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The 2025 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2

New Zealand Fisheries Assessment Report 2026/28

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PLAIN LANGUAGE SUMMARY

This report documents the 2025 stock assessment of red rock lobsters in CRA 2. The stock model was fitted to standardised catch-per-unit-effort indices, length frequency data, proportion male data, and tag-recapture growth increment data. Modelling was done using a new lobster stock assessment software called *decamod* coded in RTMB. This stock assessment estimated generally increasing catch removals as a percentage of the population from 1979 to 2016. Catch cuts and a period of improved recruitment have helped the stock rebuild since the 2017 and 2022 stock assessments.

EXECUTIVE SUMMARY

Rudd, M.B.[1]; Webber, D.N.[2]; Starr, P.J.[3]; Roberts, J.[4]; Pons, M.[5] (2026) The 2025 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2.

***New Zealand Fisheries Assessment Report* 2026/28. 140 p.**

This document describes the 2025 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2. The stock assessment used the new *decamod* length-structured stock assessment model coded in RTMB. Data inputs and technical decisions were discussed and agreed upon by the Rock Lobster Working Group (RLWG), who oversaw this work. Covariates and data included catch estimates for all sectors of the CRA 2 fishery, catch-per-unit-effort (CPUE) indices, standardised proportion male, standardised length frequency (LF) distributions, standardised proportions of mature females at length, standardised proportions of females at length that were in berry (egg-bearing), and tag-recapture growth increment data.

This document describes the procedure used to find an acceptable base case model. Model inference for this assessment was based on maximum likelihood estimates and Markov chain Monte Carlo simulations. Several sensitivity trials were done to test model assumptions.

This stock assessment assumed a single-region model that combined data across the four CRA 2 Statistical Areas. This model choice was informed by a regional characterisation of the fishery data, in which CPUE and LF distributions did not vary enough spatially to warrant a multi-region approach to modelling the stock. The reconstruction of the base model began in 1979, as was done in the 2022 and 2017 assessments, due to uncertain commercial catches in the early years of the fishery and negligible differences in the stock trajectory in sensitivity analyses which started the reconstruction in 1945.

This stock assessment estimated generally increasing exploitation rates between 1979 and the mid-2010s, leading to a continuous decline in vulnerable biomass, except for a period in the 1990s when there was an increase in stock biomass driven by a strong recruitment pulse. The 2017 stock assessment estimated that the stock was below the soft limit (20% SSB_0), requiring a rebuilding plan. Voluntary shelving of annual catch entitlement (ACE) began in 2015, followed by a formal TACC reduction in 2018, and a period of improved recruitment starting around 2015 allowed the stock to rebuild after the 2017 stock assessment. The current stock assessment also updated the (vulnerable biomass) reference level for CRA 2 and the stock is now estimated to be above this. Five-year projections suggested a continued increase in stock biomass at current catch levels.

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1 INTRODUCTION

This document presents a stock assessment for red rock lobsters (*Jasus edwardsii*) in CRA 2. This stock assessment was completed in a workshop during May and June 2025. Decisions on data and modelling choices were discussed and approved by the Fisheries New Zealand Rock Lobster Working Group (RLWG). The stock assessment was presented to and approved by the Fisheries New Zealand Plenary in September 2025 (Fisheries New Zealand 2025).

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

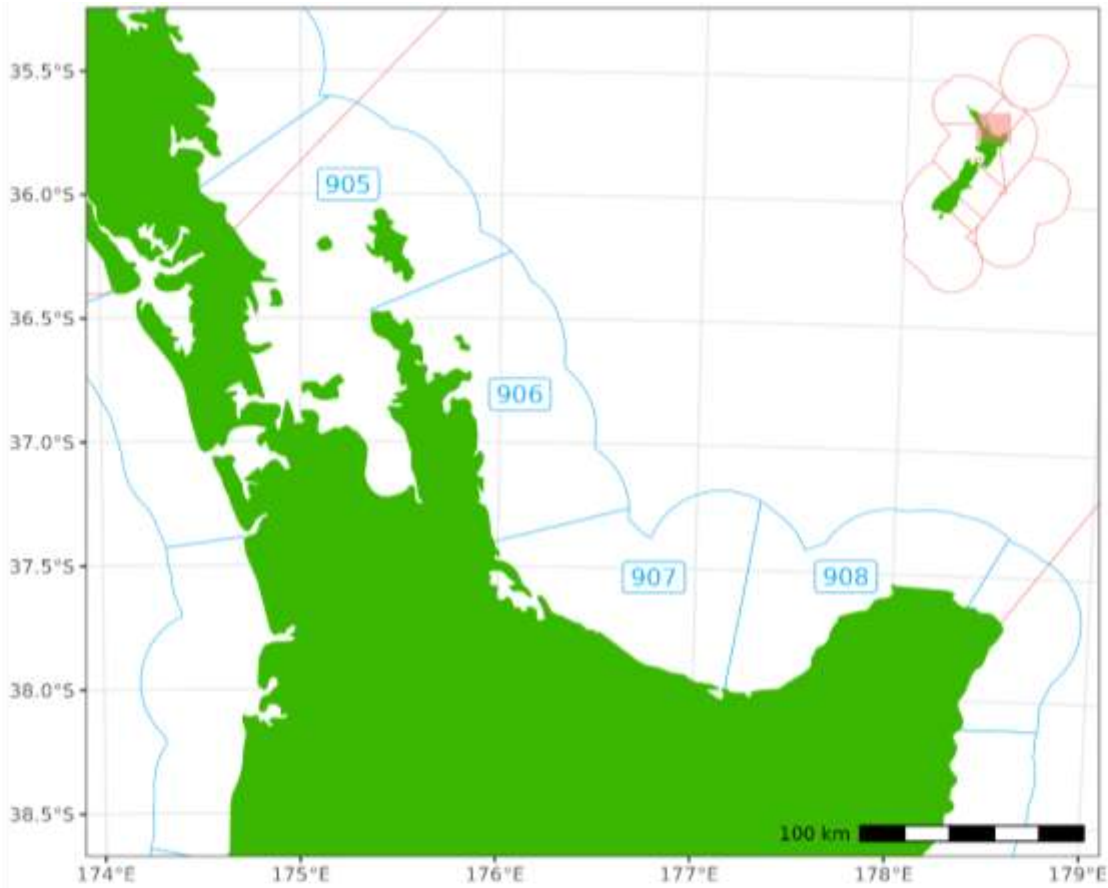

Figure 1: The CRA 2 Quota Management Area (QMA).

Beginning with the 2014–15 fishing year and extending to the 2019–20 fishing year, the CRA 2 Total Allowable Commercial Catch (TACC) was set using a management procedure (MP) that was adopted in 2013 (Webber et al. 2018) after management strategy evaluation (MSE). The MP was suspended after 2020 because the introduction of electronic reporting changed the reporting of the rock lobster catch and effort data, resulting in a lack of comparability with data collected previously on paper-based Catch Effort Landing Return (CELR) forms.

The CRA 2 TACC in 2025 was 80 tonnes. The CRA 2 non-commercial allowances set by the Minister for Oceans and Fisheries were 16.5 tonnes for customary catch, 34 tonnes for recreational catch, and 42.5 tonnes for illegal removals, for a Total Allowable Catch (TAC) of 173 tonnes. Commercial catch is constrained to stay within the TACC via the application of the controls implemented through the Quota Management System (QMS). Additional output controls directly accounted for in the stock assessment include: minimum legal sizes (MLS), which, in CRA 2, are 54 mm tail width (TW) for males and 60 mm TW for females for both the commercial and recreational fisheries; and a general prohibition of the take of berried females and soft-shelled individuals. Other management tools, such as gear restrictions, number of pots, escape apertures, and area closures are indirectly included via processes modelled in the stock assessment. The recreational fishery is restricted to a daily limit of three red rock lobsters per day, contributing to a maximum combined total of six rock lobsters per day if packhorse (PHC) are also taken. Recreational fishers are also required to clip the central telson on the tail of each lobster to identify them as being recreationally caught. Potting and hand-gathering are the preferred methods for recreational fishers in CRA 2 (see table 4 of Roberts et al. 2023). Most of the recreational catch is taken during the summer months, consistent with other red rock lobster stocks. The region also sustains a dive charter industry catering to recreational fishing during summer. Customary harvest is authorised by approved Tangata Kaitiaki/Tiaki or authorised representatives.

The 2017 CRA 2 stock assessment estimated that the spawning stock biomass (SSB) was below the 20% SSB_0 soft limit in 2016–17 (Webber et al. 2018). This result triggered management actions in the form of significant reductions to the TACC and recreational allowance in April 2018 (see Fisheries New Zealand 2018). Rapid updates of the full stock assessment in 2020 and 2021 indicated that there had been improvements in the CRA 2 stock status after the implementation of these catch reductions (Webber et al. 2021a; Rudd et al. 2022). The 2022 stock assessment estimated a continued upward biomass trajectory for CRA 2 (Rudd et al. 2023). Rapid updates in 2023 and 2024 suggested a slower increase than was estimated in the 2022 stock assessment (Pons et al. 2025).

This document presents a new stock assessment for CRA 2, which includes updates to the catch-per-unit-effort (CPUE) standardisation procedure and other inputs up to the end of the 2024[2] fishing year.

2 DATA AND COVARIATES

2.1 Data

The data sets used to inform this stock assessment included commercial fishery CPUE time series, length frequencies (LFs) and proportions male of the commercial catch, and tag-recapture growth increment data collected by commercial and recreational fishers.

2.1.1 Catch per unit effort (CPUE)

Five CPUE data sources were considered for use in this stock assessment:

- The catch rate (CR) series is an annual arithmetic daily catch rate (kg/day) from 1966 to 1973. This series is documented in Bentley et al. (2005) and was only used in the sensitivity analysis that started the model in 1945.
- The Fisheries Statistics Unit (FSU) series is a seasonal standardised index from the autumn-winter season (AW) of 1979 to AW 1989. The standardisation model was fitted to biomass-based catch rate data aggregated by year, month, Statistical Area, and vessel. Explanatory variables included period (the six-month autumn-winter/spring-summer season within each 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 Catch Effort Landing Return (CELR) series is a seasonal standardised series based on biomass-based catch rate data from the spring-summer season (SS) of 1989 to AW 2019. The standardisation model was fitted to biomass-based catch rate data aggregated by year, month, Statistical Area, and vessel. Explanatory variables included period, month, Statistical Area, and vessel.

[2] The 2024–25 fishing year is referred to in this document with the first year (2024) of the pair of years.

- The CELR series was gradually replaced by a new Electronic Reporting System (ERS) over the period April-September 2019. The ERS series is a seasonal standardised series based on biomass-based catch rate data from AW 2019 to SS 2024. The standardisation model was fitted to biomass-based catch rate data aggregated by year, month, Statistical Area, and vessel. Explanatory variables included period, month, Statistical Area, and vessel. Furthermore, each stratified observation within this model was weighted by the vessel correction factor (VCF[3]) within the likelihood (i.e., a VCF of 1 had full data set weight, but a VCF above/below 1 received lower weight). The Electronic Reporting System (ERS) data were considered but not used in this assessment.
- The logbook (LB) series is a seasonal standardised series based on numerical catch rate information from AW 1993 to SS 2024 (the CRA 2 LB programme was initiated in 1993). Starr (2012) noted that the CPUE series calculated from the CRA 2, CRA 5, and CRA 8 voluntary logbook programmes were a good match with the CPUE series based on the compulsory catch and effort reports to MPI/Fisheries New Zealand. Therefore, a Bayesian standardised logbook CPUE series was developed for use as an index of abundance for CRA 2 from 1993 to 2024.

The CR, FSU, and CELR series were not updated for this stock assessment as there were no new data collected since the 2022 assessment. The models producing the FSU and CELR indices are described in Webber & Starr (2022). 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 2022 for the evidence supporting this decision).

For the LB CPUE series, there was no formal model comparison/optimisation process. Instead, a generic 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). This model structure was:

$$N \sim log(pots) + period + area + (1|month) + (1|vessel) + (1|period{:}area)$$

A negative binomial distribution was assumed. The data were aggregated to the trip level prior to model fitting, to speed up the model run times. Several alternative dependent variables were explored, including:

- the number of legal lobsters (above the MLS and not a berried female),
- the number of lobsters above the MLS,
- the number of lobsters below the MLS,
- the total number of lobsters (above and below the MLS),
- the number of female lobsters above the MLS, and
- the number of male lobsters above the MLS.

All six series showed similar patterns in CPUE; therefore, the series that modelled the number of legal lobsters per pot was used in this stock assessment. No issues were detected in the MCMC diagnostics for any model run (i.e., there were no divergent transitions, R-hat statistics were acceptable, and visual inspection of the MCMC trace plots was satisfactory; Figure A.1). The negative binomial assumption was also acceptable (Figure A.2). Standardisation did little to change the unstandardised series (Figure 2), and the logbook CPUE series was very consistent across Statistical Areas (Figure 3). Spatiotemporal CPUE modelling with the R package *tinyVAST* was also explored using the spatially resolved logbook data. This model produced an almost identical series during AW but a much greater increase in CPUE from 2020 in SS. The series was not used in the assessment because the cause of this seasonal difference was not fully understood.

[3]The vessel correction factor (VCF) is the ratio of estimated catch to landed catch for a vessel within a fishing year.

A separate exploratory CPUE series was fitted to biomass-based ERS catch rate data, but this was not used in the stock assessment given the limited number of years for which data were available at the time that this assessment was undertaken. This series resembled the LB series, although the ERS series was relatively flat and uncertain, and commenced after the increase in CPUE that occurred between 2017 and 2019 (Figure 4).

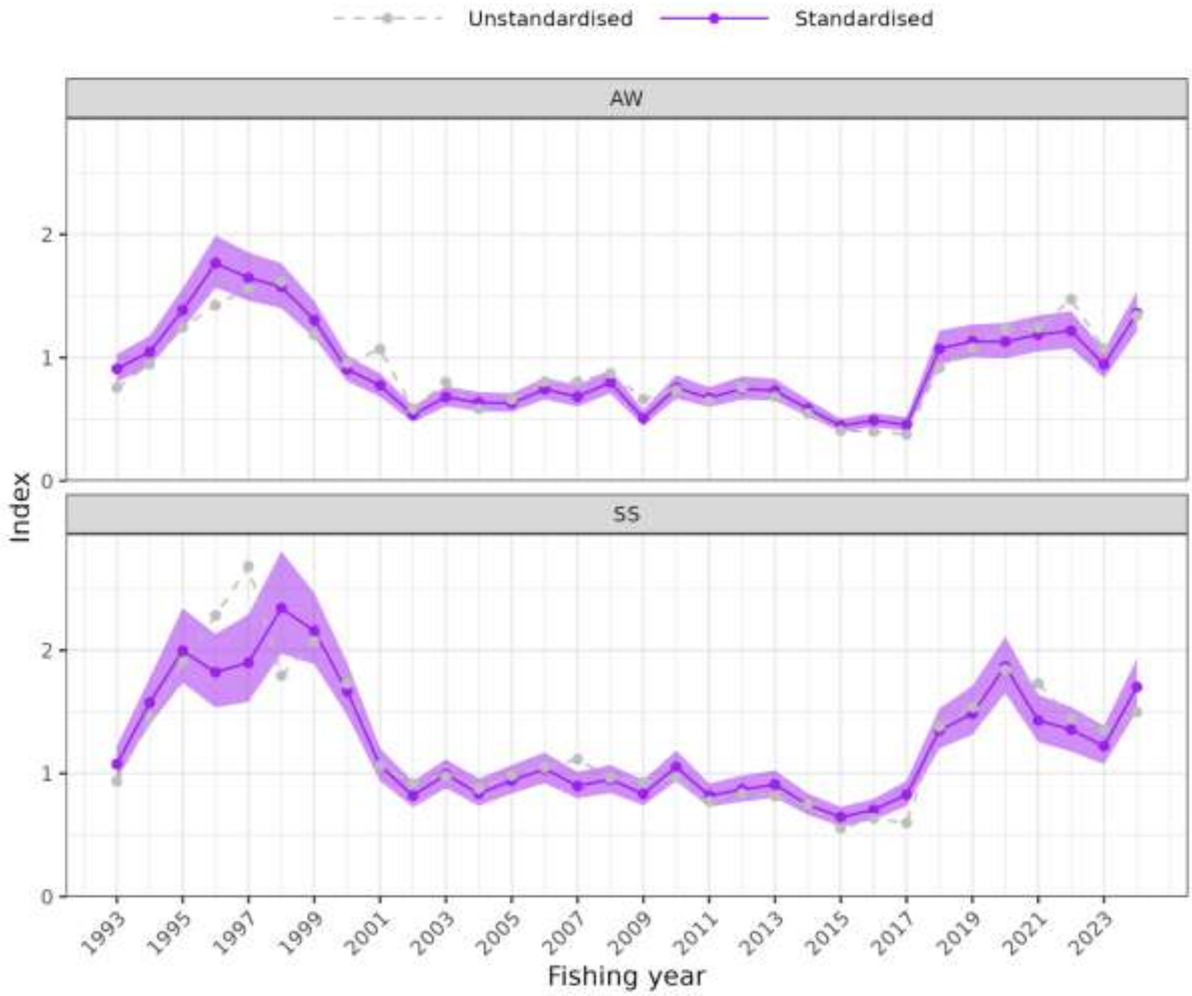

Figure 2: Logbook model standardised and unstandardised relative abundance indices from 1993 to 2024, faceted by season: autumn/winter (AW, top panel) and spring/summer (SS, bottom panel). The solid purple lines represent the standardised index derived from the Bayesian mixed-effects model (brms), with the purple shaded regions illustrating the 50% posterior credible intervals (25th to 75th percentiles). Dashed grey lines indicate the raw, unstandardised index trends for comparison.

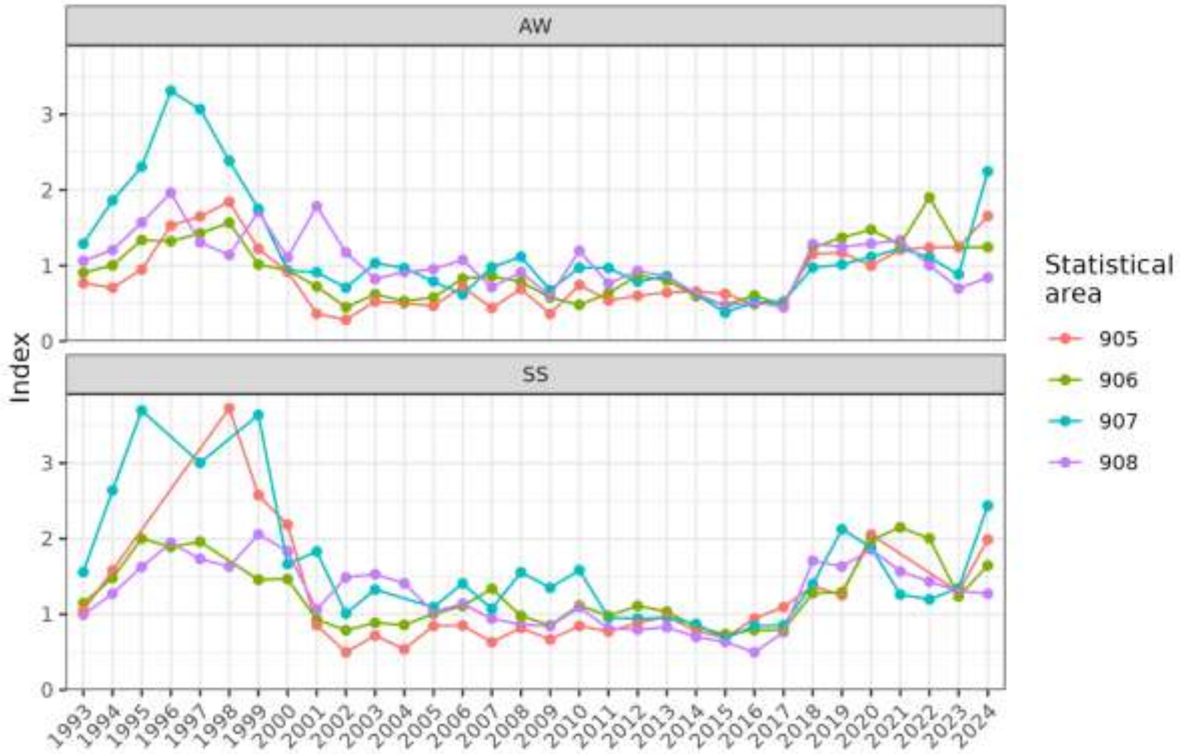

Figure 3: Logbook model standardised CPUE trends from 1993 to 2024 for the four Statistical Areas (905, 906, 907, and 908), stratified by season: autumn/winter (AW, top panel) and spring/summer (SS, bottom panel).

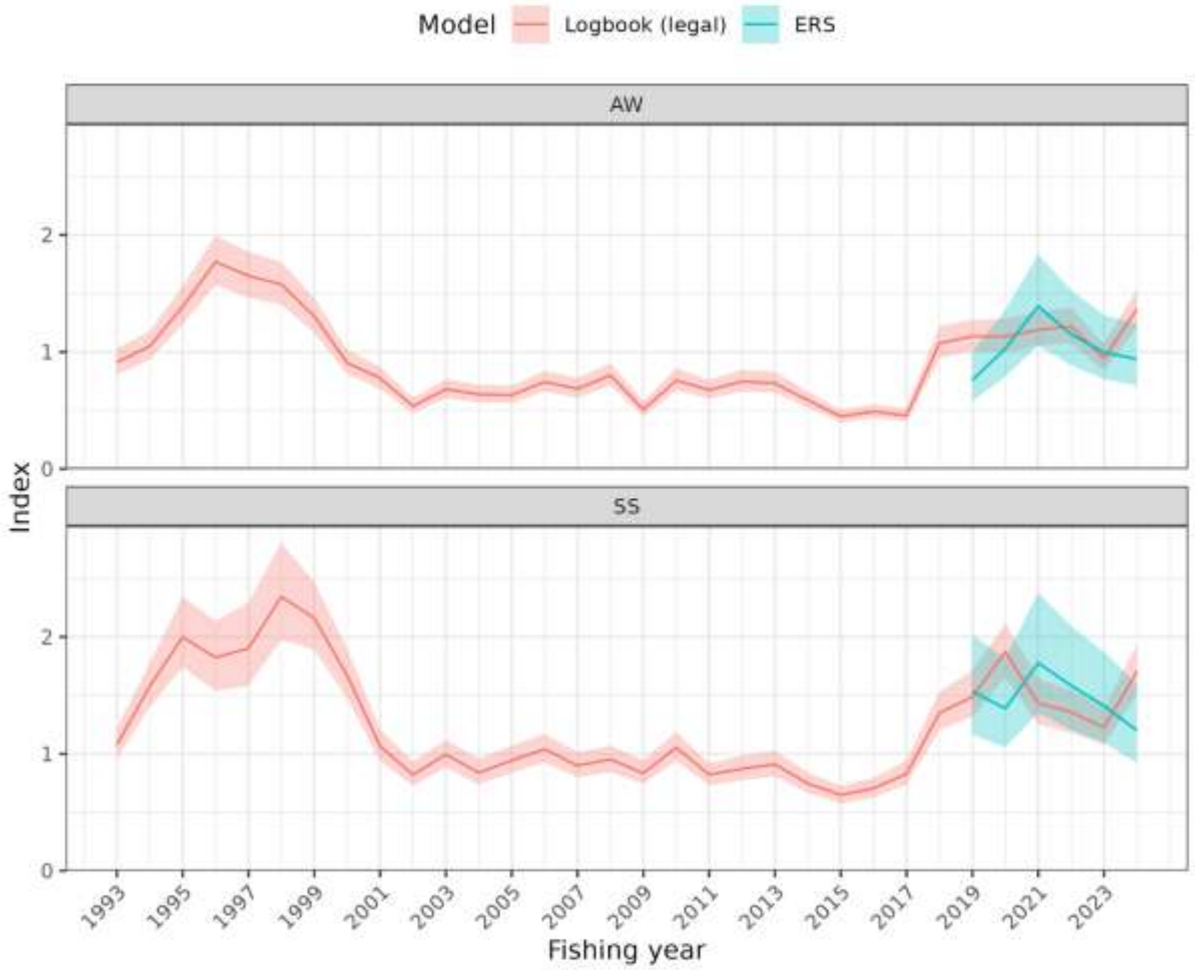

Figure 4: Comparison of relative abundance indices derived from the logbook (legal) series (1993–2024) and the ERS series (2019–2024), faceted by season: autumn/winter (AW, top panel) and spring/summer (SS, bottom panel). Solid lines represent model medians, with shaded ribbons indicating the 50% posterior credible intervals (25th to 75th percentiles). To facilitate direct comparison over the overlapping period, the ERS series has been rescaled to the geometric mean of the logbook series.

2.1.2 Proportion male and length frequency

The CRA 2 fishing industry made a strong commitment to the voluntary logbook programme when it was introduced in 1993 and has continued to use it as the primary source of stock-monitoring information. CRA 2 was also identified in the mid-1990s as an important area for tagging experiments, generating substantial effort into the 2000s. Auxiliary observer catch sampling at sea continued through to the 2023–24 fishing year, usually for 12 days per year. Its primary purpose was to verify the voluntary logbook data; the two data sources were broadly comparable and both were used in the 2025 assessment.

Webber (2022) developed a model-based procedure that unified the two data sources into a single series, to predict the uncertainty associated with each sampled year/month/statistical area stratum and correctly weight between the two data sources if both were present in the same stratum. Furthermore, the procedure predicted LF distributions for strata with unsampled catch, for those years for which observational LF data were available. LFs generated using this procedure were incorporated into the 2025 CRA 2 stock assessment. The same procedure was applied to the sex ratio data derived from the two data sources.

2.1.2.1 Proportion male in the catch

Following the approach of Webber (2022), a *brms* model was constructed to predict the proportion male in the catch by fishing year, month, Statistical Area, and vessel. Model explanatory variables included fishing year, month, Statistical Area, vessel, a fishing year by month interaction term, and a fishing year by Statistical Area interaction term. The fishing year, month, and Statistical Area 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, Statistical Area, 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 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 B.1). This model was then used to simulate the sex ratios by year, month, and Statistical Area from the posterior distribution. This model-based approach also predicted the sex ratios if there was catch in a stratum but no catch sampling from either data source, and combined the available sex ratio data from both data sources if both were present in the respective stratum.

The catch (tonnes) in each fishing year, month, and Statistical Area stratum was calculated from the catch and effort database, using the F0_LFX algorithm (appendix D in Starr 2025). The simulated sex ratios were rescaled by the monthly catch in each Statistical Area and aggregated by posterior sample, fishing year, season, and sex category (i.e., month and Statistical Area were rolled up).

The model-based standardisation and subsequent catch scaling did little to alter the time series of raw averaged sex ratios by fishing year and season (Figure 5). The proportion male in the catch had no obvious long-term trend over the time series of the data, although it decreased slightly around the turn of the millennium and increased after 2018 during AW but not during SS.

Only the proportion male component of the sex ratio was used by the stock assessment. The mean and associated standard deviation (SD) were calculated for each fishing year and season stratum, and the respective data set weights for each fishing year and season were calculated from the posterior SD values (see Webber 2022).

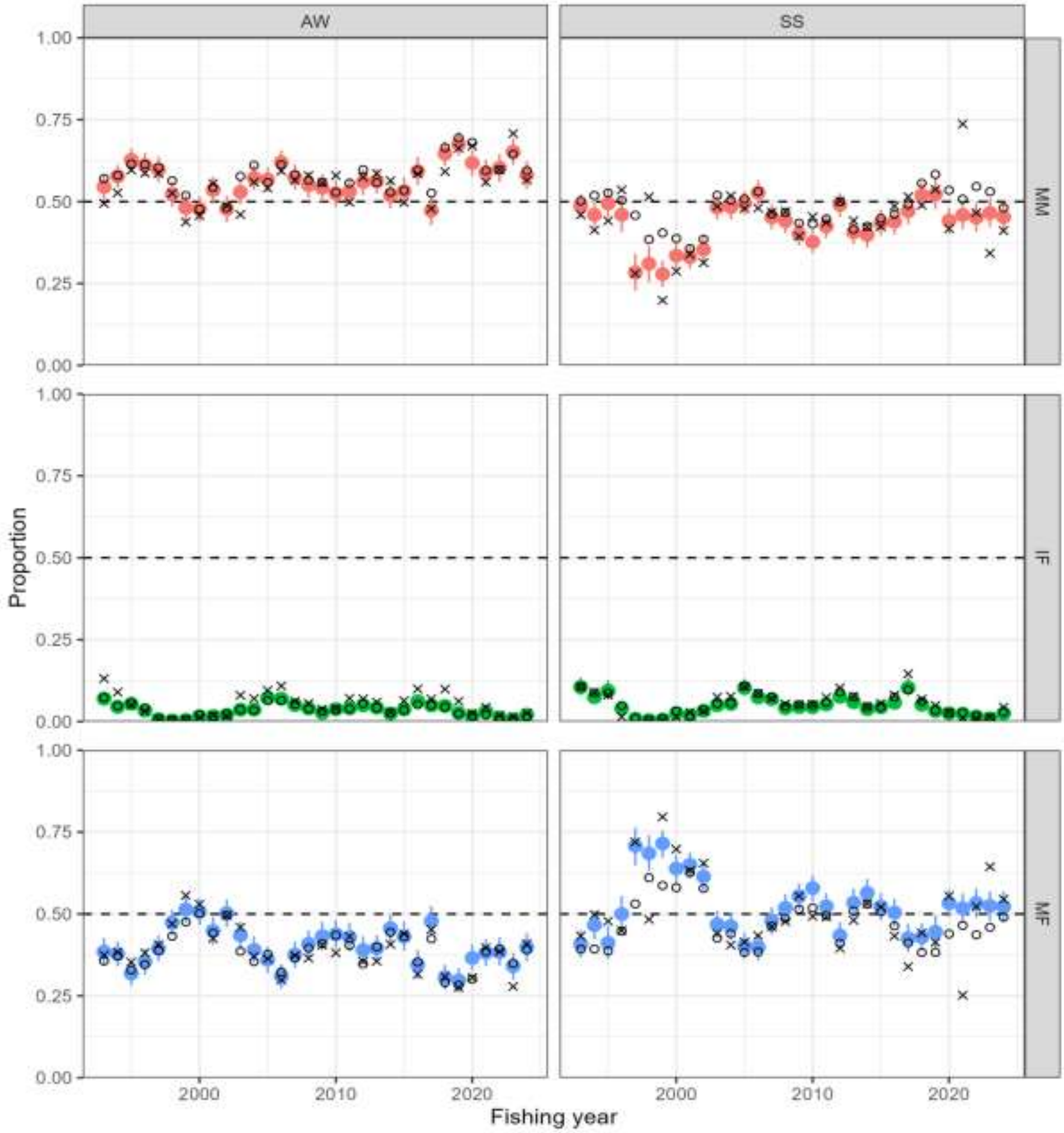

Figure 5: Sex ratio (SR) of males (MM), immature females (IF), and mature females (MF) by fishing year and season (AW = autumn/winter, SS = spring/summer), showing raw SRs (black crosses), predicted SRs (open black circles), and scaled SRs (closed circles with error bars representing 95% credible intervals).

2.1.2.2 Length frequency of the catch

Following the approach of Webber (2022), a *brms* model was constructed that estimated the proportion at length of the catch by sex, fishing year, month, and Statistical Area. Model explanatory variables included: fishing year, month, Statistical Area, data source (i.e., observer catch sampling or voluntary logbook sampling), a source × vessel interaction term, and a fishing year × Statistical Area interaction term. All model terms were treated as group-level (random) effects.

For a given sex category (female or male), fishing year, month, Statistical Area, data source (LB or CS), and vessel, 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 using a Poisson-decomposed multinomial distribution and the default *brms* priors were used. MCMC mixing was acceptable (Figure B.3, Figure B.4).

The fitted LF models for each sex were used to simulate the predicted LF by sex, fishing year, month, and Statistical Area 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. It also pooled the available LF data from both data sources if both were present in the stratum. The catch (tonnes) in each fishing year, month, and Statistical Area stratum was calculated from the commercial catch and effort data, using the F0_LFX algorithm (appendix D in Starr 2025). The simulated LFs were scaled, first by the sex ratio model, then by the monthly catch in each statistical area and aggregated by posterior sample, region, fishing year, season, sex category, and length bin, then converted to proportions. The mean and SD by fishing year, season, sex category, and length bin were calculated from the posterior distribution. Finally, the data set weight for each fishing year, season, and sex category was calculated from the posterior SD.

In most years, the sample sizes were reasonably high, although sampling prior to 1993 was obtained from fewer than 3 vessels annually, so was excluded from this analysis (Table B.1). The standardised LFs (i.e., the scaled, predicted LFs) were very similar to the LFs produced from the raw data (Figure B.2, and Figure B.5 to Figure B.12), but at lower sample sizes (e.g., males and females in SS of 1997 and 1998) (Figure B.5, Figure B.9) the procedure was more likely to adjust the LFs for the respective stratum. 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 combined data set that is essentially self-weighting for the catch.

Based on the standardised LFs, the size distribution of the catch increased during the 1990s up to a peak in the late-1990s, before decreasing gradually through to the mid to late 2010s, then increasing again up to the final year (Figure 6, Figure 7). This temporal pattern was observed in both seasons and for both sexes. The periods of increasing and decreasing size distribution were coincident with periods of increasing and decreasing CPUE, respectively (comparing Figure 4 with Figure 6) and also track the changes in raw average TW over time, noting that the increase in average TW since 2017 was observed in all statistical areas (Figure 7).

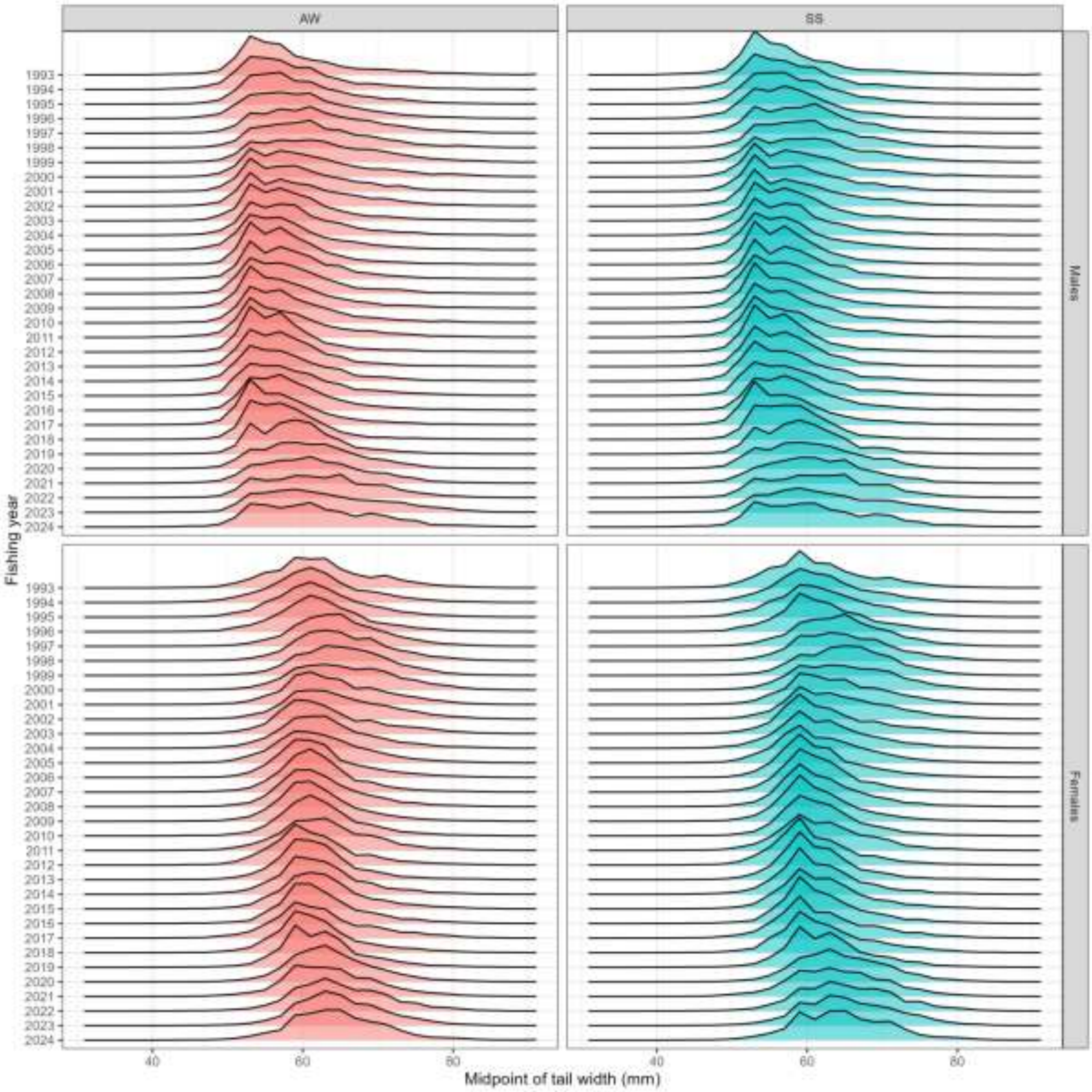

Figure 6: Predicted standardised LFs by fishing year (from 1993 to 2024), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex.

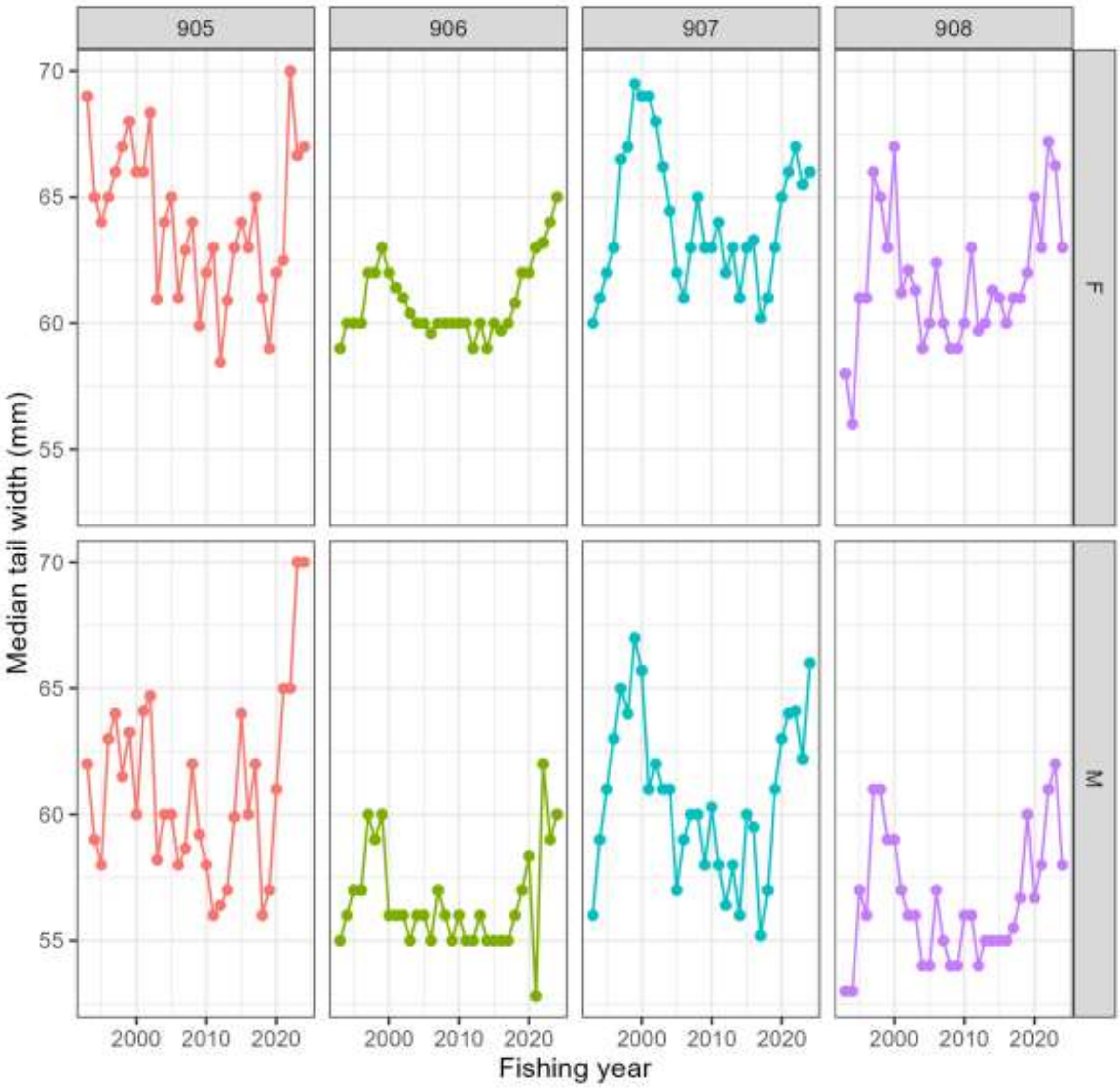

Figure 7: Median tail width (mm) by fishing year, sex (M = males, F = females), and statistical area, based on the pooled, unstandardised observer catch-at-sea sampling and logbook data.

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 are also useful for informing decisions about stock structure and movement. Tag data for all CRA areas were obtained in May 2025 from Fisheries New Zealand (replog 16686).

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 linking every tag release-recapture event to create a single record while discarding all tags with no recaptures. Processing, linking, and formatting were done using purpose-built software written in the R statistical computing language (see Roberts et al. 2023 for a description of these preparatory steps).

The new data extract was compared with previous extracts to confirm that no existing records were missing and to quantify new records. The 2025 tag-data extract was identical to the 2024 extract.

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 (30.42%) and the lowest rate in CRA 9 (2%) (Table C.1). There were 36 204 complete release/recovery record pairs (i.e., not missing a key piece of information such as sex, QMA, initial size, recapture size, or time at liberty) available in the New Zealand rock lobster tagging data set, of which 22 303 were males and the remaining 13 901 were females (Table C.2). The CRA QMA with most recovered tags was CRA 8, and the fewest recaptured tags came from CRA 6 and CRA 9, which had 269 recoveries and 129 recoveries respectively (Table C.2). Tagged lobsters were primarily recaptured in the QMA and statistical area of release, but there was evidence that some individuals moved much greater distances (Table C.3, Table C.4).

The 2025 assessment used paired individual tag–recapture observations from all releases; the previous assessment used only initial release–recovery pairs. Data came from all CRA 2 Statistical Areas (905–908). Most lobsters were tagged and recaptured within CRA 2; a few were recaptured outside it or had an unknown release or recapture area but were linked to CRA 2 by project ID (Table C.3).

Nearly all CRA 2 tagging effort occurred after 1996; only 5.3% of release–recovery observations were from 1985 or earlier (Table C.5). The remaining observations spanned releases from 1996 to 2023. Statistical Area 906 accounted for about 55.2% of recoveries, followed by Statistical Area 907 (21.5%) and Statistical Area 908 (18.8%). Of 5033 recaptures, 2485 were females and 2548 were males (Table C.5).

The monthly distribution of releases that resulted in recaptures is shown in Table C.6. Time at liberty ranged from 1 day to just over 3350 days (about 9 years) for both sexes (Table C.7); the processing procedure excluded recoveries after more than 10 years. Median time at liberty was 260 days for males and 351 days for females. Repeated-release records ranged from 7 to 11 releases for males and from 5 to 8 for females. Re-releases accounted for 41% of male recoveries and 26% of female recoveries.

Observed growth increments ranged from −37 to 28 mm TW for males and from −24 to 25 mm TW for females (Table C.8).

The RLWG agreed to exclude tagged lobsters that had been at liberty for less than six months. This exclusion was 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. The zero-growth increment bin was interpreted as lobsters which had failed to moult after tagging, and there was concern that the inclusion of short time at liberty observations in the growth model, in conjunction with seasonal tagging effort, would bias the estimate of growth. Note that it is not possible to infer whether a lobster has recently moulted through observation of the sampled animal. While the analysis concluded that nearly all lobsters had grown 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. For CRA 2, 65% of the tag data were retained when using the six-month exclusion (Table C.9).

2.2 Covariates

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

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.

Table 1: Fixed quantities used in the CRA 2 base case stock assessment model. The resulting recruitment proportion at tail width is shown in Figure 12.

Quantity	Value	Quantity	Value
Data set weights		**Fixed parameters**	
Tags	1	Male length-weight a	4.16e-6
FSU CPUE	0.75	Male length-weight b	2.935
CELR CPUE	1.88	Female length-weight a	1.30e-5
LB CPUE	1.09	Female length-weight b	2.545
Sex Ratio	184	catchability creep	1%
LF males	11.9		
LF females	2.68	**Recruitment**	
		years for ARIMA projections / autocorrelation	1980–2020
Catch and handling		sigmaR	0.4
Handling mortality, 1945–1989	0.1	recruitment size mean	32 mm
Handling mortality, 1990–2029	0.05	recruitment size SD	2 mm
Projected SL commercial catch	80.0 t		
Projected SL recreational catch	8.7 t	**Growth and maturity**	
Projected NSL illegal catch	8.0 t	length at Galpha	30 mm
Projected NSL customary catch	5.0 t	length at Gbeta	80 mm
		Gmin	1e-04
		growth at Galpha (male)	12
		growth at Galpha (female)	14

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 used because a significant fraction of the catch came from Fiordland where it was permissible to tail lobsters at sea. The MLS was changed to a width measurement (in millimetres) across the spines of the second abdominal segment (called the tail width or TW) in 1988 for all New Zealand red rock lobsters, requiring the conversion of the pre-1988 regulations into equivalent TW measurements for use in the stock assessment model (Breen et al. 1988). The current MLS in CRA 2 is 54 mm TW for males and 60 mm for females (Table 2).

Table 2: Minimum legal size over time.

Period	Males (mm TW)	Females (mm TW)
< 1950	–	–
1950–1951	47	49
1952–1958	51	53
1959–1988	53	58
1988–1991	54	58
> 1991	54	60

2.2.2 Proportion of females mature or in berry

For the 2025 assessment of CRA 2, female maturity (Appendix D) and the incidence of berried females were modelled separately from the stock assessment model (Appendix E). The proportion of females that were mature in the underlying population was predicted for each length bin using a GLMM fitted to observations from the observer catch sampling and voluntary logbook programmes. The model was fitted using data from CRA 1, CRA 2, CRA 3 and CRA 4, with separate ogives predicted for each QMA, including CRA 2 (Figure 8). The proportion of all (i.e., mature and immature) females in berry in the catch was predicted for each length bin and by season using another GLMM fitted to observations from the observer catch sampling and voluntary logbook programmes. This model was also fitted using data from CRA 1, CRA 2, CRA 3, and CRA 4, with a separate ogive predicted for CRA 2. The predicted proportions in berry were weighted by the seasonal distribution of the catch (Figure 9).

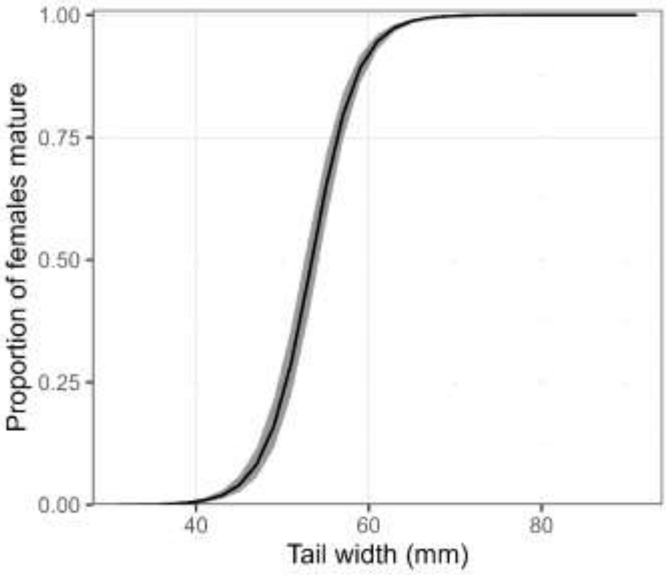

Figure 8: Predicted proportion of females that were mature by tail width bin, as used by the CRA 2 stock assessment.

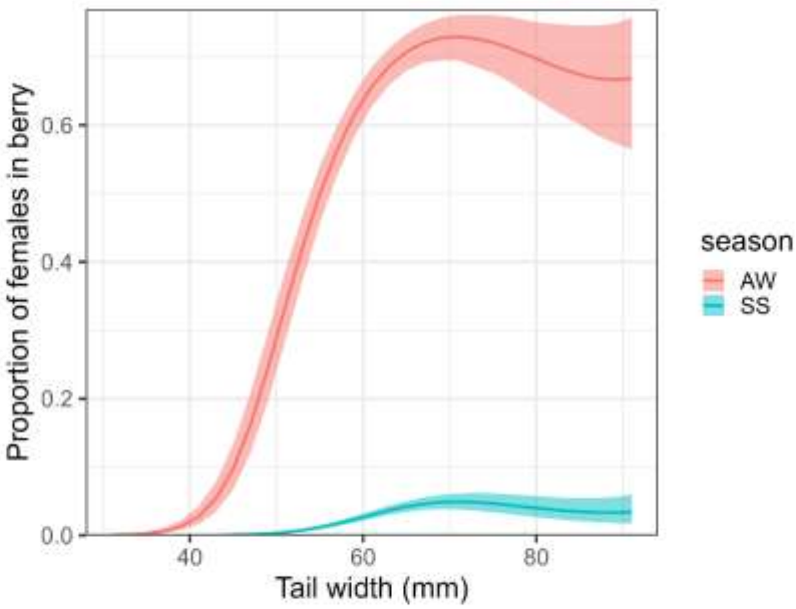

Figure 9: Predicted proportion of females in berry by tail width bin, as used by the CRA 2 stock assessment.

2.2.3 Catch

2.2.3.1 Commercial catch

The base run CRA 2 stock assessment starts in 1979, so there was no requirement to prepare pre-1979 catch histories. However, the sensitivity run which started in 1945 used historical catches which were separated into two seasons: April-September autumn/winter (AW) and October-March spring/summer (SS). This was a change from how these catches were handled in previous CRA 2 sensitivity trials, where the pre-1979 catches were left as annual estimates. For the 2025 CRA 2 *start_1945* sensitivity run, the pre-1979 catch data were split seasonally based on the seasonal information in the Annala & King (1983) data set which covered the period January 1963 to December 1973. Annual catches before 1963 from the Marine Department (Bentley et al. 2005) were split seasonally using the average CRA 2 seasonal split for 1963–1967. The annual CRA 2 1974–1978 (Annala & Esterman 1986) catches were split using the 1969–1973 Annala & King estimates.

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). There is some uncertainty in the quality of the catch estimates in the years before the FSU system began in 1979, but there is confidence in the quality of the catch estimates from the 1980s when the FSU system was operating. Catch estimates generated from the FSU data available to the stock assessment team are consistent with published historical catch estimates from the FSU system.

From 1 April 1986 to 31 March 1988, monthly reported catch totals for all of New Zealand were obtained from Quota Management Returns (QMRs) maintained by the Ministry of Agriculture and Fisheries. Because QMR returns by individual QMAs were not available for this period, these total New Zealand catches were divided into QMA catches based on the proportional landings reported on FSU forms. From 1 April 1988 to 30 September 2001, catches were summarised from monthly QMRs available for each QMA. The QMRs were replaced by Monthly Harvest Returns (MHRs) on 1 October 2001, but the same information is available from these new forms. Catch by season was assigned based on month, where AW spans from 1 April to 30 September, and SS spans from 1 October to 31 March annually.

Commercial fishing in CRA 2 is primarily confined to the Bay of Plenty, extending from the eastern side of the Coromandel Peninsula to East Cape (Figure 1). Between the mid-1990s and 2017–18, the number of vessels operating in the CRA 2 fishery was typically in the 30s, but this decreased abruptly to 18 vessels with the drop in TACC in 2018–19 and has remained around this size since (Starr 2025). This fishery supports processing and export operations primarily in Tauranga, Whitianga, and Auckland.

Commercial catches in CRA 2 averaged 196 tonnes/year before 1979, with a short period in the late 1960s when catches exceeded 300 tonnes/year (Figure 10). CRA 2 commercial catches were higher in the period leading up to the introduction of rock lobster into the QMS (1979–1988), with catches peaking at 445 tonnes in 1980–81 and averaging just over 300 tonnes/year during that decade. Commercial catches in CRA 2 have generally closely matched the TACC since the introduction of rock lobster into the QMS in 1990–91 (Figure 10), except the period from 2015–16 to 2017–18, when the commercial catch was reduced due to voluntary shelving of quota.

2.2.3.2 Recreational catch

Fourteen recreational survey catch estimates are available for CRA 2, but only nine of these are considered plausible (Table 3). The 1994 and 1996 telephone/diary surveys were considered biased in a review of the available recreational surveys (unpublished minutes, Recreational Technical Working Group [NIWA, Auckland, 10–11 June 2004]) because the interview questions likely underestimated fisher participation rates by allowing for an easy exit from the interview (‘soft refusal’ bias). Estimates from the two Kingett Mitchell national surveys (Boyd et al. 2004; Boyd & Reilly 2004) were not accepted by the RLWG for the 2013 CRA 2 stock assessment (Starr et al. 2014a) because these survey estimates were considered implausibly high for CRA 2 (and for most other fish stocks). For this reason, these four surveys were not included in the 2025 recreational catch reconstruction process. The WG also decided to exclude the 2011 western Bay of Plenty Holdsworth estimate because the concurrent 2011–12 National Panel Survey (NPS) estimate for all of CRA 2 was thought to be more reliable.

A large-scale population-based diary/interview NPS survey was conducted under contract for MPI from 1 October 2011–30 September 2012 (Wynne-Jones et al. 2014). The NPS was repeated from 1 October 2017 to 30 September 2018 (Wynne-Jones et al. 2019) and again from 1 October 2022 to 30 September 2023 (Heinemann & Gray 2024) using directly comparable methods. These surveys were designed to estimate annual catches by FMA and QMA for all important finfish and non-finfish species harvested by recreational fishers (Heinemann et al. 2015). These surveys were based on a design that resembled the New Zealand national census, making use of the census population strata (‘mesh blocks’) of dwellings as the basis for identifying recreational fishers. A door-to-door survey of households in randomly selected mesh blocks was used to select participants who were asked to report their catch for an entire year. A structured and carefully designed Computer Assisted Telephone Interview (CATI) method was used to record harvest in detail from those who had fished. The 2011–12 survey results were thought to be plausible for CRA 2, with 69 diary fishers reporting 168 red rock lobster catch events (Wynne-Jones et al. 2014) with a relatively low CV (0.24). The 2017–18 and 2022–23 surveys were not as successful in recruiting CATI participants in CRA 2, with 33 and 25 diary fishers reporting 79 and 48 red rock lobster catch events, resulting in a higher overall CV (0.36 and 0.31) (Wynne-Jones et al. 2019; Heinemann & Gray 2024). The surveys made estimates of the distribution of fishing platforms used to take lobsters in CRA 2, with most catch taken from trailer boats and only 8–12% taken from the land (Table 4). The primary capture method used to take rock lobster in CRA 2 was diving (Table 4).

For the NPS surveys, panellists provided data in terms of number of fish. Mean recreational catch weights for the most important finfish and non-finfish species QMAs were estimated in parallel projects (Hartill & Davey 2015; Davey et al. 2019, 2024).

Table 3: Survey estimates used to model recreational catch for CRA 2. Survey estimates for 2019 to 2024 are from a project that is ongoing, where estimates are based on a model updated annually. Mean weight for NPS provided by Hartill & Davey (2015) and Davey et al. (2019, 2024).

Survey	Year	Numbers	Mean weight (kg)	Catch weight (t)	CV
Holdsworth 2016	2010	55260	0.741	40.900	0.36
NPS: Wynne-Jones et al. (2014)	2011	58413	0.701	40.570	0.24
NPS: Wynne-Jones et al. (2019)	2017	19123	0.743	14.210	0.36
Maggs et al. (2024)	2019	–	–	26.864	–
Maggs et al. (2024)	2020	–	–	26.449	–
Maggs et al. (2024)	2021	–	–	26.132	–
NPS: Heinemann and Gray (2024)	2022	11593	0.860	14.000	0.31
Maggs et al. (2024)	2023	–	–	8.755	–
Maggs et al. (2024)	2024	–	–	7.101	–

Table 4: **Fishing platform and capture method categories for CRA 2 estimated by the national NPS recreational surveys (Wynne-Jones et al. 2014, 2019, Heinemann & Gray 2024).**

	2011			2017			2022		
Category	Catch (t)	CV	Percent of total	Catch (t)	CV	Percent of total	Catch (t)	CV	Percent of total
Capture method	–	–	–	–	–	–	–	–	–
Hand gathered by diving	33.80	0.26	83.3	13.44	0.38	94.6	9.93	0.31	99.4
Pot	6.33	0.75	15.6	0.77	0.70	5.4	0.06	1.00	0.6
Other	0.44	0.94	1.1	–	–	–	–	–	–
Platform	–	–	–	–	–	–	–	–	–
Trailer boat	25.57	0.31	63.0	9.98	0.45	70.2	8.40	0.35	84.1
Larger motor boat or launch	8.35	0.56	20.6	2.12	0.44	14.9	0.70	0.71	7.0
Off land	5.25	0.30	12.9	1.18	0.46	8.3	0.89	0.45	8.9
Other	1.39	0.62	3.4	0.93	0.78	6.5	–	–	–

A recreational catch vector from 1979 to 2024 was developed by assuming that recreational catch had been proportional to the CRA 2 spring-summer (SS) abundance, as reflected by the SS FSU and CELR CPUE from 1979–1992 and from the logbook CPUE series from 1993–2024. The recreational catch vector was scaled to the 2010 survey (Holdsworth 2016), and the three NPS surveys from 2011, 2017, and 2022. A scalar quantity ϕ was estimated by obtaining the best fit to these four survey estimates when minimising a lognormal likelihood using the CVs indicated in Table 3.

$$W_t = w_t N_t$$

$$\widehat{W}_y = \hat{\phi} I_y$$

$$L = \min\left[\sum_{t=1}^{T} \frac{\left(log(W_t) - log(\widehat{W}_t)\right)^2}{2\sigma_t^2}\right] \qquad (1)$$

where W_t is the surveyed recreational catch in tonnes, w_t is the mean SS weight greater than or equal to the MLS for sampled lobster in year/survey t for CRA 2, N_t is the mean number of lobsters in the year/survey t for CRA 2, $\widehat{W}_y$ is the estimated recreational catch by weight for year y for CRA 2, I_y is the SS standardised CPUE from 1979 to 2018 for CRA 2, $\sigma_t = \sqrt{log(CV^2) + 1}$ and L is the minimised function. This recreational catch vector was only used to fill in the years not directly informed by surveys.

Onsite surveys were commissioned by Fisheries New Zealand for monitoring recreational catch in CRA 2 as part of the rebuilding plan implemented in 2018–19 to address the poor stock status estimated by the 2017 stock assessment. Boat ramp surveys were conducted at 11 sites across CRA 2 in fishing years 2011, 2017, and 2019–2024 (with monitoring at a reduced set of ramps in 2025), spanning the period October to February in each year, with the intent of scaling the summer survey information with the total catch estimates obtained by the NPS (Maggs et al. 2024). Estimates of total recreational catch were used for 2011, 2017, and 2019–2024 for the 2025 CRA 2 stock assessment. Because these estimates are model-based, they will continue to be updated annually. By agreement in the RLWG, these estimates were used without any additional scaling because they were considered to have been already scaled. The 2019–2024 estimates were not used to scale the catch from 1979–2018 because they were outside the period requiring recreational catch scaling and interpolation.

For assessments conducted since 2006, the RLWG has included recreational landings made by commercial vessels under section 111 of the Fisheries Act. Greenweight landings with destination code 'F' were extracted from the CRACE database (Bentley et al. 2005). The RLWG has agreed to add the annual estimated S.111 catches to the recreational catch vector in each year beginning with 1979 (Figure 11). For those years without an S.111 catch estimate, the average S.111 catch was added. Additionally, the RLWG agreed to add in annual Amateur Charter Vessel – Activity Catch Reporting (ACV-ACR) catch totals which are available for 2020 onwards (which were not included in the boat ramp sampling or NPS catch estimates). These additional catches have resulted in a total 1979–2024 recreational catch in the model to be 2088 tonnes.

The recreational catch trajectory was estimated as follows:

1. from 1979 through to 2009, use the recreational catch vector scaled by recreational catch surveys and SS CPUE,
2. 2010: use Holdsworth survey estimate (Table 3),
3. 2011, 2017, 2022: use NPS estimates (Table 3),
4. 2019 through to 2024 (except 2022): use modelled NIWA recreational survey estimates,
5. Missing years between 2010 to present: interpolate between survey estimates,
6. Apply 20% of the 1979 estimate to 1945 and scale linearly to 1979 (for the *start_1945* sensitivity run),
7. Add annual reported S.111 catches, and average S. 111 catches during years when this information is missing, and
8. Add charter catches.

The assumed recreational catch trajectory is well below the 2011–12 NPS and the 2010 Holdsworth estimates but matches the 2017–18 NPS survey and is well above the 2022–23 NPS surveys (Figure 11). Recreational catches were split between seasons, with 90% assumed taken in the SS and the balance in the AW.

2.2.3.3 Customary catch

The 2025 CRA 2 stock assessment used 5 tonnes per year for customary catch, with 90% assumed to have been taken in the SS and the balance in the AW. This was the same assumption as used in the 2022 CRA 2 stock assessment.

2.2.3.4 Illegal catch

Recent red rock lobster stock assessments have opted to use a fixed percentage of the total commercial catch before 1990 when rock lobsters were brought into the QMS (usually in the 10% to 20% range), which was then dropped to a lower level in 1990 in recognition of the impact of the introduction to the QMS, as greater control over the sale and receipt of lobsters was introduced once they became a tradeable asset. In line with these decisions and recognising the lack of information that can be used to estimate this catch category, the RLWG chose to set the CRA 2 illegal catch to 20% of the commercial catch in each year prior to 1990 and 10% of the commercial catch in each year from 1990 onwards. This led to very minor changes in the overall magnitude of illegal catch removed from CRA 2 over the time series (2652 tonnes assumed in the 2024 rapid update, versus 2660 tonnes assumed in the 2025 assessment). However, there was a change in the temporal distribution of illegal catch removals, with notably lower recent illegal catches since the late 2010s (Figure 10). Illegal catches were split between seasons using the seasonal split returned by the commercial catch in the same year.

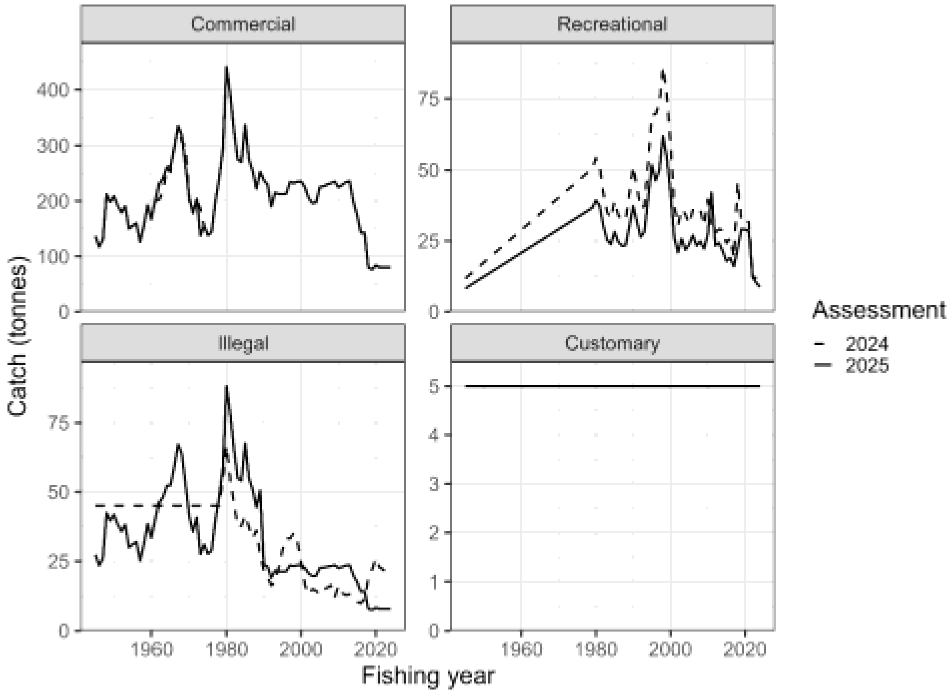

Figure 10: Catches for the 2025 CRA 2 stock assessment by sector (solid black line), compared with catches used for the 2024 rapid update (dashed line).

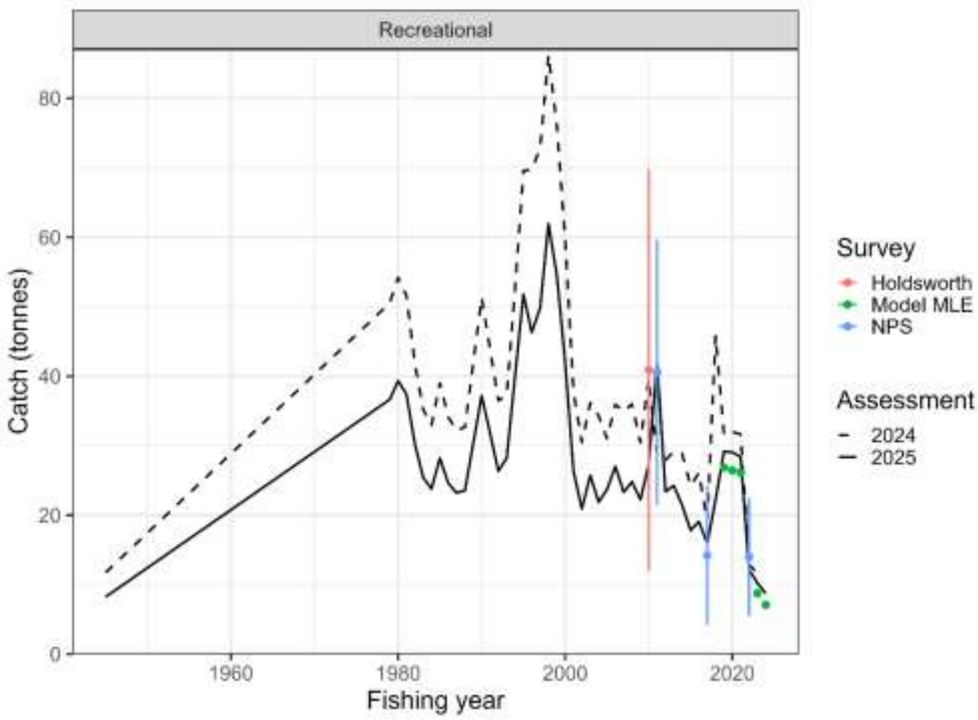

Figure 11: Recreational catch trajectory based on SS seasonal CPUE series fitted to four recreational catch surveys (Holdsworth and NPS), including survey-based harvest estimates substituted when available (Model MLE), and including section 111 catches and charter catches. 2025 series (solid line) is compared with the series used in the 2024 rapid update (dashed line).

3 STOCK ASSESSMENT

The previous stock assessment of CRA 2 (Rudd et al. 2023) used the lobster stock dynamics (LSD) model (Webber et al. 2023). The LSD model was coded in Stan (Stan Development Team 2016, 2017) and had been used as the main assessment software for all recently assessed rock lobster stocks in New Zealand, including CRA 2 (2017, Webber et al. 2018, 2022 Rudd et al. 2023), CRA 6 (2018, Rudd et al. 2019, 2024), CRA 1 (2019, Rudd et al. 2021b), CRA 3 (2019, Webber et al. 2020 and 2024 Roberts et al. 2025), CRA 4 (2020, Rudd, et al. 2021a, 2024 Rudd et al. 2025), CRA 5 (2020, Webber et al. 2021b), and CRA 7&8 (2021, Webber et al. 2022).

A new model, *decamod,* written in RTMB, was used for this 2025 stock assessment. A key difference between LSD and *decamod* is the switch from three sexes (males, immature females, and mature females) to two sexes (males and females). Because of this change, maturation and proportion berried needed to be treated differently between the two model structures by estimating these biological processes outside of the model structure.

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

The data and covariates used in this stock assessment are documented in Section 2. Bridging analyses between the previous stock assessment model LSD and new model *decamod* are in Section 3.4.1 and the bringing in of updated data series is documented in Section 3.4.2. The 2025 stock assessment model settings are described in Section 3.5.1 and model parameters and priors are defined in Section 3.2. The stock assessment outputs including stock status indicators are defined in Section 3.5.2 and Section 3.5.4. Sensitivity trials are detailed in Section 0.

3.1 Model

The *decamod* model was new for the 2025 stock assessment. The model tracks numbers of individual lobsters in two-sex categories (males and females) for each of 31 two-mm TW bins, by year, and season.

Like the previous CRA 2 stock assessment model, the first model year was set to 1979 and an equilibrium population structure with an initial exploitation rate (U_0) was estimated. This was done because there is uncertainty in the quality of catch estimates before the FSU system began in 1979, but there is confidence in the quality of commercial catch estimates from the FSU and QMS systems. The last year in the reconstruction of the stock was 2024, but this was extended to 2030 for the projections. All catches in the base case model were split into the AW and SS seasons, including the sensitivity run starting in 1945. All model years are fishing years which extend from 1 April to 31 March. The model uses two six-month seasons within a model year: AW (April to September) and SS (October to March).

The 2025 stock assessment treated CRA 2 as a single homogeneous area, as was done in the previous three assessments for this stock in 2022 (Rudd et al. 2023), 2017 (Webber et al. 2018), and 2013 (Starr et al. 2014b). This choice was informed by a lack of regional variation in CPUE, length frequency distribution, and growth rate from the available tag-recapture data, as well as in the regional distribution of catch through time.

New recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm; Figure 12). 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 as random effects from 1979–2020. Recruitments in the final four years were constrained using an order 1 autoregressive (AR1) model, where the AR1 parameter was derived using the period 1980–2020. This was an update from previous stock assessments using LSD which fixed the final four years to be the same as the final estimated recruitment deviate, or re-wrote the final four recruitments in the projections.

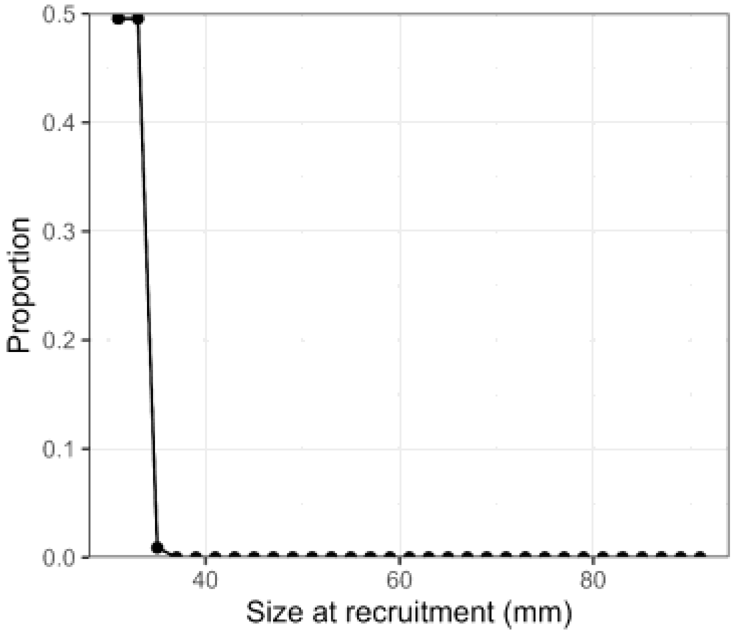

Figure 12: Distribution of recruitment size (mm) assumed in the CRA 2 stock assessment.

For each sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or transitioning to another size class. Previous rock lobster stock assessments using LSD modelled immature and mature females separately, and the maturation of females was estimated as a two-parameter logistic curve. The 2025 stock assessment modelled all females combined. Female maturity and the incidence of berried females were modelled separately outside of the stock assessment model as described in Appendix D and Appendix E, respectively.

A logistic selectivity ogive was assumed to define the size composition of the fishery catch (i.e., the commercial and recreational catch), which was assumed to be sex-specific and time-invariant. The *selmax* parameters defined the relative scaling (i.e., the height) of the selectivity curves by sex and season. These parameters by sex and season were estimated relative to males in the AW, and were allowed to be estimated to be relatively lower (below 1.0) or higher (above 1.0) than for AW males. The only differences in the structure of estimating selectivity and vulnerability between this assessment and the 2022 stock assessment were 1) two sexes versus three sexes and 2) in the previous assessment the *selmax* parameters were constrained to be below 1.0 (lower than AW males).

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

Natural, fishing, and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to vary by length but was sex and time invariant. Similar to the 2022 assessment, *decamod* removed catch from the population by using discrete exploitation rates, instead of instantaneous fishing mortality rates as was done in rock lobster stock assessments in 2021 and earlier. Exploitation rates were determined from observed catch and model biomass, modified by selectivity, vulnerability, legal status (e.g. MLS, proportion berried females) for the SL fishery, while only selectivity and vulnerability were needed to define exploitation rates for the NSL fishery. It was determined from the logbook data that discarding of legal lobsters was infrequent in CRA 2, making it unnecessary to model this process.

Model parameters were estimated by the *decamod* model using penalised maximum likelihood. Bayesian inference was used to estimate parameter uncertainty. Samples from the posterior were generated with Markov chain Monte Carlo (MCMC) simulations using the Hamiltonian Monte Carlo (HMC) algorithm. Estimated parameter descriptions are provided in Table 5 and priors and bounds are provided in Table 6. Fixed parameters and their values are given in Table 1 (also see the maturity and proportion berried ogives shown in Figure 8 and Figure 9).

3.2 Parameters and priors

Estimated model parameters included productivity parameters (i.e., average recruitment, natural mortality, and growth), and fishery parameters (i.e., catchability, selectivity, and vulnerability). All model parameters and their associated priors are listed in Table 5 and Table 6.

Table 5: Definitions of parameters and derived quantities discussed in the text.

Parameter	Number	Description
M_a	1	Instantaneous natural mortality estimated at 60 mm TW
R_0	1	Unfished equilibrium recruitment (numbers)
Rdevs	1-41	Annual recruitment deviations
U_0	1	Initial exploitation rate (the first model year is in equilibrium using this
q	1	Catchability coefficient for the FSU series
	2	Catchability coefficient for the CELR series
	3	Catchability coefficient for the logbook series
pow	1	CPUE power parameter for the CELR series
	2	CPUE power parameter for the logbook series
Galpha	1	Annual growth increment at 30 mm TW, males
	2	Annual growth increment at 30 mm TW, females
Gbeta	1	Annual growth increment at 80 mm TW, males
	2	Annual growth increment at 80 mm TW, females
Gdiff	1	The ratio of *Gbeta* to *Galpha* (*Gbeta* = *Gdiff* * *Galpha*), males
	2	The ratio of *Gbeta* to *Galpha* (*Gbeta* = *Gdiff* * *Galpha*), females
Gshape	1	Parameter for shape of growth curve, males: 1 implies von Bertalanffy straight line, >1 implies a concave upwards curve
	2	Parameter for shape of growth curve, females
GCV	1	Standard deviation of growth-at-size divided by growth-at-size, males
	2	Standard deviation of growth-at-size divided by growth-at-size, females
Gobs	1	Standard deviation of observation error for tag-recaptures
sel50	1	Length at 50% selectivity (males)
	2	Length at 50% selectivity (females)
sel95	1	Difference in length at 95% selectivity from 50% (males)
	2	Difference in length at 95% selectivity from 50% (females)
selmax	1	Maximum selectivity (vulnerability) for females in AW relative to males in AW
	2	Maximum selectivity (vulnerability) for males in SS relative to males in AW
	3	Maximum selectivity (vulnerability) for females in SS relative to males in AW

Table 6: Specifications for estimated parameters including the upper and lower bounds, prior type, and prior parameters.

		Bounds		Prior		
Sex	Parameter	Lower	Upper	Type	Parameter 1	Parameter 2
–	*logit_U₀*	-Inf	0.000	normal	0	1.50
–	*log_R₀*	1.000	25.000	normal	12	2.50
–	*log_Mₐ*	-4.605	-0.693	normal	log(0.12)	0.40
–	*log_q*	-25.000	1.000	uniform	–	–
–	*log_pow*	-2.303	2.303	normal	log(1)	0.30
–	*logit_gdiff*	-Inf	Inf	normal	-2	1.50
Male	*log_gshape*	-2.303	2.303	normal	log(1)	0.60
Female	*log_gshape*	-2.303	2.303	normal	log(1)	0.60
Male	*log_gcv*	-4.605	0.693	normal	log(0.59)	0.44
Female	*log_gcv*	-4.605	0.693	normal	log(0.82)	0.34
–	*log_gobs*	-11.513	1.609	normal	log(1.48)	0.05
–	*log_sel50*	3.401	4.382	normal	log(50)	0.50
–	*log_sel95*	0.000	3.912	normal	log(10)	1.12
–	*log_selmax*	-4.605	0.693	normal	log(1)	1.00
–	*Rdev_yr*	-2.300	2.300	uniform	–	–

3.3 Assessment indicators

This assessment (used the same indicators that were used in the 2022 CRA 2 assessment Table 7, Table 8). The main indicators were related to the relative estimates of AW adjusted vulnerable biomass, SSB, and total biomass. AW adjusted vulnerable biomass was compared with the reference level (B_R), and the current and projected exploitation rate was compared with the fixed exploitation rate that would reach the reference level at equilibrium (U_R). Probabilities were calculated to determine whether each of the biomass indicators would fall below current levels, the reference level (in terms of vulnerable biomass) and the soft and hard limits (in terms of SSB) after projecting the current catch forward for five years (Section 3.5.4). Probabilities were calculated over all samples of the posterior distribution.

Table 7: Assessment indicators and reference points.

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_{MIN}	The lowest beginning AW adjusted vulnerable biomass in the series
B_{2025}	Beginning of season AW adjusted vulnerable biomass for 2025
B_{2030}	Beginning of season AW adjusted vulnerable biomass for 2030
SSB_{2025}	Beginning of season spawning stock biomass for 2025
SSB_{2030}	Beginning of season spawning stock biomass for 2030
T_{2025}	Beginning of season total biomass for 2025
T_{2030}	Beginning of season total biomass for 2030
U_{2024}	Annual exploitation rate (approximated by the weighted average across seasons) for the final model year 2024
U_{2029}	Annual exploitation rate (approximated by the weighted average across seasons) for the final projection year 2029
H_{2024}	Annual handling mortality for the final model year 2024
H_{2029}	Annual handling mortality for the final projection year 2029
B_R	Average AW vulnerable biomass between projected fixed catch and fixed U rules that maximise catch while meeting risk constraints
U_R	Annual exploitation rate associated with BR at equilibrium, weighted across seasons by seasonal vulnerable biomass

Table 8: Performance indicators and stock status probabilities.

Type	Description
Performance indicators	
B_{2025}/B_0	Ratio of B_{2025} to B_0
B_{2030}/B_0	Ratio of B_{2030} to B_0
B_{2030}/B_{2025}	Ratio of B_{2030} to B_{2025}
SSB_{2025}/SSB_0	Ratio of SSB_{2025} to SSB_0
SSB_{2030}/SSB_0	Ratio of SSB_{2030} to SSB_0
SSB_{2030}/SSB_{2025}	Ratio of SSB_{2030} to SSB_{2025}
T_{2025}/T_0	Ratio of T_{2025} to T_0
T_{2030}/T_0	Ratio of T_{2030} to T_0
T_{2030}/T_{2025}	Ratio of T_{2030} to T_{2025}
B_{2025}/B_R	Ratio of B_{2025} to B_R
B_{2030}/B_R	Ratio of B_{2030} to B_R
U_{2024}/U_R	Ratio of U_{2024} to U_R
U_{2029}/U_R	Ratio of U_{2029} to U_R
U_{2029}/U_{2024}	Ratio of U_{2029} to U_{2024}
Probabilities	
$P(B_{2025} > B_{MIN})$	Probability B_{2025} is greater than B_{MIN}
$P(SSB_{2025} > 20\% SSB_0)$	Probability SSB_{2025} is greater than 20% SSB_0
$P(SSB_{2025} > 10\% SSB_0)$	Probability SSB_{2025} is greater than 10% SSB_0
$P(SSB_{2030} > 20\% SSB_0)$	Probability SSB_{2030} is greater than 20% SSB_0
$P(SSB_{2030} > 10\% SSB_0)$	Probability SSB_{2030} is greater than 10% SSB_0
$P(B_{2030} > B_{2025})$	Probability B_{2030} is greater than B_{2025}
$P(SSB_{2030} > SSB_{2025})$	Probability SSB_{2030} is greater than SSB_{2025}
$P(T_{2030} > T_{2025})$	Probability T_{2030} is greater than T_{2025}
$P(B_{2025} > B_R)$	Probability B_{2025} is greater than B_R
$P(B_{2030} > B_R)$	Probability B_{2030} is greater than B_R
$P(U_{2024} > U_R)$	Probability U_{2024} is greater than U_R
$P(U_{2029} > U_R)$	Probability U_{2029} is greater than U_R

3.4 Developing a base case

3.4.1 Matching a new model with previous model

The goal of this section is to compare the new *decamod* model with the previous LSD model in two steps: 1) check that *decamod* can produce nearly identical results to the 2024 rapid update run with LSD with fixed parameter values, and 2) check how close *decamod* comes to the 2024 rapid update with estimated parameters. Data used in this section are the same as the data used in the 2024 rapid update. The models run in this section have final model year 2023, estimating parameters or groups of parameters one at a time:

1. *decamod fixed par*: using the *decamod* model, with all parameters fixed at the 2024 rapid update values,
2. *est1_q*: estimate q parameters only,
3. *est2_U0*: estimate q and U_0 parameters,
4. *est3_sel*: estimate q, U_0, and selectivity parameters,
5. *est4_recdevs*: estimate all of the above as well as recruitment deviates, keeping R_0 fixed,
6. *est4_rec*: estimate all of the above, estimating recruitment deviates and R_0,
7. *est4_berry_lengthvar*: estimate all of the above including recruitment parameters, but assume length-varying proportion in berry,
8. *est5_growth*: estimate growth parameters in addition to all other parameters, assuming length-varying proportion in berry,

9. *decamod est par*: same as *est5_growth*. In some figures, it made more sense to name this model *est5_growth* to show that all growth parameters were estimated, but in other figures, this was renamed *decamod est par* to compare with all parameters fixed vs. estimated,
10. *decamod reweight*: estimate all parameters, with data reweighting.

The *decamod* model reproduced the 2024 rapid update well when parameters were fixed to the same values as the LSD 2024 rapid update estimates (Figure 13, Figure 14, Figure 15).

Initial model runs estimated all parameters and produced trajectories that differed enough to require further examination of the differences between *decamod* and LSD. For example, estimates of *Ma* increased to more than 0.3, compared with 0.187 in the 2024 rapid update.

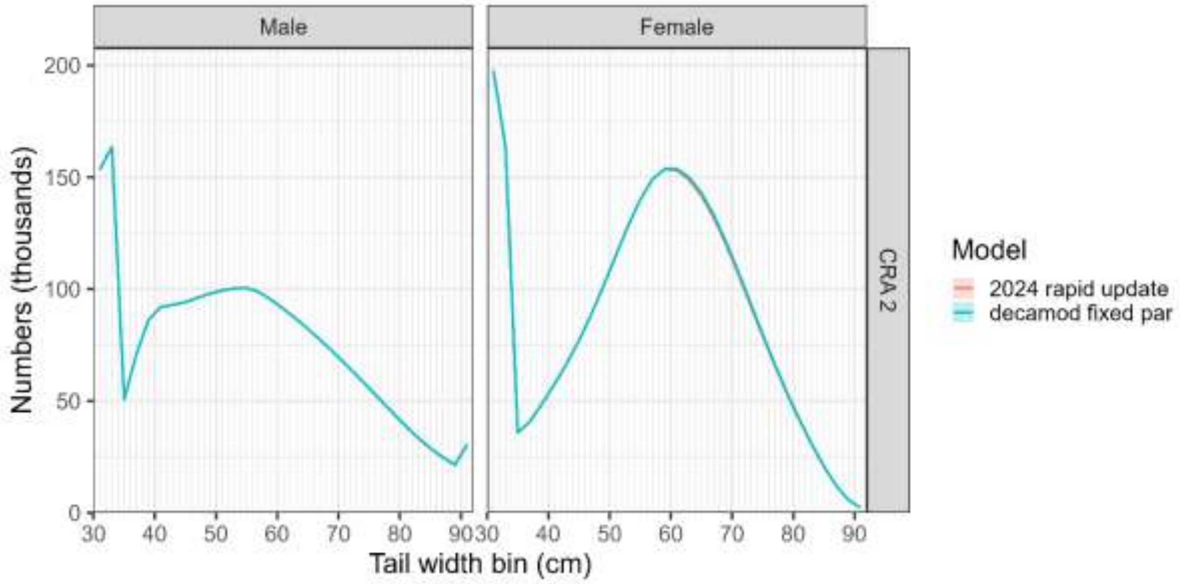

Figure 13: Comparison of initial numbers: 2024 rapid update vs. *decamod* with fixed parameters.

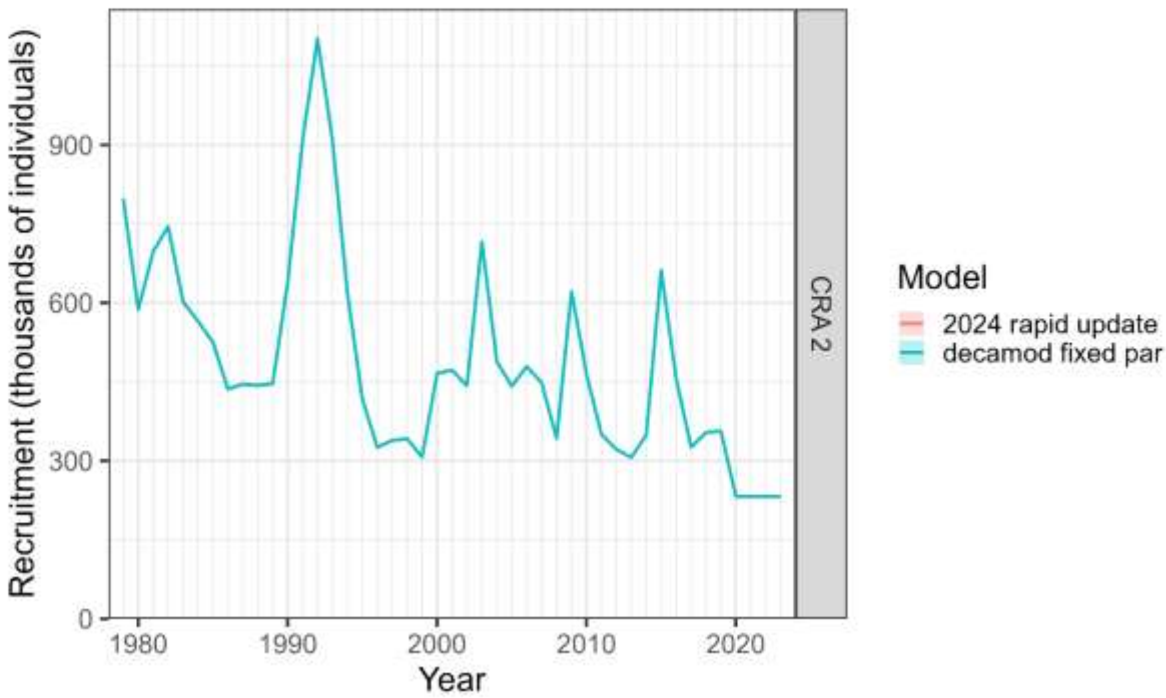

Figure 14: Comparison of recruitment: 2024 rapid update vs. *decamod* with fixed parameters. Red line (2024 rapid update) is directly underneath the blue line (*decamod* fixed par).

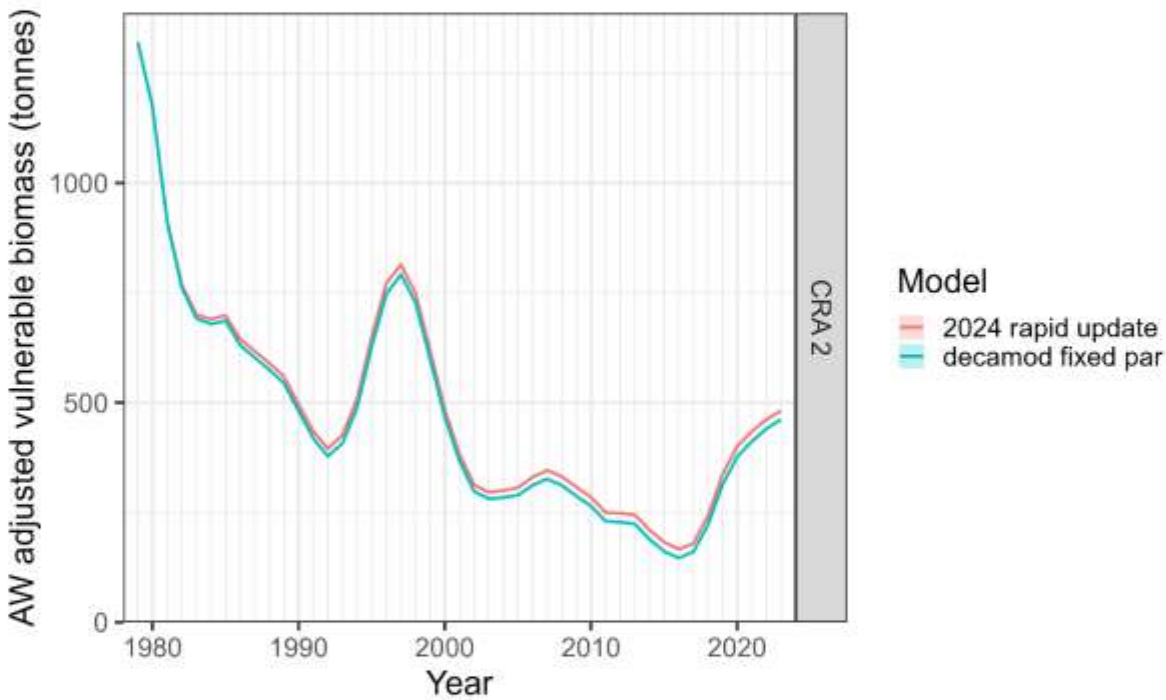

Figure 15: Comparison of AW adjusted vulnerable biomass: 2024 rapid update vs. *decamod* with fixed parameters.

Estimating q, U_0, and selectivity parameters had negligible changes from the *decamod* model with all parameters fixed. However, estimating recruitment deviates and R_0 resulted in major differences in parameter estimates and key derived quantities (e.g. initial numbers, Figure 16; recruitment, Figure 17).

Including length-varying proportion in berry improved the ability of the two-sex *decamod* model to match the previous three-sex LSD model. This accounted for the fact that in the previous model, immature females that were above the MLS would have been retained. In the two-sex model, the length-varying proportion in berry is needed to account for immature females above the MLS (Figure 16; Figure 17).

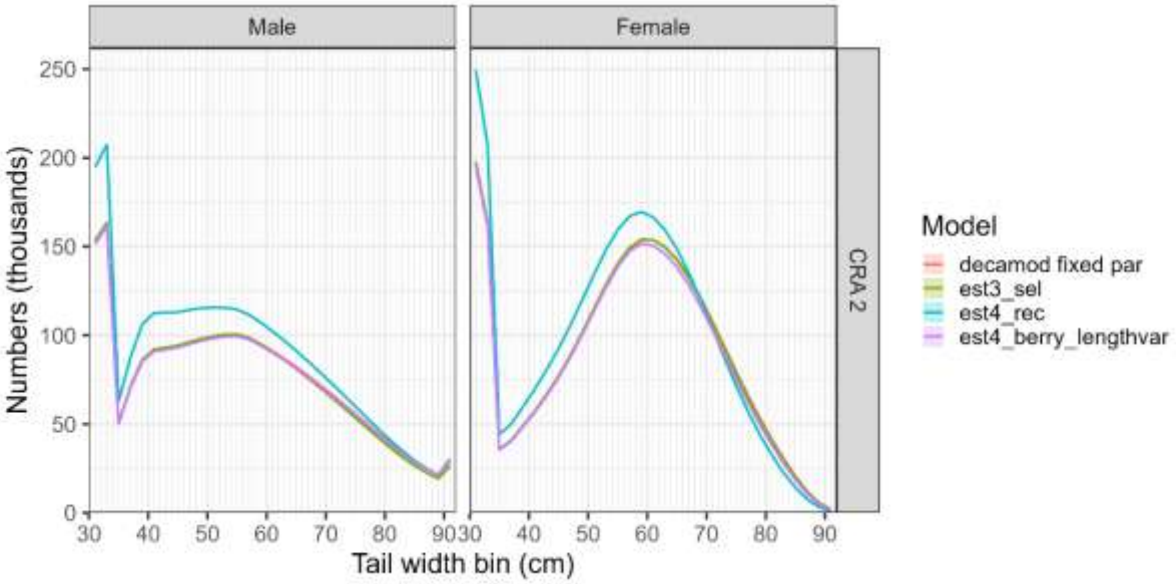

Figure 16: Comparison of initial numbers: *decamod* with fixed parameters and estimating parameters one at a time. Including length-varying proportion in berry (est4_berry_lengthvar) improved the ability of *decamod* to match the LSD 2024 rapid update. Red line (*decamod* fixed par) is directly underneath the green and purple lines (*est3_sel* and *est4_berry_lengthvar*).

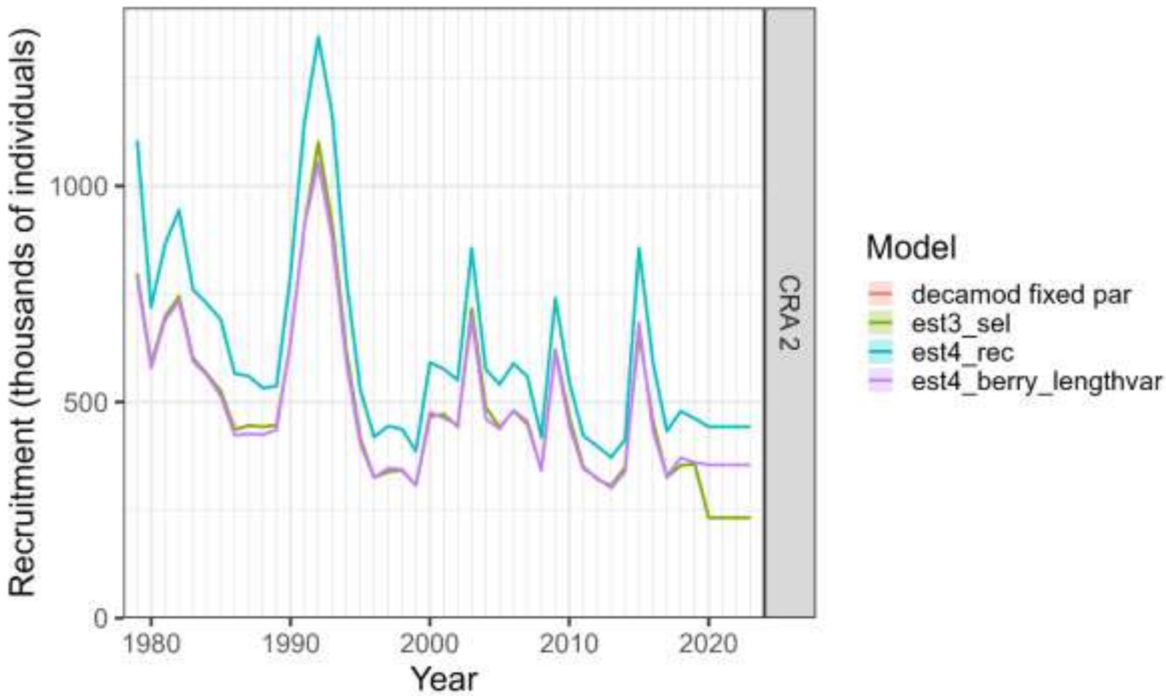

Figure 17: Comparison of recruitment: *decamod* with fixed parameters and estimating parameters one at a time. Including length-varying proportion in berry (*est4_berry_lengthvar)* improved the ability of *decamod* to match the LSD 2024 rapid update.

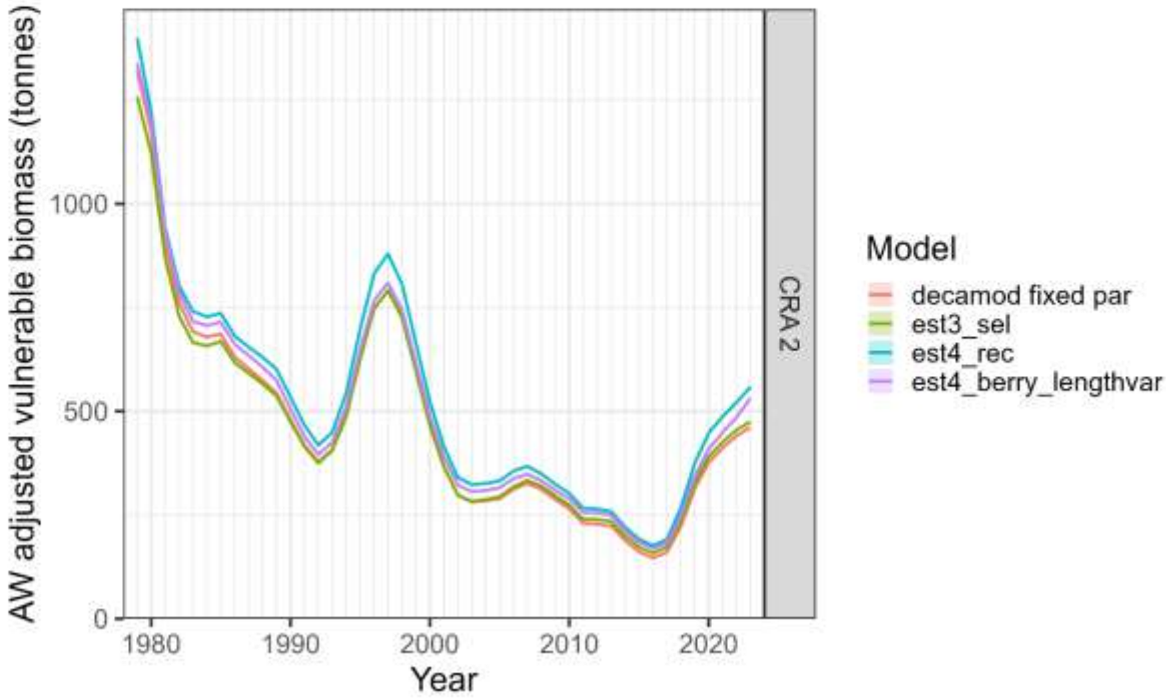

Figure 18: Comparison of AW adjusted vulnerable biomass: *decamod* with fixed parameters and estimating parameters one at a time. Including length-varying proportion in berry (*est4_berry_lengthvar)* improved the ability of *decamod* to match the LSD 2024 rapid update.

Estimating *Galpha* at 50 mm TW, as was done for the previous stock assessment and the rapid update, resulted in much higher estimates of *Galpha* and *M* compared with the 2024 rapid update. Not much tagging information was available for the stock assessment model to estimate growth at sizes less than 50 TW. Without fixing *Gshape*, growth at smaller sizes was highly uncertain and difficult to estimate. In this case, it resulted in an unrealistically high estimate of *M* due to confounding between *Galpha* and *M*. Priors on *Gdiff* and *Gshape* were developed (see Table 6), as well as *Galpha* at 30 mm TW based on juvenile growth studies (*Galpha* estimated in log space, with a normally distributed prior with mean 1 and standard deviation 1). This helped temper estimates of *M* and *Galpha* at reasonable values and *decamod* was then capable of estimating parameters that approximately matched the 2024 rapid update (Figure 19, Figure 20, Figure 21, Figure 22).

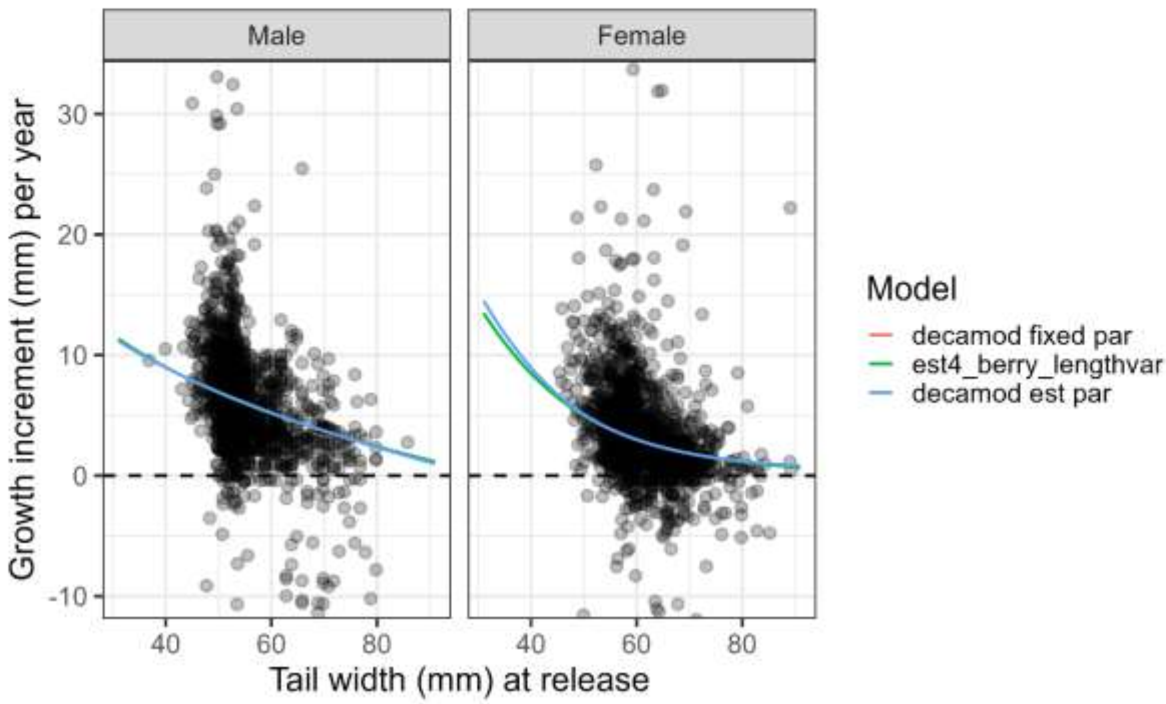

Figure 19: Comparison of growth increment: *decamod* with fixed parameters, including length-varying proportion in berry with fixed growth, and estimating all parameters including growth.

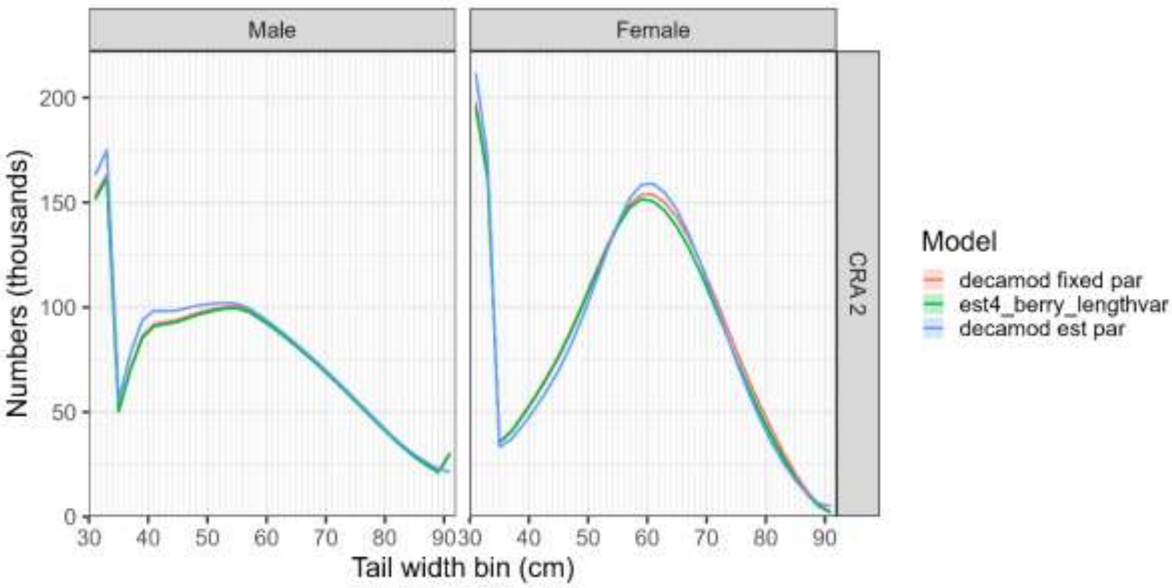

Figure 20: Comparison of initial numbers: *decamod* with fixed parameters, including length-varying proportion in berry with fixed growth, and estimating all parameters including growth.

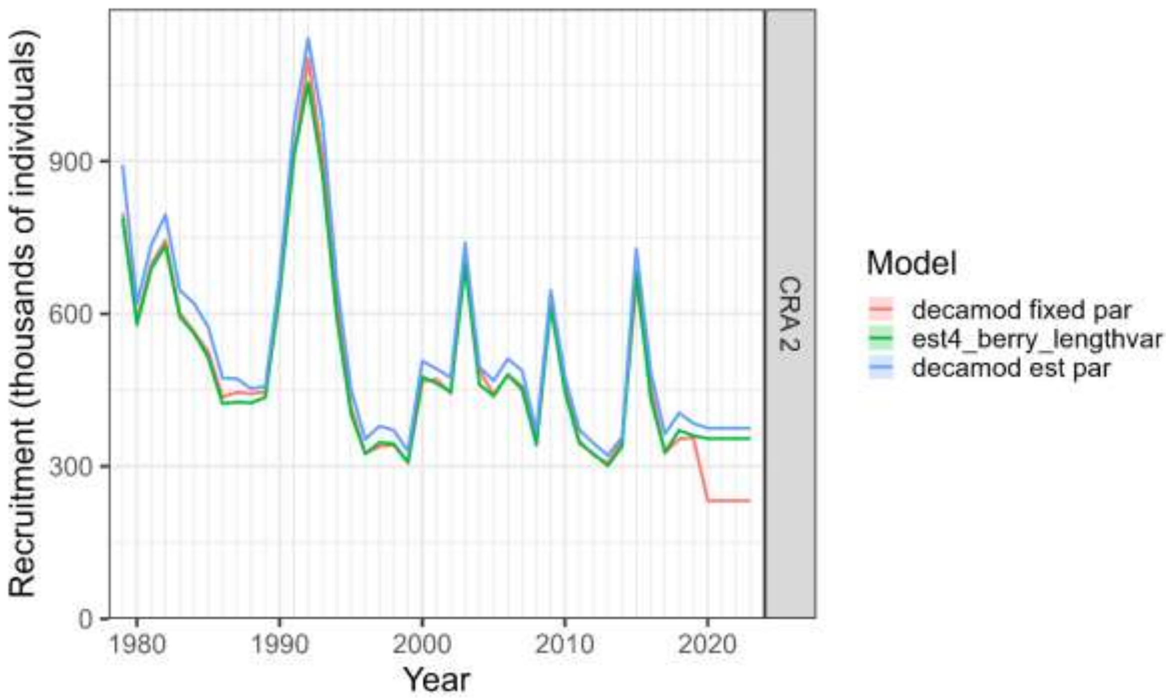

Figure 21: Comparison of recruitment: *decamod* with fixed parameters, including length-varying proportion in berry with fixed growth, and estimating all parameters including growth.

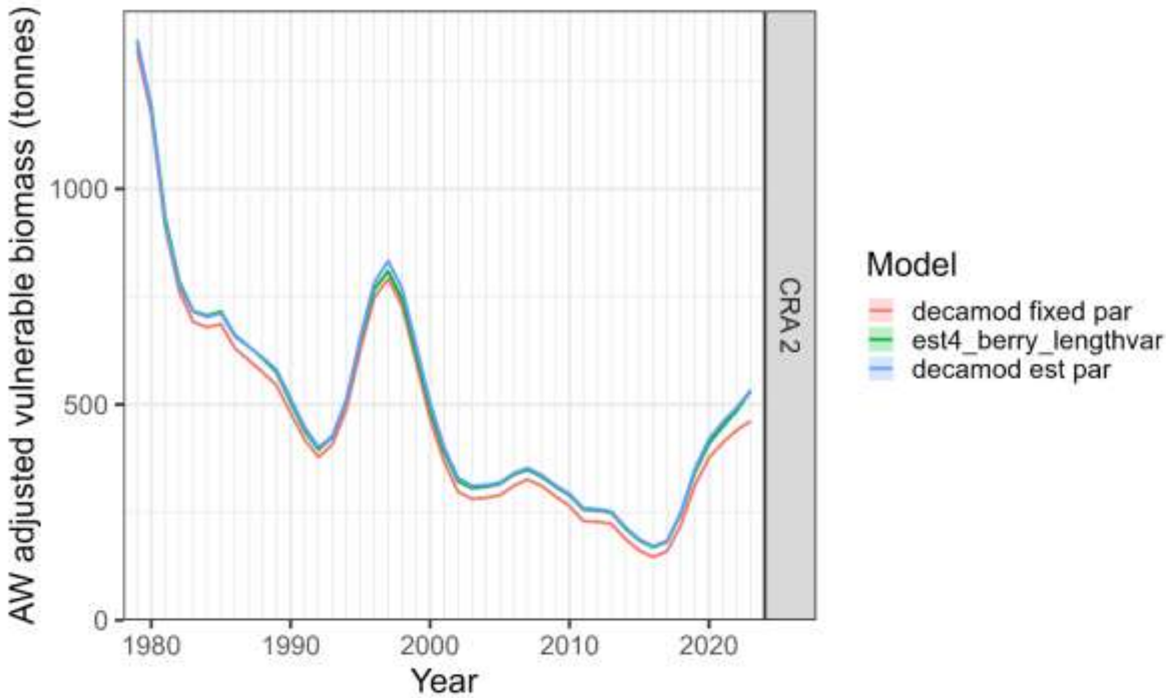

Figure 22: Comparison of AW adjusted vulnerable biomass: *decamod* with fixed parameters, including length-varying proportion in berry with fixed growth, and estimating all parameters including growth.

Table 9: Parameter comparison for 2024 rapid update estimates (*decamod fixed par*), including length-varying proportion in berry with fixed growth, estimating all parameters including growth (*decamod est par*), and estimating all parameters with data-reweighting (*decamod reweight*). Note that models *decamod est par* and *decamod reweight* estimate Galpha at 30 mm TW, while the 2024 rapid update estimated Galpha at 50 mm TW.

Parameter	Number	*decamod fixed par*	*est3_sel*	*est4_rec*	*est4_berry _lengthvar*	*decamod est par*	*decamod reweight*
M_a	1	0.187	0.186	0.232	0.186	0.206	0.204
R_0	1	554439	–	706300	547560	593634	581809
U_0	1	0.067	0.075	0.051	0.067	0.060	0.061
galpha	1	6.893	–	–	–	11.441	11.661
galpha	2	4.989	–	–	–	15.248	15.324
gcv	1	0.429	–	–	–	0.420	0.419
gcv	2	0.732	–	–	–	0.742	0.743
gdiff	1	0.351	–	–	–	0.206	0.201
gdiff	2	0.229	–	–	–	0.079	0.079
gobs	1	1.051	–	–	–	1.136	1.137
gshape	1	1.789	–	–	–	1.644	1.712
gshape	2	4.032	–	–	–	4.462	4.484
q	1	0.001	0.001	0.001	0.001	0.001	0.001
q	2	0.002	0.003	0.002	0.002	0.002	0.002
q	3	0.000	0.000	0.000	0.000	0.000	0.000
sel50	1	50.900	50.795	50.977	50.936	50.947	50.919
sel50	2	55.542	53.500	53.848	53.593	53.314	53.290
sel95	1	4.684	4.666	4.683	4.711	4.679	4.675
sel95	2	7.561	7.930	7.959	7.994	8.149	8.164
selmax	1	0.590	0.515	0.538	0.515	0.503	0.505
selmax	2	0.901	0.864	0.913	0.919	0.912	0.913
selmax	3	0.725	0.703	0.719	0.680	0.669	0.671

An overall comparison of LSD and *decamod* is shown in Table 9 and the figures below, beginning with the comparison of *decamod fixed par,* which had parameters fixed at the values from the 2024 rapid update and was shown to be nearly identical to the 2024 rapid update in LSD, and with *decamod reweight* which estimated all model parameters, including *Galpha* at 50 mm TW, after reweighting the data. While the parameter estimates and model fits were slightly different between LSD and *decamod*, *decamod* had arguably better model fits to proportion male in the catch (Figure 23, Figure 24, Figure 25, Figure 26), CPUE (Figure 27; Figure 28, Figure 29), and LFs (Figure 30; Figure 31; Figure 32; Figure 33; Figure 34).

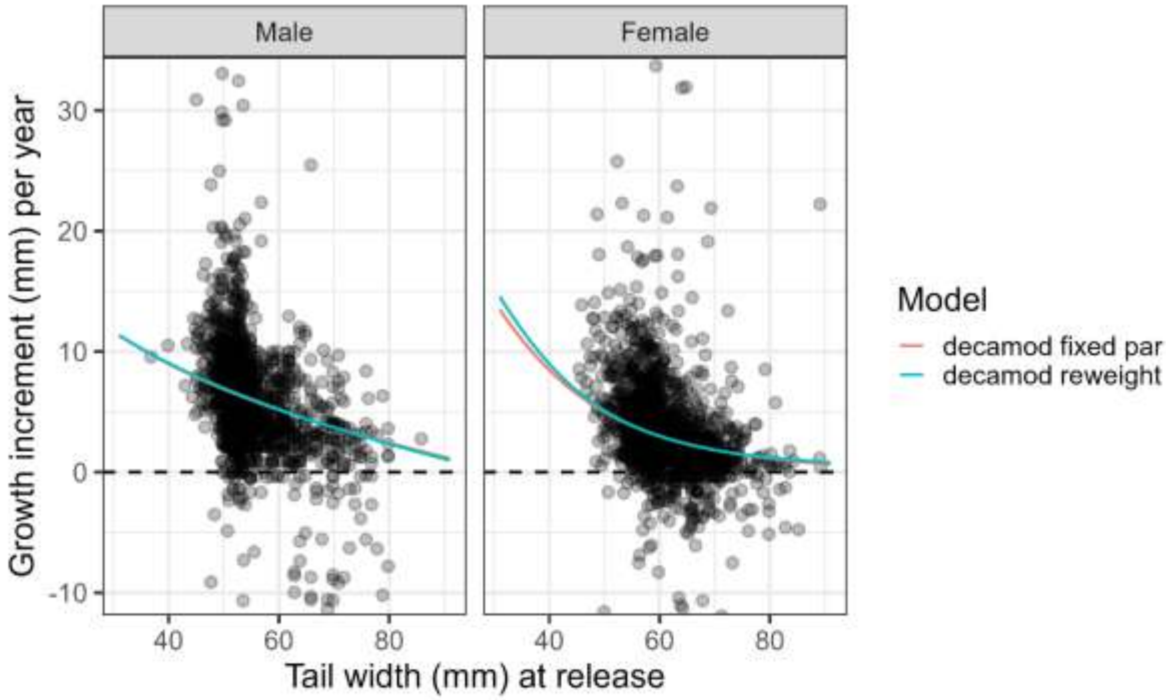

Figure 23: LSD vs. *decamod* growth increment.

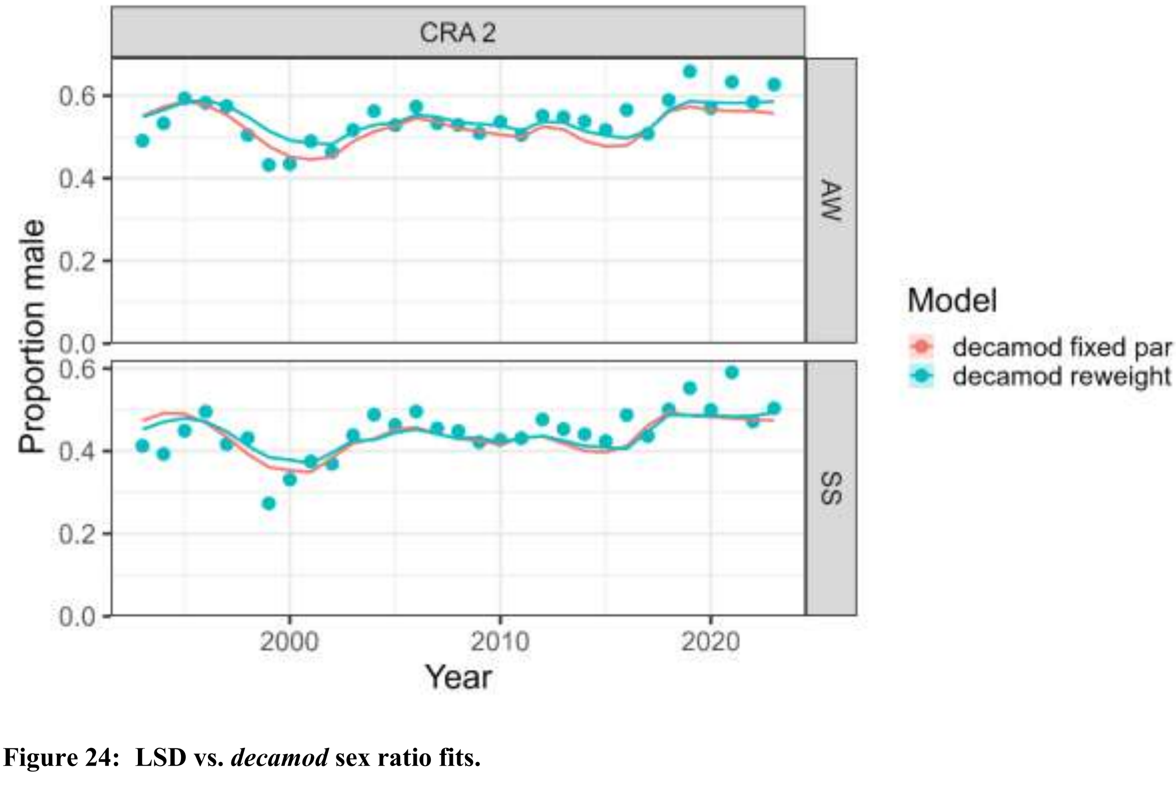

Figure 24: LSD vs. *decamod* sex ratio fits.

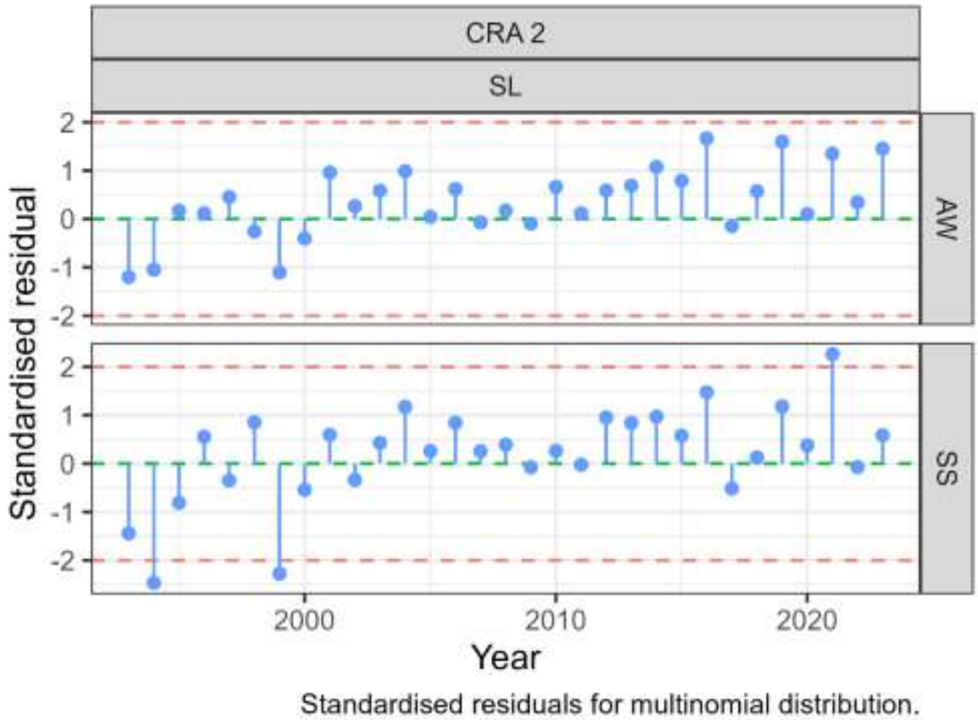

Figure 25: Sex ratio probability integral transformed (PIT) residuals for *decamod fixed par* (LSD parameter estimates).

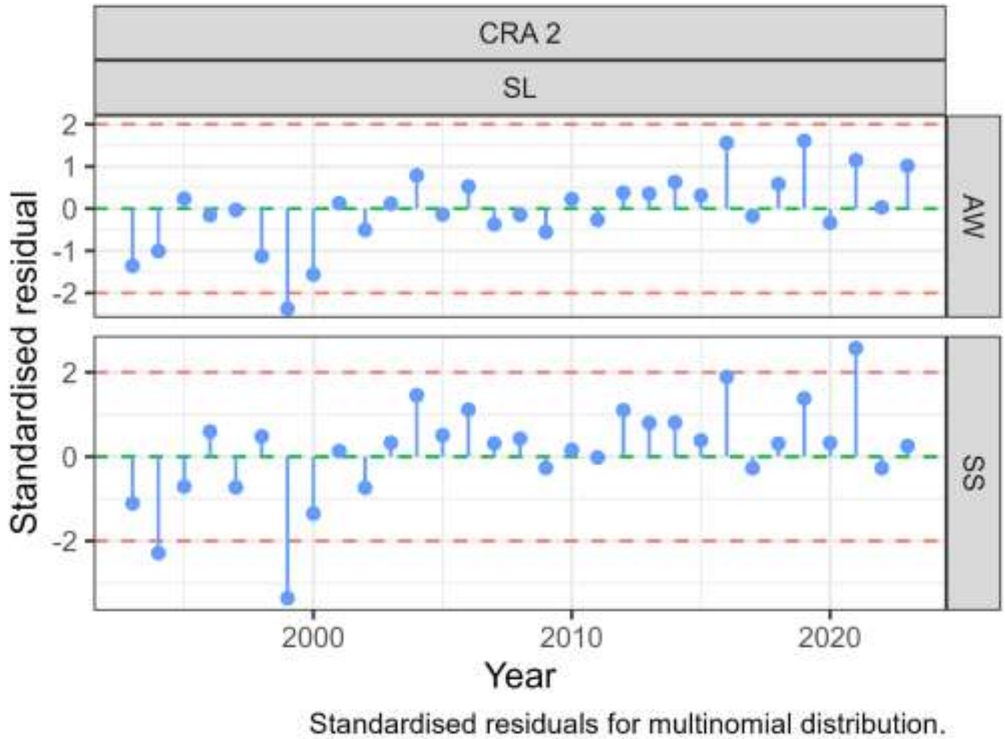

Figure 26: Sex ratio probability integral transformed (PIT) residuals for *decamod reweight* (*decamod* parameter estimates).

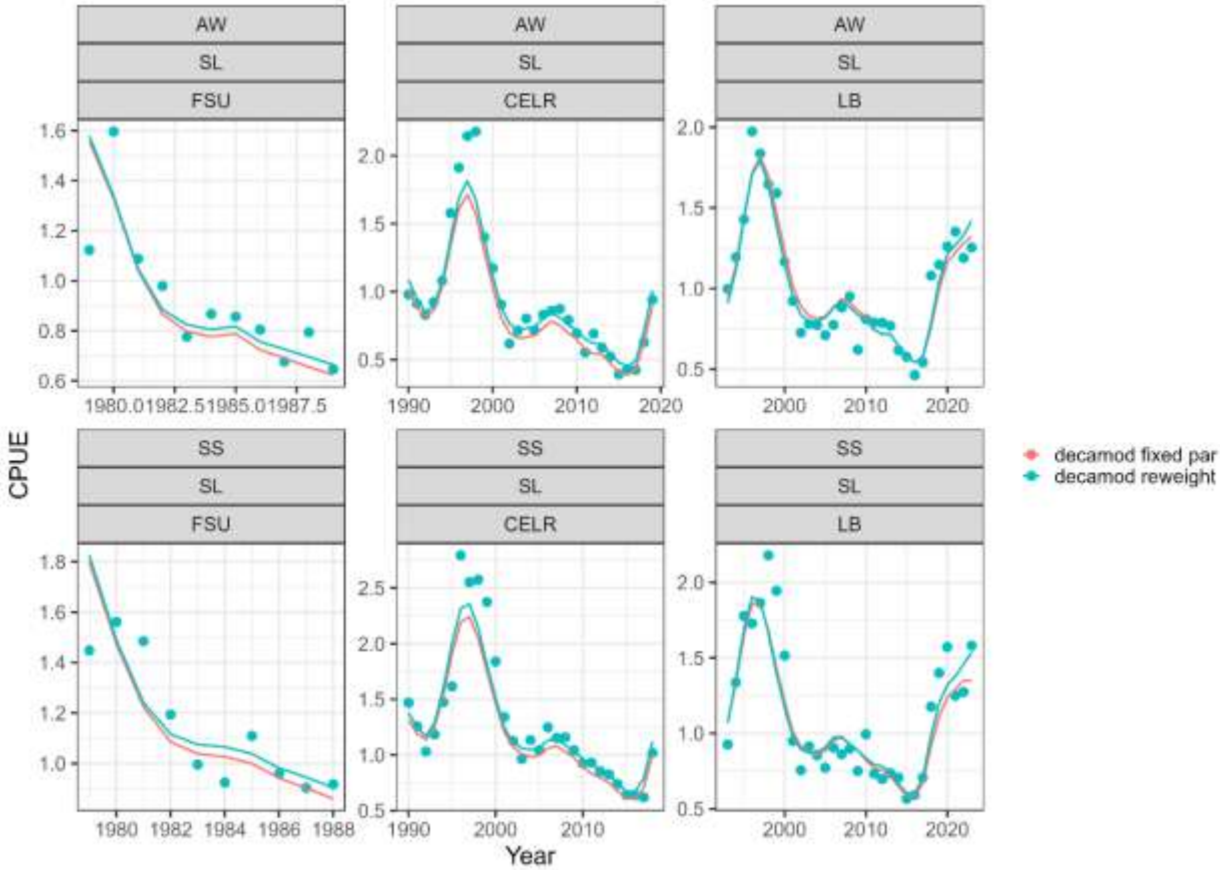

Figure 27: LSD vs. *decamod* CPUE fits.

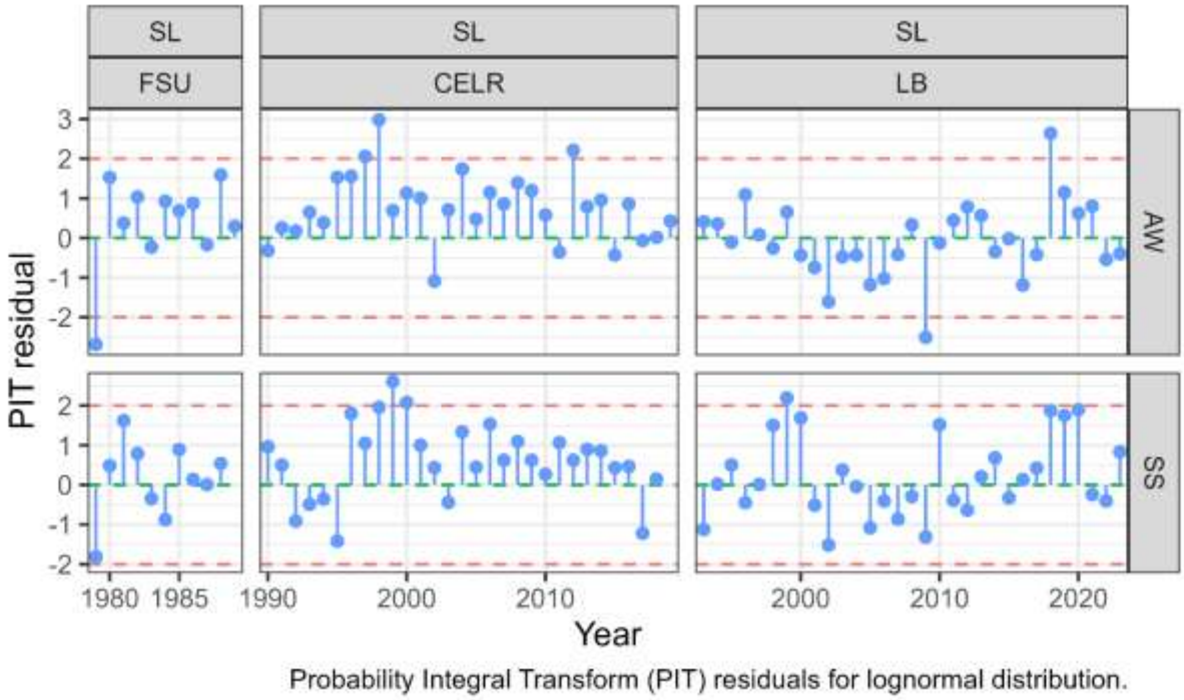

Figure 28: CPUE probability integral transformed (PIT) residuals for *decamod fixed par* (LSD parameter estimates).

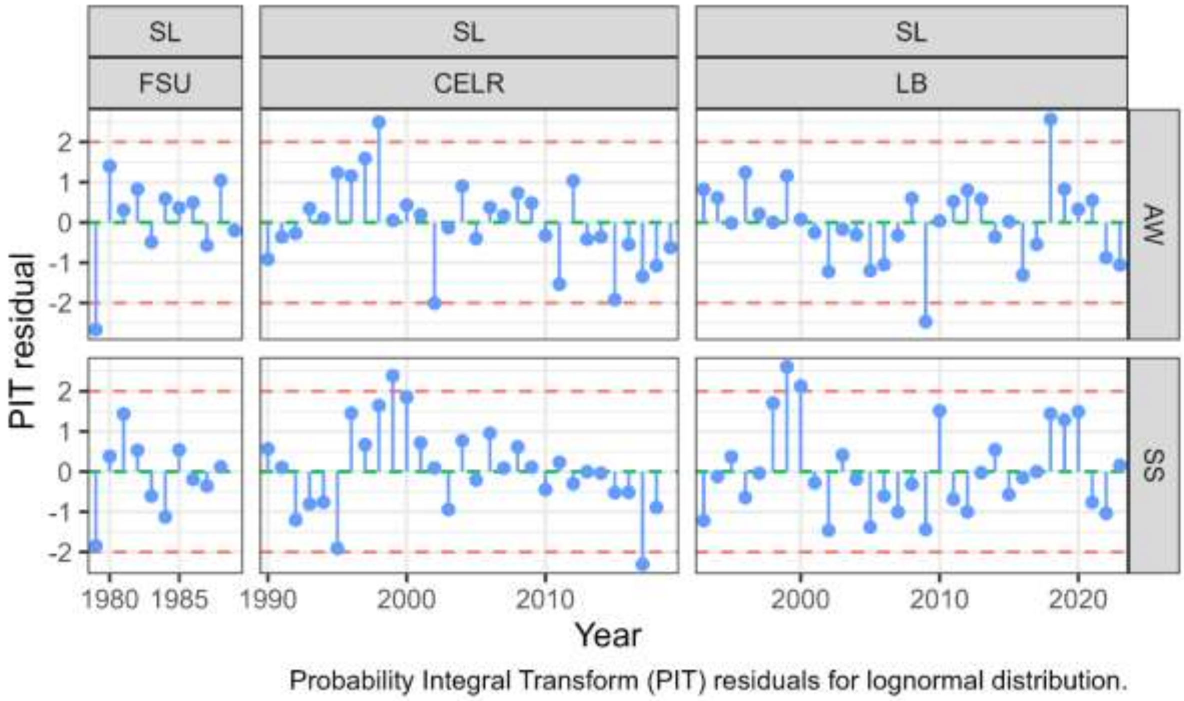

Figure 29: CPUE probability integral transformed (PIT) residuals for *decamod reweight* (*decamod* parameter estimates).

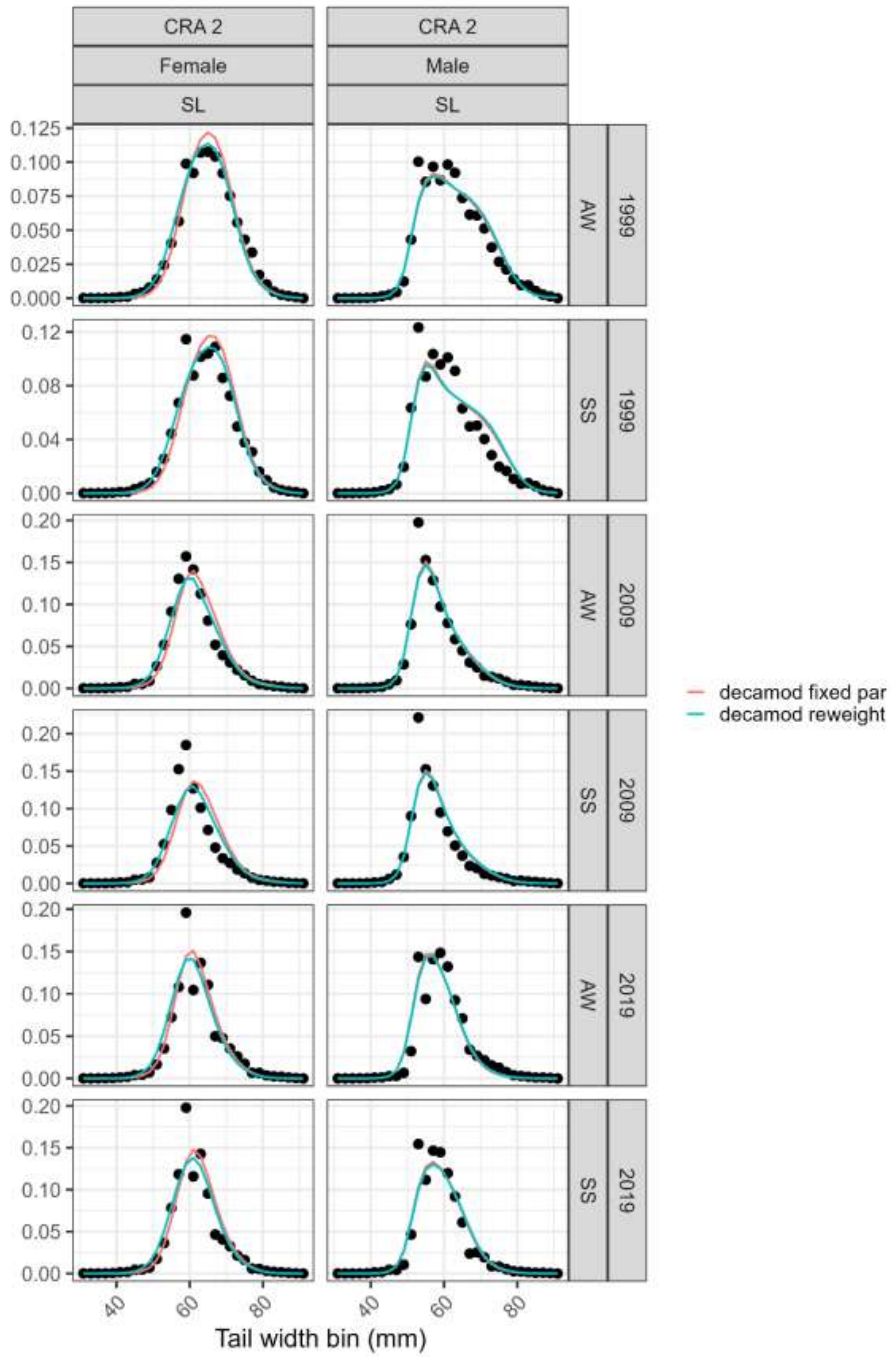

Figure 30: LSD vs. *decamod* LF fits for selected years.

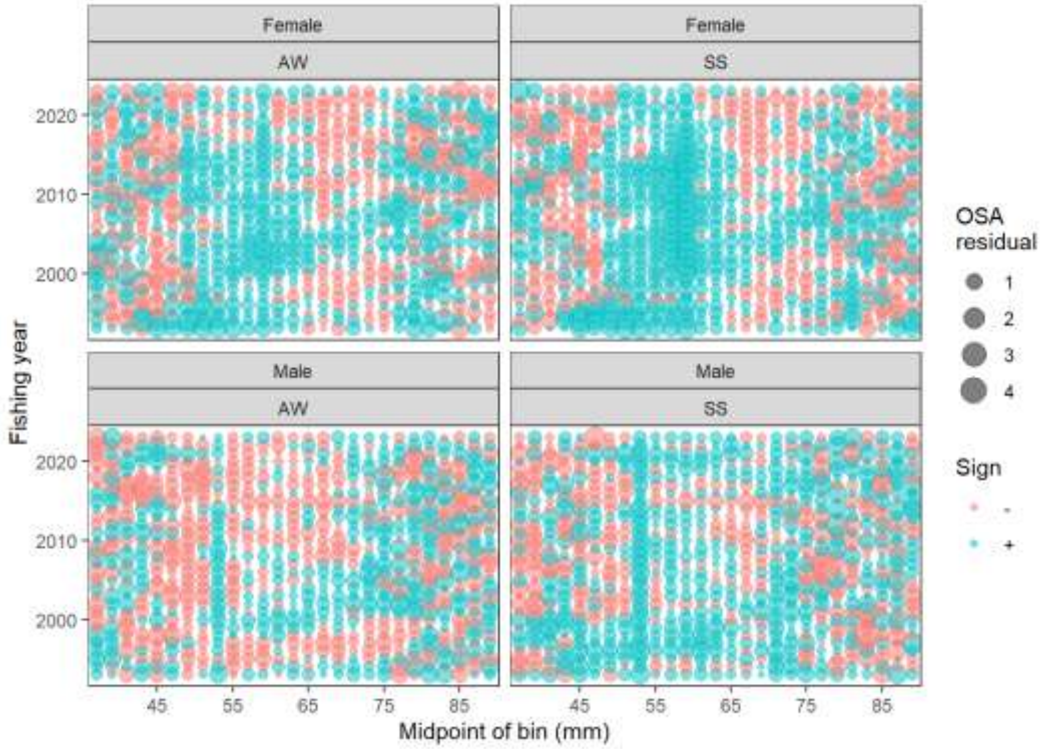

Figure 31: One-step-ahead (OSA) LF residuals by size, year, sex, and season for *decamod fixed par* (LSD parameter estimates).

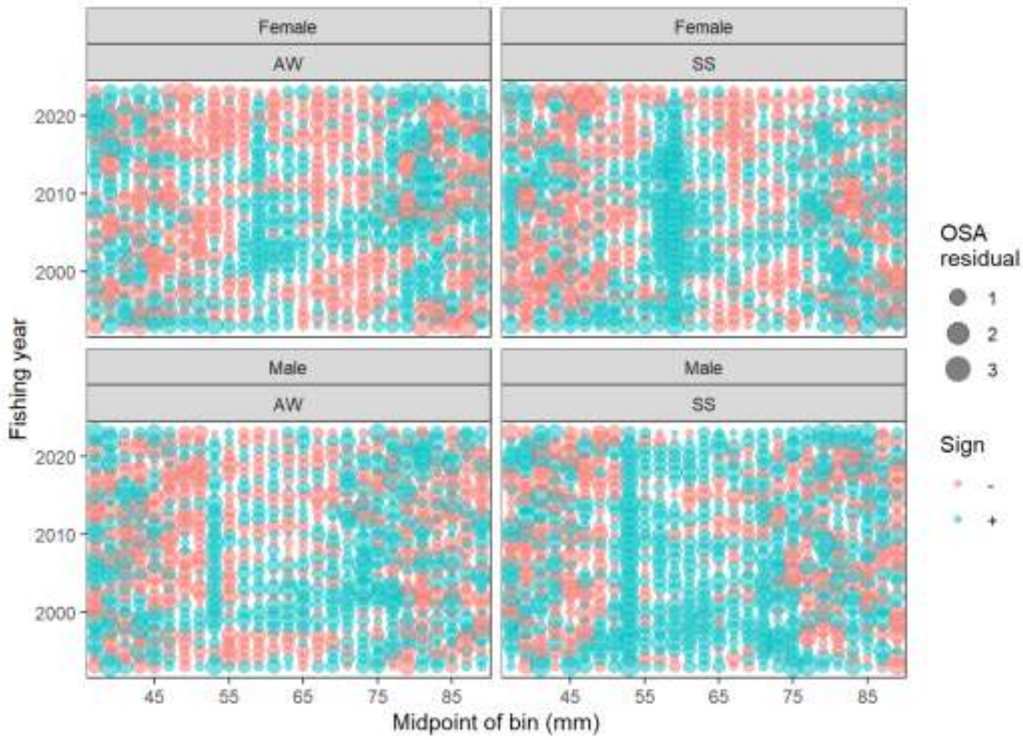

Figure 32: One-step-ahead (OSA) LF residuals by size, year, sex, and season for *decamod reweight* (decamod parameter estimates).

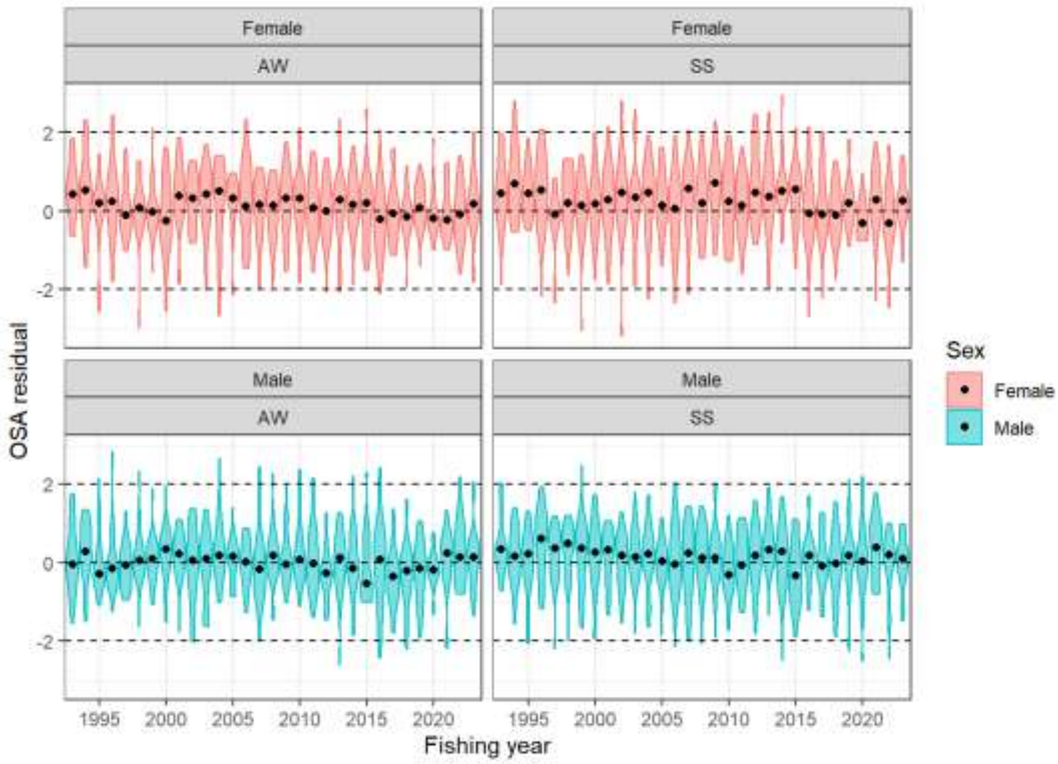

Figure 33: One-step-ahead (OSA) LF residuals by year, sex, and season for *decamod fixed par* (LSD parameter estimates).

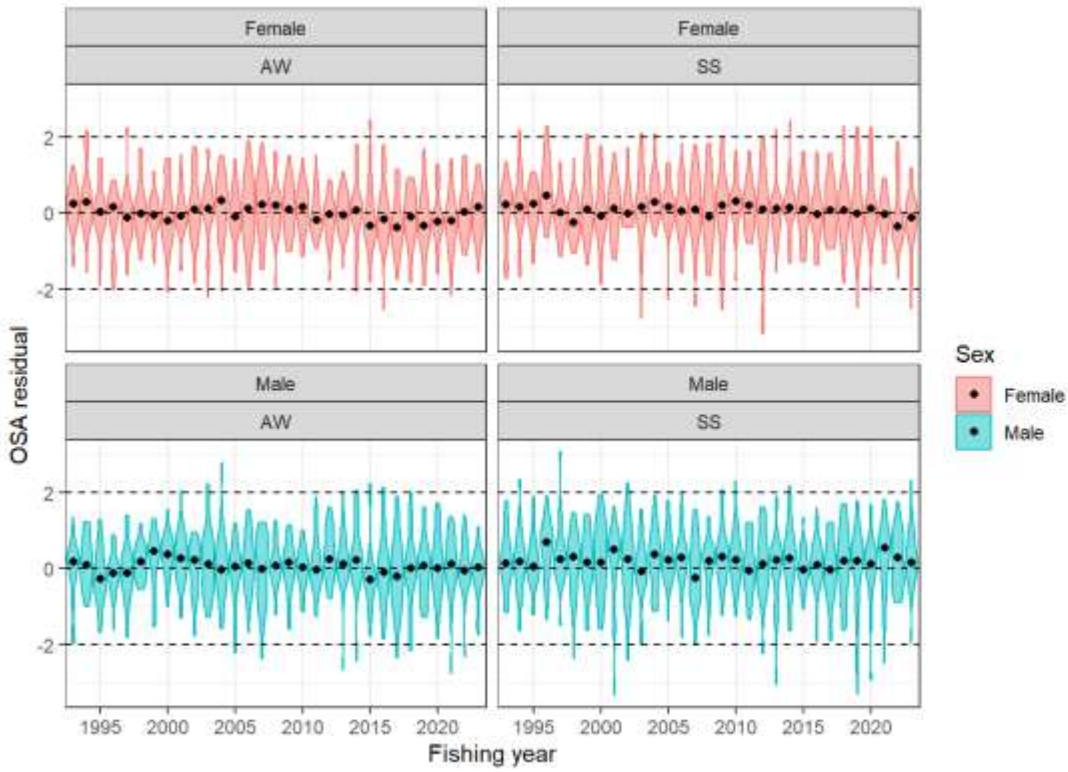

Figure 34: One-step-ahead (OSA) LF residuals by year, sex, and season for *decamod reweight* (decamod parameter estimates).

3.4.2 Bridging analysis: updated datasets

This section updated the *decamod* model for CRA 2 with updated model settings and data series for the 2025 assessment. Starting with *decamod reweight*, using all data series from the 2024 rapid update, model settings and data series were brought in one at a time to work up to a new base model for 2025:

1. *2024 decamod reweight*: same data and model settings as used in the 2024 rapid update. Identical to *decamod reweight* in Section 3.4.1,
2. *updated settings*: same data as the 2024 rapid update (final model year 2023), but fixed a bug in the exploitation rate calculation, removed a bias adjustment on recruitment deviates, and included time-invariant proportion mature appropriate for a two-sex model,
3. *catches*: catch assumptions for the 2025 stock assessment, keeping the final model year 2023,
4. *tags*: exclude proportion at liberty less than six months and growth increments less than -10 mm TW, keeping the final model year 2023,
5. *sex ratio*: include updated sex ratios as a result of standardisation models, keeping the final model year 2023,
6. *LF*: include updated length frequencies as a result of standardisation models, keeping the final model year 2023,
7. *cpue:* include updated CPUE series, keeping the final model year 2023,
8. *2025:* full series for the 2025 assessment, bringing all data series through to the final model year 2024.

The first model *updated settings* had negligible impacts on estimated growth, *M*, and recruitment, the latter of which had a very small increase due to the removal of bias adjustment (Figure 35).

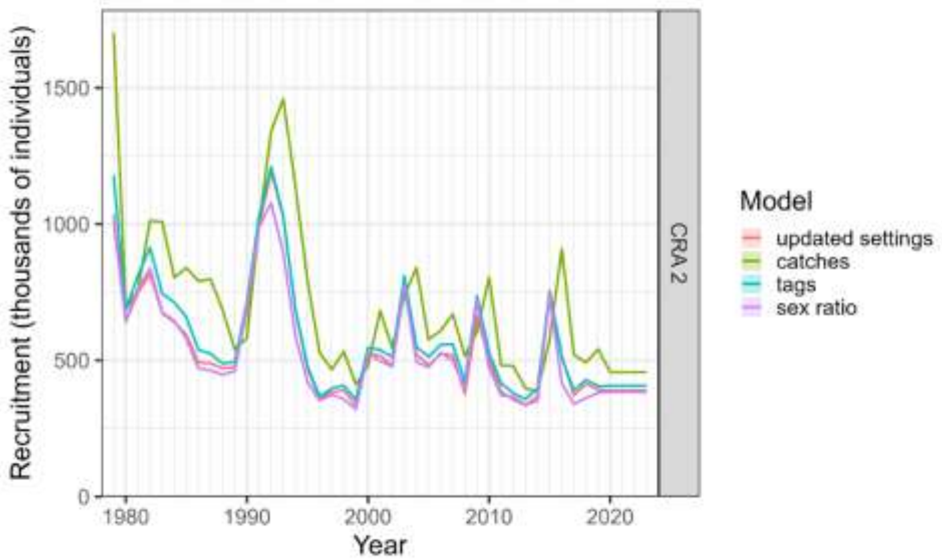

Figure 35: Comparison of recruitment: *updated model settings* (i.e. *decamod* with 2024 data reweighted and removal of recruitment bias adjustment term), *catches* updated catch series, *tags* updated tag assumptions, and *sex ratio* updated standardised sex ratio inputs.

There were some updated assumptions about catches for the 2025 assessment, specifically for illegal catches (Figure 10). The same amount of illegal catch was assumed to have been taken, but previously illegal catches were distributed based on SS CPUE, and the 2025 assessment assumed that they were a constant fixed percentage of the commercial catch (i.e. with the same pattern as commercial catch). Switching out the previous catch series with the updated catch series resulted in faster growth for small individuals (higher *Galpha*) (Figure 36) and in turn, higher *M*. Due to these updates in growth and *M*, recruitment was higher and lagged to be one year later compared with the 2024 catch assumptions (Figure 35).

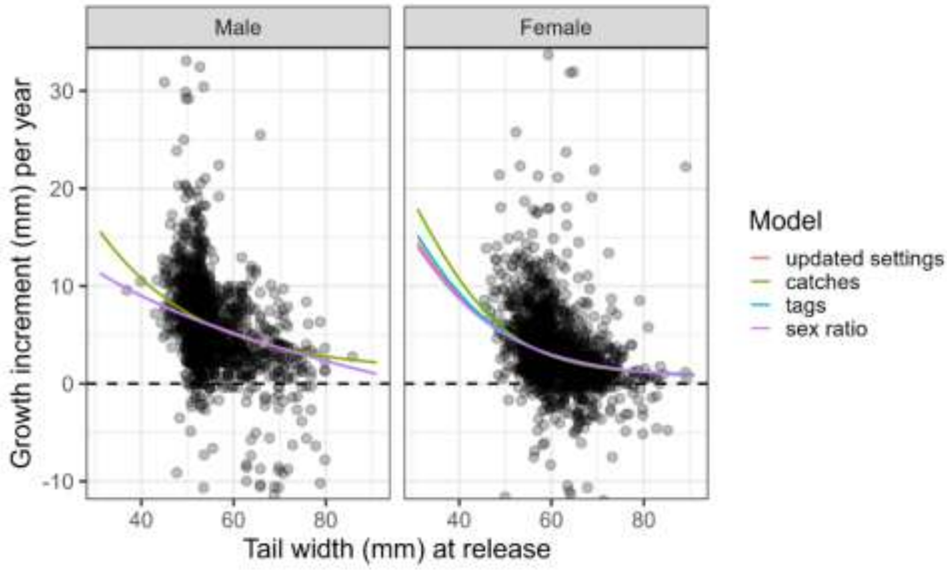

Figure 36: Comparison of growth increment: *decamod* with 2024 data, reweighted with *updated settings* (e.g. removal of recruitment bias adjustment term), *catches* updated catch series, *tags* updated tag assumptions, and *sex ratio* updated standardised sex ratio inputs.

Although the 2024 and 2025 tag-data extracts were identical, the assessments applied different filters. The 2024 rapid update used only initial release-recovery pairs and did not filter by time at liberty or observed growth increment. The 2025 assessment instead included multiple recoveries of the same tag, retained observations with more than six months at liberty, and excluded growth increments below −10 mm TW. These changes returned Galpha and M estimates to levels similar to those from the model using 2024 catch assumptions and the previous tag extract (Figure 36). Updating the sex-ratio data reduced M further. The model with updated catch assumptions, tag data, and sex ratios was very similar to *decamod* with the 2024 data (compare sex ratio with updated settings in Figure 35).

Updated length frequency data led to higher estimates for *Galpha* and *M*, and a similar increase and lag in recruitment to account for the faster growth of small individuals and higher *M* (Figure 37 to Figure 42).

Including the updated CPUE series for 2025 resulted in *M* estimates that were higher than any of the previous models, along with high estimates for *Galpha*. Adding all data through to 2025 resulted in an additional year in the CPUE series with a slightly different fit at the end of the series, bringing the *M* estimate down slightly but still remaining unrealistically high (Table 10).

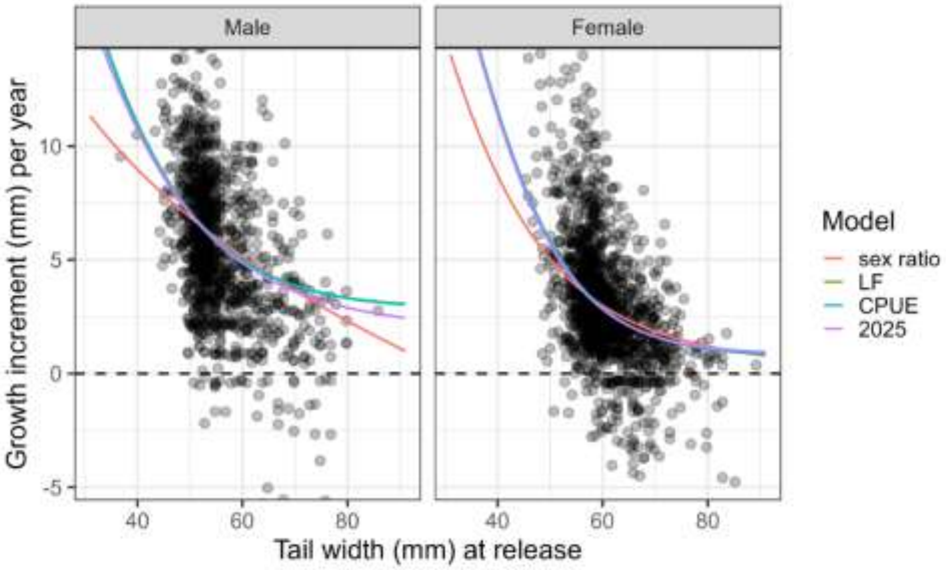

Figure 37: Comparison of growth increment: *sex ratio* (2024 *decamod* reweight including updated standardised sex ratio inputs), compared with *LF* updated standardised length frequency inputs, *cpue* updated CPUE series, and *2025* all data series updated for the 2025 assessment, through final year 2024.

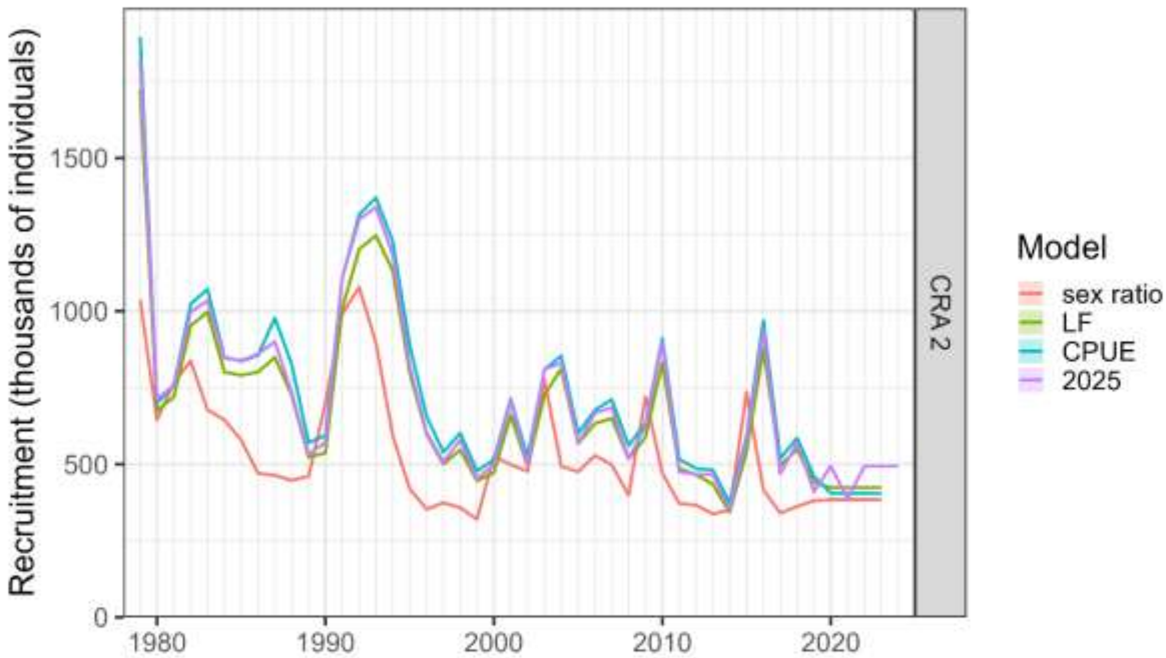

Figure 38: Comparison of recruitment: *sex ratio* (2024 *decamod* reweight including updated standardised sex ratio inputs), compared with *LF* updated standardised length frequency inputs, *cpue* updated CPUE series, and *2025* all data series updated for the 2025 assessment, through to final year 2024.

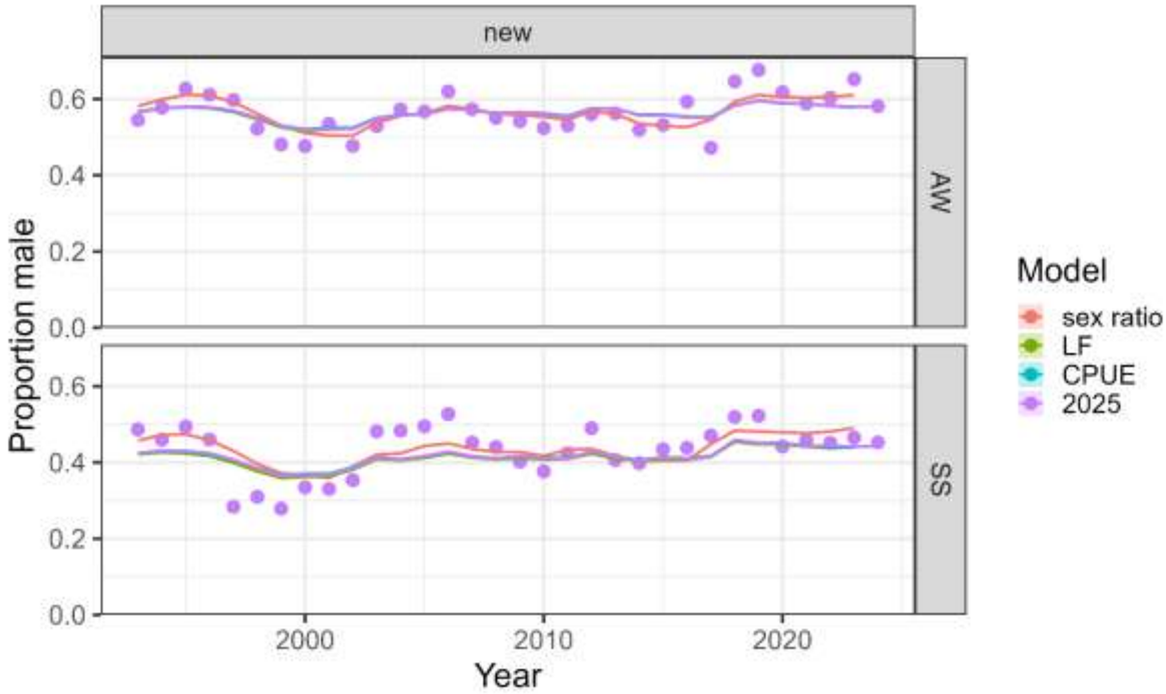

Figure 39: Sex ratio comparison: *sex ratio* (2024 decamod reweight including updated standardised sex ratio inputs), compared with *LF* updated standardised length frequency inputs, *cpue* updated CPUE series, and *2025* all data series updated for the 2025 assessment, through to final year 2024.

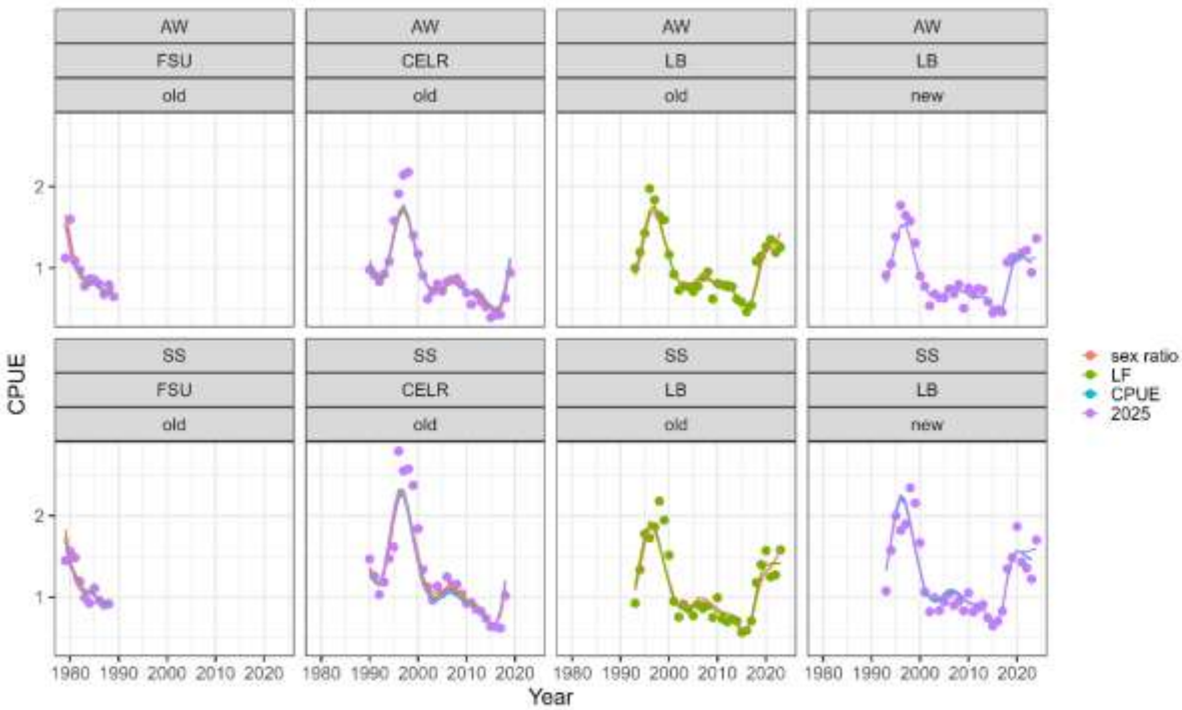

Figure 40: CPUE fit comparison: *sex ratio* (2024 decamod reweight including updated standardised sex ratio inputs), compared with *LF* updated standardised length frequency inputs, *cpue* updated CPUE series, and *2025* all data series updated for the 2025 assessment, through to final year 2024.

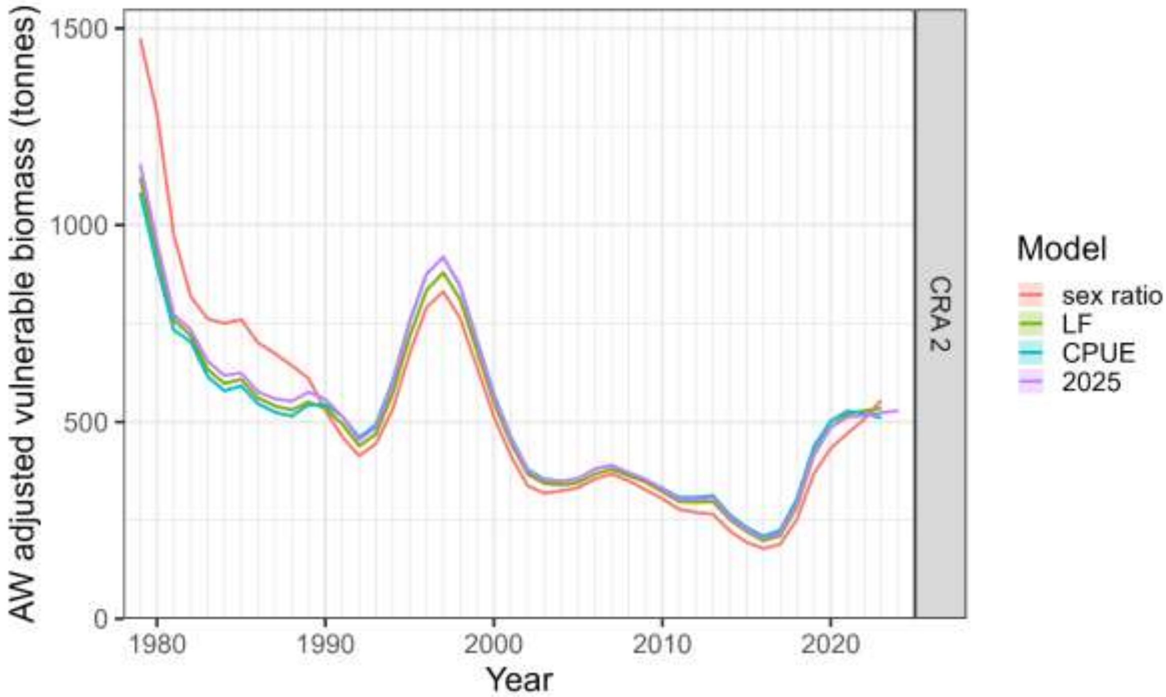

Figure 41: Vulnerable biomass comparison: *sex ratio* (2024 decamod reweight including updated standardised sex ratio inputs), compared with *LF* updated standardised length frequency inputs, *cpue* updated CPUE series, and *2025* all data series updated for the 2025 assessment, through to final year 2024.

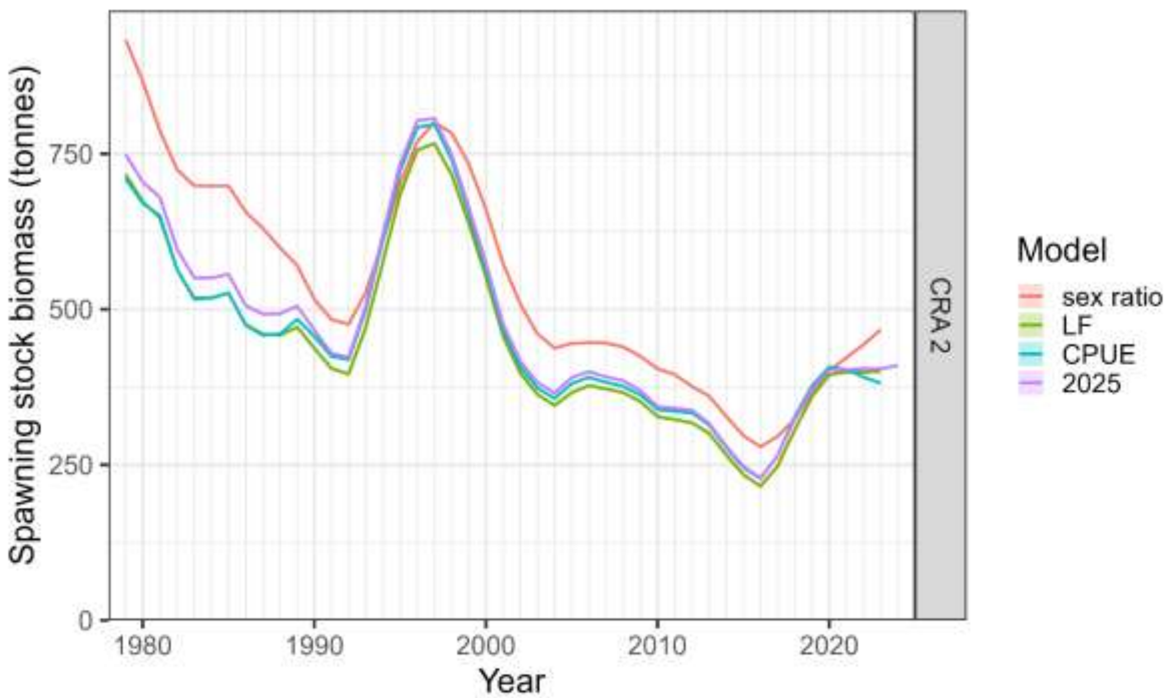

Figure 42: Spawning stock biomass comparison: *sex ratio* (2024 decamod reweight including updated standardised sex ratio inputs), compared with *LF* updated standardised length frequency inputs, *cpue* updated CPUE series, and *2025* all data series updated for the 2025 assessment, through to final year 2024.

Table 10: Parameter comparison: Impact of bringing 2025 data sets in one at a time.

Parameter	Number	*2024 decamod reweight*	*updated settings*	*catches*	*tags*	*sex ratio*	*LF*	*CPUE*	*2025*
Ma	1	0.204	0.203	0.303	0.219	0.198	0.320	0.340	0.323
R0	1	581 809	568 827	710 728	606348	553660	687784	741724	718031
U0	1	0.061	0.049	0.036	0.039	0.046	0.045	0.047	0.039
galpha	1	11.661	11.609	16.228	11.631	11.612	17.275	17.192	16.613
galpha	2	15.324	15.242	18.754	15.958	14.746	20.000	20.000	19.829
gcv	1	0.419	0.419	0.413	0.406	0.406	0.414	0.415	0.442
gcv	2	0.743	0.743	0.751	0.716	0.722	0.706	0.704	0.707
gdiff	1	0.201	0.202	0.173	0.200	0.199	0.191	0.193	0.174
gdiff	2	0.079	0.079	0.065	0.077	0.082	0.054	0.054	0.058
gobs	1	1.137	1.136	1.147	1.518	1.510	1.533	1.534	1.480
gshape	1	1.712	1.703	3.477	1.745	1.742	4.241	4.236	3.877
gshape	2	4.484	4.459	5.925	4.742	4.287	6.278	6.276	6.376
q	1	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
q	2	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
q	3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
sel50	1	50.919	50.917	50.635	50.925	50.880	51.130	51.174	51.142
sel50	2	53.290	53.321	52.309	53.171	53.603	55.390	55.417	55.548
sel95	1	4.675	4.673	4.778	4.661	4.654	4.884	4.882	4.821
sel95	2	8.164	8.162	8.329	8.237	8.145	7.701	7.677	7.808
selmax	1	0.505	0.507	0.603	0.504	0.476	0.653	0.653	0.644
selmax	2	0.913	0.913	0.903	0.913	0.884	0.837	0.800	0.813
selmax	3	0.671	0.673	0.809	0.670	0.687	0.940	0.888	0.888

3.5 Base case

Bridging analyses and exploratory model runs were done to develop a new base case stock assessment model. The following is an abbreviated sequence of steps that led to the CRA 2 base case:

1. Estimating model parameters one at a time to identify differences between LSD and *decamod* (Section 3.4.1);
2. Updated data sets for the 2025 assessment, through to fishing year 2024–25. This included updated standardised data and covariates (Section 3.4.2);
3. Catchability creep fixed to 1% for all CPUE series (and not just for the CELR series as was done in previous assessments), following reviewer comments from the previous stock assessment;
4. Recruitment deviates modelled as a random effect assuming AR1 for the final four model years. This is an update from recent assessments, which estimated recruitment deviates up to three years prior to the final model year, leaving the final year constant but rewriting them with projected recruitment deviates to determine derived quantities in the current year. Assuming an AR1 process for the final four model years, based on standard deviation and autocorrelation throughout the time series, allows for the estimation of recent recruitment within the stock assessment model with AR1 model constraints;
5. Length-based *M*, following reviewer comments from recent assessments and an improved ability to fit to key time series (e.g. sex ratios and length frequency);
6. Fix *Galpha* at 30 mm TW to 12 mm for males and 14 mm for females. This was the result of the bridging analysis which estimated one parameter at a time (Section 3.4.1) where we found that *Galpha* and *M* were highly confounded, and the estimation of *Galpha* resulted in an

unrealistically high *M*, as well as an unrealistically high *Galpha* based on juvenile growth studies. Assumed values for *Galpha* were based on fishery tag data, which showed annual growth at 40 mm TW to range from 10–13 mm TW. Based on data collected by a Halfmoon Bay juvenile dive survey (in CRA 7), at 30 mm TW (the fixed length assumed for *Galpha*), growth would be about 15% faster than at 40 mm TW (11.5–15 mm TW at 30 mm TW). The assumed values for the base model *Galpha* are in the range supported by the Halfmoon Bay juvenile dive survey.

7. Estimating CPUE power parameters for the CELR and logbook series. Initial model runs indicated that CPUE fits were poor for the periods of highest and lowest CPUE. Estimating power parameters allows for hyperdepletion, giving the model the freedom to fit the CPUE indices that reduce more quickly than expected, based on the population size as fishing effort increases. Adding this additional parameter improved the fit to both the logbook and CELR CPUE series.

3.5.1 Base case description

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

- **Years**: 1979 to 2024, estimating an initial exploitation rate on a population that is in equilibrium with average recruitment;
- **Seasons**: two six-month seasons AW (April to September) and SS (October to March) during each fishing year;
- **Sex categories**: males and females;
- **Tail width bins**: 31 two-mm bins with midpoints from 31 mm to 91 mm tail width (last bin was a “plus group” or accumulator bin);
- **Regions**: a single region including Statistical Areas 905, 906, 907, 908;
- **Recruitment**: annual recruitment determined by the mean recruitment parameter (R_0) and the estimated annual deviations from mean recruitment without modification by a stock-recruitment function. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero and standard deviation 0.4. Recruitment deviations were estimated for 1979 to 2020. The 2021–2024 recruitment deviations were estimated from an autoregression AR1 function, estimated over the period 1980 to 2020;
- **Growth**: sex-specific using the Schnute-Francis growth model. To address confounding between growth of small individuals and natural mortality, the *Galpha* parameter set at 30 mm TW was fixed to a growth increment of 12 mm for males and 14 mm for females. No density-dependent growth was modelled. This included only CRA 2 tag release/recovery pairs, excluding recaptures that were at liberty less than 6 months or had observed growth increments less than -10 mm TW, but included multiple recoveries of the same tag;
- **Maturity**: Maturity and the incidence of berried females were modelled separately from the stock assessment model and included in the model as fixed parameters. The maturity ogive was assumed constant over time, and the proportion of berried females varied by season but was constant across years;
- **Natural mortality**: Natural mortality was assumed to be independent of sex but varying with length. The *M~a* parameter was estimated at 60 mm TW. The shape parameter of the length-varying mortality function was fixed to -1 (Lorenzen 2022);
- **Selectivity**: logistic, sex-specific, and time-invariant. Selectivity height (vulnerability) was assumed to be one for males in the AW season, and estimated relative to this for males in the SS and females in both seasons; these estimated relative vulnerabilities were not capped at one;
- **Handling mortality**: two periods: 1979 to 1989 fixed at 0.1 and 1990 to 2029 fixed at 0.05;
- **Catch**: fixed values from 1979 to 2024 using updated assumptions on commercial, illegal, recreational, and customary (Section 2.2.3). Catch is removed using discrete exploitation rates;
- **Abundance indices**: three CPUE series (FSU, CELR, LB), each with a separate catchability coefficient (q). Assumed a fixed *qcreep* at 1% per year for all CPUE series to account for

improvement in catchability due to learning. Estimated two CPUE power parameters (*pow*), one for the CELR and one for the LB series to model hyperdepletion and improve model fits to these series;

- **Likelihoods**:
    - CPUE series: Lognormal
    - Tags: Robust-normal
    - LFs: Multinomial
    - Sex ratios: Logit-normal;
- **Data weighting**: determined iteratively and simultaneously for all data types. The LFs were iteratively weighted following the method of Francis (method TA, 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 the tag data was required because they are self-weighting through the estimation of an observation error parameter.

3.5.2 Model fits, diagnostics, and parameter estimates

The catch was removed without invoking the catch penalty. Fits to the CPUE indices in the more recent years were good, particularly with the logbook CPUE AW series (Figure 43; Figure F.10).

MCMC trace plots indicated that MCMC chains were well-mixed, there were no divergent transitions after the warm-up phase (Figure F.1), and all R-hat statistics were acceptable (Figure F.2). Some parameters had an effective sample size close to but not above 400, but no parameters had an R-hat greater than 1.05 (Figure F.2; Figure F.3; Figure F.4). The traces for key estimated biological parameters, such as M and R_0, showed an acceptable level of stability, with MCMC chains staying away from parameter bounds. The posterior distributions for most model parameters updated the prior (Figure F.7). Likelihoods, the standard deviation of the normalised residual (SDNR), and parameter estimates were inspected, as were the derived parameters and probabilities, including projections, for the base case and were found to be acceptable.

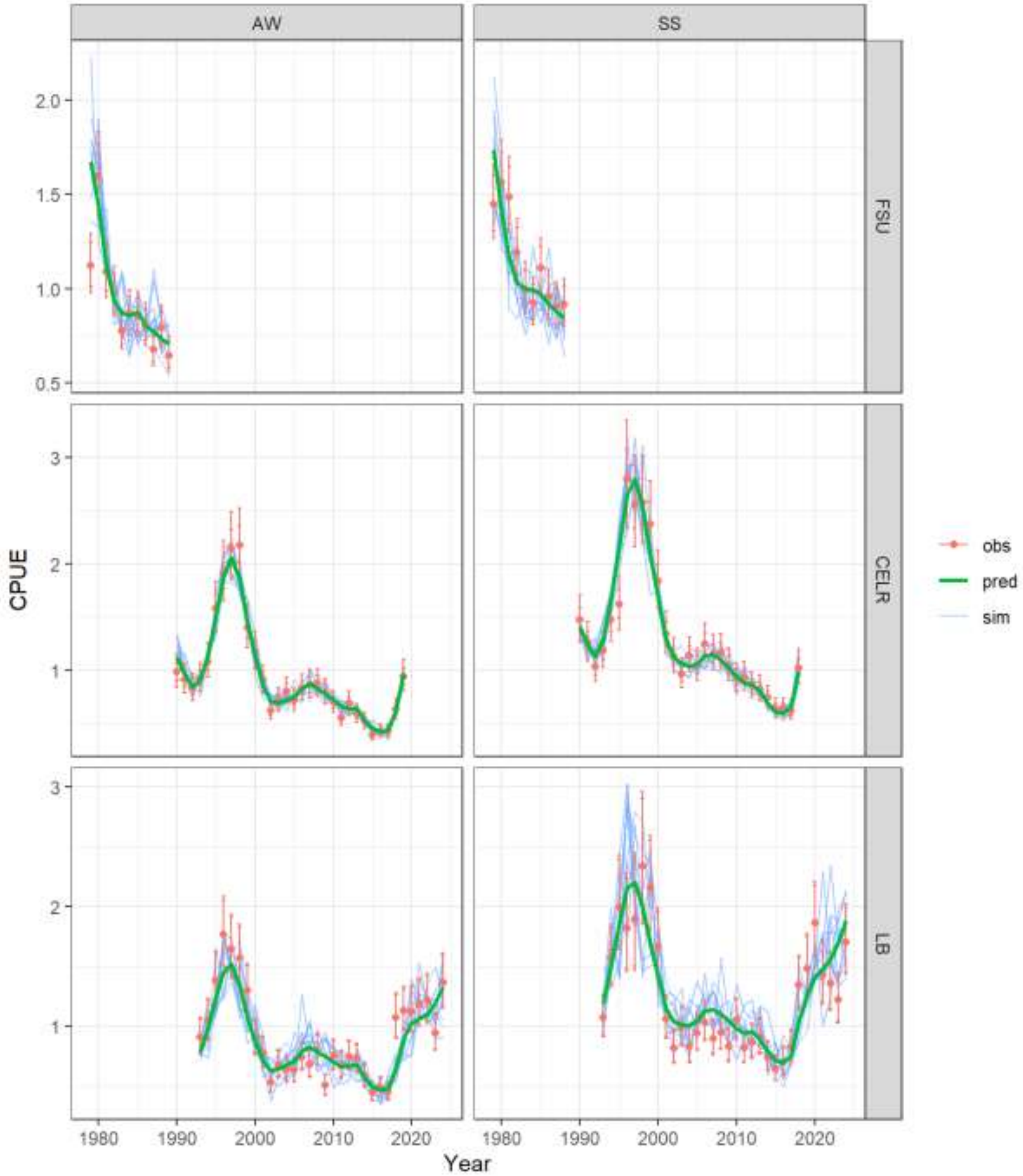

Figure 43: Fits to the FSU, CELR, and logbook CPUE series for the CRA 2 base model, where points show the observed CPUE with ±1 SD, blue lines show simulation replicates of CPUE to demonstrate uncertainty in observed CPUE, and the green line shows the MLE for predicted CPUE.

The base case model fitted to the sex ratio data was good, except for some departures in the SS season during the late 1990s (Figure 44, Figure F.11). Model fits to the LF data were acceptable (Figure F.12, Figure F.13). There was some structure in the one-step-ahead (OSA) LF residuals (Figure F.14), particularly around the MLS for each sex, but most of the residuals were within the -2 to 2 range (Figure F.14, Figure F.15).

By fixing the *Galpha* parameters, other growth parameters and *M* were estimated at reasonable values (i.e. length-varying natural mortality rate on smaller individuals was within a reasonable range, Table 11, Figure 45), particularly for individuals smaller than 50 mm TW, for which there is very little information available.

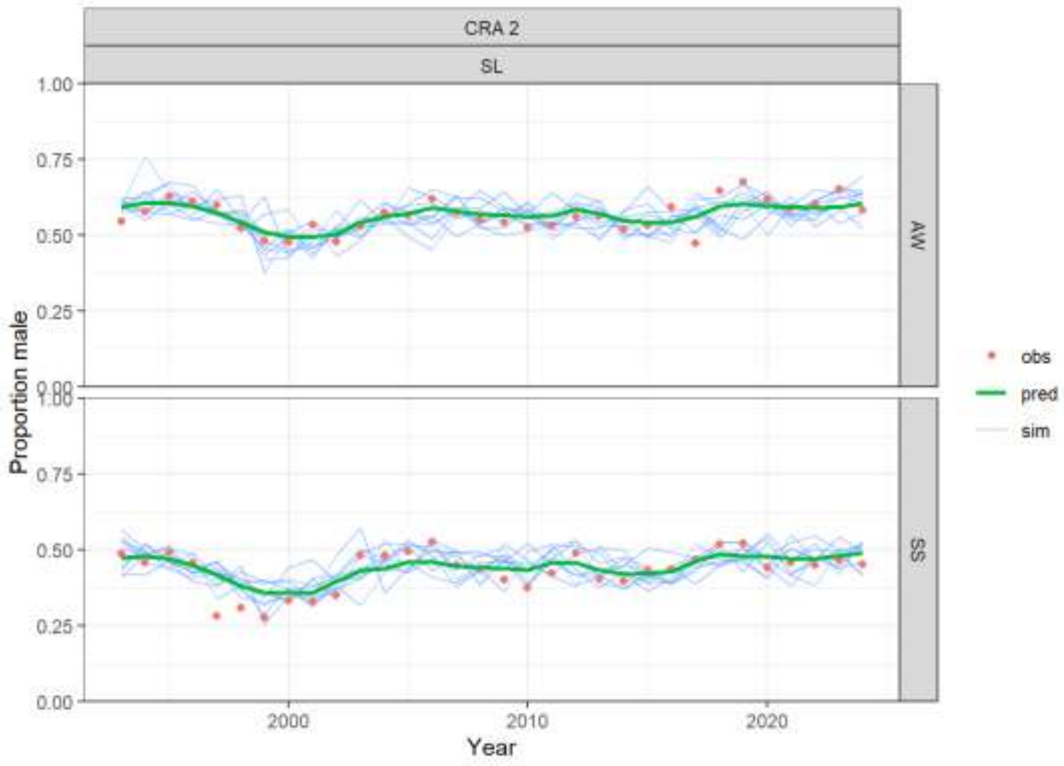

Figure 44: Model fit to sex ratio data (green) and simulations (blue).

Table 11: Summary of the posterior distribution for the model parameter estimates for the base model. The mean, standard deviation (SD) of the mean, median, and 90% credible intervals (i.e. 5% and 95%) are reported. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers.

Parameter	Number	5%	Median	Mean	95%
M_a	1	0.185	0.203	0.203	0.223
R_0	1	585018	678114	681552	791021
U_0	1	0.041	0.066	0.067	0.093
gcv	1	0.433	0.458	0.458	0.484
gcv	2	0.704	0.744	0.745	0.787
gdiff	1	0.184	0.197	0.198	0.213
gdiff	2	0.079	0.084	0.084	0.090
gobs	1	1.325	1.419	1.421	1.522
gshape	1	2.122	2.251	2.253	2.390
gshape	2	3.985	4.105	4.107	4.230
pow	1	1.489	1.586	1.589	1.693
pow	2	1.161	1.282	1.283	1.412
q	1	0.001	0.001	0.001	0.002
q	2	0.000	0.000	0.000	0.000
q	3	0.000	0.000	0.000	0.000
sel50	1	51.331	51.488	51.489	51.641
sel50	2	56.105	56.416	56.419	56.746
sel95	1	4.492	4.701	4.700	4.903
sel95	2	6.564	6.942	6.954	7.369
selmax	1	0.526	0.567	0.567	0.610
selmax	2	0.759	0.782	0.782	0.806
selmax	3	0.652	0.692	0.693	0.736

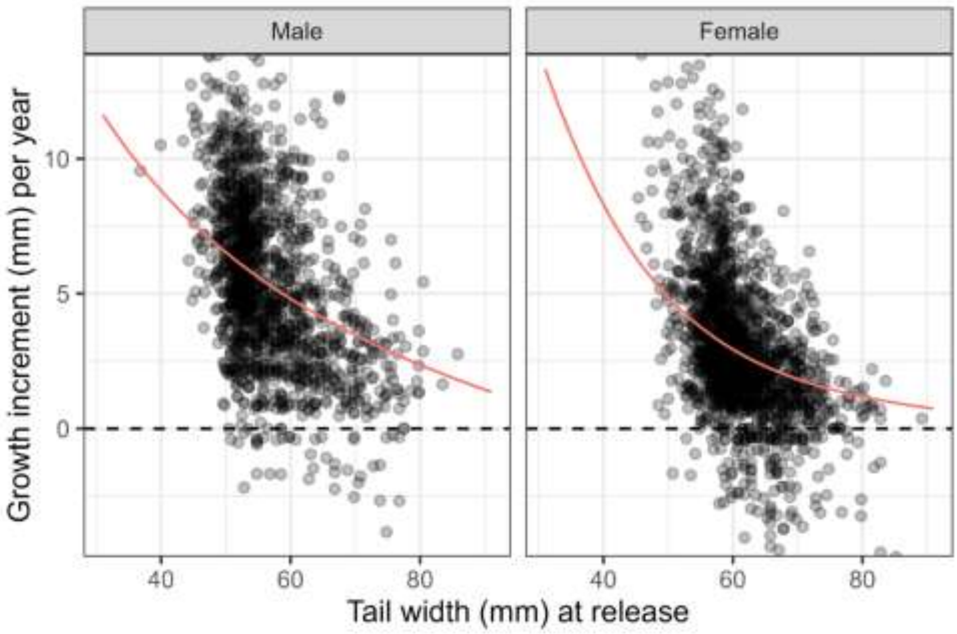

Figure 45: Annual growth increment (mm) by tail width at release and sex.

Likelihood profiles were produced for natural mortality (M; Figures 46 and 47) and average recruitment (R0; Figures 48 and 49). The second plot for each parameter compares the maximum-likelihood profile with the posterior distribution of likelihoods. The profiles for M indicate that the CPUE and length-frequency data are consistent with higher estimates, whereas the sex-ratio and tagging data and the prior support a lower estimate. The R0 profiles show the same contrast. The prior used for R0 (Tables 5 and 6) appears to be quite informative.Natural mortality was assumed to be length-varying, with a median M_a at 60 mm TW of 0.203 (Figure 50).

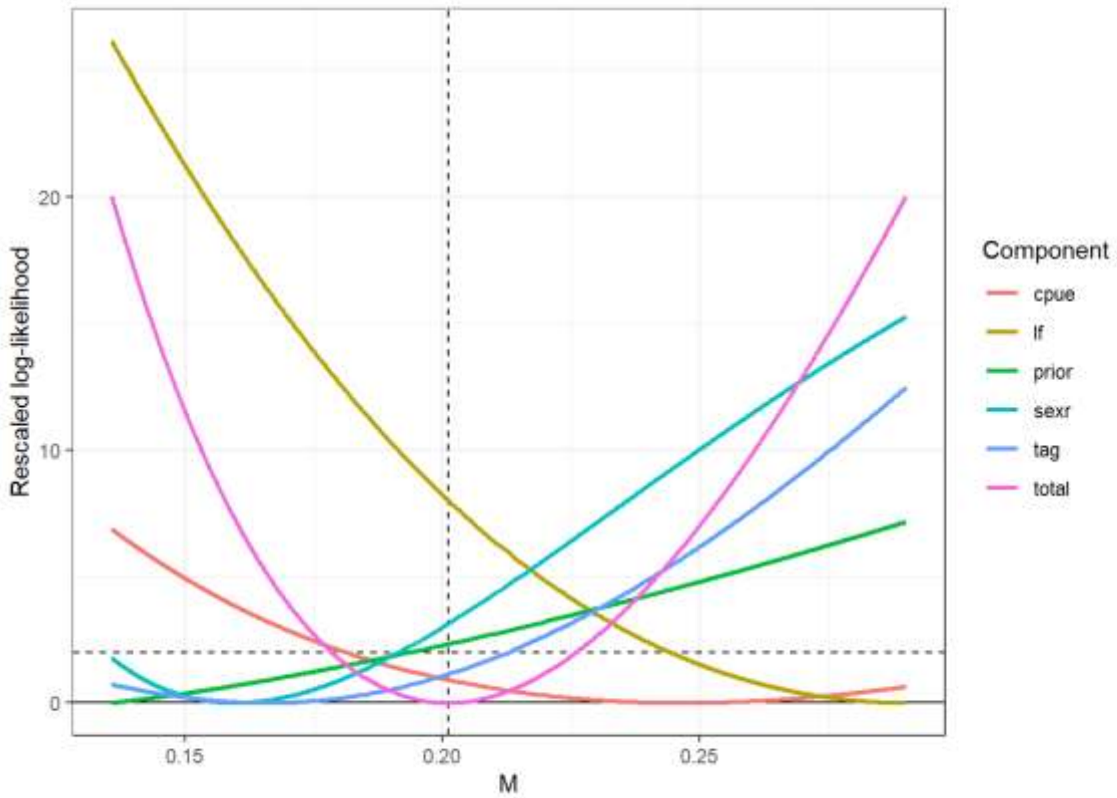

Figure 46: Likelihood profile for natural mortality (*M*). The dashed vertical line is the MLE and the dashed horizontal line indicates two likelihood units.

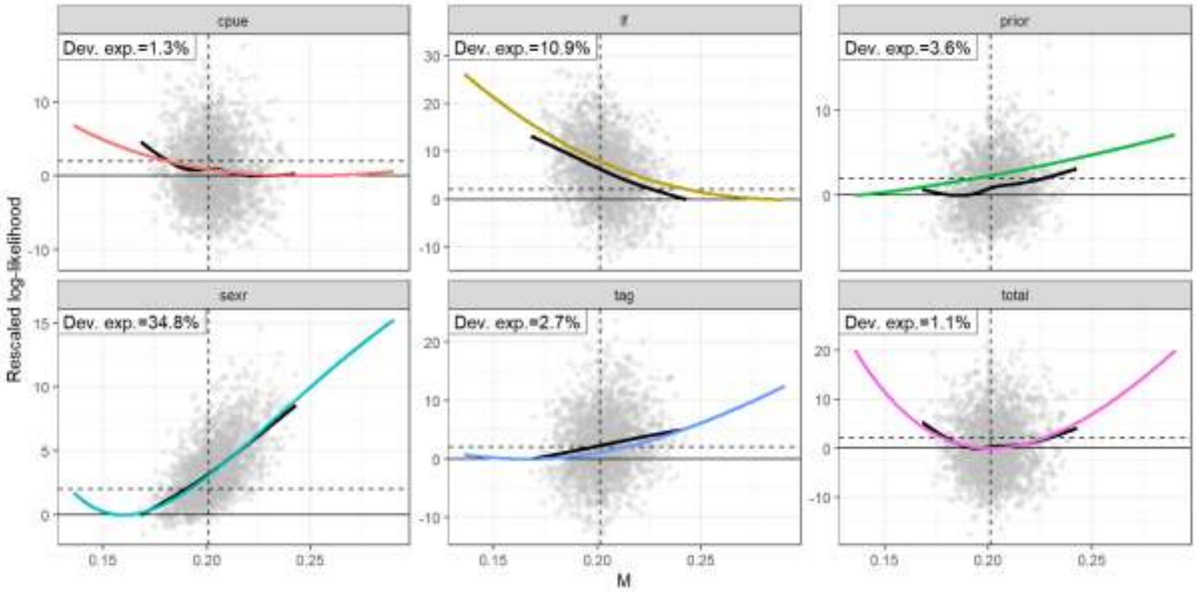

Figure 47: Likelihood profile for natural mortality (*M*) comparing the MLE profile for each data component (plus the total likelihood) with the distribution of equivalent likelihoods drawn from the posterior MCMC samples. The dashed vertical line is the MLE and the dashed horizontal line indicates two likelihood units. The solid black line in each panel is a smoother fit to the MCMC samples.

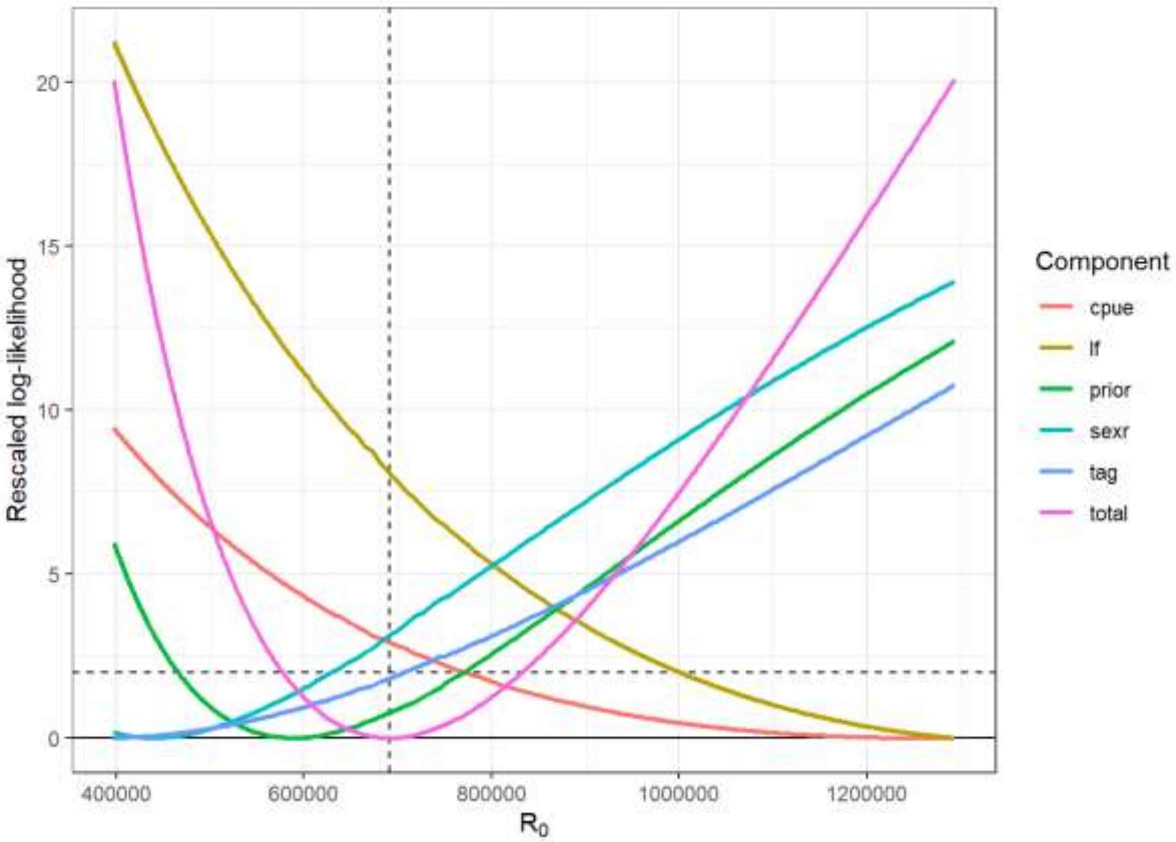

Figure 48: Likelihood profile for average recruitment (R_0). The dashed vertical line is the MLE and the dashed horizontal line indicates two likelihood units.

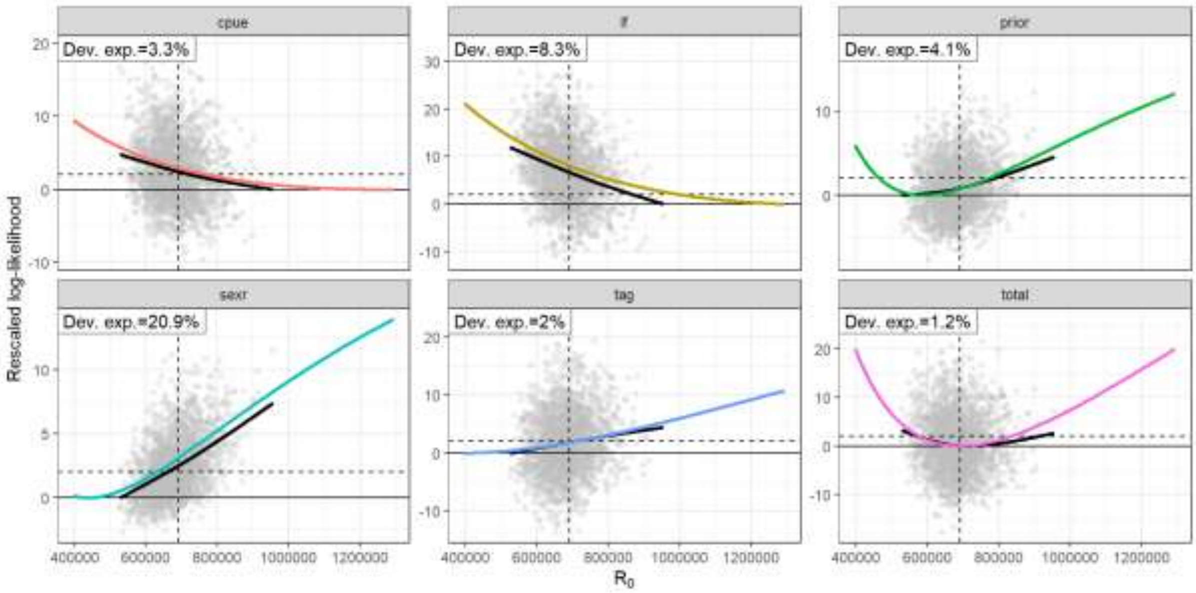

Figure 49: Likelihood profile for average recruitment (*R₀*) comparing the MLE profile for each data component (plus the total likelihood) with the distribution of equivalent likelihoods drawn from the posterior MCMC samples. The dashed vertical line is the MLE and the dashed horizontal line indicates two likelihood units. The solid black line in each panel is a smoother fit to the MCMC samples.

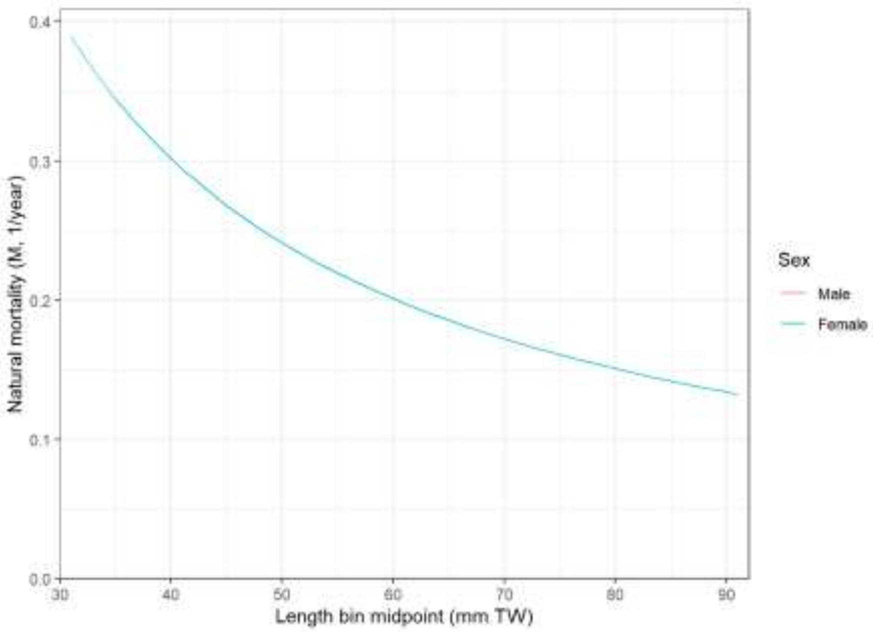

Figure 50: Natural mortality (*M*) by length.

The selectivity functions by sex and season (Figure 51) were assumed to be logistic. Each function reflects the estimated length at 50% selectivity, the length at 95% selectivity, and the relative vulnerability. The vulnerabilities of males in the SS and females in each season were estimated relative to males in AW. Note that the relative vulnerability was allowed to exceed 1.0 if the data required it, which did not occur. Uncertainty in selectivity is considerably lower than in the previous assessment, probably due to the combined female sex category (modelling immature and mature females together, rather than separately) and the fixed maturity relationship estimated outside the model.

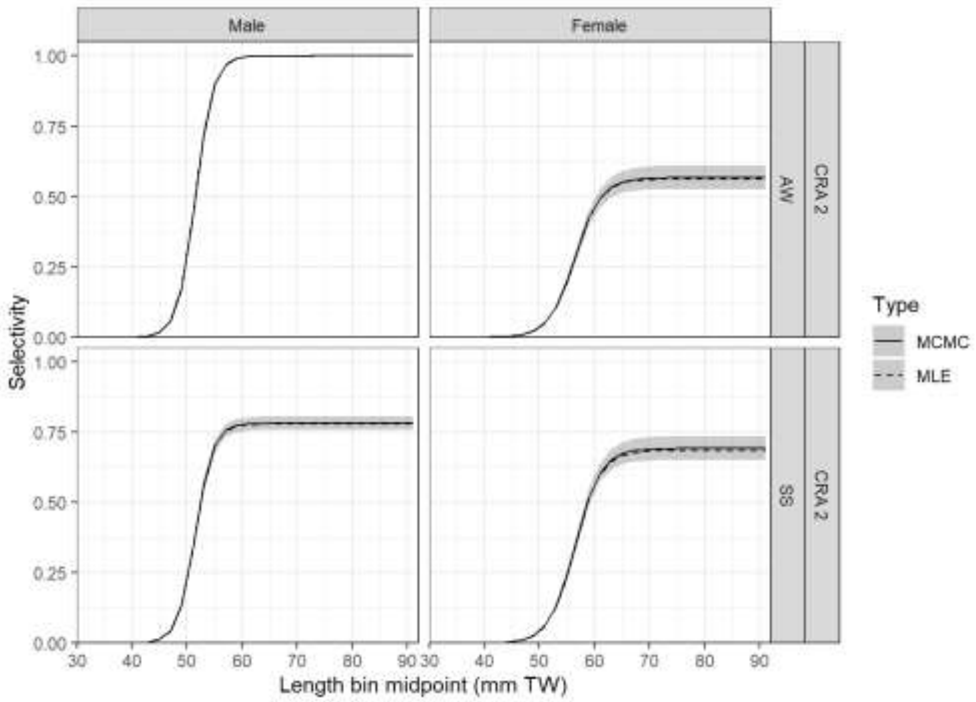

Figure 51: Selectivity by sex and season by length bin for the base model.

3.5.3 Reference level

Model-based reference levels for red rock lobster stocks have been calculated for the past few years (see more detailed discussion in Rudd et al. 2021c). This procedure develops B_{MSY} proxy reference levels specific for the population that is vulnerable to fishing (B_R) using the most recently accepted stock assessment model to project the vulnerable biomass under a range of harvest rules through simulation. Starting with the CRA 2 base case model, projections were made across a range of fixed catch and fixed *U* levels. These simulations were run for 50 years across the 2000 MCMC posterior samples, with each simulation replicate drawing random recruitment deviates from a normal distribution based on the mean, standard deviation, and autocorrelation of the model-estimated recruitment deviates spanning a period that starts in the first year with a reasonable amount of observed length data and which ends four years before the final model year (the 'data period'). For CRA 2, the data period included 28 years from 1993 to 2020. This is also the period used for basing the estimate of SSB_0 (SSB_{0_data}).

Only the size-limited catches are modelled in the reference level projections, with the non-size-limited catch (sum of illegal and customary catch) held constant at the 2024 level. Rules that had a probability more than 5% of falling below 20% SSB_{0_data} in the final projection year were rejected. The constant catch rules were further constrained by the requirement that there should be less than a 20% probability of the population crashing under specified catch levels by the final year of the projection period. The vulnerable biomass associated with the fixed catch and fixed *U* levels that maximised the catch for each harvest strategy while satisfying the constraints in the final simulation year were then averaged to obtain the interim target reference level for CRA 2 (see Rudd et al. 2021c).

To provide an exploitation rate indicator (U_R), the exploitation rate associated with B_R was calculated, which was defined as the *U* that resulted in an equilibrium biomass equal to the B_R. U_R was identified by finding the fixed *U* resulting in a median vulnerable biomass of B_R in the final projection year for the reference level calculation (i.e. projection year 50).

3.5.4 Projections and stock status

A five-year projection, for the fishing years 2025 to 2029, was calculated for the base model. All catches were assumed to be the same as the final model year (2024), including the seasonal catch splits, and were held constant when projecting forward (Table 12; Figure 52; Figure 53). The projected commercial catch in 2025 matched the current TACC (80 tonnes).

Table 12: Projected catches held constant for each fishing year from 2025–2029.

Fishery	AW	SS	Total
Commercial	43.398	36.559	79.957
Recreational	0.873	7.854	8.726
Illegal	4.340	3.656	7.996
Customary	0.500	4.500	5.000

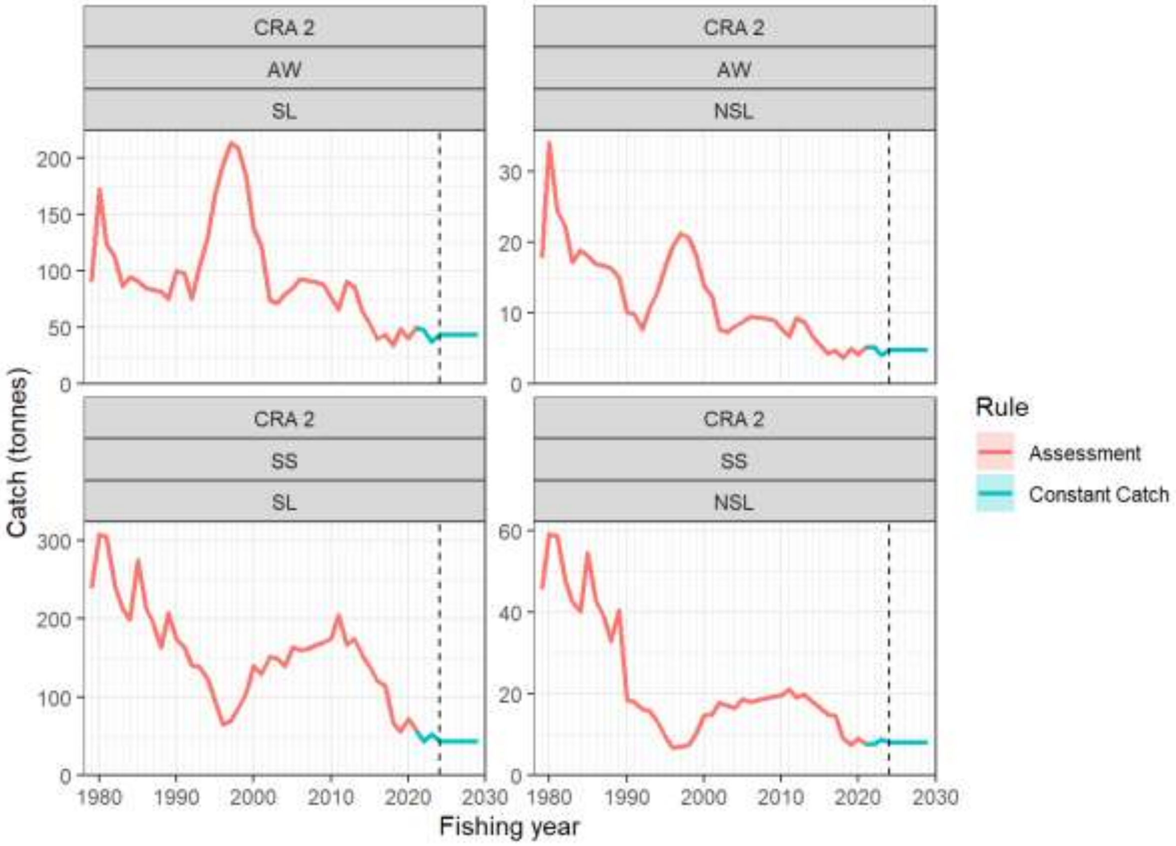

Figure 52: Catch by fishing year, season, and fishery (SL = size-limited, NSL = non-size-limited) for the base model. The dashed vertical line indicates the final year of stock reconstruction.

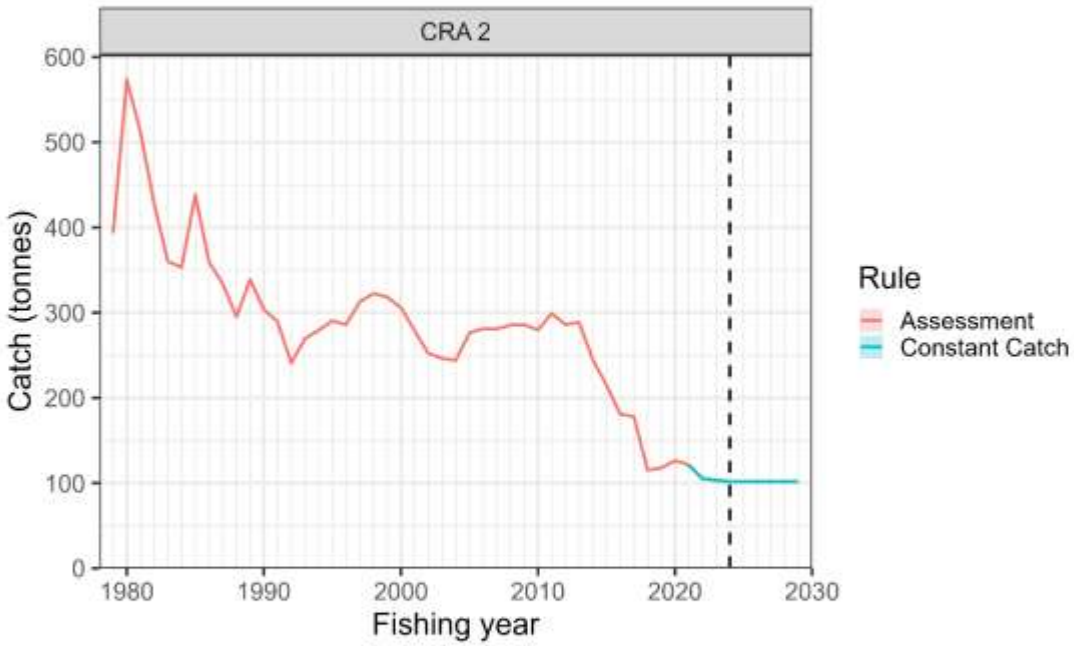

Figure 53: Total catch by fishing year for the base model. The dashed vertical line indicates the final year of stock reconstruction.

One broad strong recruitment pulse was estimated in the early 1990s, followed by three lesser recruitment events in the 2000s and 2010s (Figure 54). Current stock status estimates were calculated using model-estimated recruitment deviates, based on lognormally-distributed recruitment deviates through to 2020 and then recruitment deviates based on AR1 (estimated over the period 1980 through to 2020) for the final four model years (which could not be estimated as they were only partially recruited). To calculate five-year projected stock status, the four final model years assuming AR1 recruitment (2021–2024) were overwritten by the projected recruitment using ARIMA models (Figure 54) and continued through to 2030. This approach reduced the influence of any patterns in uncertain recent recruitment and instead used longer-term information to inform short-term recruitment.

Median recruitment has been declining below R_0 over the stock reconstruction period. This can be seen in the recruitment used for the five-year projections (green) based on ARIMA models. Projected recruitment has a median well below R_0 but the 90% credible intervals include the posterior distribution for R_0 (Figure 54).

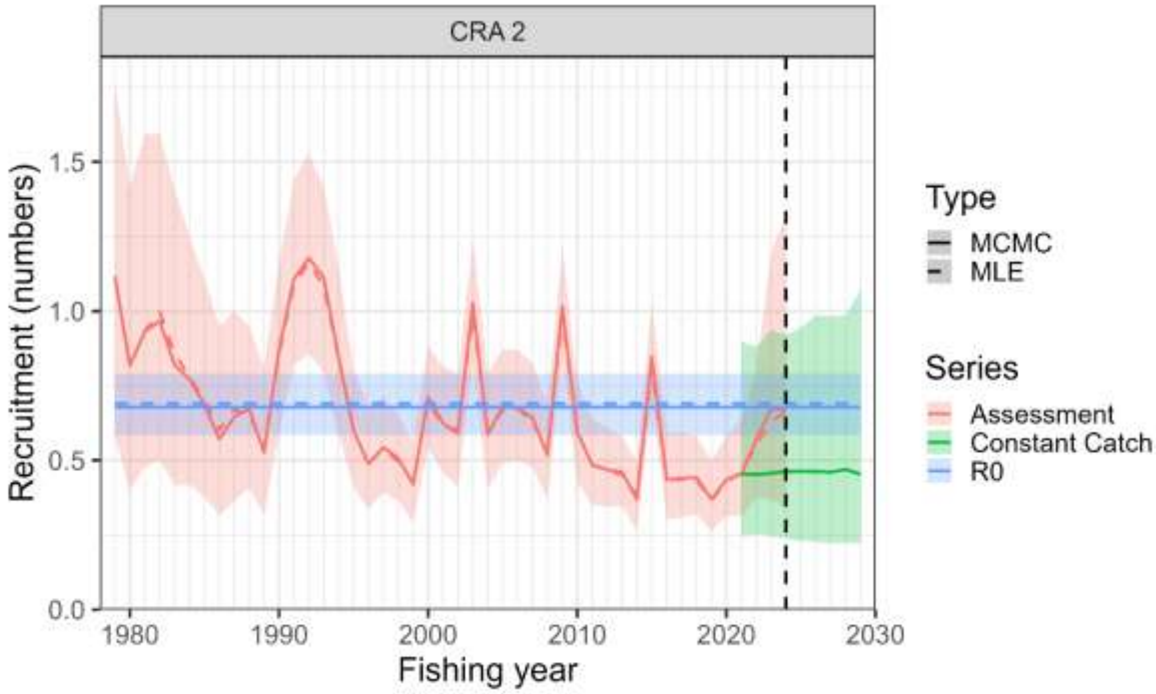

Figure 54: Estimated recruitment for the base model (red) compared with R_0 (blue) and projected recruitment using ARIMA for the five-year projection (green). The solid line indicates the median of the posterior and shading indicates the 90% credible interval, and the dashed line matching the colour of each series shows the MLE. The black dashed vertical line indicates the final year of stock reconstruction.

The NSL exploitation rates were very low compared with the SL exploitation rates, reflecting the much lower catch taken in this category (Figure 55). AW SL exploitation rates increased until about 2000, when they began to decline overall. SS SL exploitation rates declined to a low of 8% in the mid-1990s, then increased to a peak of 54% of the vulnerable population taken in 2011. After this peak, both AW and SS exploitation rates have steadily declined to low levels (Figure 56; Figure 57).

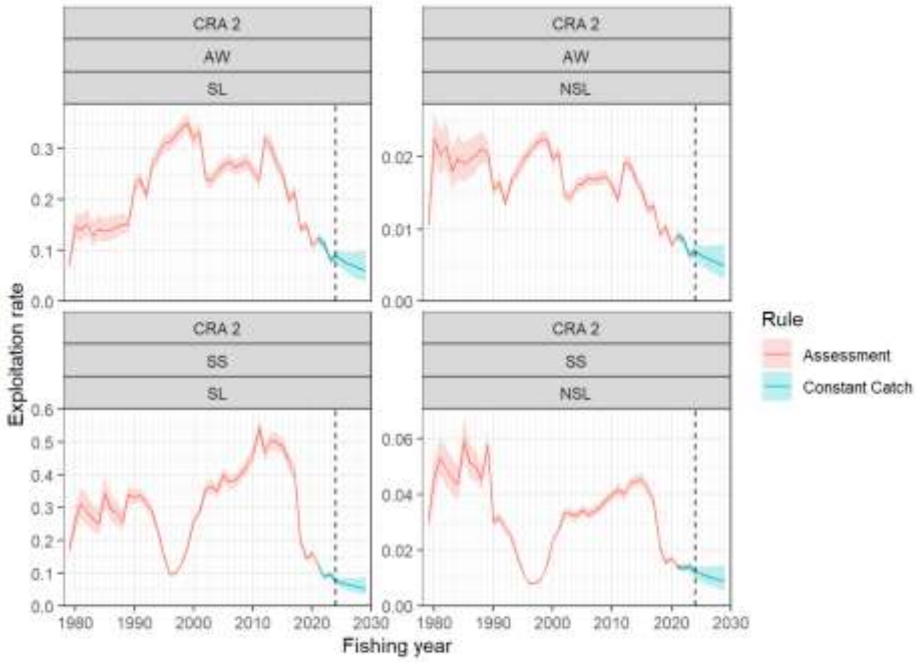

Figure 55: Posterior distribution of exploitation rate (U) by fishing year, season, and fishery (SL = size-limited, NSL = non-size-limited) for the base model run. The solid line indicates the median of the posterior and shading indicates the 90% credible interval. The dashed vertical line indicates the final year of stock reconstruction. Blue shading indicates years influenced by the rewritten last four years of recruitment by the ARIMA models, which only affects the five-year projection.

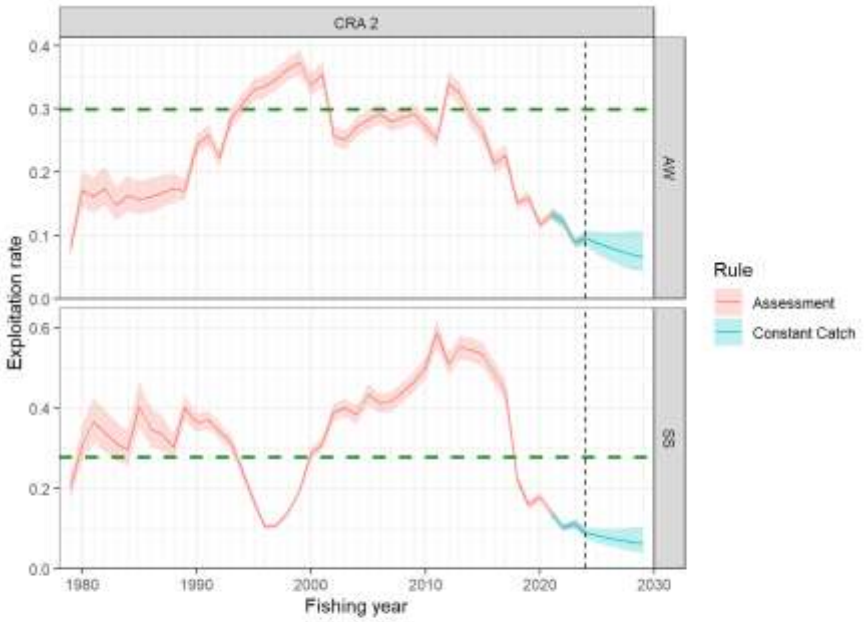

Figure 56: Posterior distribution of exploitation rate (U) by fishing year and season, combined across fisheries (SL + NSL). The solid line indicates the median of the posterior and shading indicates the 90% credible interval. The horizontal dashed green line shows the exploitation rate associated with the reference level by season. The vertical dashed black line indicates the final year of stock reconstruction. Blue shading indicates years influenced by the rewritten last four years of recruitment by the ARIMA models, which only affects the five-year projection.

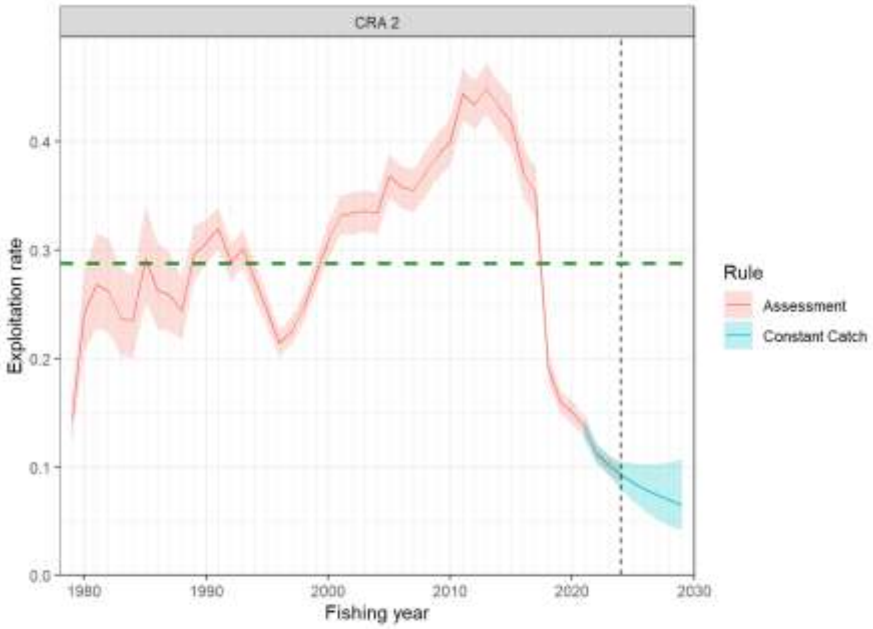

Figure 57: Approximate exploitation rate (*U*) by fishing year, calculated as a weighted average across seasons by the seasonal vulnerable biomass. The solid line indicates the median of the posterior and shading indicates the 90% credible interval. The horizontal dashed green line shows the approximated annual exploitation rate associated with the reference level based on the weighted average across seasons. The vertical dashed black line indicates the final year of stock reconstruction. Blue shading indicates years influenced by the rewritten last four years of recruitment by the ARIMA models, which only affects the five-year projection.

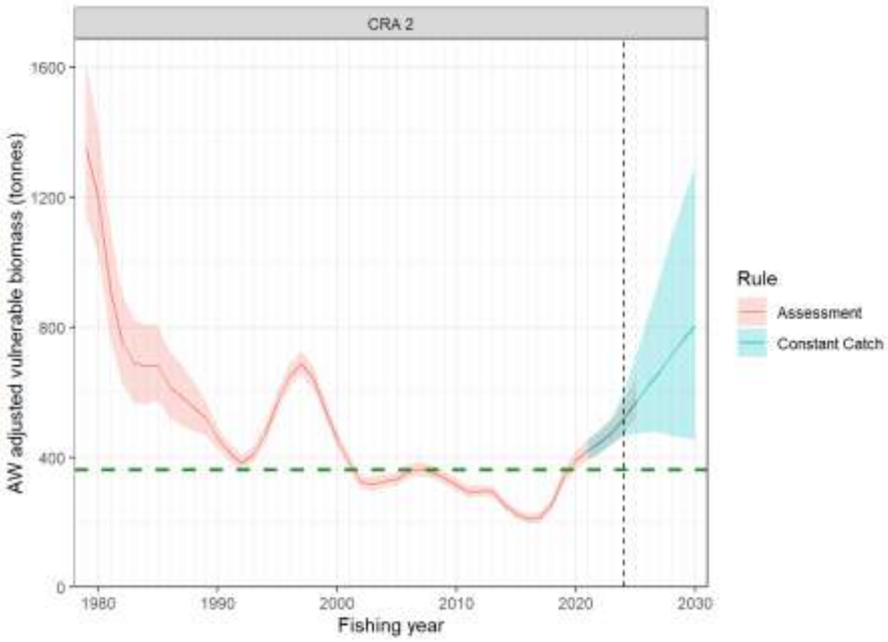

Figure 58: Projected vulnerable biomass. The green dashed horizontal line is the reference level. The dashed vertical line shows the final year of stock reconstruction. The final year from the assessment is the current stock status, calculated as the end of the final fishing year (start of the first projection year). The "Constant catch" series indicates projections which use recruitment that overwrites the last four years of the assessment.

The AW adjusted vulnerable biomass in CRA 2 declined steeply from the first model year 1979 through the early 1990s. There was an increase in vulnerable biomass driven by a recruitment pulse during the early to mid-1990s (Figure 54), followed by a steep decline in the late 1990s which levelled out to a slower decline from the mid-2000s through to 2017 (Figure 58). Lower catches (Figure 53) and better recruitment (Figure 54) are likely to have contributed to the increase in vulnerable biomass that began after 2017 (Figure 58; Figure 59). Median vulnerable biomass at the beginning of 2025 was 20% B_0 and 160% of B_R (90% credible interval: 144–179%; Table 13, Figures 58 and 59). There was a probability of 1.0 that B_{2025} was greater than B_R (Table 14). Vulnerable biomass was projected to continue to increase by 2030 to a median of 27% B_0 and 222% of B_R.

The overall SSB abundance trend was more influenced by recruitment than was the vulnerable-biomass trend, but the two followed similar patterns. There was a general decline from the first model year 1979, with a recruitment pulse in SSB in the early to mid-1990s. Since then, there has been an overall decline in spawning biomass until SSB began to increase again after 2016 (Figure 60; Figure 61). The pattern in total biomass was similar to that of spawning biomass (Figure 62; Figure 63). Median spawning stock biomass at the beginning of 2025 was 38% SSB_0 (90% credible interval: 33–44%; Table 13, Figure 61). There was a probability of 1 that SSB_{2025} was above the soft limit (Table 14). Spawning stock biomass was projected to continue to increase by 2030 to a median of 45% SSB_0.

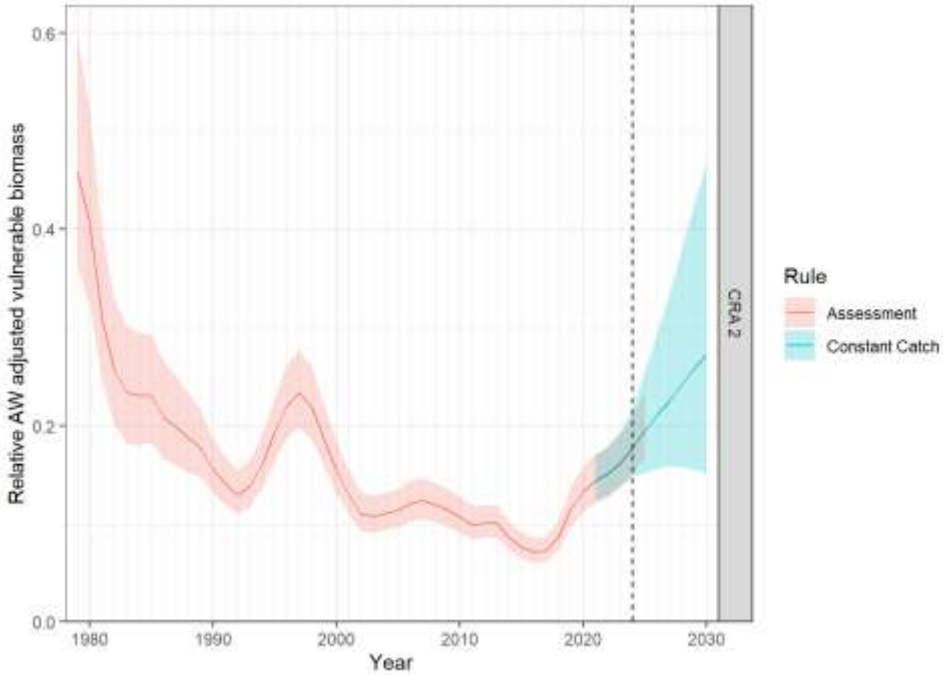

Figure 59: Projected relative vulnerable biomass (*B/B*0) by fishing year. The dashed vertical line shows the final year of stock reconstruction. The final year from the assessment is the current stock status, calculated at the end of the final fishing year (start of the first projection year). The "Constant catch" series indicates projections which use recruitment that overwrites the last four years of the assessment.

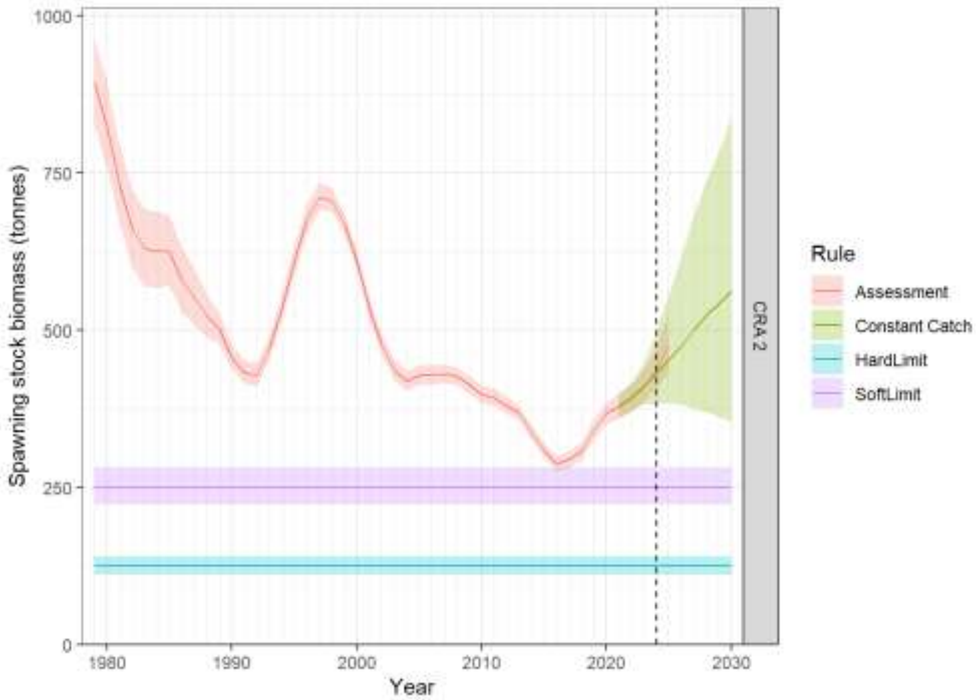

Figure 60: Projected spawning stock biomass (*SSB*) by fishing year. The dashed vertical line shows the final year of stock reconstruction. The final year from the assessment is the current stock status, calculated at the end of the final fishing year (start of the first projection year). Also plotted are the soft limit (0.2 SSB_0) and the hard limit (0.1 SSB_0). The "Constant catch" series indicates projections which use recruitment that overwrites the last four years of the assessment.

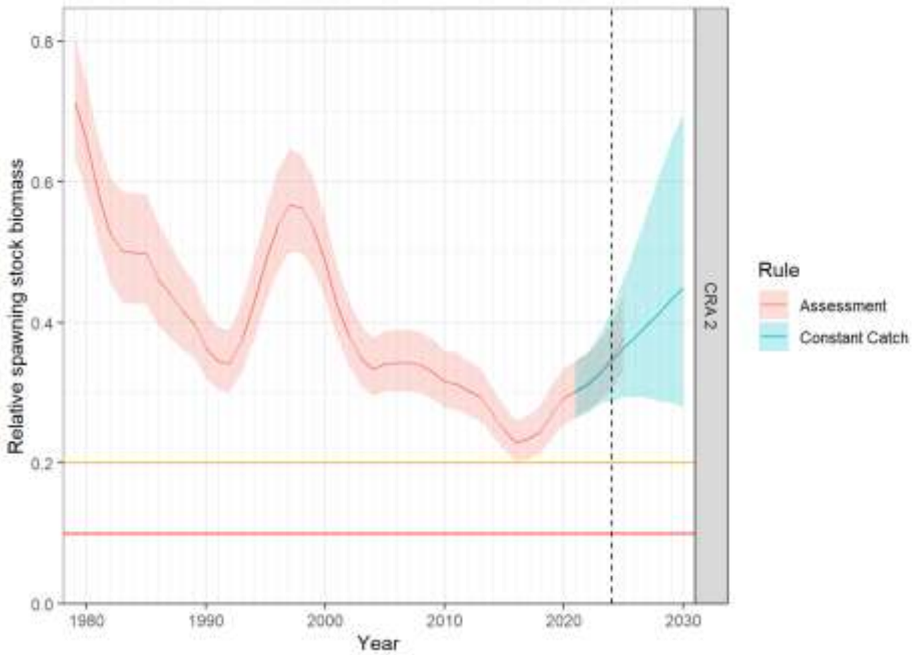

Figure 61: Projected relative (to SSB_0) spawning stock biomass (*SSB*) by fishing year showing the 90% credible interval. The dashed vertical line shows the final year of stock reconstruction. The final year from the assessment is the current stock status, calculated at the end of the final fishing year (start of the first projection year). Also plotted are the soft limit (0.2 SSB_0) and the hard limit (0.1 SSB_0). The "Constant catch" series indicates projections which use recruitment that overwrites the last four years of the assessment.

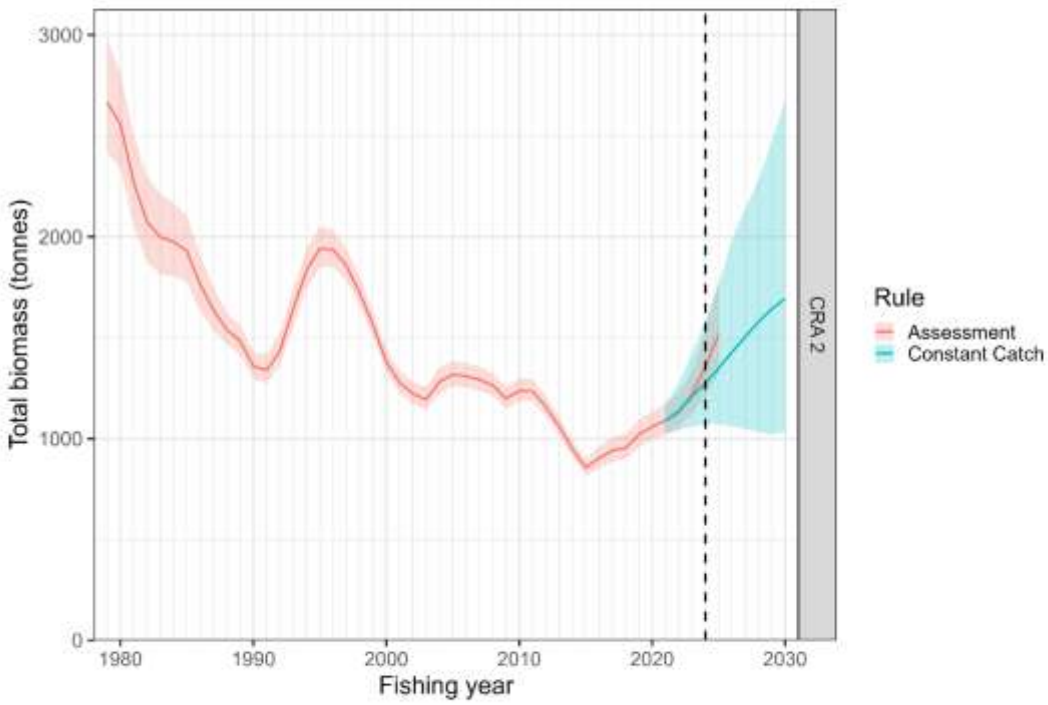

Figure 62: Projected total biomass. The dashed vertical line shows the beginning of the final year of stock reconstruction. The final year from the assessment is the current stock status, calculated at the end of the final reconstruction year (start of the first projection year). The "Constant catch" series indicates projections which use recruitment that overwrites the last four years of the assessment.

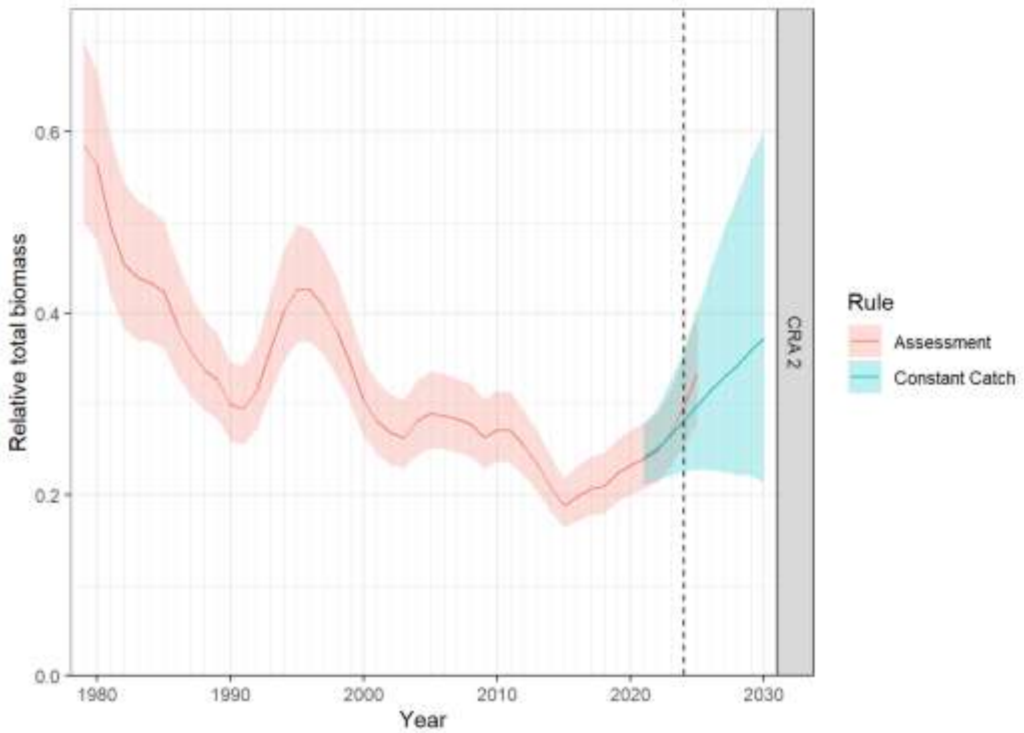

Figure 63: Projected relative (to T_0) total biomass (T) by fishing year. The dashed vertical line shows the beginning of the final reconstruction year. The final year from the assessment is the current stock status, calculated as the end of the final reconstruction year (start of the first projection year). The "Constant catch" series indicates projections which use recruitment that overwrites the last four years of the assessment.

The phase plot shows recent decreases in fishing intensity below U_R after 2019 with corresponding increases in B above B_R after 2020 (Figure 64). Stock status in 2025 is estimated to be entirely in the preferred lower right-hand quadrant, resulting in an evaluation that the stock is not undergoing overfishing and is not overfished (Figure 64).

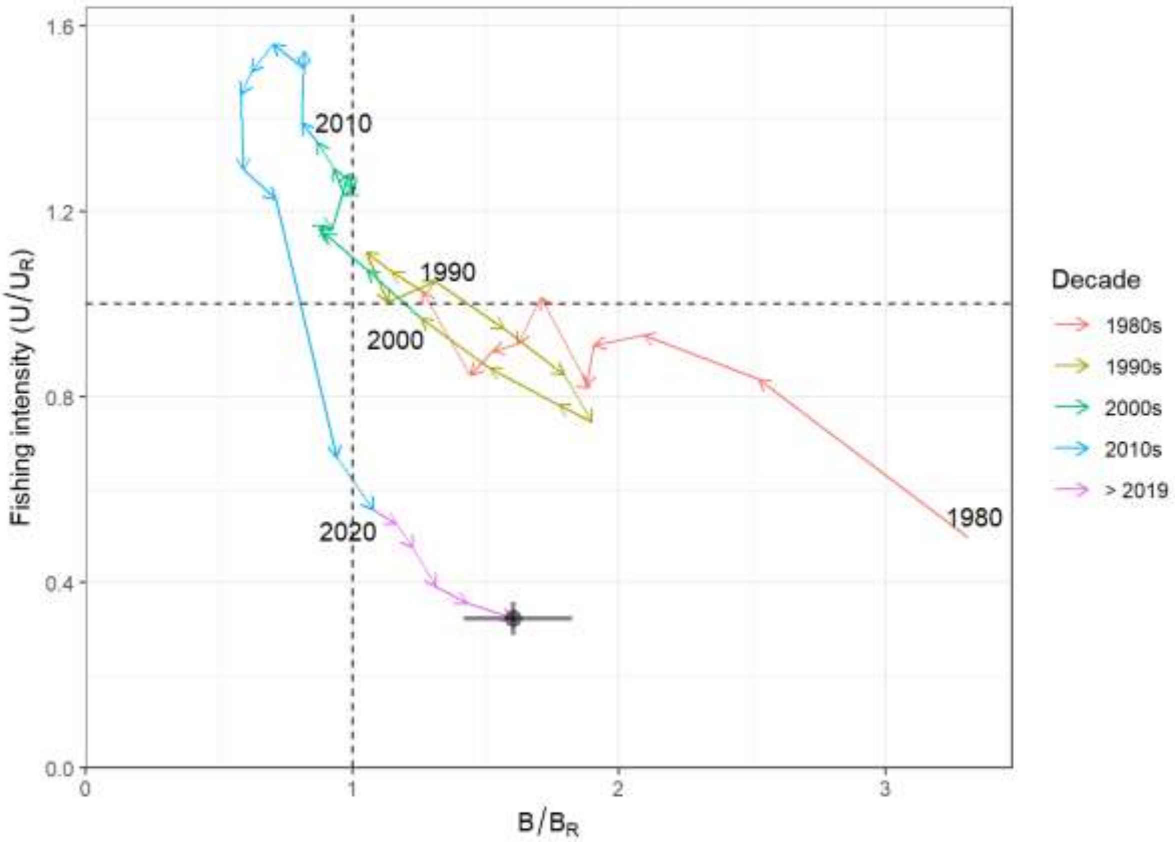

Figure 64: Phase plot showing stock status B relative to B_R (in terms of AW adjusted vulnerable biomass) and U relative to U_R (in terms of the weighted exploitation rate across seasons). Years for U were lagged to match the U from the previous year that led to the resulting start-of-year AW vulnerable biomass (B) (e.g. the final year shows B_{2025} on the x-axis and U_{2024} on the y-axis).

Table 13: Summary of the posterior distribution for the derived quantities for the base model. The mean, median, and 90% credible interval (i.e. 5% and 95%) are reported. Biomass values and handling mortality (H) are reported in tonnes.

Variable	Year	5%	Median	Mean	95%
B_0	–	2565.337	2937.512	2944.644	3354.774
B_R	–	361.414	361.414	361.414	361.414
B_R / B_0	–	0.108	0.123	0.124	0.141
B_{MIN}	–	195.178	209.532	209.745	224.866
SSB_0	–	1114.999	1254.751	1258.566	1408.892
T_0	–	4036.189	4550.783	4563.850	5111.431
U_R	–	0.288	0.288	0.288	0.288
B	2025	520.196	579.721	581.460	647.514
B	2030	453.690	804.076	835.264	1299.141
B / B_0	2025	0.168	0.197	0.199	0.235
B / B_0	2030	0.152	0.272	0.287	0.468
B / B_{MIN}	2025	2.458	2.769	2.776	3.135
B / B_{MIN}	2030	2.196	3.870	3.980	6.238

Variable	Year	5%	Median	Mean	95%
B / B_R	2025	1.439	1.604	1.609	1.792
B / B_R	2030	1.255	2.225	2.311	3.595
SSB	2025	434.235	477.372	479.507	529.521
SSB	2030	355.832	562.642	576.934	839.551
SSB / SSB_0	2025	0.331	0.380	0.383	0.441
SSB / SSB_0	2030	0.280	0.450	0.462	0.699
T	2025	1314.875	1517.730	1530.382	1802.022
T	2030	1033.865	1692.751	1752.663	2676.668
T / T_0	2025	0.278	0.334	0.337	0.409
T / T_0	2030	0.214	0.373	0.387	0.601
U	2024	0.084	0.093	0.093	0.101
U	2029	0.042	0.065	0.068	0.107
U / U_R	2024	0.292	0.322	0.322	0.352
U / U_R	2029	0.145	0.226	0.238	0.373
H	2024	1.190	1.279	1.279	1.371
H	2029	0.855	1.004	1.012	1.201

Table 14: Probabilities based on the posterior distributions of derived quantities for the base model.

Variable	Probability
$P(SSB_{2025} < 20\% \ SSB_0)$	0.000
$P(SSB_{2025} < 10\% \ SSB_0)$	0.000
$P(SSB_{2030} < 20\% \ SSB_0)$	0.006
$P(SSB_{2030} < 10\% \ SSB_0)$	0.000
$P(SSB_{2030} > SSB_{2025})$	0.740
$P(B_{2030} > B_{2025})$	0.842
$P(B_{2025} > B_R)$	1.000
$P(B_{2030} > B_R)$	0.983
$P(B_{2025} > B_{MIN})$	1.000
$P(B_{2030} > B_{MIN})$	0.998
$P(U_{2029} > U_{2024})$	0.115
$P(U_{2024} > U_R)$	0.000
$P(U_{2029} > U_R)$	0.000
$P(T_{2030} > T_{2025})$	0.649

3.6 Model sensitivity trials

Sensitivity trials were used to test some of the base case model assumptions. The RLWG decided on five sensitivity trials as single variants relative to the base case:

1. *no_pow*: no CPUE power parameter, fix the CPUE power parameter to 1.0 (consistent with previous CRA 2 stock assessments);
2. *Mlow*: fix the *Ma* parameter to 0.16, the *Ma* value associated with the minimum in the sex ratio likelihood profile on *Ma* (Figure 46);
3. *Mhigh*: fix the *Ma* parameter to 0.25, the *Ma* value associated with the minimum in the CPUE likelihood profile on *Ma* (Figure 46);

4. *start_1945*: equilibrium start for the CRA 2 stock assessment in 1945, requiring the use of historical catches before 1979 and fixing the U_0 parameter to 0.0; this model run included the CR CPUE series;
5. *logbook_q*: estimate separate *q* parameters for the logbook CPUE series, a) prior to 2018 and b) from 2018 to 2025. This sensitivity trial was made to test for potential change in logbook reporting resulting from the 2018 TACC reduction.

Results from the base case and sensitivity trials are compared in Table 15, Table 16 and Figure 65 through to Figure 80.

No CPUE power parameters: Fixing the CPUE power parameters at 1.0 (*no_pow*) resulted in estimates for the primary derived parameters (equilibrium vulnerable biomass B_0, equilibrium spawning biomass SSB_0, current vulnerable biomass B_{2025}, and current spawning biomass SSB_{2025}) being nearly the same as for the base case run (Tables 15 and 16), indicating that, while estimating the additional power parameter greatly improved the fit to the CPUE series (Figure 65), there was little impact in terms of the management advice because the stock status conclusions were the same as for the base case.

Start model in 1945: Both B_0 and SSB_0 were estimated to be smaller when starting the model in 1945 than for the base case. However, estimates of stock size in 2025 were similar to those made by the base case run. This resulted in stock status estimates (B_{2025}/B_0 and SSB_{2025}/SSB_0) that were somewhat higher than for the base run (median B_{2025}/B_0 = 0.216 for *start_1945* compared with 0.197 for the base run; median SSB_{2025}/SSB_0 = 0.41 for *start_1945* compared with 0.38 for the base run).

fix M lower: The sensitivity run fixing *Ma* to 0.16 resulted in a better fit to the SS sex ratios in the late 1990s to which the base model did not fit well, but arguably a worse fit to the other sex ratio values (Figure 69). Both B_0 and SSB_0 were larger in size compared to the base run while current (2025) stock size was similar to the base run; consequently, the ratio of B_{2025}/B_0 was lower (median = 0.158) for this sensitivity run than for the base run (median = 0.197). The same relationship was true for the spawning biomass, resulting in an SSB_{2025}/SSB_0 ratio that was lower for this sensitivity run (median = 0.322) than for the base run (median = 0.38). A lower *M* resulted in a more pessimistic stock assessment, but this model was not as well supported by the data when compared with the base run or the fix *M* higher run. Based on recommendation from the Plenary review, a five-year projection with constant catch was run for the *Mlow* model (see methods from Section 3.5.4) which resulted in a relatively similar relative vulnerable biomass in 2030, and similar probability of falling below the soft limit in 2030.

fix M higher: when *Ma* was fixed to 0.25, both B_0 and SSB_0 were smaller in size compared to the base run while current (2025) stock size was again similar to the base run. Consequently, the ratio of B_{2025}/B_0 was higher (median = 0.244) for this sensitivity trial than for the base run (median = 0.197). The same relationship was again true for the spawning biomass, resulting in an SSB_{2025}/SSB_0 ratio that was higher for this sensitivity trial (median = 0.434) than for the base run (median = 0.38). A higher *M* resulted in a more optimistic stock assessment, which appeared to fit the data as well as the base run.

Separate logbook q parameters before and after 2018: Estimating separate *q* parameters for the logbook series, split in 2018, led to a better fit to the AW logbook series from 2018–2022, but ignored the lower point in 2023 as did the other series (Figure 66; Figure 67; Figure 68). Similarly, the predicted fit to the SS logbook series from 2018 onwards was somewhat higher than the other models over those years. For the *logbook_q* model, the CPUE power parameter for the logbook series was estimated very close to 1.0, thus missing the peaks in the logbook series prior to 2000 which were better fit by the other runs. This sensitivity run resulted in the lowest B_{2025} among all the runs, and with B_0 very close to the base run value. Therefore B_{2025}/B_0 was lower (median = 0.170) compared with the base run (median = 0.197). The same pattern was true for *SSB*, resulting in a SSB_{2025}/SSB_0 ratio that was lower for this sensitivity trial (median = 0.345) than for the base run (median = 0.38). However, this difference was not enough to change the categorisation of stock status nor did this sensitivity trial provide fits to the LB CPUE series that were notably better than for the base run.

All sensitivity trials had zero probability of being below the soft and hard limit or falling below B_{MIN} (Table 17).

Table 15: Base case and sensitivity trials reporting the median and 90% credible intervals of the posterior distribution for each parameter (excluding catchability coefficients).

Parameter	Number	Model	5%	Median	Mean	95%
Ma	1	*base*	0.185	0.203	0.203	0.223
Ma	1	*no_pow*	0.182	0.203	0.203	0.227
Ma	1	*start_1945*	0.197	0.214	0.215	0.234
Ma	1	*logbook_q*	0.182	0.201	0.201	0.220
R0	1	*base*	585018	678114	681552	791021
R0	1	*no_pow*	574870	675631	680154	800175
R0	1	*Mlow*	475077	525283	525993	577810
R0	1	*Mhigh*	812105	894905	895712	982034
R0	1	*start_1945*	601978	689773	694777	804937
R0	1	*logbook_q*	567350	660500	663665	767222
U0	1	*base*	0.041	0.066	0.067	0.093
U0	1	*no_pow*	0.029	0.054	0.054	0.080
U0	1	*Mlow*	0.059	0.081	0.081	0.107
U0	1	*Mhigh*	0.023	0.044	0.045	0.072
U0	1	*logbook_q*	0.042	0.065	0.066	0.095
gcv	1	*base*	0.433	0.458	0.458	0.484
gcv	1	*no_pow*	0.436	0.459	0.459	0.484
gcv	1	*Mlow*	0.428	0.454	0.454	0.481
gcv	1	*Mhigh*	0.434	0.459	0.459	0.485
gcv	1	*start_1945*	0.429	0.455	0.455	0.481
gcv	1	*logbook_q*	0.434	0.460	0.460	0.486
gcv	2	*base*	0.704	0.744	0.745	0.787
gcv	2	*no_pow*	0.711	0.752	0.752	0.795
gcv	2	*Mlow*	0.700	0.739	0.739	0.779
gcv	2	*Mhigh*	0.715	0.756	0.756	0.798
gcv	2	*start_1945*	0.703	0.744	0.744	0.785
gcv	2	*logbook_q*	0.709	0.749	0.749	0.792
gdiff	1	*base*	0.184	0.197	0.198	0.213
gdiff	1	*no_pow*	0.183	0.196	0.196	0.210
gdiff	1	*Mlow*	0.184	0.196	0.197	0.210
gdiff	1	*Mhigh*	0.182	0.195	0.195	0.209
gdiff	1	*start_1945*	0.183	0.196	0.196	0.211
gdiff	1	*logbook_q*	0.186	0.200	0.200	0.214
gdiff	2	*base*	0.079	0.084	0.084	0.090
gdiff	2	*no_pow*	0.077	0.082	0.082	0.088
gdiff	2	*Mlow*	0.078	0.083	0.083	0.088
gdiff	2	*Mhigh*	0.081	0.086	0.086	0.091
gdiff	2	*start_1945*	0.080	0.085	0.085	0.090

Parameter	Number	Model	5%	Median	Mean	95%
gdiff	2	*logbook_q*	0.079	0.084	0.084	0.089
gobs	1	*base*	1.325	1.419	1.421	1.522
gobs	1	*no_pow*	1.316	1.408	1.409	1.505
gobs	1	*Mlow*	1.351	1.444	1.445	1.548
gobs	1	*Mhigh*	1.301	1.398	1.398	1.495
gobs	1	*start_1945*	1.321	1.418	1.419	1.522
gobs	1	*logbook_q*	1.323	1.415	1.415	1.511
gshape	1	*base*	2.122	2.251	2.253	2.390
gshape	1	*no_pow*	2.106	2.232	2.233	2.371
gshape	1	*Mlow*	2.083	2.208	2.211	2.349
gshape	1	*Mhigh*	2.140	2.262	2.263	2.394
gshape	1	*start_1945*	2.094	2.230	2.233	2.371
gshape	1	*logbook_q*	2.110	2.247	2.246	2.386
gshape	2	*base*	3.985	4.105	4.107	4.230
gshape	2	*no_pow*	3.952	4.078	4.078	4.205
gshape	2	*Mlow*	4.068	4.184	4.184	4.303
gshape	2	*Mhigh*	3.914	4.029	4.030	4.152
gshape	2	*start_1945*	3.977	4.093	4.095	4.217
gshape	2	*logbook_q*	3.992	4.111	4.111	4.233
pow	1	*base*	1.489	1.586	1.589	1.693
pow	1	*Mlow*	1.356	1.505	1.506	1.662
pow	1	*Mhigh*	1.480	1.582	1.583	1.691
pow	1	*start_1945*	1.490	1.584	1.584	1.685
pow	1	*logbook_q*	1.406	1.490	1.492	1.584
pow	2	*base*	1.161	1.282	1.283	1.412
pow	2	*Mlow*	1.028	1.193	1.191	1.356
pow	2	*Mhigh*	1.184	1.299	1.301	1.426
pow	2	*start_1945*	1.167	1.294	1.294	1.422
pow	2	*logbook_q*	0.973	1.063	1.062	1.152
sel50	1	*base*	51.331	51.488	51.489	51.641
sel50	1	*no_pow*	51.349	51.508	51.508	51.668
sel50	1	*Mlow*	51.220	51.381	51.380	51.536
sel50	1	*Mhigh*	51.433	51.583	51.585	51.747
sel50	1	*start_1945*	51.352	51.513	51.516	51.687
sel50	1	*logbook_q*	51.357	51.504	51.505	51.661
sel50	2	*base*	56.105	56.416	56.419	56.746
sel50	2	*no_pow*	56.066	56.414	56.412	56.754
sel50	2	*Mlow*	55.994	56.299	56.300	56.605
sel50	2	*Mhigh*	56.292	56.599	56.603	56.910
sel50	2	*start_1945*	56.143	56.451	56.455	56.784
sel50	2	*logbook_q*	56.069	56.385	56.382	56.714
sel95	1	*base*	4.492	4.701	4.700	4.903
sel95	1	*no_pow*	4.507	4.718	4.718	4.935
sel95	1	*Mlow*	4.492	4.702	4.705	4.926

Parameter	Number	Model	5%	Median	Mean	95%
sel95	1	*Mhigh*	4.495	4.690	4.693	4.894
sel95	1	*start_1945*	4.500	4.696	4.702	4.917
sel95	1	*logbook_q*	4.527	4.717	4.719	4.921
sel95	2	*base*	6.564	6.942	6.954	7.369
sel95	2	*no_pow*	6.522	6.949	6.957	7.413
sel95	2	*Mlow*	6.617	7.005	7.017	7.447
sel95	2	*Mhigh*	6.564	6.922	6.925	7.303
sel95	2	*start_1945*	6.560	6.942	6.939	7.323
sel95	2	*logbook_q*	6.552	6.942	6.946	7.346
selmax	1	*base*	0.526	0.567	0.567	0.610
selmax	1	*no_pow*	0.523	0.563	0.564	0.610
selmax	1	*Mlow*	0.514	0.550	0.552	0.590
selmax	1	*Mhigh*	0.554	0.596	0.596	0.639
selmax	1	*start_1945*	0.529	0.568	0.570	0.614
selmax	1	*logbook_q*	0.514	0.554	0.555	0.598
selmax	2	*base*	0.759	0.782	0.782	0.806
selmax	2	*no_pow*	0.799	0.840	0.841	0.885
selmax	2	*Mlow*	0.735	0.771	0.772	0.810
selmax	2	*Mhigh*	0.778	0.799	0.800	0.824
selmax	2	*start_1945*	0.769	0.790	0.790	0.812
selmax	2	*logbook_q*	0.768	0.793	0.793	0.818
selmax	3	*base*	0.652	0.692	0.693	0.736
selmax	3	*no_pow*	0.692	0.750	0.750	0.811
selmax	3	*Mlow*	0.632	0.677	0.679	0.729
selmax	3	*Mhigh*	0.691	0.733	0.733	0.776
selmax	3	*start_1945*	0.654	0.697	0.697	0.740
selmax	3	*logbook_q*	0.652	0.695	0.696	0.740

Table 16: Base case and sensitivity run MCMC derived quantities, reporting the median and 90% credible intervals of the posterior distribution. Biomass values in tonnes, *H* (handling mortality) in tonnes, *U* is an exploitation rate bounded between 0 and 1.

Variable	Model	5%	Median	95%
B	*base*	520.196	579.721	647.514
B	*no_pow*	500.961	585.534	679.679
B	*Mlow*	514.700	600.488	702.272
B	*Mhigh*	522.495	578.655	642.970
B	*start_1945*	512.482	571.215	636.931
B	*logbook_q*	414.352	496.507	597.246
B / B_0	*base*	0.168	0.197	0.235
B / B_0	*no_pow*	0.163	0.200	0.247
B / B_0	*Mlow*	0.133	0.158	0.188
B / B_0	*Mhigh*	0.215	0.244	0.280
B / B_0	*start_1945*	0.186	0.216	0.252
B / B_0	*logbook_q*	0.134	0.170	0.209

Variable	Model	5%	Median	95%
B / B_{MIN}	*base*	2.458	2.769	3.135
B / B_{MIN}	*no_pow*	2.587	3.019	3.526
B / B_{MIN}	*Mlow*	2.721	3.171	3.694
B / B_{MIN}	*Mhigh*	2.254	2.505	2.790
B / B_{MIN}	*start_1945*	2.370	2.674	3.021
B / B_{MIN}	*logbook_q*	2.071	2.478	2.993
B_0	*base*	2565.337	2937.512	3354.774
B_0	*no_pow*	2518.062	2915.767	3398.690
B_0	*Mlow*	3417.945	3790.108	4178.370
B_0	*Mhigh*	2151.853	2370.421	2603.133
B_0	*start_1945*	2349.991	2638.188	2966.171
B_0	*logbook_q*	2558.571	2939.969	3420.678
SSB	*base*	434.235	477.372	529.521
SSB	*no_pow*	425.184	482.826	547.515
SSB	*Mlow*	441.695	496.561	563.357
SSB	*Mhigh*	426.040	471.319	523.552
SSB	*start_1945*	425.731	469.890	521.716
SSB	*logbook_q*	373.776	430.391	497.946
SSB / SSB_0	*base*	0.331	0.380	0.441
SSB / SSB_0	*no_pow*	0.329	0.385	0.457
SSB / SSB_0	*Mlow*	0.279	0.322	0.372
SSB / SSB_0	*Mhigh*	0.382	0.434	0.495
SSB / SSB_0	*start_1945*	0.361	0.410	0.470
SSB / SSB_0	*logbook_q*	0.287	0.345	0.406
SSB_0	*base*	1114.999	1254.751	1408.892
SSB_0	*no_pow*	1100.210	1249.100	1422.477
SSB_0	*Mlow*	1391.187	1539.979	1700.753
SSB_0	*Mhigh*	983.815	1087.301	1192.898
SSB_0	*start_1945*	1038.812	1146.072	1267.646
SSB_0	*logbook_q*	1106.713	1250.379	1427.892
T	*base*	1314.875	1517.730	1802.022
T	*no_pow*	1294.387	1529.884	1836.317
T	*Mlow*	1279.326	1500.681	1785.284
T	*Mhigh*	1340.194	1582.705	1897.466
T	*start_1945*	1282.855	1503.148	1802.756
T	*logbook_q*	1112.676	1358.139	1679.417
T / T_0	*base*	0.278	0.334	0.409
T / T_0	*no_pow*	0.275	0.337	0.420
T / T_0	*Mlow*	0.227	0.270	0.326
T / T_0	*Mhigh*	0.336	0.402	0.485
T / T_0	*start_1945*	0.303	0.362	0.441
T / T_0	*logbook_q*	0.238	0.299	0.376
T_0	*base*	4036.189	4550.783	5111.431
T_0	*no_pow*	3990.065	4528.925	5145.956

Variable	Model	5%	Median	95%
T_0	*Mlow*	5024.851	5566.853	6135.056
T_0	*Mhigh*	3578.206	3943.751	4321.114
T_0	*start_1945*	3778.369	4160.879	4595.556
T_0	*logbook_q*	4025.968	4542.483	5180.093
U	*base*	0.084	0.093	0.101
U	*no_pow*	0.077	0.088	0.101
U	*Mlow*	0.079	0.091	0.105
U	*Mhigh*	0.083	0.091	0.099
U	*start_1945*	0.085	0.093	0.102
U	*logbook_q*	0.090	0.106	0.124
H	*base*	1.190	1.279	1.371
H	*no_pow*	1.199	1.285	1.376
H	*Mlow*	1.191	1.273	1.367
H	*Mhigh*	1.202	1.292	1.396
H	*start_1945*	1.188	1.274	1.370
H	*logbook_q*	1.214	1.306	1.412

Table 17: Probabilities calculated from the MCMC posteriors for the indicated derived quantities.

Variable	*base*	*no_pow*	*Mlow*	*Mhigh*	*start_1945*	*logbook_q*
$P(SSB_{2025} < 20\% \ SSB_0)$	0.000	0.000	0.000	0.000	0.000	0.000
$P(SSB_{2025} < 10\% \ SSB_0)$	0.000	0.000	0.000	0.000	0.000	0.000
$P(B_{2025} > B_{MIN})$	1.000	1.000	1.000	1.000	1.000	1.000

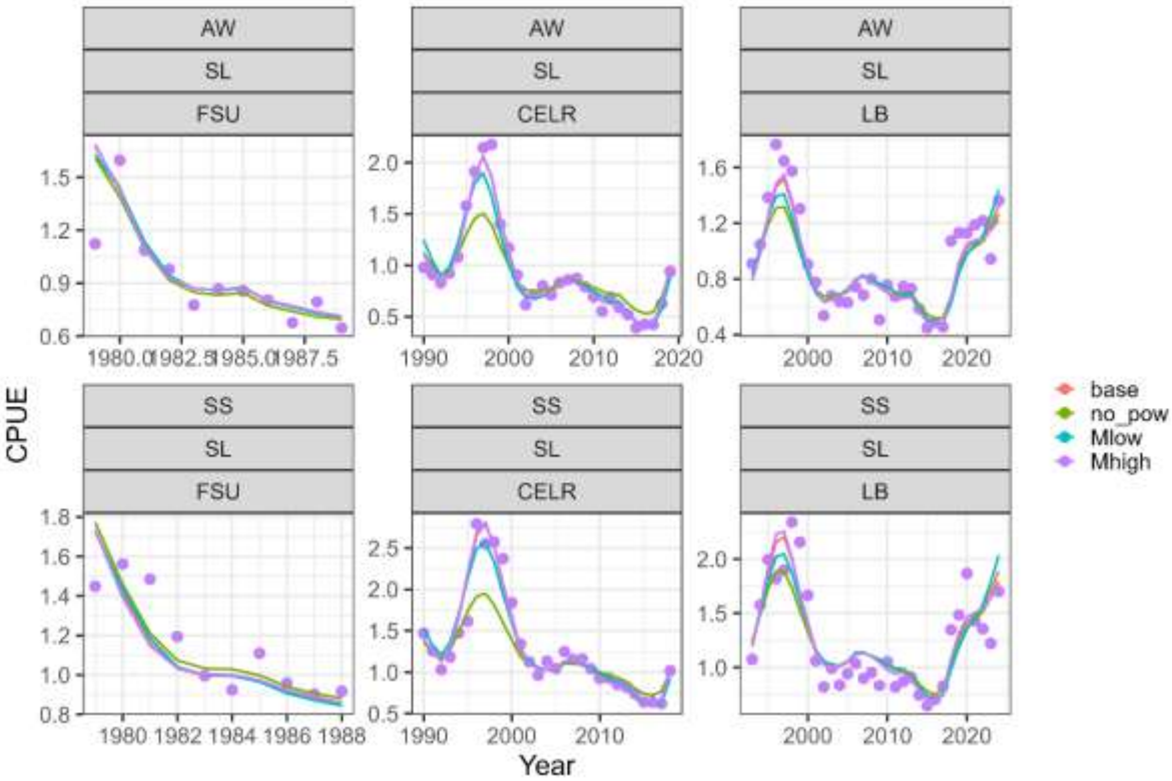

Figure 65: Comparison of CPUE fits for model sensitivity trials *no_pow*, *Mlow*, and *Mhigh*.

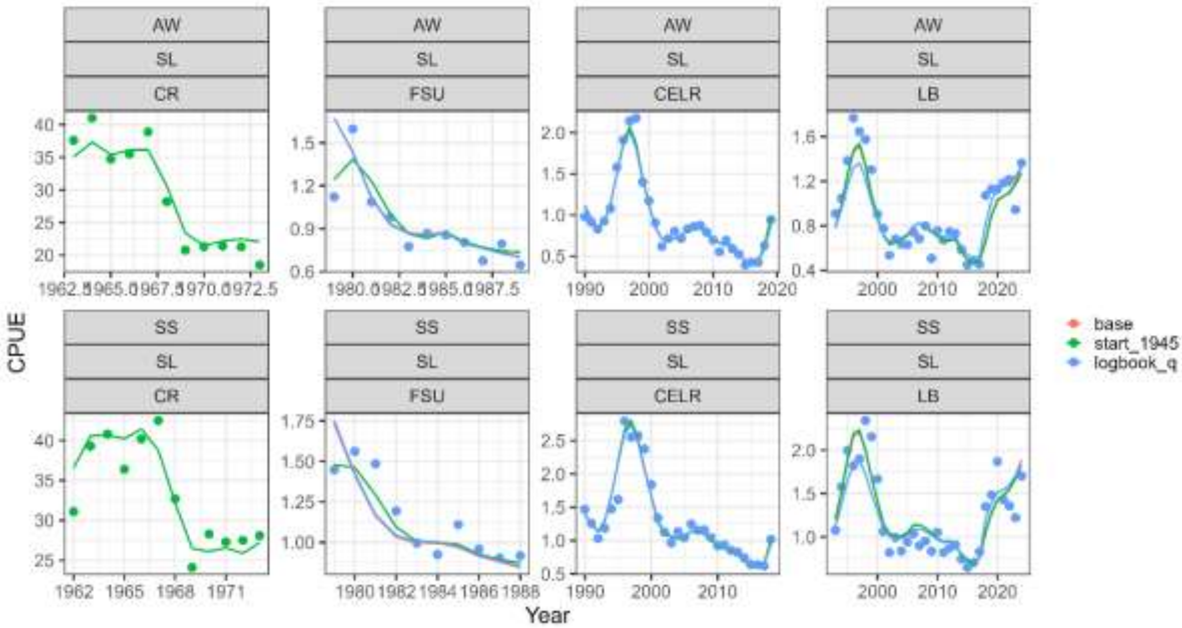

Figure 66: Comparison of CPUE fits for model sensitivity trials *start_1945* and *logbook_q*.

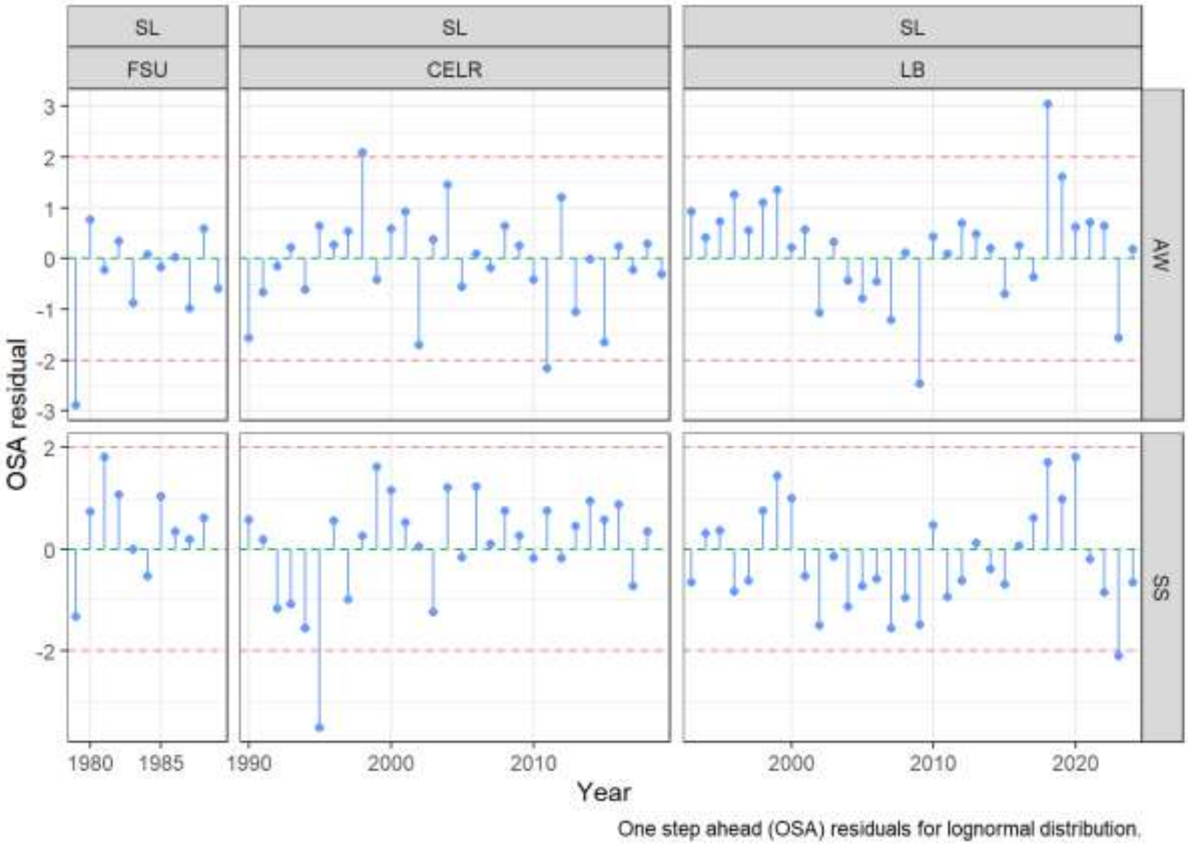

Figure 67: CPUE one-step-ahead (OSA) residuals for the base case.

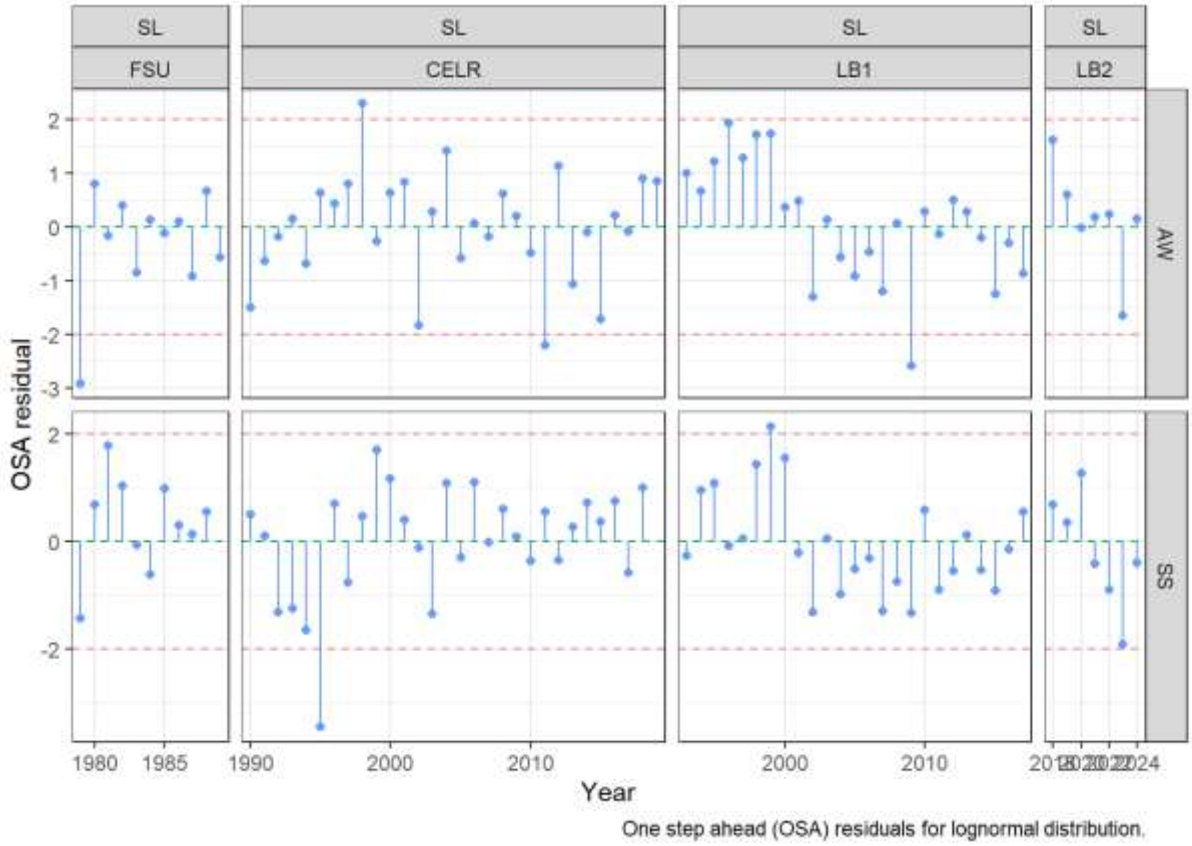

Figure 68: CPUE one-step-ahead (OSA) residuals for the *logbook_q* sensitivity trial.

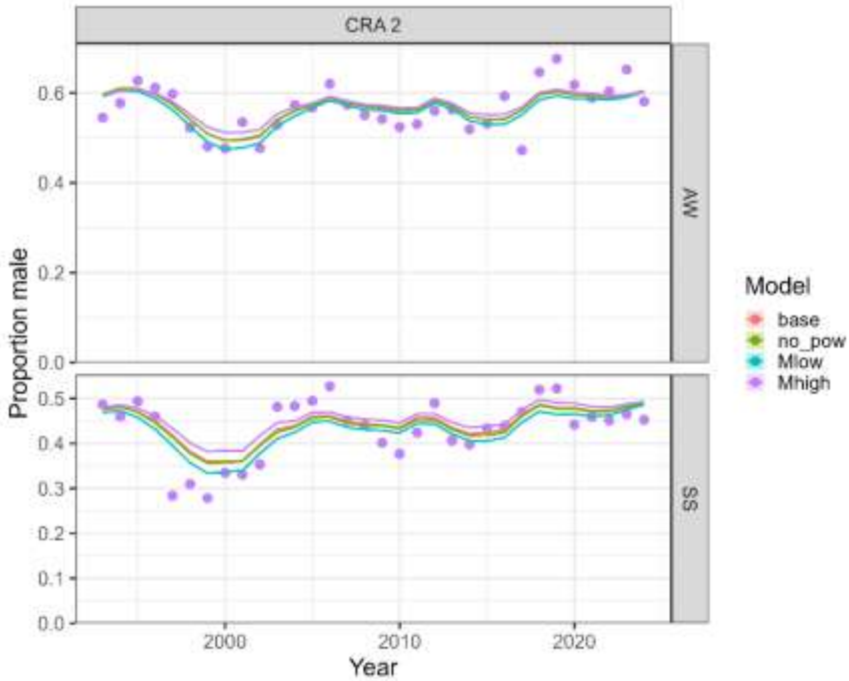

Figure 69: Comparison of sex ratio fits for model sensitivity trials *no_pow*, *Mlow*, and *Mhigh*.

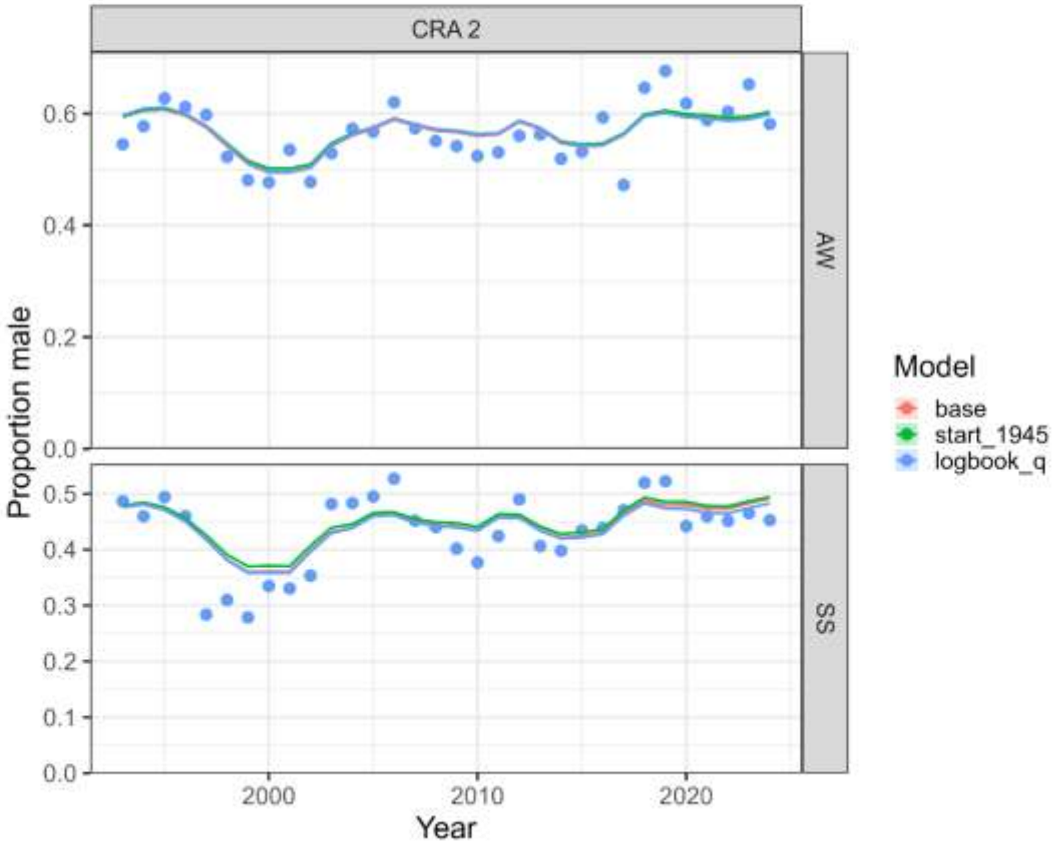

Figure 70: Comparison of sex ratio fits for model sensitivity trials *start_1945* and *logbook_q*.

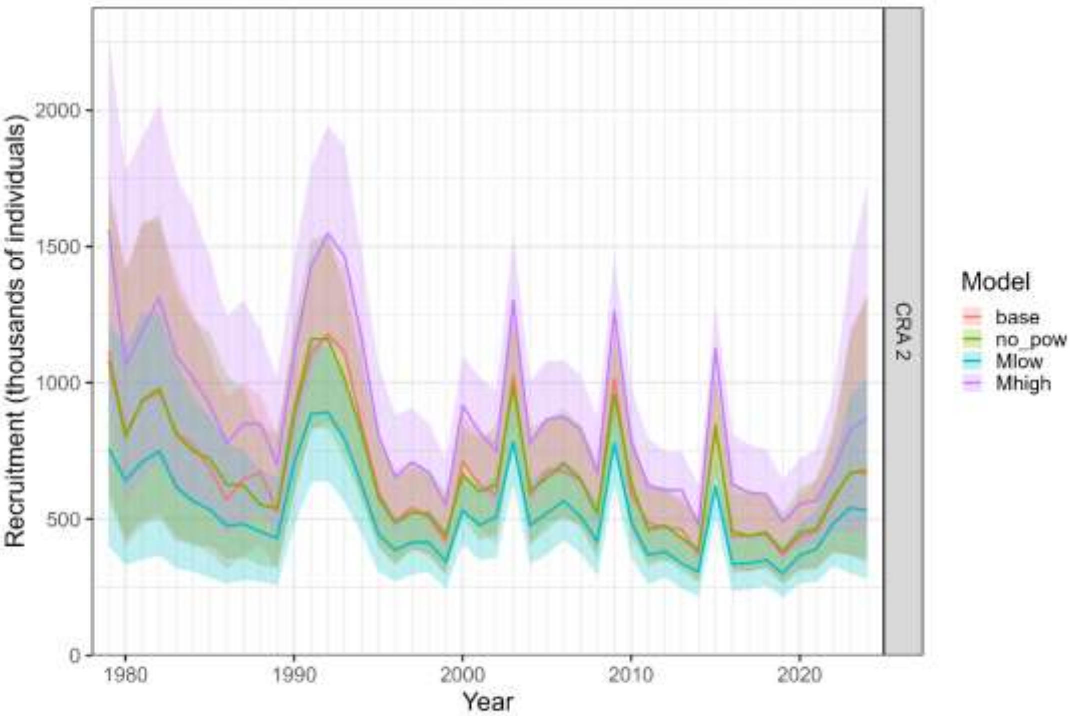

Figure 71: Comparison of recruitment by fishing year for model sensitivity trials *no_pow*, *Mlow*, and *Mhigh*.

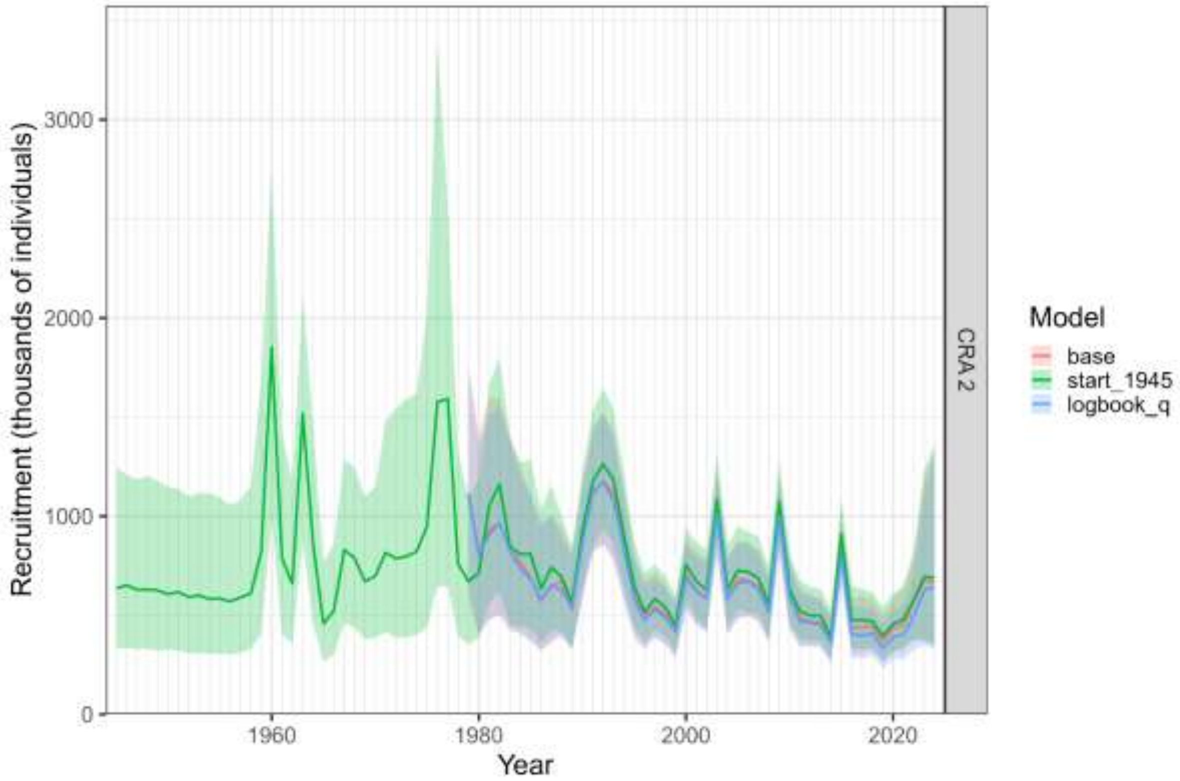

Figure 72: Comparison of recruitment by fishing year for model sensitivity trials *start_1945* and *logbook_q*.

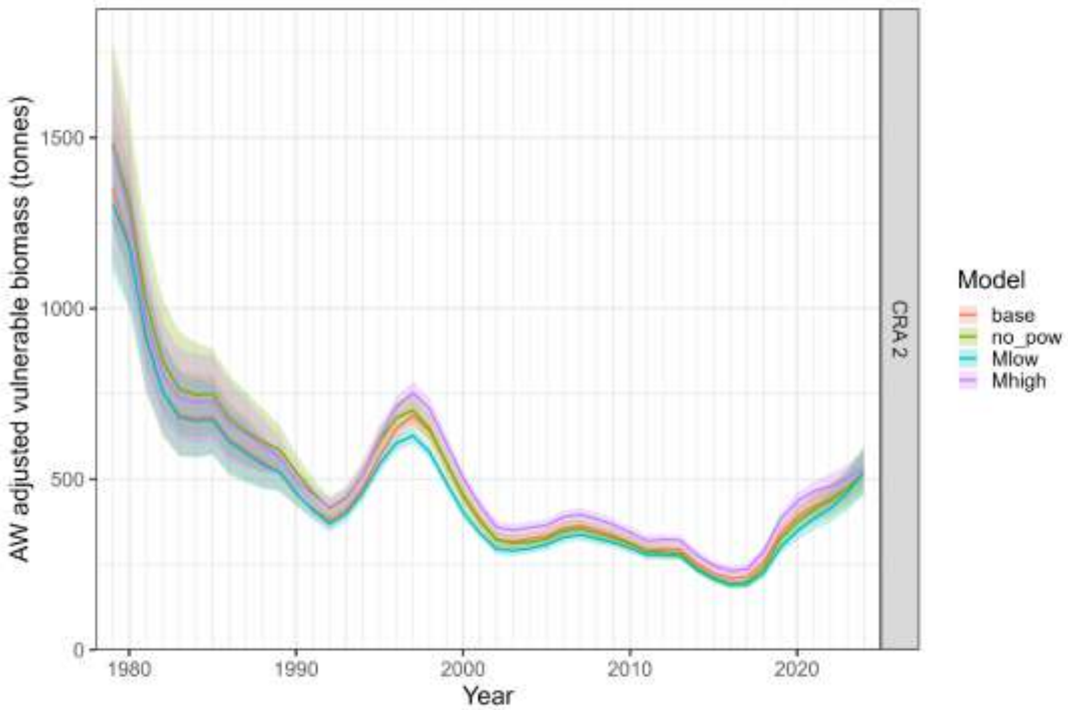

Figure 73: Comparison of AW adjusted vulnerable biomass by fishing year for model sensitivity trials *no_pow*, *Mlow*, and *Mhigh*.

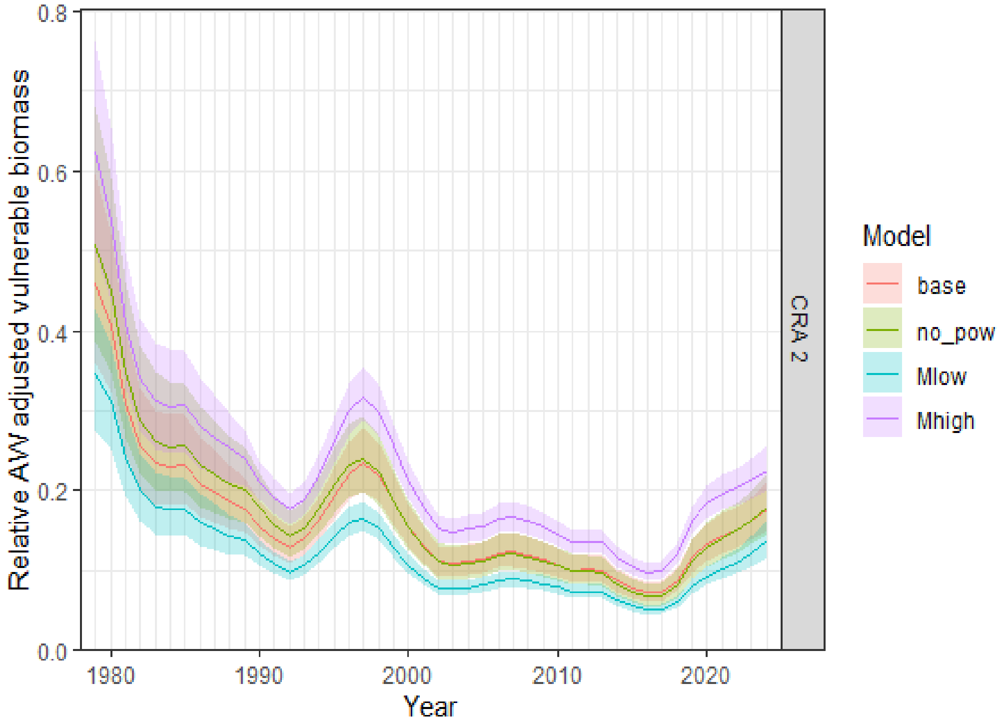

Figure 74: Comparison of relative AW adjusted vulnerable biomass by fishing year for model sensitivity trials *no_pow*, *Mlow*, and *Mhigh*.

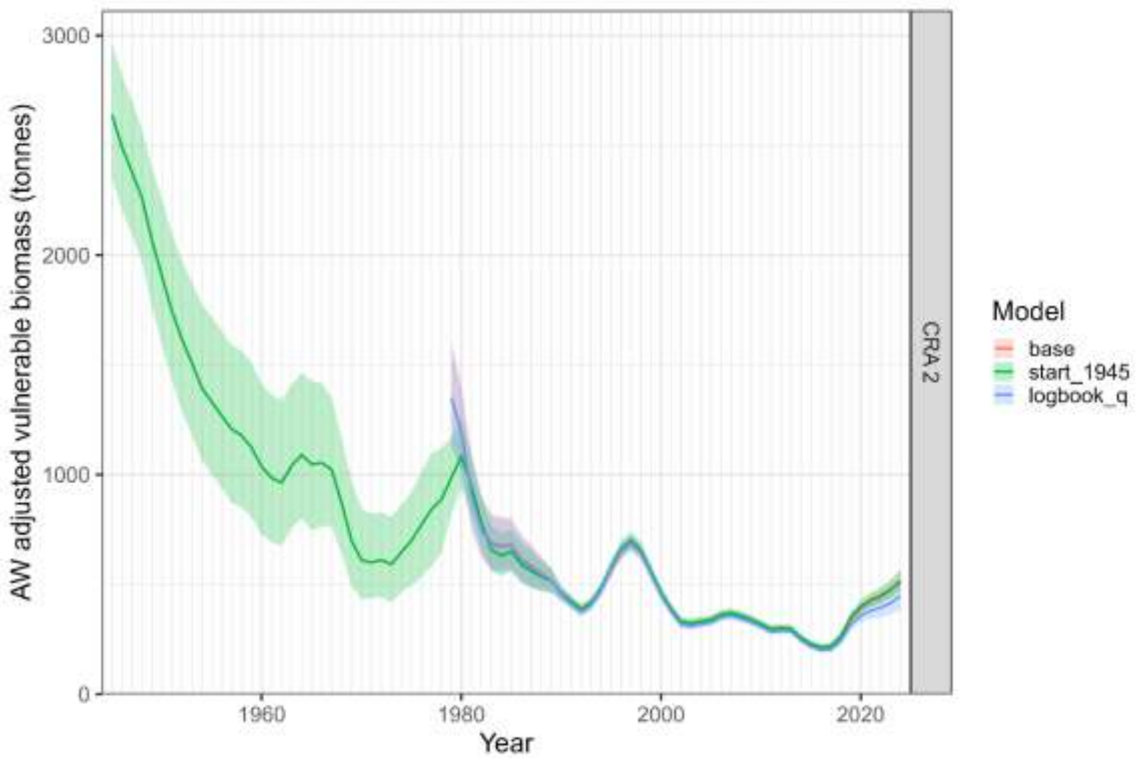

Figure 75: Comparison of AW adjusted vulnerable biomass by fishing year for model sensitivity trials *start_1945* and *logbook_q*.

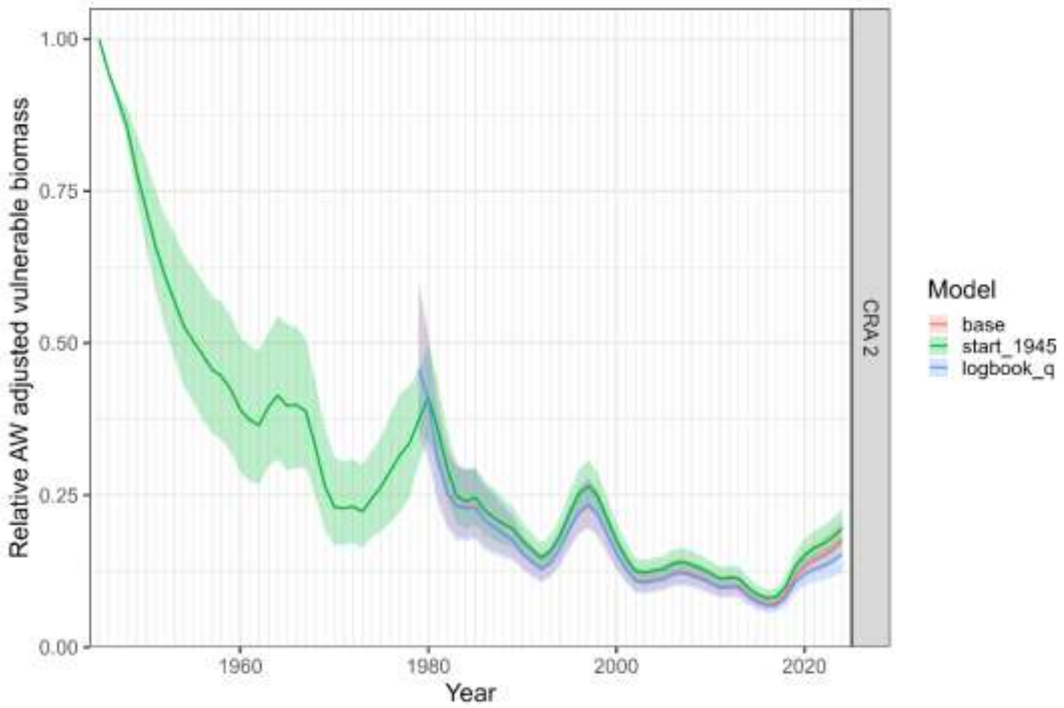

Figure 76: Comparison of relative AW adjusted vulnerable biomass by fishing year for model sensitivity trials *start_1945* and *logbook_q*.

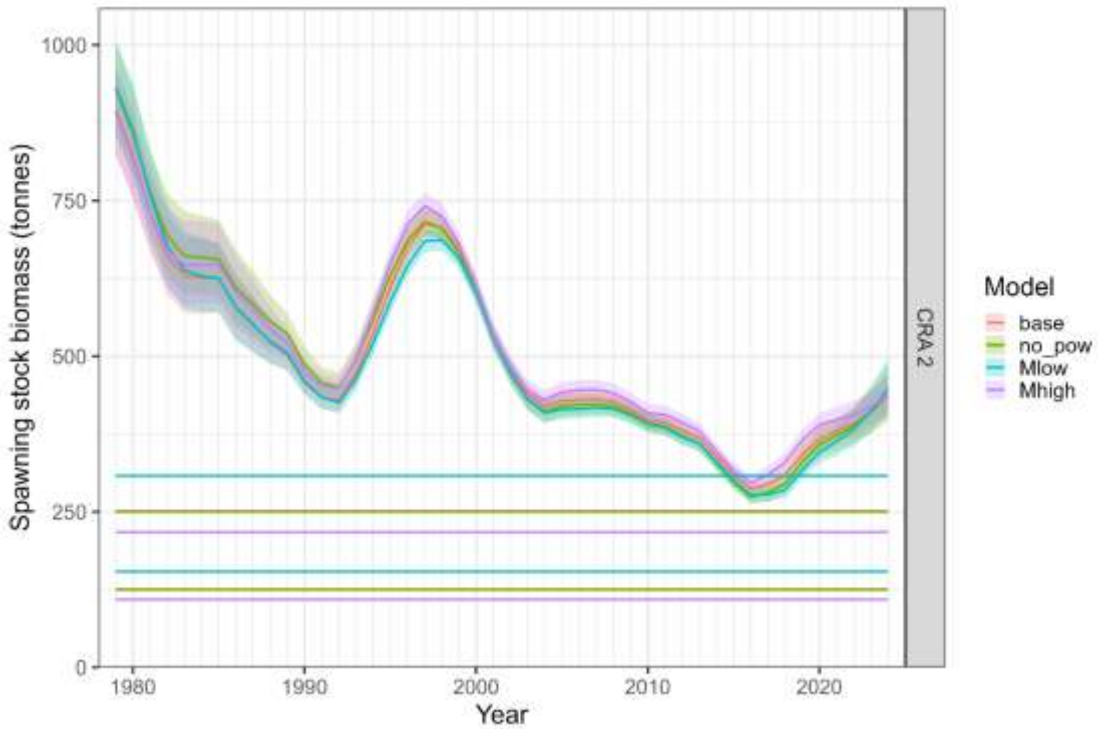

Figure 77: Comparison of spawning stock biomass by fishing year for model sensitivity trials *no_pow*, *Mlow*, and *Mhigh*. Horizontal lines represent the soft limit (upper) and hard limit (lower) for each sensitivity trial (specified by colour).

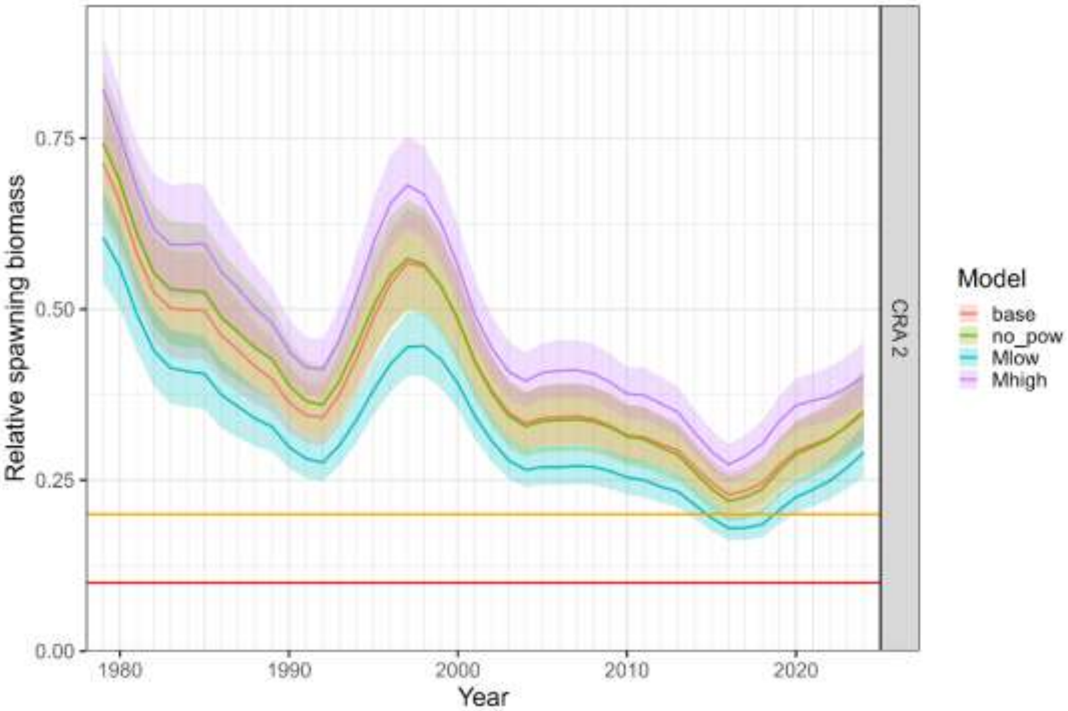

Figure 78: Comparison of relative spawning stock biomass by fishing year for model sensitivity trials *no_pow*, *Mlow*, and *Mhigh*, relative to soft limit (orange line) and hard limit (red line).

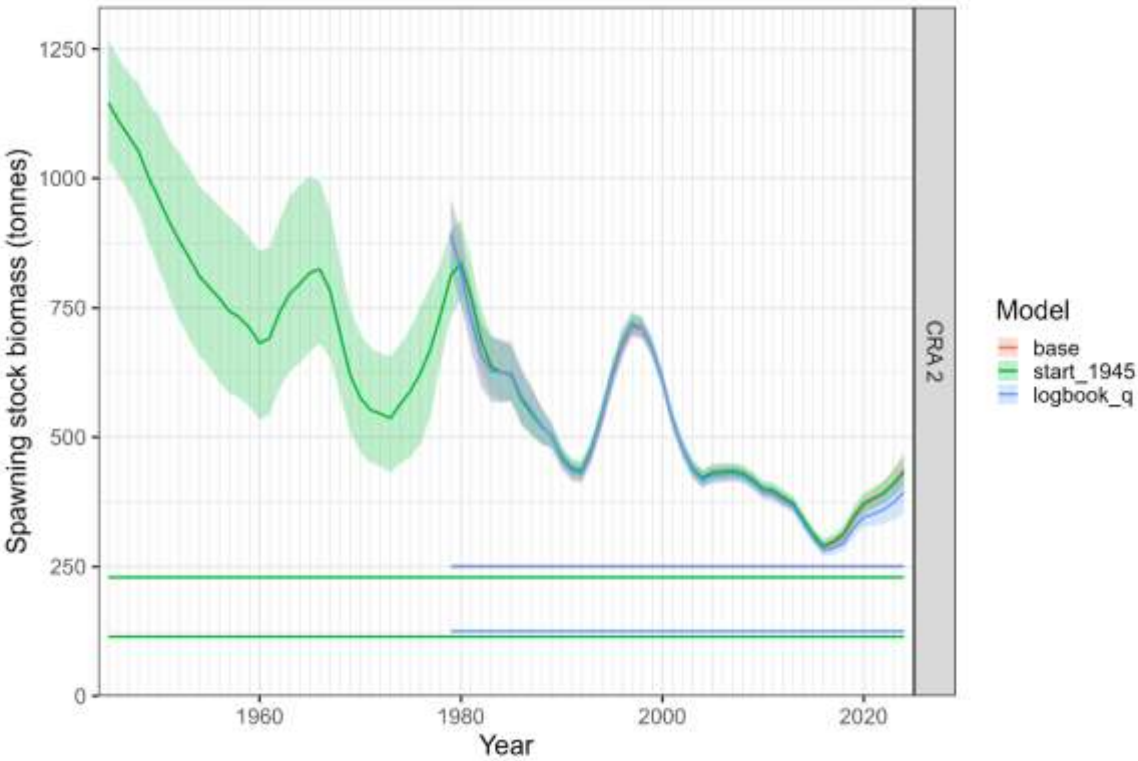

Figure 79: Comparison of spawning stock biomass by fishing year for model sensitivity trials *start_1945* and *logbook_q*. Horizontal lines represent the soft limit (upper) and hard limit (lower) for each sensitivity trial (specified by colour).

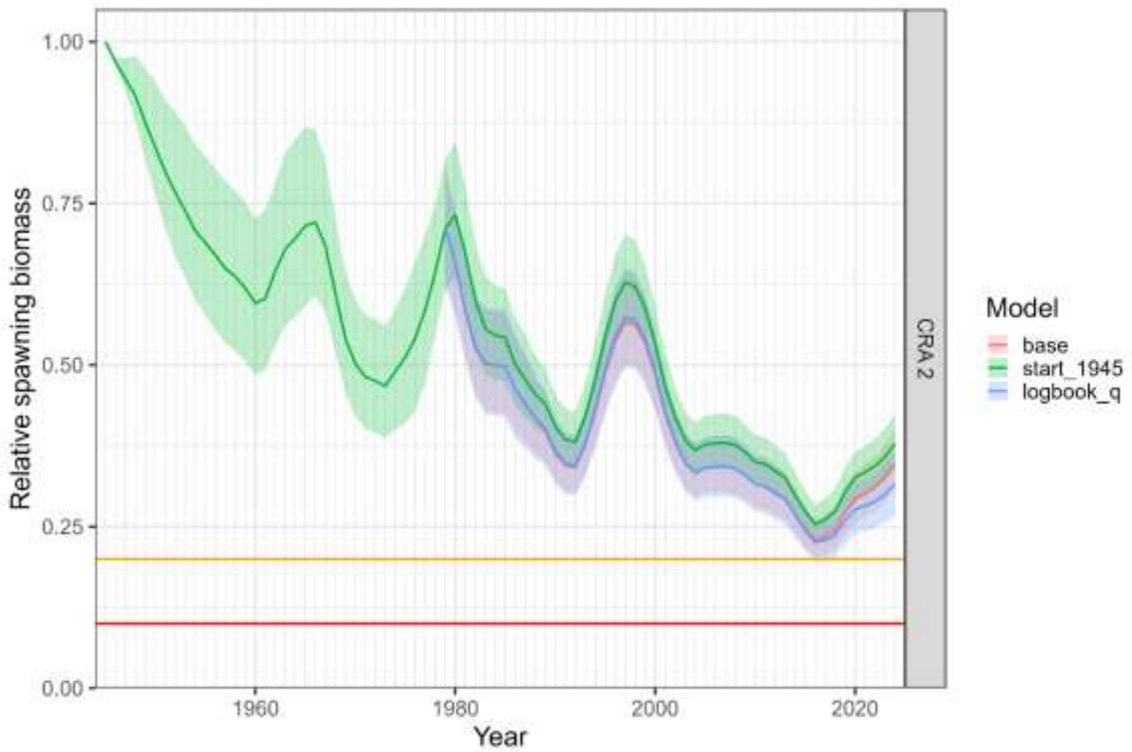

Figure 80: Comparison of relative spawning stock biomass by fishing year for model sensitivity trials *start_1945* and *logbook_q*, relative to soft limit (orange line) and hard limit (red line).

4 DISCUSSION

The 2025 assessment made several improvements over the previous assessment of CRA 2 (Rudd et al. 2023). Covariate and data input improvements included:

- fitted to an updated logbook CPUE index of relative abundance from 1993 to 2024;
- fitted to standardised length frequencies and proportion male in the catch, with more defensible data weightings for these observation types resulting in improvements in model fits to these data;
- improved assumptions about the magnitude of historical recreational and illegal catches;
- used an externally estimated maturity ogive;
- used an externally estimated proportion berried at length ogive to describe female egg bearing dynamics;
- excluded tag release-recovery pairs that were at liberty for less than six months, to reduce or eliminate bias in growth estimation resulting from recoveries of lobsters that had not yet moulted.

Model structure improvements included:

- by introducing the new RTMB *decamod* model, the 2025 stock assessment moved from modelling three sexes in the previous lobster stock dynamics (LSD) model to two sexes using *decamod*;

- *decamod* also modelled recruitment deviates in the final four years constrained using an order 1 autoregressive (AR1) model. This manner of handling recruitments in the final reconstruction years is preferable to returning recruitments to a fixed value, usually R_0;
- introduced length-varying natural mortality, a more plausible representation for a length-based model;
- fixed the *Galpha* parameter at 30 mm TW, to obtain sensible estimates of M_a and to force the model to use a *Galpha* value that was consistent with dive survey observations of growth in pre-recruit lobsters;
- estimated CPUE power parameters for the CELR and logbook CPUE series, to obtain better fits to the extreme peaks in the CPUE series;
- implemented effort 'creep' (or learning) in all CPUE series;
- simplified vulnerability to take advantage of the reduction in the number of sex categories: assumed to be one for males in the AW season, then estimated the relative female vulnerabilities in both seasons and the SS male vulnerability, with all estimated vulnerabilities allowed to exceed one.

The base case model fitted the CRA 2 data well. Estimating CPUE power parameters for the CELR and logbook series led to an improvement in the fit to the CELR series over the fits in the 2022 stock assessment (see Figure 43 compared with Rudd et al. 2023 figure 45). Similar to the 2022 stock assessment, there was an apparent bias in the fits to the tag-based growth information with respect to size at release (Figure F.16). There is likely to be conflicting growth information from the tag data and LF data, as demonstrated in likelihood profiles on *M* (Figure 46) and R_0 (Figure 48). An alternative source of growth information, such as epigenetic ageing, may be useful to determine growth more accurately. Direct ageing using gastric ossicles (e.g. Gnanalingam et al. 2018, Gnanalingam & Alexander 2024) was explored but was not useful for red rock lobster in New Zealand.

The new *decamod* model improved the capacity to quickly and easily run, save, compare, and communicate models using RTMB, with better optimisation over the previous *LSD* model runs with Stan (see Section 3.4.1). However, there was difficulty estimating the *Galpha* parameter at 50 mm TW, allowing growth to be unrealistically fast at smaller sizes and natural mortality M_a to be unrealistically high in order to kill off those individuals with fast growth. To solve this, *Galpha* was first estimated at 30 mm TW, using a prior that was developed based on juvenile growth analyses, to try to keep *Galpha* and M_a at more realistic levels. However, this approach failed to estimate plausible *Galpha* values, so *Galpha* was fixed based on growth analyses of pre-recruited lobsters obtained through dive surveys. Despite these issues, the model was considered to have done a reasonable job at representing the CRA 2 stock.

This assessment describes a stock that was lightly fished initially (median initial $U = 0.066$) in the late 1970s, but which then experienced a rising level of exploitation up to the late 2010s in the SS, but which levelled out in the AW in the mid-1990s (Figure 55). This pattern in exploitation rates resulted in a declining trend in vulnerable biomass up to the end of the 2010s, which was interrupted by a biomass increase resulting from strong recruitment in the early to mid-1990s that was observed all along the east coast of the North Island. This increased abundance was fished down by high exploitation rates (compare Figure 55 and Figure 58), resulting in a stock abundance by the late 2010s that was below the reference level (B_R) (Figure 58). The decline in stock abundance was exacerbated by a period of low recruitment after the above-average recruitment during the early 1990s (Figure 54). This generated a strong management response which began in the mid-2010s and then accelerated in 2018, resulting in a cumulative 60% cut to the TACC and consequently in a rapid restoration of stock abundance to a level above the reference level (Figure 58). Fortunately, these management actions also benefitted from above-average recruitment in recent years (Figure 54).

Researchers at the University of Auckland and their collaborators have monitored rock lobsters at selected shallow-reef sites in northern Statistical Area 905 and eastern Statistical Area 906. Long-term diver surveys include sites within and near the Cape Rodney, Tāwharanui, and Te Whanganui-o-Hei (Hahei) marine reserves (MacDiarmid 1991; Kelly et al. 2000; LaScala-Gruenewald et al. 2021; Hanns et al. 2022; Nessia et al. 2024). These studies reported initial increases in reserve abundance followed by declines from about 2008. Analyses extending beyond the 2018 TACC reduction found limited and spatially variable recovery at the surveyed shallow-reef sites, in contrast to the stronger post-2018 increase in abundance indicated by the CRA 2 logbook CPUE series used in the stock assessment.

Potting surveys in 2018 and 2019 also found much lower abundance at fished sites adjacent to the Cape Rodney and Tāwharanui reserves than inside the reserves (Hanns 2021; Hanns et al. 2022). Broader Hauraki Gulf dive surveys in 2021 and 2022 similarly reported low densities, particularly in the inner Gulf (Nessia et al. 2024).

These surveys provide useful local ecological observations, but they are not an alternative estimate of CRA 2 stock status. Their selected sites cover a small part of northern and western CRA 2, whereas most commercial catch and effort occur farther east, from the Bay of Plenty to East Cape. They sample shallow-reef habitats with modest geographic and sample coverage for a cryptic species, so their results are specific to site selection, habitat, depth, visibility, timing, and lobster behaviour. Marine-reserve abundance is not directly equivalent to the unfished biomass used by the stock assessment: the reserves are small, movement across their boundaries occurs, fishing is concentrated near some boundaries, and lobster abundance within the reserves has itself declined. Consequently, the reported reserve-to-fished ratios should be interpreted as local contrasts rather than CRA 2-wide estimates of depletion.

However, because the discrepancy could indicate a post-2018 change in the relationship between logbook CPUE and biomass, the assessment included a sensitivity trial estimating separate logbook catchability (q) parameters before and after 2018. This produced a slightly better fit to the final logbook indices but poorer fits to the early series because the accompanying CPUE power parameter was estimated near 1.0 compared with the base model CPUE power parameter estimate of 1.3. Estimates of vulnerable and spawning biomass in 2025 were slightly lower than in the base case, but vulnerable biomass remained above B_R and the projected rebuilding trend was unchanged (Figures 68 and 75). Other data and model assumptions, including catch history and growth, also supported a marked post-2018 biomass increase.

5 POTENTIAL RESEARCH

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

- trial specifying multiple fisheries groups within the same region (i.e., the 'areas as fisheries' concept using different selectivities; this would enable different selectivities for any of the statistical areas within CRA 2);
- investigate the influence of growth priors where the posteriors are substantially different from the respective priors (e.g., *Gobs* and perhaps also *Gshape* for males) to determine whether these priors are appropriate and influential, and/or whether the growth meta-analysis needs to be redone;
- further explore the growth function, including possible separation by season; and
- explore alternative selectivity functions.

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

- develop a CPUE index series based on electronic reporting data as soon as possible;
- investigate alternative handling mortality assumptions;
- develop a model-standardised estimate of the proportion of mature females in the catch that are in berry in each season;
- further investigate the development of climate covariates, including SST series, for predicting temporal recruitment variability, as experienced by the fishery; and

- investigate alternative methods for collecting growth information across the vulnerable size range, such as direct ageing via the development of an epigenetic clock for red rock lobster.

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

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

7 ACKNOWLEDGEMENTS

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Wynne-Jones, J.; Gray, A.; Hill, L.; Heinemann, A. (2014). National Panel Survey of Marine Recreational Fishers 2011–12: Harvest Estimates. *New Zealand Fisheries Assessment Report 2014/67*. 139 p.

APPENDIX A. LOGBOOK CPUE DIAGNOSTICS

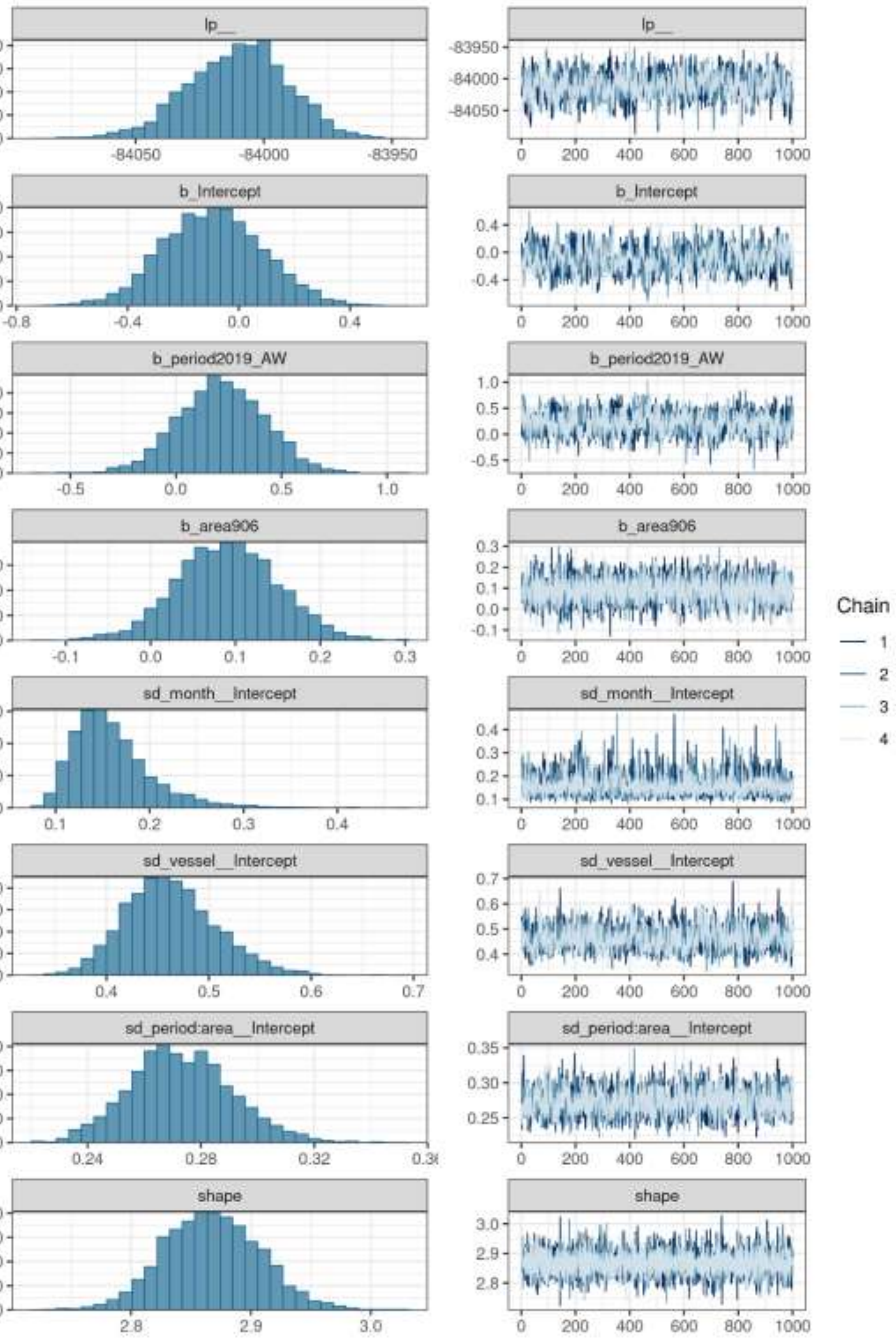

Figure A.1: MCMC trace plots for a subset of model parameters from the logbook CPUE model including legal status lobsters only.

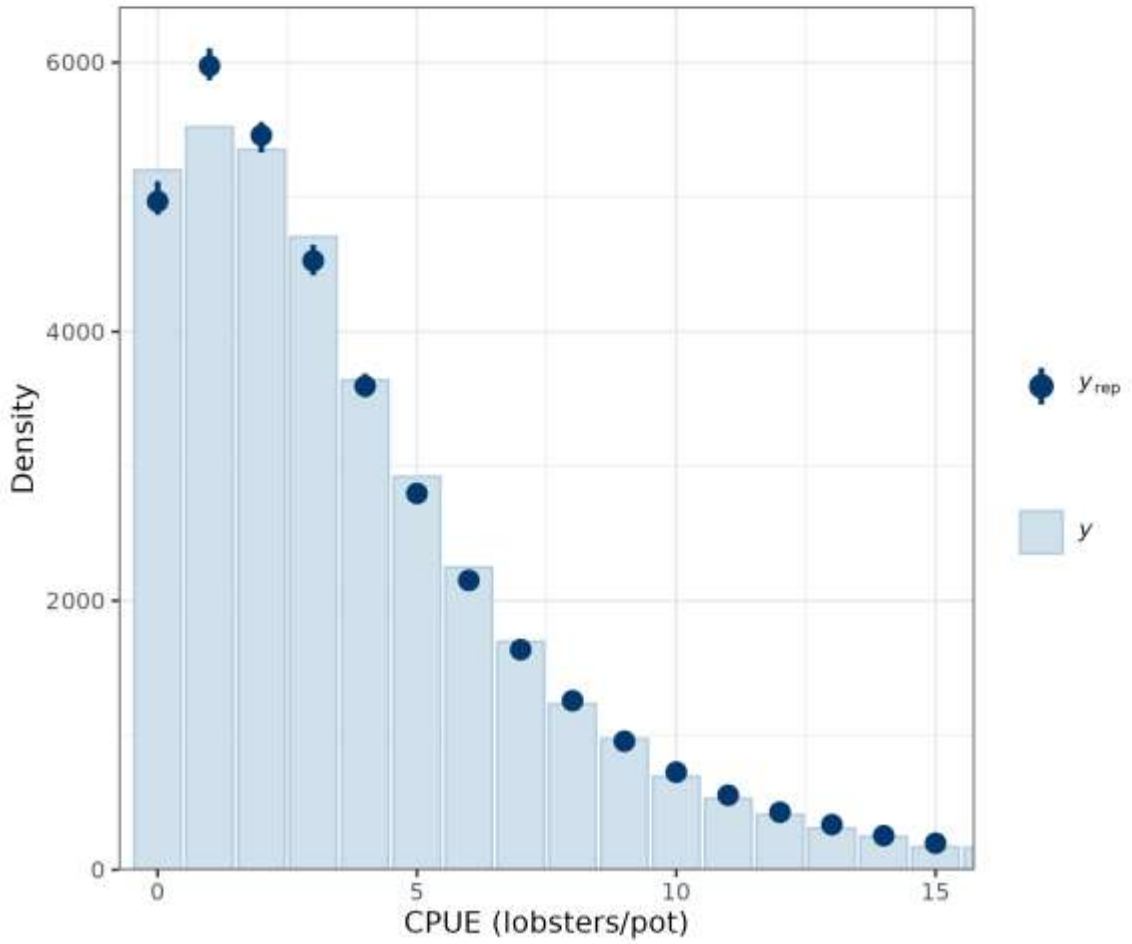

Figure A.2: Posterior predictive check plot for the number of lobsters per pot estimated by the logbook CPUE model including legal status lobsters only.

APPENDIX B. CATCH COMPOSITION ANALYSIS ADDITIONAL OUTPUTS

Table B.1: Summary of the catch sampling data from CRA 2 by the number of vessels, days, trips, pots and lobsters sampled under the catch sampling and logbook programmes. The data from years prior to 1993 shaded grey in this table were obtained from patchy sampling by fewer than 3 vessels annually, so were excluded from the catch composition analysis.

	Catch Sampling					Logbook					
Fishing year	Vessels	Days	Trips	Pots	Lobsters	Vessels	Skippers	Days	Trips	Pots	Lobsters
1986	2	3	3	159	562	–	–	–	–	–	–
1987	1	3	3	79	233	–	–	–	–	–	–
1988	–	–	–	–	–	–	–	–	–	–	–
1989	–	–	–	–	–	–	–	–	–	–	–
1990	2	3	3	127	364	–	–	–	–	–	–
1991	1	2	2	115	918	–	–	–	–	–	–
1992	–	–	–	–	–	–	–	–	–	–	–
1993	–	–	–	–	–	26	23	253	1 915	4 494	18 092
1994	–	–	–	–	–	30	25	254	1 613	4 307	18 133
1995	–	–	–	–	–	26	21	176	1 048	2 809	11 657
1996	–	–	–	–	–	21	19	187	902	2 508	12 522
1997	–	–	–	–	–	19	16	169	766	2 111	9 224
1998	–	–	–	–	–	21	17	191	781	2 199	9 172
1999	11	11	11	837	2 855	20	17	153	949	2 642	10 323
2000	13	13	13	1 002	3 022	16	16	198	950	2 568	9 186
2001	10	11	11	859	3 014	13	13	268	743	1 787	5 893
2002	12	13	14	724	2 274	18	18	267	1 197	2 738	8 269
2003	12	12	12	737	1 898	13	13	289	979	2 421	7 371
2004	12	12	12	530	1 353	14	14	319	1 139	2 602	7 980
2005	10	12	12	752	2 303	18	18	301	1 439	3 538	10 663
2006	9	12	12	772	1 964	17	17	251	1 057	2 762	8 823
2007	11	12	12	828	2 237	14	13	245	1 031	2 502	8 314
2008	7	12	12	874	2 568	15	15	257	1 274	3 227	10 105
2009	8	11	14	881	2 769	15	14	237	1 166	2 782	8 204
2010	12	13	13	783	1 926	16	16	266	1 390	3 261	10 092
2011	12	14	17	857	2 175	19	21	252	1 348	3 156	8 755
2012	11	13	13	835	2 465	17	17	255	1 426	3 485	10 230
2013	9	10	12	864	2 868	20	19	283	1 476	3 506	9 783
2014	8	12	12	882	2 666	16	17	266	1 417	3 229	8 154
2015	8	13	13	768	1 450	16	17	274	1 342	2 921	6 315
2016	9	13	13	763	2 005	15	16	223	831	1 785	3 471
2017	9	14	14	873	2 652	14	14	235	928	1 971	4 234
2018	9	11	12	965	2 785	11	11	176	453	1 230	4 374
2019	–	–	–	–	–	13	13	172	437	1 220	3 769
2020	10	16	19	1 551	5 174	15	15	157	483	1 387	4 657
2021	12	18	18	1 458	6 870	13	13	220	488	1 281	3 867
2022	11	13	15	1 067	2 823	12	13	148	416	1 164	3 434
2023	8	13	15	1 017	2 609	11	12	203	496	1 342	3 508
2024	–	–	–	–	–	14	14	232	559	1 540	4 867

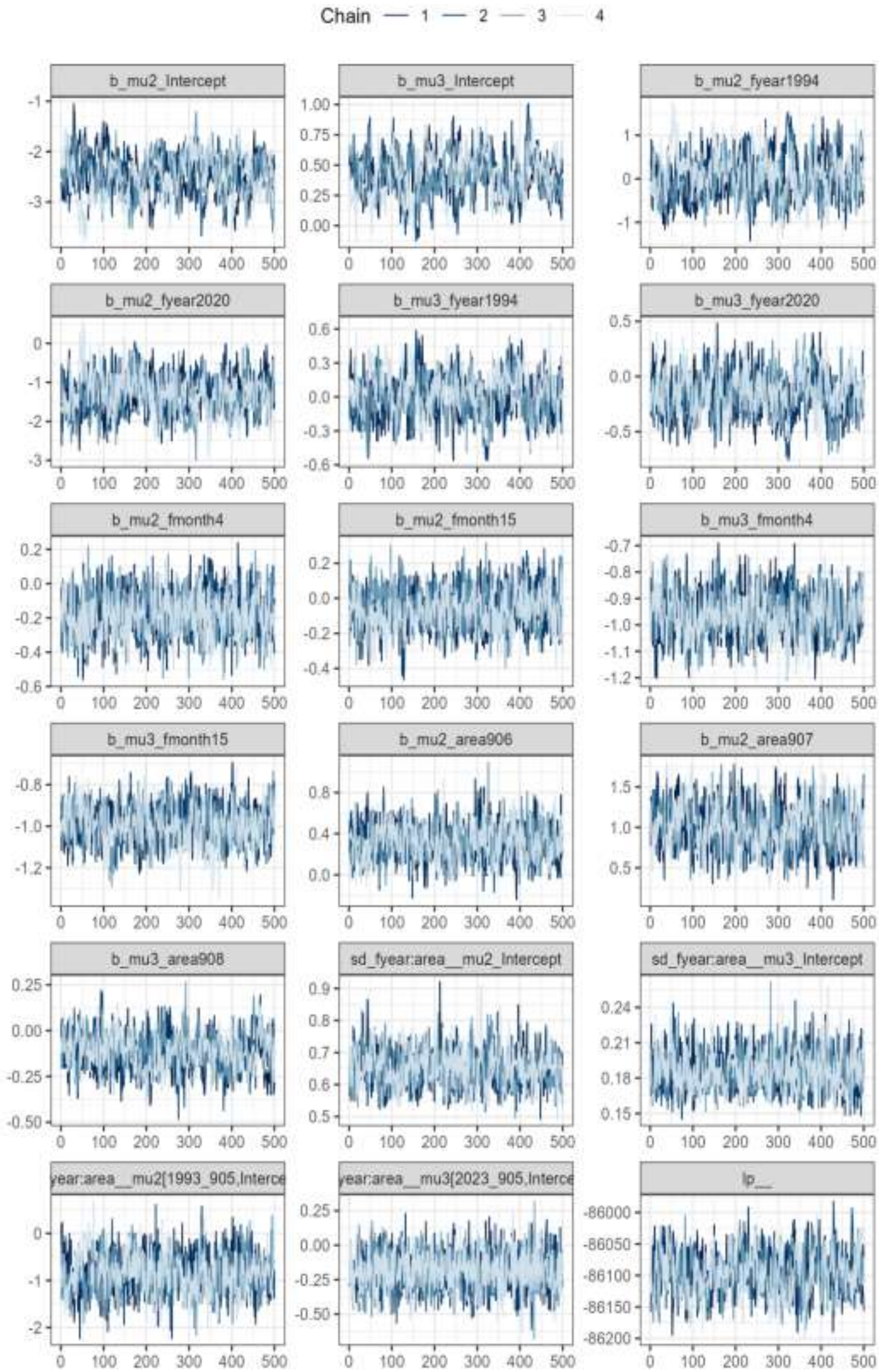

Figure B.1: MCMC trace plots for a subset of model parameters from the sex ratio model.

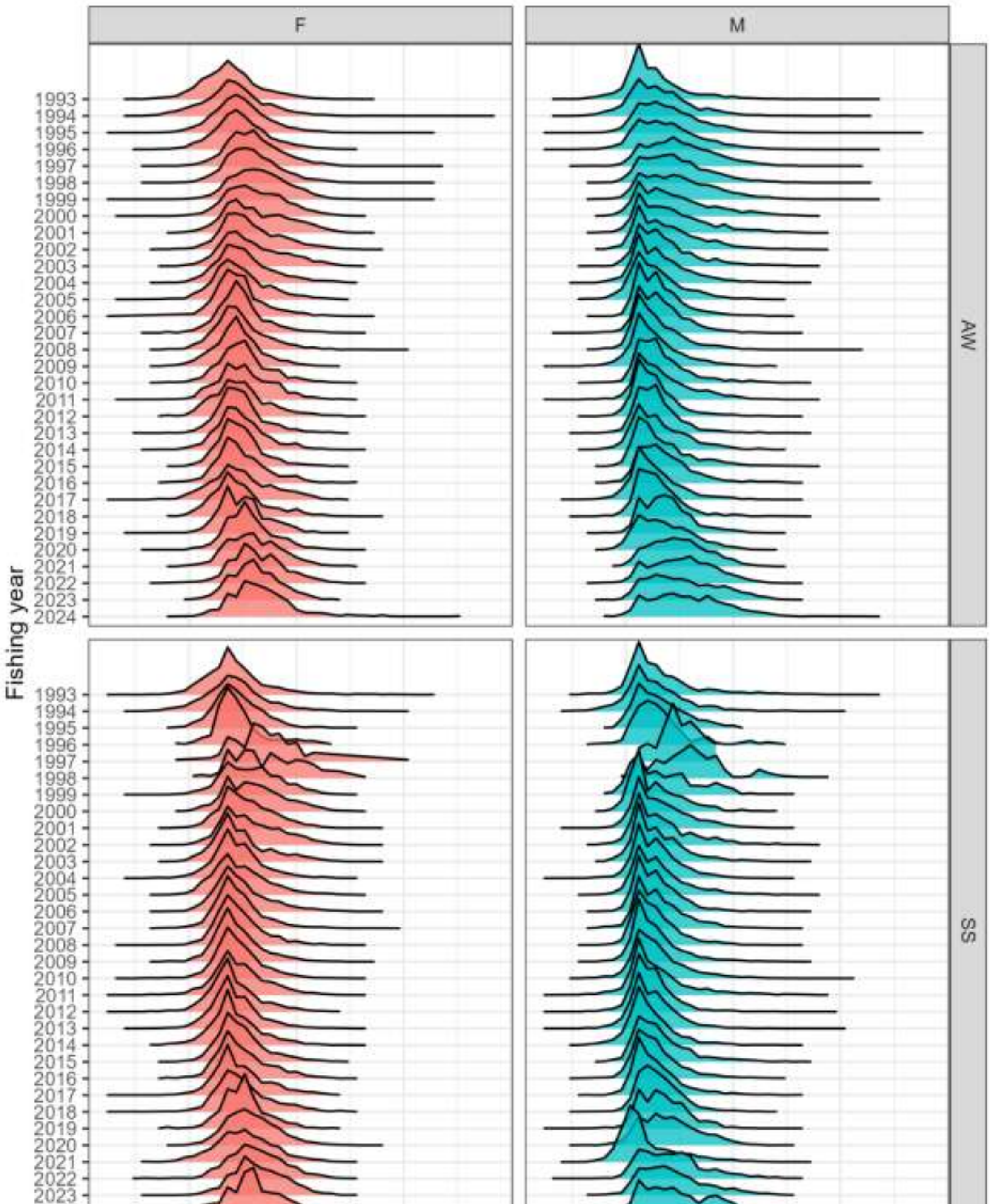

Figure B.2: Raw length frequencies by sex, season, and fishing year.

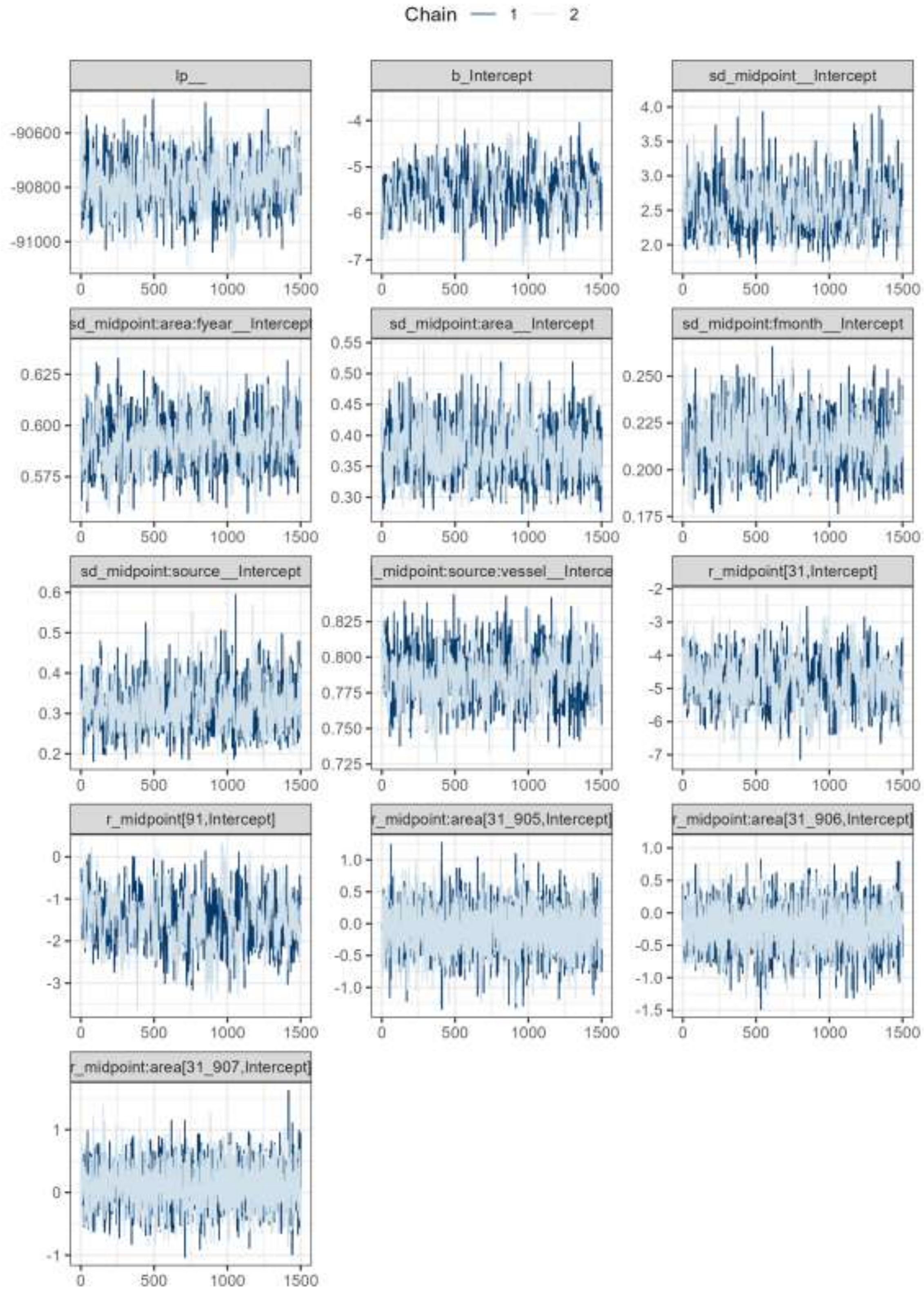

Figure B.3: MCMC trace plots for a subset of model parameters from the <u>male</u> LF model.

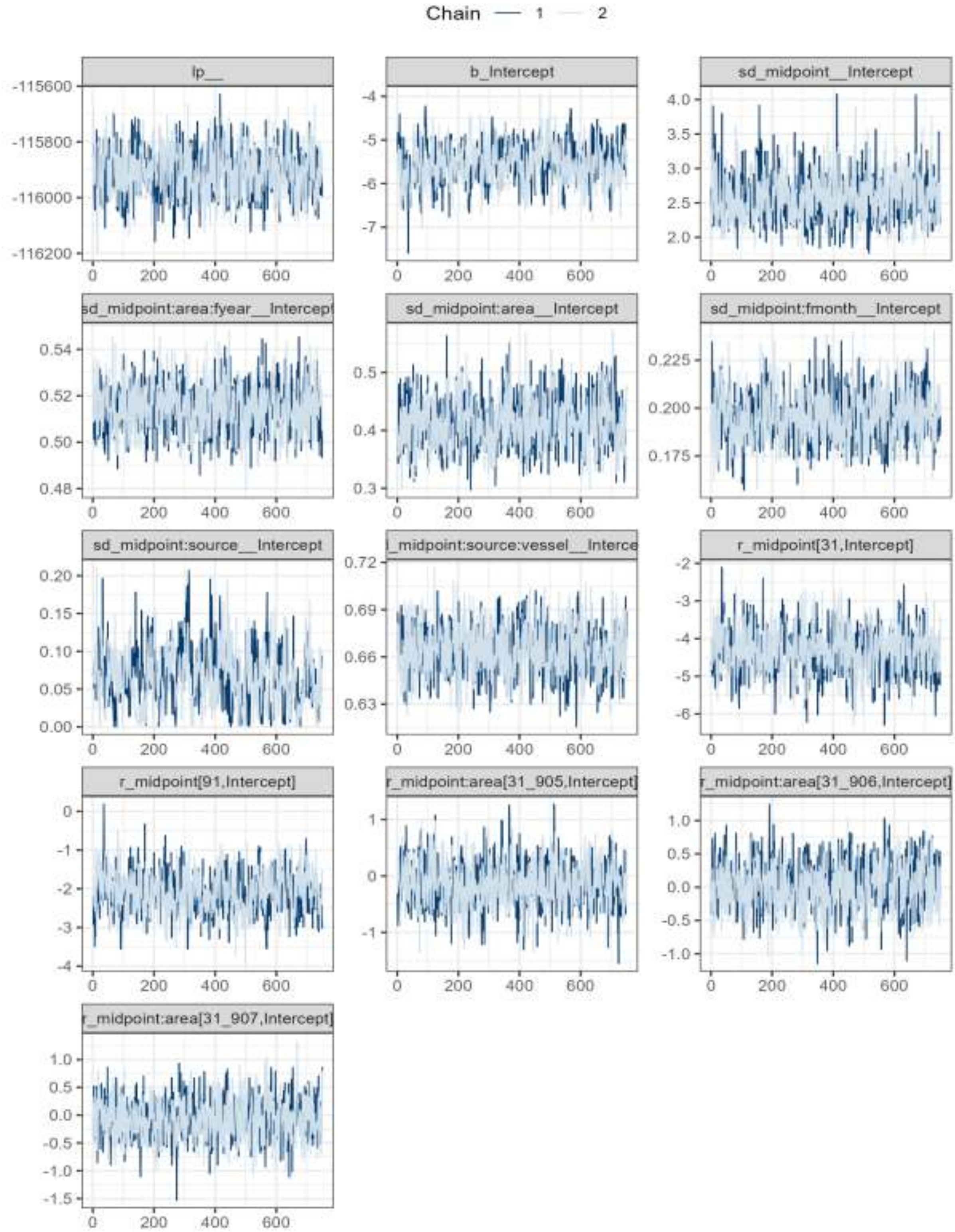

Figure B.4: MCMC trace plots for a subset of model parameters from the <u>female</u> LF model.

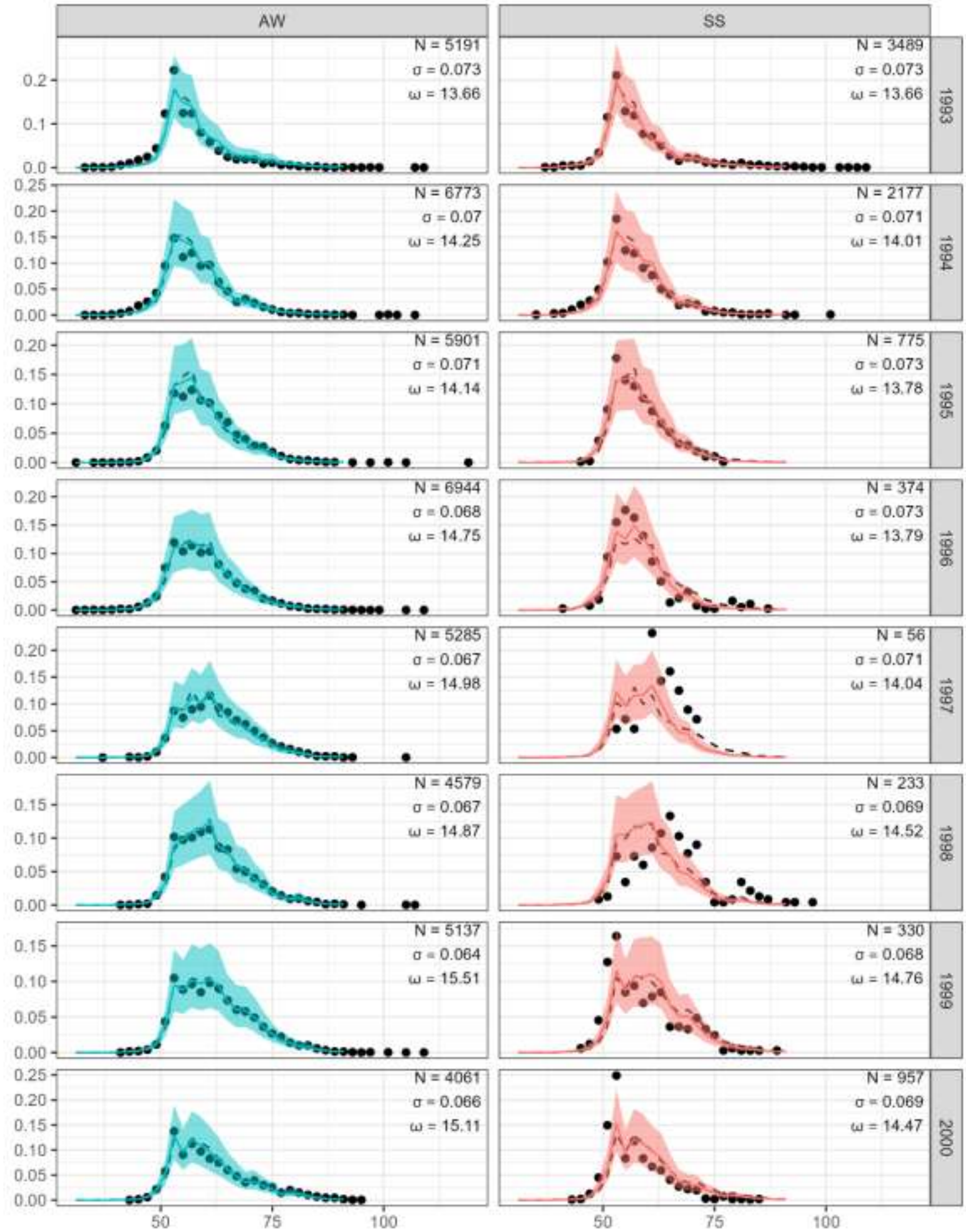

Figure B.5: CRA 2 LFs for <u>males</u> by fishing year (from 1993 to 2000), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).

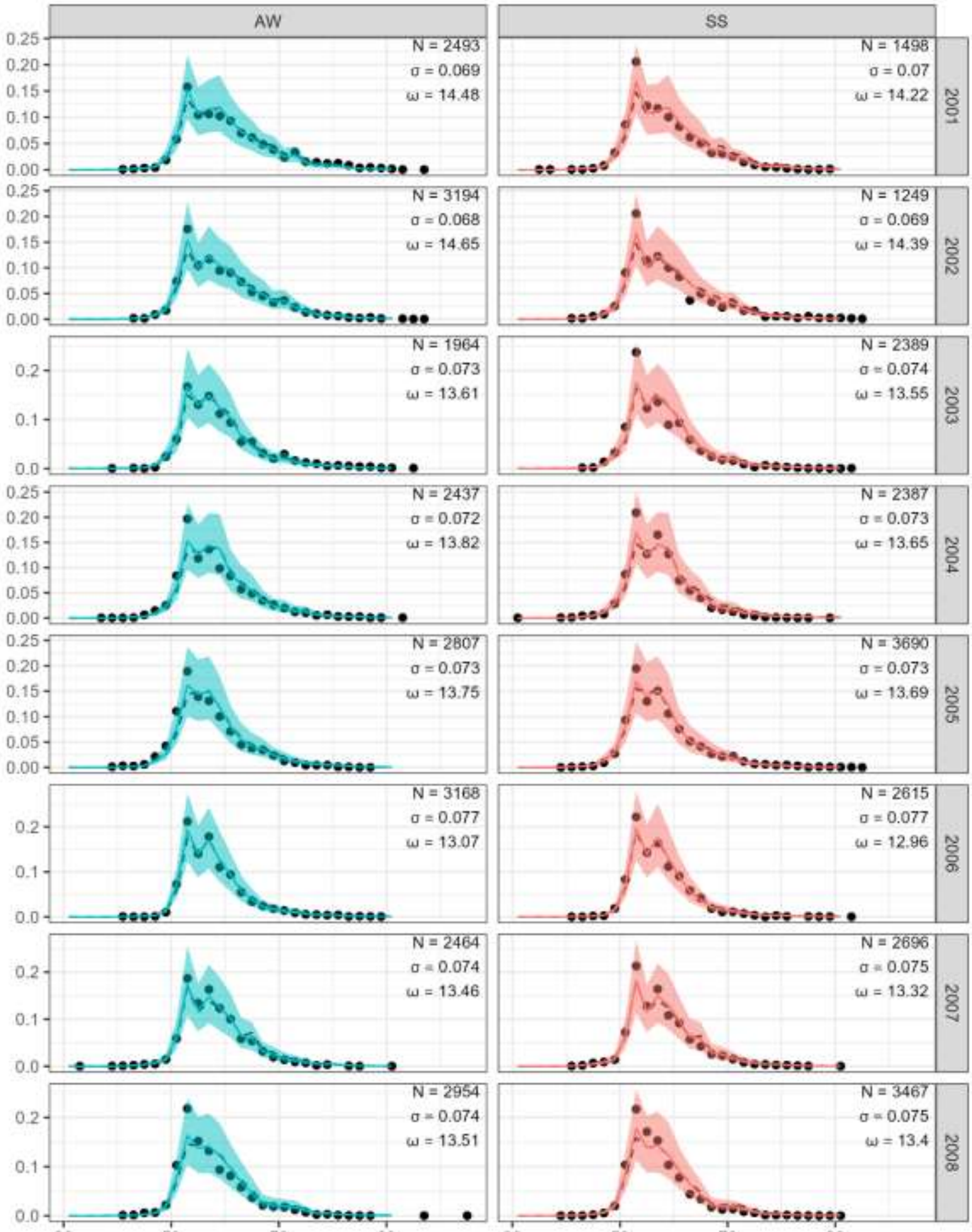

Figure B.6: CRA 2 LFs for <u>males</u> by fishing year (from 2001 to 2008), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).

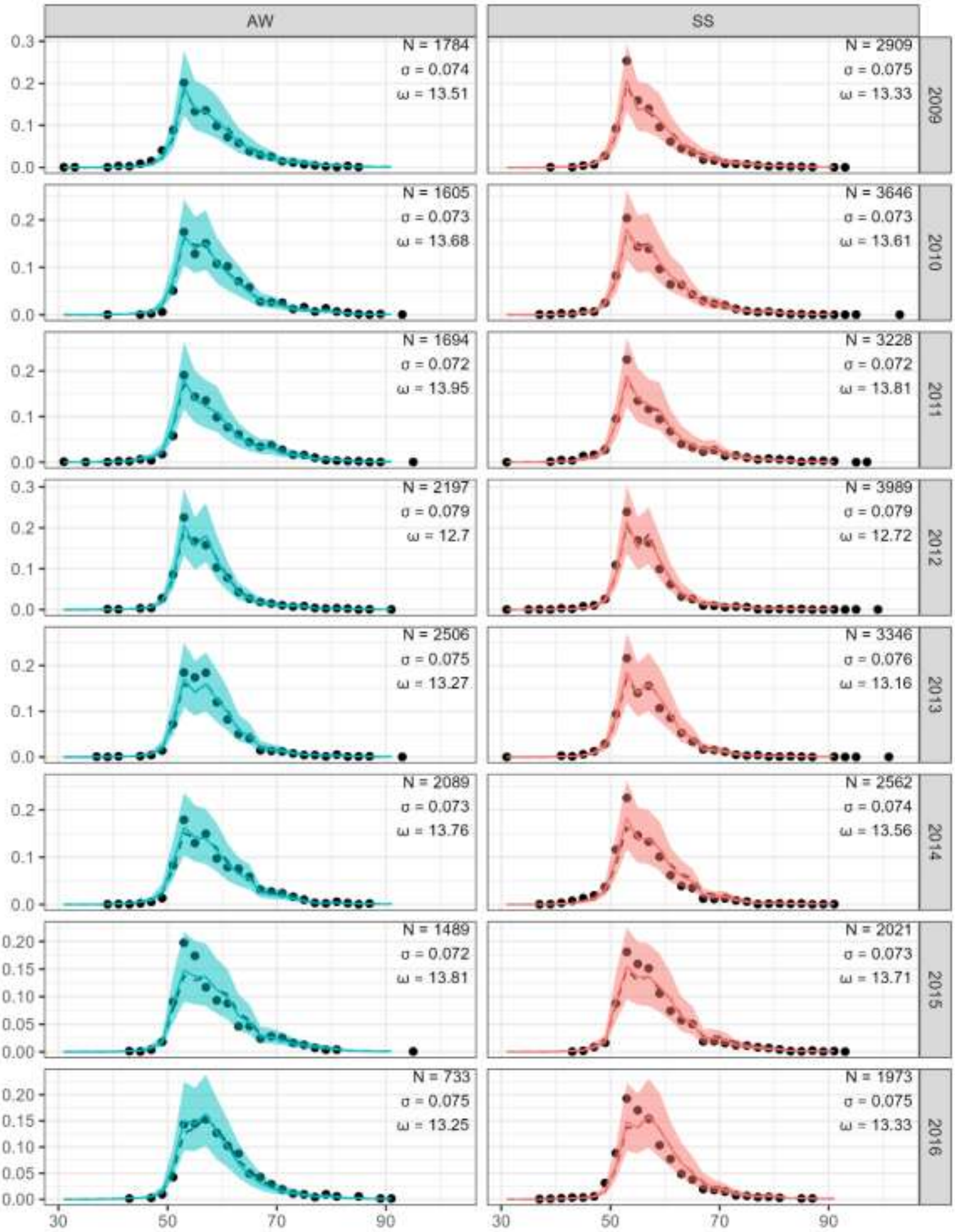

Figure B.7: CRA 2 LFs for <u>males</u> by fishing year (from 2009 to 2016), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).

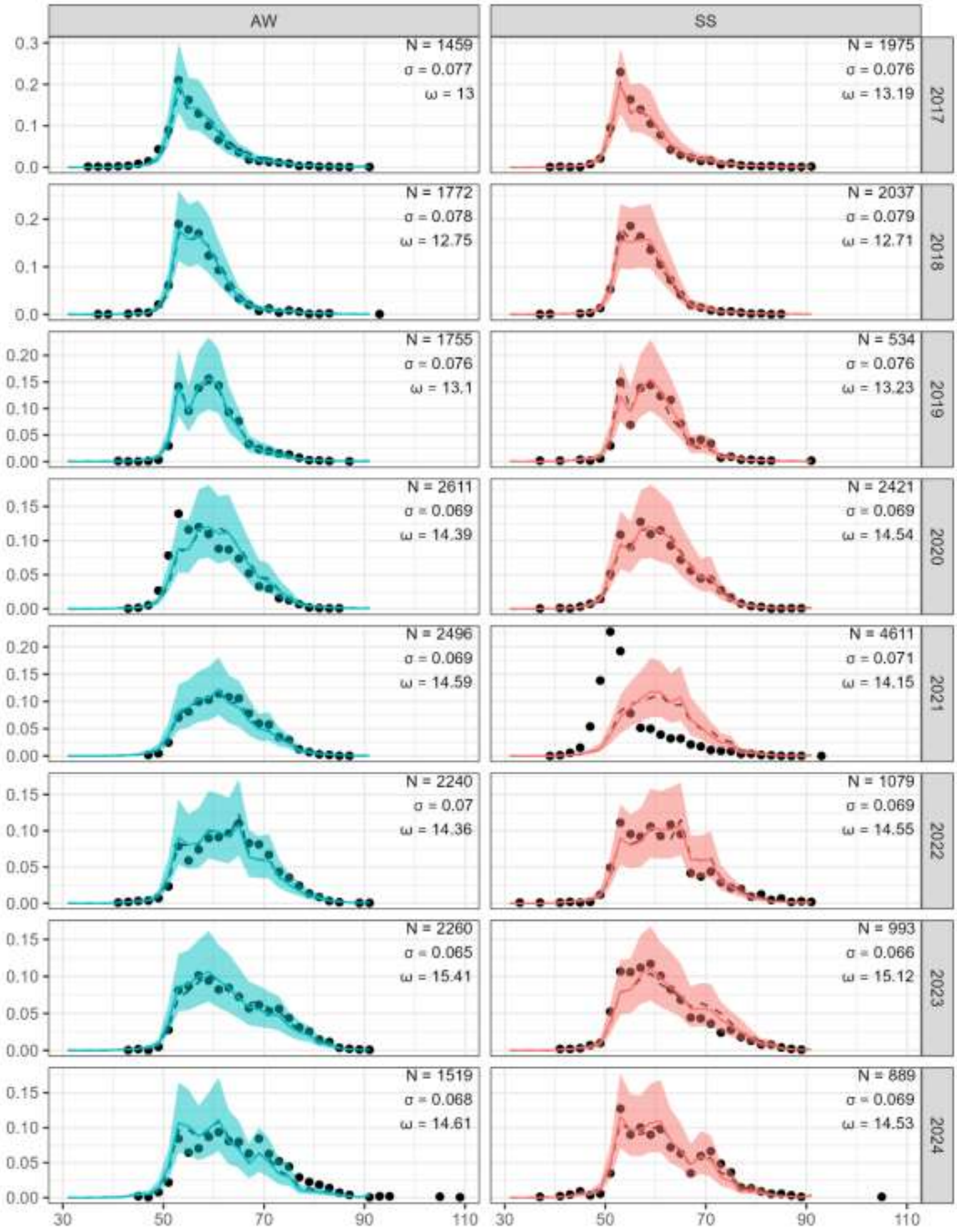

Figure B.8: **CRA 2 LFs for <u>males</u> by fishing year (from 2017 to 2024), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).**

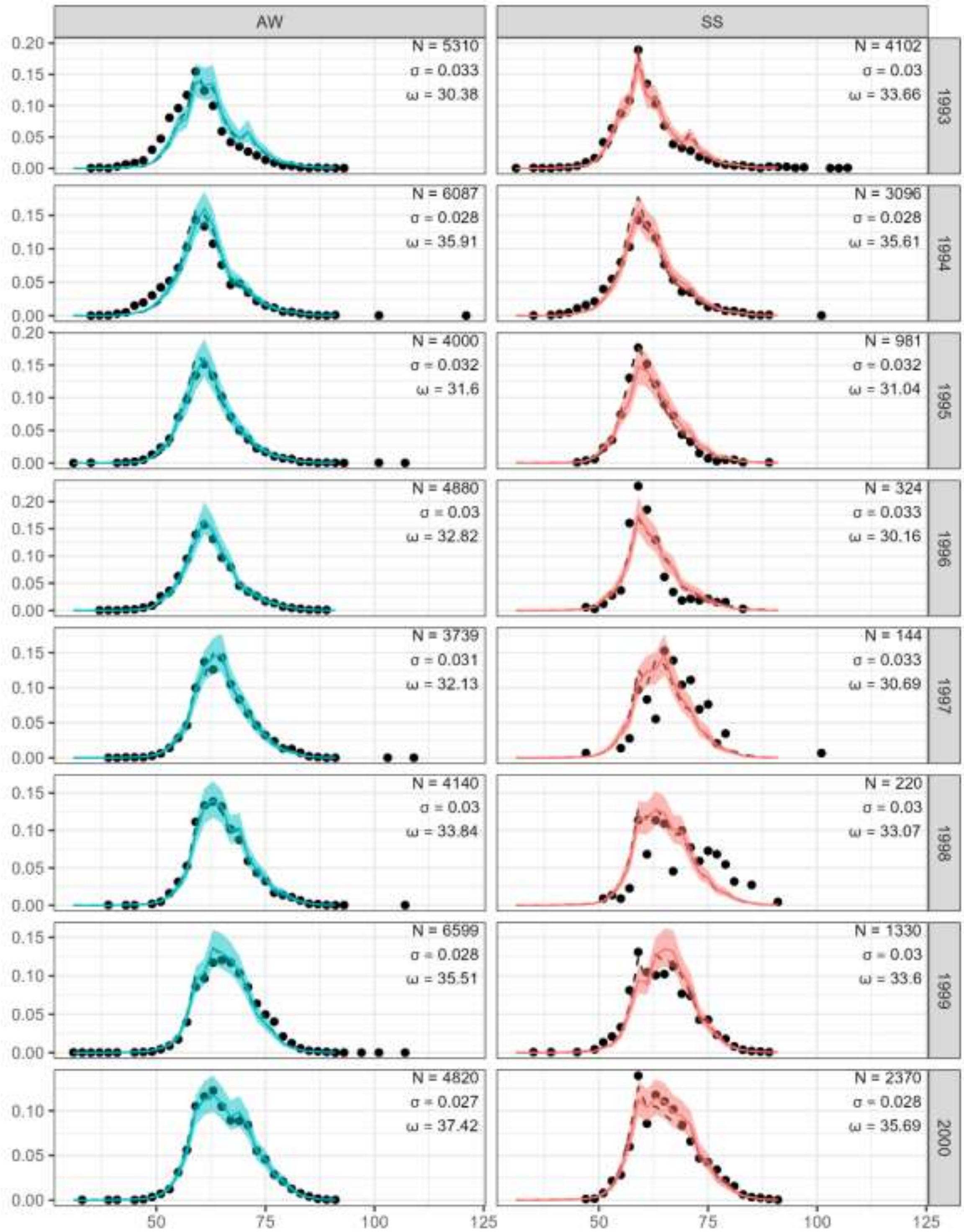

Figure B.9: CRA 2 LFs for <u>females</u> by fishing year (from 1993 to 2000), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).

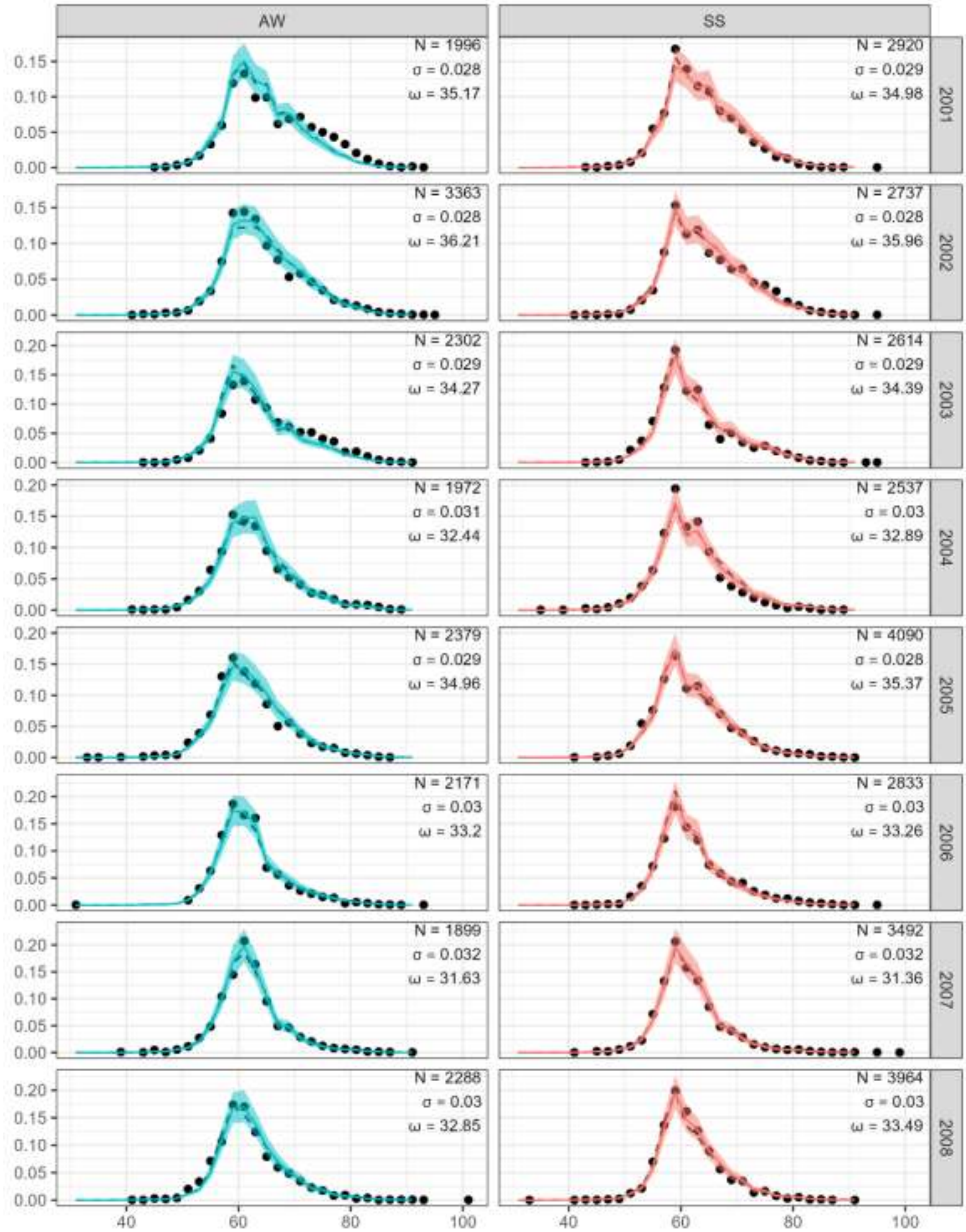

Figure B.10: CRA 2 LFs for <u>females</u> by fishing year (from 2001 to 2008), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).

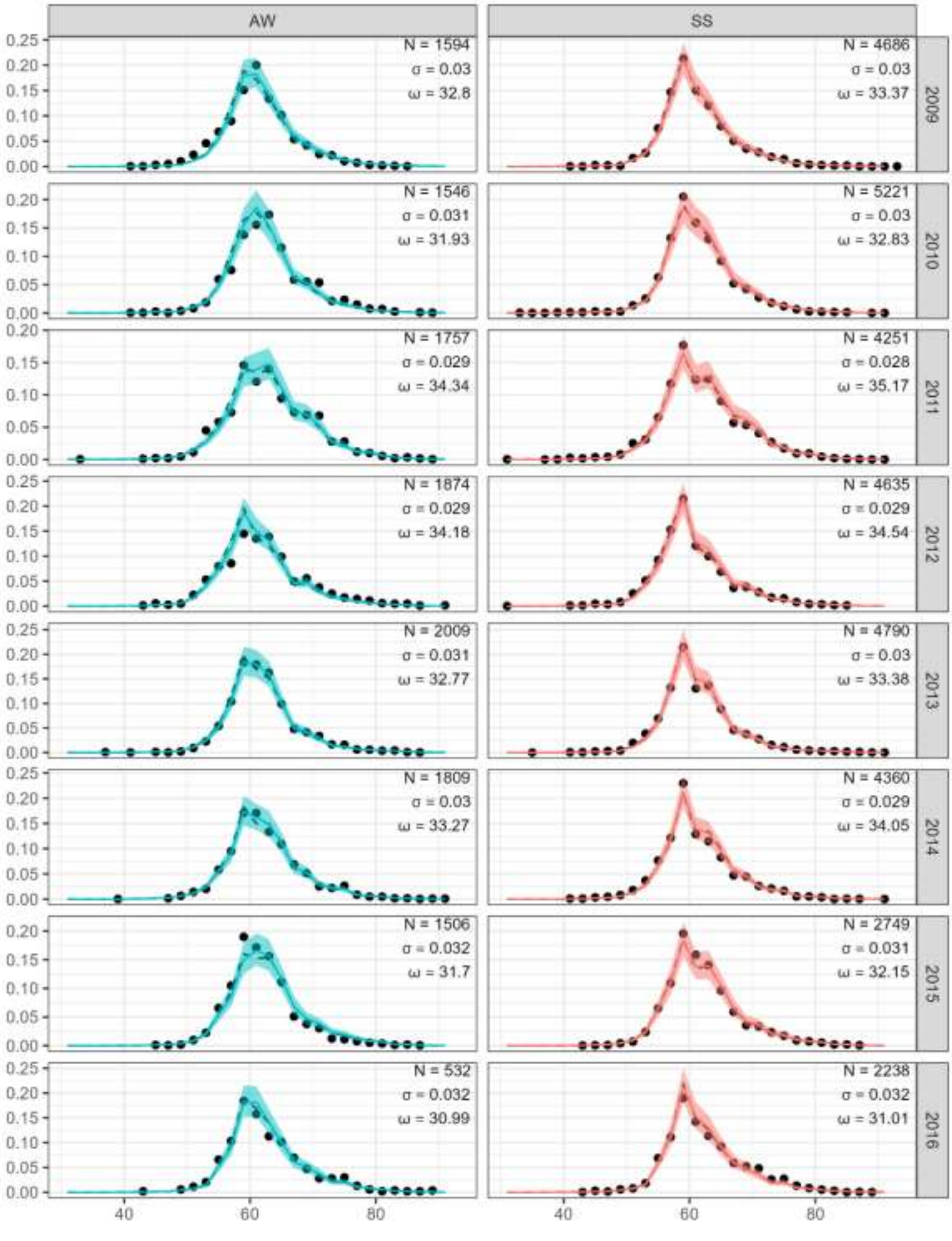

Figure B.11: CRA 2 LFs for <u>females</u> by fishing year (from 2009 to 2016), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).

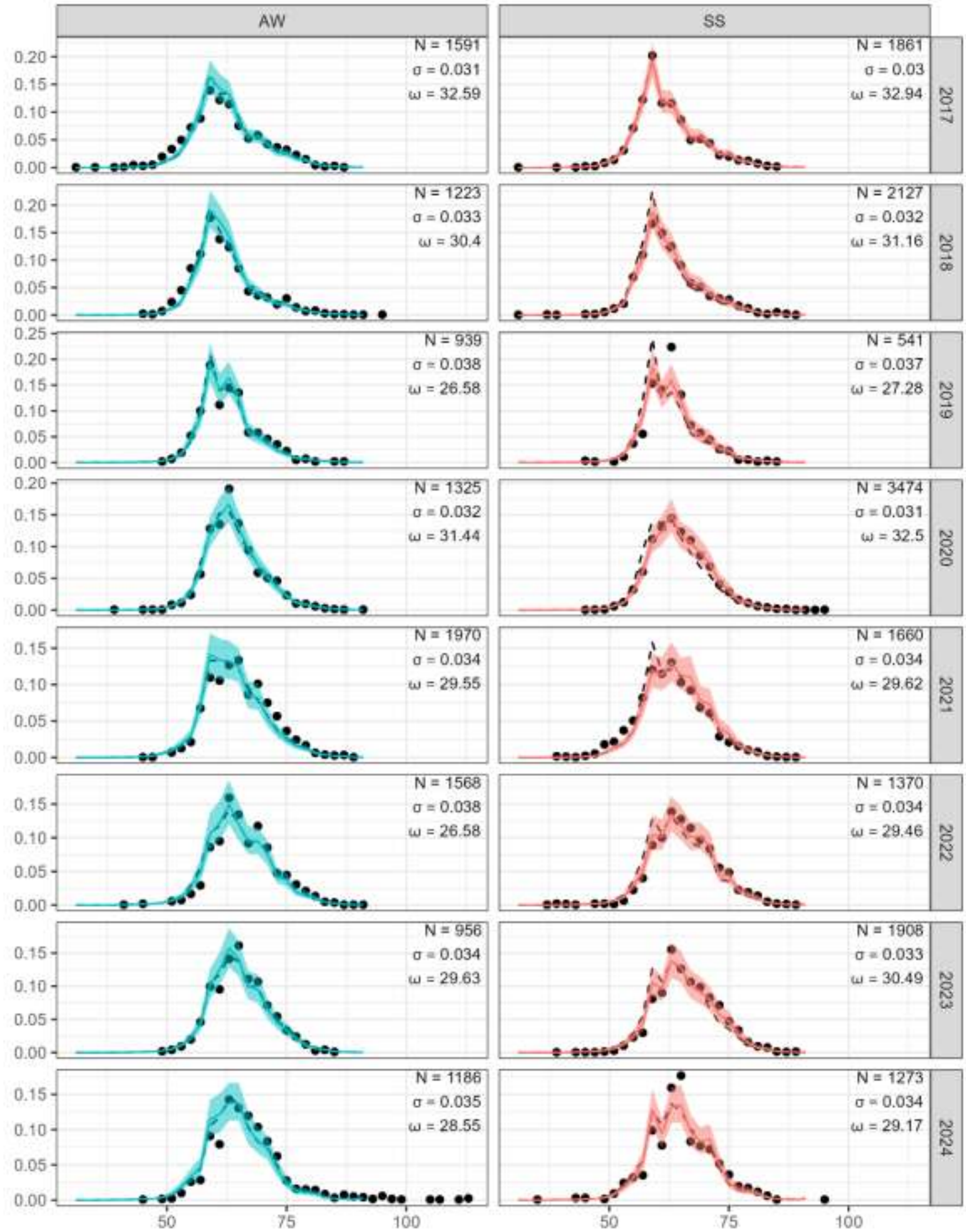

Figure B.12: CRA 2 LFs for <u>females</u> by fishing year (from 2017 to 2024), season (AW = autumn/winter, SS = spring/summer), and TW bin. The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions 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).

APPENDIX C. TAG RECAPTURE DATA

Table C.1: 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	19 744	2 259	17 485	11.4
CRA 2	29 163	5 033	24 130	17.3
CRA 3	43 858	5 801	38 057	13.2
CRA 4	42 622	3 159	39 463	7.4
CRA 5	44 699	7 613	37 086	17.0
CRA 6	10 802	269	10 533	2.5
CRA 7	12 999	913	12 086	7.0
CRA 8	36 253	11 028	25 225	30.4
CRA 9	6 575	129	6 446	2.0

Table C.2: 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	974	1 285	2 259
CRA 2	2 548	2 485	5 033
CRA 3	4 436	1 365	5 801
CRA 4	2 438	721	3 159
CRA 5	5 281	2 332	7 613
CRA 6	62	207	269
CRA 7	445	468	913
CRA 8	6 085	4 943	11 028
CRA 9	34	95	129
Total	22 303	13 901	36 204

Table C.3: 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.

	Recapture QMA									
Release QMA	CRA 1	CRA 2	CRA3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9	Total
CRA 1	2 229	–	30	–	–	–	–	–	–	2 259
CRA 2	1	5 027	5	–	–	–	–	–	–	5 033
CRA 3	–	5	5 735	8	1	–	–	52	–	5 801
CRA 4	–	–	–	3 152	7	–	–	–	–	3 159
CRA 5	–	–	–	2	7 605	–	6	–	–	7 613
CRA 6	–	–	–	–	–	269	–	–	–	269
CRA 7	–	–	6	–	–	–	861	46	–	913
CRA 8	–	1	121	–	–	–	1	10 902	3	11 028
CRA 9	–	–	–	–	–	–	–	–	129	129
Total	2 230	5 033	5 897	3 162	7 613	269	868	11 000	132	36 204

Table C.4: Proportion of tags that were recaptured outside of the statistical area of release. Proportions based on fewer than ten recaptures were left blank.

QMA	Statistical Area	Total recaptured	Proportion in new area
CRA 1	901	326	0.009
	902	2	–
	903	22	0.000
	904	–	–
	939	1 902	0.050
CRA2	905	191	0.037
	906	2 778	0.012
	907	1 081	0.015
	908	947	0.023
CRA 3	909	1 020	0.002
	910	3 464	0.016
	911	1 304	0.011
CRA 4	912	386	0.000
	913	1 079	0.025
	914	1 283	0.047
	915	408	0.029
	934	3	–
CRA 5	917	2 891	0.000
	918	238	0.029
	919	–	–
	916	3 177	0.005
	932	–	–
	933	1 123	0.006
CRA 6	940	91	0.055
	941	101	0.010
	942	75	0.040
	943	–	–
CRA 7	920	530	0.160
	921	383	0.073
CRA 8	922	34	0.794
	923	239	0.460
	924	2 608	0.067
	925	20	0.300
	926	1 505	0.182
	927	5 333	0.009
	928	542	0.011
CRA 9	938	–	–
	937	–	–
	936	19	0.000
	935	98	0.000
	931	10	0.000
	930	–	–
	929	2	–

Table C.5: Number of recaptured lobsters for CRA 2 releases, by fishing year of release, sex, and statistical area. 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.

	Numbers by release statistical area					Sex		
Release fishing year	Unknown	905	906	907	908	Males	Females	Total
1983	0	0	190	0	0	78	112	190
1984	1	0	60	0	0	25	36	61
1985	0	0	18	0	0	10	8	18
1996	0	38	750	252	190	689	541	1230
1997	0	2	399	72	130	472	131	603
1998	0	5	273	21	17	244	72	316
1999	0	1	45	19	9	42	32	74
2000	0	0	2	0	0	0	2	2
2001	0	0	10	0	3	5	8	13
2002	0	18	223	12	26	77	202	279
2003	0	67	460	102	39	245	423	668
2004	0	6	94	23	1	60	64	124
2005	0	2	35	5	6	13	35	48
2006	0	0	1	3	0	0	4	4
2007	0	0	0	3	2	1	4	5
2008	0	5	61	20	66	52	100	152
2009	2	2	13	2	26	27	18	45
2010	0	0	13	2	5	3	17	20
2011	0	0	2	0	1	1	2	3
2012	0	9	0	0	1	3	7	10
2014	27	25	58	103	208	214	207	421
2015	0	0	8	77	67	65	87	152
2016	1	8	38	143	32	67	155	222
2017	1	2	16	72	13	38	66	104
2018	0	1	1	7	3	3	9	12
2019	1	0	0	92	59	73	79	152
2020	3	0	1	30	8	20	22	42
2021	0	0	7	15	31	14	39	53
2022	0	0	0	5	4	7	2	9
2023	0	0	0	1	0	0	1	1

Table C.6: Number of tag releases by sex, release month, and release statistical area for CRA 2.

	Statistical Area of release					Sex		
Release month	Unknown	905	906	907	908	Males	Females	Total
Jan	1	2	30	74	94	69	132	201
Feb	0	7	27	64	48	67	79	146
Mar	1	0	31	8	3	22	21	43
Apr	0	0	78	42	0	98	22	120
May	0	0	168	1	0	154	15	169
Jun	1	1	80	6	143	142	89	231
Jul	2	57	385	80	151	370	305	675
Aug	10	29	348	343	140	501	369	870
Sep	7	65	665	178	224	515	624	1 139
Oct	10	16	478	227	84	287	528	815
Nov	1	14	384	36	32	254	213	467
Dec	3	0	104	22	28	69	88	157

Table C.7: Days-at-liberty statistics for recaptures of CRA 2 releases. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

				Days at liberty				
Statistical Area of release	Sex	N	N at liberty > 6 months	Minimum	5%	Median	95%	Maximum
Unknown	Male	24	4	2	3	70	599	754
	Female	12	4	6	9	102	575	711
905	Male	27	17	17	26	308	710	1 053
	Female	164	114	1	25	373	1 061	3 288
906	Male	1 528	887	1	7	242	683	2 171
	Female	1 250	847	1	20	355	1 148	3 350
907	Male	500	283	1	3	323	788	1 836
	Female	581	391	1	5	360	1 506	3 006
908	Male	469	294	1	7	276	708	2 512
	Female	478	309	1	15	308	1 230	3 099
QMA	Male	2 548	1 485	1	5	260	726	2 512
	Female	2 485	1 766	1	13	351	1 280	3 350

Table C.8: Statistics for tail width growth increments (mm) for recaptures of CRA 2. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

			Tail width growth increment (mm)				
Statistical Area of release	Sex	N	Minimum	5%	Median	95%	Maximum
Unknown	Male	24	-2.0	-1.00	0.50	13.20	19.0
	Female	12	-1.0	-0.45	1.00	5.00	5.0
905	Male	27	-1.0	0.15	4.90	15.40	15.7
	Female	164	-4.0	-0.17	2.00	10.98	20.7
906	Male	1528	-37.0	-1.00	3.00	12.70	27.7
	Female	1250	-19.3	-1.30	2.16	10.30	20.7
907	Male	500	-23.0	-0.30	3.35	16.03	26.7
	Female	581	-24.3	-1.00	3.20	14.70	24.7
908	Male	469	-9.3	-0.40	2.40	10.92	25.5
	Female	478	-22.3	-1.30	2.00	10.70	20.5
QMA	Male	2548	-37.0	-1.00	2.75	13.63	27.7
	Female	2485	-24.3	-1.30	2.50	11.30	24.7

Table C.9: The number and proportion of recaptured tag releases by period at liberty category and by QMA.

QMA of	Number of tags spending period at liberty			Proportion of tags spending period at liberty	
release	< 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

APPENDIX D. PROPORTION MATURE ANALYSIS

Introduction

The proportion of females mature by tail width (TW) is a covariate that is used to calculate spawning stock biomass (SSB), given model predictions of numbers by TW and year. All recent red rock lobster stock assessments estimated maturation (the rate at which females become mature by TW) parameters inside the model. Up until 1998, red rock lobster stock assessments did not separate out mature and immature females at the model fitting phase. Maturity was estimated outside of the model and applied to model outputs to estimate SSB. From 1999, length-based stock assessments modelled immature and mature female size and sex-composition data separately, which informed the estimation of maturity at TW within the model. This allowed the representation of potential differences in vulnerability of immature and mature females, although this approach has some issues:

- for some stock assessments (e.g., the 2024 assessment of CRA 3), there were too few data to estimate vulnerabilities separately from maturation and other model parameters, causing convergence issues for the assessment model;
- for some QMAs, model estimates of maturation can vary in model sensitivity trials, with implications for SSB;
- immature female length-frequencies (LFs) and sex ratio proportions (SRs) appeared to overly influence model fits for some assessments, even when few of these are captured (e.g., the 2024 assessment of CRA 3); and
- separating out immature and mature females complicates models, slows model run times, and may unnecessarily increase the volume of model outputs.

By comparison, the current assessment is a two-sex model (males and females of all maturity stages) that does not distinguish females by maturity stage at the model-fitting stage and thus requires a *maturity* TW ogive to be estimated outside of the stock assessment model to assign maturity stage post-model fitting. This appendix gives a summary of the analysis producing this maturity ogive.

Methods

Data

The main sources of female maturity stage information are both fishery-dependent:

- at-sea pot-based catch sampling by technicians (CS), and
- voluntary logbook sampling by commercial fishers (LB).

These sources differ in terms of their perceived accuracy (CS data are collected by trained technicians, so are likely to be more accurate) and representativeness (LB data are collected over a much greater number of fishing trips, so are likely to be more representative).

Initial exploration identified problems estimating maturity for some South Island QMAs, including confounding with maturation-related movement between CRA 7 and CRA 8 and poor-quality LB maturity data for some vessels in northern CRA 5. The current analysis was therefore restricted to CRA 1–4 around the North Island, with the intention of extending it to South Island QMAs in future.

Individuals were classified as mature if they were recorded as having ovigerous setae, being in berry, or spent; a small number with unknown status were excluded. The sex codes used for mature females differed between the CS and LB programmes:

- **CS sex codes**: 3 (female with setae), 4 (berried female), 5 (berried female, eyed eggs), 6 (spent female with infertile eggs), and 7 (spent female with no infertile eggs).
- **LB sex codes**: 3 (mature female), 4 (berried female), and 5 (spent female).

A small number of logbook vessels that had never recorded an immature female were excluded from this analysis. The recorded statistical areas (and QMAs) associated with maturity stage observations were assigned based on reported geolocation where this was supplied and then based on the reported statistical area.

Modelling approach

Initial model explorations were done using binomial (1 = mature, 0 = immature) Generalised Additive Models (GAMs) (Wood, 2011), with the intention of identifying useful model terms and structures to be carried forward to formal *brms* model runs (Bürkner, 2017). Model terms trialled for the initial GAM-based modelling exploration included tail width in mm (TW) (a forced model term), QMA/stock assessment region (*qma_region*), fishing year (*fyear*), autumn-winter or spring-summer season (*season*), and 20 m binned bathymetric depth (*depth*). Statistical area was not considered, since we needed maturity by assessment QMA/region and did not need to weight for the catch (we want the maturity of all females, not just the captured portion). The selection of model terms was based on the percentage of null model deviance explained.

The *brms* models were also specified as binomial models fitted to the total number of females that were mature, given the total number of females sampled (trials) in each fishing year–QMA/region–1 mm TW-bin stratum, which dramatically sped up model run times. The default *brms* priors were assumed for all estimated parameters. *brms* model selection was based on Expected Log Pointwise Predictive Density difference (δ-ELPD) comparing model runs and the standard error of this difference (SE δ-ELPD), where a model was judged to be superior if δ-ELPD was at least 4 times greater than (SE δ-ELPD). Models were considered to have converged when all estimated parameters had a Gelman-Rubin diagnostic ($\hat{R}$) < 1.05 and the MCMC traces were visually acceptable. The degree of model fit to the data was assessed based on posterior predictive check plots and plots of Pearson residuals.

The final predictions from the optimal *brms* model were not catch-weighted, given that we are ultimately interested in the maturity of the wider population, rather than just the lobsters that are vulnerable to the fishery.

Results

Data summary

A large sample of females was available for all the assessed QMA/regions, representing a broad range of tail widths (Figure D.2). The raw data were used to produce plots of the proportion of females mature by tail width (Figure D.3). These plots indicate that females mature at larger sizes in CRA 1 and CRA 2 than in CRA 3 and CRA 4, though with better agreement between data sources in some QMA/regions (CRA 4 and region 1 of CRA 3) than others (CRA 1 and region 2 of CRA 3).

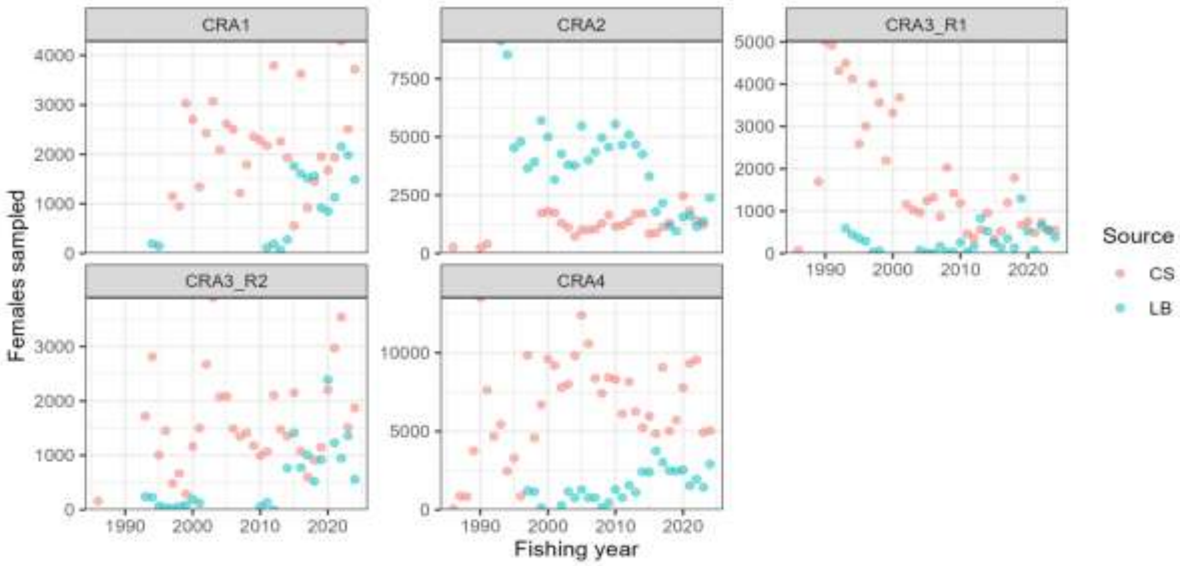

Figure D.1: Sample size of females used in maturity analysis by fishing year, data source ('CS' = observer catch sampling, 'LB' = voluntary logbook), and QMA/region.

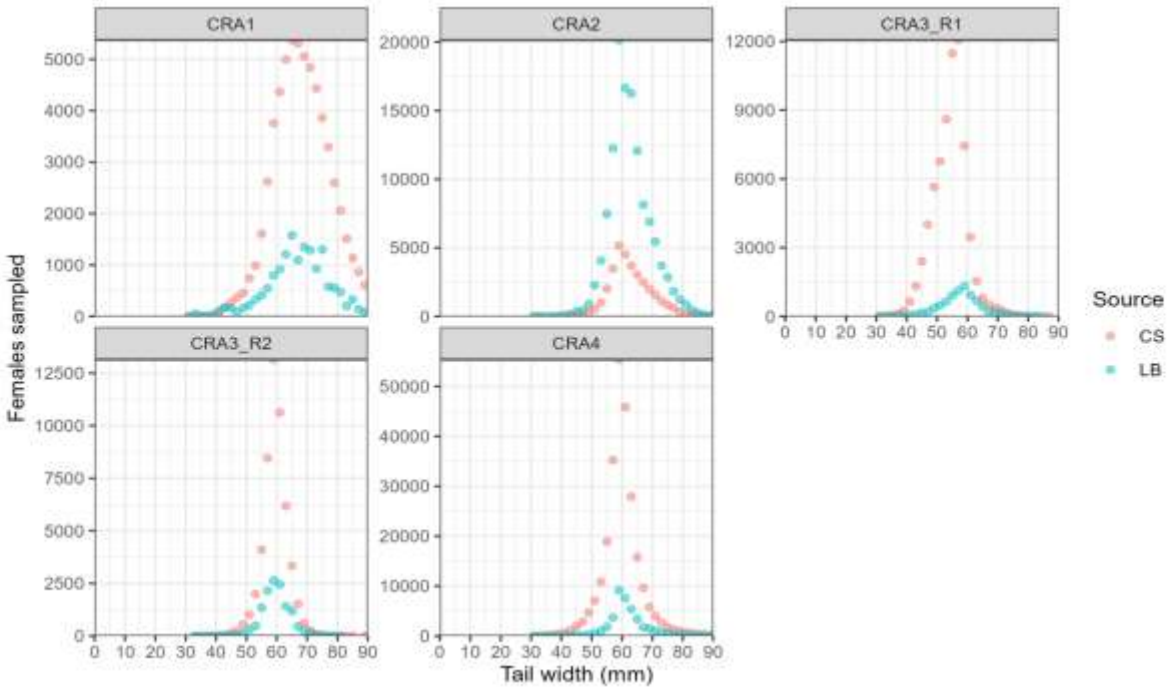

Figure D.2: Sample size of females used in maturity analysis by 1 mm tail width bin, data source ('CS' = observer catch sampling, 'LB' = voluntary logbook), and QMA/region.

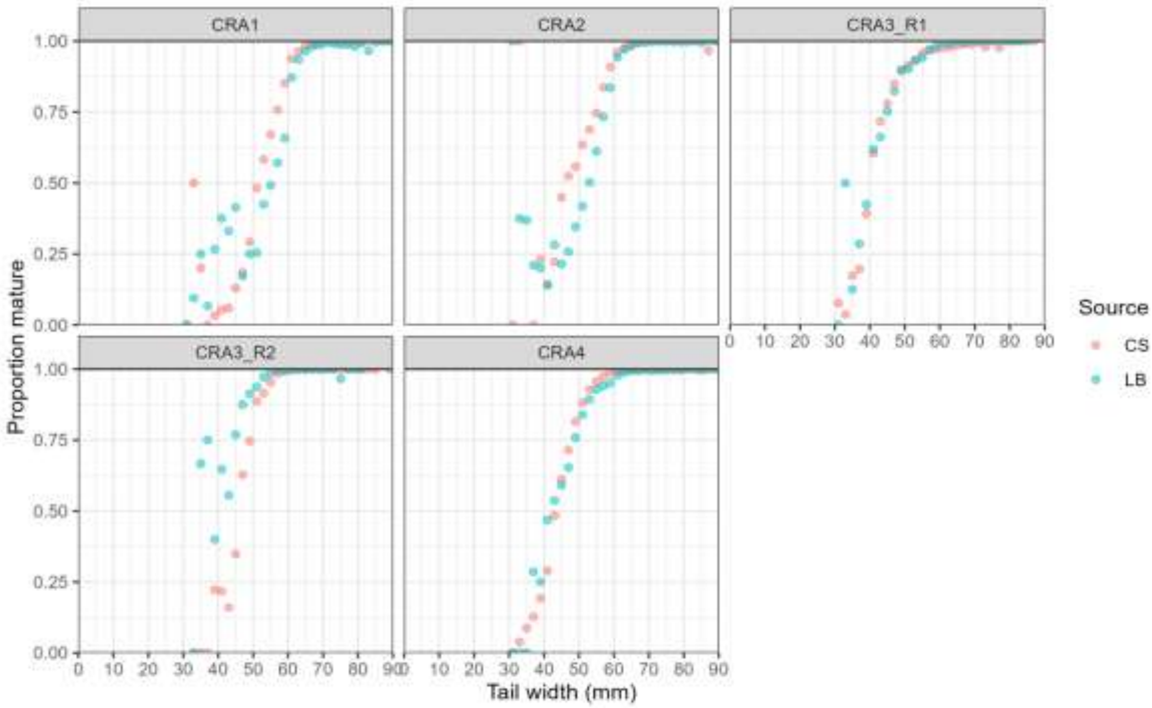

Figure D.3: Proportion of females mature by 1 mm tail width bin, data source (‘CS’ = observer catch sampling, ‘LB’ = voluntary logbook), and QMA/region.

Initial model exploration

Season and depth bin were not found to explain much of the model deviance so were excluded, while fishing year and QMA or QMA/region explained a good portion of this deviance. Thus, the optimal model structure from this phase of model development was

maturity ~ TW + qma_region + TW:qma_region + s(fyear, qma_region, bs = “re”)

where the tail width–QMA/region interaction term allowed the gradient of the tail width effect to vary by QMA/region. Fishing year was specified as a random effect that was allowed to vary by QMA/region. This model explained 35.4% of the null model deviance.

brms models

Subsequent model exploration was done using *brms* models, which focused on model structures for dealing with poor-quality data from some LB vessels. These vessels had implausibly high proportions of smaller lobsters (< 35 mm TW) that were recorded as mature. This was achieved via the inclusion of vessel effects, using alternative parameterisations and excluding the fishing year effect (Table D.1). The best model (*fit8*) in terms of ELPD specified correlated random slopes and intercepts for the vessel effect with respect to TW, with vessel nested within QMA/region to account for some vessels operating in both regions of CRA 3.

The final model runs included a longer run of *fit8* (called *fit11*) and runs that included additional year effects, specified either as a random intercept by QMA/region (*fit12*), or as a spline, also by QMA/region (*fit13*) (Table D.2). Of these, *fit12* was the best in terms of model ELPD, although outputs are summarised for this model as well as the year-invariant model (*fit11*), which was ultimately used to generate outputs for the CRA 1 and CRA 2 stock assessments.

The MCMC chains for models *fit11*, *fit12*, and *fit13* mixed acceptably (Figure D.4, Figure D.5, Figure D.6), with no divergent transitions reported. The model fits to the data were good (Figure D.7, Figure D.8, Figure D.9, Figure D.10, Figure D.11, Figure D.12). The posteriors of the estimated parameters for these models are summarised in Table D.3, Table D.4 and Table D.5.

Table D.1: Comparison of *brms* maturity models exploring different parameterisations of the vessel effect.

<table>
<tr><th>Label</th><th>Model structure</th><th>delta-ELPD</th><th>SE delta-ELPD</th></tr>
<tr><td>fit8</td><td>mature | trials(trials) ~ tw_bin2 + (1 + tw_bin2 | qma_region) + (1 + tw_bin2 | qma_region:vessel)</td><td>0</td><td>0</td></tr>
<tr><td>fit7</td><td>mature | trials(trials) ~ tw_bin2 + tw_bin2:qma_region + qma_region + (1 + tw_bin2 | vessel)</td><td>-114</td><td>26</td></tr>
<tr><td>fit6</td><td>mature | trials(trials) ~ tw_bin2 + tw_bin2:qma_region + qma_region + (1 | vessel)</td><td>-1 743</td><td>150</td></tr>
<tr><td>fit4</td><td>mature | trials(trials) ~ tw_bin2 + tw_bin2:qma_region + qma_region</td><td>-14 141</td><td>760</td></tr>
</table>

Table D.2: Comparison of *brms* maturity models exploring different parameterisations of the year effect.

<table>
<tr><th>Label</th><th>Model structure</th><th>delta-ELPD</th><th>SE delta-ELPD</th></tr>
<tr><td>fit12</td><td>mature | trials(trials) ~ tw_bin2 + (1 + tw_bin2 | qma_region) + (1 + tw_bin2 | qma_region:vessel) + (1 | qma_region:fyear)</td><td>0</td><td>0</td></tr>
<tr><td>fit13</td><td>mature | trials(trials) ~ tw_bin2 + (1 + tw_bin2 | qma_region) + (1 + tw_bin2 | qma_region:vessel) + s(fyear, by = qma_region)</td><td>-2 101</td><td>195</td></tr>
<tr><td>fit11</td><td>mature | trials(trials) ~ tw_bin2 + (1 + tw_bin2 | qma_region) + (1 + tw_bin2 | qma_region:vessel)</td><td>-4 232</td><td>296</td></tr>
</table>

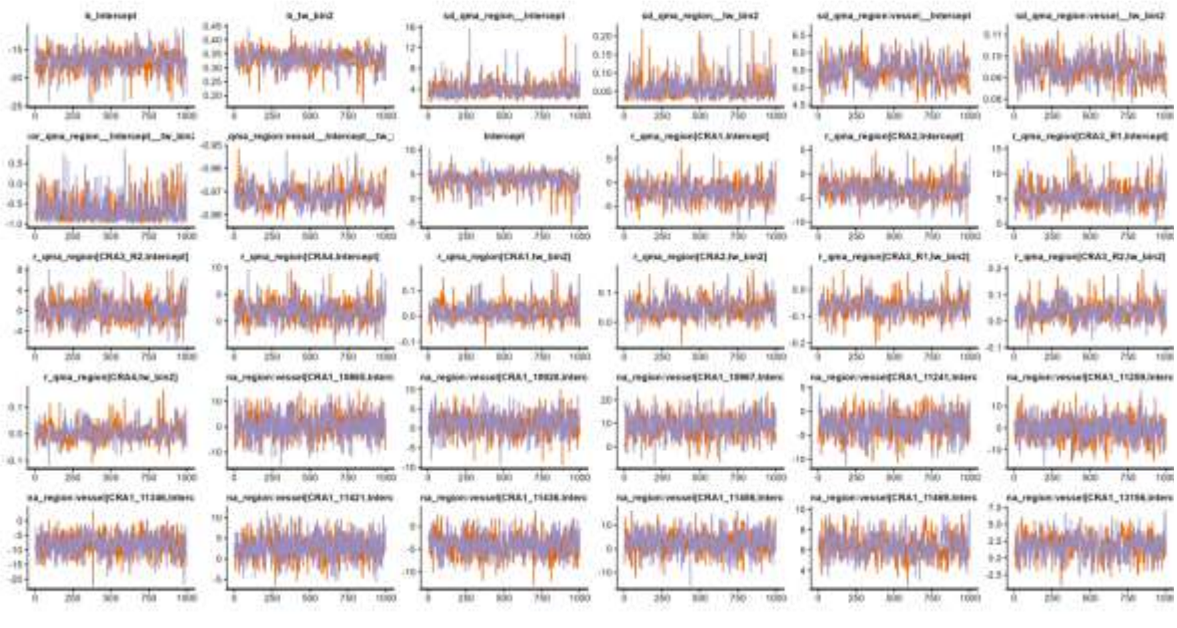

Figure D.4: MCMC trace plots for selected model parameters for maturity models *fit11*.

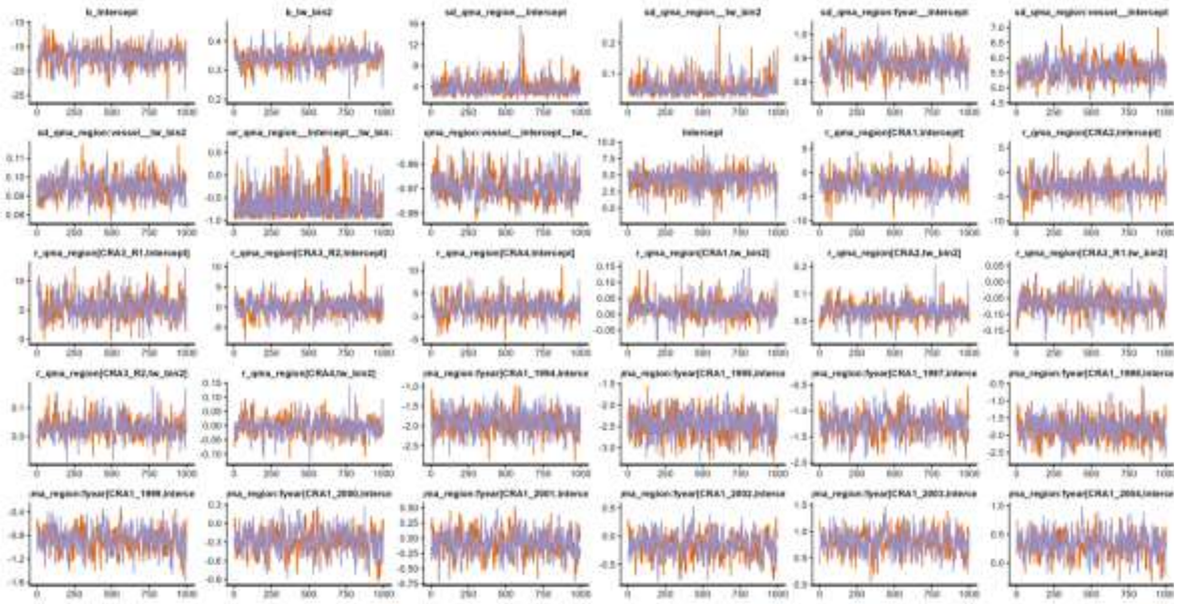

Figure D.5: MCMC trace plots for selected model parameters for maturity models *fit12*.

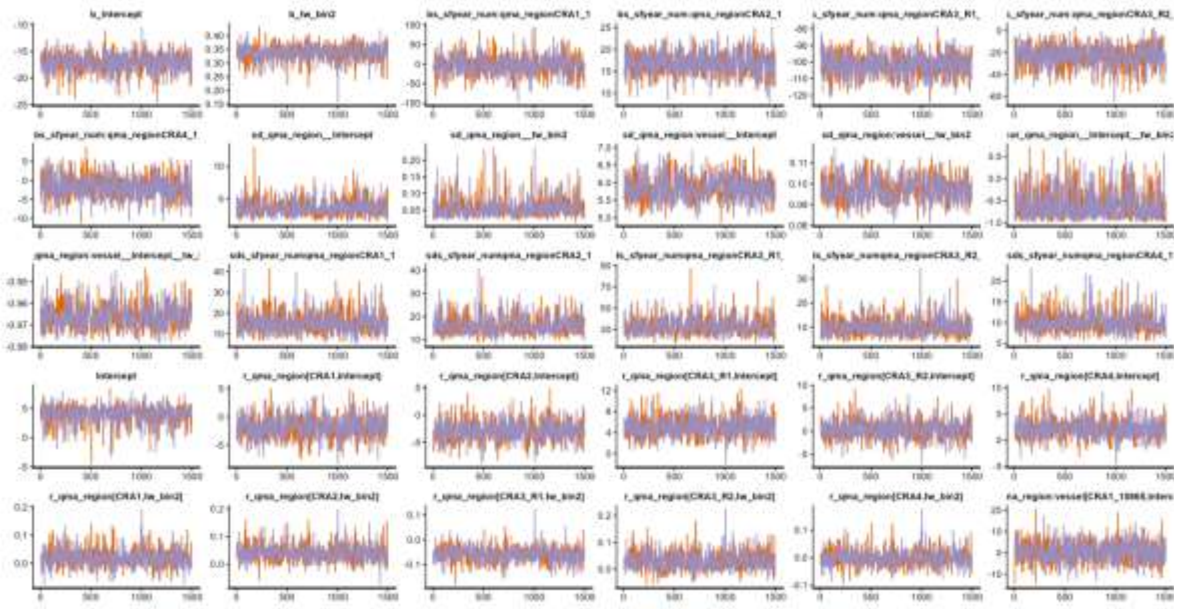

Figure D.6: MCMC trace plots for selected model parameters for maturity models *fit13*.

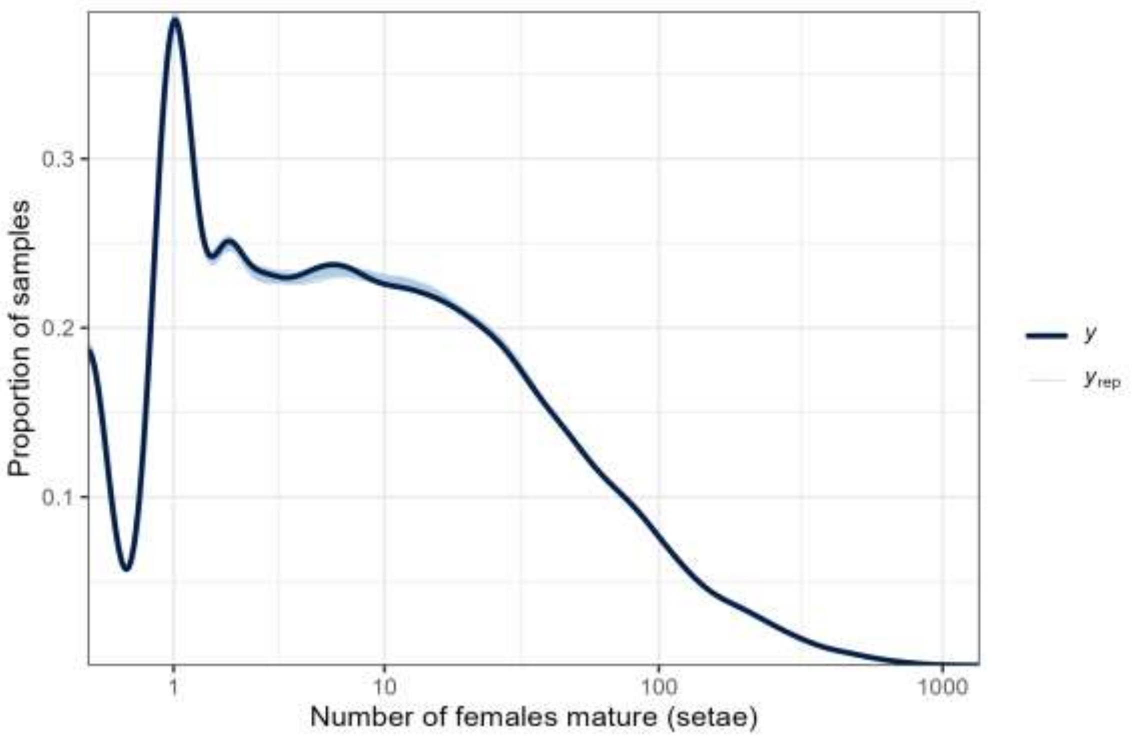

Figure D.7: Posterior predictive check plot for maturity model *fit11*. The navy-blue line represents the distribution of the data and the light blue lines are simulations from the model.

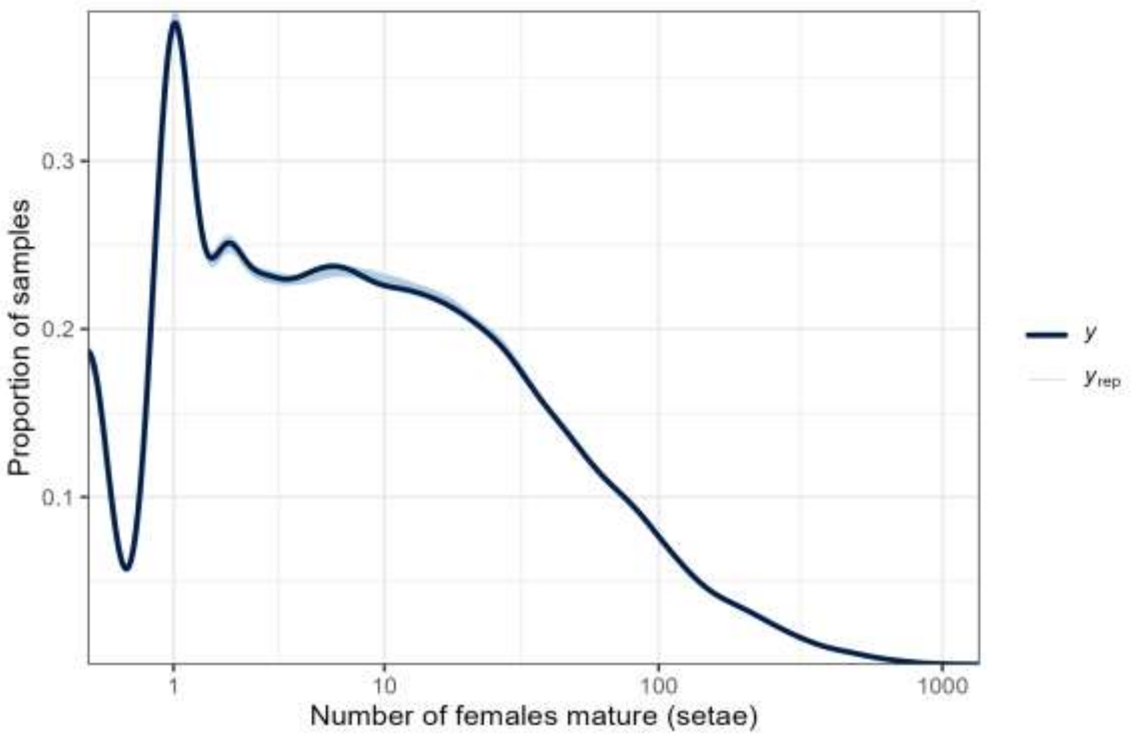

Figure D.8: Posterior predictive check plot for maturity model *fit12*. The navy-blue line represents the distribution of the data and the light blue lines are simulations from the model.

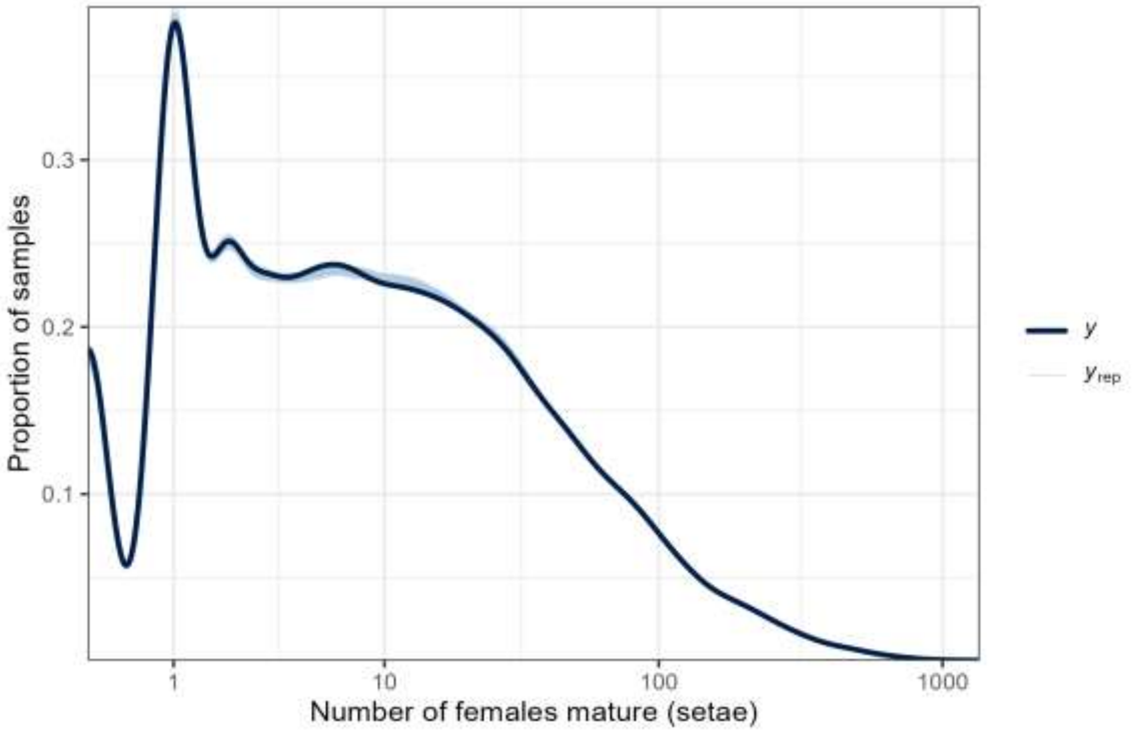

Figure D.9: Posterior predictive check plot for maturity model *fit13*. The navy-blue line represents the distribution of the data and the light blue lines are simulations from the model.

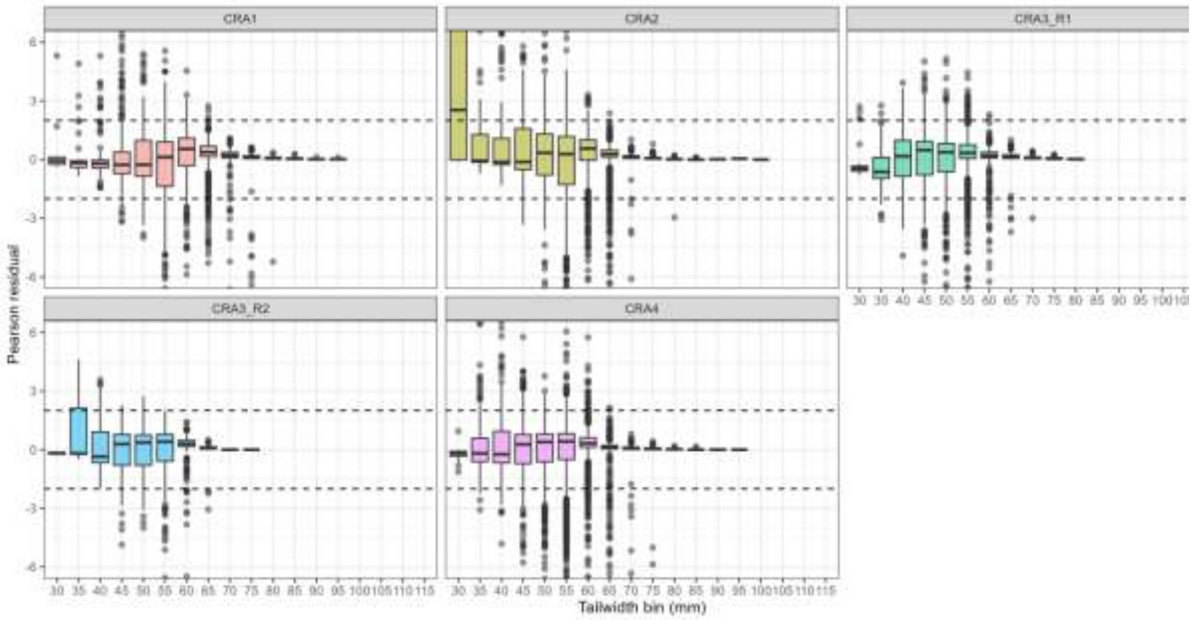

Figure D.10: Boxplot of model residuals with respect to tail width for maturity model *fit11*, aggregated into 5 mm TW bins.

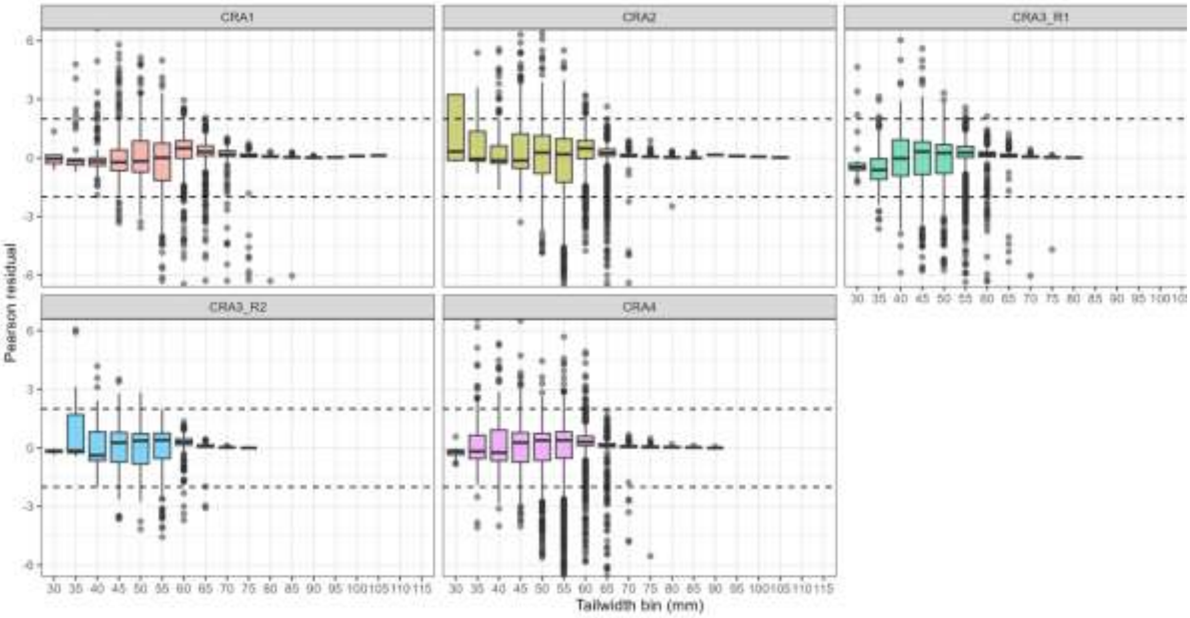

Figure D.11: Boxplot of model residuals with respect to tail width for maturity model *fit12*, aggregated into 5 mm TW bins.

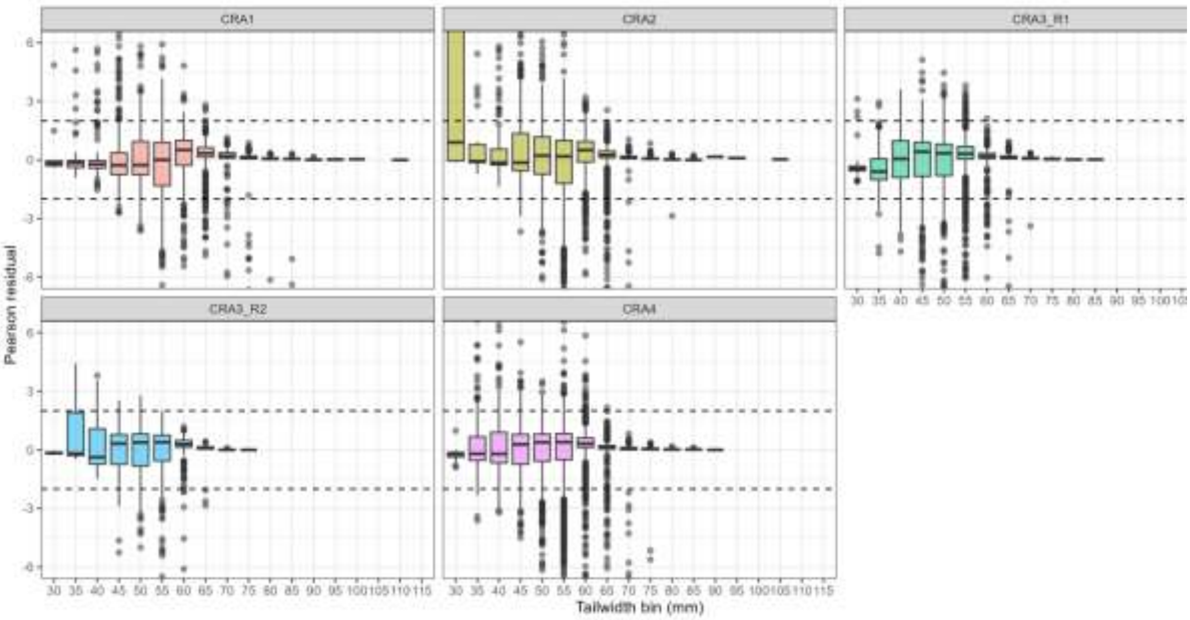

Figure D.12: Boxplot of model residuals with respect to tail width for maturity model *fit13*, aggregated into 5 mm TW bins.

Table D.3: Summary of parameter estimates of *fit11*. This table excludes parameters relating to vessel effects.

Parameter	Median	5%	97.5%
b_Intercept	-17.0036500	-21.2675350	-13.4844025
b_tw_bin2	0.3367275	0.2569196	0.3865438
sd_qma_region__Intercept	3.5393550	2.0238480	7.2600945
sd_qma_region__tw_bin2	0.0509604	0.0262227	0.1293170
cor_qma_region__Intercept__tw_bin2	-0.7395535	-0.9691850	0.1631356
Intercept	4.0866150	-0.5053241	6.2647695
r_qma_region[CRA1,Intercept]	-1.9396700	-5.9914178	2.3274707
r_qma_region[CRA2,Intercept]	-3.2855900	-6.7436715	0.6388211
r_qma_region[CRA3_R1,Intercept]	5.5120700	1.8666733	10.2324925
r_qma_region[CRA3_R2,Intercept]	-0.2163770	-4.1683900	4.5971585
r_qma_region[CRA4,Intercept]	1.7356950	-1.5775015	5.9430397
r_qma_region[CRA1,tw_bin2]	0.0164189	-0.0393287	0.0991895
r_qma_region[CRA2,tw_bin2]	0.0440019	-0.0111733	0.1206429
r_qma_region[CRA3_R1,tw_bin2]	-0.0662500	-0.1285173	0.0119692
r_qma_region[CRA3_R2,tw_bin2]	0.0353264	-0.0266464	0.1239696
r_qma_region[CRA4,tw_bin2]	0.0022515	-0.0527785	0.0820241

Table D.4: Summary of parameter estimates of *fit12*. This table excludes parameters relating to fishing year and vessel effects.

Parameter	Median	5%	97.5%
b_Intercept	-16.9903500	-21.1497775	-13.2907450
b_tw_bin2	0.3414530	0.2759581	0.3958130
sd_qma_region__Intercept	3.4158150	1.9968192	7.3428822
sd_qma_region__tw_bin2	0.0485276	0.0229169	0.1229533
cor_qma_region__Intercept__tw_bin2	-0.7730100	-0.9714280	0.1498542
Intercept	4.5380700	1.2000360	6.9019032
r_qma_region[CRA1,Intercept]	-2.1079300	-6.1152588	1.8683530
r_qma_region[CRA2,Intercept]	-2.9145000	-6.6166872	1.2667257
r_qma_region[CRA3_R1,Intercept]	5.4356850	1.8550760	9.7374862
r_qma_region[CRA3_R2,Intercept]	-0.0646694	-4.1296722	4.2958055
r_qma_region[CRA4,Intercept]	1.8625250	-2.0794200	6.2959257
r_qma_region[CRA1,tw_bin2]	0.0173210	-0.0376764	0.0879743
r_qma_region[CRA2,tw_bin2]	0.0355511	-0.0160316	0.1036902
r_qma_region[CRA3_R1,tw_bin2]	-0.0649712	-0.1308689	-0.0033718
r_qma_region[CRA3_R2,tw_bin2]	0.0280776	-0.0285610	0.1072304
r_qma_region[CRA4,tw_bin2]	-0.0048398	-0.0636303	0.0648948

Table D.5: Summary of parameter estimates of *fit13*. This table excludes parameters relating to fishing year and vessel effects.

Parameter	Median	5%	97.5%
b_Intercept	-16.9889500	-20.9317800	-13.8390125
b_tw_bin2	0.3389495	0.2687898	0.3886714
sd_qma_region__Intercept	3.3427100	1.8814510	6.6799810
sd_qma_region__tw_bin2	0.0489704	0.0233588	0.1340948
cor_qma_region__Intercept__tw_bin2	-0.7038560	-0.9670891	0.2466327
Intercept	4.2668500	0.0448734	6.5053755
r_qma_region[CRA1,Intercept]	-1.8079800	-5.6678935	2.0773270
r_qma_region[CRA2,Intercept]	-2.9435400	-6.4884485	0.8508440
r_qma_region[CRA3_R1,Intercept]	4.9629800	1.5154165	9.2060352
r_qma_region[CRA3_R2,Intercept]	0.1885170	-3.6555628	4.6130832
r_qma_region[CRA4,Intercept]	2.0833350	-1.3003835	6.1255495
r_qma_region[CRA1,tw_bin2]	0.0162599	-0.0388907	0.0977639
r_qma_region[CRA2,tw_bin2]	0.0386408	-0.0104284	0.1124190
r_qma_region[CRA3_R1,tw_bin2]	-0.0582759	-0.1216099	0.0002700
r_qma_region[CRA3_R2,tw_bin2]	0.0290382	-0.0245429	0.1062946
r_qma_region[CRA4,tw_bin2]	-0.0033732	-0.0577511	0.0662992

The year-invariant model (*fit11*) was used to predict the proportion of females mature by tail width and QMA/region (Figure D.13) because only one maturity function was preferred for the stock assessment. These indicate that 50% maturity of females occurred around 53 mm TW in CRA 1 and CRA 2, but was closer to 45 mm TW in CRA 3 and CRA 4. The year-varying model specifying a fishing year random intercept (*fit12*) was also used to predict the proportion of females mature, except this time by fishing year as well as QMA/region for a selection of tail width values (Figure D.14). For CRA 2, this model predicted that females matured at smaller sizes in the late 1990s (50% maturity < 50 mm TW) than in fishing years after this period. For CRA 4, the model predictions were consistent with lobsters maturing at larger sizes over time since the mid-1990s. The annual predictions for CRA 1 and both regions of CRA 3 were more uncertain with no obvious long-term trends.

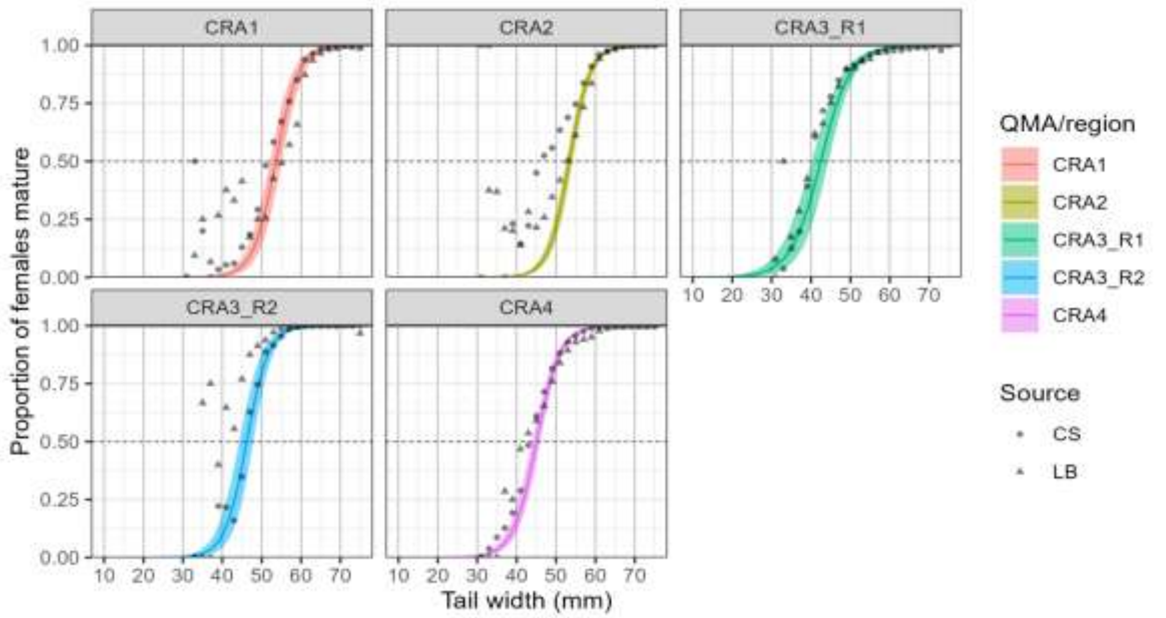

Figure D.13: Predicted proportion of females mature by tail width and QMA/region from maturity model *fit11*. The lines and shaded areas represent the median and 95% credible range of the predictions. The points represent the tail width binned averages of the raw data (‘CS’ = observer catch sampling, ‘LB’ = voluntary logbook).

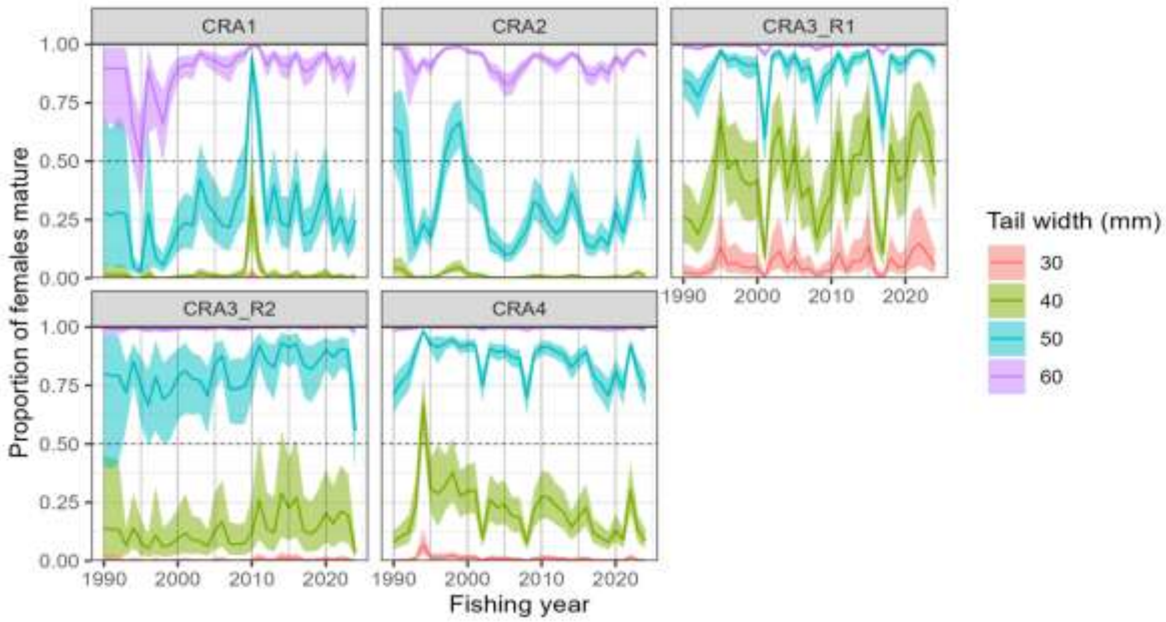

Figure D.14: Predicted proportion of females mature by fishing year and QMA/region for a series of tail width values from maturity model *fit12*. The lines and shaded areas represent the median and 95% credible range of the predictions.

APPENDIX E. PROPORTION IN BERRY ANALYSIS

Introduction

In recent assessments, the proportion of mature females in berry was used as a covariate to exclude berried females from the size-limited (SL) catch, comprising legal commercial and recreational catch, because regulations require all females carrying visible eggs to be returned to sea. The current CRA 1 and CRA 2 stock assessment model, however, does not distinguish immature from mature females within a size bin. The updated assessment therefore required the proportion of all females in berry, regardless of maturity stage, by tail width (TW), season, and QMA/region to model the discard of berried females correctly.

Following the approach used in the 2024 assessments of CRA 3 and CRA 4 (Roberts et al. 2025, Rudd et al. 2025), biological data from both the at-sea observer catch sampling (CS) and voluntary logbook (LB) programmes were used to derive standardised proportions of berried females by tail width, QMA/stock assessment region, and AW/SS season.

Methods

Data

The main sources of female maturity stage information are both fishery-dependent:

- at-sea pot-based catch sampling by technicians (CS), and
- voluntary logbook sampling by commercial fishers (LB).

The data used are the same as for the maturity analysis, which are summarised in Figure D.3. Berried status was defined as:

- **CS sex codes**: 4 (berried female) or 5 (berried female, eyed eggs).
- **LB sex codes**: 4 (berried female).

Modelling approach

The model development process was implemented using *brms* models (Bürkner 2017), which were also used to make final predictions of the proportion berried by tail width. Model terms trialled included the tail width in mm (a forced model term), QMA/stock assessment region (*qma_region*), fishing month (*fmonth*), fishing year (*fyear*), and vessel (*vessel*). Following the approach of the maturity analysis (Appendix D), *brms* models were specified as binomial models (1 = in berry, 0 = not in berry) fitted to the total number of females that were in berry, given the total number of females sampled (trials) in each fishing year–QMA/region–TW-bin stratum (5 mm bins were used for TW in order to reduce the overall number of strata, to speed up model run times). The default *brms* priors were assumed for all estimated parameters. Model selection was based on Expected Log Pointwise Predictive Density difference (δ-ELPD) comparing model runs and the standard error of this difference (SE δ-ELPD), where a model was judged to be superior if δ-ELPD was at least 4 times greater than (SE δ-ELPD). Models were considered to have converged when all estimated parameters had a Gelman-Rubin diagnostic ($\hat{R}$) < 1.05 and the MCMC traces were visually acceptable. The degree of model fit to the data was assessed based on posterior predictive check plots and plots of Pearson residuals.

Unlike the maturity analysis described in Appendix D, the analysis required information that is representative of the captured portion of the stock, rather than the wider stock. As such, the predictions from the optimal *brms* model were catch-weighted. Thus, there were two stages to the analysis that generated the proportion in berry estimates:

1. a *brms* model-based standardisation predicted the proportion of females that were berried/not berried in each QMA/region-season-TW bin stratum; then

2. using the reported catch in each (QMA/region-season-TW) stratum, catch-weighted values of the proportion of females in berry were produced for each stock-region and season and (as required) fishing year. The catch weighting used the ‘F0_LFX algorithm’, i.e., all reported landings, legal discards, and recreational take by commercial fishers.

Results

Initial model exploration

Exploratory GAMs (not reported here) showed that fishing month was the best predictor of the proportion of females in berry and that the seasonal pattern varied by QMA. Therefore, the initial *brms* models all included a fishing month random intercept with a fishing month:QMA/region interaction random intercept. The first set of *brms* model comparisons explored alternative parameterisations with respect to the TW effect (Table E.1), including TW splines that allowed less than 100% of females to be berried outside of their spawning period and for some individuals to skip spawning. The best models in terms of ELPD all included a TW spline by QMA/region, although they differed in terms of the basis dimension smooth (k) value, which controlled the variability of the splines. The optimal value for this was found to be k = 4, as used by *fit4* (*fit6,* which allowed splines with greater variability, was better in terms of ELPD, although δ-ELPD compared with *fit4* was less than 4 × SE δ-ELPD).

Table E.1: Comparison of *brms* proportion berried models exploring different parameterisations of the tail width (TW) effect.

Label	Model structure	delta-ELPD	SE delta-ELPD
fit6	berried | trials ~s(TW, qma_region, k = 5) + (1 | fmonth) + (1 | fmonth:qma_region)	0	0
fit4	berried | trials ~s(TW, qma_region, k = 4) + (1 | fmonth) + (1 | fmonth:qma_region)	-170	84
fit5	berried | trials ~s(TW, qma_region, k = 3) + (1 | fmonth) + (1 | fmonth:qma_region)	-1 276	225
fit3	berried | trials ~ TW + qma_region + TW:qma_region + (1 | fmonth) + (1 | fmonth:qma_region)	-3 442	350
fit2	berried | trials ~ (1 | fmonth) + (1 | fmonth:qma_region)	-9 567	774

In the next phase of model development, a vessel effect was included using alternative parameterisations (Table E.2). The best model in terms of ELPD (*fit8*) specified correlated random slopes and intercepts for the vessel effect with respect to TW, with vessel nested within QMA/region to account for some vessels operating in both regions of CRA 3 (i.e., the same parameterisation used by the optimal maturity model described in Appendix D). However, *fit8* mixed poorly and a simpler parameterisation (*fit9*) was found to be sufficient for obtaining a good model fit to the data (see below). Unlike the maturity models, fishing year was not trialled, because year-varying proportions in berry were found to have a negligible effect on the outputs in previous stock assessment model development. Thus, *fit9* was chosen as the optimal model for making predictions of the proportion of females in berry.

Table E.2: Comparison of *brms* proportion-in-berry models exploring different parameterisations of the vessel effect.

Label	Model structure	delta-ELPD	SE delta-ELPD
fit8	berried | trials(trials) ~ s(tw_bin5, by = qma_region, k = 4) + (1 | fmonth) + (1 | fmonth:qma_region) + (1 + tw_bin5 | qma_region) + (1 + tw_bin5 | qma_region:vessel)	0	0
fit9	berried | trials(trials) ~ s(tw_bin5, by = qma_region, k = 4) + (1 | fmonth) + (1 | fmonth:qma_region) + (1 + tw_bin5 | qma_region:vessel)	-52	14
fit4	berried | trials(trials) ~ s(tw_bin5, by = qma_region, k = 4) + (1 | fmonth) + (1 | fmonth:qma_region)	-7 557	701

The MCMC chains for model *fit9* mixed acceptably (Figure E.), with no divergent transitions reported. The model fits to the data were good (Figure E.2, Figure E.3, Figure E.4). The posteriors of the estimated parameters of model *fit9* are summarised in Table E.3.

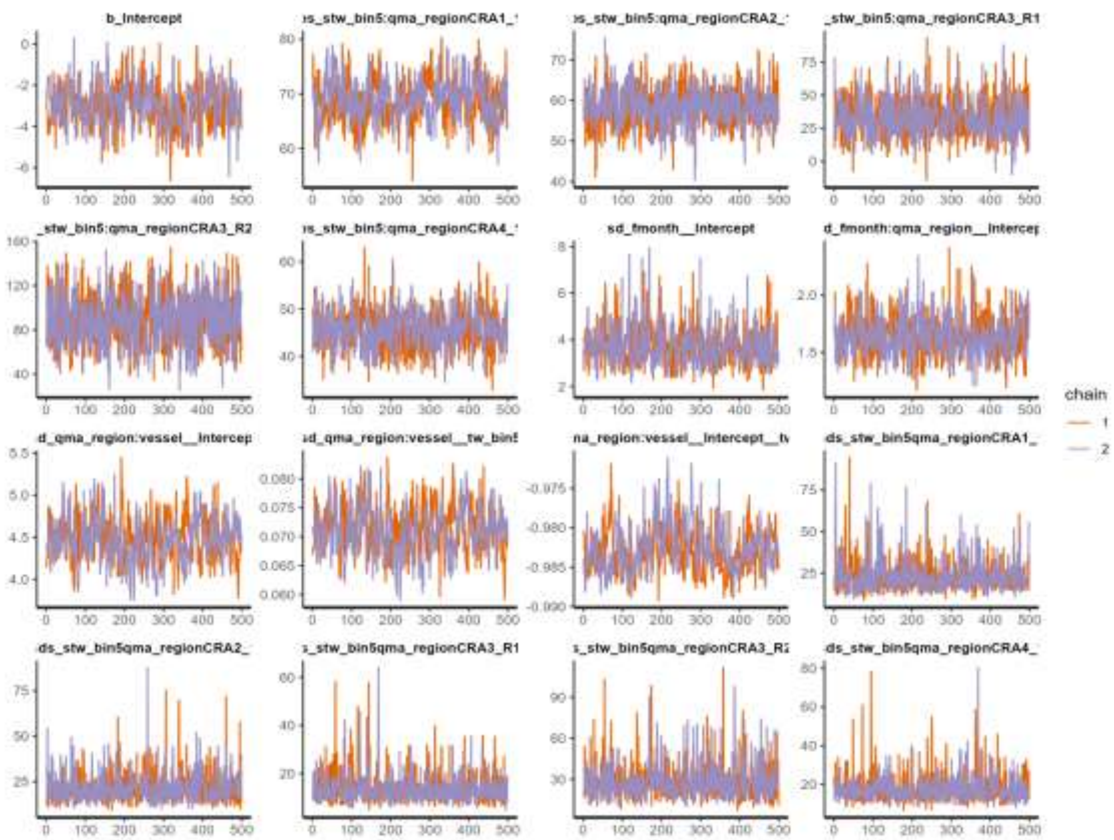

Figure E.1: MCMC trace plots for selected model parameters for proportion in berry model *fit9*.

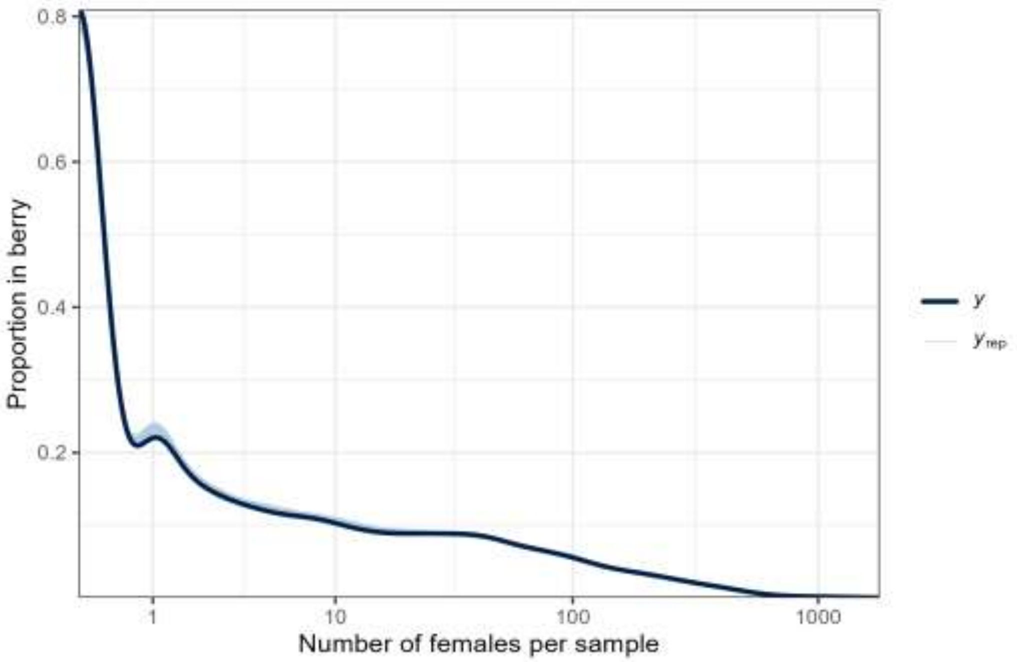

Figure E.2: Posterior predictive check plot for proportion in berry model *fit9*. The navy blue line represents the distribution of the data and the light blue lines are simulations from the model.

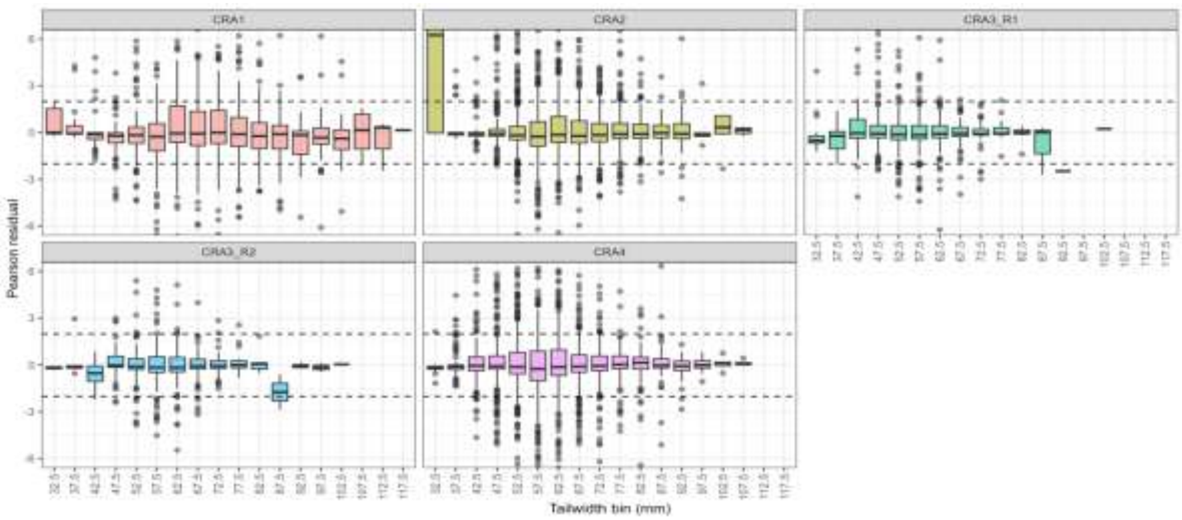

Figure E.3: Boxplot of model residuals with respect to tail width for proportion in berry model *fit9*, aggregated into 5 mm TW bins.

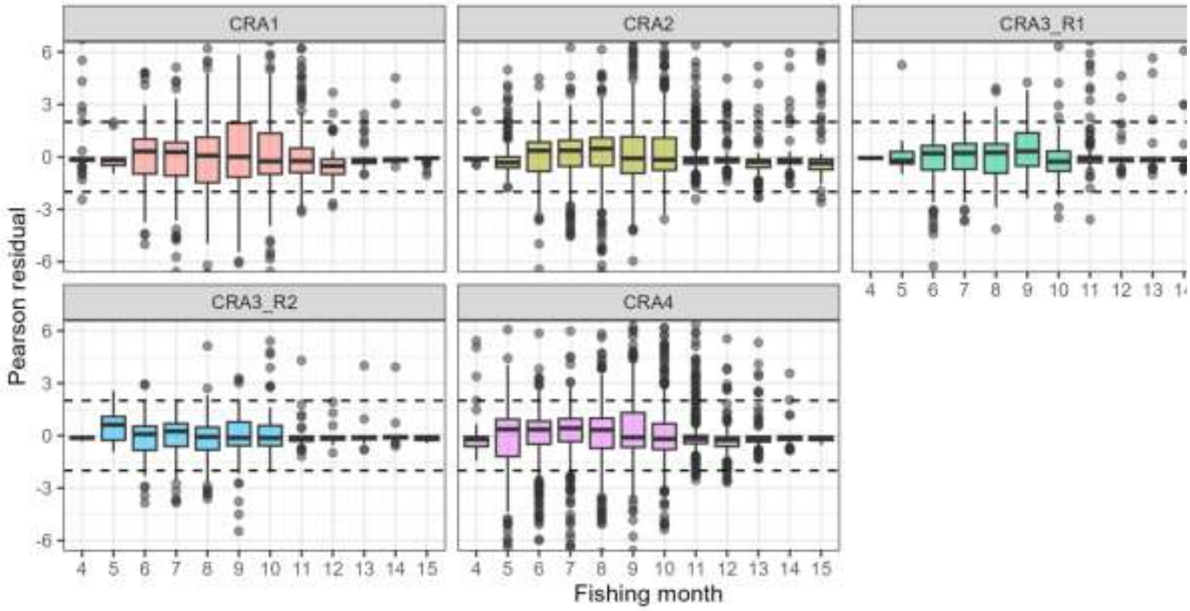

Figure E.4: Boxplot of model residuals with respect to fishing month for proportion in berry model *fit9*. Month 4 = April.

Table E.3: Summary of parameter estimates of proportion berried model *fit9*. This table excludes parameters relating to vessel effects and fishing month-QMA/region interaction terms.

Parameter	Median	5%	97.5%
b_Intercept	-3.0400100	-4.989423	-0.9304992
bs_stw_bin5:qma_regionCRA1_1	68.9084000	61.321950	77.1601250
bs_stw_bin5:qma_regionCRA2_1	58.2920500	49.221425	68.3541075
bs_stw_bin5:qma_regionCRA3_R1_1	31.7548500	7.202310	66.4681050
bs_stw_bin5:qma_regionCRA3_R2_1	88.0555500	43.693892	138.1366500
bs_stw_bin5:qma_regionCRA4_1	45.5793000	37.499072	54.4578400
sd_fmonth__Intercept	3.6052900	2.466248	5.8622873
sd_fmonth:qma_region__Intercept	1.6246050	1.316537	2.0299373
Intercept	-3.0400100	-4.989423	-0.9304992
r_fmonth[10,Intercept]	-0.6223005	-2.903931	1.8211875
r_fmonth[11,Intercept]	-2.5971150	-4.827538	-0.0020723
r_fmonth[12,Intercept]	-2.8636200	-5.193777	-0.3830868
r_fmonth[13,Intercept]	-3.6008300	-6.216906	-1.2406880
r_fmonth[14,Intercept]	-4.1659500	-6.714747	-1.7148110
r_fmonth[15,Intercept]	-4.3704850	-6.930707	-1.7970810
r_fmonth[4,Intercept]	-3.9328250	-6.519539	-1.3593800
r_fmonth[5,Intercept]	0.0079958	-2.252636	2.4624410
r_fmonth[6,Intercept]	4.4733450	2.072057	6.8195635
r_fmonth[7,Intercept]	4.8651950	2.558020	7.3215187
r_fmonth[8,Intercept]	4.0842000	1.799858	6.5146070
r_fmonth[9,Intercept]	1.3561400	-1.111430	3.7500112

Predictions of the non-catch-weighted proportion of females in berry from *fit9* are shown by TW, QMA/region, and fishing month in Figure E.5. The model predictions are a good representation of the monthly data and are consistent with spawning starting at larger TW and having a shorter duration in

CRA 1 and CRA 2, the two more northerly QMAs. The seasonal catch-weighted predictions used to generate inputs for the current CRA 1 and CRA 2 stock assessment models are shown in Figure E.6.

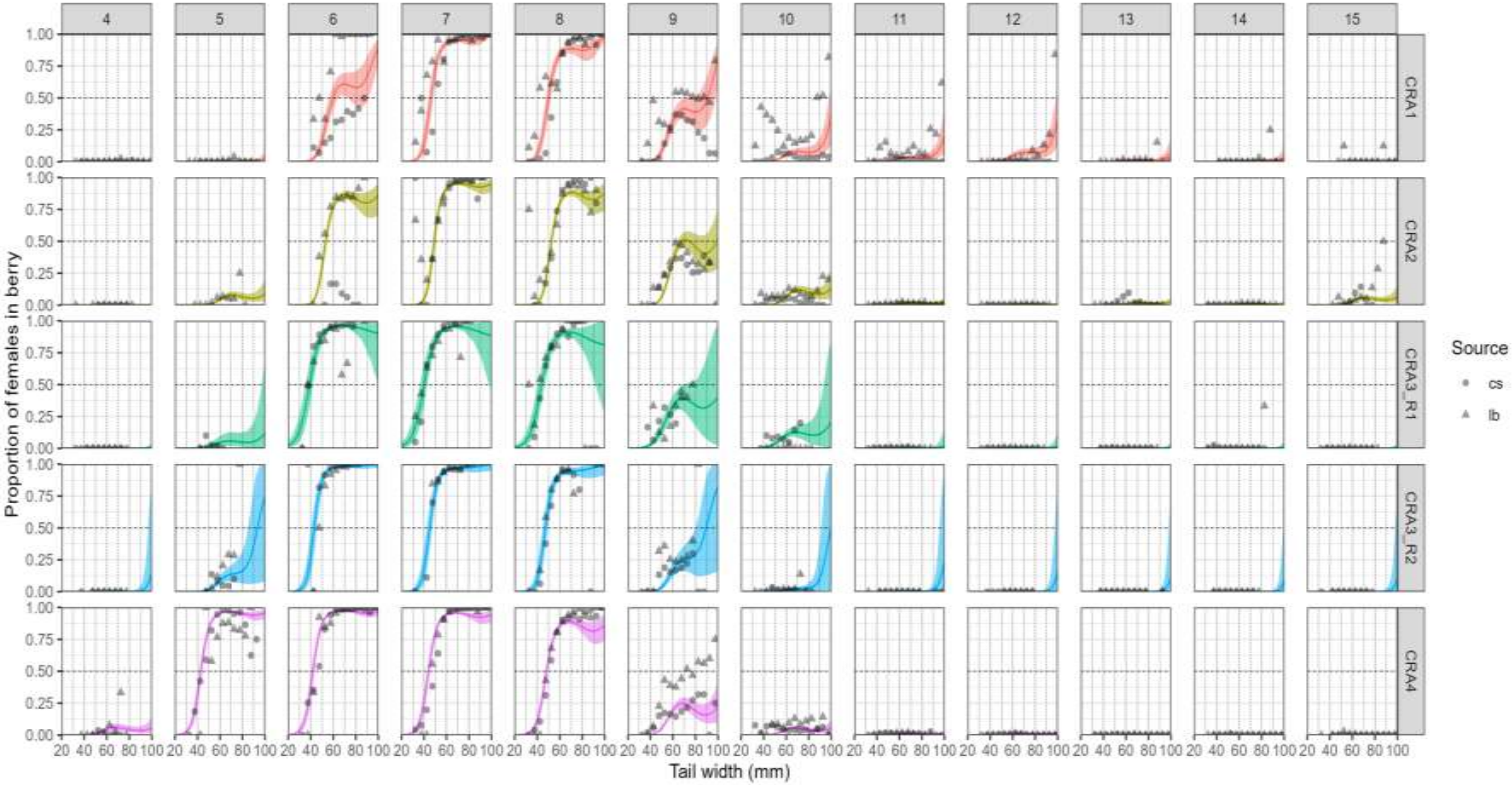

Figure E.5: Non-catch-weighted predicted proportion of females in berry by tail width and QMA/region and fishing month, from model *fit9*. The lines and shaded areas represent the median and 95% credible range of the predictions. The points represent the tail width binned averages of the raw data ('CS' = observer catch sampling, 'LB' = voluntary logbook).

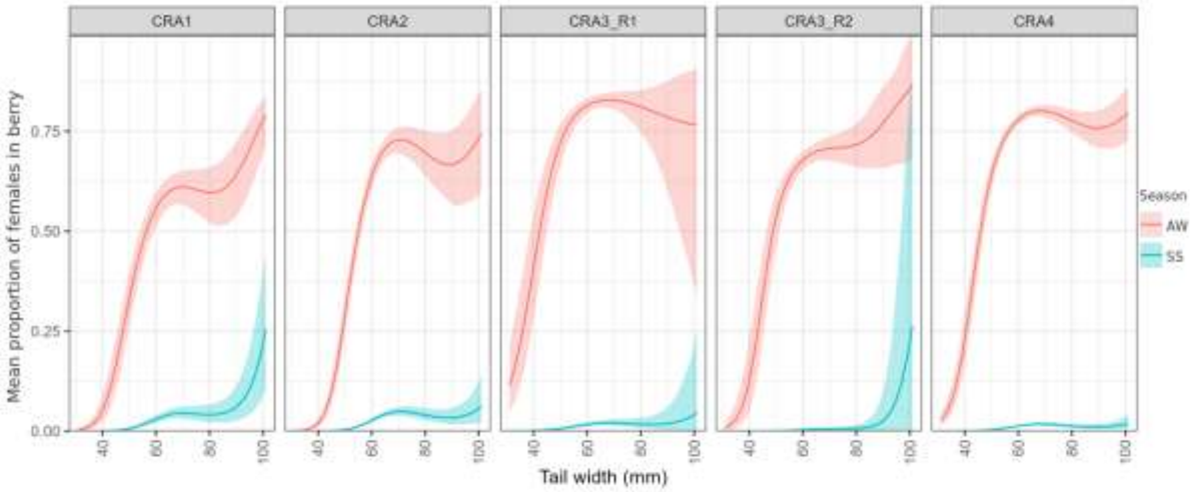

Figure E.6: Catch-weighted predicted proportion of females in berry by tail width, QMA/region and season, from model *fit9*. The lines and shaded areas represent the median and 95% credible range of the predictions. AW = autumn/winter; SS = spring/summer.

APPENDIX F. BASE CASE DIAGNOSTICS

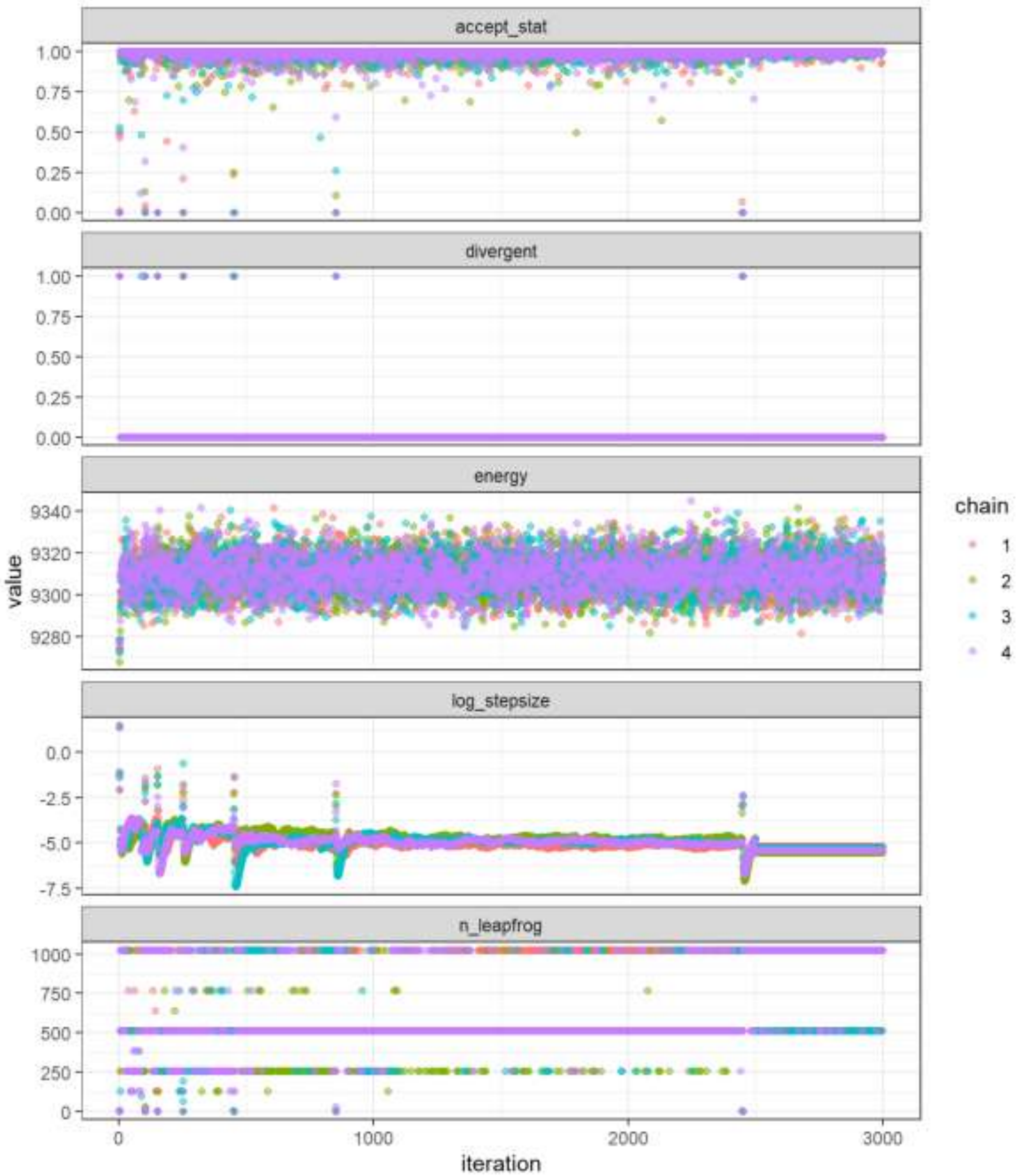

Figure F.1: Adaptation metrics for the MCMC.

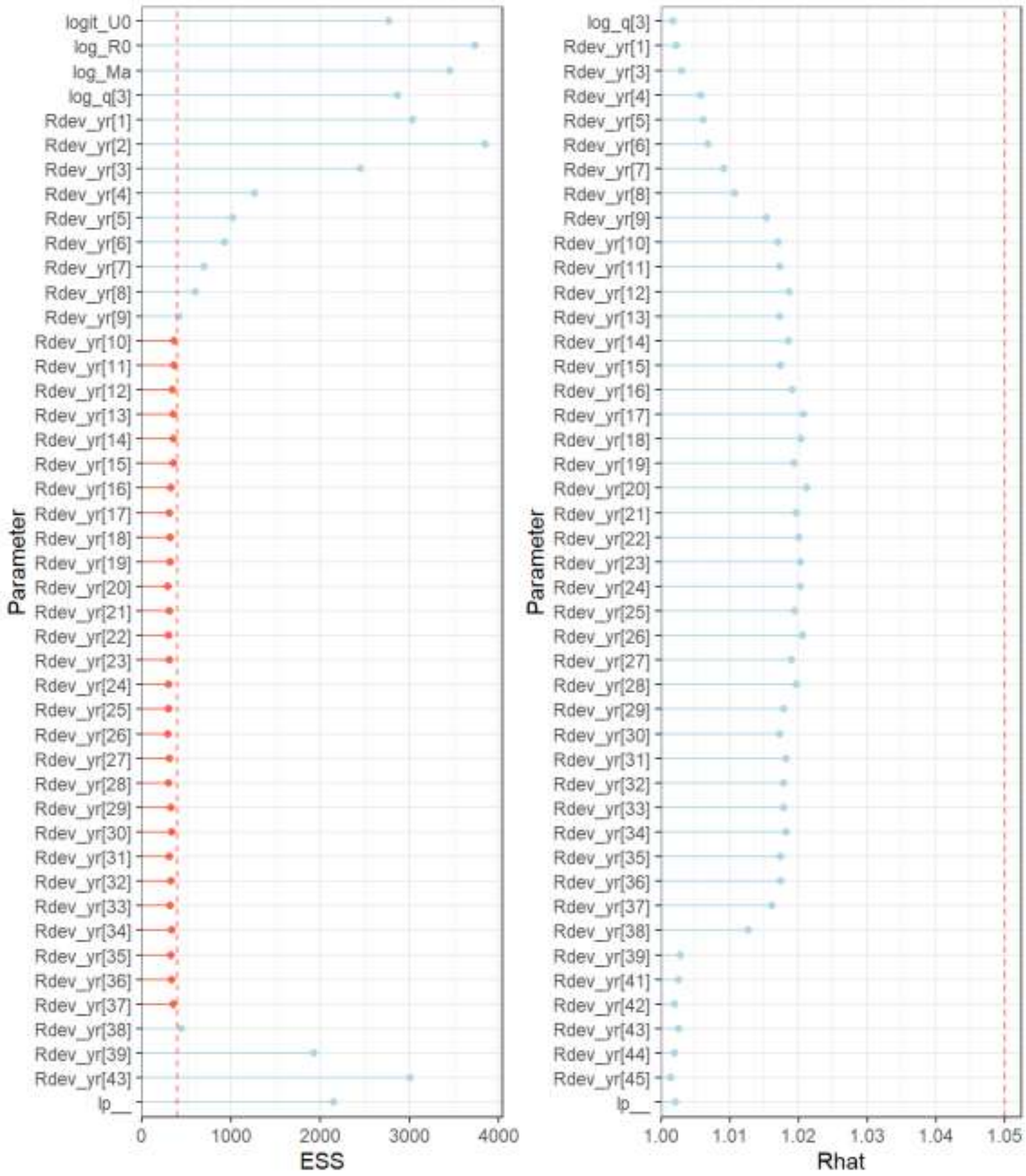

Figure F.2: Effective sample size (ESS) and R-hat values for the 45 worst mixing parameters.

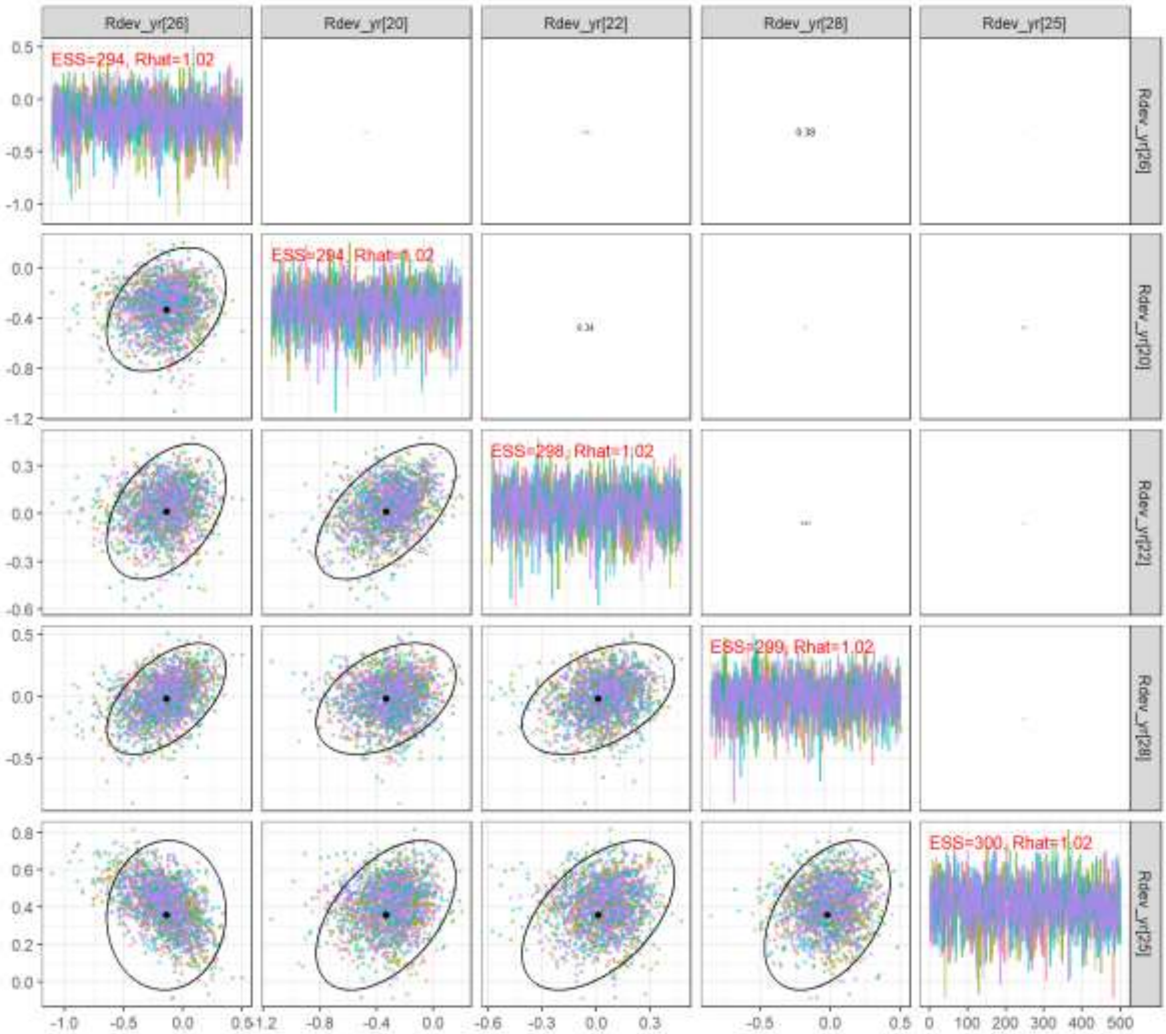

Figure F.3: Pairwise scatterplots of samples for the slowest mixing parameters. Plot shows MLE (ellipses) and MCMC samples (points) for each comparison.

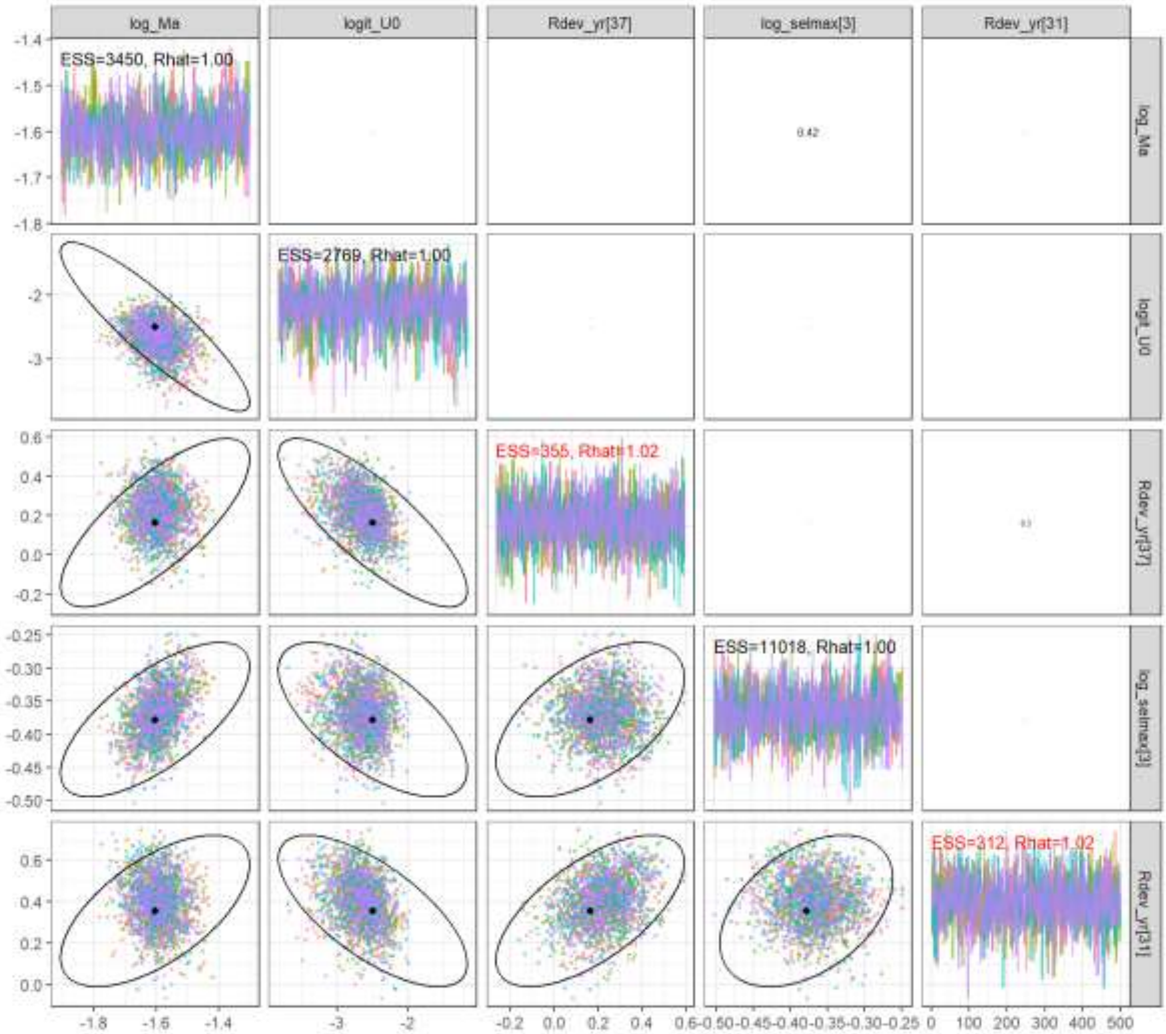

Figure F.4: Pairwise scatterplots of samples for the parameters with greatest mismatch between MLE (ellipses) and MCMC samples (points). Plot shows MLE (ellipses) and MCMC samples (points) for each comparison.

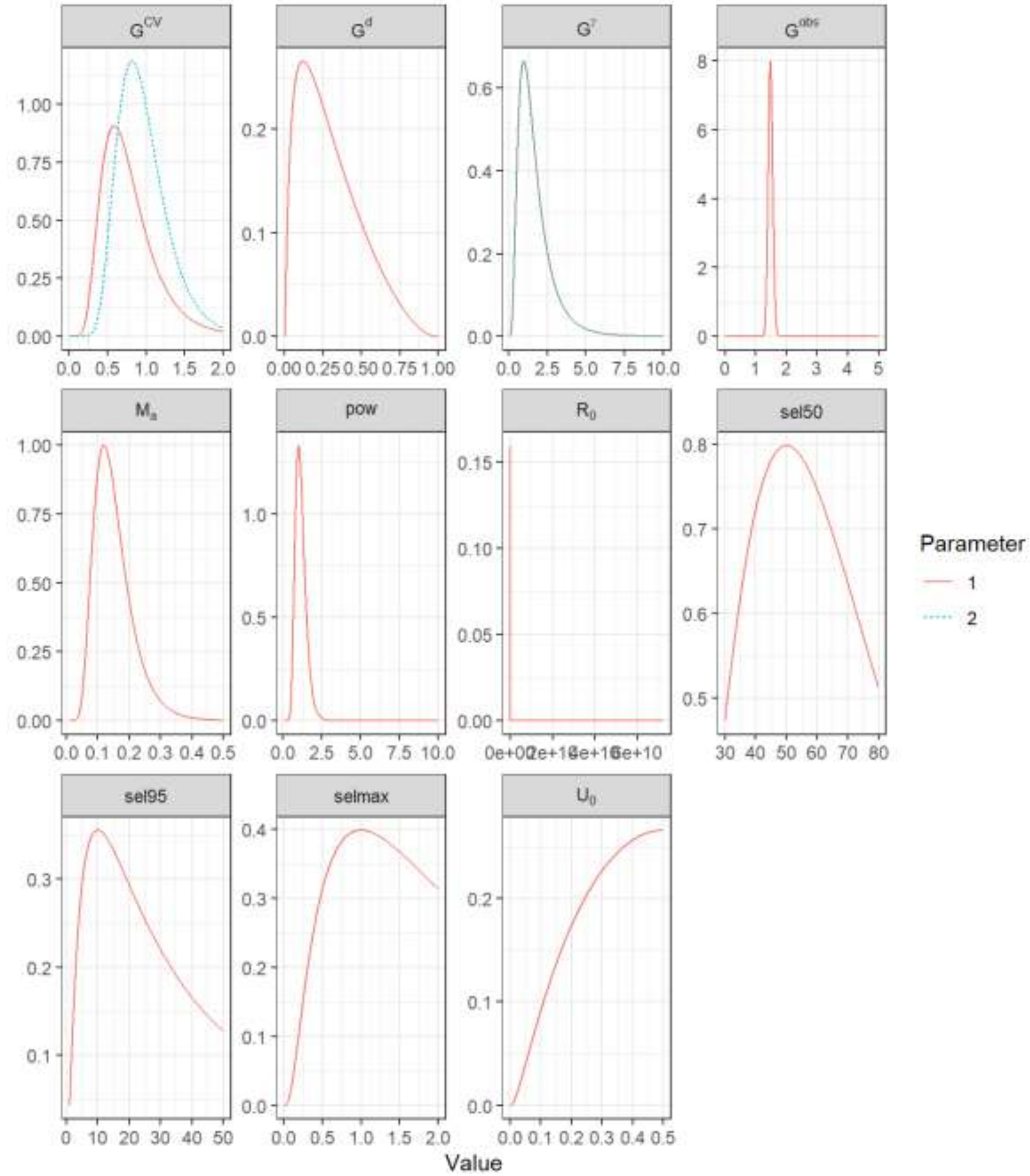

Figure F.5: Assumed prior distributions.

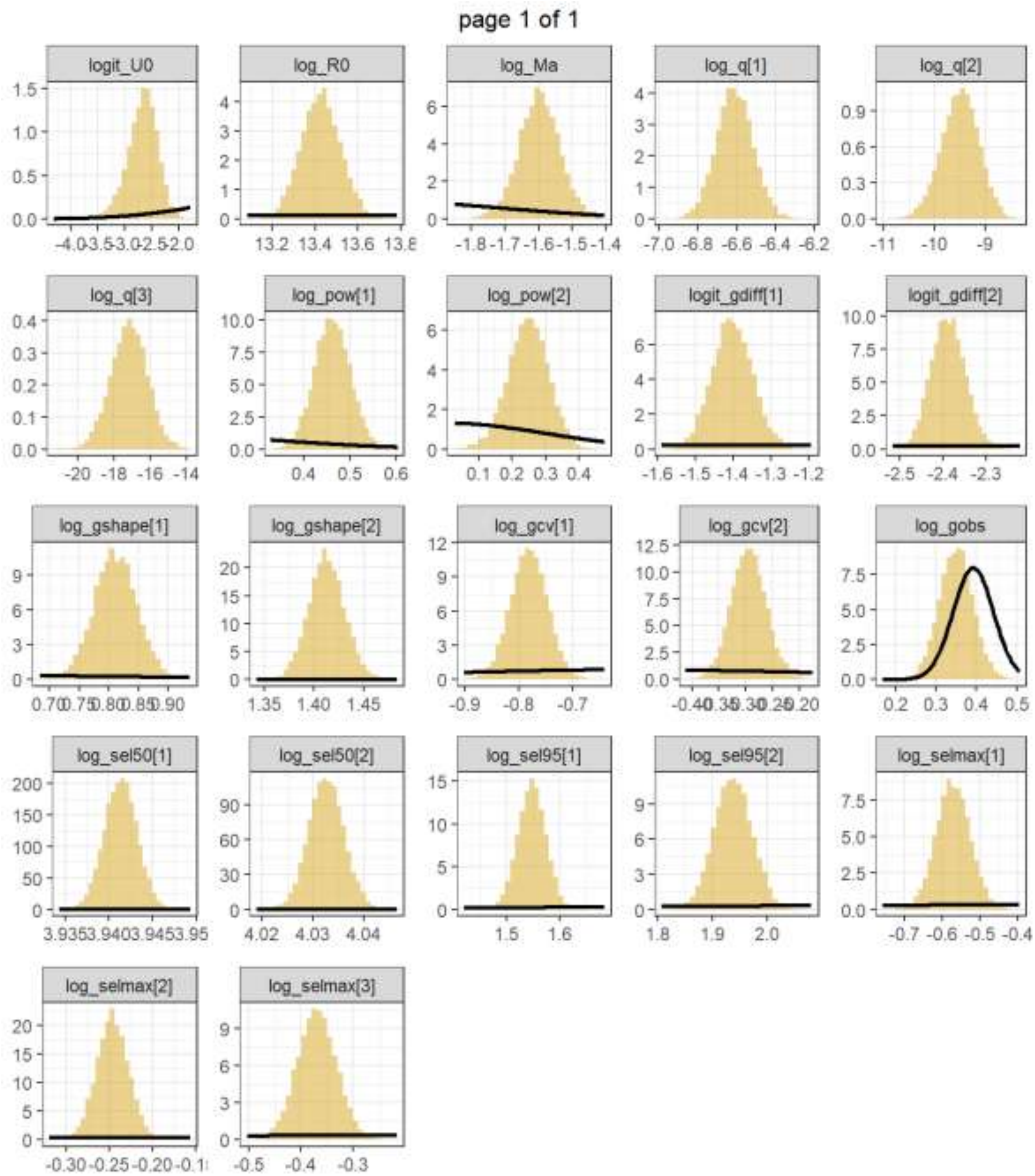

Figure F.6: Posterior distributions for key model parameters (bars) compared with prior distributions (black lines). The x-axis for each panel was set by posterior minimum and maximum.

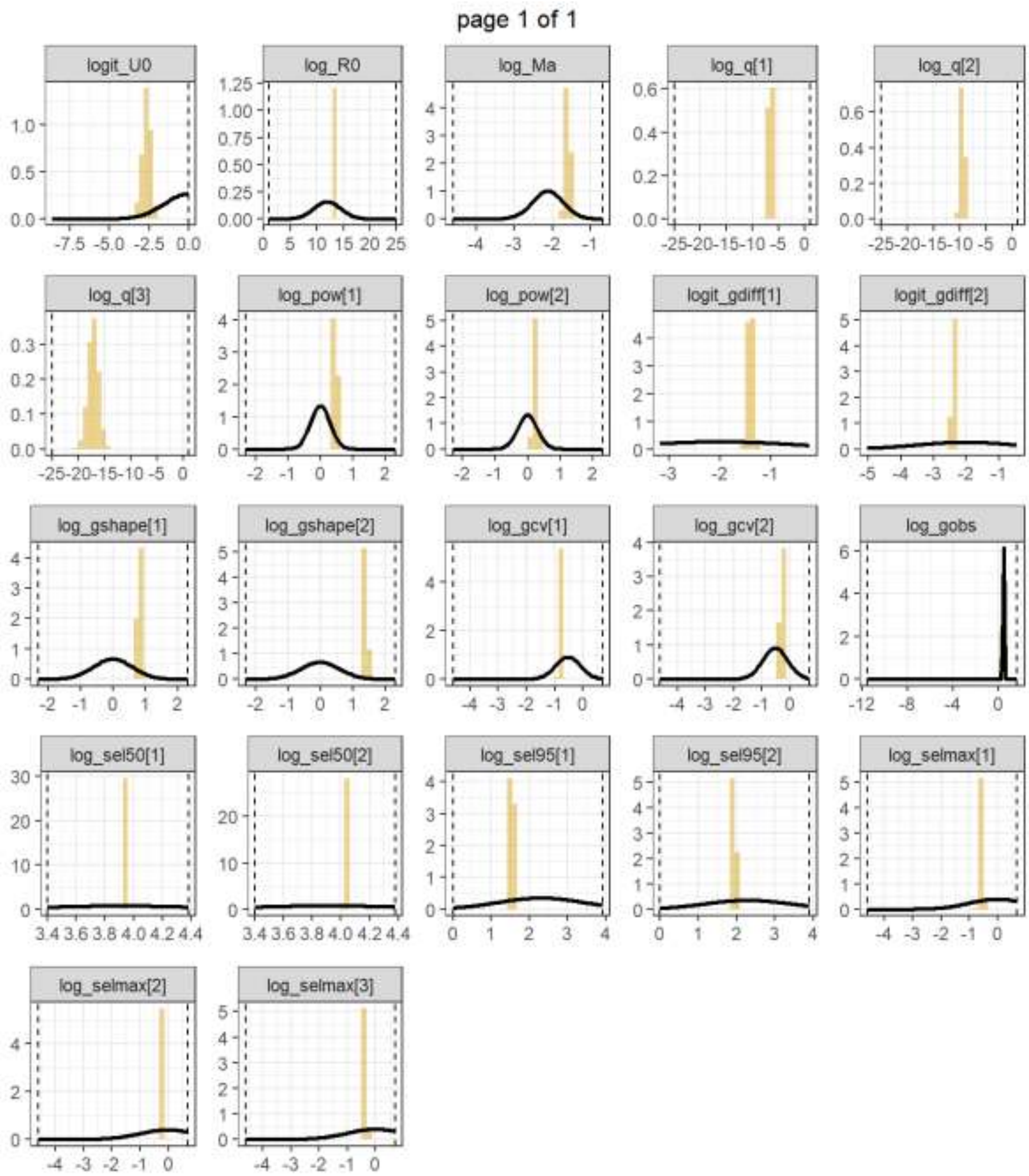

Figure F.7: Posterior distributions for key model parameters (bars) compared with prior distributions (black lines). The x-axis for each panel was set by parameter bounds.

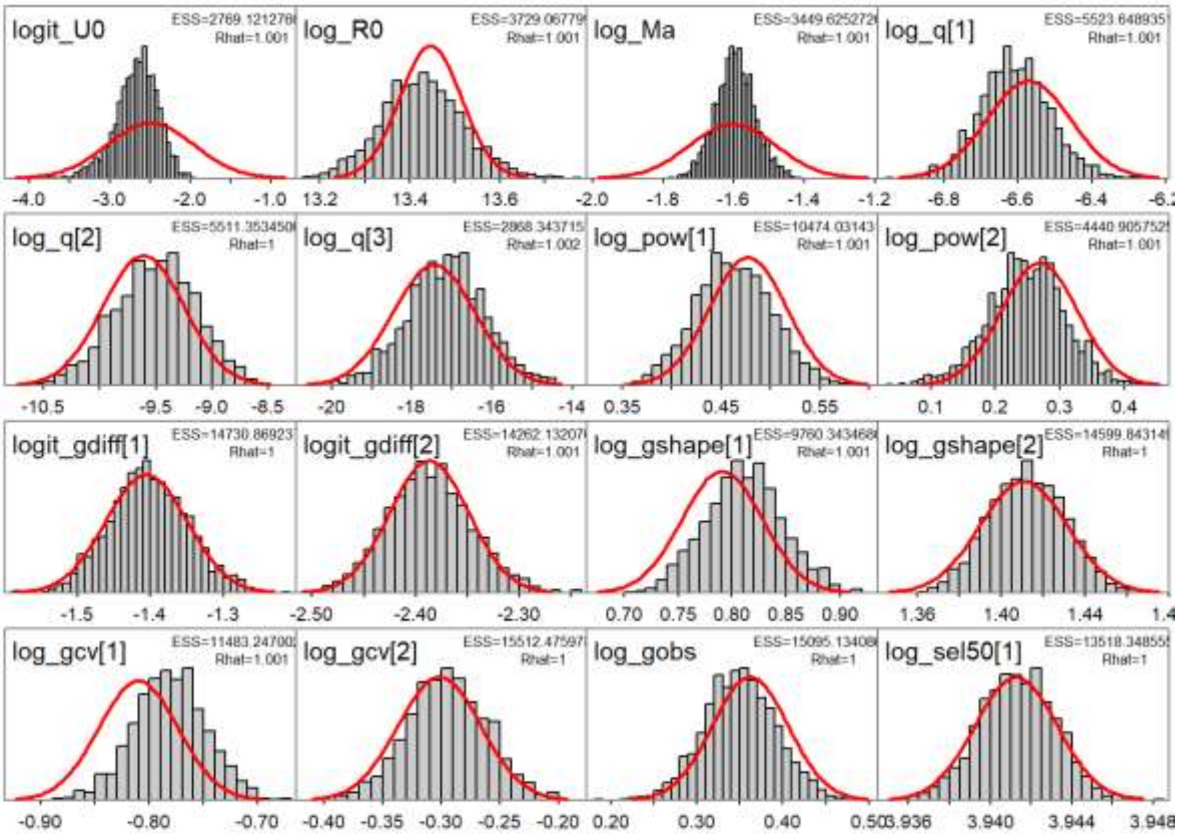

Figure F.8: Posterior distributions for a subset of model parameters (grey bars) and the asymptotic uncertainty derived from the MLE (red lines).

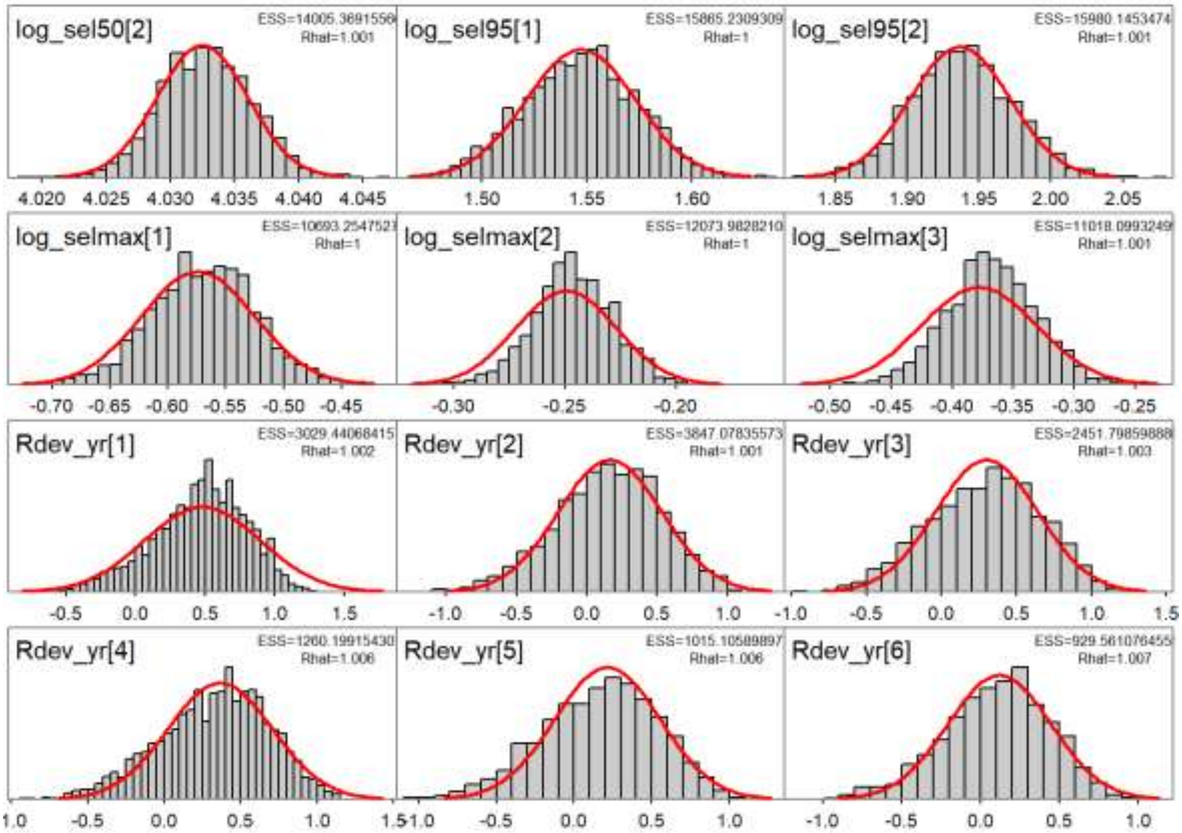

Figure F.9: Posterior distributions for a subset of model parameters (grey bars) and the asymptotic uncertainty derived from the MLE (red lines).

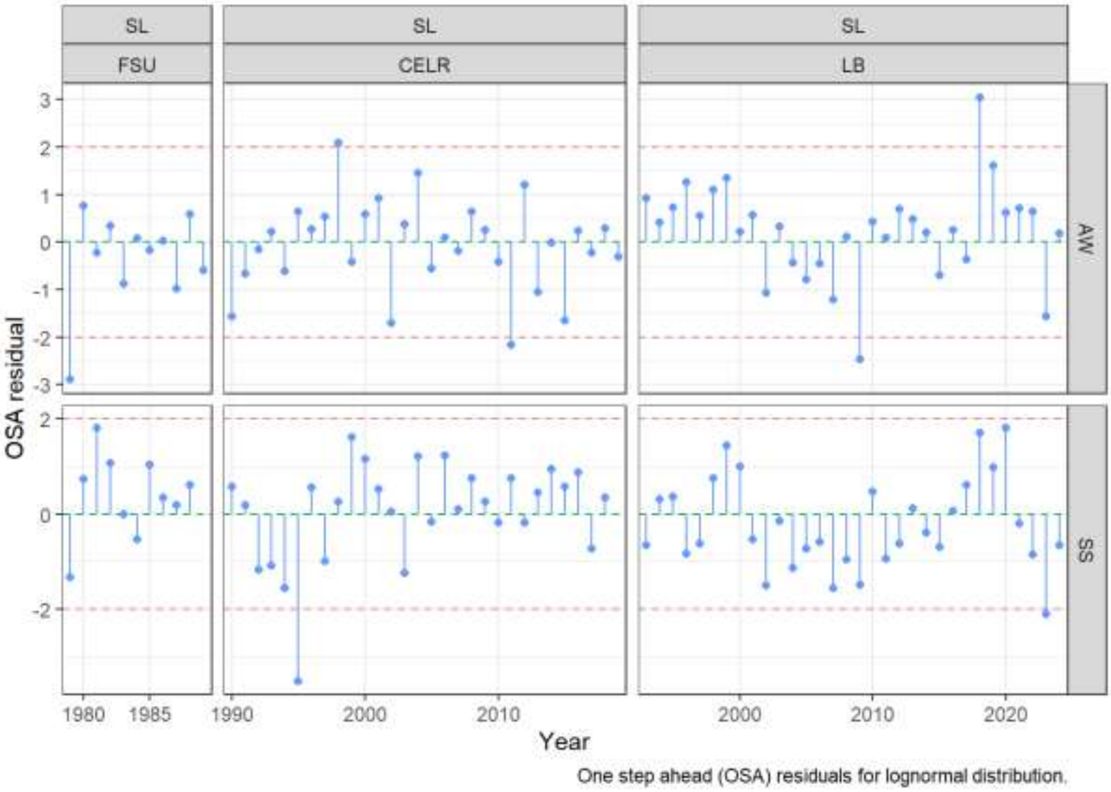

Figure F.10: CPUE one-step-ahead (OSA) residuals.

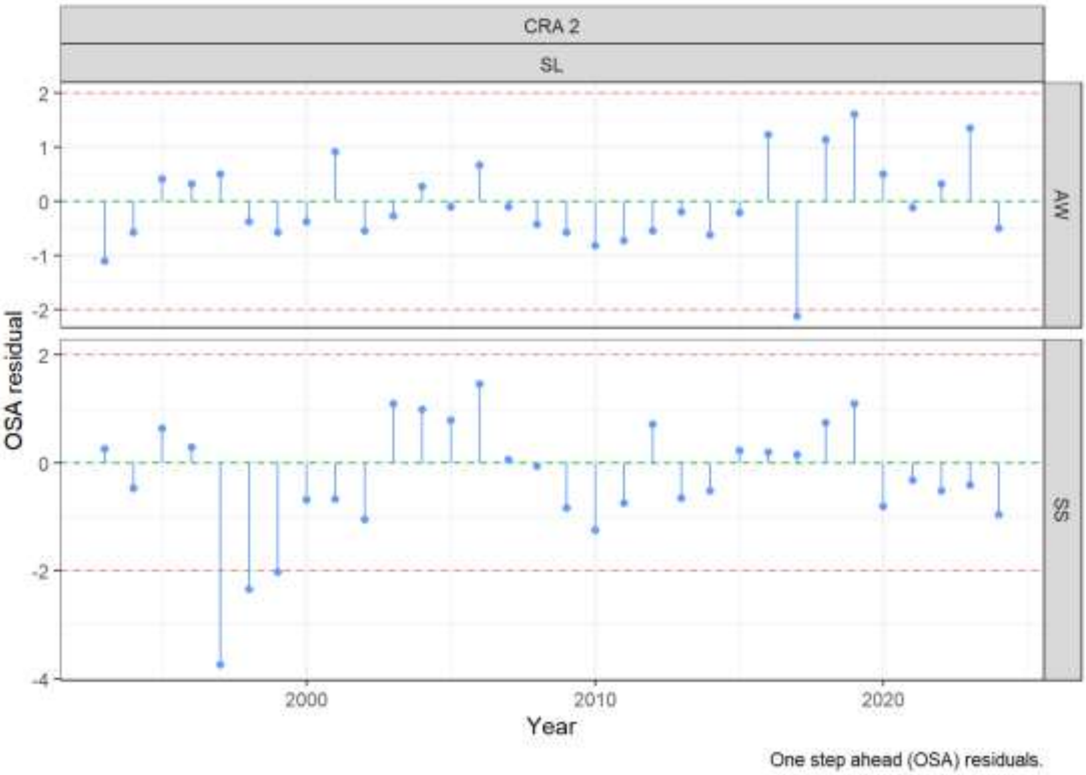

Figure F.11: Sex ratio one-step-ahead residuals.

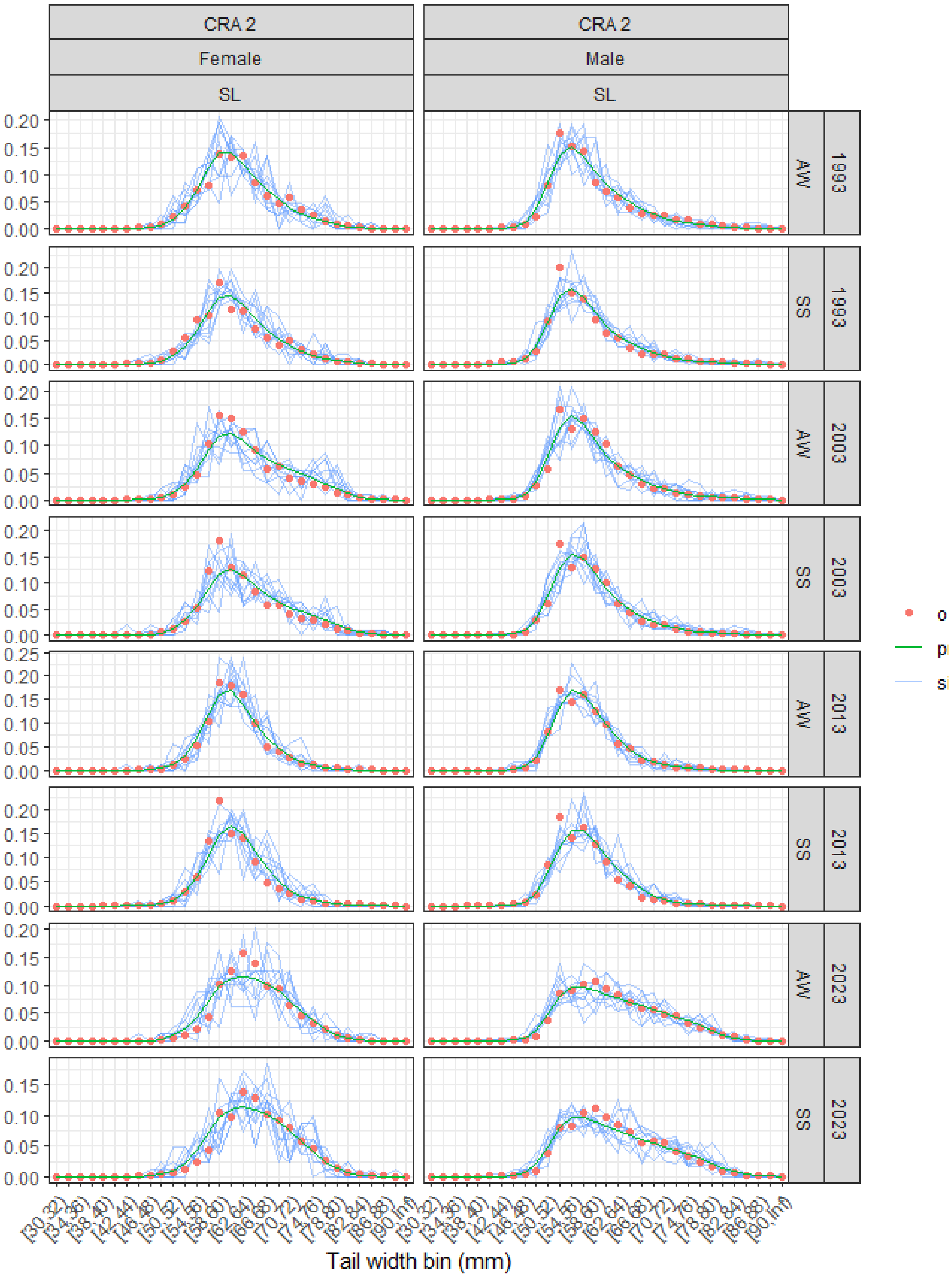

Figure F.12: Model fits to length-frequency (LF) observations (green), with simulations to demonstrate the range of uncertainty (blue).

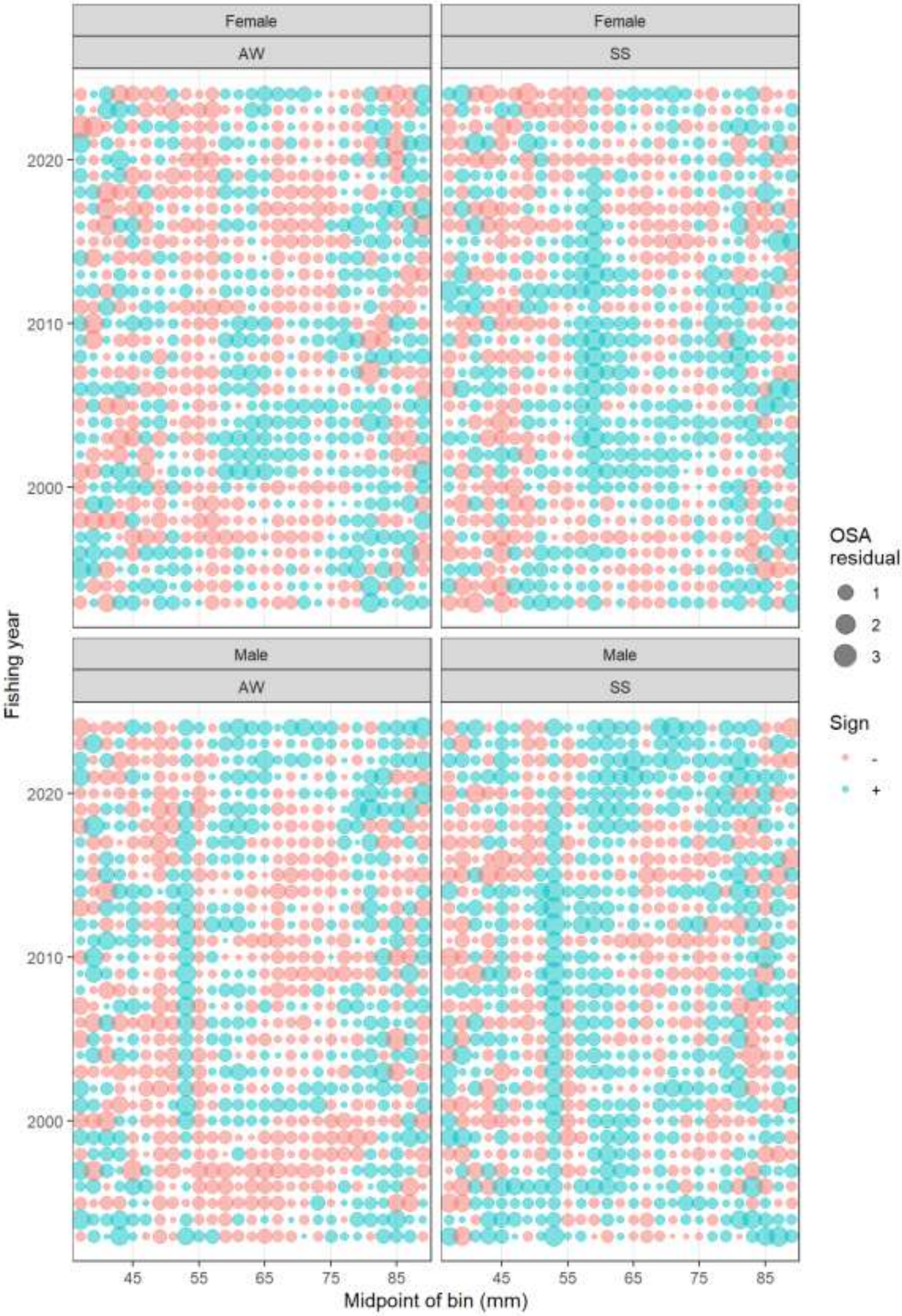

Figure F.13: One-step-ahead (OSA) LF residuals by size, year, sex, and season.

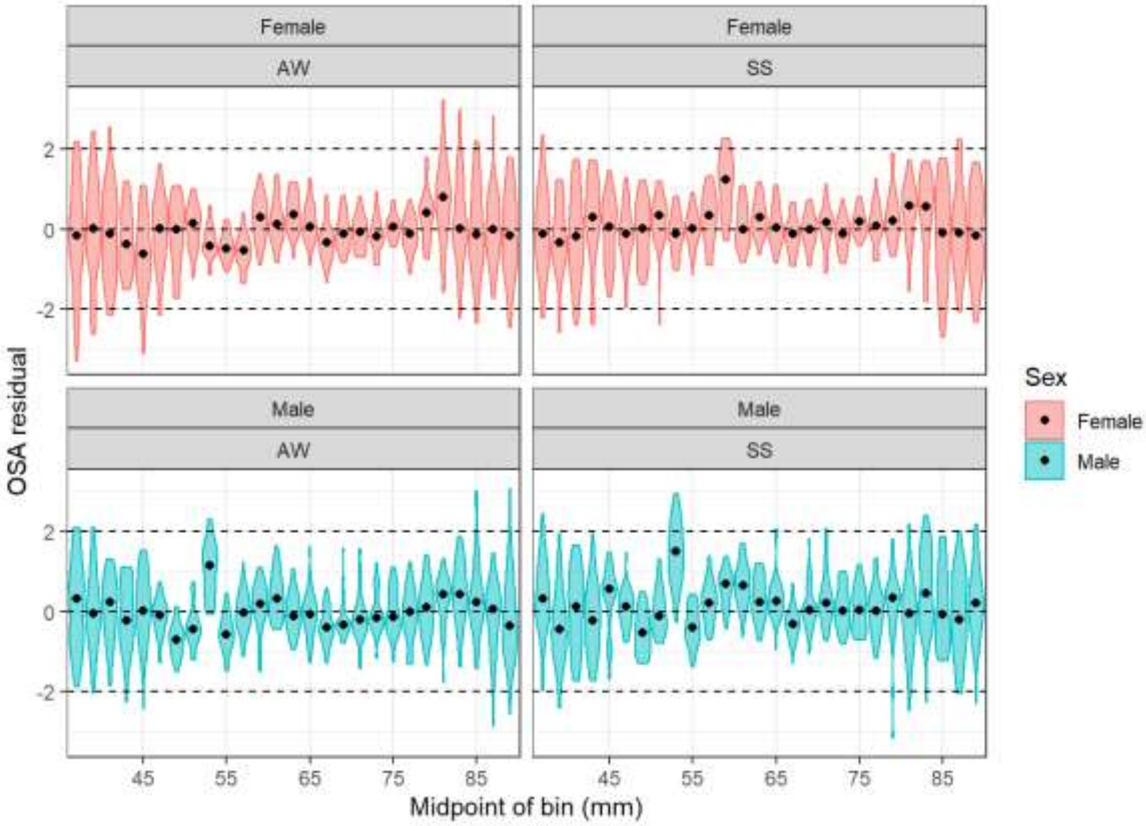

Figure F.14: One-step-ahead (OSA) LF residuals by size, sex, and season.

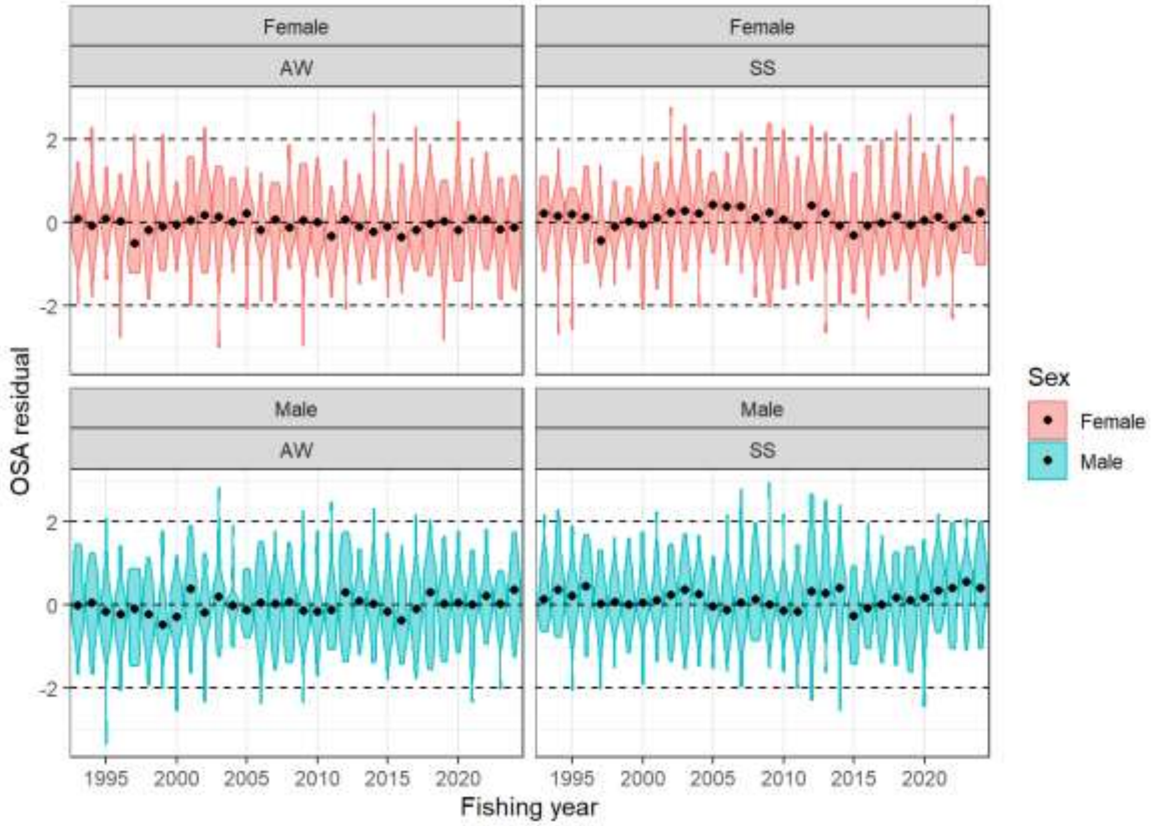

Figure F.15: One-step-ahead (OSA) LF residuals by year, sex, and season.

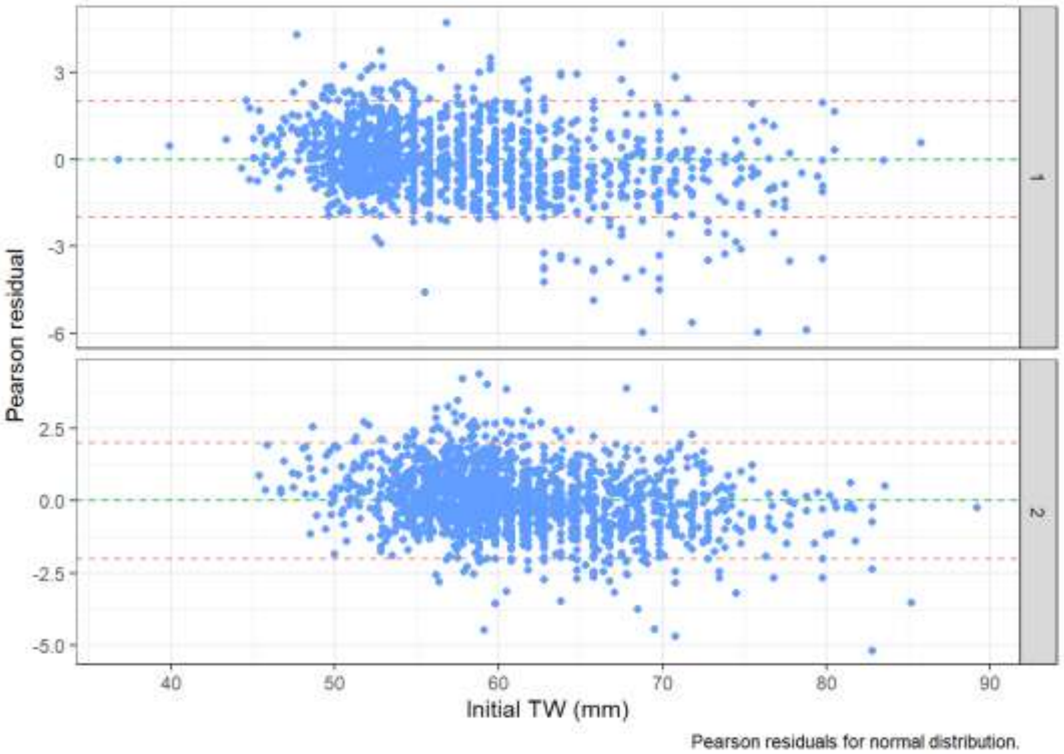

Figure F.16: Pearson tag residuals by tail width (TW) at release.

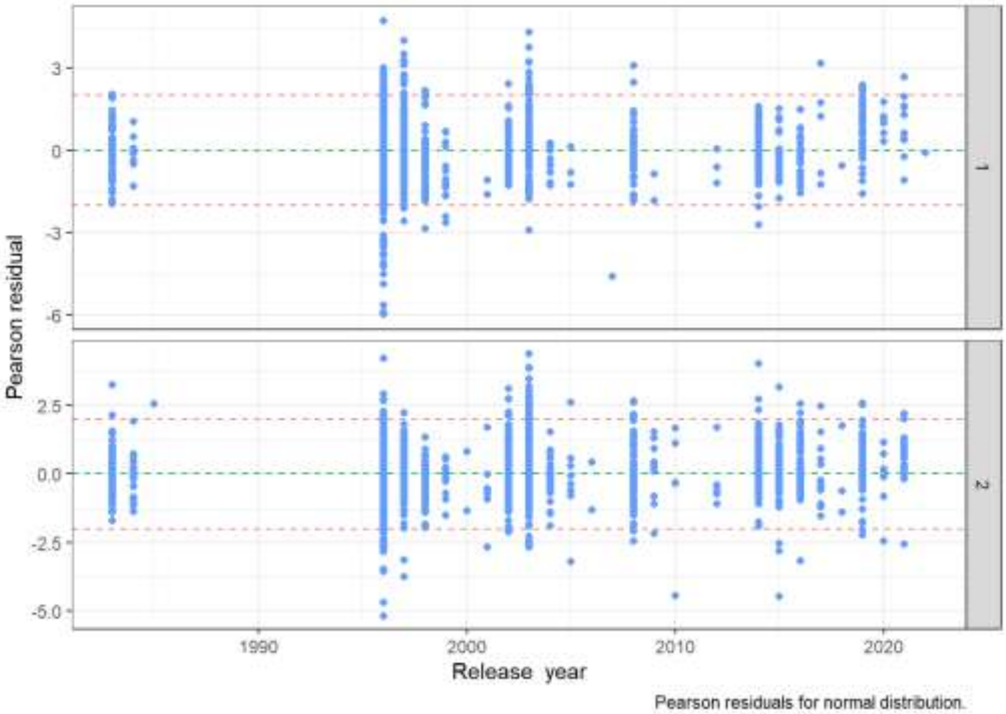

Figure F.17: Pearson tag residuals by release year.

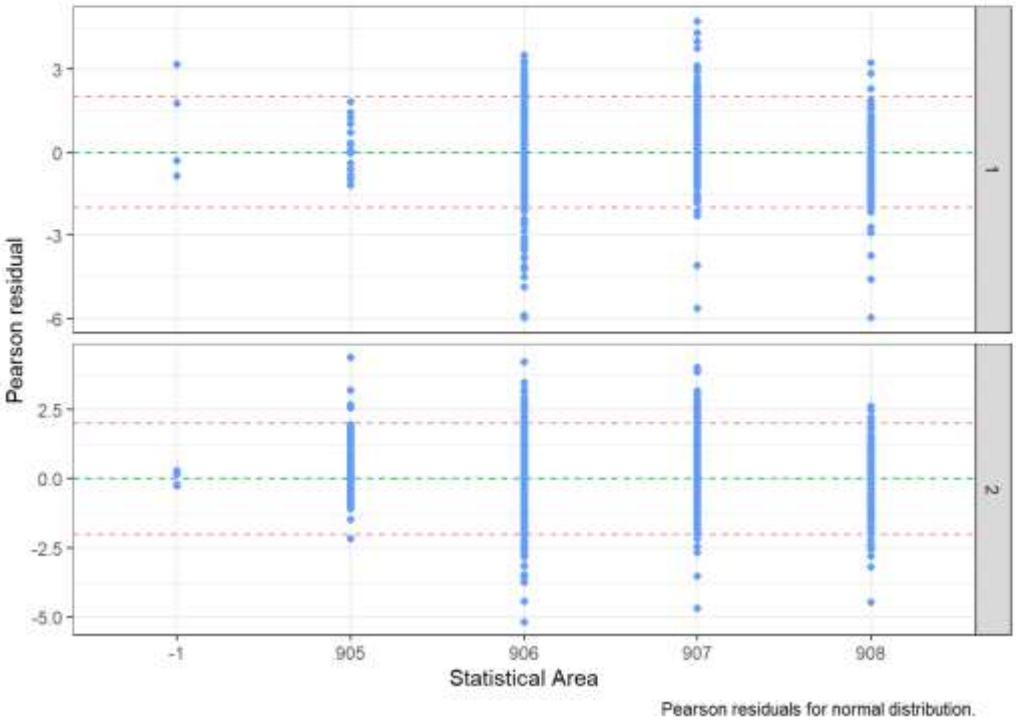

Figure F.18: Pearson tag residuals by Statistical Area.

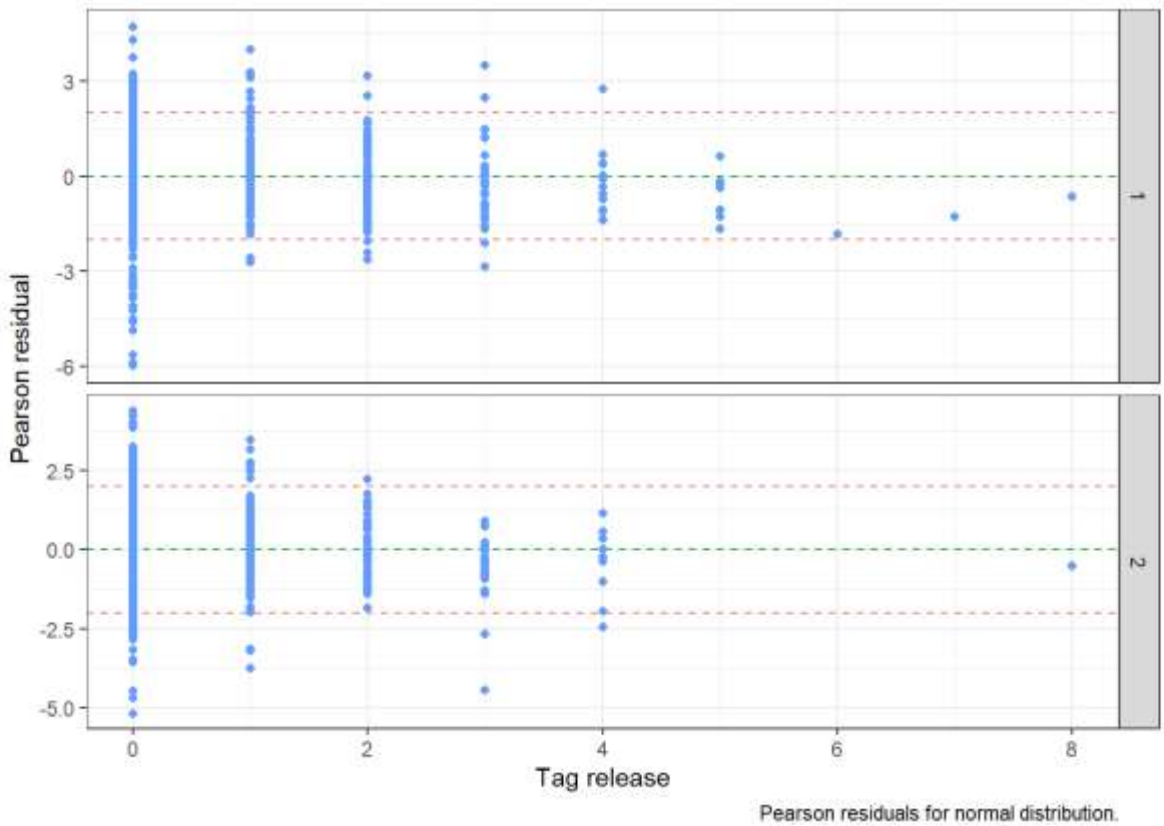

Figure F.19: Pearson tag residuals by tag release number.