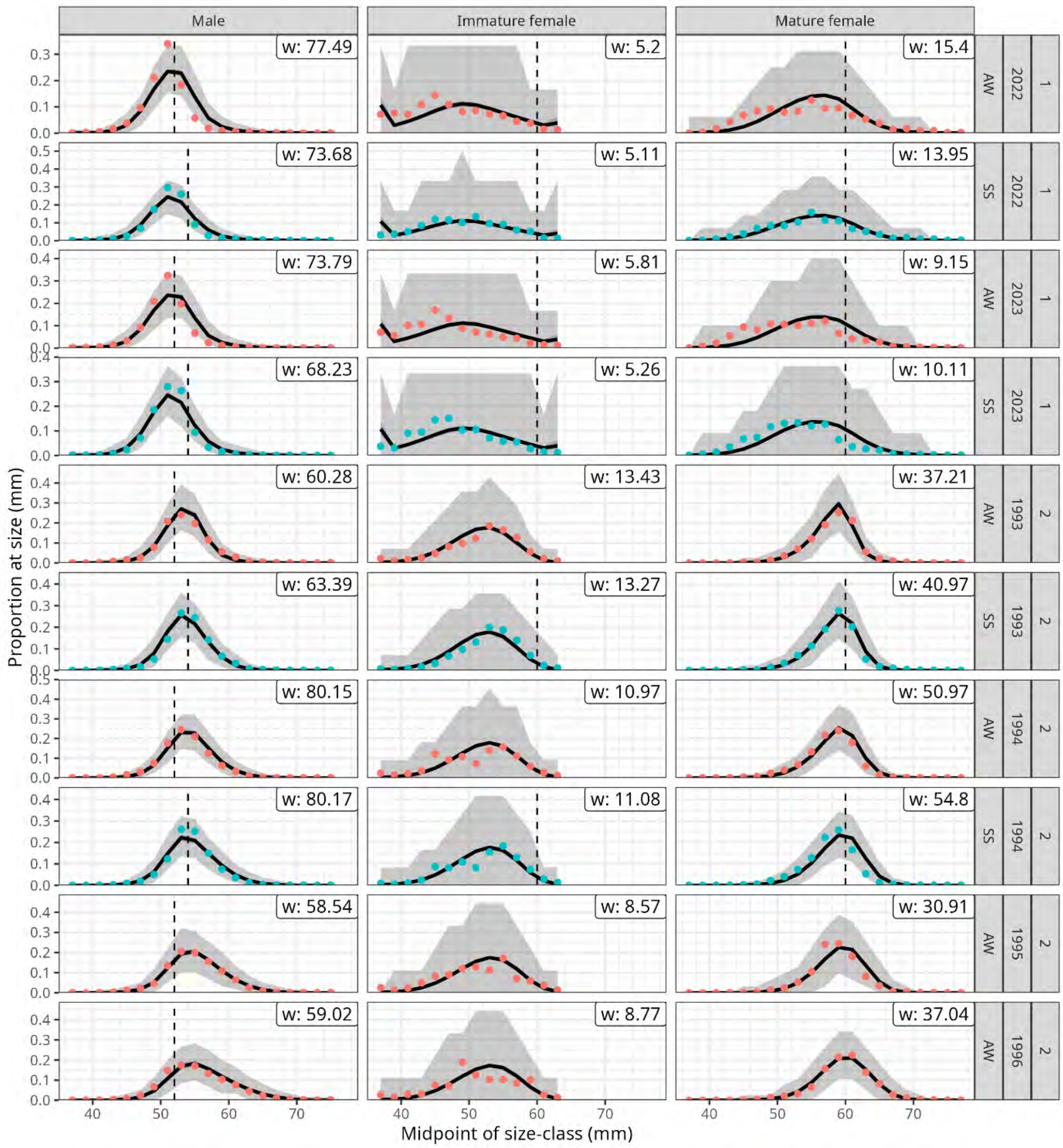

Figure I.10 (cont.)

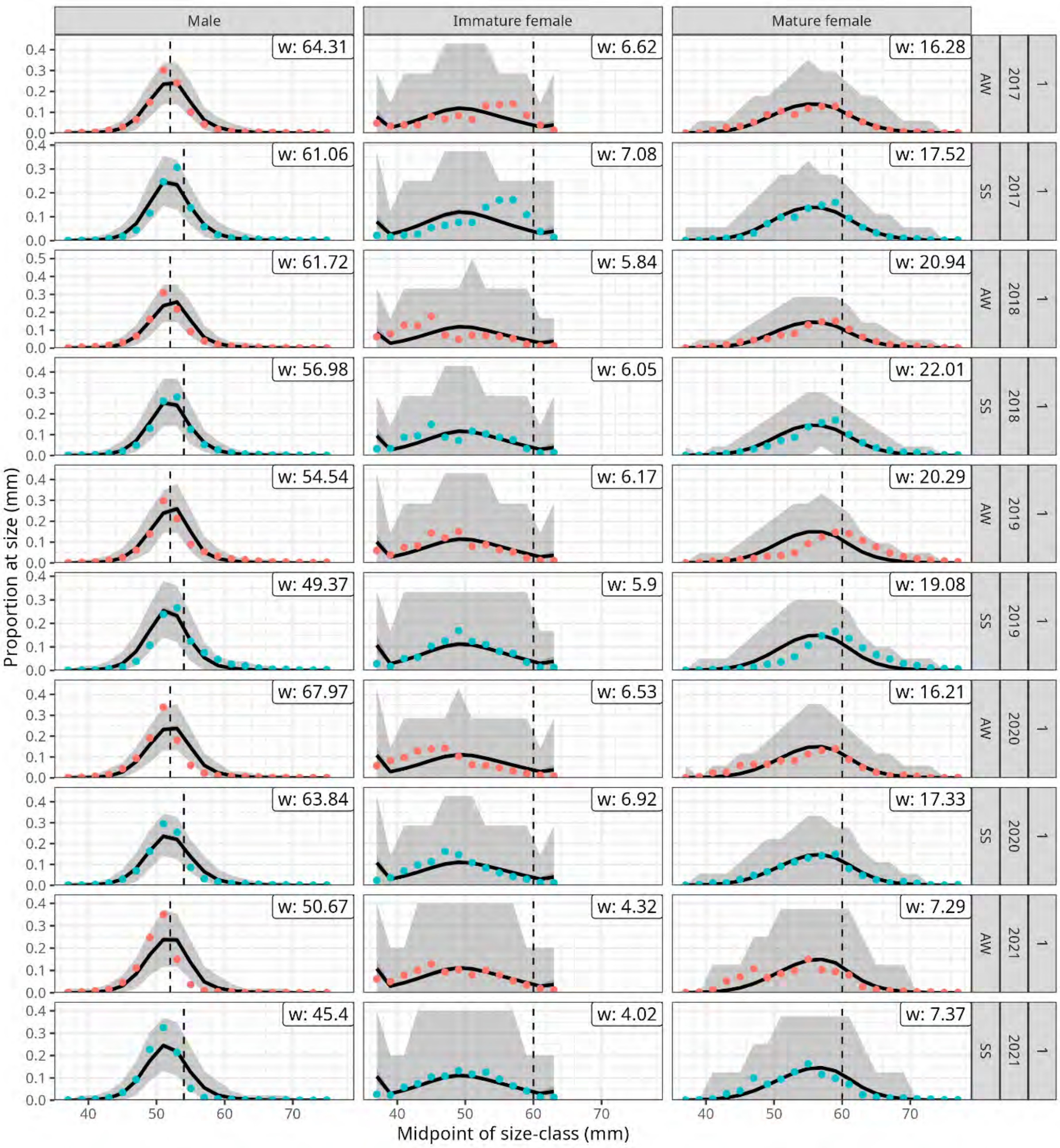

Figure I.10 (cont.)

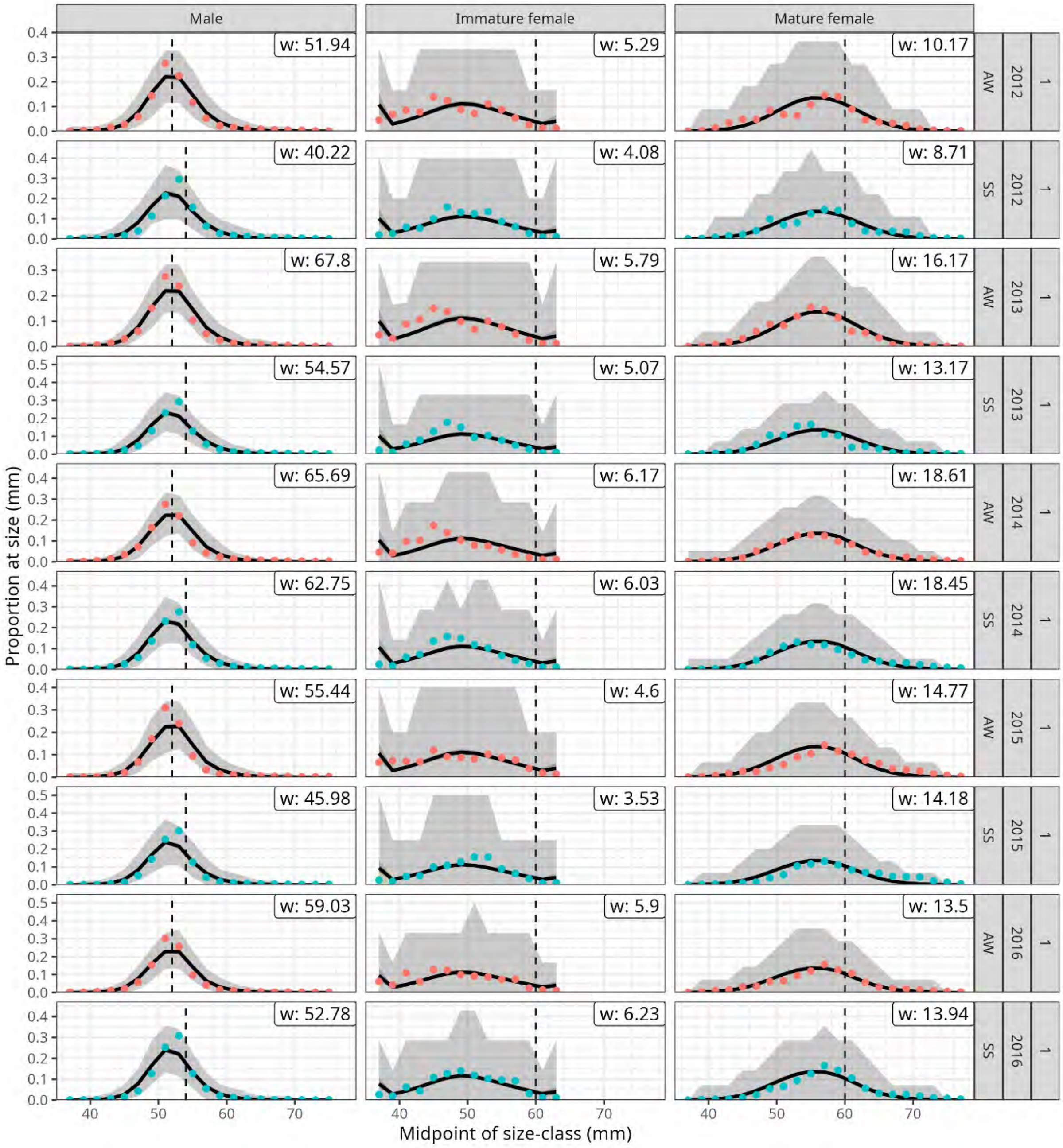

Figure I.10 (cont.)

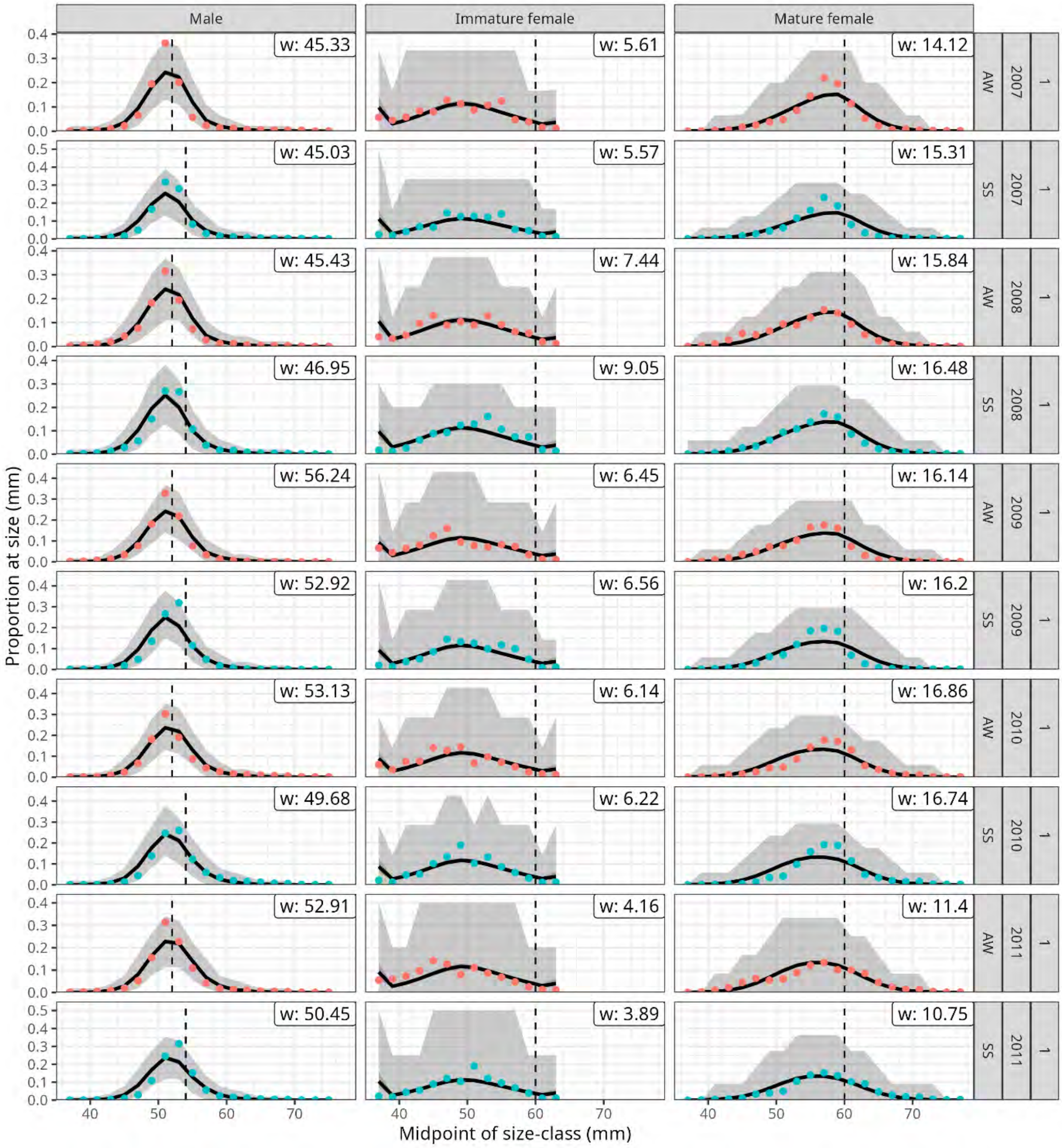

Figure I.10 (cont.)

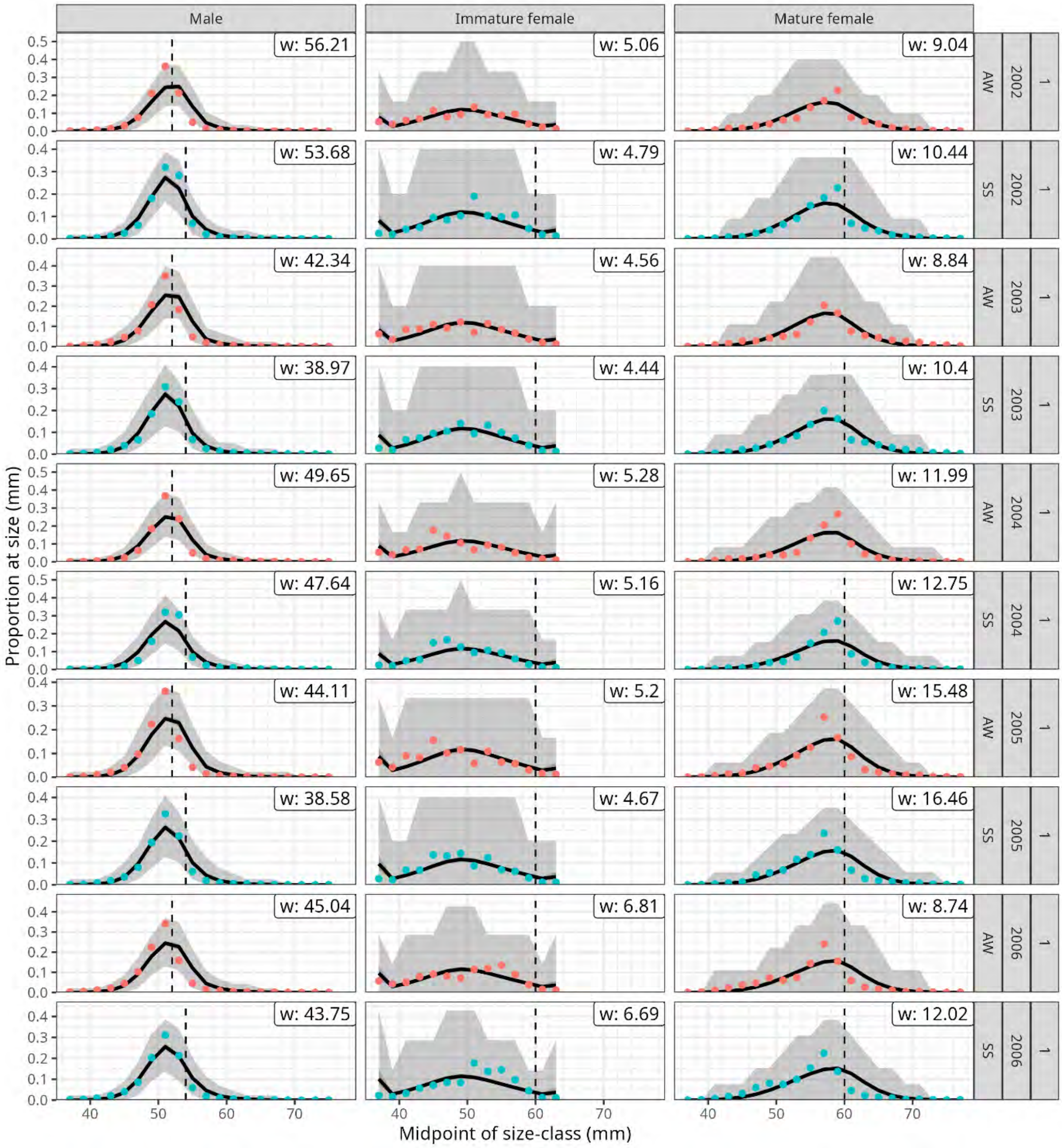

Figure I.10 (cont.)

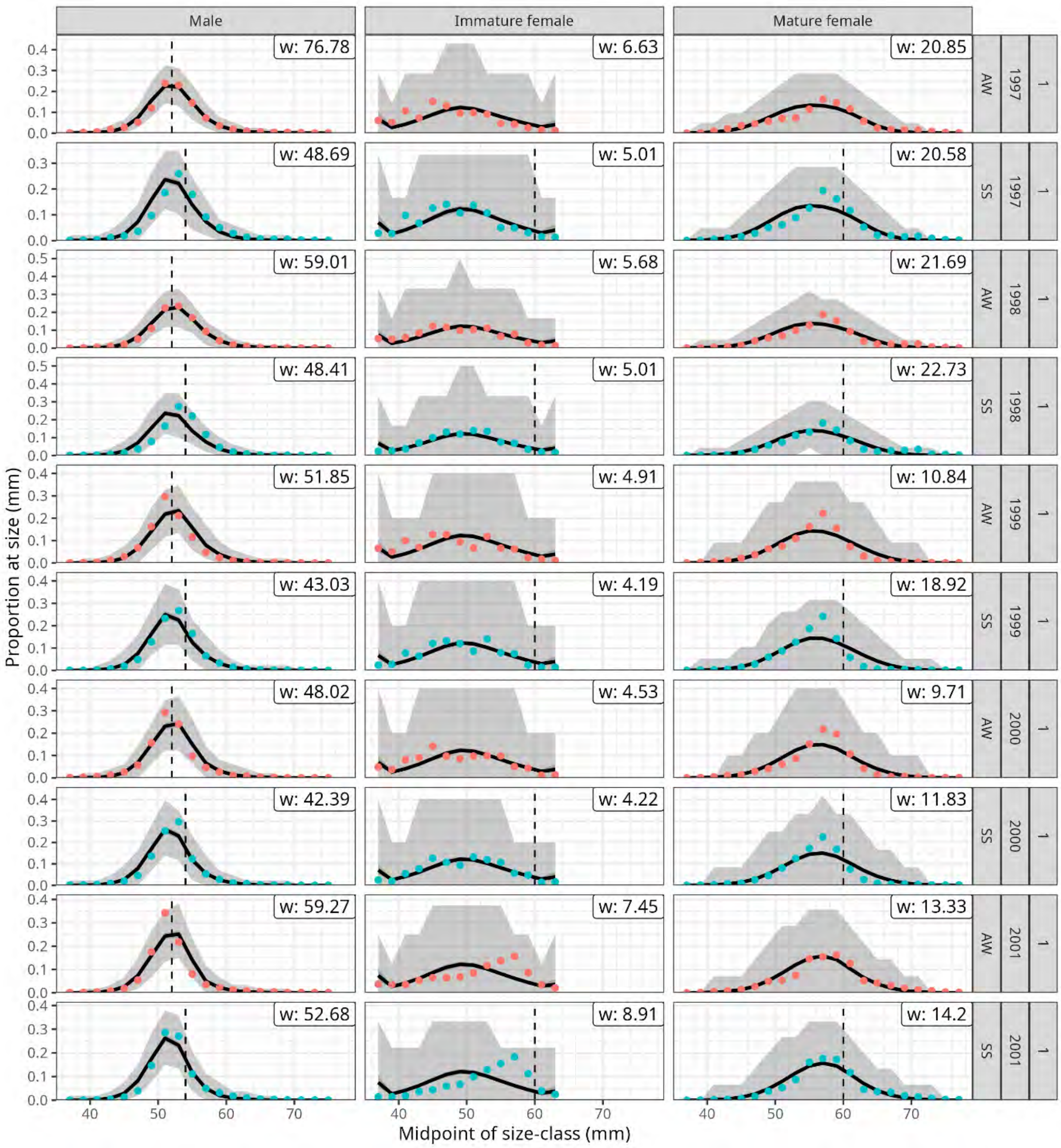

Figure I.10 (cont.)

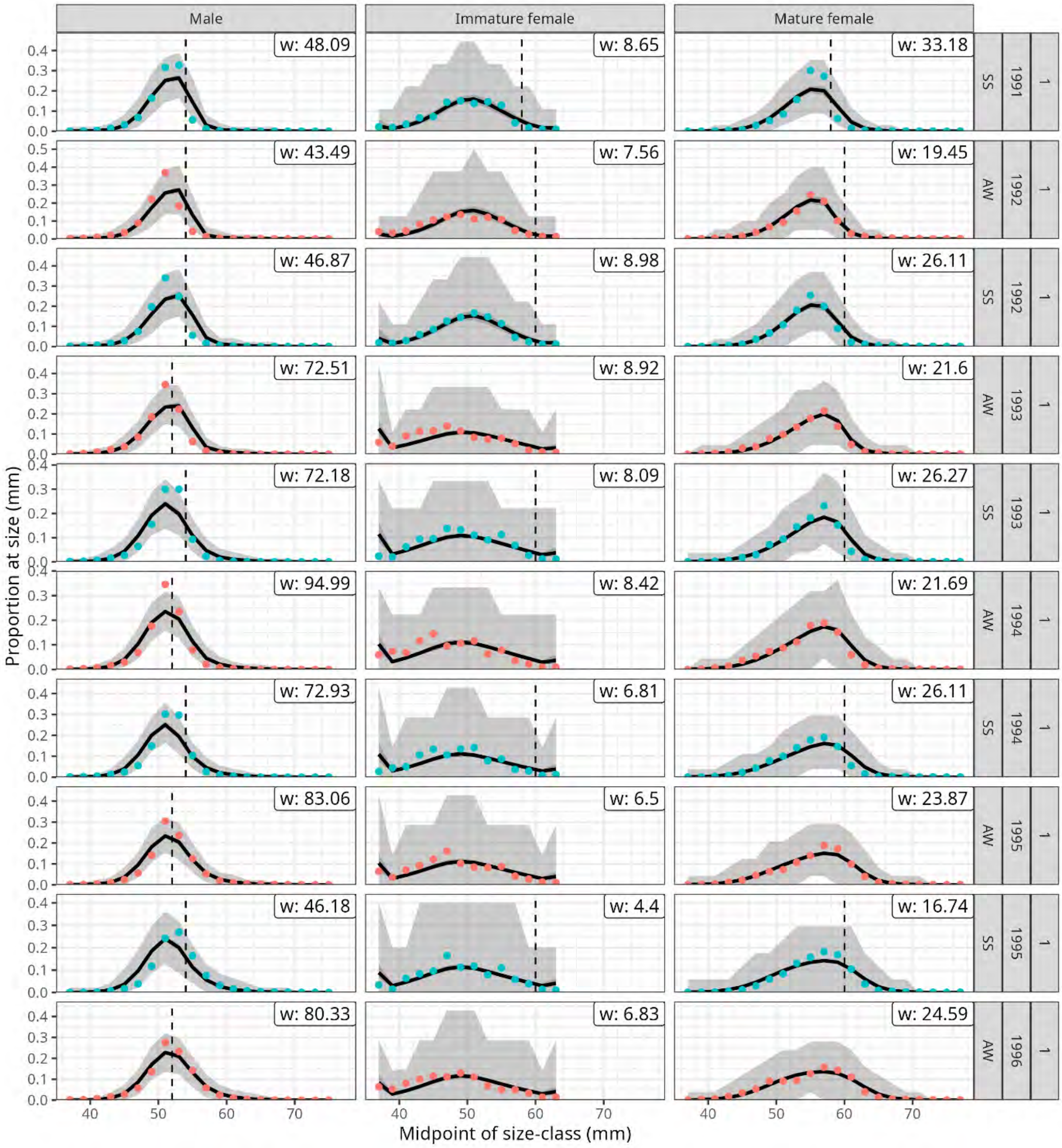

Figure I.10 (cont.)

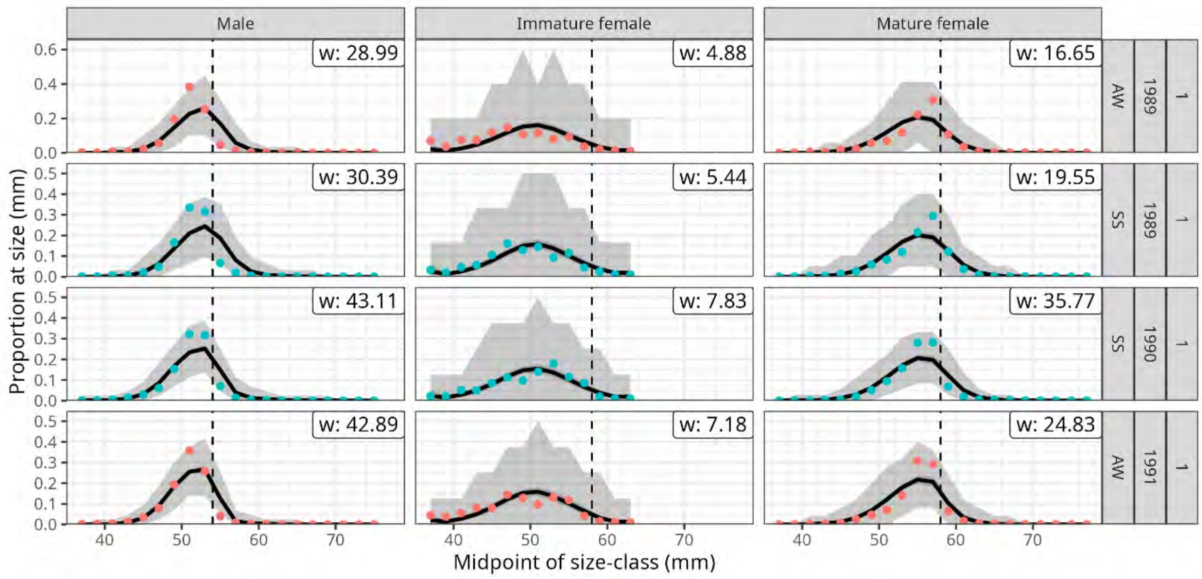

Figure I.10 (cont.)

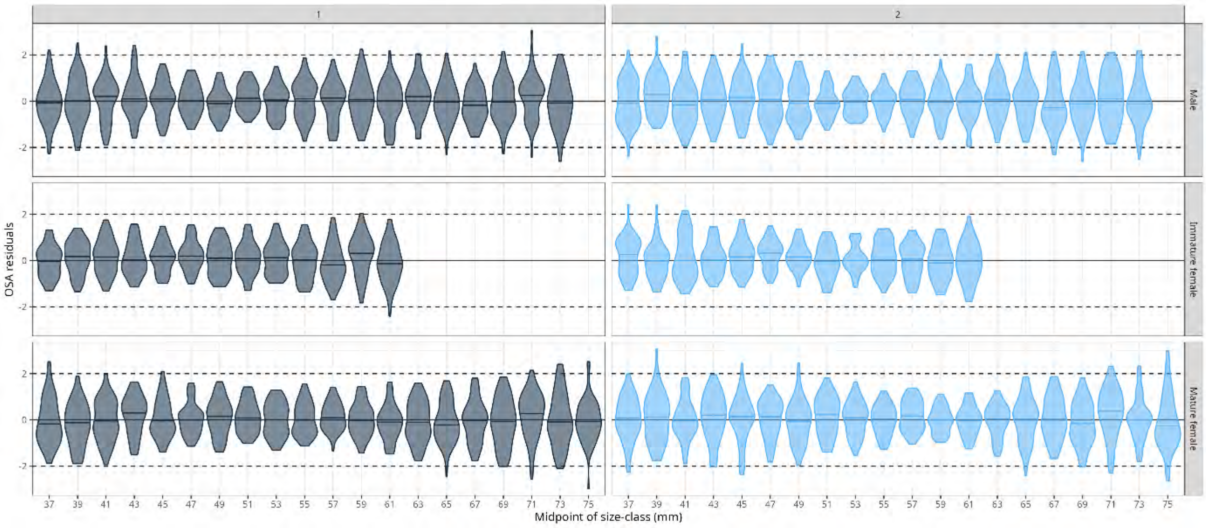

Figure I.11: Posterior distribution of OSA residuals from fits to the LF data by sex and 2 mm TW bin.

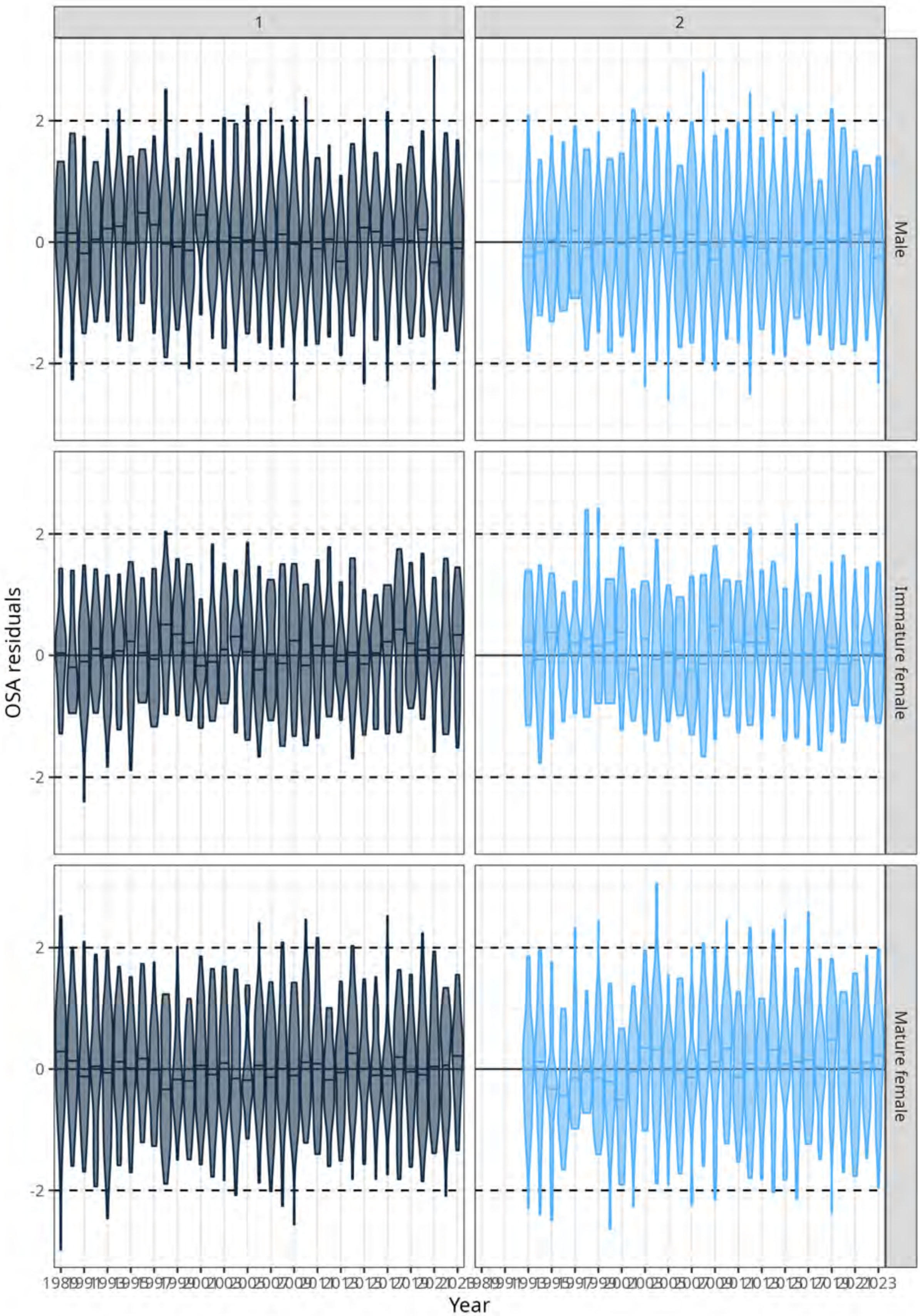

Figure I.12: Posterior distribution of OSA residuals from fits to the LF data by sex and fishing year.

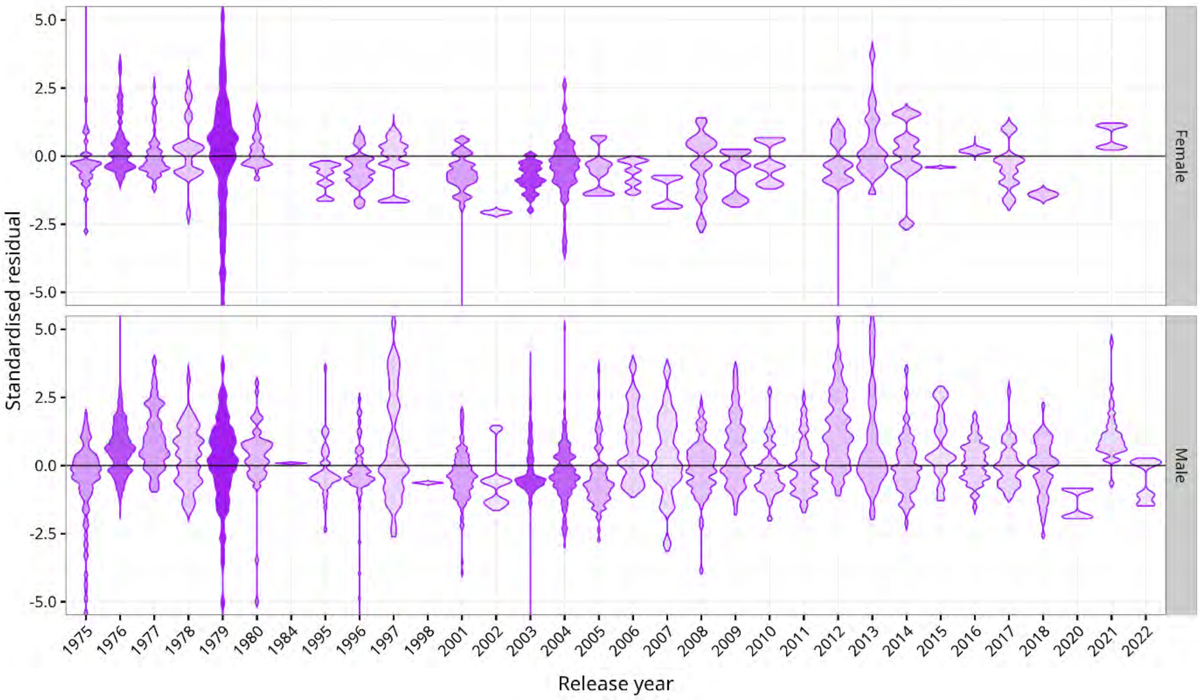

Figure I.13: Posterior distribution of standardised residuals from model fit to the tag data by fishing year of release and sex in the <u>base</u> model run. Shading intensity varies with number of observations.

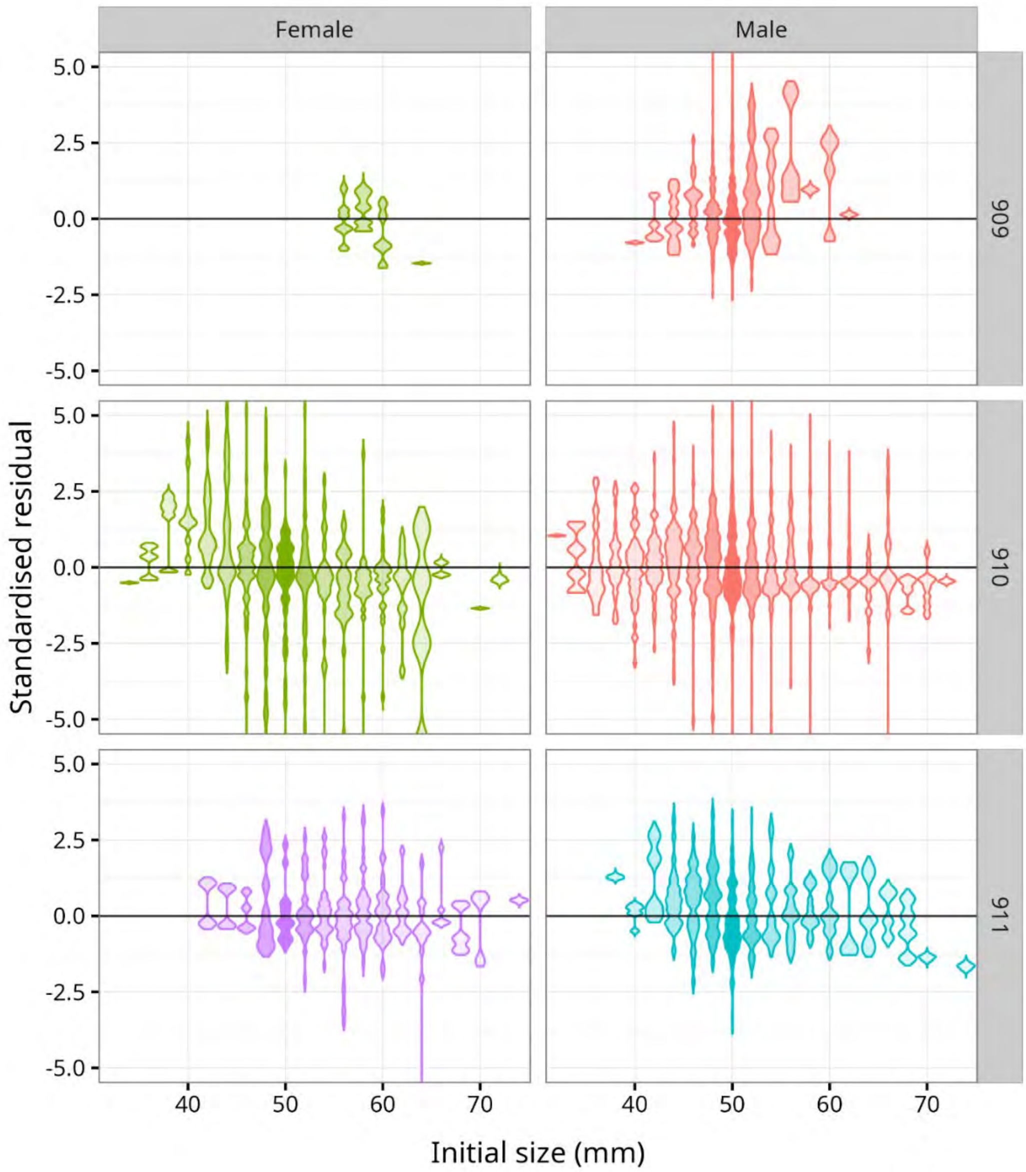

Figure I.14: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release, initial size, and sex in the base model run. Shading intensity varies with number of observations.