Fisheries New Zealand

Tini a Tangaroa

The 2024 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4

New Zealand Fisheries Assessment Report 2025/20

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

ISSN 1179-5352 (online)
ISBN 978-1-991345-54-7 (online)

April 2025

Te Kāwanatanga o Aotearoa
New Zealand Government

Disclaimer

Requests for further copies should be directed to:

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

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

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-and-resources/publications
http://fs.fish.govt.nz go to Document library/Research reports

Please cite this report as:

Rudd, M.B.; Webber, D.N.; Starr, P.J.; Roberts, J.; Pons, M. (2025). The 2024 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4. *New Zealand Fisheries Assessment Report 2025/20.* 139 p.

TABLE OF CONTENTS

PLAIN LANGUAGE SUMMARY

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

This document describes a stock assessment of red rock lobster in CRA 4 up to the 2023–24 fishing year. This stock assessment suggests that CRA 4 has experienced periods of biomass peaks and troughs over the time series modelled and has been increasing towards a peak for the past decade. This pattern has likely been driven by variability in recruitment and catch rates. Projections suggest the stock may hit a peak in biomass over the next five years.

EXECUTIVE SUMMARY

Rudd, M.B.[1]; Webber, D.N.[2]; Starr, P.J.[3]; Roberts, J.[4]; Pons, M.[5] (2025). The 2024 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4. *New Zealand Fisheries Assessment Report 2025/20. 139* p.

This document describes the 2024 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4. Covariates and data included catch estimates for all sectors of the CRA 4 fishery, catch-per-unit-effort (CPUE) indices, standardised length frequency (LF) distributions and sex ratios, standardised proportions of mature females that were in berry (egg-bearing), and tag-recapture growth increment data. The tag recapture sample size from CRA 4 was small for larger lobsters, necessitating the inclusion of tag recapture data from CRA 5, where the catch size composition, stock status, and sea temperatures were considered to be comparable to CRA 4. The stock assessment used the lobster stock dynamics (LSD) model. Data inputs and technical decisions were discussed and agreed upon by the Rock Lobster Working Group, who oversaw this work.

This stock assessment assumed a single-region model that combined data across the five CRA 4 statistical areas. There were some differences in the size composition of sampled lobsters among the statistical areas near Wellington, but a multi-region assessment was not possible due to the limited amount of data and the apparent small contribution of catch from these statistical areas. The reconstruction of the catch began in 1945 because this was the first year with usable catch data. However, this stock assessment model was started in 1979 in a non-equilibrium state, instead of starting in 1945, without compromising the stock assessment conclusions and eliminating the dependence on the early uncertain catch history.

This document describes the procedure used to find an acceptable base case model and shows the model fits. Several sensitivity runs were done to test assumptions in the base case model. Model inference for this assessment was based on maximum *a posteriori* fits and Markov chain Monte Carlo simulations.

The stock assessment estimated a low initial exploitation rate in the first model year (1979), followed by high exploitation during the 1980s. This high early exploitation resulted in a decline in the CRA 4 vulnerable biomass through to the early 1990s. Since then, CRA 4 has experienced periods of relatively low and high fishing mortality coupled with at least two major recruitment events, leading to oscillations in the estimated population biomass. Due to low female vulnerability, the spawning biomass has remained well above the 20% SSB_0 soft limit throughout the time series. The stock assessment estimated CRA 4 at the end of 2023–24 to be at a relatively high point in the cycle between lower and higher population biomass. Projections suggested that continued harvest at current catch levels, with recruitment similar to the past ten years, would likely lead to a peak in vulnerable biomass over the next two to three years and the start of a population decline by the end of a five-year period. However, the stock was predicted to remain well over the soft limit and the calculated reference level over the five-year projection period.

[1] Scaleability LLC, Seattle, USA
[2] Quantifish Ltd, Tauranga, New Zealand
[3] Starrfish, Wellington, New Zealand
[4] Anemone Consulting Ltd, Wellington, New Zealand
[5] Independent consultant, Montevideo, Uruguay

1. INTRODUCTION

Fisheries New Zealand and the National Rock Lobster Management Group (NRLMG) directed that stock assessments for the CRA 3 and CRA 4 red rock lobster (*Jasus edwardsii*, CRA) Quota Management Areas (QMAs) should be done in 2024. The CRA 4 assessment was completed during May and June 2024, in fulfilment of Objective 6 of Fisheries New Zealand contract CRA2022-01. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Working Group (RLWG). The stock assessment was presented to and approved by the Fisheries New Zealand mid-year Plenary on 6 August 2024 (Fisheries New Zealand 2024).

The CRA 4 QMA for red rock lobster extends from the Wairoa River in northern Hawke Bay, southwards through Hawke Bay, the Wairarapa and the Wellington coasts, then passing north to the Manawatu River on the Kapiti coast and is comprised of five statistical areas (912, 913, 914, 915, and 934) (Figure 1).

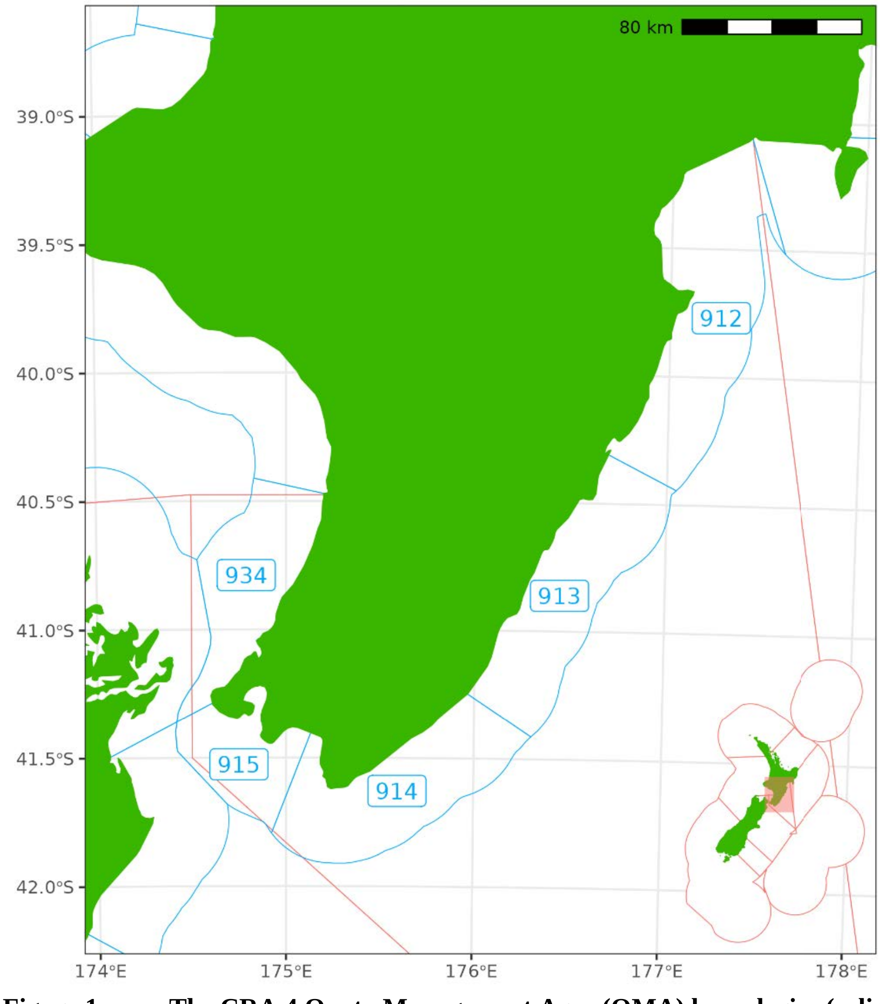


Figure 1: The CRA 4 Quota Management Area (QMA) boundaries (solid red lines) and statistical area boundaries (solid blue lines).

Potting and hand-gathering are the preferred methods for recreational fishers in CRA 4. Most of the recreational catch is taken during the summer months, which is consistent with all New Zealand rock lobster recreational fisheries. The region also sustains several charter boat operators that cater to recreational fishers that are predominantly diving during the summer months. Lobsters are important to Māori in this area, and the customary allowance allows lobsters to be taken under permit.

The CRA 4 commercial fishery is by regulation a trap or pot fishery, fished by small boats primarily on day trips and in relatively shallow waters. Most vessels in the fleet operate from coastal bases in isolated rural areas along the coastline. The CRA 4 commercial catch supports processing and export operations in Napier, Wellington, and Auckland.

The number of commercial vessels operating in CRA 4 has declined through time, with a high of 100 vessels counted catching at least 1 tonne/year in 1993–94 and a low of 26 vessels in 2022–23 (Starr 2025). A fixed annual Total Allowable Commercial Catch (TACC) was set for CRA 4 at 280 tonnes (t) beginning with 2021–22. Allowances of 40 t for recreational catch, 33 t for 'other fishing mortality', and 35 t for customary catch were added by the Minister of Fisheries to produce a Total Allowable Catch (TAC) of 388 t. The TAC and TACC have remained unchanged since 2021–22.

The current minimum legal size (MLS) for red rock lobsters in the CRA 4 commercial and recreational fisheries is 54 mm tail width (TW) for males and 60 mm TW for females. There is also a general prohibition for the commercial and recreational fisheries on the taking of berried females and soft-shelled individuals.

The 2020 stock assessment of CRA 4 by Rudd et al. (2021a) was an integrated length-based model fitted to length frequency data, sex ratio data, tag-recapture growth increment data, and standardised catch-per-unit-effort (CPUE) indices. That assessment estimated alternating periods of relatively high and low fishing mortality coupled with at least two major recruitment events which led to oscillations in the estimated population biomass. The 2020 assessment concluded that CRA 4 was at a relatively low point in the cycle between lower and higher population biomass at the end of the reconstruction period. Projections suggested that continued harvesting at a constant current catch would be likely to lead to a decline in the vulnerable biomass and spawning stock biomass, but with no probability of dropping below the soft limit. The TACC, the recreational allowance, and the 'other mortality' allowance were lowered on the basis of the 2020 stock assessment.

This document presents a new stock assessment for CRA 4, which includes new CPUE series based on logbook and catch sampling data, updates to the length frequency and sex ratio standardisation procedures, and estimation of the proportion of mature females in berry by season up to the end of the 2023[6] fishing year. The CRA 4 stock was assessed assuming a single homogeneous stock across the five statistical areas, using the lobster stock dynamics (LSD) model (Webber et al. 2018a, Rudd et al. 2021a). This document summarises the updated stock assessment for CRA 4 and the generation of the stock assessment inputs (a change from recent CRA assessments which reported the data inputs and covariates in a separate FAR from the stock assessment outputs, e.g., Rudd et al. 2024; Webber et al. 2024).

The covariates and data used in this stock assessment are summarised in Section 2.1 and Section 2.2, below. The stock assessment model settings are described in Section 3.1, model parameters and priors are defined in Section 3.2, and the stock assessment outputs including stock status indicators are defined in Section 3.3. The stock assessment results are presented in Section 3.4 to Section 3.7.

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

2. DATA AND COVARIATES

2.1 Data

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

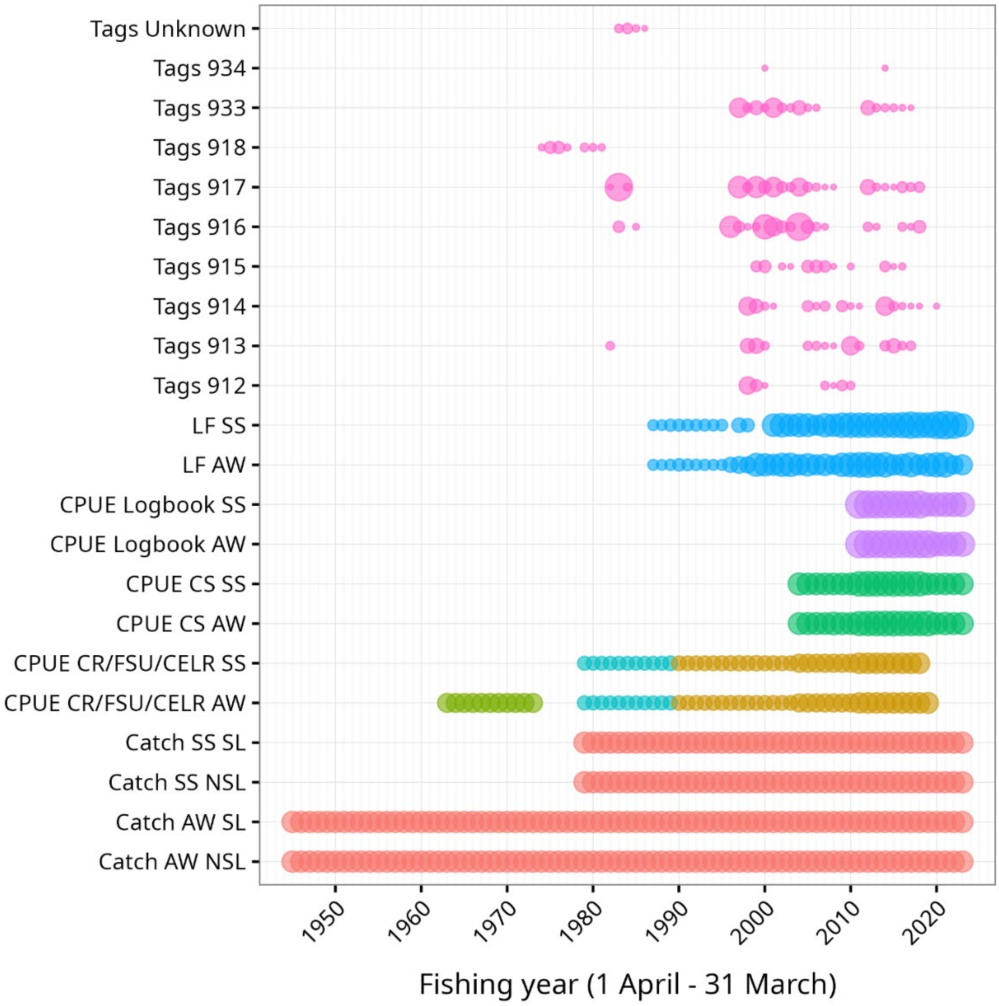


Figure 2: Data extent by fishing year used in the CRA 4 stock assessment. The size of the bubbles represents the relative number of recaptured tags by statistical area, the effective sample size for length frequency distributions, the standard deviation for CPUE, or a fixed size for catch. Bubble colours vary for the different data sets (CPUE colours: CR = light green, LB = purple, CS = dark green, FSU = teal, and CELR = gold). See Section 2.1.1 for a detailed description of these data.

2.1.1 Catch per unit effort (CPUE)

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

- The **catch rate (CR)** series, which is an annual arithmetic daily catch rate from 1966 to 1973. This series is documented in Bentley et al. (2005).
- The **Fisheries Statistics Unit (FSU)** series, which is a seasonal standardised series extending from autumn/winter (AW) 1979 to AW 1989. The standardisation model was fitted to data

aggregated by month, and included year, month, statistical area, and vessel explanatory variables. 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, which is a seasonal standardised series extending from spring/summer (SS) 1989 to AW 2019. The standardisation model included year, month, statistical area, and vessel explanatory variables. The CELR CPUE standardisation data set only included vessels that had fished for at least five years in CRA 4. The data used for this analysis were unchanged from the 2020 CRA 4 stock assessment (Starr et al. 2021).
- The **logbook (LB)** series, which is a seasonal standardised series extending from AW 2011 to SS 2023 (2011 was the first year when sufficient vessels participated in the programme during both seasons; Table A.1). The standardisation model was fitted to data aggregated by trip and included the number of pots, period, month, statistical area, and vessel explanatory variables. The logbook CPUE standardisation included all vessels that reported logbook data in CRA 4 and all live lobsters above the MLS. This is because, when the catch in a pot exceeded the pot measuring limit of 25 lobsters, excess lobsters were enumerated as being above or below the MLS, with no accounting for berried females. The data used in this analysis were obtained from Fishserve (John Olver, pers. comm.) in May 2024.
- The **catch sampling (CS)** series, which is a seasonal standardised series extending from AW 2004 to SS 2023 (too few vessels participated in the sampling for both seasons before 2004; Table B.1). The standardisation model was trip-based and included the number of pots, period, month, statistical area, and vessel explanatory variables. The catch sampling CPUE standardisation included all vessels that reported catch sampling data in CRA 4 and all live lobsters above and below the MLS. This was because samplers were allowed to skip pots if they fell behind in their measuring, as long as they recorded the total number of lobsters in the skipped pot. The data used in this analysis were obtained as a raw data extract from the MPI RDM (replog 16129) in September 2024.

An apparent change in reporting behaviour associated with the change in commercial catch and effort data collection from paper forms to electronic monitoring prevented the extension of the CELR CPUE abundance series beyond the AW of the 2019 fishing year (see appendix B in Starr 2025 for the evidence supporting this decision).

Neither the FSU nor the CELR series required updating for this stock assessment, as there were no new CELR data reported since the 2020 assessment. The models producing these series are described in Starr et al. (2021). For the LB and CS CPUE series (i.e., the new model-based CPUE series produced for this assessment), 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). For the LB and CS series, the data were aggregated to the trip level prior to model fitting to speed up the model run times, given the large amount of data when fitting at the pot-by-pot level, as well as the strong similarity in CPUE trend comparing the two levels of aggregation.

Diagnostic plots and other outputs for the LB and CS CPUE models are provided in Appendix A and Appendix B, respectively. For the Logbook CPUE model: there was good data overlap through time with respect to different statistical areas, months, and vessels (Figure A.1, Figure A.2, Figure A.3). Acceptable model convergence was achieved (Figure A.4), there was a good agreement with the assumed statistical distribution (Figure A.5), and the coefficient distribution influence (CDI) plots indicated a minimal correction effect on the resulting CPUE series with respect to vessel, month, and statistical area, particularly in the most recent years (Figure A.6, Figure A.7, and Figure A.8). The predicted catch rate was also shown with respect to statistical area, the number of pots, and month

(Figure A.9 and Figure A.10), noting that the month effect was very similar comparing the CELR, CS, FSU, and LB models. The predicted CPUE index series was shown by statistical area, which indicated very similar trends occurring across all of CRA 4 (Figure A.11).

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

Series	Response unit	Data aggregation	Model structure	Assumed statistical distribution	Period
Fisheries statistics unit	Kg per pot of legal lobsters	By month	CPUE ~ period + (1 | month) + (1 | vessel) + area + (1 | period:area)	Lognormal	1979 AW – 1989 AW
Catch effort landing return	Kg per pot of legal lobsters	By month	CPUE ~ period + (1 | month) + (1 | vessel) + area + (1 | period:area)	Lognormal	1989 SS – 2018 SS
Logbook	Number per pot above the MLS	By trip	lobsters ~ log(pots) + period + (1 | month) + (1 | vessel) + area + (1 | period:area)	Negative binomial	2011 AW – 2023 SS
Catch sampling	Number per pot of all lobsters	By trip	lobsters ~ log(pots) + period + (1 | month) + (1 | vessel) + area + (1 | period:area)	Negative binomial	2004 AW – 2023 SS

The CS CPUE series had reasonable overlap over time with respect to statistical areas, months, and vessels since 2004 (Figure B.1, Figure B.2, Figure B.3). The resulting CS model had an acceptable level of convergence (Figure B.4) and agreed with the assumed statistical distribution (Figure B.5), although there was a greater influence of vessel on the period effect compared to the LB model (compare Figure B.6 and Figure A.6). The predicted catch rate with respect to statistical area and pots (Figure B.9) showed the expected increasing number of lobsters with increasing pots, and CPUE trends were also similar when comparing across the CRA 4 statistical areas (Figure B.10).

The three overlapping CPUE series used by this assessment (CELR, CS, and LB) showed similar trends across the respective overlapping years, although the LB series exhibited higher levels of uncertainty, particularly in the early years of the series (Figure 3). While not shown, and not currently accepted for use in the assessment, an exploratory CPUE series fitted to data collected using electronic monitoring data showed a similar increasing trend since 2019.

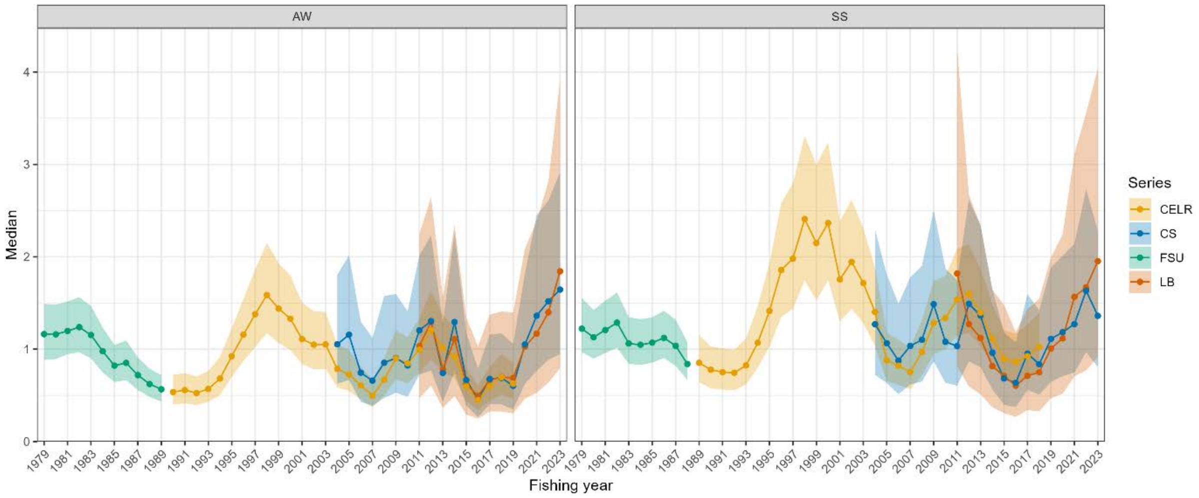


Figure 3: Comparison plot by season from 1979 to 2023 showing the four CPUE series used in the CRA 4 stock assessment. ‘FSU’ = Fisheries Statistics Unit; ‘CELR’ = Catch Effort Landing [paper] Returns; ‘CS’ = catch sampling; and ‘LB’ = logbook.

2.1.2 Length frequency and sex ratio

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

The designs of the observer CS and LB programmes are summarised by Webber et al. (2024) and both programmes are considered to be good spatial and temporal representations of the catch in CRA 4. With one exception (1996), the CRA 4 CS programme sampled at least 8000 lobsters in each fishing year since 1989 (Table 2). The 1987 and 1988 samples were also comprised of large samples of lobsters and were included in the analysis, while the 1986 sample was deemed by the RLWG to be too small to be representative and was excluded.

The CRA 4 LB programme started in 1996 with one participant, rapidly expanding to 10 participants by 2011, with stable vessel participation since then. While the number of lobsters sampled by the LB programme is smaller than for the CS programme, the number of trips and days of sampling are much greater for the LB programme, e.g., more than 150 trips sampled by the LB programme annually since 2010, compared with fewer than 55 trips sampled annually by the CS programme over the same period (Table 2). This reflects the difference in the design of these two programmes, with the LB programme asking fishers to sample the same three to five pots every fishing day while the CS programme puts trained samplers on fishing vessels and attempts to sample the entire daily catch from a limited number of days fishing.

Towards the end of this stock assessment, an error was identified in the CS data in the *rlcs* database, affecting measurements made since July 2020. A calliper adjustment had erroneously not been applied to the most recent TW measurements, causing the affected CS measurements to be approximately 2 mm TW smaller than they should have been. This error is being fixed. Also, for the LB data, the reported statistical areas for the respective TW measurements were updated using fisher-reported latitude and longitude data, affecting the attributed statistical area for some biological samples. Thus,

[7] see Section 2.1.1 for the LB and CS data sources.
[8] commercial catch data were obtained from the MPI EDW database in May 2024 (replog 15830).

the SR and LF models were run using two versions of the data: once using corrected TW data (summing the reported calliper adjustment measurement and the TW measurement for the affected trips) and attributed statistical areas, and once using uncorrected values. Only model runs using the corrected measurements and statistical areas are described here, although the model structures, model diagnostics, and outputs were very similar for the two runs, except that lobsters using the uncorrected data were slightly smaller after 2020 relative to the model run using the corrected data.

Table 2: Number of vessels, skippers, trips, days sampled, pots lifted, and lobsters measured in the observer catch sampling (CS) and voluntary logbook (LB) programmes each fishing year. The fishing year indicated in grey was not included in the LF and SR models.

Fishing	Observer catch sampling					Voluntary logbook				
year	Vessels	Days	Trips	Pots	Lobsters	Vessels	Days	Trips	Pots	Lobsters
1986	2	2	2	78	544	–	–	–	–	–
1987	2	15	15	797	3 992	–	–	–	–	–
1988	4	15	15	849	4 777	–	–	–	–	–
1989	5	23	25	1 720	8 473	–	–	–	–	–
1990	5	37	39	2 803	25 480	–	–	–	–	–
1991	3	19	22	1 862	19 105	–	–	–	–	–
1992	3	20	20	1 761	18 390	–	–	–	–	–
1993	2	20	20	1 621	12 168	–	–	–	–	–
1994	4	12	12	983	8 070	–	–	–	–	–
1995	4	15	16	1 255	9 768	–	–	–	–	–
1996	5	6	7	603	4 549	–	–	–	–	–
1997	12	24	34	3 256	34 001	1	1	60	60	193
1998	11	23	27	1 964	19 132	3	3	40	50	151
1999	14	26	39	3 014	25 115	1	1	33	33	85
2000	15	29	39	2 797	22 524	1	1	7	7	23
2001	13	22	32	2 868	20 677	–	–	–	–	–
2002	17	22	35	3 273	20 977	1	1	48	48	138
2003	19	26	35	3 119	18 558	1	1	93	93	275
2004	17	28	36	3 182	23 086	1	1	72	72	181
2005	16	32	46	4 157	26 083	2	2	108	126	442
2006	15	28	46	4 302	22 337	2	2	101	115	342
2007	17	32	47	3 966	20 306	1	1	71	71	208
2008	17	34	40	3 126	20 306	1	1	39	39	116
2009	15	31	42	3 366	20 330	2	2	37	37	124
2010	15	35	43	2 940	18 340	8	7	137	197	552
2011	14	39	43	3 000	19 290	10	10	115	188	645
2012	17	36	44	3 664	22 640	6	6	142	214	688
2014	15	35	45	4 076	19 637	4	4	123	158	494
2015	15	34	41	3 184	16 413	9	9	159	315	1 064
2016	14	34	41	3 420	15 018	11	11	205	539	1 556
2017	19	37	43	3 080	13 734	14	14	210	670	1 989
2018	17	39	47	3 547	19 912	13	13	183	480	1 438
2019	18	39	45	3 316	14 840	15	13	205	602	1 826
2020	17	41	46	3 203	16 913	13	13	168	385	1 251
2021	17	43	53	3 934	25 692	11	10	177	384	1 282
2022	19	41	51	3 754	40 640	12	12	172	297	1 002
2023	15	45	51	3 553	34 600	11	11	175	290	900

2.1.2.1 Sex ratio of the catch

Following the approach of Webber (2022), a model was constructed where the predictor term for each sex category estimated the SR for each fishing year, month, statistical area, and fishing vessel. The explanatory variables included: fishing year, month, statistical area, vessel, fishing year by month interaction term, and 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 C.1). This model was then used to simulate the SR by year, month, and statistical area from the posterior distribution. This model-based approach also predicted the SR if there was catch in a stratum but no catch sampling from either data source, and combined the available SR data from both data sources if both were present in the respective stratum.

The catch (tonnes) in each fishing year, month, and statistical area was calculated from the catch and effort database[8]. The simulated SRs were scaled by the monthly catch in each statistical area and aggregated by posterior sample, fishing year, season, and sex category then converted to proportions (i.e., month and statistical area were rolled up). The mean and standard deviation (SD, i.e., uncertainty) by fishing year, season, and sex category were calculated from this distribution of sex ratios. Finally, the SR data set weight for each fishing year and season was calculated from the posterior SD (see Webber 2022).

The standardisation and the catch scaling did little to alter the time series of raw sex ratios by fishing year and season (Figure 4).

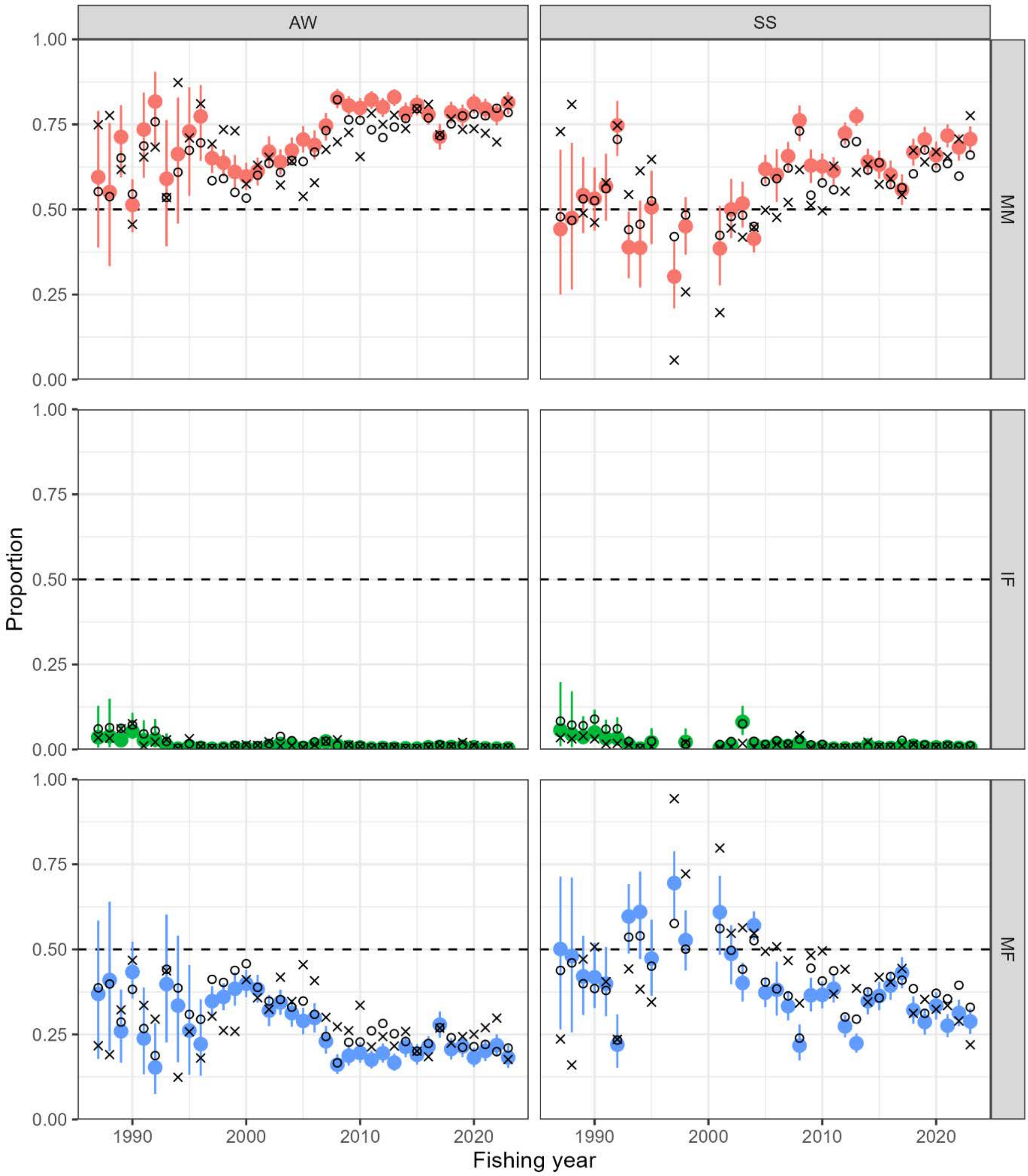


Figure 4. **Sex ratios (SRs) by fishing year and season, showing raw SRs (black crosses), predicted SRs (open black circles), and scaled SRs (closed circles with error bars representing 95% credible intervals) for males (MM), immature females (IF), and mature females (MF) by fishing year and season (AW = autumn/winter, SS = spring/summer).**

2.1.2.2 Length frequency of the catch

Following the approach of Webber (2022), a model was constructed that estimated the proportion at length by 2 mm bin intervals for each fishing year, month, and statistical area. The explanatory variables included: fishing year, month, statistical area, and a fishing year by statistical area interaction term. All terms were treated as group-level (random) effects.

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

The fitted LF models were used to simulate the predicted LF by sex category, fishing year, month, and 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, and combined 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 was calculated from the commercial catch and effort data[8]. The simulated LFs were scaled, first by the sex ratio model estimates, then by the monthly catch in each statistical area and aggregated by posterior sample, region, fishing year, season, sex category, and length bin which were 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 and the standardised LFs (i.e., the scaled, predicted LFs) were very similar to the LFs produced from the raw data, but at lower sample sizes (e.g., the late-1980s), the procedure adjusted the LFs considerably (Figure C.5 to Figure C.12). 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 was designed to mimic fishing patterns, resulting in a data set that is essentially self-weighting. In general, the standardised CRA 4 LFs were similar comparing adjacent years, with periods of slightly larger male and female lobsters in the late-1990s and since 2021 (Figure 5). Accordingly, the mean tail width by sex category and season was relatively stable since the late-1990s in both the CS and LB data sets and has increased a little since 2020 (Figure 6).

The standardised LFs were similar to the uncorrected CS data, except that the resulting TW distributions were composed of slightly smaller individuals on average since 2020 (compare Figure 5 and Figure C.13).

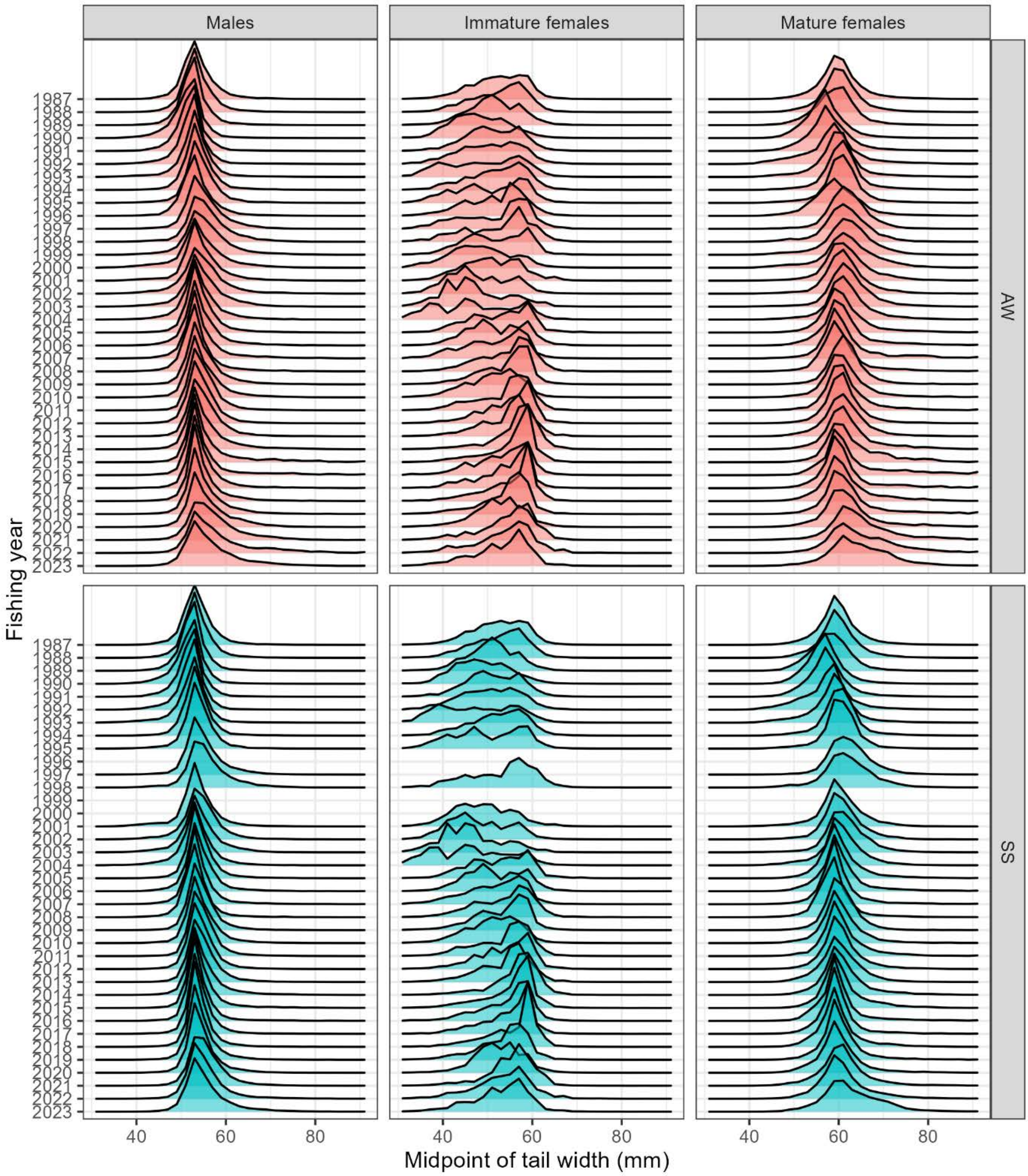


Figure 5. Predicted standardised LFs by fishing year (from 1987 to 2023), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex. See Figure C.5 to Figure C.12 for a comparison of raw and standardised LF distributions by year, season and sex.

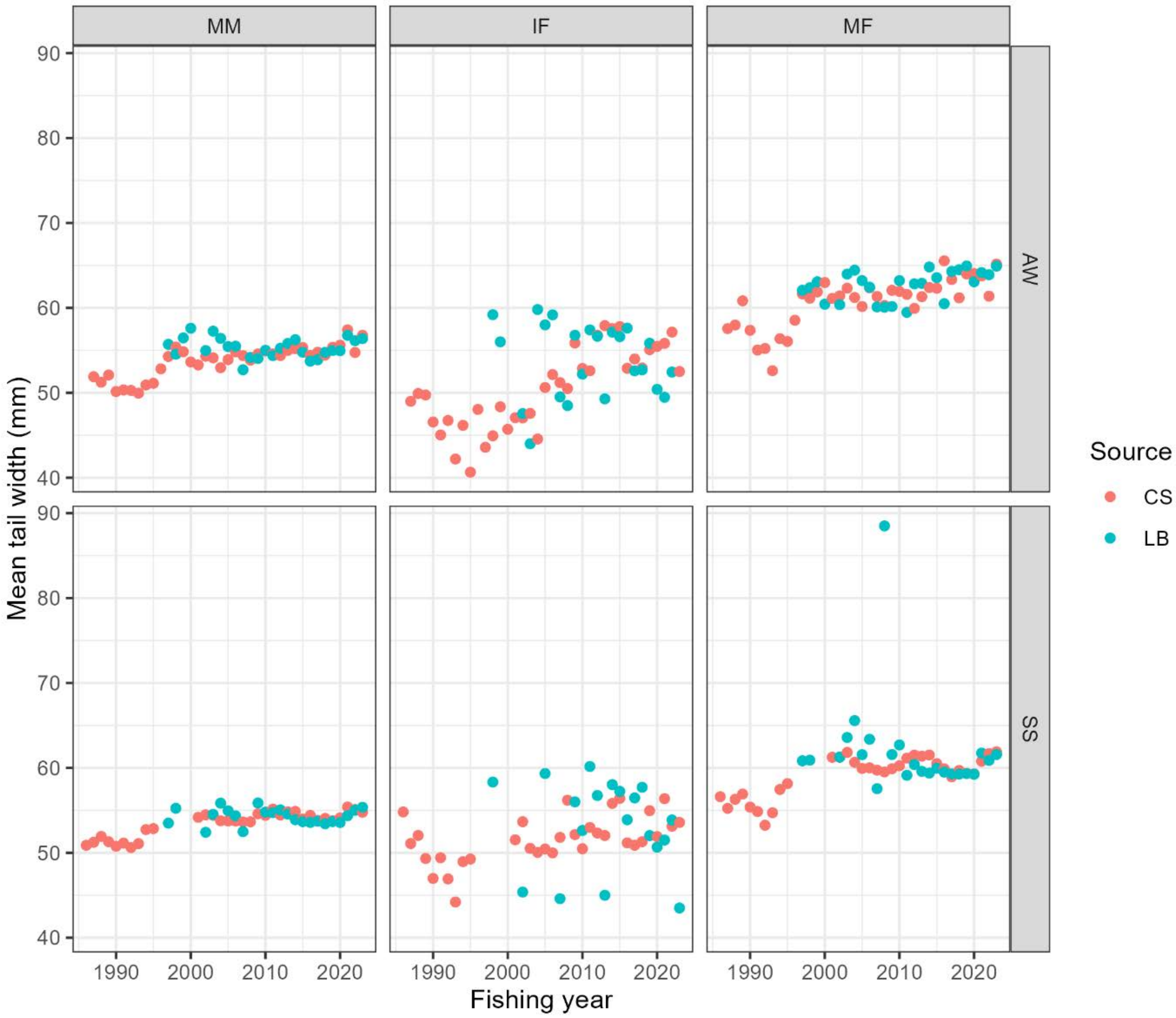


Figure 6. Mean tail width (mm) by fishing year, sex category (MM = males, IF = immature females, MF = mature females), season (AW = autumn/winter, SS = spring/summer), and data source (CS = observer catch sampling, LB = voluntary logbook).

2.1.3 Tag-recapture data

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

2.1.3.1 Data processing

Before the tag data were used to inform growth in stock assessments, they were processed (i.e., obvious errors were corrected and records that could not be used were removed). This procedure required that every release-recapture event for a tag was linked to create a single record while all tags with no recaptures were discarded. Processing, linking, and formatting were done using purpose-built software written in the *R* statistical computing language (see section 5.1 in Starr et al. 2021 for a description of these preparatory steps).

A comparison was done to ensure that the new data extract was not missing records that were available in previous years and to see how many new data records were available (Table D.1, Table D.2). This comparison showed an overall increase in the number of usable recoveries of 117 tags for all New Zealand compared to the same total from last year, with nearly all the new usable recaptures coming from recaptures made since 2022–23.

2.1.3.2 Tag data summary

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

The updated CRA 4 assessment used paired individual tag-recapture observations from initial tag releases (i.e., not from re-released lobsters) in all five CRA 4 Statistical Areas (912, 913, 914, 915, and 934). In addition, the RLWG agreed that this assessment should also use CRA 5 tag-recapture data, because they provided additional growth information at larger sizes (Figure 2, Figure D.1, Figure D.2) and because the water temperature regime was comparable (Roberts & Webber 2024). All subsequent summaries of the tag data included the combined CRA 4 and CRA 5 data.

Nearly all the tagging effort in CRA 4 took place after 1998, with only ten release/recovery observations reported during 1983–1985 (Table D.6, Table D.7). The remaining 3149 release/recovery observations spanned the release years 1998–2020. Tagging effort in CRA 4 has been distributed across all four major statistical areas, with Statistical Area 914 (south Wairarapa) having about 40% of the recoveries and Statistical Area 913 (north Wairarapa) having about 25% of the recoveries. The remaining recoveries were distributed almost equally (near 20%) between Statistical Areas 912 (Hawke's Bay) and 915 (Wellington). The CRA 5 tagging information included data from releases from 1975–76 to 2022–23. The total number of CRA 5 tag recoveries consisted of 7613 recaptures (Table D.6, Table D.7). Across CRA 4 and CRA 5, there was a total of 10 772 recaptures of which 3053 were females and 7719 were males (Table D.6, Table D.7). All subsequent tag data summaries reported below include both QMAs.

The monthly distribution of tag releases resulting in recaptures is shown in Table D.8. Few recaptures were made outside of the statistical area of release (Table D.9). Times at liberty in the processed tag data varied from 1 day to slightly more than 3500 days (~10 years) for both sexes (Table D.10), noting that the data processing procedure dropped apparent recoveries that were at liberty for more than 10 years. The median periods at liberty were 201 days for males and 280 days for females (Table D.10). A few males were re-released seven to thirteen-times, and from five to seven-times for females (Table D.11). Of male recoveries 30% came from re-releases while the equivalent percentage for females was 18%.

Growth increments (mm) ranged from -30 to +35 mm TW for males and from -30 to +31 mm TW for females (Table D.12). The CRA 5 tag data included growth increment data for males up to 70 mm TW and females up to 80 mm TW, which is approximately 10 mm larger than the respective maximum sizes for each sex from the CRA 4 data (Figure D.1, Figure D.2).

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 (Figure D.3). 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 growth rate estimates. While the analysis concluded that nearly all zero-growth lobsters had disappeared by the time they had been at liberty for eight months, the RLWG agreed that a six-month exclusion was a reasonable compromise without excluding too much data

(Table D.13).

2.2 Covariates

The covariates used in this stock assessment included the catch, assumed handling mortality rates associated with the commercial and recreational catch, the MLS, estimates of the proportion of mature females in berry (i.e., egg bearing), mean and SD of recruitment size (Figure 7), and other fixed quantities (Table 3).

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 3: Fixed quantities used in the CRA 4 base case stock assessment model.

Quantity	Value	Quantity	Value
Data set weights		**Length-weight**	
Tags	1	male *a*	4.16e-6
FSU CPUE	1.17	male *b*	2.935
CELR CPUE	2.60	female *a*	1.3e-5
CS CPUE	2.75	female *b*	2.545
LB CPUE	5.0	**Maturation**	
sex ratio	1.1	*mat95* (mm)	1.458
LFs	0.284	proportion *matfem* in berry (AW)	0.7935
Catch and handling		proportion *matfem* in berry (SS)	0.0691
handling mortality, 1945–1989	0.1	**Recruitment**	
handling mortality, 1990–2023	0.05	*sigmaR*	0.4
projected SL commercial catch	280 t	last year of estimated *Rdevs*	2020
projected SL recreational catch	69.9 t	years for estimating *Rdevs* for projections	2011–2020
Projected NSL illegal catch	34.4 t	*Rdevs* ‘data years’ for reference level simulation	1987–2020
Projected NSL customary catch	8 t	years for estimating autocorrelation	1986–2020
Growth		recruitment size mean	33.35 mm
length at *Galpha*	50	recruitment size SD	4 mm
length at *Gbeta*	80	recruitment autocorrelation	0.051
length at *Gmin*	0.0001	**Tail compression**	
Gdd	0	male bins	6 to 26
		immature female bins	1 to 20
		mature female bins	7 to 28

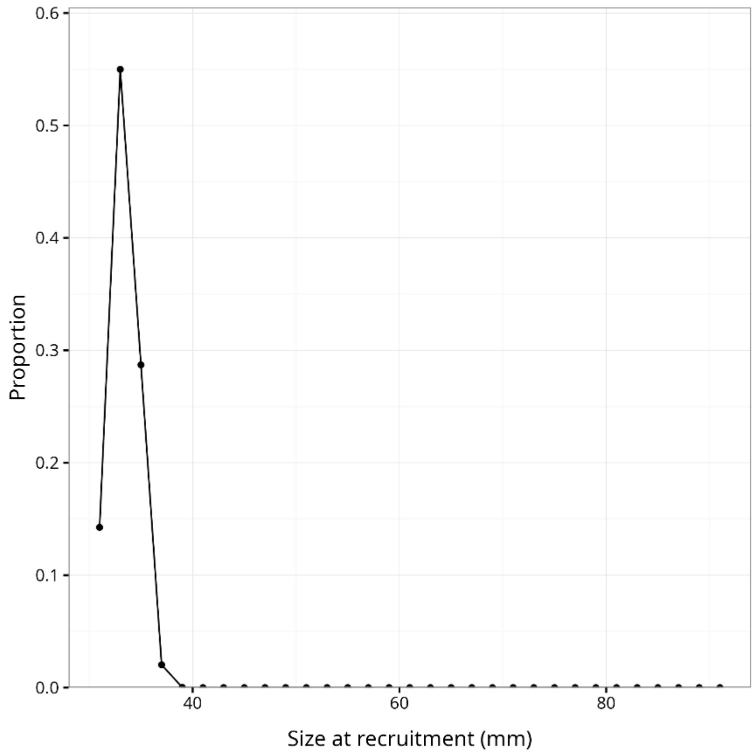


Figure 7: Distribution of size at recruitment size (mm) assumed in the CRA 4 stock assessment.

2.2.1 Minimum legal size (MLS)

Prior to 1949, there was no MLS for red rock lobster in New Zealand. MLS restrictions were initially implemented for New Zealand red rock lobster as measurements of tail length in inches. This measurement standard was subject to some abuse because tails could be stretched, but it was required because a significant fraction of the catch came from Fiordland where it was permissible to tail lobsters at sea. The MLS was changed to a width measurement (in mm) across the spines of the second abdominal segment (called the tail width or TW) in 1988 for all New Zealand red rock lobsters, requiring the conversion of the pre-1988 regulations into equivalent TW measurements for use in the stock assessment model (Breen et al. 1988). The current MLS in CRA 4 is 54 mm for males and 60 mm for females (Table 4).

Table 4: The tail-width (mm) minimum legal size (MLS) limits for males and females over time in CRA 4. Note that MLS before 1987 were expressed in terms of tail-length and have been converted to tail-width using the procedure described by Breen et al. (1988).

Period	Males	Females
1945–1949	None	None
1950–1951	47	49
1952–1958	51	53
1959–1987	53	58
1988–1991	54	58
1992–2023	54	60

2.2.2 Proportion of mature females in berry

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

Following the approach used in the most recent CRA 6 assessment (Webber et al. 2024), the LB data[7] were used to derive standardised proportions of berried females during the AW and SS seasons for CRA 4. This analysis also estimated proportions in berry for the other assessed QMAs/stock regions, which were shown here for completeness.

Of a total of 2 222 490 individual lobsters in the LB extract, 1 154 745 were males, 172 805 were immature females, 4 032 were unidentified stage females, and 1 689 had no sex stage information. Excluding these resulted in total sample of 889 219 mature female lobsters. In addition, 9 061 records lacked information of statistical area of sampling, so were also excluded, yielding a total sample of 880 158 mature females that were used by this analysis.

Berried females were defined as having sex code = 4 (‘berried female’) or sex code = 5 (‘spent female’). Using this definition, 513 577 females were assumed to be berried and 366 581 were not.

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

1. a *brms* model-based standardisation was used to produce predictions of the proportion of mature females that were berried/not berried by statistical area, fishing year, and month; then
2. using the reported catch in each (area/fishing year/month) stratum[8], catch-weighted values of the proportion of mature females in berry were produced for each stock-region and season and (as required) fishing year.

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

$$\underline{n\_berried} \mid trials \sim (1 \mid fmonth) + (1 \mid area) + (1 \mid fyear) + (1 \mid fmonth{:}area) + (1 \mid fyear{:}area)$$

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

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

The predicted proportions for each QMA/stock assessment region are shown for each season (Table E.3, Figure E.3), noting that differences when comparing assessment regions reflected differences of the monthly catch distribution as well as the reproductive cycle of females. Only the mean estimates (across all fishing years) were used by the CRA 4 stock assessment, i.e., 0.794 in AW and 0.069 in SS.

2.2.3 Catch

2.2.3.1 Commercial catch

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

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.

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 that are available to the stock assessment team are consistent with published historical catch estimates from the FSU system.

CRA 4 was managed by a management procedure (MP) from 2007 until 2018, with the first two years based on the voluntary shelving of ACE by quota holders. Beginning in 2009, the then Ministry of Fisheries implemented a formal MP, which was operated successfully from 2009 to 2018, resulting in eight Total Allowable Commercial Catch (TACC) changes over this 10-year period. The CRA 4 MP was calculated for 2019 and 2020, but, in both years, the MP-proposed increases were opposed by some stakeholders, resulting in the rejection of the proposed increases by the Minister of Fisheries. All rock lobster MPs were suspended after the introduction of the introduction of Electronic Reporting during 2019.

2.2.3.2 Recreational catch

Seven annual recreational survey catch estimates are available for CRA 4, but only the three National Panel Surveys (NPS) estimates were used in the stock assessment (Table 5). Estimates from the two Kingett Mitchell National Surveys (Boyd & Reilly 2004, Boyd et al. 2004) were not accepted by the RLWG for the 2016 CRA 4 stock assessment (Breen et al. 2017) because these survey estimates were considered implausibly high for CRA 4. The earlier 1994 and 1996 surveys, conducted by researchers at the University of Otago, were considered biased in a review of the available recreational surveys (unpublished minutes: Recreational Technical Working Group [Auckland NIWA, 10–11 June 2004]) because the interview questions possibly underestimated fisher participation rates by allowing for an easy exit from the interview (‘soft refusal’ bias). The RLWG considered that both the Boyd and the Otago surveys were biased high because recreational logbook participants were not closely supervised and may not have accurately recorded their fishing activity. The much higher harvest estimates in the Boyd surveys are likely to have resulted from the high level of claimed participation in recreational saltwater fishing from the initial screening survey.

Three large-scale population-based diary/interview surveys (National Panel Survey or NPS) were conducted under contract for MPI from 1 October 2011 to 30 September 2012 (Wynne-Jones et al.

2014), from 1 October 2017 to 30 September 2018 (Wynne-Jones et al. 2019) and from 1 October 2022 to 30 September 2023 (Heinemann & Gray 2024). These surveys were designed to estimate FMA-and QMA-specific annual catches for all major finfish and non-finfish species (Heinemann et al. 2015), based on an initial screening survey of the resident population of New Zealand, which was sampled from 'mesh block' dwelling cluster strata that had been enumerated by Statistics New Zealand during the most recent national census. A door-to-door survey of households drawn from randomly selected mesh block strata was used to select one putative fisher panellist from any household that claimed to contain at least one marine fisher, who was invited to report their catch during the upcoming October to September finfish fishing year. Each panellist was contacted at least once per month to see if they had been fishing, and those that claimed to have done so were interviewed using a structured and carefully designed Computer Assisted Telephone Interview (CATI) method to record trip effort and harvest data for any trips that had been reported since the previous reporting period. The survey results were thought to be plausible for CRA 4, with 69 (2011), 72 (2017) and 44 (2022) fishers providing 206, 195 and 129 trip reports during each of these survey years (Wynne-Jones et al. 2014, Wynne-Jones et al. 2019, Heinemann & Gray 2024). The first two estimates have reasonable CVs (0.17 in 2011 and 0.23 in 2017, Table 5) but there was a considerable increase in the CV associated with the 2022 survey (0.39, Table 5). The surveys made estimates of the distribution of fishing platforms used to take lobsters in CRA 4, with most catch taken from trailer boats but over a third taken from the land in 2011–12 and 2017 (Table 6). The primary capture method used to take rock lobster in CRA 4 was diving (Table 6). NPS survey results from logbook participants were in terms of numbers of fish harvested. Mean recreational catch weights for the most important finfish and non-finfish species QMAs were estimated by concurrent boat ramp surveys (Hartill & Davey 2015, Davey et al. 2019, Davey et al. 2024).

Table 5: Information available to estimate recreational catch for CRA 4.

Survey	Numbers	Mean weight (kg)	Catch weight (t)	CV
2011–12 (NPS: Wynne-Jones et al.2014)	53 847	0.82	43.36	0.17
2017–18 (NPS: Wynne-Jones et al. 2019)	52 023	0.79	41.26	0.23
2022–23 (NPS; Heinemann & Gray 2024)	46 483	0.70	32.58	0.39
Maximum reported s.111 landings (t) (in 2012–13)	–	–	5.835	–

Table 6: Fishing platform and capture method categories for CRA 4 estimated by the national NPS recreational surveys (Wynne-Jones et al. 2014; 2019, Heinemann & Gray 2024).

	2011–12			2017–18			2022–23		
Category	Catch (t)	CV	% of total	Catch (t)	CV	% of total	Catch (t)	CV	% of total
Capture method									
Hand gather by diving	29.39	0.22	67.8	31.10	0.29	75.4	23.68	0.52	72.7
Pot	13.13	0.28	30.3	10.11	0.30	24.5	8.90	0.41	27.3
Other	0.84	0.62	1.9	0.05	1.00	0.1	-	-	-
Platform									
Trailer boat	26.44	0.22	61.0	23.71	0.36	57.5	27.23	0.46	83.6
Larger motor boat or launch	0.56	0.72	1.3	1.3	0.54	3.2	-	-	-
Off land	15.38	0.23	35.5	16.05	0.25	38.9	5.23	0.3	16.1
Other	0.99	0.59	2.3	0.2	0.58	0.5	0.12	1	0.4

A recreational catch vector was developed by assuming that recreational catch was proportional to the CRA 4 spring/summer (SS) abundance, as reflected in the maximum likelihood estimation (MLE) standardised SS CPUE for all of CRA 4. By agreement in the RLWG, the recreational catch vector was based on the three NPS survey estimates (in tonnes – see Table 5), using the CVs in Table 5. Because of the break in the CRA 4 CPUE abundance series in 2019 with the introduction of electronic reporting, alternative CPUE series were developed from the data available from the catch sampling and logbook programmes (see Section 2.1.1). Annual CPUE estimates from the three available series were averaged beginning in 2014 to create a composite CPUE series for use in Eq.1. A scalar quantity q (Eq. 1) was estimated by obtaining the best fit to the three survey estimates when minimising a log-normal distribution using the CVs indicated in Table 5:

$$\textbf{Eq. 1:}\quad \boldsymbol{W_t = w_t N_t}$$
$$\boldsymbol{\widehat{W}_t = \widehat{q_t} CPUE_t}$$
$$\boldsymbol{LL = \sum_{t=1}^{t=3} \frac{\left(\log(W_t) - \log(\widehat{W}_t)\right)^2}{2\sigma_t^2}}$$

where t subscripts represent the three recreational surveys estimates (Table 5: 1 = 2011–12 NPS; 2 = 2017–18 NPS; 3 = 2022–23 NPS); w_t is the mean SS weight ≥ MLS for sampled lobster in year/survey *t* for CRA 4; N_t is the mean number of lobsters in year/survey *t* for CRA 4; $CPUE_t$ is the CRA 4 SS standardised CPUE in year *t*; and $\widehat{W_t}$ is the CRA 4 estimated recreational catch (tonnes) for year *t*.

$$\textbf{Eq. 2:}\quad \boldsymbol{\widehat{W}_{1945} = 0.2\widehat{W}_{1979}}$$
$$\boldsymbol{\widehat{W}_y = \widehat{q} CPUE_y} \quad \text{if y} \geq 1979$$
$$\boldsymbol{\widehat{W}_y = \widehat{W}_{y-1} + \frac{\widehat{W}_{1979} - \widehat{W}_{1945}}{1979 - 1945}} \quad \text{if y} > 1945 \;\&\; \text{y} < 1979$$

The estimated recreational catch trajectory (Figure 8) was constructed in the following manner:

1. CRA 4 SS CPUE was used to scale recreational catch using the *q* estimated in Eq.1 (Eq. 2)
2. assume recreational catch in 1945 was 20% of recreational catch in 1979 and scale linearly between 1945 and 1979.
3. Add section 111 destination code F annual values when available, otherwise use the maximum value over the CELR period (=5.8 t observed in the 2012–13 fishing year);
4. add charter boat estimates in the years available based on ACV-ACR reporting data;
5. Replace estimated recreational catch values in NPS Years (2011, 2017, and 2022) with the sum of the NPS survey catches, the estimated charter vessel catches and the declared section 111 catches. Charter boat catches reported by panellists were excluded when calculating NPS estimates, to avoid any double counting of charter boat catches.

90% of recreational catch was assumed to be caught in the SS, and 10% in AW. The estimated recreational catch vector used in the stock assessment accounted for 2902 t of historical catch from 1945 to 2023 and 1907 t from 1979 to 2023.

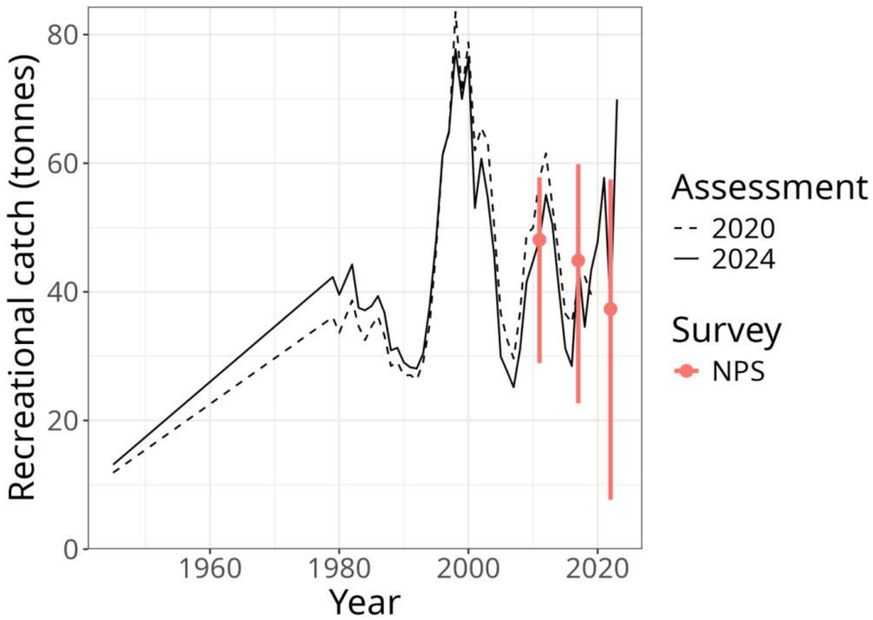


Figure 8: **CRA 4 recreational catch trajectory (tonnes) (Eq. 1) based on the CRA 4 SS seasonal CPUE series fitted to three NPS recreational catch surveys (Eq. 1 and Table 5). Error bars are ±2 SE, assuming a lognormal distribution. Also shown is the equivalent recreational catch series used in the 2020 CRA 4 stock assessment.**

2.2.3.3 Customary catch

Fisheries New Zealand were asked to provide estimates of current and historical customary catches, and an appreciation of their uncertainty. Fisheries New Zealand advised that a constant customary catch of 8 t should be assumed, a value consistent with what was assumed in past CRA 4 stock assessments. 90% of customary catch was assumed to be caught in the SS, and 10% in AW.

2.2.3.4 Illegal catch

Following the decisions made for the 2020 stock assessment, the RLWG agreed once again to discard the previously used MPI Compliance and 'export discrepancy' estimates of illegal catch. For 2024, the RLWG agreed to follow the 2020 stock assessment decision to use 10% of the total commercial catch summed over the period 1945–1989, followed by 5% of the summed commercial catch from 1990 to 2019 (Figure 9). The lower percentage was used for the post-1989 illegal catches on the assumption that illegal activity would be lower once rock lobster entered the QMS. These fixed catches were then scaled by the standardised SS CRA 4 CPUE, beginning in 1979. Note that the same CPUE used to calculate recreational catches was used to calculate illegal catches, where SS CPUE was averaged from 2014–2023 to obtain a composite CPUE index for each year where there were multiple series available. Before 1979, the illegal catches were assumed to be constant. Illegal catch was assumed to have the same AW/SS split as commercial catch.

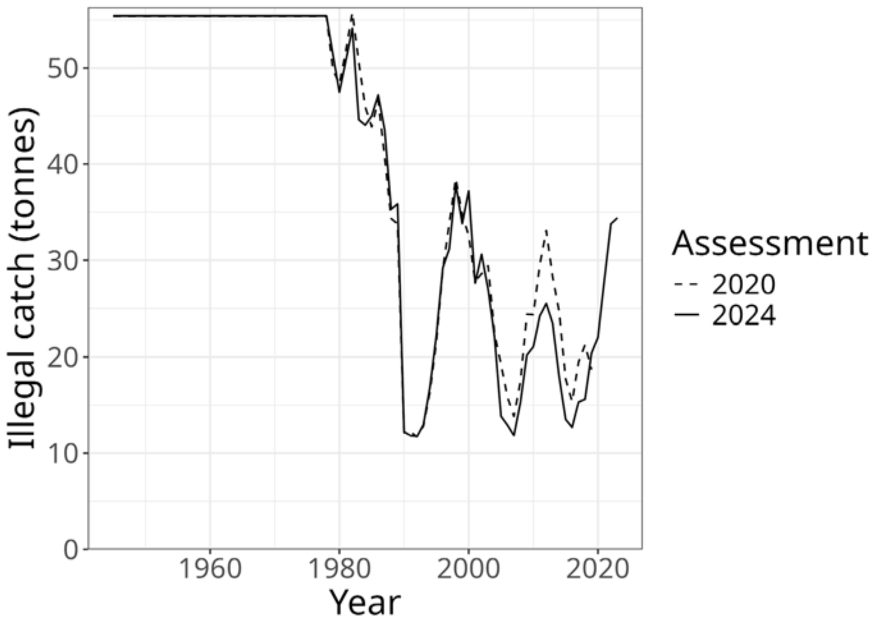


Figure 9: **Base case [pre-1990=10%*∑(1945–1989 catch) and post-1989=5%*∑(1990–2023 catch)] illegal catch trajectory used in the 2024 CRA 4 stock assessment Also plotted is the illegal catch series used in the 2020 CRA 4 base case stock assessment. Each series was scaled by the MLE annual CPUE, beginning in 1979.**

In the past, estimates for illegal catch from MPI Compliance Services have been provided in two categories (‘reported’ or ‘R’ and ‘not reported’ or ‘NR’) for some QMAs. The category of ‘commercial illegal reported’ or ‘reported’ was assumed to represent illegal commercial catch that was eventually reported to the QMS as legitimate catch. Therefore, this catch was subtracted from the reported commercial catch to avoid double-counting. However, given the considerable uncertainty associated with the illegal catches, the RLWG decided in 2020 that it had no confidence in this categorisation of the illegal catch, opting instead to discontinue this practice. This decision was repeated for the 2024 stock assessment.

The estimated illegal catch vector used in the stock assessment accounted for 1 884 t of historical catch from 1945 to 1978 and for 1 974 t from 1979 to 2023.

3. STOCK ASSESSMENT

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

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

MAP runs were used to develop a base case model and then a series of MAP model runs were used to explore the sensitivity of model outputs to changes in model structure and inputs. Full Bayesian inference using MCMC was completed for the base case model run and a subset of the sensitivity model runs. The posterior distribution of the base case model run was used to derive the CRA 4 reference level (Rudd et al. 2021c). Finally, the posterior distribution from the base case was used to project forward five years for providing management advice.

3.1 Model

The lobster stock dynamics (LSD) model (Webber et al. 2023) was set up to track the numbers of individual lobsters in three sex categories (immature females, mature females, and males) for each of 31 two-mm TW bins (from 30 mm to 90+ mm), by year, and season. Unlike the previous CRA 4 stock assessment model, the first model year was set to 1979 due to uncertainty in early data inputs as well as limited differences in early stock dynamics when starting the model in 1945 versus 1979. The last year in the reconstruction of the stock was 2023, but this was extended to 2028 for the projections. The model used two six-month seasons within a model year: AW (April to September) and SS (October to March). The 2024 stock assessment treated CRA 4 as a single homogenous area, as was done in the previous assessment for this stock in 2020 (Rudd et al. 2021a) which examined the available data for differences among the four major statistical areas (catches and data are very minor from Statistical Area 934) and concluded that, apart from Statistical Area 915, the remaining statistical areas were remarkably consistent with respect to CPUE trends and length frequencies. The WG agreed to proceed with a single region model because the differences between the three Wairarapa statistical areas and Statistical Area 915 were considered minor and because the latter statistical area only represented 10–15% of the recent catch and was represented by a limited amount of data.

New recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (33.35 mm) and standard deviation (4 mm), truncated at the smallest size class (30 mm) (Figure 7). Recruitment in a specific year was determined by the mean recruitment parameter (R_0) and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero and standard deviation of 0.4. Recruitment deviations were estimated for 1979–2020. Stock assessments for other QMAs typically estimated recruitment deviates up to two years before the final model year. This was adjusted for the 2022 CRA 2 stock assessment due to an estimated recruitment spike in 2019, when that recruitment deviate was estimated. While this could be caused by an observation of small individuals recruited in recent years or model weighting to fit increasing CPUE, the Plenary was uncomfortable with including this recruitment spike and wanted to wait until more years of data were available to inform it. This practice was continued for the 2024 CRA 4 stock assessment, so the most recent estimated recruitment deviate was for 2020 in this stock assessment. The 2021 to 2023 recruitment deviations were fixed to be the same as the 2020 recruitment deviation during the model fitting phase.

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

A logistic selectivity ogive was used to define the size composition of the catch, which was assumed to be size class and sex specific and the same for both immature and mature females. Selectivity was also assumed to be the same during the AW and SS seasons. Note that the assumed selectivity ogive differed from the 2020 assessment (Rudd et al. 2021a), which assumed a double normal ogive with a large fixed value specifying the right-hand limb. The 2020 assessment also assumed that selectivity varied across two time periods, split at 1993 to account for a change in escape gap regulations (to larger gap size), but this was dropped from the 2024 model because there were insufficient data available before 1993 to estimate an independent selectivity function. Vulnerability parameters defined the relative scaling (i.e., the height) of the selectivity curves by sex and season. Vulnerability parameters were estimated relatively, with the vulnerability for males fixed to one in each season and the remaining vulnerability parameters estimated to be between zero and one for immature females and mature females. Separate vulnerability parameters were estimated using 1993 as the cut-off year, to allow for the change in escape gap regulations.

To account for retention and discarding, retention was defined as the probability of retaining an individual lobster by year, season, sex, and size class. For CRA 4, this probability was determined by legal status regulation definitions (MLS and the proportion of mature females in berry) but did not include other forms of retention, such as high-grading.

Natural, fishing, and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and size. Exploitation rates were determined from observed catch and model biomass, modified by sex-specific MLS, proportions of mature females in berry, sex/season specific vulnerabilities, and sex-specific selectivity. Discarding of large lobsters appeared to be infrequent in CRA 4, given the low use of destination code ‘X’ in this QMA; it is not known if this reflected a lack of discarding or a failure to record legal discards, but discarding of large lobsters was not modelled in this stock assessment. Exploitation rates for each fishery were calculated from the catch, model biomass, and natural mortality.

The LSD model removed catch from the population using discrete exploitation rates, a change from the 2020 CRA 4 assessment which used instantaneous fishing mortality. The combination of selectivity, vulnerability, and retention was used to define exploitation rates (U) for the SL fishery, while only selectivity and vulnerability were needed to define exploitation rates for the NSL fishery. Handling mortality is calculated separately for the SL fishery.

3.2 Parameters and priors

Estimated model parameters included productivity parameters (i.e., average recruitment, natural mortality, and growth), maturation parameters, and fishery parameters (i.e., catchability, selectivity, and vulnerability) (see Table 7). Eight vulnerability parameters (i.e., *vuln1*, …, *vuln8*) were estimated, allowing for AW, SS, immature and mature females split at 1993 separately (Table 8). These parameters were estimated relative to the maximum selectivity of one for males during the AW and SS and before and after 1993 respectively.

Uninformative priors with wide parameter bounds were specified for most model parameters (Table 8). Wide uniform priors were specified for the catchability coefficient (q) for each of the CPUE series (Table 8). Beta distributions, with both shape parameters set to one, were used for priors for all parameters bounded between zero and one, including the growth parameter *Gdiff* and all vulnerability parameters (Table 8). An informative lognormal prior was specified for natural mortality (M); and informative normal priors were specified for the growth parameters *Gshape*, *GCV*, and *Gobs*, based on an unpublished meta-analysis (Table 8). Uninformative normal prior distributions were specified for all other model parameters (Table 8). These uninformative normal priors were essentially flat across sensible ranges for each of these parameters and, therefore, did not influence the outcome of the stock assessment, although they helped the model software (Stan) during the warm-up phase of the MCMC algorithm.

Table 7: Definitions of parameters and derived quantities discussed in the text.

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

Table 8: Specifications for estimated parameters in the CRA 4 models including the upper and lower bounds, prior type, and prior parameters.

Sex	Parameter	Lower bound	Upper bound	Prior type	Prior parameter 1	Prior parameter 2
	R_0	exp(1)	exp(25)	normal	1e6	1e7
	M	0.01	0.40	lognormal	0.12	0.4
	*Rdev*s	-2.3	2.3	uniform		
	qCR	exp(-25)	1	uniform		
	qFSU	exp(-25)	1	uniform		
	qCELR	exp(-25)	1	uniform		
	qLB	exp(-25)	1	uniform		
	qCS	exp(-25)	1	uniform		
	Mat50	30	80	normal	50	10
	Mat95	1	60	normal	fixed[1]	fixed[1]
male	*Galpha*	1	20	normal	2	30
male	*Gdiff*	0.001	0.99	beta	1	1
male	*Gshape*	0.1	15	normal	4.81	0.48
male	*GCV*	0.01	2	normal	0.59	0.18
female	*Galpha*	1	20	normal	2	30
female	*Gdiff*	0.001	0.99	beta	1	1
female	*Gshape*	0.1	15	normal	4.51	0.45
female	*GCV*	0.01	2	normal	0.82	0.25
	Gobs	0.0001	10	normal	1.48	0.074
	SelL	1	50	normal	10	10
	SelM	30	90	normal	50	30
	vuln	0.01	1	beta	1	1
	U_0	0.00	0.99	beta	1	1

3.3 Assessment indicators

This assessment used the same indicators that were used in the 2022 CRA 2 assessment (Webber et al. 2023), using a discrete exploitation rate in place of the instantaneous fishing mortality rate that was used in previous rock lobster stock assessments (Table 9, Table 10). The exploitation rate associated with the reference level (U_R, see Section 3.6) was updated to be defined as the fixed exploitation rate associated with a median vulnerable biomass equal to B_R at equilibrium. The main indicators were related to the relative estimates of adjusted vulnerable biomass[9], SSB, and total biomass, including the probabilities that each of the biomass indicators would fall below current levels and management reference points, after projecting the current catch forward for five years (see Section 3.7). Probabilities were calculated over all samples of the posterior distribution.

In the past, vulnerable biomass was defined as start-of-season AW biomass, which did not include any mature females because they were all assumed to be in berry and were thus excluded from harvest. However, in this assessment, a small proportion of mature females (about 0.2, which is the proportion not in berry – see the AW proportion in berry estimate given in Table 3) was included in the AW vulnerable biomass. Vulnerable biomass accounts for the MLS, selectivity, and sex/seasonal vulnerability, and was the estimated biomass available to be caught by the fishery at the beginning of the AW season. Adjusted vulnerable biomass was calculated by applying the MLS and selectivity from the final model year to all previous years, including those years when earlier alternative regulations were enforced, thus allowing for a consistent definition of vulnerable biomass across all years.

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

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

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

Table 9: Reference points for the CRA 4 stock assessment.

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

Table 10: Performance indicators and stock status probabilities for the CRA 4 stock assessment.

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

3.4 Developing a base case

3.4.1 Matching the previous assessment model

In every year since its initial development, the LSD model code and the preparation of the input data have been improved to ensure that these procedures are consistent with current best practices in stock assessment. Because this is an ongoing process that can occur multiple times in the interval between full stock assessments for any CRA QMA, it is necessary to track how these improvements may have affected the results obtained by the previous base case stock assessment. Key LSD model updates since the 2020 CRA 4 stock assessment included:

1. Calculate discrete exploitation rates instead of instantaneous fishing mortality rates.
2. Develop standardised length frequency and sex ratio inputs.

3. Development of logbook and catch sampling CPUE series, including updated likelihood functions, to replace the break in the CPUE series based on the statutory catch and effort data.
4. Develop an updated model for predicting TW from CL, primarily used to convert older tag data into TW.
5. Estimate proportion of mature females in berry rather than a binary process.
6. Updated assumptions about illegal, recreational, and customary catches.

Starting with the 2023 CRA 4 rapid update (Pons et al. 2024), which had the same base model structure as the 2020 stock assessment but with data through to 2023, new features were added incrementally to this initial model to identify where changes occurred. Initial model *v4_U* included updates to CPUE, length frequency, and sex ratio inputs and likelihoods as well as calculated exploitation rates (Figure 10, Figure 11). It was determined that there were differences specifically associated with calculating exploitation rates as opposed to fishing mortality rates for CRA 4 that were not observed when this approach was previously applied to CRA 2 and CRA 6. Initial CRA 4 explorations found higher M, higher R_0, and a change in the q for the CR series.

There was no change associated with the updated tag data extract (*1_tags*, Figure 10, Figure 11). Updated catch assumptions also led to negligible changes (*2_catches*, Figure 12, Figure 13). Updated length frequency and sex ratio inputs for the 2024 assessment led to some minor shifts from the *2_catches* run (*3_LF_SR*, Figure 12, Figure 13). Finally, the updated CPUE series for the 2024 assessment led to a strong increasing trend in the final four model years (*5_2023*, Figure 12, Figure 13). Overall, the starting point for the 2024 assessment included several model updates that changed some parameter estimates leading to some differences in biomass patterns over time.

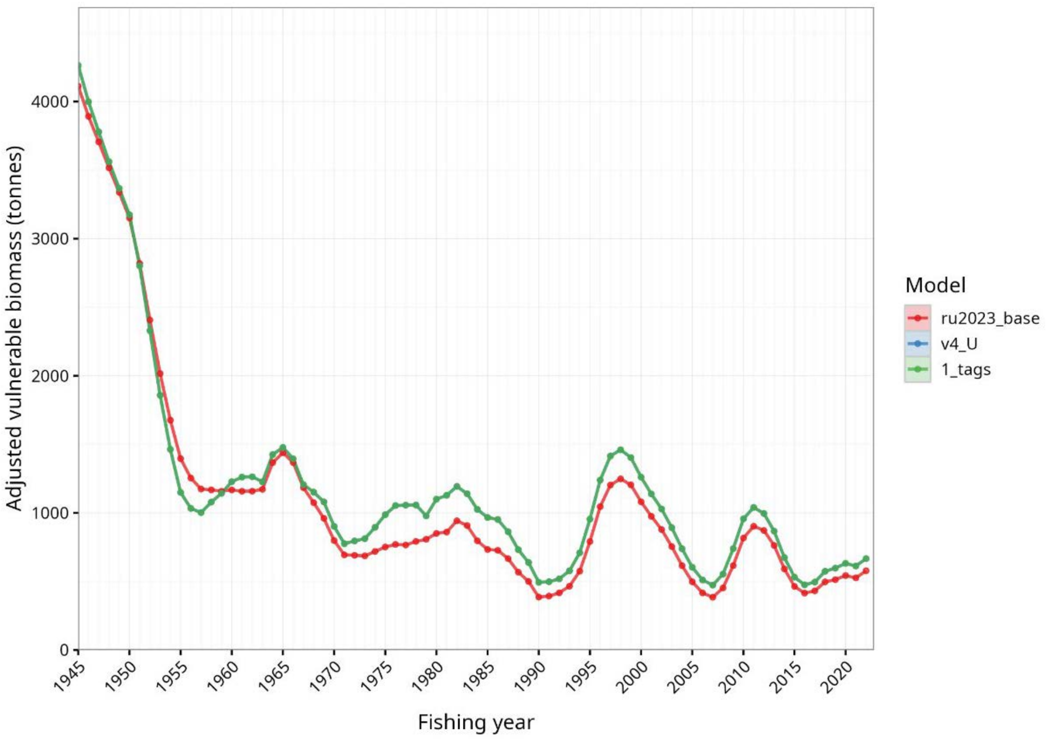


Figure 10: MAP of adjusted vulnerable biomass for initial models building up from the 2023 rapid update (*ru2023_base*): calculating exploitation rates instead of fishing mortality rates (*v4_U*) and updated tag data extract (*1_tags*). Note that *1_tags* overlays *v4_U* exactly.

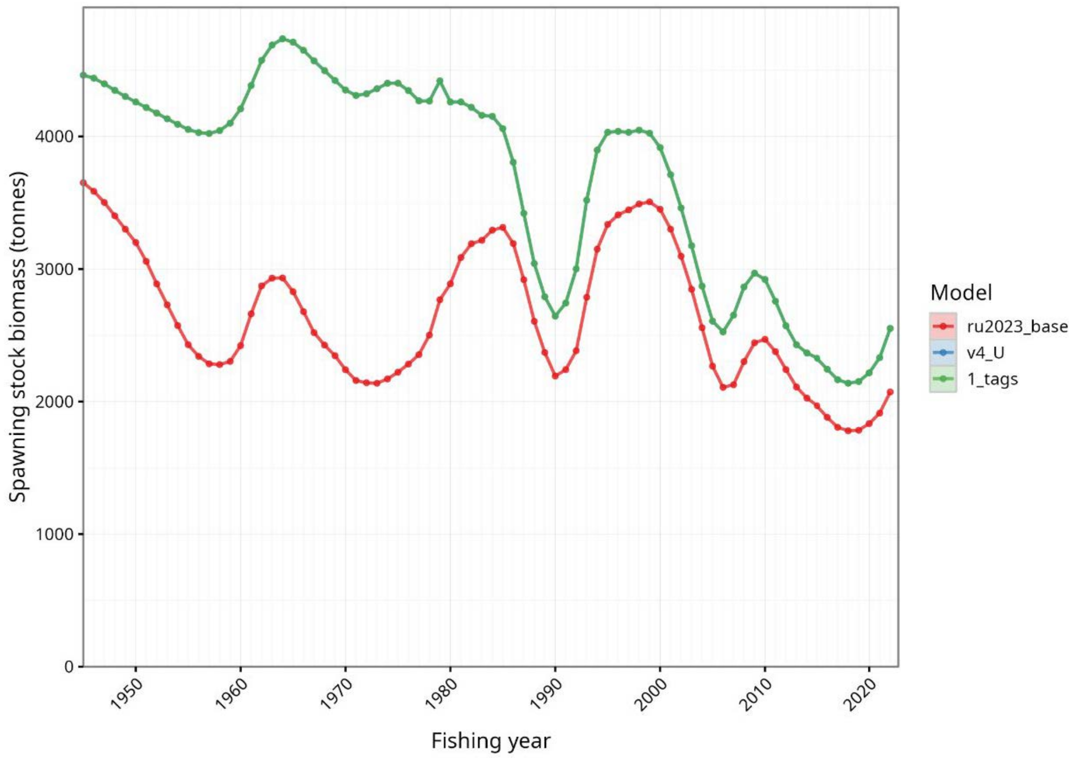


Figure 11: MAP of spawning stock biomass for initial models building up from the 2023 rapid update (*ru2023_base*): calculating exploitation rates instead of fishing mortality rates (*v4_U*) and updated tag data extract (*1_tags*). Note that *1_tags* overlays *v4_U* exactly.

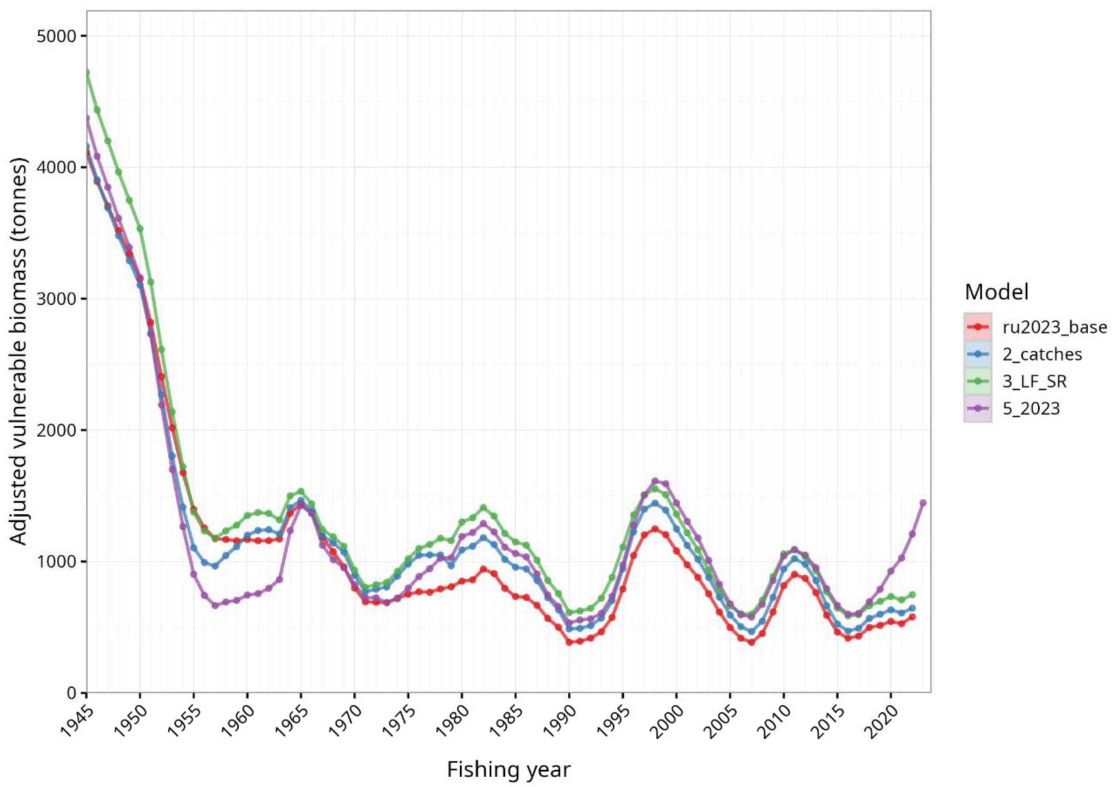


Figure 12: MAP of adjusted vulnerable biomass for initial models building up from the 2023 rapid update (*ru2023_base*): updated catch assumptions (*2_catches*), updated length frequency and sex ratio inputs (*3_LF_SR*), and updated CPUE inputs through the 2023 fishing year (*5_2023*).

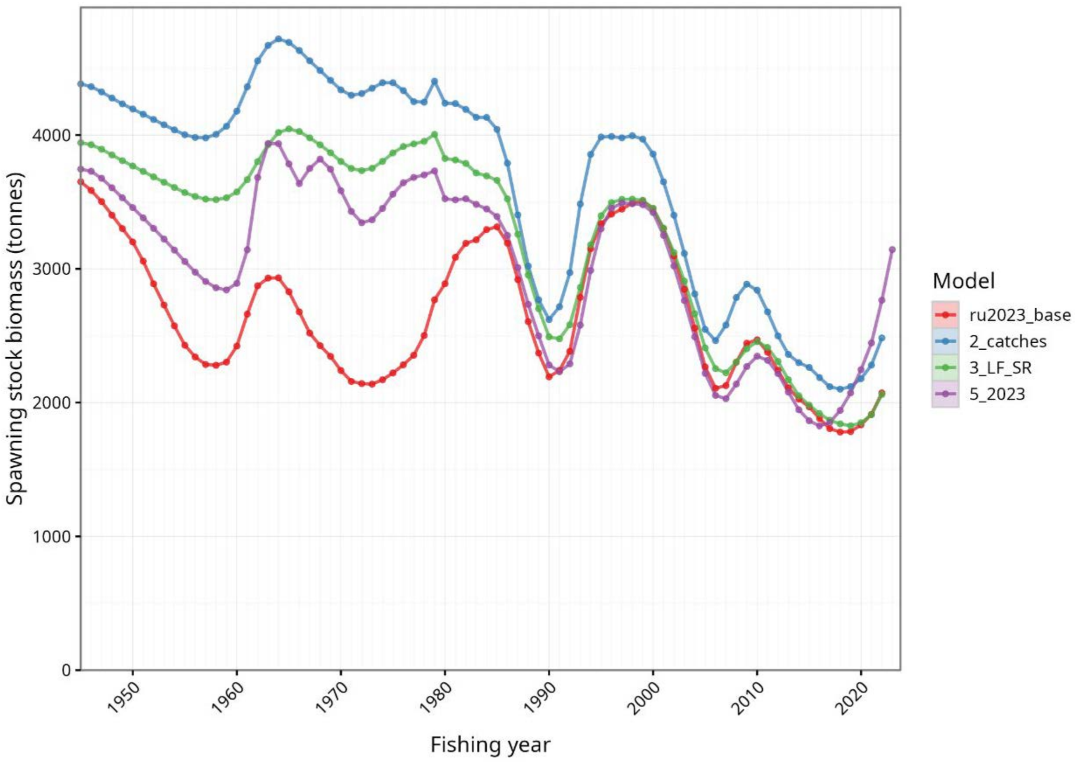


Figure 13: MAP of spawning stock biomass for initial models building up from the 2023 rapid update (*ru2023_base*): updated catch assumptions (*2_catches*), updated length frequency and sex ratio inputs (*3_LF_SR*), and updated CPUE inputs through to the 2023 fishing year (*5_2023*).

3.4.2 Searching for a new base case

Exploratory model runs were done to develop a new base case stock assessment model. The following is an abbreviated sequence of steps that led to the CRA 4 base case as data were updated and model changes were implemented:

1. Calculation of discrete exploitation rates instead of instantaneous fishing mortality rates: running the Newton-Raphson algorithm iteratively to calculate fishing mortality rates is no longer required, which improved speed of model runs. There were some differences in model results associated with calculating exploitation rates vs. fishing mortality rates that were not observed for CRA 2 or CRA 6, including higher estimated M, higher R_0, and change in the CR series q.
2. Updated tag data extract.
3. Updated assumptions about illegal, recreational, and customary catches: The RLWG agreed on the assumption of illegal catch as 10% of reported legal catch before 1990 and 5% of QMA/MHR catch since 1990. Followed the typical approach to scale recreational catch to available surveys, but used an updated logbook CPUE series to extend the series; this led to small decreases in recreational catch from the late 1990s through to 2019 and a slight increase in recreational catch for the early part of the series, from 1945 through to the mid-1990s. Annual estimates of NPS surveys and estimated charter vessel catches were used at face value in place of estimated recreational catch when available. Annual S.111 catches were also used instead of the maximum S.111 catch over the CELR series. Assumed customary catches were decreased from 20 t per year to 8 t per year as agreed by the RLWG.
4. Added standardised length frequencies (using a Bayesian Poisson-decomposed multinomial GLMM model) and sex ratios (using a Bayesian multinomial GLMM model). This approach replaced that used for the 2020 assessment, which kept catch sampling and logbook data

separate using ad-hoc weightings; the updated approach used standardised LF and sex ratios, resulting in a single series for each year, season, and sex category.

5. Developed and included logbook and catch sampling CPUE series: updated model code so that the newly developed logbook CPUE series from 2011–2023 could be fitted in numbers per potlift above the MLS and catch sampling CPUE series from 2004–2023 in terms of total numbers per potlift above and below the MLS. The FSU series (1979–1989) and overlapping CELR (1990–2019 AW) were maintained as kg/potlift. CPUE likelihood weights were proportionately reduced for those years where the CELR, logbook, or catch sampling series overlapped (i.e., 2004–2023).
6. Estimated recruitment deviates through to 2020 (three years prior to final model year) rather than 2021 (other rock lobster stock assessments have typically used two years prior to final model year). This approach was adopted during the 2022 CRA 2 assessment given concerns about whether recent data could adequately inform recent recruitment deviates.
7. Used average proportion of mature females in berry covariate estimated using logbook data to update the 2020 binary assumption of 100% berried in AW and 0% berried in SS. The 2024 stock assessment used an average over years by season. This is expected to model the SSB and vulnerable biomass more accurately. CRA 4 proportion of berried females for the 2024 assessment was assumed to be 0.7935 AW and 0.0691 SS (see Appendix E).
8. Fixed increasing trend in catchability coefficient (*qdrift*) on CELR series at 1%/year.
9. Model started in 1979, requiring an estimated initial exploitation rate.
10. Mean size at recruitment was set = 33.35 mm with a standard deviation = 4 mm, based on juvenile growth work done in 2020; this was a change from 2020, where the mean size was 32 mm (SD = 2 mm).

At this point, there were some initial concerns about the previous model structure during the development of a base model. These included poor fits to sex ratios, a recruitment spike in final estimated year (2020), and a very high estimate for *M*. Changes to model assumptions attempted to address these issues, including:

11. Assumed sex-specific logistic selectivity, by season for females and the same logistic selectivity for males across both seasons; having removed the selectivity epoch split in 1993 (the 2020 stock assessment used a double normal selectivity with a large fixed value for the right-hand limb and included the 1993 epoch split).
12. Updated fixed value for the *mat95* parameter (2.58 in 2020, updated to 1.46, an early MAP estimate during the 2024 assessment).
13. Male vulnerability was fixed to 1 each season, then separate vulnerabilities by season were estimated for immature females and mature females; an epoch split was preserved in 1993 (2020 assessment fixed immature females in AW to 1 and estimated male and female vulnerabilities by season relative to this one stratum; there was no epoch split for the 2020 vulnerability).
14. Included CRA 5 tags, excluding recaptures at liberty less than 6 months. This was justified based on similar sea surface temperatures comparing CRA 4 and CRA 5, with the intention to boost the overall sample and help inform growth of larger lobsters. This was supported by analysis of tag return information to better understand inclusion/exclusion of these observations.

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

- **Years**: 1979 to 2023[10], estimating an initial exploitation rate.
- **Seasons**: two six-month seasons AW (April-September) and SS (October-March) during each fishing year.
- **Sex categories**: males, immature females, and mature females.
- **Tail width bins**: 31 two-mm wide bins with midpoints from 31 mm to 91 mm tail width (last bin was a ‘plus group’ or accumulator bin).

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

- **Regions**: a single region including Statistical Areas 912, 913, 914, 915, and 934.
- **Recruitment**: recruitment deviations (*Rdevs*) estimated from the first model year through to 2020. The final three model years were set to the 2020 estimate, given no real information in data for these recruitments and no puerulus settlement index. No stock recruitment relationship was assumed. Size at recruitment was assumed to have a mean of 33.35 mm and standard deviation 4 mm, based on recent studies of juvenile growth (Figure 7, Roberts & Webber 2022).
- **Growth**: sex-specific using the Schnute-Francis growth model. No density-dependent growth. Included CRA 4 and CRA 5 tags, excluding recaptures at liberty less than 6 months.
- **Maturation**: female only logistic ogive, with *mat95* fixed at 1.46.
- **Natural mortality**: a single *M*, shared between sexes.
- **Selectivity**: logistic, sex specific, and different for females during the AW and SS.
- **Vulnerability**: male vulnerability was fixed to 1 each season, then eight separate vulnerabilities by season were estimated for immature females and mature females; an epoch split was preserved in 1993 (prior to 1993, and 1993 onwards, see Table 8).
- **Handling mortality**: two periods: 1979 to 1989 fixed at 0.1, and 1990 to 2028 fixed at 0.05.
- **Catch**: from 1979 to 2023 using updated assumptions commercial, illegal, recreational, and customary (see sections 2.2, 2.3, and 2.4). Removed using discrete exploitation rates.
- **Abundance indices**: four CPUE series (FSU, CELR, CS, and LB), each with a separate catchability coefficient (*q*). Fixed *qdrift* at 1% per year for the CELR series. No *qdrift* assumed for the FSU, CS, or LB series.
- **Likelihoods**:
  - Lognormal for all CPUE series (FSU, CELR, CS, and logbook)
  - Robust normal for tags
  - Multinomial for LFs, fitted to standardised proportions at length for males, immature females, and mature females, with each sex category normalised separately
  - Multinomial for sex ratios
- **Data weighting**: determined iteratively and simultaneously for all data types. The LFs were weighted following the TA1.8 weighting method of Francis (2011) and the other data types were weighted aiming for a standard deviation of the normalised residual (SDNR) of one. No re-weighting of tag data because they are self-weighting through the estimation of an observation error parameter.

3.4.3 MCMC base case

MCMC was used to obtain samples from the posterior distribution of the *base* case model. The MAP values were used as starting values. MCMC trace plots indicated that MCMC chains were well-mixed (Figure F.1, Figure F.2, Figure F.3, and Figure F.4) and all Rhat statistics were good (Table 12). The traces for the key estimated biological parameters, such as *M* and R_0, showed an acceptable level of stability, with MCMC chains staying away from parameter bounds. The posterior distributions for most model parameters updated the prior (Figure F.5, Figure F.6, Figure F.7). Likelihoods, the standard deviation of the normalised residual (SDNR), and parameter estimates were inspected (Table 11), as were the derived parameters and probabilities, including projections, for the base case (Table 12).

The CRA 4 stock assessment was accepted by the Plenary in August 2024, including all MCMC and MAP sensitivity runs relative to the base model. Between August and November 2024, it was determined that there had been an issue with the catch sampling length frequency data processing related to the calliper adjustment (see Section 2.1.2). The base model was run again with the updated length frequency data, and recruitment was estimated to be lower from 2019 onwards and without a strong recruitment spike in 2020 compared to the original base model (Figure 14). The WG agreed to use the updated version of the base model with the corrected length frequency calliper adjustments. These results are labelled *base2* and comparisons to the first *base* are shown in Figure 14 through to Figure 17.

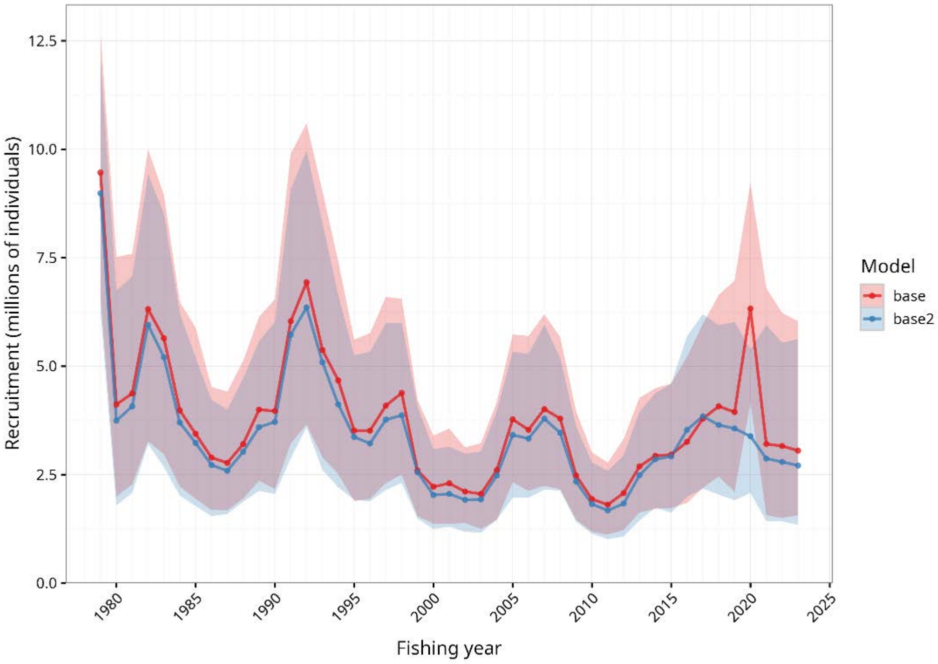


Figure 14: **Recruitment for the *base2* (correct calliper adjustment applied for the length frequency data, and used as the base case model for the CRA 4 2024 stock assessment) vs. *base* (length frequency data without the calliper adjustment, for relative comparison with sensitivity runs).**

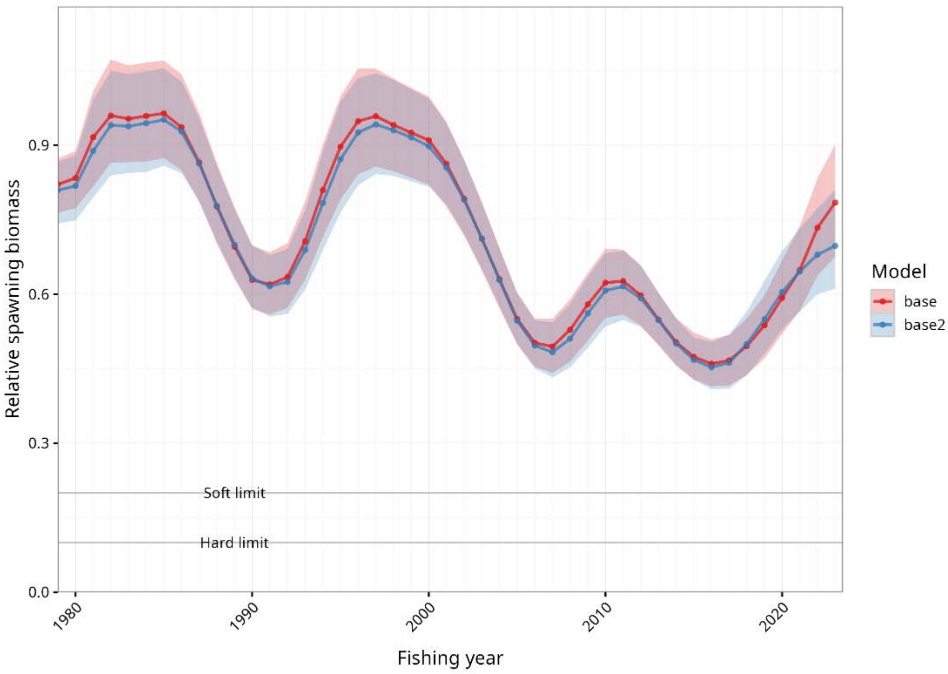


Figure 15: **Relative spawning stock biomass for *base2* (calliper adjustments applied to recent length frequency data, and used as the base case model for the CRA 4 2024 stock assessment) vs. *base* (length frequency data without the calliper adjustment, for relative comparison with sensitivity runs).**

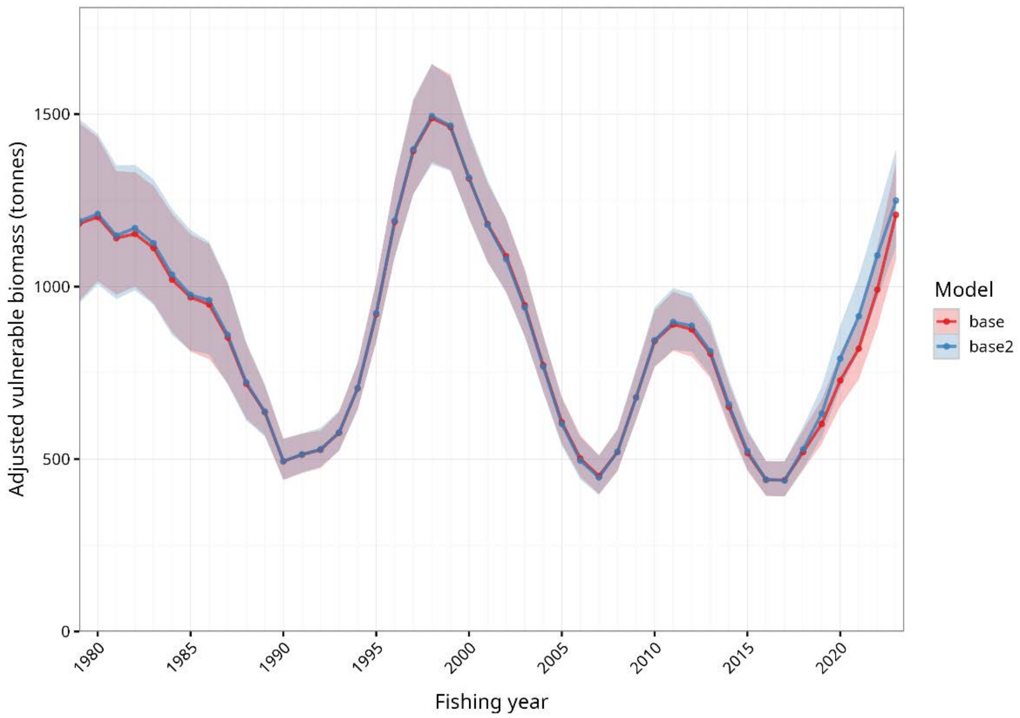


Figure 16: **Adjusted vulnerable biomass for *base2* (calliper adjustments applied to recent length frequency data, and used as the base case model for the CRA 4 2024 stock assessment) vs. *base* (length frequency data without the calliper adjustment, for relative comparison with sensitivity runs).**

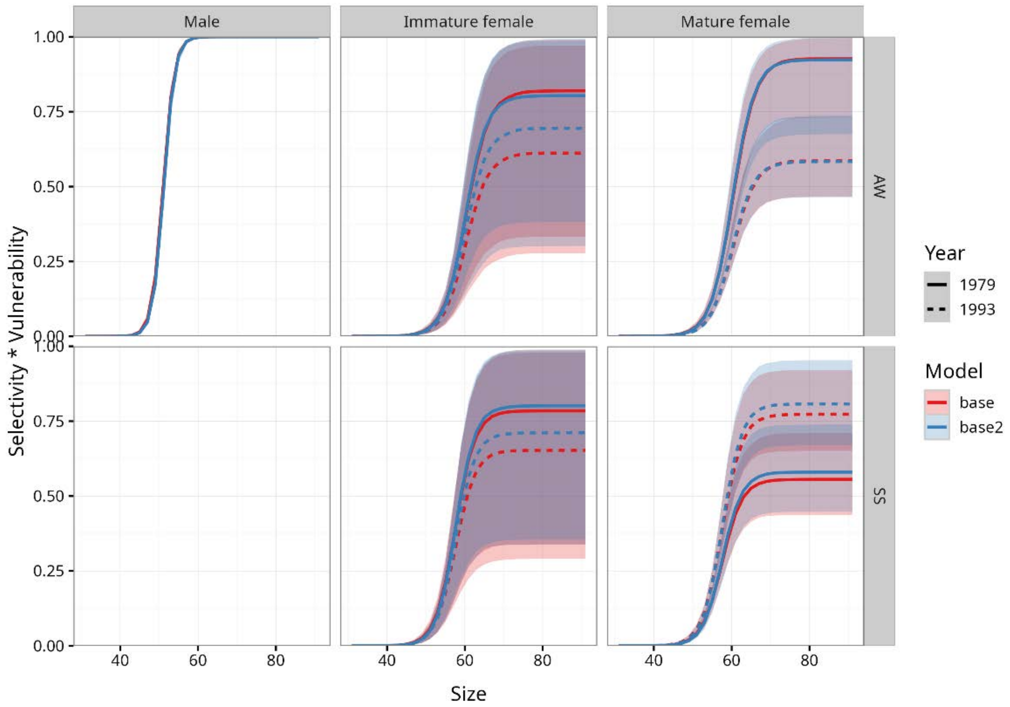


Figure 17: **Selectivity × vulnerability for *base2* (scaler adjustments applied to recent length frequency data, and used as the base case model for the CRA 4 2024 stock assessment) vs. *base* (length frequency data without the calliper adjustment, for relative comparison with sensitivity runs).**

Table 11: CRA 4 summary of the posterior distributions for the model likelihoods and standard deviation of the normalised residual (SDNR) for the *base2* model. The mean, standard deviation (SD) of the mean, median, and 90% credible interval (i.e., 5% and 95%). Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. '–': not applicable.

	Mean	SD	5%	Median	95%
Likelihoods					
Total	16 531	6	16 522	16 530	16 541
Prior	60	7	50	60	71
Penalty	0	0	0	0	0
Tags	8 254	6	8 245	8 254	8 264
Sex ratio	1 495	3	1 491	1 494	1 501
LFs	6 951	6	6 941	6 952	6 961
CPUE [CR]	-35	2	-39	-35	-31
CPUE [FSU]	-112	4	-117	-112	-105
CPUE [CELR]	-46	1	-48	-46	-43
CPUE [LB]	-37	2	-40	-37	-34
SDNR					
Tags	1.226	0.014	1.203	1.225	1.249
Sex ratio	0.988	0.060	0.919	0.973	1.103
LFs	0.565	0.032	0.518	0.561	0.621
CPUE [FSU]	1.125	0.097	0.975	1.124	1.288
CPUE [CELR]	1.111	0.055	1.026	1.108	1.204
CPUE [CS]	1.041	0.031	0.991	1.038	1.095
CPUE [LB]	1.030	0.064	0.932	1.027	1.143

Table 12: CRA 4 summary of the posterior distribution for the model parameter estimates for the *base2* model. The mean, standard deviation (SD) of the mean, median, 90% credible interval (i.e., 5% and 95%), effective number of samples, and Rhat statistic are reported. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. '–': not applicable.

	Mean	SD	5%	Median	95%	Effective N	Rhat
R_0	3 930 070	603 428	3 045 850	3 896 630	5 001 010	1073	0.999
M	0.291	0.021	0.257	0.291	0.329	1114	1.001
U_0	0.240	0.050	0.162	0.237	0.326	971	1.008
qFSU	1.05E-03	1.07E-04	8.87E-04	1.04E-03	1.24E-03	1071	1.002
qCELR	1.21E-03	7.44E-05	1.09E-03	1.21E-03	1.34E-03	982	0.999
qCS	2.78E-06	1.71E-07	2.49E-06	2.77E-06	3.06E-06	1059	1.000
qLB	2.46E-06	1.53E-07	2.22E-06	2.45E-06	2.71E-06	1035	1.000
mat50	42.935	0.941	41.423	42.927	44.429	988	1.000
mat95	1.458		1.458	1.458	1.458		
Galpha [M]	3.154	0.042	3.086	3.154	3.221	969	1.000
Galpha [F]	2.931	0.082	2.794	2.934	3.060	1047	1.002
Gdiff [M]	0.919	0.035	0.861	0.919	0.975	1005	0.999
Gdiff [F]	0.502	0.027	0.461	0.502	0.548	982	0.999
Gshape [M]	6.346	0.410	5.659	6.355	7.007	1003	0.999
Gshape [F]	4.600	0.547	3.650	4.700	5.337	1003	1.002
GCV [M]	0.625	0.015	0.601	0.625	0.651	1034	1.001
GCV [F]	0.881	0.027	0.840	0.880	0.928	921	1.005
Gobs	0.951	0.051	0.861	0.953	1.033	1057	1.002
vuln AW [IF] < 1993	0.770	0.174	0.434	0.804	0.984	972	0.999
vuln SS [IF] < 1993	0.757	0.182	0.430	0.802	0.978	934	0.999
vuln AW [MF] < 1993	0.899	0.087	0.717	0.924	0.994	982	0.999
vuln SS [MF] < 1993	0.583	0.077	0.467	0.580	0.718	920	0.999
vuln AW [IF] ≥ 1993	0.685	0.190	0.355	0.695	0.967	943	1.000
vuln SS [IF] ≥ 1993	0.697	0.181	0.381	0.712	0.962	930	1.002
vuln AW [MF] ≥ 1993	0.589	0.071	0.483	0.584	0.714	925	0.999
vuln SS [MF] ≥ 1993	0.808	0.072	0.690	0.808	0.930	980	0.999
selL [M]	4.143	0.201	3.828	4.134	4.481	1028	1.000
selL [F] AW	8.168	0.665	7.097	8.157	9.262	931	1.000
sell [F] SS	7.282	0.562	6.390	7.269	8.208	943	1.000
selM [M]	51.194	0.163	50.924	51.191	51.452	1008	0.999
selM [F] AW	60.105	0.600	59.171	60.095	61.152	1012	1.000
selM [F] SS	57.617	0.400	56.994	57.591	58.332	801	1.001

Table 13: CRA 4 summary of the posterior distribution for the derived quantities for the *base2* model. The mean, standard deviation (SD) of the mean, median, and 90% credible interval (i.e., 5% and 95%) are reported. Biomass values and handling mortality (*H*) are reported in tonnes.

	Mean	SD	5%	50%	95%
Vulnerable biomass					
B_0	4 011	353	3 464	3 990	4 641
B_{0now}	3 132	260	2 744	3 108	3 585
B_{MIN}	431	30	386	430	483
B_R	656		656	656	656
B_{2024}	1 344	110	1 175	1 342	1 533
B_{2028}	1 393	326	918	1 369	1 929
B_R / B_0	0.165	0.014	0.141	0.165	0.189
B_R / B_{0now}	0.211	0.017	0.183	0.211	0.239
B_{2024} / B_0	0.338	0.042	0.276	0.334	0.412
B_{2028} / B_0	0.349	0.084	0.229	0.344	0.500
B_{2024} / B_{0now}	0.431	0.043	0.363	0.430	0.505
B_{2028} / B_{0now}	0.445	0.101	0.300	0.442	0.620

	Mean	SD	5%	50%	95%
B_{2028} / B_{2024}	1.034	0.214	0.715	1.020	1.398
B_{2024} / B_R	2.047	0.168	1.791	2.045	2.336
B_{2028} / B_R	2.123	0.497	1.400	2.086	2.940
Exploitation					
U_R	0.361	–	0.361	0.361	0.361
U_{2024}	0.130	0.011	0.113	0.130	0.148
U_{2028}	0.130	0.027	0.092	0.127	0.179
U_{2028} / U_{2024}	0.995	0.169	0.753	0.978	1.286
U_{2024} / U_R	0.361	0.030	0.313	0.359	0.410
U_{2028} / U_R	0.360	0.076	0.255	0.352	0.496
Spawning stock biomass					
SSB_0	3 147	245	2 763	3 146	3 536
SSB_{0now}	2 457	174	2 194	2 452	2 765
SSB_{2024}	2 219	273	1 828	2 191	2 733
SSB_{2028}	2 155	357	1 625	2 129	2 765
SSB_{2024} / SSB_0	0.706	0.074	0.602	0.698	0.840
SSB_{2028} / SSB_0	0.685	0.104	0.531	0.677	0.877
SSB_{2024} / SSB_{0now}	0.901	0.072	0.804	0.891	1.042
SSB_{2028} / SSB_{0now}	0.875	0.121	0.694	0.868	1.080
SSB_{2028} / SSB_{2024}	0.971	0.112	0.801	0.968	1.163
Total biomass					
T_0	10 647	731	9 496	10 632	11 830
T_{0now}	8314	494	7568	8289	9165
T_{2024}	6432	949	5096	6339	8132
T_{2028}	6302	1120	4608	6217	8245
T_{2024} / T_0	0.605	0.085	0.485	0.595	0.755
T_{2028} / T_0	0.592	0.101	0.441	0.586	0.774
T_{2024} / T_{0now}	0.772	0.094	0.639	0.758	0.945
T_{2028} / T_{0now}	0.757	0.119	0.572	0.749	0.965
T_{2028} / T_{2024}	0.983	0.126	0.797	0.971	1.199
$T_0^{male} / T_0^{female}$	1.584	0.077	1.468	1.577	1.733
$T_{2024}^{male} / T_{2024}^{female}$	1.212	0.039	1.153	1.209	1.280
Other quantities					
Rmean	3 068 360	455 377	2 424 150	3 017 700	3 909 060
Rrho	0.049	0.021	0.01	0.052	0.079
H_{2023}	10	1	9	10	12
H_{2028}	9	1	7	9	11

Table 14: CRA 4 summary of the posterior distribution for the derived quantities for the *base2* model.

Indicator	Probability	Indicator	Probability
P($B_{2024} > B_{MIN}$)	1.000	P($SSB_{2024} > 20\% \ SSB_0$)	1.000
P($B_{2024} > B_R$)	1.000	P($SSB_{2024} > 10\% \ SSB_0$)	1.000
P($B_{2028} > B_R$)	0.998	P($SSB_{2028} > 20\% \ SSB_0$)	1.000
P($B_{2028} > B_{2024}$)	0.540	P($SSB_{2028} > 10\% \ SSB_0$)	1.000
P($T_{2028} > T_{2024}$)	0.408	P($SSB_{2024} > 20\% \ SSB_{0now}$)	1.000
P($U_{2024} > U_R$)	0.000	P($SSB_{2024} > 10\% \ SSB_{0now}$)	1.000
P($U_{2028} > U_R$)	0.000	P($SSB_{2028} > 20\% \ SSB_{0now}$)	1.000
P($U_{2028} > U_{2024}$)	0.449	P($SSB_{2028} > 10\% \ SSB_{0now}$)	1.000
		P($SSB_{2028} > SSB_{2024}$)	0.385

Effort creep (*q_drift*) was fixed at 1% for the CELR series only. The model fits to the four CPUE series were good (Figure 18), with only a small number of years when the standardised residuals were outside of the ±2 range (Figure F.8).

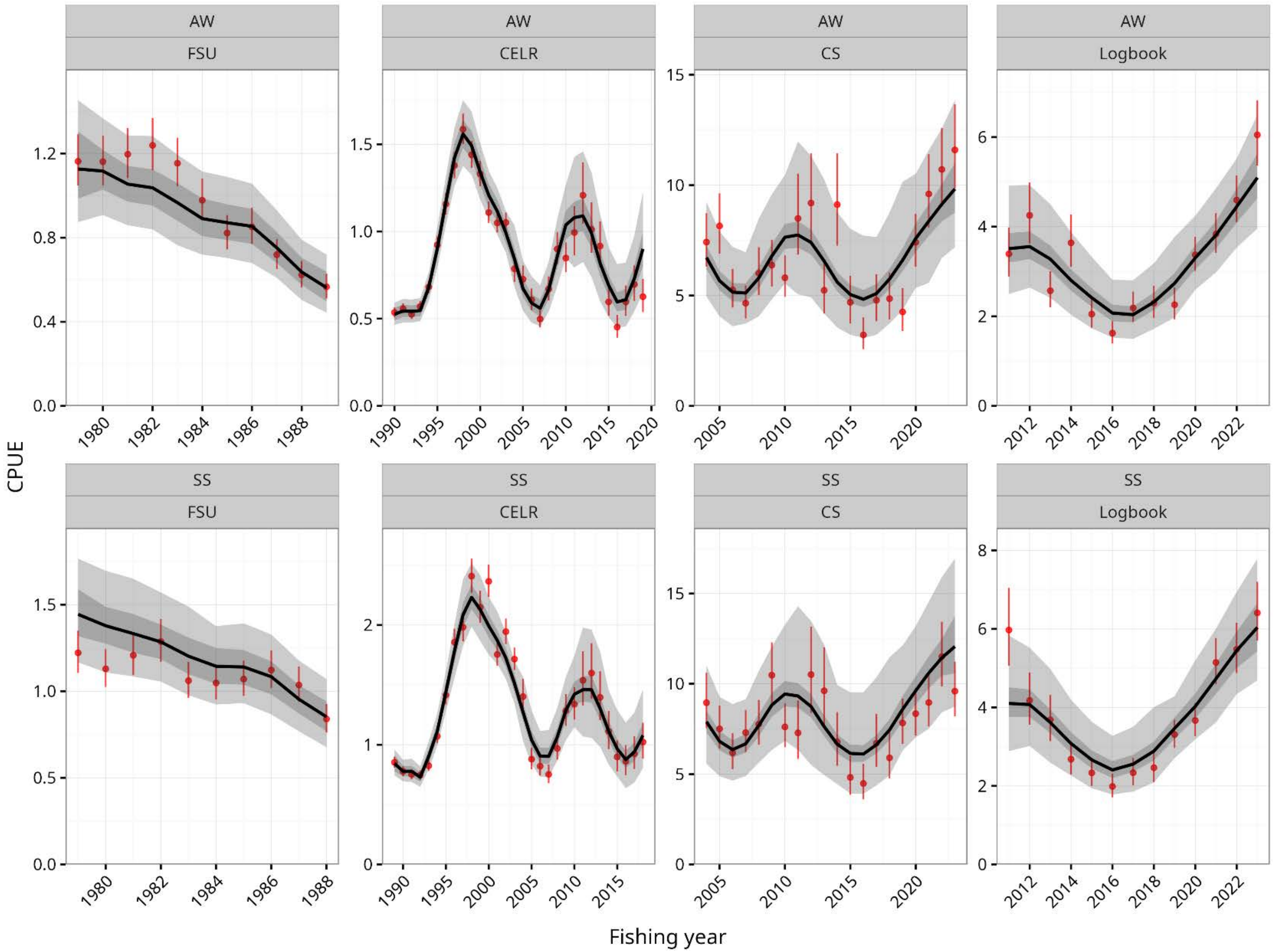


Figure 18: Posterior predicted CPUE for the FSU, CELR, CS, and LB series by fishing year in the base2 model run. The solid line indicates the posterior median and grey shading with variable intensity indicates 90% credible intervals for the posterior distribution and the posterior predictive distribution. Error bars are +/- one standard deviation.

With the exception of a few years, the base case model fit to the sex ratio data was reasonably good (Figure 19), with no pronounced pattern in the one step ahead residuals by year/season (Figure F.9).

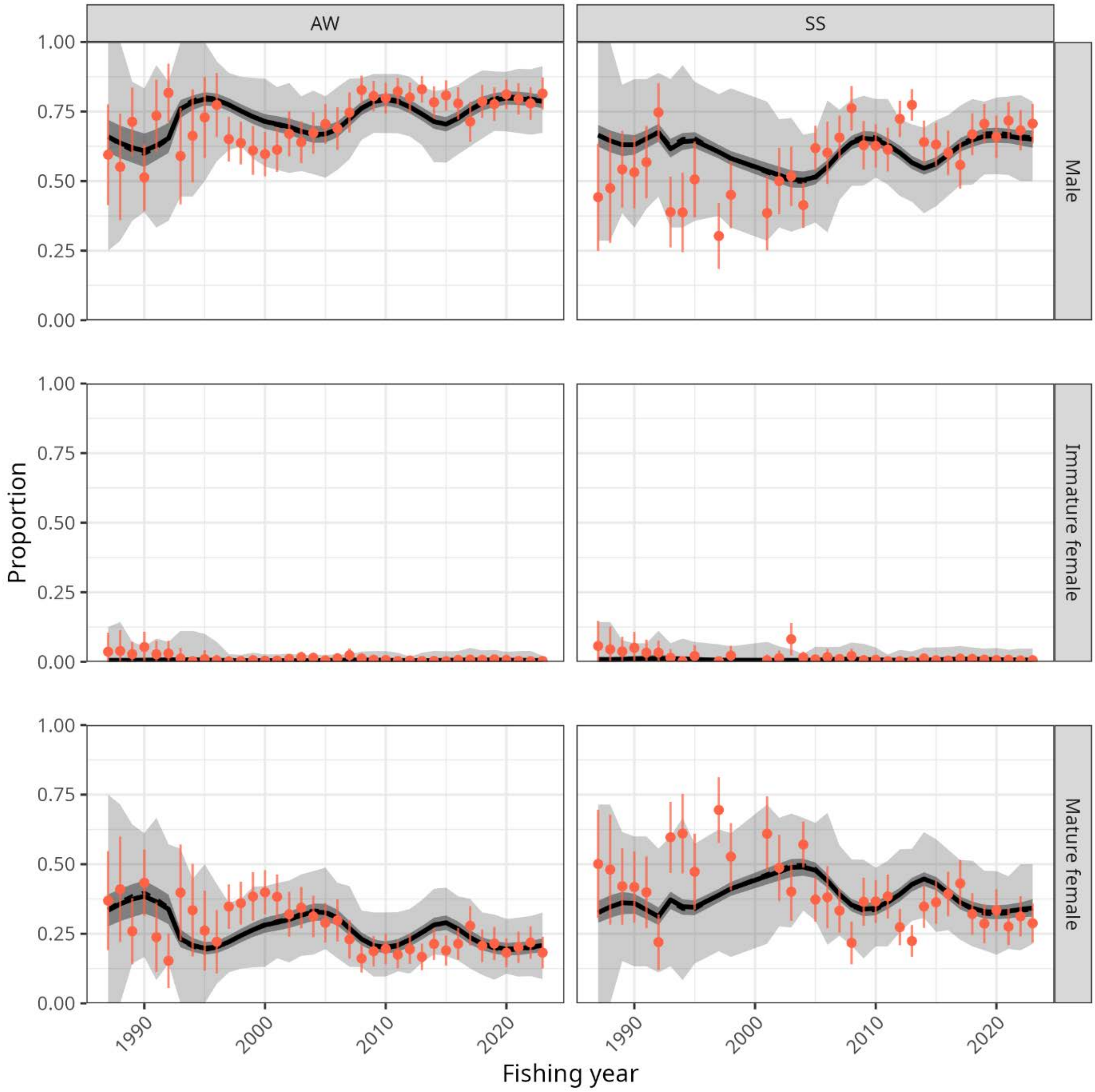


Figure 19: Posterior distribution of the sex ratios compared to the observed sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer) and sex, in the base2 model run. The solid line indicates the posterior median and grey shading indicates the 90% credible intervals or the posterior and posterior predictive distributions. Error bars are +/- one standard deviation.

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

The most notable feature of the tagging data used to estimate growth was the extreme variability in the observed individual growth increments, through which the model finds an average (Figure 20). This variation could be attributed to measurement error, individual variability in growth, spatial-temporal variability, or the short time period many lobsters spend at liberty. However, it is important to note that this model is using a continuous growth function to model growth, while lobster growth is a discrete process (i.e., growth can only occur after moulting). Attempts were made in the early 2000s to model growth more realistically, but these were unsuccessful because there was no reliable indicator, when examining an individual lobster, of whether it has recently moulted. However, while the residuals in this growth model are large, there is little evidence for a systematic bias by sex in terms of year of release (Figure F.13) or by statistical area of release (Figure F.14).

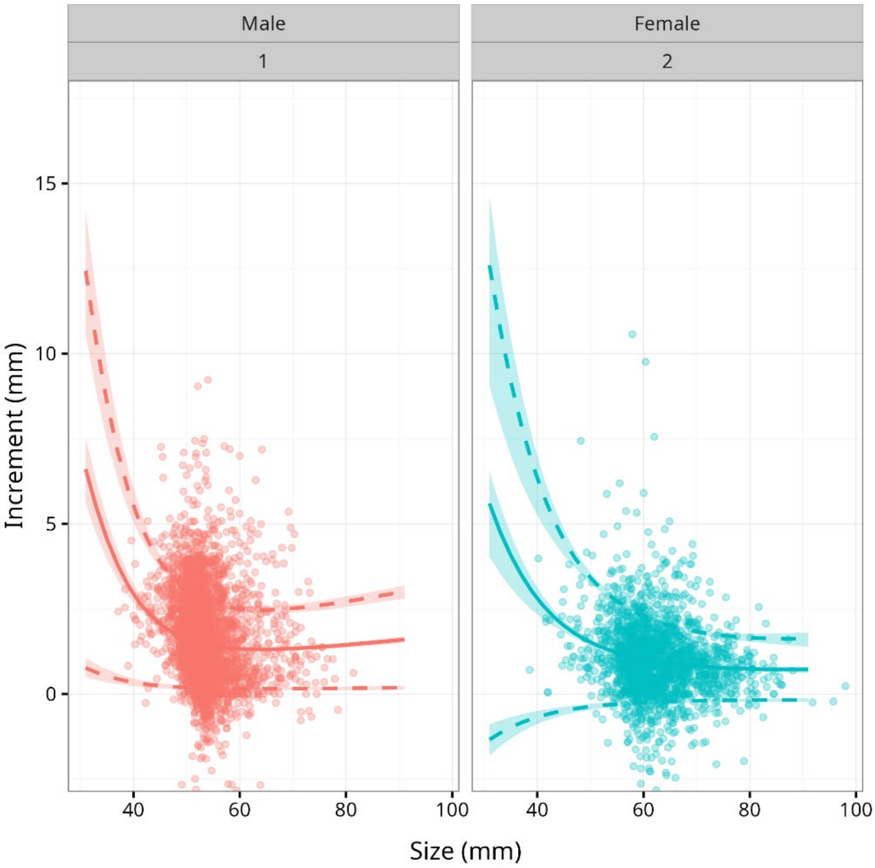


Figure 20: Posterior distribution of predicted six-monthly growth increment by size (mm) and sex in the base2 model run showing the mean (solid line), ±1 standard deviation (dashed line). Shading shows 90% credible interval.

The estimated size distribution of the unfished population (Figure 21) demonstrates how mature females were relatively invulnerable to the fishery even at the beginning of the fishery, due to the small size of mature females. This observation changes very little even by the end of the model reconstruction period. Males, on the other hand, were more vulnerable to the fishery and the distributions of numbers-at-length has changed shape from the beginning to end of the model reconstruction period.

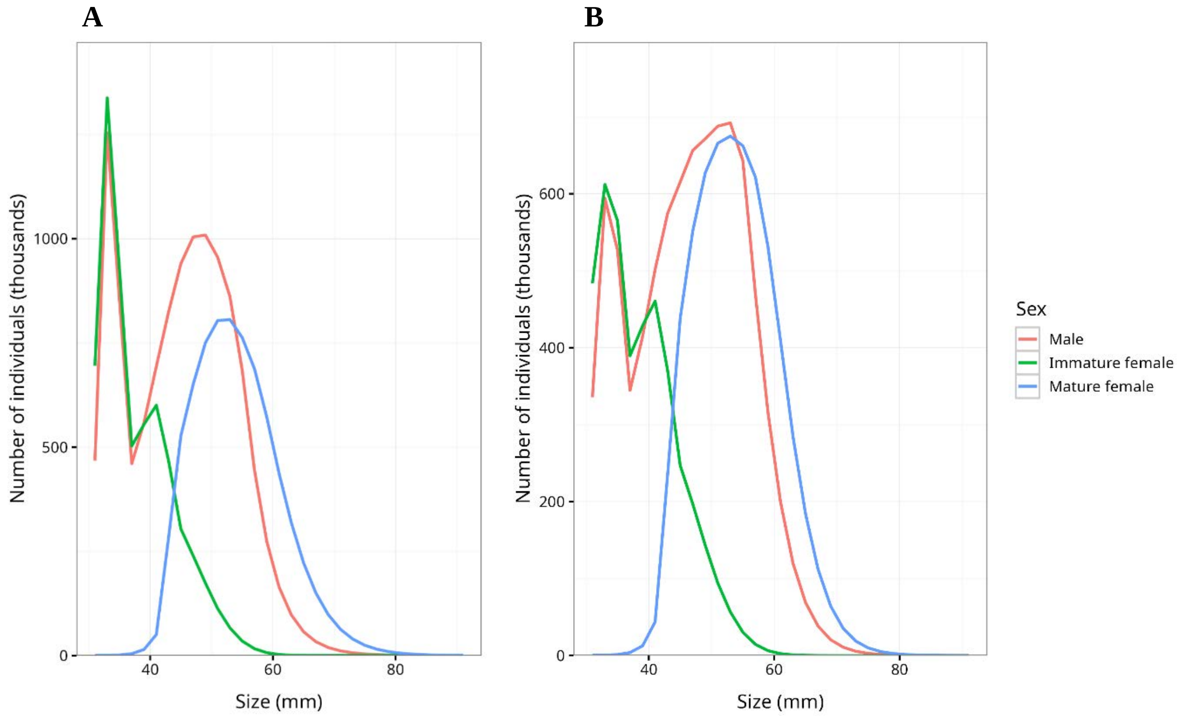


Figure 21: Median number of individuals by size and sex category in the *base2* model run for A) the first model year (1979) and B) the final model year (2023).

The selectivity functions by sex (Figure 22) were simplified from previous assessments that fixed the right limb at nearly logistic selectivity by assuming logistic selectivity. Selectivity multiplied by vulnerability provided an improved visualisation of the relative probabilities of each sex being captured by the gear in the fishery (Figure 22). The selectivity posterior plot for the *base2* model showed little uncertainty in these parameters, indicating that selectivity was well defined by the data (see the tight posterior density plots for selectivity in Figure F.7). However, there is much more uncertainty in vulnerability (again demonstrated by the wide posteriors for the vulnerability parameters in Figure F.7) by sex and season when estimated separately for mature and particularly for immature females (Figure 22). Note that some of the uncertainty in the female vulnerabilities likely incorporated uncertainty in the male vulnerabilities, which were fixed at 1.0 as part of the estimation procedure.

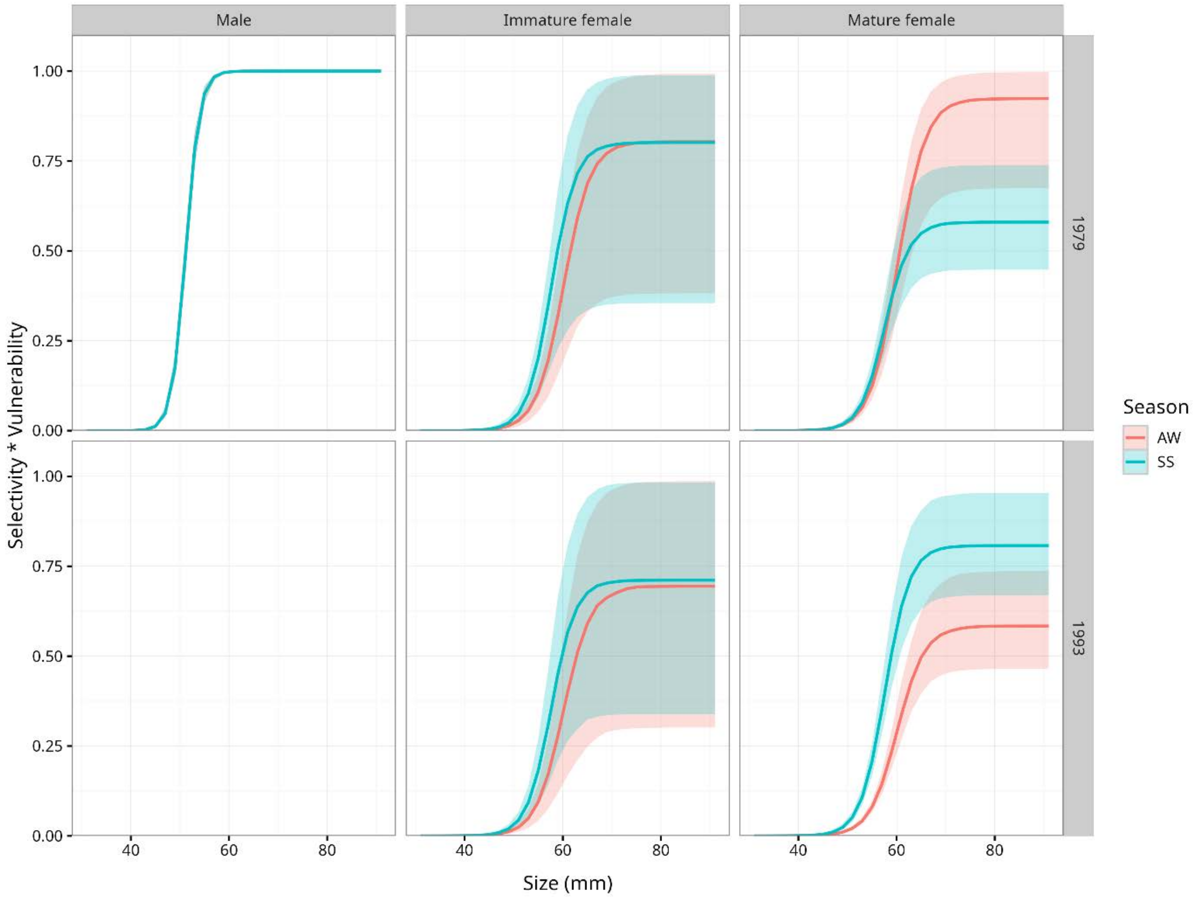


Figure 22: Posterior distribution of selectivity by size multiplied by vulnerability by sex and season in the *base2* model run. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

The size at 50% of female maturation was estimated to occur at just over 42 mm TW in CRA 4 (Figure 23). This CRA 4 maturity is considerably smaller than the equivalent maturity estimated for CRA 7&8, where 50% maturity was estimated to be near 60 mm TW (Webber et al. 2022). With a female MLS of 60 mm TW, many mature females would be selected to the gear in CRA 7&8, unlike for CRA 4 where only a few females would be vulnerable to the fishery (Figure 21). Consequently, vulnerability for mature females is relatively low compared to other QMAs. In the recent epoch (1993-onwards) mature females had a median vulnerability of 0.584 in the AW and 0.808 in the SS.

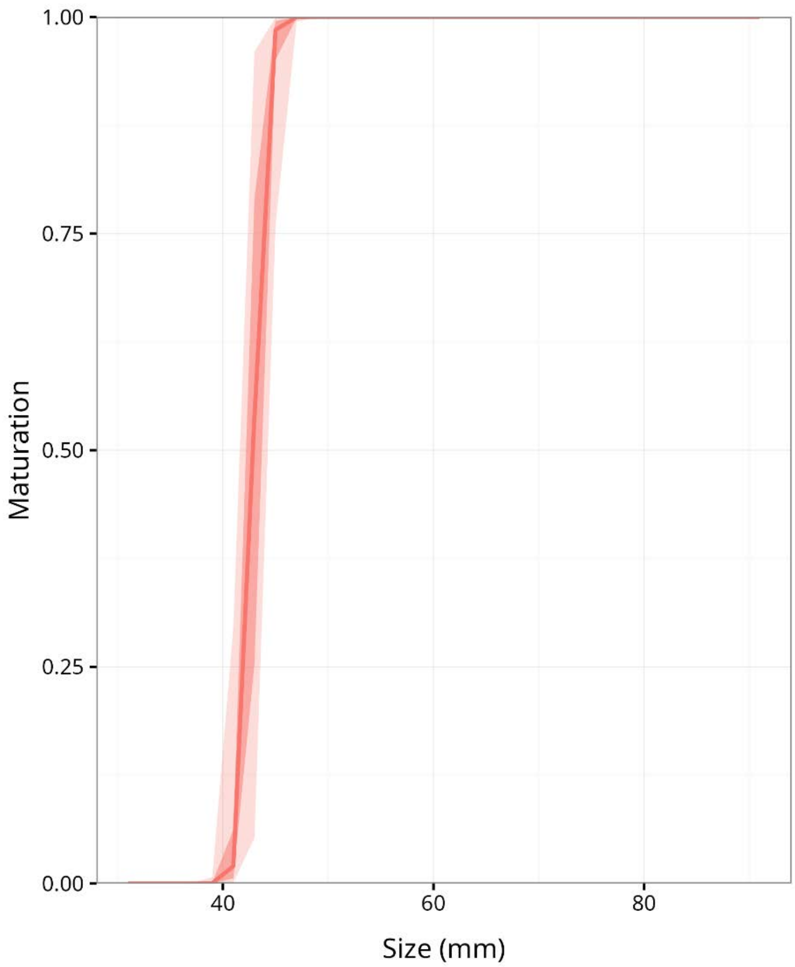


Figure 23: Posterior distribution of female maturation curve by size in the *base2* model run. The solid line indicates the posterior median and red shading indicates the 50% and 90% credible intervals. Note that the mat95 parameter was fixed at 1.458.

The NSL exploitation rates were very low compared with the SL exploitation rates, reflecting the small amount of catch in this category (Figure 24). AW SL exploitation rates increased until about 2000, when they began to decline overall. SS SL exploitation rates increased to over 60% of the vulnerable population until about 1990, followed by a period of very low SS SL exploitation rates when the SS catches dropped in the 1990s (Figure 25). Since the late 2000s SS SL exploitation rates have oscillated with periods of high recruitment.

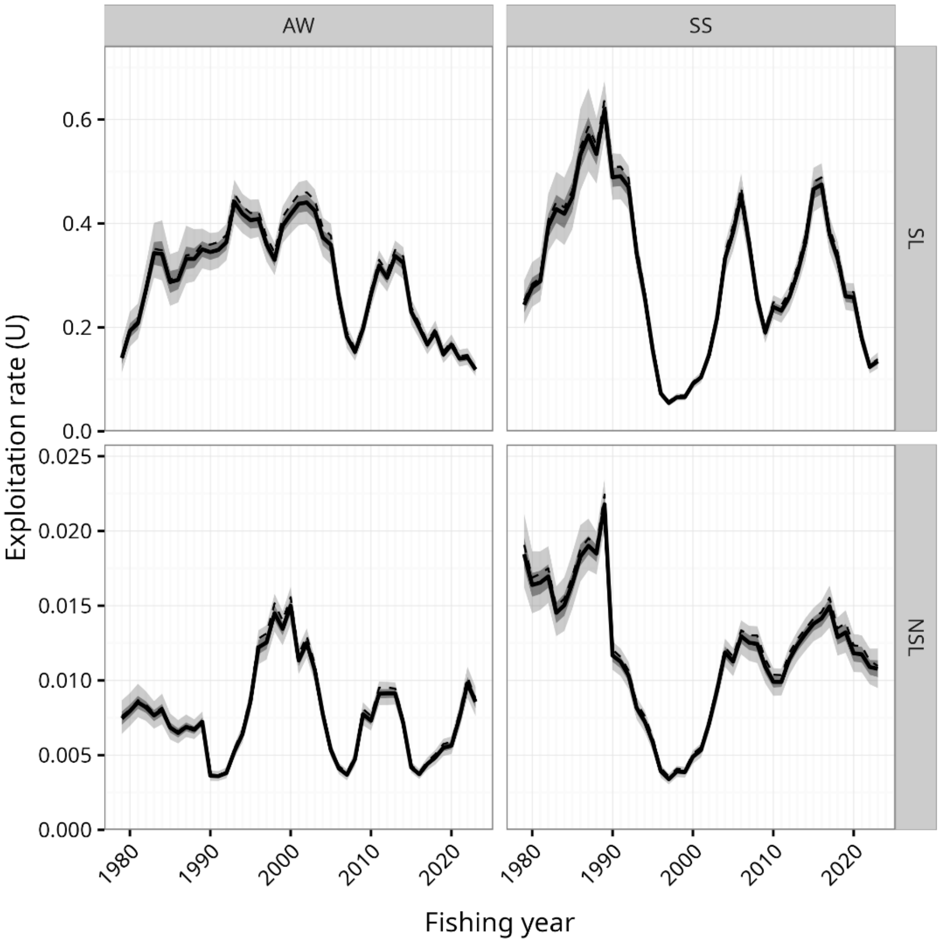


Figure 24: Posterior distribution of exploitation rate (U) by fishing year, season, and fishery (SL = size-limited; NSL = non-size-limited) for the *base2* model run. The solid black line indicates the median of the posterior and variable shading intensity indicating the 50% and 90% credible intervals. The dashed black line is the MAP.

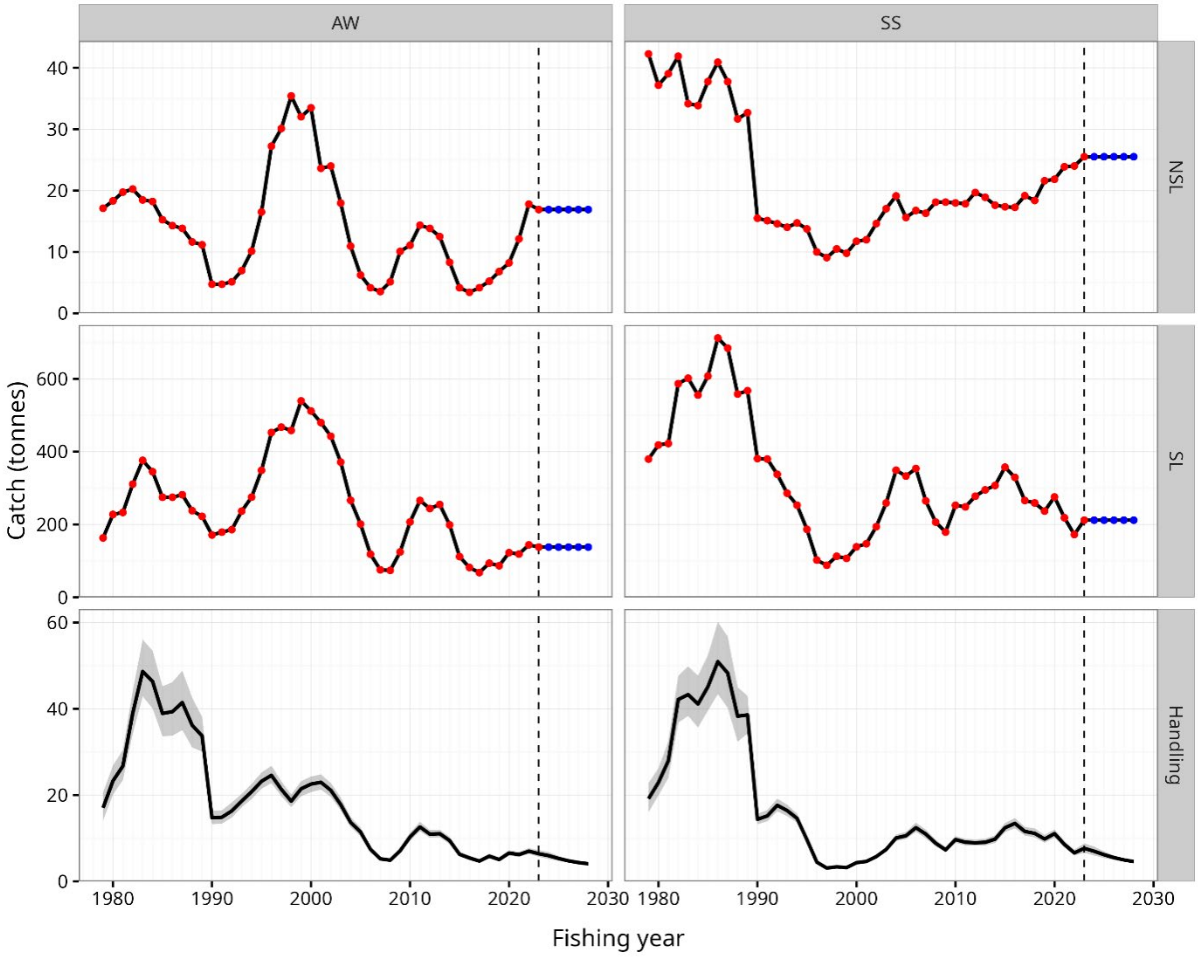


Figure 25: Posterior distribution of the catch and handling mortality by fishing year, season, region, and fishery (SL = size-limited; NSL = non-size-limited) for the *base2* model run. The solid black line indicates the median of the posterior and shading indicates the 90% credible interval. The vertical dashed line is the final year of the reconstruction period after which the projected catch and estimated handling mortality is shown.

Two strong recruitment pulses were estimated early on in CRA 4, one in the early 1980s, and the second in the early 1990s (Figure 26). Median recruitment has been below R_0 since the mid-1990s, with oscillating periods of relative highs (late 2000s, late 2010s) and lows (early 2000s, early 2010s).

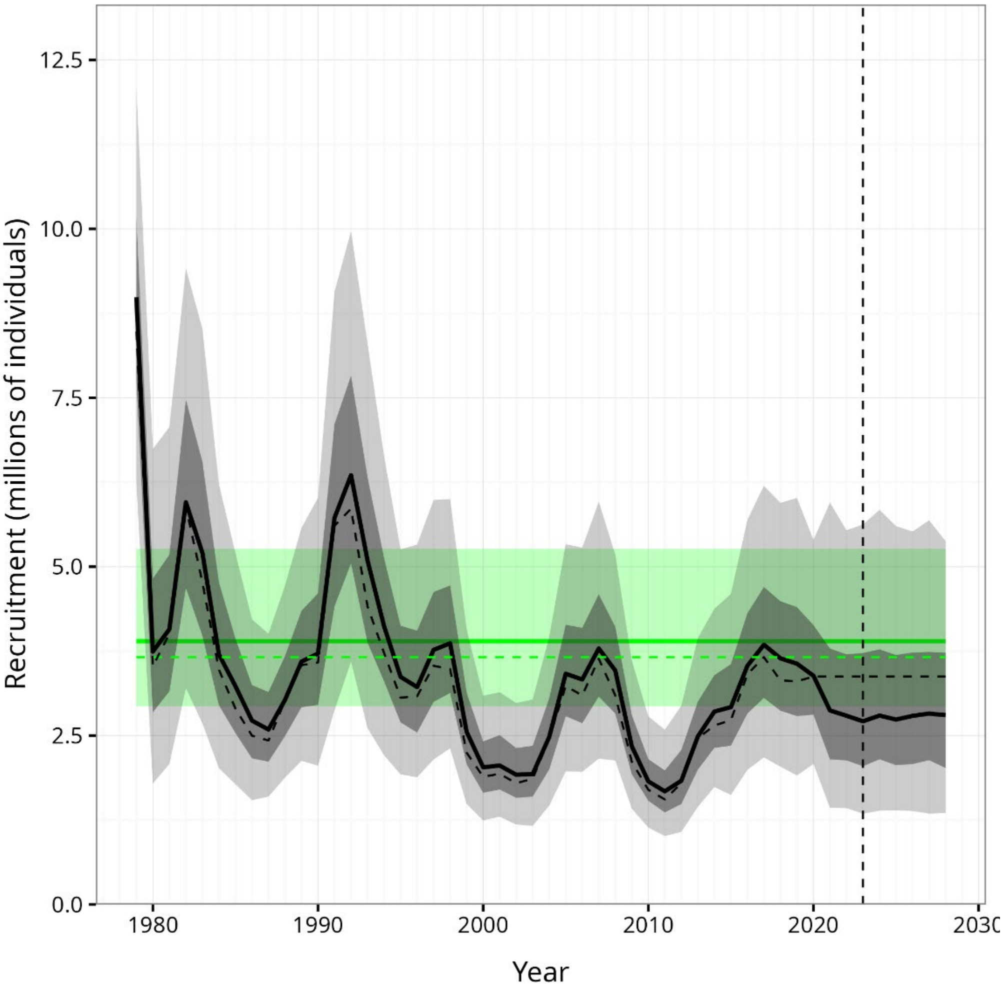


Figure 26: Posterior distribution of recruitment for the *base2* model run. The horizontal green line is R_0 and the vertical dashed line is the final year of the reconstruction period, after which the projected recruitment is shown. The solid black line indicates the median of the posterior and variable shading intensity indicates the 50% and 90% credible intervals. The dashed lines indicate the MAP.

The AW adjusted vulnerable biomass in CRA 4 has fluctuated through time with peaks around 1980, 1998, and 2011, and troughs around 1990, 2007, and 2016 (Figure 27). Since 2017, the AW adjusted vulnerable biomass has been increasing, possibly due to the recruitment pulse estimated in the late 2010s (Figure 26). Median estimated vulnerable biomass at the beginning of 2024 was 33% B_0, but was 205% of the B_R (90% credible interval: 179–234%) (Table 13). There was an estimated probability of 1.0 that B_{2024} was greater than B_R (Table 14). The overall SSB abundance trend was more influenced by the pattern in recruitment than was the vulnerable biomass, with a general decline since 2000 and showing periods of higher and lower SSB that aligned with periods of higher and lower recruitment (Figure 28). The pattern in total biomass was similar to that of the spawning biomass (Figure 29). Median estimated spawning biomass at the beginning of 2024 was 70% of SSB_0, (Table 13), with a probability of 1.0 of being above 20% SSB_0 (Table 14). The snail trail plot shows that the *base2* model run combined the recent increase in the CRA 4 vulnerable biomass with a drop in exploitation rate, resulting in a 2024 stock status estimate fully in the preferred lower righthand quadrant (Figure 30).

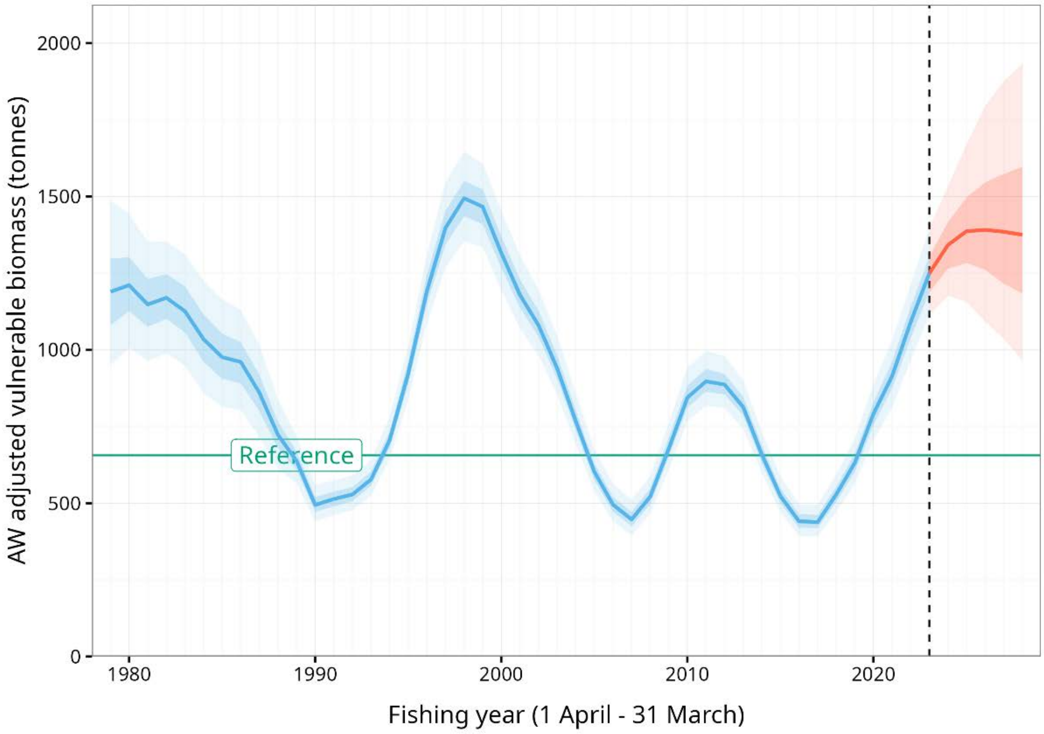


Figure 27: Posterior distribution of the AW adjusted vulnerable biomass (tonnes) by fishing year, including the projections years (beyond the dashed vertical line / in red), for the *base2* model run compared with the reference level.

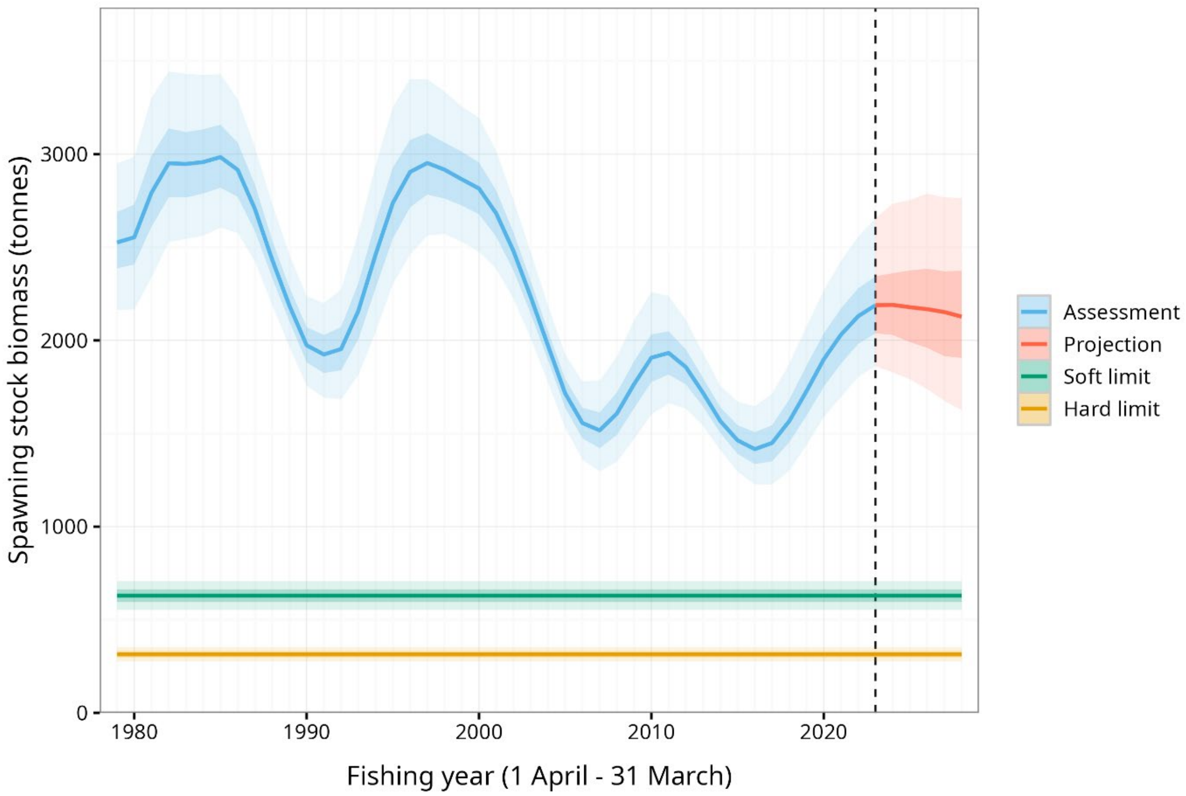


Figure 28: Posterior distribution of beginning year spawning stock biomass (tonnes) by fishing year, including the projections years (beyond the dashed vertical line), for the *base2* model run. The associated soft (20% SSB_0) and hard limits (10% SSB_0) are also shown.

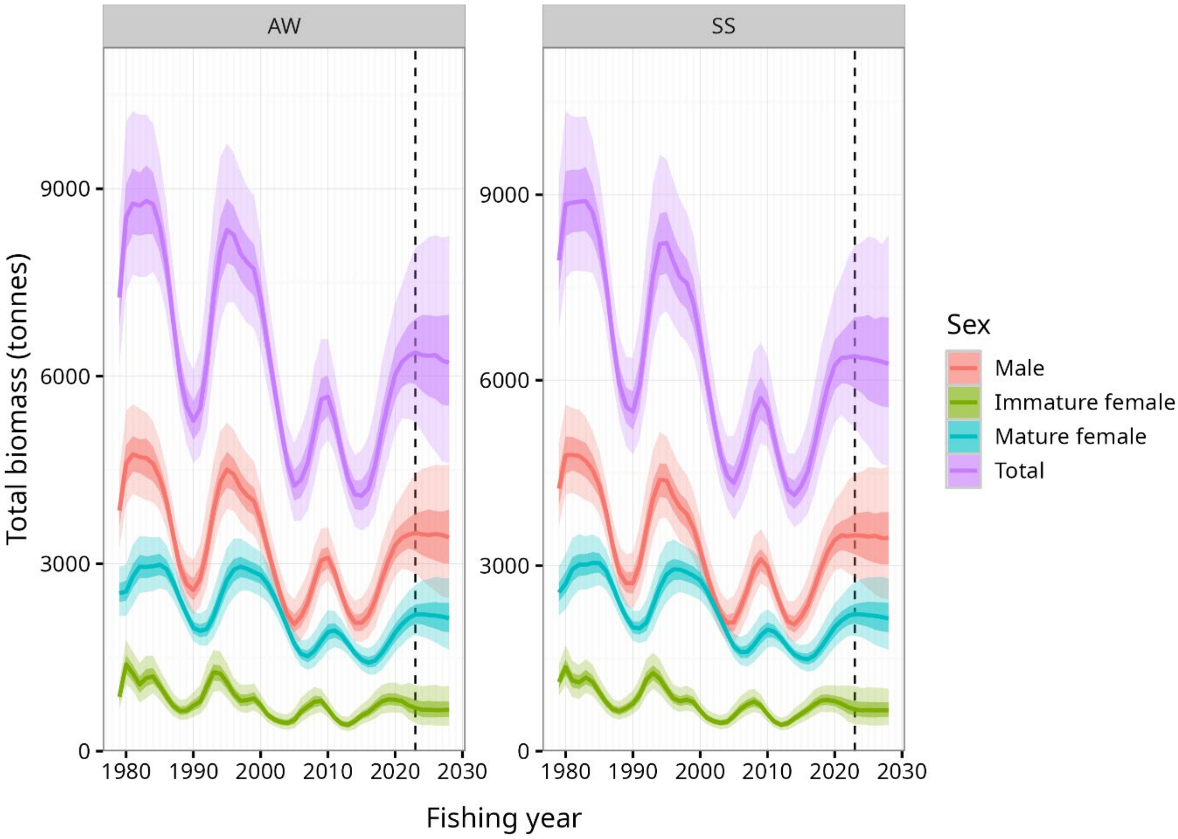


Figure 29: Posterior distribution of the beginning year total biomass by sex, season, and fishing year for the *base2* model run. Variable shading intensity indicates the 50% and 90% credible intervals.

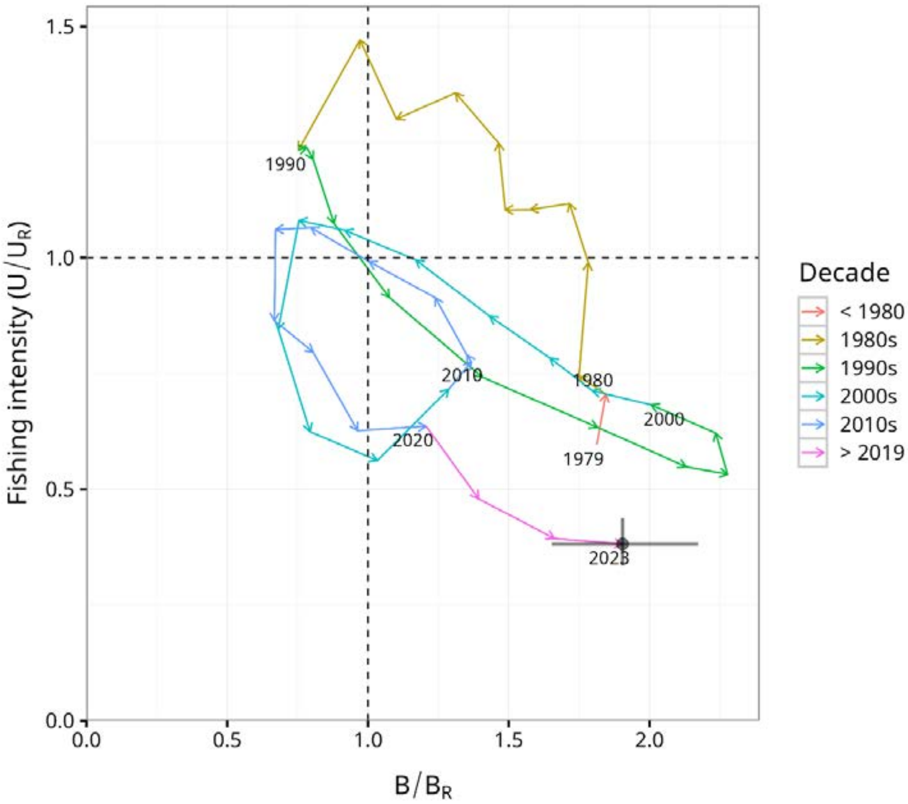


Figure 30: Snail trail from the CRA 4 *base2* model. This figure shows the median of the posterior distribution of the AW vulnerable biomass as a proportion of the vulnerable biomass reference level in each year against the fishing intensity (exploitation rate relative to the overfishing threshold, the exploitation rate associated with the reference level). The 95th percentiles are shown for the final year.

The 2024 CRA 4 stock assessment included several model updates, including likelihood and data inputs (see Section 3.4.1) and structural changes that aimed to improve model fits. The estimated recruitment time series for the 2024 assessment generally matched the recruitment time series estimated in the 2020 assessment, with some lag. The 2024 estimated recruitment trajectory differed from that of the 2020 assessment beginning around 2014, where the 2020 assessment estimated relatively constant recent recruitment from 2014 to the final estimated deviate in 2017. However, the 2024 assessment estimated much higher recruitment from 2014 through to 2020 (Figure 31), possibly driven by the updated CPUE series.

Because the 2020 and 2024 assessments had similar patterns in recruitment with some time lag, the adjusted vulnerable biomass and spawning biomass trajectories also followed a similar pattern but at slightly different scales (Figure 32, Figure 33). The 2024 CRA 4 assessment was more optimistic (in terms of vulnerable biomass and SSB) when comparing the years since the 2020 assessment, possibly due to the higher recruitment driven by the increased recent CPUE series.

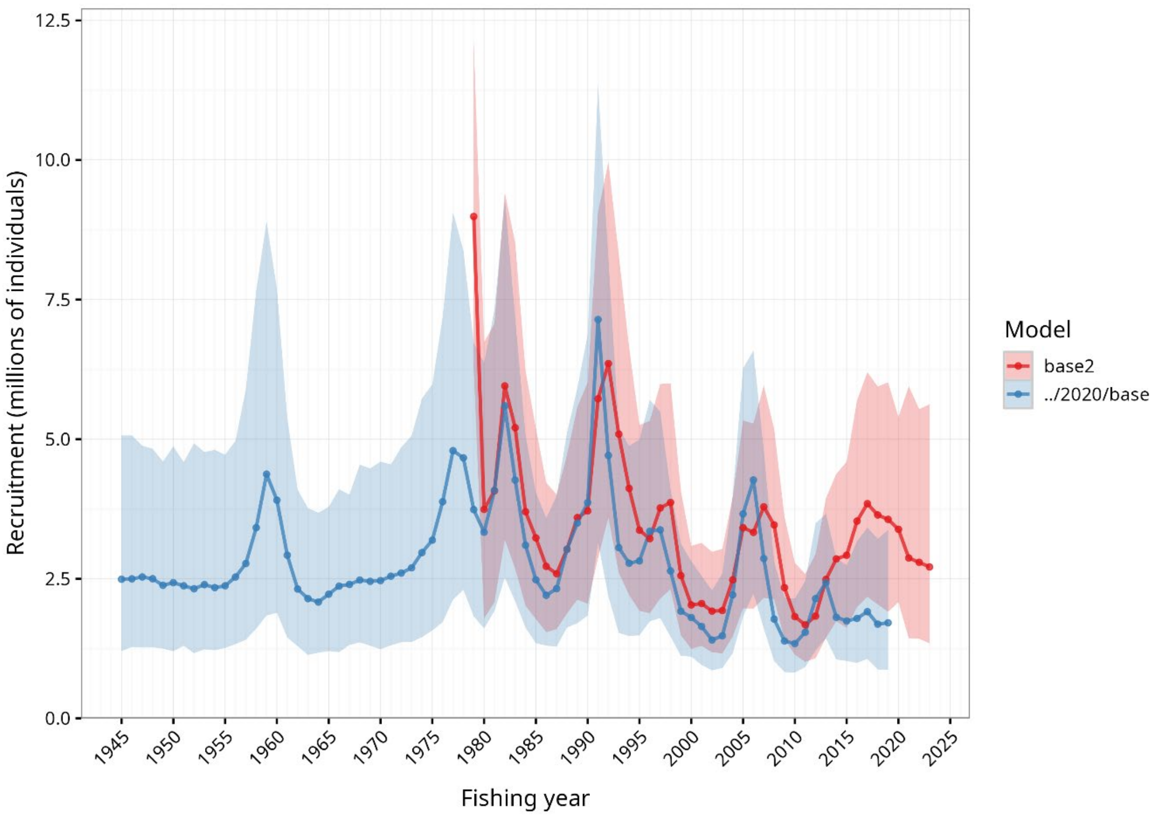


Figure 31: Posterior distribution of recruitment for the 2024 (base2) and 2020 base case stock assessment model runs.

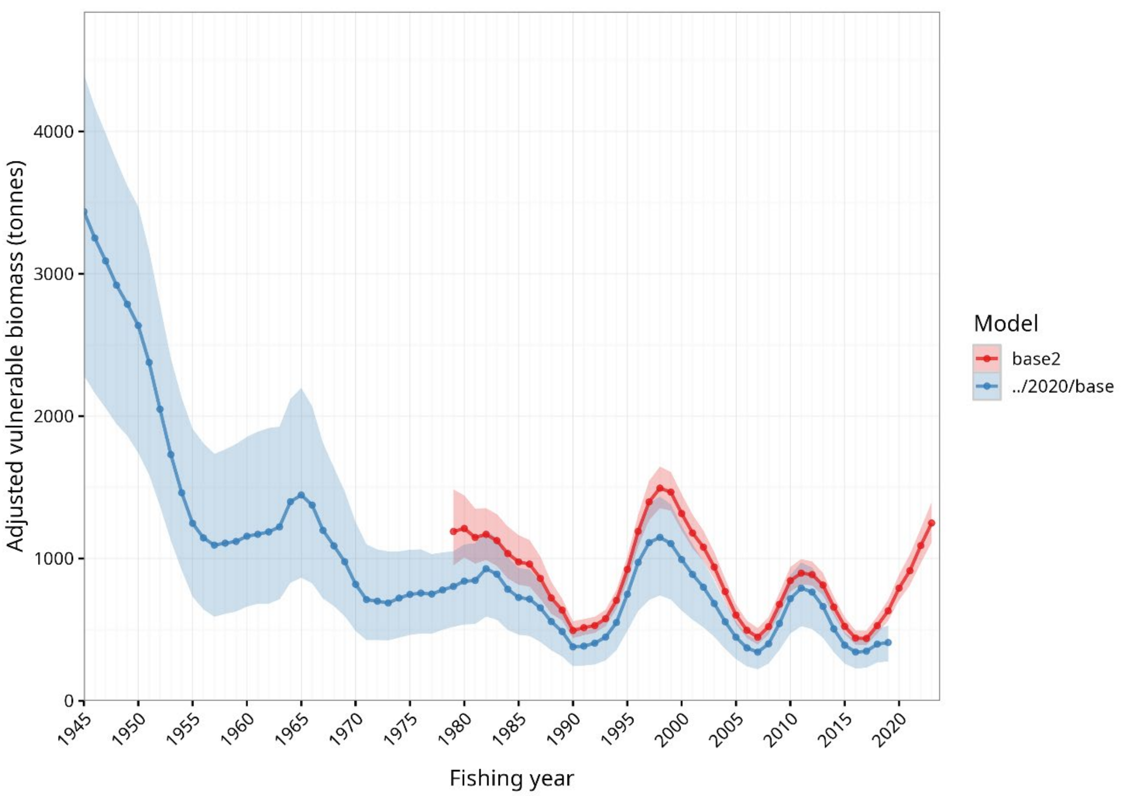


Figure 32: Posterior distribution of adjusted vulnerable biomass for the 2024 (base2) and 2020 base case stock assessment model runs.

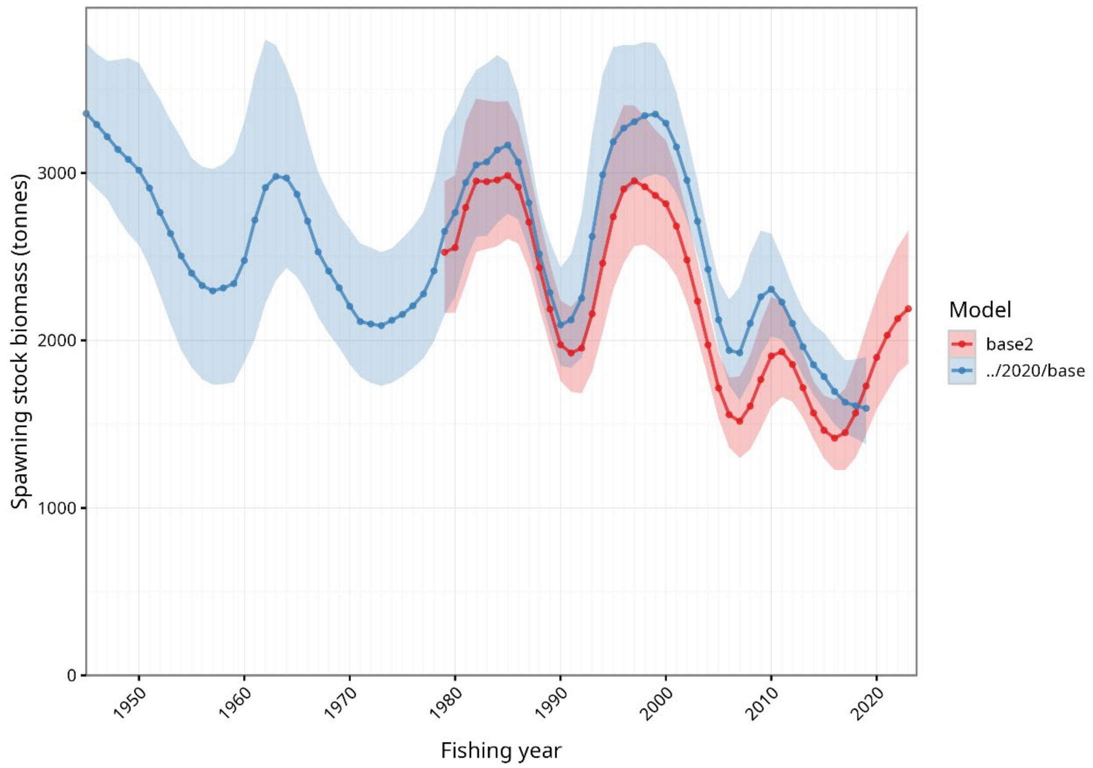


Figure 33: Posterior distribution of spawning stock biomass for the 2024 (*base2*) and 2020 base case stock assessment model runs.

3.5 Model sensitivity runs

The MCMC and MAP sensitivity runs in this section were informed by the length frequency data before it was discovered that the calliper offset adjustments had not been correctly applied to these data beginning in 2020. These sensitivity runs are compared with a base model which also lacked the calliper adjustment (labelled *base*). Comparisons of *base* with the subsequently accepted *base2* base case model, with the only difference being the presence or absence of the calliper adjustment, are shown in Figure 14 through to Figure 17 within Section 3.4.3.

3.5.1 MAP sensitivity runs

Sensitivity runs were used to test some of the *base* case model assumptions. The RLWG decided on seven sensitivity runs as single variants relative to the *base* case (Table 15). These included sensitivity runs testing assumptions related to the use of CRA 5 tags and *M* assumptions (Group 1: *CRA4_alltags*, *fixM*), the model start year (Group 2: *start1945*), treatment of additional assumptions for tag data (Group 3: *alltags*, *CRA4_6mo*), and assumptions about vulnerability and selectivity (Group 4: *vuln4*, *sel1993*).

Table 15: List of maximum *a posteriori* (MAP) sensitivity runs. Each model run below the *base* model run implements a single change to the *base* model run.

Group	Model name	Model description	MCMC
0	*base*	Start model in 1979, male selectivity same in AW/SS with seasonal female selectivity, 8 vulnerability parameters (IF and MF with different vulnerabilities by season and epoch), CRA 4 and CRA 5 tags at liberty over 182 days (> 6 months)	Yes
1	*CRA4_alltags*	All CRA 4 tags (same as 2020 assessment)	Yes
1	*fixM*	Fix M at median from 2020 assessment (M = 0.223)	Yes
2	*start1945*	Start the model in 1945	Yes
3	*alltags*	All CRA 4 and CRA 5 tags regardless of time at liberty	No
3	*CRA4_6mo*	Only CRA 4 tags at liberty more than 182 days (> 6 months)	No
4	*vuln4*	Four vulnerability parameters (IF and MF shared, by season and epoch)	No
4	*sel1993*	Male and female selectivity prior to 1993 and 1993-onwards, not seasonal (same as 2020 assessment)	No

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the seven sensitivity runs were compared with each other and the base (*base*) case without the length frequency calliper adjustment (Table 16). These comparisons with the *base* case were grouped in four blocks of related runs (Table 15).

Fixing *M* at a lower value (*M* = 0.223, the median estimate from the 2020 assessment, compared with the 2024 median *M* = 0.291) led to an overall lower estimated R_0 to account for the effective lower productivity in the population (Table 16). Recruitment was shifted downward without any annual lag compared with the *base* model with the higher *M* (Figure 34). The adjusted vulnerable biomass trajectory was only slightly lower than that of the *base* (Figure 35), and spawning stock biomass was lower than *base* with a one-year lag (i.e. changes in population size occurred one year later compared with *base*). Growth, maturation, initial exploitation rates, vulnerabilities, and fits to the CPUE were similar between *fixM* and *base*.

Including all CRA 4 tags (regardless of time at liberty and excluding CRA 5 tags) led to higher estimated R_0, lower *M*, and slower growth compared with *base* (Table 16). Maturation was similar between *CRA4_alltags* and *base*. Higher recruitment was also lagged from *base* such that recruitment peaks and troughs occurred about one year earlier than *base*, possibly related to the slower growth (Figure 34). Vulnerable biomass was shifted higher than *base* (Figure 35). Spawning biomass was at a similar level as *base* but lagged behind *base* by one year (not shown).

Starting the model in 1945 had negligible differences with *base*, supporting the decision to start the model in 1979 for *base* (Table 16). This result also demonstrated that the early data had low influence on model parameter and derived parameter estimates.

Including all CRA 4 and CRA 5 tags led to a slightly lower recruitment trajectory which was lagged slower than *base* by one year, i.e., reaching a recruitment peak the next year, possibly due to slower estimated growth (Figure 34). Including only CRA 4 tags at liberty more than six months led to higher recruitment compared with *base*, which was also lagged faster than *base* by one year, possibly due to faster estimated growth (Figure 34). The vulnerable biomass trajectories for *base* and *alltags* were the same (Figure 35), with differences in recruitment accounted for by small differences in mature female vulnerability (Figure 34). The vulnerable biomass trajectory for *CRA4_alltags* was shifted higher than the equivalent *base* trajectory (Figure 34).

There were negligible differences in model results between *base*, *vuln4*, and *sel1993* (Table 16). These model runs were made to explore possible better fits to the sex ratio data or to help determine why *M* was estimated so high. However, neither of these runs demonstrated much improvement, either by notably improving the fit to the sex ratios or estimating a lower *M*).

Table 16: CRA 4 MAP outputs showing likelihoods, standard deviation of normalised residuals (SDNRs), median absolute residuals (MARs), likelihood weights, and parameter estimates. Parameter estimates for time varying selectivities and vulnerabilities shown for blocks [1] (1979–1999), [2] (2000–2009), and [3] (2010–2021, which is applied to any projection years). Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. '–': not applicable. Fixed values are indicated in grey. SDNRs or MARs for tags and LFs are not included because the tag likelihood is self-weighting and the LFs were iteratively reweighted using the Francis method (Francis 2011). (Continued on next page)

		Group 1		Group 2	Group 3		Group 4	
	base	CRA4 alltags	fixM	start1945	alltags	CRA4 6mo	vuln4	sel1993
Likelihoods								
Total	18122	13021	17905	18183	20312	11961	18124	18136
Prior	49	118	52	21	125	38	48	54
tag	8255	2847	8250	8383	10364	2012	8255	8256
Sex ratio	1401	1545	1185	1400	1402	1619	1403	1398
LF	8658	8739	8658	8657	8662	8513	8659	8670
CR	–	–	–	-35.768	–	–	–	–
FSU	-38.091	-35.381	-38.742	-39.249	-39.456	-35.679	-37.664	-38.220
CELR	-118.527	-111.451	-117.489	-118.511	-117.991	-105.767	-118.762	-120.448
Catch sampling CPUE	-46.590	-45.188	-46.941	-46.567	-47.054	-44.262	-46.526	-46.686
Logbook CPUE	-37.384	-36.094	-37.279	-37.355	-37.326	-34.504	-37.414	-37.226
	Standard deviation of normalised residual (SDNR)							
Sex ratio	0.992	0.982	1.008	0.985	1.009	1.009	1.018	0.955
CR	–	–	–	0.981	–	–	–	–
FSU	1.023	0.994	0.991	0.965	0.982	1.076	1.044	1.017
CELR	1.024	1.037	1.030	1.025	1.033	0.970	1.021	0.992
Catch sampling CPUE	1.035	1.041	1.026	1.036	1.034	0.998	1.037	1.033
Logbook CPUE	0.973	1.025	0.978	0.974	0.973	1.047	0.972	0.980
	Median of absolute residual (MAR)							
Sex ratio	0.560	0.569	0.551	0.546	0.553	0.552	0.558	0.491
CR	–	–	–	0.446	–	–	–	–
FSU	0.597	0.517	0.667	0.849	0.630	0.537	0.576	0.653
CELR	0.584	0.566	0.624	0.642	0.613	0.513	0.583	0.550
Catch sampling CPUE	0.647	0.717	0.613	0.663	0.634	0.706	0.652	0.711
Logbook CPUE	0.772	0.822	0.737	0.765	0.745	0.901	0.763	0.851
Likelihood weights								
Sex ratio	0.950	1.050	0.800	0.950	0.950	1.100	0.950	0.950
LF	0.368	0.373	0.368	0.368	0.368	0.363	0.368	0.368
CR	–	–	–	12.000	–	–	–	–
FSU	1.170	1.000	1.170	1.170	1.200	1.100	1.170	1.170
CELR	2.630	2.370	2.600	2.630	2.630	2.020	2.630	2.630
Catch sampling CPUE	2.750	2.670	2.750	2.750	2.780	2.500	2.750	2.750
Logbook CPUE	4.680	4.680	4.680	4.680	4.670	4.500	4.680	4.680
Parameters								
R_0	4000150	5072910	2757120	4266250	3091090	5881590	4025470	4175950
M	0.278	0.252	0.223	0.296	0.255	0.249	0.282	0.283
mat50	42.575	42.967	42.499	42.531	42.688	42.912	42.763	42.434
Galpha [male]	3.128	2.563	3.154	3.128	3.143	2.464	3.131	3.122
Gbeta [male]	2.930	2.531	2.934	2.921	2.735	2.433	2.925	2.920
Gshape [male]	5.977	5.573	6.372	5.565	6.294	5.429	6.013	5.907
GCV [male]	0.626	0.733	0.623	0.617	0.677	0.617	0.625	0.626
Galpha [female]	2.884	2.010	2.730	2.908	2.828	1.927	2.901	2.905
Gbeta [female]	1.430	1.400	1.420	1.425	1.497	1.315	1.432	1.431
Gshape [female]	3.769	5.715	3.369	3.772	3.699	5.869	3.845	3.801
GCV [female]	0.875	1.250	0.891	0.866	0.923	1.233	0.875	0.874
Gobs	0.943	0.478	0.942	0.955	0.427	1.116	0.943	0.945
U_0	0.267	0.250	0.272	0.000	0.255	0.245	0.264	0.259
qCR	–	–	–	1.341E-01	–	–	–	–
qFSU	1.077E-03	9.583E-04	1.122E-03	1.055E-03	1.096E-03	8.831E-04	1.074E-03	1.024E-03
qCELR	1.282E-03	1.108E-03	1.379E-03	1.266E-03	1.321E-03	9.969E-04	1.273E-03	1.250E-03
qCS	2.811E-06	2.375E-06	3.001E-06	2.780E-06	2.901E-06	2.124E-06	2.792E-06	2.806E-06
*q*Logbook	2.658E-06	2.289E-06	2.827E-06	2.630E-06	2.740E-06	2.042E-06	2.637E-06	2.627E-06
vuln AW [IF] < 1993	0.994	0.995	0.994	0.985	0.994	0.995	–	0.994

	base	CRA4 alltags	fixM	start1945	alltags	CRA4 6mo	vuln4	sel1993
		Group 1		Group 2	Group 3		Group 4	
vuln SS [IF] < 1993	0.998	0.998	0.998	0.987	0.998	0.998	–	0.998
vuln AW [MF] < 1993	0.999	0.999	0.999	0.998	0.999	0.999	–	0.999
vuln SS [MF] < 1993	0.607	0.591	0.610	0.567	0.637	0.564	–	0.664
vuln AW [IF] ≥ 1993	0.971	0.972	0.971	0.957	0.971	0.974	0.999	0.970
vuln SS [IF] ≥ 1993	0.988	0.988	0.988	0.969	0.988	0.989	0.625	0.988
vuln AW [MF] ≥ 1993	0.627	0.592	0.653	0.608	0.685	0.566	0.633	0.510
vuln SS [MF] ≥ 1993	0.848	0.776	0.864	0.824	0.914	0.741	0.851	0.875
selL [M]	4.177	4.095	4.290	4.117	4.329	4.055	4.179	–
selL [F] AW	7.196	7.810	6.872	7.188	7.239	7.723	7.300	–
selL [F] SS	6.524	7.051	6.257	6.512	6.542	6.980	6.600	–
selM [M]	51.048	51.259	50.877	51.117	50.880	51.289	51.045	–
selM [F] AW	59.594	60.578	59.258	59.676	59.541	60.577	59.635	–
selM [F] SS	57.239	58.110	56.926	57.329	57.117	58.157	57.268	–
selL [M] < 1993	–	–	–	–	–	–	–	4.956
selL [F] < 1993	–	–	–	–	–	–	–	8.052
selL [M] ≥ 1993	–	–	–	–	–	–	–	4.133
selL [F] ≥ 1993	–	–	–	–	–	–	–	6.725
selM [M] < 1993	–	–	–	–	–	–	–	49.938
selM [F] < 1993	–	–	–	–	–	–	–	56.293
selM [M] ≥ 1993	–	–	–	–	–	–	–	51.075
selM [F] ≥ 1993	–	–	–	–	–	–	–	58.166
Derived parameters: adjusted vulnerable biomass								
B_0	4332	4796	5351	3771	4482	5023	4253	4244
B_{0now}	3546	4272	4425	3372	3649	4594	3491	3506
B_{MIN}	420	488	385	425	409	559	422	427
B_{2024}	1463	1544	1427	1442	1459	1650	1472	1492
B_{2024} / B_0	0.338	0.322	0.267	0.382	0.326	0.328	0.346	0.352
Derived parameters: spawning stock biomass (females only)								
SSB_0	3195	4558	3041	3284	2822	5306	3169	3264
SSB_{0now}	2615	4060	2515	2757	2297	4853	2601	2696
SSB_{2024}	2839	4242	2306	3094	2307	4856	2848	3013
SSB_{2024} / SSB_0	0.889	0.931	0.758	0.942	0.817	0.915	0.899	0.923
Derived parameters: total biomass								
T_0	11242	14659	11181	10843	10205	16658	11140	11362
T_{0now}	9202	13058	9246	9610	8307	15236	9143	9386
T_{2024}	10079	13185	8361	10955	8291	14399	10126	10619
Other derived parameters								
H_{2023}	13.713	14.496	13.232	13.823	13.186	14.951	13.796	13.502
T_{male} / T_{female}	1.313	1.194	1.345	1.292	1.346	1.175	1.310	1.308

Table 17: CRA 4 MCMC outputs, reporting the 5%, 50% (median), and 95% quantiles of the posterior distribution, showing likelihoods, standard deviation of normalised residuals (SDNRs), median absolute residuals (MARs), and parameter estimates. These values are for the base case and five sensitivity runs. Growth increment values in mm TW, biomass values in tonnes, and R_0 in numbers. Fixed values are indicated in grey. '–': not applicable. (Continued on next page)

	base			*CRA4_alltags*			*fixM*			*start1945* \		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods												
Total	18149	18158	18169	13048	13057	13068	17932	17941	17951	18226	18237	18249
Prior	50.197	60.299	71.106	118.693	129.602	140.346	53.361	63.842	75.925	34.761	46.010	58.971
Tag	8248	8256	8266	2837	2847	2859	8242	8251	8262	8376	8384	8395
Sex ratio	1396	1398	1405	1544	1547	1551	1184	1189	1195	1396	1399	1407
LFs	8661	8671	8680	8739	8750	8762	8654	8664	8676	8656	8667	8678
CPUE [CR]	–	–	–	–	–	–	–	–	–	-35.106	-32.276	-27.895
CPUE [FSU]	-38.557	-35.285	-30.951	-35.909	-32.914	-28.376	-39.011	-36.055	-31.406	-39.507	-36.495	-31.811
CPUE [CELR]	-117.848	-111.957	-104.743	-111.438	-105.821	-99.050	-116.843	-111.682	-105.218	-117.316	-111.936	-105.141
CPUE [CS]	-47.365	-45.032	-42.250	-46.113	-44.151	-41.465	-47.971	-46.132	-43.701	-47.335	-45.122	-42.302
CPUE [LB]	-39.126	-36.404	-32.789	-38.111	-34.928	-30.740	-38.928	-36.138	-32.585	-39.065	-36.405	-32.588
SDNR												
Tag	1.203	1.226	1.248	1.514	1.564	1.618	1.201	1.225	1.248	1.204	1.226	1.248
Sex ratio	0.888	0.933	1.071	0.967	1.013	1.093	0.985	1.103	1.276	0.897	0.958	1.119
LFs	0.519	0.553	0.600	0.501	0.534	0.579	0.528	0.560	0.601	0.520	0.554	0.597
CPUE [CR]	–	–	–	–	–	–	–	–	–	1.009	1.247	1.541
CPUE [FSU]	0.983	1.131	1.301	0.952	1.088	1.273	0.958	1.098	1.290	0.932	1.076	1.255
CPUE [CELR]	1.033	1.122	1.221	1.031	1.119	1.218	1.037	1.116	1.206	1.036	1.122	1.218
CPUE [CS]	1.011	1.062	1.120	1.010	1.055	1.107	0.995	1.035	1.085	1.010	1.059	1.115
CPUE [LB]	0.887	0.991	1.127	0.930	1.053	1.193	0.896	1.002	1.128	0.890	0.993	1.135
MAR												
Tag	0.700	0.714	0.726	0.644	0.664	0.686	0.698	0.712	0.726	0.700	0.713	0.726
Sex ratio	0.471	0.517	0.599	0.515	0.557	0.622	0.530	0.598	0.687	0.477	0.528	0.609
LFs	0.095	0.103	0.115	0.093	0.101	0.110	0.105	0.112	0.120	0.095	0.105	0.116
CPUE [CR]	–	–	–	–	–	–	–	–	–	0.430	0.795	1.218
CPUE [FSU]	0.546	0.768	1.048	0.407	0.672	0.943	0.550	0.790	1.073	0.581	0.812	1.077
CPUE [CELR]	0.578	0.693	0.823	0.585	0.685	0.809	0.595	0.711	0.843	0.577	0.690	0.823
CPUE [CS]	0.646	0.753	0.852	0.684	0.768	0.851	0.584	0.691	0.789	0.657	0.758	0.855
CPUE [LB]	0.575	0.773	0.994	0.619	0.848	1.060	0.552	0.746	0.941	0.589	0.777	1.002
Parameters												
R_0	3205824	4215930	5450797	3878925	5431970	7594173	2409083	2734765	3053942	3543597	4550140	5906676
U_0	0.164	0.239	0.329	0.158	0.232	0.328	0.199	0.264	0.355	–	0.000	–
M	0.269	0.304	0.337	0.227	0.265	0.303	–	0.223	–	0.279	0.316	0.353
q[CR]	–	–	–	–	–	–	–	–	–	5.67E-02	8.62E-02	1.24E-01
q[FSU]	8.91E-04	1.05E-03	1.23E-03	7.86E-04	9.40E-04	1.11E-03	9.61E-04	1.11E-03	1.31E-03	8.32E-04	9.84E-04	1.18E-03

	base			*CRA4_alltags*			*fixM*			*start1945* \		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
q[CELR]	1.10E-03	1.22E-03	1.34E-03	9.40E-04	1.06E-03	1.17E-03	1.27E-03	1.36E-03	1.46E-03	1.08E-03	1.20E-03	1.32E-03
q[CS]	2.41e-06	2.67e-06	2.93e-06	2.03e-06	2.29e-06	2.53e-06	2.76e-06	2.97e-06	3.22e-06	2.38e-06	2.65e-06	2.91e-06
q[LB]	2.30e-06	2.53e-06	2.79e-06	1.95e-06	2.19e-06	2.48e-06	2.57e-06	2.81e-06	3.04e-06	2.26e-06	2.52e-06	2.77e-06
mat50	41.607	43.012	44.422	41.945	43.243	44.561	41.034	42.403	43.579	41.400	42.763	44.051
Galpha male	3.078	3.141	3.210	2.461	2.550	2.642	3.088	3.148	3.214	3.064	3.126	3.194
Gbeta male	2.749	2.914	3.052	2.271	2.436	2.556	2.750	2.921	3.049	2.730	2.902	3.057
Gshape male	5.652	6.305	7.018	4.725	5.454	6.112	5.773	6.419	7.035	5.061	5.751	6.442
GCV male	0.600	0.625	0.649	0.704	0.742	0.780	0.602	0.626	0.652	0.594	0.619	0.643
Galpha female	2.812	2.945	3.084	1.881	2.061	2.249	2.637	2.732	2.836	2.812	2.946	3.085
Gbeta female	1.391	1.496	1.600	1.224	1.377	1.533	1.322	1.418	1.517	1.358	1.468	1.587
Gshape female	3.792	5.071	5.525	5.191	5.621	6.061	2.973	3.392	3.883	3.541	4.744	5.408
GCV female	0.838	0.881	0.927	1.136	1.243	1.361	0.852	0.893	0.938	0.829	0.873	0.920
Gobs	0.872	0.952	1.036	0.432	0.479	0.529	0.856	0.942	1.023	0.878	0.958	1.044
vuln AW [IF] < 1993	0.417	0.820	0.985	0.455	0.839	0.987	0.361	0.794	0.985	0.421	0.806	0.982
vuln SS [IF] < 1993	0.396	0.785	0.981	0.464	0.831	0.986	0.365	0.770	0.979	0.434	0.806	0.980
vuln AW [MF] < 1993	0.769	0.927	0.992	0.740	0.928	0.993	0.816	0.948	0.996	0.763	0.926	0.996
vuln SS [MF] < 1993	0.451	0.556	0.674	0.469	0.579	0.717	0.508	0.609	0.744	0.426	0.527	0.647
vuln AW [IF] ≥ 1993	0.312	0.612	0.942	0.403	0.748	0.976	0.492	0.822	0.982	0.341	0.681	0.971
vuln SS [IF] ≥ 1993	0.329	0.653	0.959	0.462	0.790	0.979	0.509	0.813	0.982	0.348	0.687	0.958
vuln AW [MF] ≥ 1993	0.482	0.586	0.701	0.473	0.574	0.717	0.560	0.657	0.759	0.476	0.574	0.687
vuln SS [MF] ≥ 1993	0.670	0.773	0.898	0.649	0.767	0.895	0.780	0.871	0.965	0.658	0.770	0.907
selL [M]	3.948	4.228	4.528	3.853	4.102	4.363	4.018	4.311	4.632	3.864	4.129	4.413
selL [F] AW	7.199	8.516	9.390	7.362	7.938	8.656	6.501	6.913	7.409	6.918	7.996	9.129
selL [F] SS	6.539	7.559	8.326	6.669	7.189	7.768	5.908	6.308	6.711	6.265	7.180	8.141
selM [M]	50.770	51.032	51.277	51.010	51.262	51.506	50.600	50.844	51.093	50.888	51.111	51.360
selM [F] AW	59.306	60.229	61.114	59.847	60.511	61.273	58.651	59.223	59.802	59.267	60.088	61.113
selM [F] SS	56.921	57.515	58.096	57.579	58.094	58.689	56.484	56.909	57.354	56.949	57.547	58.229

Table 18: CRA 4 base case and sensitivity run MCMC derived quantities, reporting the 5%, 50% (median), and 95% quantiles of the posterior distributions. Biomass values in tonnes, *H* (handling mortality) in tonnes, *U* is an exploitation rate bounded between 0 and 1. '–': not applicable.

			base			*CRA4_alltags*			*fixM*			*start1945*
Variable	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
B_0	3359	3790	4395	3880	4504	5304	4872	5321	5746	3110	3463	3946
B_{0now}	2806	3126	3595	3454	4069	4883	4113	4398	4756	2719	3106	3612
B_{min}	385	429	483	443	506	578	347	381	414	376	433	490
B_R	–	663	–	–	–	–	–	–	–	–	–	–
B_{2024}	1253	1433	1630	1390	1579	1824	1197	1356	1545	1255	1445	1642
B_{2024}/B_0	0.304	0.375	0.452	0.283	0.350	0.434	0.220	0.256	0.298	0.341	0.416	0.495
B_{2024}/B_{0now}	0.387	0.456	0.530	0.320	0.388	0.469	0.285	0.309	0.335	0.389	0.464	0.536
B_{2024}/B_R	1.891	2.162	2.459	2.097	2.383	2.752	1.806	2.046	2.331	1.894	2.180	2.477
U_{2024}	0.105	0.120	0.138	0.092	0.106	0.121	0.109	0.125	0.142	0.104	0.119	0.136
U_{2024}/U_R	0.264	0.301	0.346	0.232	0.267	0.304	0.275	0.314	0.356	0.261	0.298	0.342
SSB_0	2853	3249	3691	3952	4549	5370	2711	3028	3338	3002	3396	3890
SSB_{0now}	2384	2673	3051	3493	4099	4963	2265	2503	2782	2532	2877	3310
SSB_{2024}	2133	2564	3197	3093	3873	5038	1744	1997	2342	2306	2818	3539
SSB_{2024}/SSB_0	0.676	0.793	0.936	0.724	0.855	1.026	0.588	0.664	0.766	0.703	0.835	0.990
SSB_{2024}/SSB_{0now}	0.857	0.957	1.108	0.850	0.942	1.080	0.750	0.797	0.874	0.873	0.976	1.139
Total biomass												
T_0	9473	10787	12043	12937	14684	16953	10020	11117	12131	9680	10717	12116
T_{0now}	7970	8828	9976	11421	13244	15933	8418	9160	10126	8554	9569	10875
T_{2024}	5791	7371	9467	8619	11213	15154	5046	6010	7395	6591	8310	10802
T_{2024}/T_0	0.552	0.687	0.850	0.617	0.763	0.952	0.458	0.543	0.659	0.624	0.773	0.966
T_{2024}/T_{0now}	0.695	0.827	1.014	0.713	0.842	1.032	0.573	0.652	0.762	0.730	0.861	1.066
Other derived parameters												
H_{2023}	11.516	12.915	14.649	12.781	14.273	15.925	10.915	12.079	13.423	11.891	13.283	14.991
T_{male}/T_{female}	1.159	1.206	1.287	1.138	1.186	1.232	1.234	1.295	1.352	1.154	1.214	1.298

Table 19: Probabilities calculated from the MCMC posteriors for the indicated derived parameters.

Variable	*base*	*CRA4_alltags*	*fixM*	*start1945*
P($B_{2024} > B_{min}$)	1.000	1.000	1.000	1.000
P($B_{2024} > B_R$)	1.000	1.000	1.000	1.000
P($SSB_{2024} > 20\%\ SSB_0$)	0.000	0.000	0.000	0.000
P($SSB_{2024} > 10\%\ SSB_0$)	0.000	0.000	0.000	0.000
P($U_{2024} > U_R$)	0.000	0.000	0.000	0.000

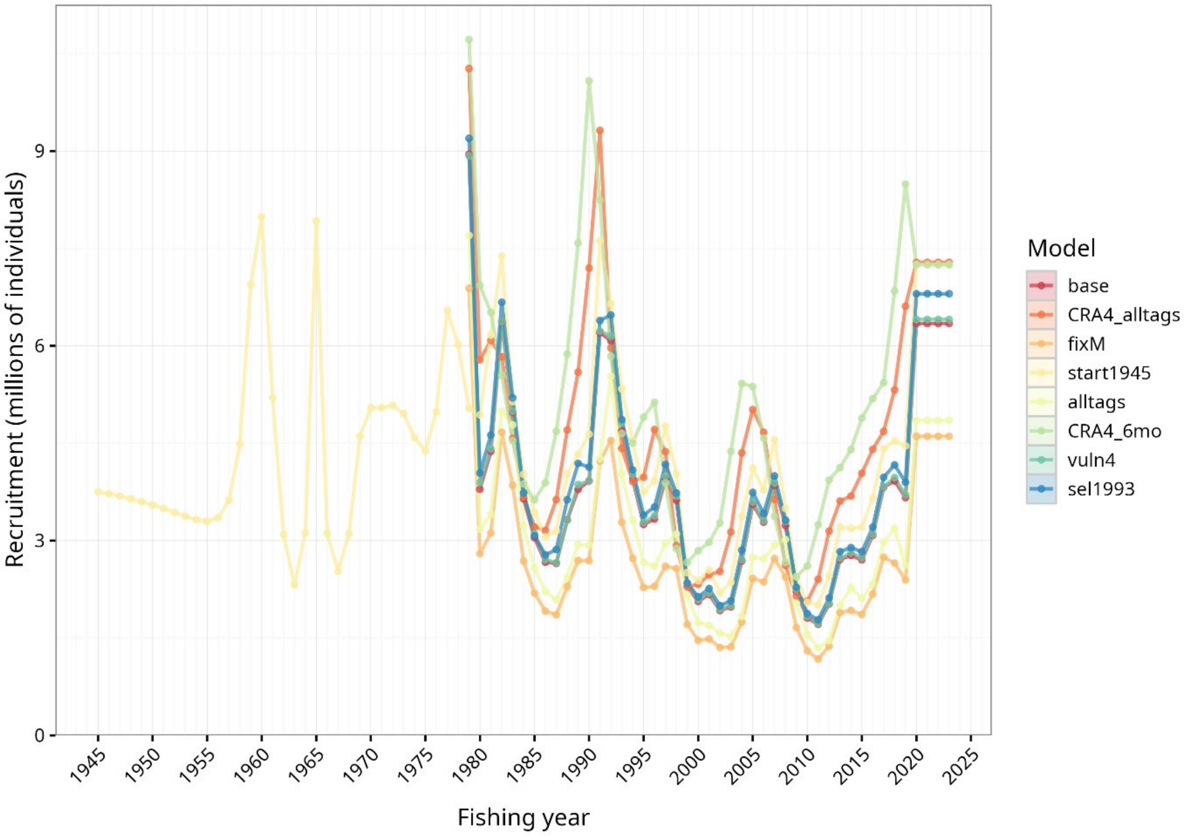


Figure 34: MAP recruitments for *base* and all MAP sensitivity runs.

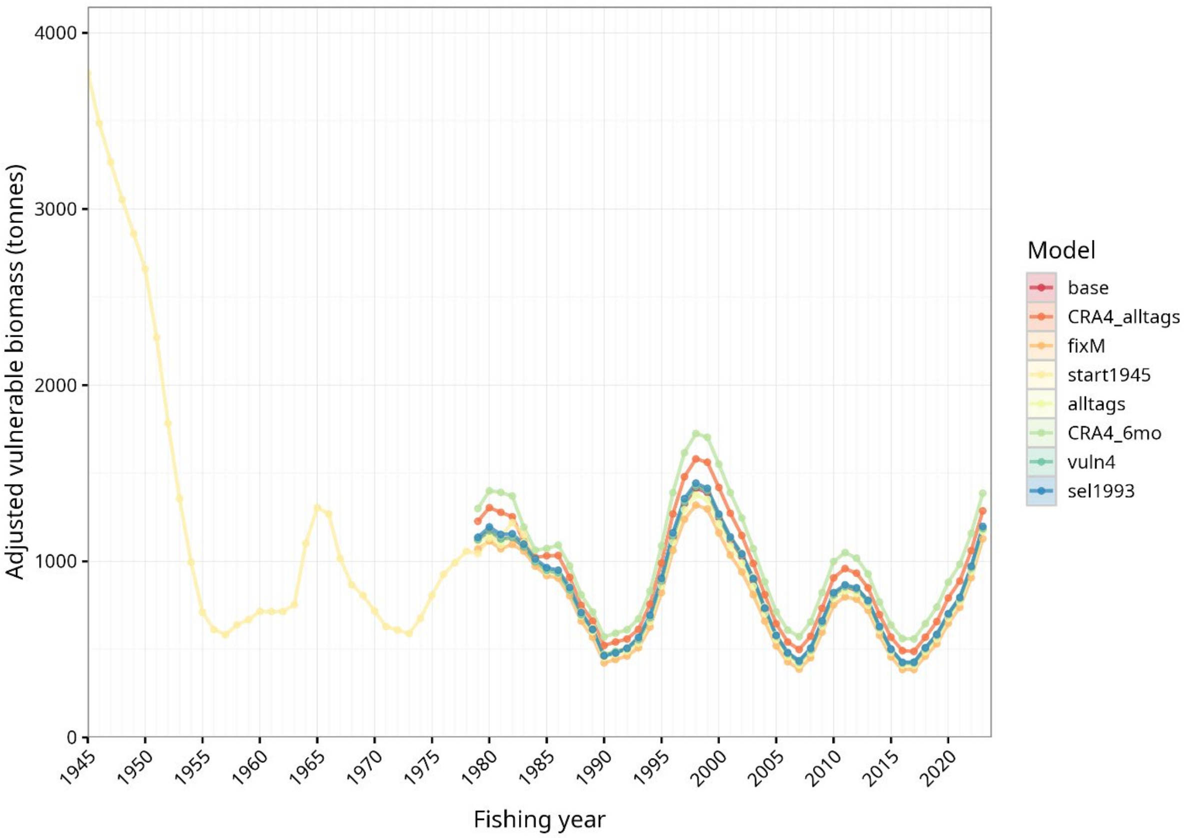


Figure 35: MAP adjusted vulnerable biomass for *base* all MAP sensitivity runs.

3.5.2 MCMC sensitivity runs

The RLWG chose three of the MAP sensitivity runs to be explored using MCMC, including the Group 1 and Group 2 runs (Table 15): *CRA4_alltags*, *fixM*, and *start1945*. The *start1945* model tested the sensitivity of the model to the information and uncertainty in early data years. The *fixM* sensitivity run forced the model to use the lower *M* estimated by the 2020 assessment, which was much lower than any of the 2024 runs. The *CRA4_alltags* model explored how population parameters were estimated based only on the CRA 4 tag recoveries, which did not include many large lobsters and which used all recoveries, including those at liberty for less than six months. This was the tag data set used in the 2020 CRA 4 stock assessment. All sensitivity runs had acceptable MCMC diagnostics (not presented).

Parameter estimates, likelihoods for all data components, indicators, and other derived parameters for the three MCMC sensitivity runs were compared with the *base* run (Table 17 and Table 18). Probabilities associated with model indicators for the three MCMC sensitivity runs and the *base* run were also compared (Table 19). Comparisons of these sensitivity runs with the *base* case were shown for selectivity (Figure 36), fits to the CELR CPUE indices (Figure 37), the logbook CPUE indices (Figure 38), recruitment (Figure 39), and adjusted vulnerable biomass (Figure 40). Also, comparison plots were shown for the trajectories of SSB (Figure 41) and SSB relative to SSB_0 (Figure 42).

The *fixM* and *CRA4_alltags* runs differed markedly from the *base* case run, but were simply explorations that were not well supported by data (*fixM*, due to none of the models estimated *M* as low as the 2020 assessment) or were alternative assumptions about what tag data were used to represent CRA 4 lobster growth (*CRA4_alltags*). After examining these runs, the RLWG agreed that the best tag dataset to use for the 2024 CRA 4 stock assessment was the one selected for the *base* and *base2* runs (including CRA 5 tags but excluding tags at liberty less than 6 months). The RLWG also agreed that it was better to estimate *M* than fix it at an arbitrary value.

The *start1945* run mirrored the *base* run in terms of parameter estimates (Table 17), derived quantities (Table 18), and probability estimates (Table 19). These overlapping results validated the selection of the shorter run for the base model because it was more parsimonious because it did not rely on poorly recorded historical catch information, without affecting the overall results.

The selectivity curves estimated by all three sensitivity runs were similar to that of the *base* run (Figure 36), as were the fits to the CELR CPUE (Figure 37) and the logbook CPUE (Figure 38). These three sensitivity runs were all evaluated to be well above the soft limit and the reference level in 2024 with a probability of 1.0 (Table 19).

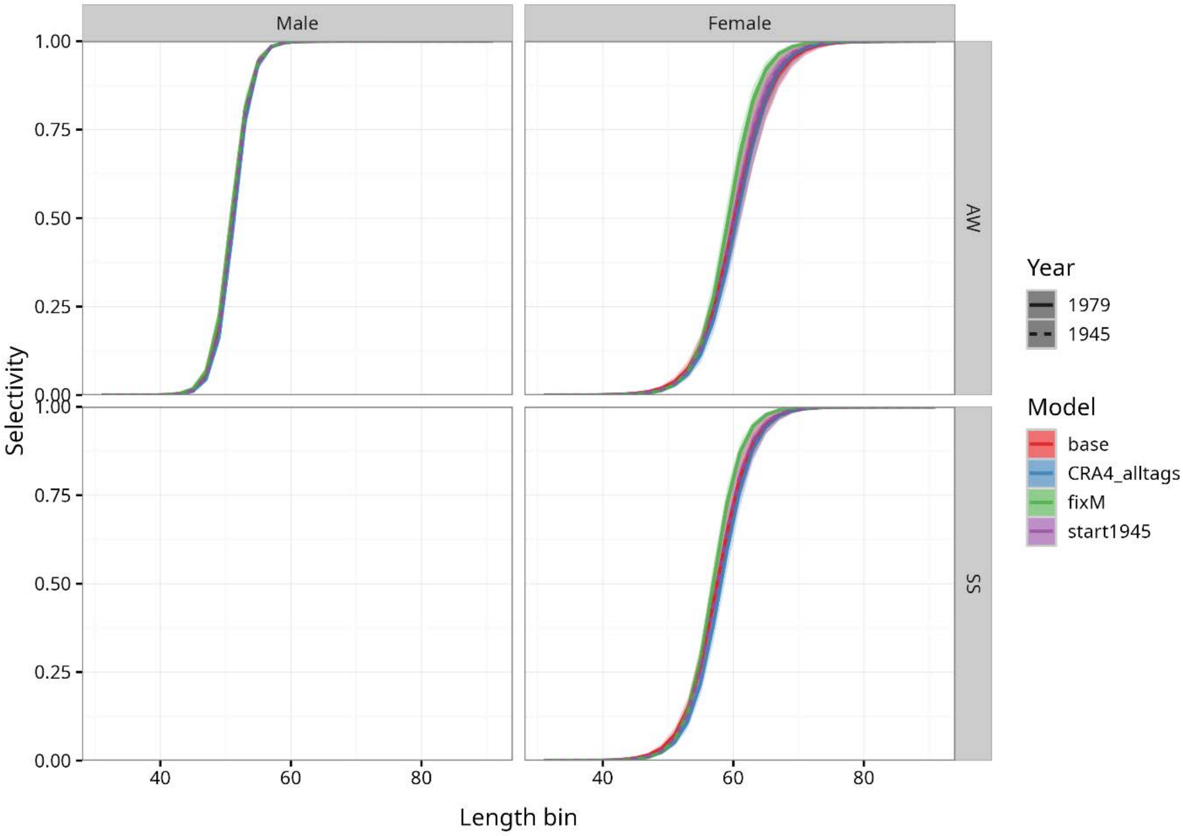


Figure 36: Posterior distribution of selectivity by sex and size comparing the *base case* with three key sensitivity runs. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

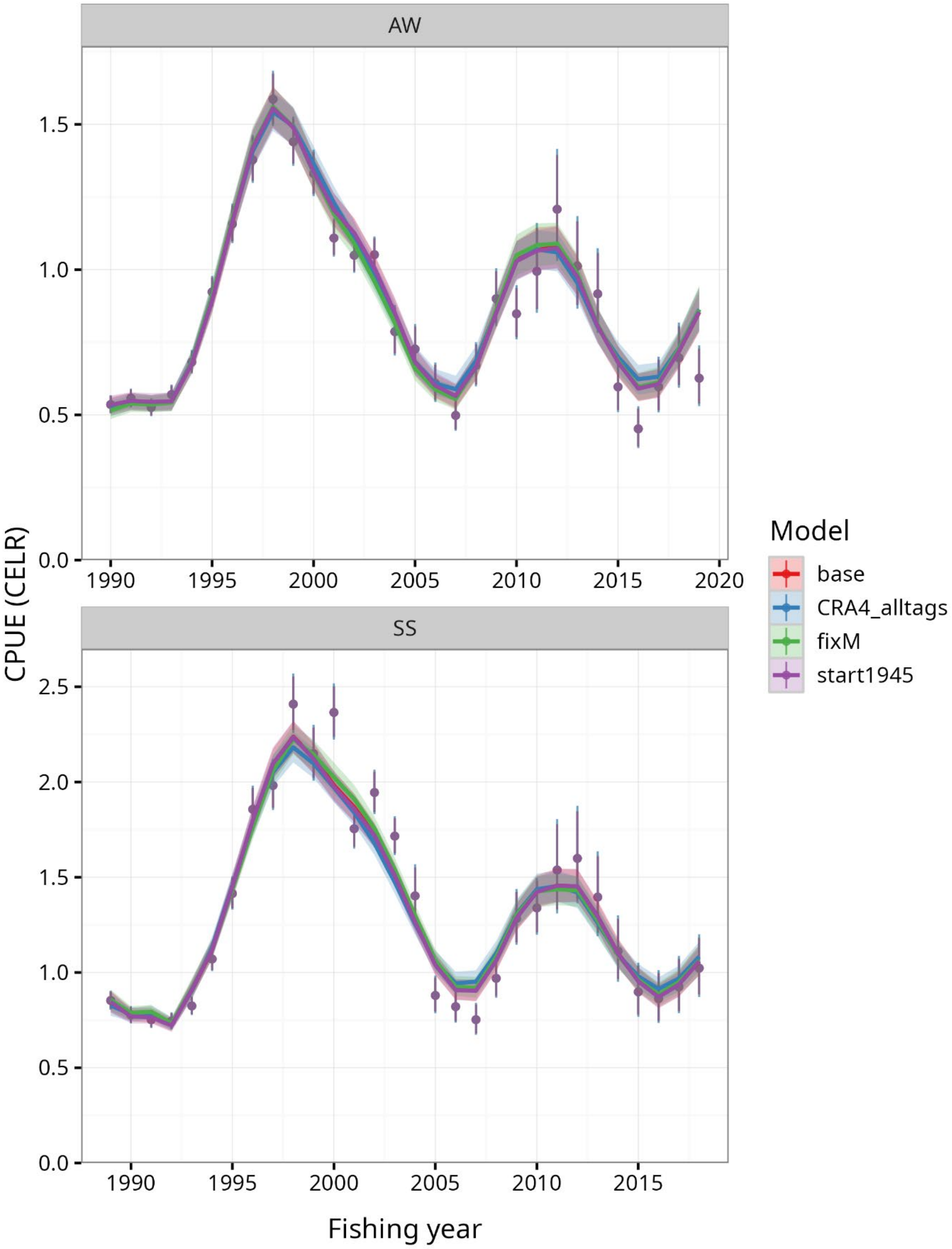


Figure 37: **Posterior predicted CPUE compared to the CELR CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) for key sensitivity runs and the base case. The solid line indicates the posterior median and shading indicates the 90% credible intervals.**

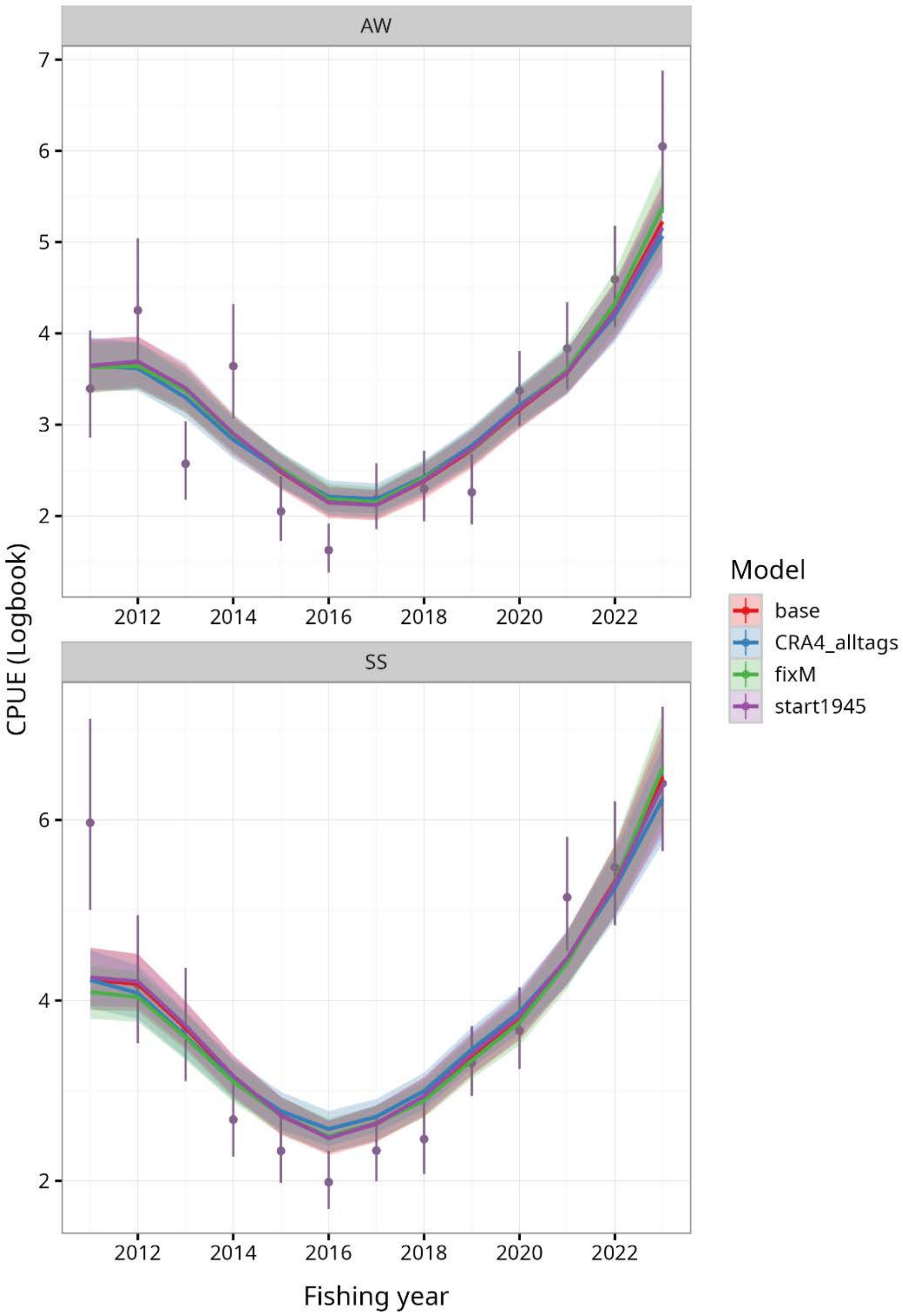


Figure 38: Posterior predicted CPUE compared to the Logbook CPUE indices by fishing year and season (AW = autumn/winter, SS = spring/summer) for key sensitivity runs and the base case. The solid line indicates the posterior median and shading indicates the 90% credible intervals.

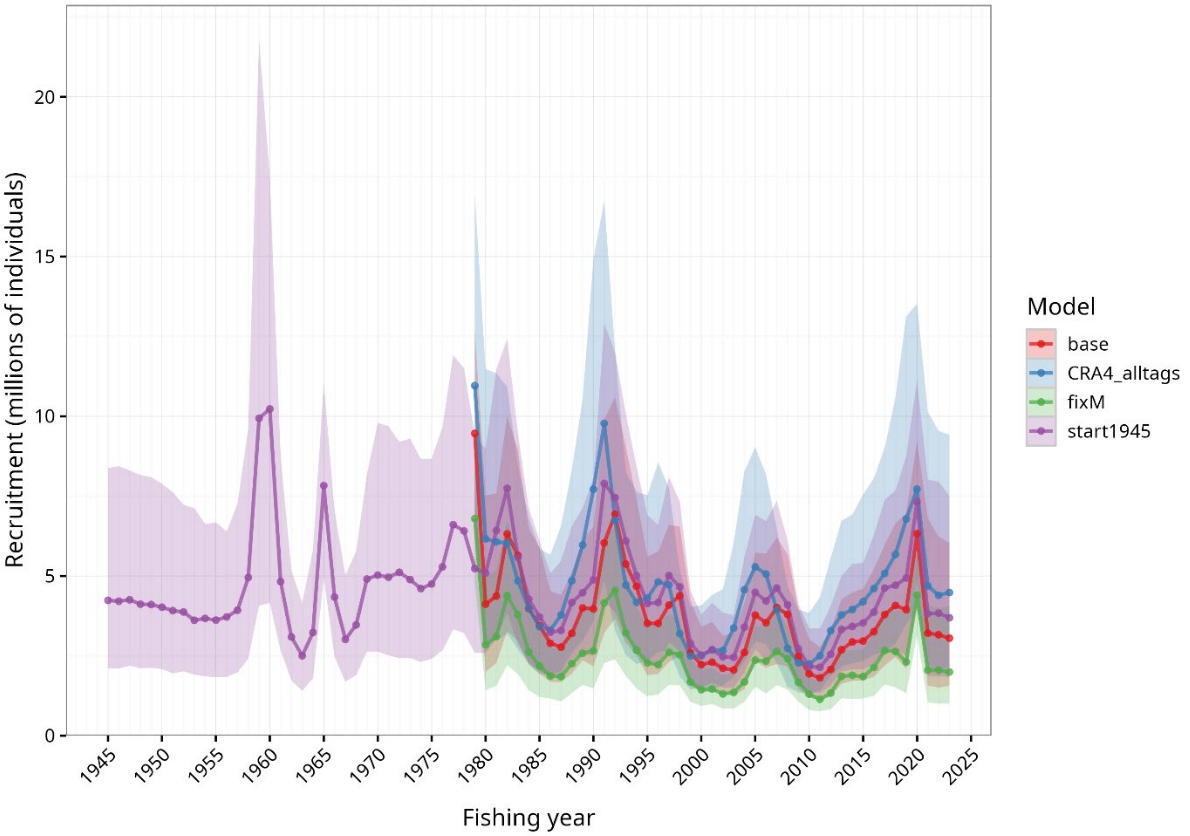


Figure 39: Posterior distribution of recruitment trajectories between the base run and key sensitivity runs.

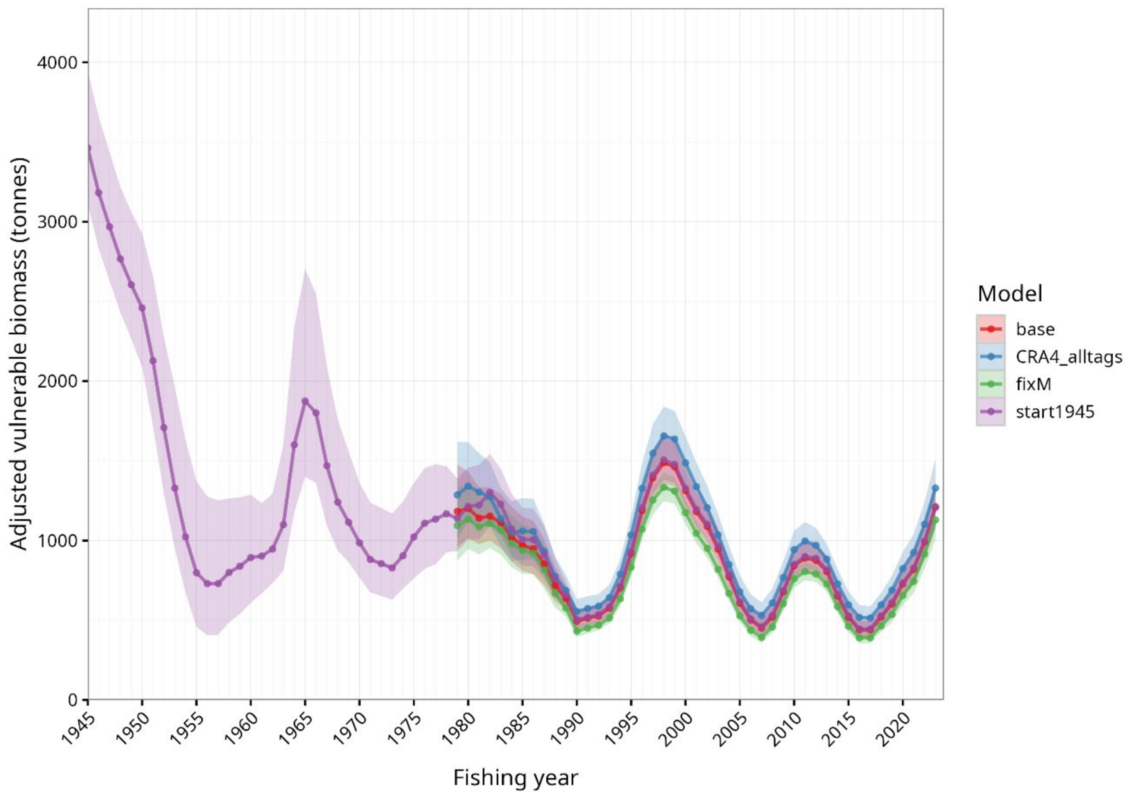


Figure 40: Posterior distribution of adjusted vulnerable biomass comparing the base case and key sensitivity runs.

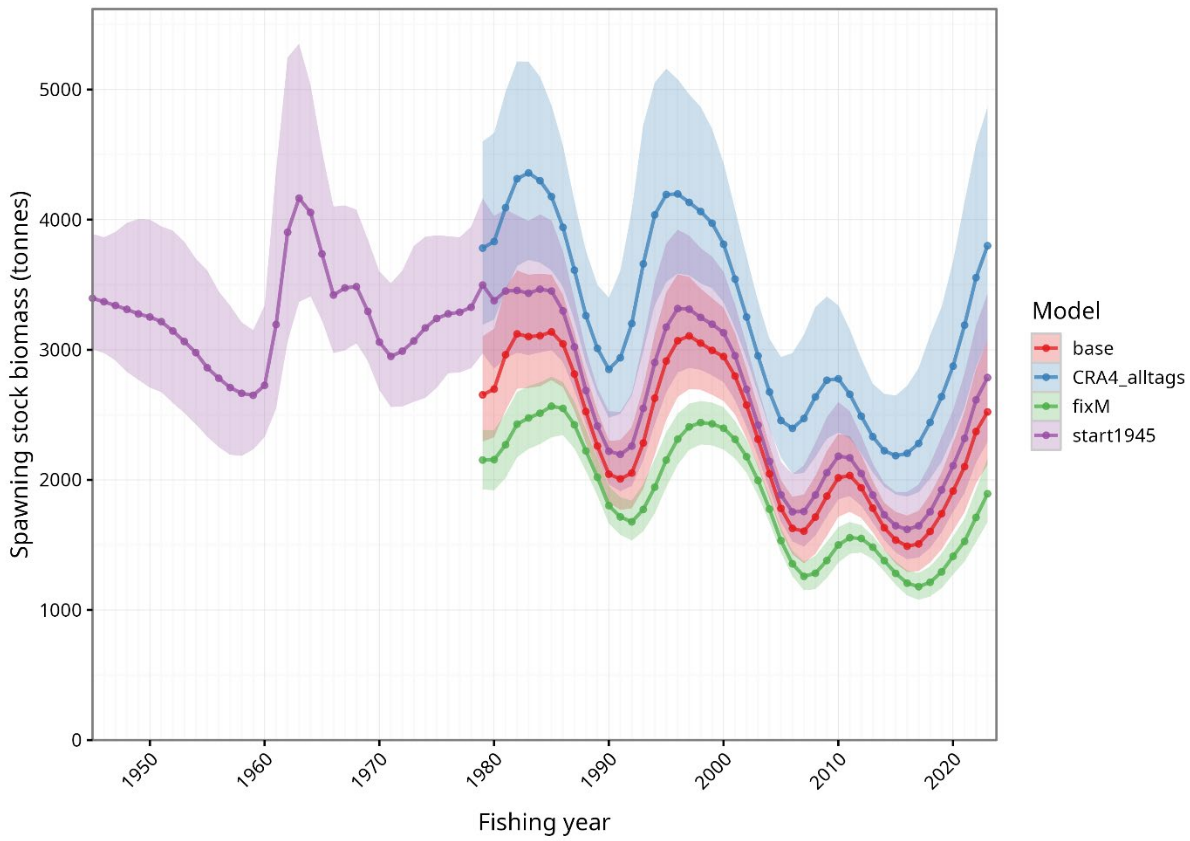


Figure 41: Posterior distribution of spawning stock biomass comparing the base case model run and key sensitivity runs.

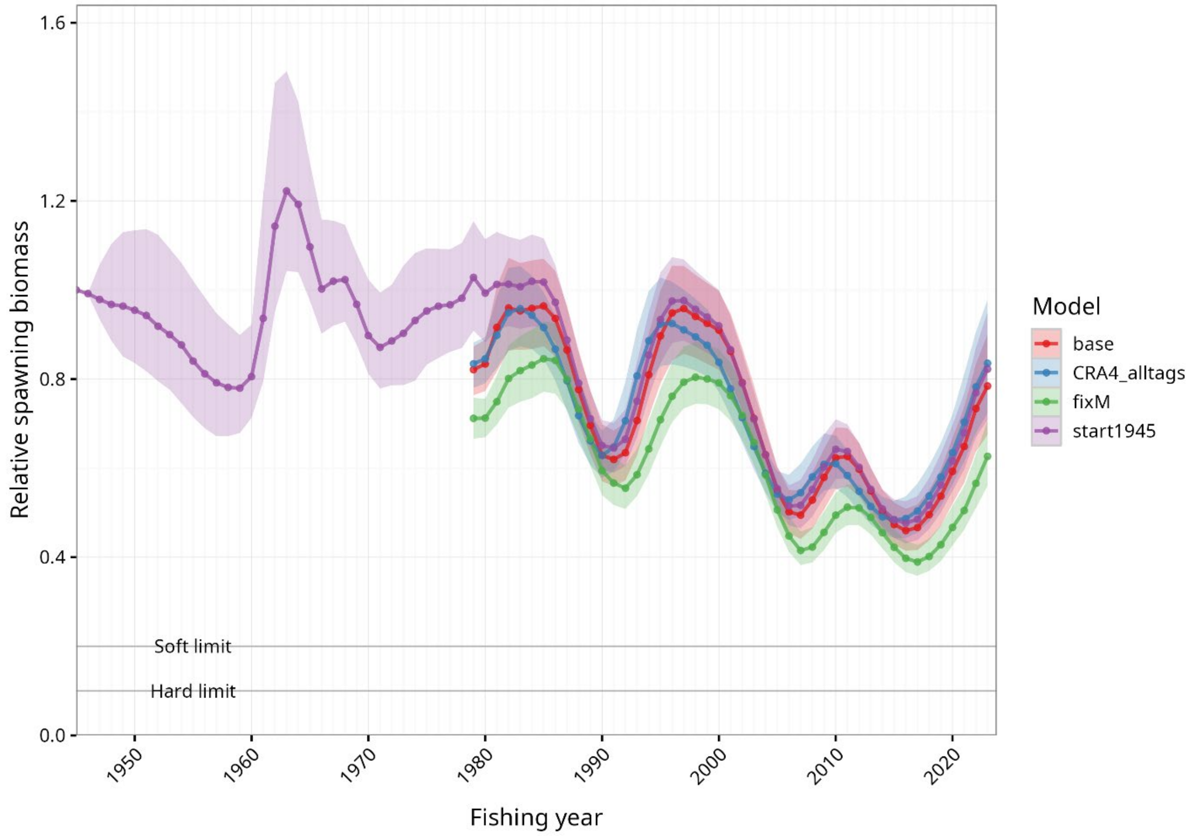


Figure 42: Posterior distribution of relative spawning stock biomass comparing the base case model run and key sensitivity runs.

3.6 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. 2021b). An interim target reference level for the population vulnerable to fishing (B_R) was developed using the stock assessment model to project the vulnerable biomass through simulation. Starting with the CRA 4 base case model (*base2*), projections were made across a range of fixed catch and fixed *U* levels. These simulations were run for 60 years across the 1000 MCMC posterior samples, with each simulation replicate drawing random recruitment deviates from a normal distribution based on the mean, standard deviation, and autocorrelation of model-estimated recruitment deviates starting in the first year with a reasonable amount of length data and ending three years before the final model year (the 'data period'). For CRA 4, the data period included 34 years from 1987 to 2020 (Table 3). This is also the period used for estimating SSB_0 (SSB_0^{data}).

Only the size-limited catches changed in these projections, with the non-size-limited catch (sum of illegal and customary catch) held constant at the 2023 level. Rules that dropped below 20% SSB_0^{data} more than 5% of the time for the final 20 simulation years were rejected. The constant catch rules were further constrained by the requirement that at least 99% of the expected catch had to be taken from at least 95% of years in the final 20 simulation years. The vulnerable biomass associated with the fixed catch and fixed *U* levels that maximised the catch for each harvest strategy, while satisfying the above constraints over the final 20 simulation years, were then averaged to obtain the interim target reference level for CRA 4 (see Rudd et al. 2021b).

To provide an exploitation rate indicator (U_R), the exploitation rate associated with B_R was calculated, which was defined as the *U* that resulted in a median equilibrium biomass equal to the B_R. U_R was identified by finding the fixed seasonal *U* resulting in a median vulnerable biomass of B_R over the final

20 simulation years of the 60-year projections described above. The seasonal U was then weighted based on the vulnerable biomass each season to obtain U_R as an annual rate.

The CRA 4 stock was predicted to be well above B_R at the beginning of 2024 AW and unlikely to be above U_R (not undergoing overfishing and or overfished) (Figure 30). B_{2024}, as estimated by the *base2* run, the *base* run and the three sensitivity runs taken to MCMC, was evaluated to be above B_R with a probability of 1.0 (Table 14, Table 19).

The 2024 assessment calculated B_R to be 662.8 tonnes, a value notably higher than the 389.1 tonnes calculated by the 2020 assessment. Possible reasons for this large change in B_R are high recent recruitment and an updated model, which led to updated R_0, M, growth, and vulnerability estimates. The 2024 base model estimated more lobsters to be in the vulnerable pool compared with the 2020 assessment. Higher vulnerable biomass with the same catch would lead to a higher B_R. The 2024 projections used to calculate B_R assumed higher recruitment than in the 2020 calculations. When the reference level, using the 2024 base model, was calculated assuming lower recruitment for the projections, the resulting B_R was lower, but not to the level of the 2020 B_R. This indicated that higher recent recruitment, resulting in higher recruitment used in the reference level projections, contributed to a higher B_R for the 2024 assessment.

3.7 Projections

A five-year projection, for the fishing years 2024 to 2028, was done for the *base2* model only. This projection was repeated for each sample from the posterior distribution. The non-commercial catches were assumed to be the same as the final model year (2023) and were set to be constant when projecting forward (Table 20). The projected commercial catch in 2024 was set to the current CRA 4 TACC of 280 tonnes, split into the two seasons based on the 2023 commercial seasonal catch distribution. (Table 20).

Table 20: Catch (tonnes) in the final model year and the projection years by season and fishing sector.

Fishing year	Commercial		Recreational		Customary		Illegal	
	AW	SS	AW	SS	AW	SS	AW	SS
2024–25	131.026	148.974	6.992	62.931	0.8	7.2	16.104	18.310
2025–26	131.026	148.974	6.992	62.931	0.8	7.2	16.104	18.310
2026–27	131.026	148.974	6.992	62.931	0.8	7.2	16.104	18.310
2027–28	131.026	148.974	6.992	62.931	0.8	7.2	16.104	18.310
2028–29	131.026	148.974	6.992	62.931	0.8	7.2	16.104	18.310

Projected recruitment deviates were simulated from a normal distribution with mean calculated from the mean of the 2011–2020 recruitment deviates, the standard deviation set to *sigmaR* (Table 3), and recruitment autocorrelation derived from the 1987–2020 recruitment deviates. Projected recruitment deviates replaced the 2021, 2022, and 2023 deviates because recruitment was not estimated in the reconstruction model for these years (Figure 26).

The projection predicted an increase in the adjusted vulnerable biomass from 2024 to 2027, but then a low rate of decrease in 2027 and 2028 (Figure 27). The projection predicted a decline in SSB from 2024 to 2028 (Figure 28). The median adjusted vulnerable biomass at the beginning of 2024 was estimated to be 33% of B_0 (B_{2024} / B_0 = 0.334 [90% credible interval (CI) = 0.276–0.412]) and was projected to increase to a median value of 34% of B_0 by 2028, at current catch (B_{2028} / B_0 = 0.344 [90% CI = 0.229–0.500]) (Table 13). The median SSB at the beginning of 2024 was estimated to be 70% of SSB_0 (SSB_{2024} / SSB_0 = 0.698 [90% CI = 0.602–0.840]) and was projected to decrease to a median value of 68% of SSB_0 (SSB_{2028} / SSB_0 0.677 [90% CI = 0.531–0.877]; Table 13) by the beginning of 2028.

The projection for the *base* case predicted that the CRA 4 stock will increase from 205% of B_R (B_{2024} / B_R = 2.045 [90% CI = 1.791–2.336]) to 209% of B_R (B_{2028} / B_R = 2.086 [90% CI = 1.400–2.940]) by the beginning of 2028 (Table 13).

4. DISCUSSION

The 2024 CRA 4 stock assessment made important improvements over the previous stock assessment of CRA 4 (Rudd et al. 2021a), including fitting to a new logbook CPUE index series of relative abundance from 2011–2023 as well as to a new catch sampling CPUE index series extending from 2004 to 2023. The preparation of the composition data was substantially improved, with model-based standardisation of the length frequencies and sex ratio data replacing the ad-hoc procedures previously used. These model-based procedures also provided more defensible data weightings for these observation types. The assessment also moved away from the binary assumption of 100% berried females in the AW and 0% in the SS to using values estimated from data for these proportions by season. This assessment also revised the assumptions underlying the setting of recreational and illegal catches. These improvements resulted in defensible changes to model outputs, with likely improvements in the accuracy of model estimates of SSB and vulnerable biomass.

The *base2* model for CRA 4 fitted the data well (Figure 18, Figure 19, Figure 20, Figure F.10) and generated parameter estimates that were considered plausible by the RLWG and Plenary reviewers. As such, the *base2* run was accepted to be a good representation of stock status at the beginning of the 2024–25 fishing year by the RLWG and the stock assessment Plenary.

The fits to the tag recapture growth data were good, indicating that adding the CRA 5 tag data was a reasonable proxy data set from which to estimate CRA 4 growth, given the small sample of tag recapture data from larger individuals in CRA 4 (Figure F.14). As well, the good fits to the tag recapture data validated the decision to drop recoveries that were less than six months at liberty in order to discard observations that had failed to moult. The *CRA4_alltags* model run, fitted only to the CRA 4 tag data and which retained all recoveries, estimated slower growth for both sexes than the *base2* run with greater uncertainty at larger sizes (Table 17), resulting in a shift of about one year earlier in the timing of the estimated recruitment pattern through time (Figure 34). The Plenary considered the model which included the CRA 5 tags and resulted in less growth uncertainty to be more plausible than the model restricted to only CRA 4 tags. While using tags from CRA 5 did not appear to have biased this assessment, tagging should continue in CRA 4 to reduce the dependency on this borrowed data set and to provide QMA-specific data for future stock assessments. The exclusion of tags spending less than six months at liberty (during which near zero growth increments that were attributed to no moulting occurred) appeared to be a good trade-off for minimising the potentially biasing effects of seasonal tag-recapture effort on growth estimates while still retaining a sufficiently large sample of data.

Several sensitivity model runs (e.g., *vuln4*, *sel1993*) were run to try for a better fit to the sex ratio data (Figure 19) or to determine why M was estimated higher relative to the previous assessment estimate of M = 0.223 (95% credible interval = 0.200 – 0.251) (Rudd et al. 2021a). These runs did not, achieve these outcomes (Table 16). Fixing M at a lower value (*fixM*) led to slower growth, but did not appear to be supported by the data, given that none of the other models produced M estimates as low as that of the 2020 assessment. The 2024 CRA 3 assessment also estimated a high M relative to the previous assessment (Roberts et al. 2025). An exploration of sex-specific CPUE for that assessment determined that the abundance of females in CRA 3 and possibly in some statistical areas of CRA 4 was likely to have declined relative to that of the males. The updated CRA 3 assessment represented this by estimating a time and sex-specific M, which effectively eliminated a strong trend in the sex ratio residuals and resulted in a more pessimistic prediction of current and projected SSB status for CRA 3 (Roberts et al. 2025). This was not explored for the 2024 CRA 4 assessment, which was completed before the CRA 3 assessment, although doing so in the future may resolve some of the issues relating to the estimation of *M*.

The *base2* case run vulnerable biomass was estimated to be above B_R at the beginning of 2024 with a probability of 1.0, and the median projected increase was 2% by 2028 (Table 13, Figure 27) at catch levels equivalent to the current TACC and constant 2023 non-commercial catches. A similar pattern was observed for the SSB, which was estimated to be well above the soft limit of 20% SSB_0 at the beginning of 2024 AW and the median SSB_{2028} was predicted to decrease from 70% in 2024 to near 68% of SSB_0 at the beginning of 2028 (Figure 28).

5. POTENTIAL RESEARCH

The RLWG and the Plenary identified several potentially useful avenues of research to evaluate or improve future CRA 4 stock assessments. Potential improvements that are specific to CRA 4 include:

- Investigate methods for collecting growth data for sub-45 mm TW lobsters and from larger lobsters (i.e., greater than 65 mm TW), so that the CRA 4 assessment is less reliant on data from QMAs that are assumed to have similar growth.
- Conduct more tagging in Statistical Areas 912 and 915.
- Explore dropping all the data from Statistical Areas 915 and 934 from the core model (due to difference in length frequency and low fishing levels).

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

- Merge mature and immature females within the assessment model and estimate maturity outside of the assessment model.
- Consider alternatives to the current parameterisation on *M*, including size-varying *M* (Lorenzen 1996) and time-varying sex-specific *M* (a plausible explanation for trends in sex ratios in the base model over time).
- Investigate the influence of growth parameter priors where the posteriors are substantially different from the prior (e.g., *GSD*) to determine whether these priors are appropriate and influential.Explore an apparent change in reporting behaviour associated with the change to electronic monitoring, with the aim of extending the CELR CPUE abundance series beyond the AW of the 2019 fishing year or establish a reliable separate, new CPUE series based on these data.
- Conduct additional morphometric work; for example, collect data and analyse relationships between tail width, carapace length, weight, sex, and somatic condition.
- Consider different time periods for resampling recruitment within projections for sensitivity analysis.
- Include random effects for certain LSD model parameters (e.g., selectivity parameters).
- Develop and evaluate alternative growth models.
- Develop computer code to include the effects of density-dependent growth and environmental effects in the LSD model.
- Investigate potential fisheries-independent survey designs.
- Improve estimates of non-commercial catch.
- Explore higher assumed levels for *q_drift*.
- Continue strong support for the logbook sampling programme.

6. FULFILMENT OF BROADER OUTCOMES

As required under Government Procurement rules[11], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic or cultural benefits) that would be generated by this project.

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

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

7. ACKNOWLEDGEMENTS

We thank Fisheries New Zealand who awarded the contract CRA2022-01 to Quantifish Ltd. We thank Bruce Hartill (chair) and members of the Rock Lobster Working Group for their peer review and helpful discussion throughout the development of this stock assessment. We also thank the National Rock Lobster Management Group (NRLMG) for their input. And finally, we thank the rock lobster fishers of New Zealand for their input and discussion and ongoing commitment to the fishery.

8. REFERENCES

Annala, J.H.; King, M.R. (1983). The 1963–73 New Zealand rock lobster landings by statistical area. *Fisheries Research Division Occasional Publication Data Series 11*. 20 p.

Bentley, N.; Starr, P.J.; Walker, N.; Breen, P.A. (2005). Catch and effort data for New Zealand rock lobster stock fisheries. *New Zealand Fisheries Assessment Report 2005/49*. 49 p.

Boyd, R.O.; Gowing; L.; Reilly, J.L. (2004). 2000–2001 national marine recreational fishing survey: diary results and harvest estimates. Final Research Report of the Ministry of Fisheries project REC9803.

Boyd, R.O.; Reilly, J.L. (2004). 1999–2000 National Marine Recreational Fishing Survey: harvest estimates. Final Research Report for the Ministry of Fisheries Project REC9803. (Unpublished report held by Fisheries New Zealand.) 28 p.

Breen, P.A.; Booth, J.D.; Tyson, P.J. (1988). Feasibility of a minimum size limit based on tail width for the New Zealand rock lobster *Jasus edwardsii*. *New Zealand Fisheries Technical Report No. 6.* 16 p.

Breen, P.A.; Starr, P.J.; Haist, V.; Edwards, C.T.T.; Webber, D.N. (2017). The 2016 stock assessment and management procedure review for rock lobsters (*Jasus edwardsii*) in CRA 4. *New Zealand Fisheries Assessment Report 2017/29*. 92 p.

[11] https://www.procurement.govt.nz/procurement/principles-charter-and-rules/government-procurement-rules/planning-your-procurement/broader-outcomes/

Davey, N K; Hartill, B H; Carter, M (2019) Mean weight estimates for recreational fisheries in 2017–18. *New Zealand Fisheries Assessment Report 2019/25*. 32 p.

Davey, N K; Johnson, K S; Maggs, J.Q. (2024) Mean weight estimates for recreational fisheries in 2022–23. *New Zealand Fisheries Assessment Report 2024/28*. 45 p.

Fisheries New Zealand (2024). *Fisheries Assessment Plenary, November 2024: stock assessments and stock status.* Compiled by the Fisheries Science Team Fisheries New Zealand, Wellington, New Zealand. 347 p.

Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68(6)*: 1124–1138.

Hartill, B.H.; Davey, N.K. (2015). Mean weight estimates for recreational fisheries in 2011–12. *New Zealand Fisheries Assessment Report 2015/25*. 37 p.

Heinemann, A.; Gray, A. (2024). National Panel Survey of Marine Recreational Fishers 2022–23. *New Zealand Fisheries Assessment Report 2024/51*. 122 p.

Heinemann, A.; Wynne-Jones, J.; Gray, A.; Hill, L. (2015). National Panel Survey of Marine Recreational Fishers 2011–12 Rationale and Methods. *New Zealand Fisheries Assessment Report 2015/48*. 94 p.

Lorenzen, K. (1996). The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. *Journal of Fish Biology, 49*: 627–642.

Ministry of Fisheries (2011). Operational Guidelines for New Zealand's Harvest Strategy Standard. Ministry of Fisheries, New Zealand. 80 p. (https://www.mpi.govt.nz/dmsdocument/19706-OPERATIONAL-GUIDELINES-FOR-NEW-ZEALANDS-HARVEST-STRATEGY-STANDARD).

Pons, M.; Webber, D.N.; Rudd, M.B.; Starr, P.J.; Roberts, J. (2024). Rapid updates for New Zealand rock lobster (*Jasus edwardsii*) stocks in 2023. *New Zealand Fisheries Assessment Report 2024/13*. 80 p.Roberts, J.; Webber, D.N. (2022). Growth of juvenile red rock lobster (*Jasus edwardsii*) in New Zealand and implications for stock assessment. *New Zealand Fisheries Assessment Report 2022/45*. 59 p.

Roberts, J.; Webber, D.N.; Starr, P.J.; Rudd, M.B.; Pons, M.; Goeden, Z. (2023). Data for the 2022 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 2. *New Zealand Fisheries Assessment Report 2023/42*. 91 p.

Roberts, J.O.; Webber, D.N. (2024). Review of red rock lobster (*Jasus edwardsii*) recruitment processes and the puerulus collector programme. *New Zealand Fisheries Assessment Report 2024/68*. 108 p.

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

Rudd, M.B.; Pons, M.; Roberts, J.; Webber, D.N.; Starr, P.J. (2021a). The 2020 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4. *New Zealand Fisheries Assessment Report 2021/80*. 112 p.

Rudd, M.B.; Webber, D.N.; Starr, P.J. (2021b). Model-based reference points for New Zealand red rock lobster (*Jasus edwardsii*). *New Zealand Fisheries Assessment Report 2021/81*. 42 p.

Rudd, M.B.; Webber, D.N.; Starr, P.J.; Roberts, J.O.; Pons, M. (2024). The 2023 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 6. *New Zealand Fisheries Assessment Report 2024/23*. 106 p.

Stan Development Team (2016). *CmdStan: User's Guide*. Version 2.16.0

Stan Development Team (2017). *Stan Modelling Language: User's Guide and Reference Manual*. Version 2.16.0.

Starr, P.J. (2025). Rock lobster catch and effort data: 1979–80 to 2023–24. *New Zealand Fisheries Assessment Report 2025/10*. 132 p.

Starr, P.J.; Webber, D.N.; Rudd, M.B.; Pons, M.; Roberts, J. (2021). Data for the 2020 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4. *New Zealand Fisheries Assessment Report 2021/56.* 80 p.

Webber, D.N. (2022). Modelling the length frequency of red rock lobsters (*Jasus edwardsii*) in New Zealand. *New Zealand Fisheries Assessment Report 2022/30.* 261 p.

Webber, D N; Haist, V; Starr, P J; Edwards, C T T (2018a) A new model for the assessment of New Zealand rock lobster (*Jasus edwardsii*) stocks and an exploratory multi-area CRA 4 assessment. *New Zealand Fisheries Assessment Report 2018/53.* 111 p.

Webber, D.N.; Roberts, J.O.; Starr, P.J.; Rudd, M.B.; Pons, M. (2024). Data for the 2023 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 6. *New Zealand Fisheries Assessment Report 2024/19*. 73 p.

Webber, D.N.; Rudd, M.B.; Starr, P.J.; Roberts, J.; Pons, M. (2023). The lobster stock dynamics (LSD) model. *New Zealand Fisheries Assessment Report 2023/11*. 28 p.

Webber, D.N.; Starr, P.J.; Rudd, M.B.; Roberts, J.; Pons, M. (2022). The 2021 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 7 and CRA 8. *New Zealand Fisheries Assessment Report 2022/17.* 113 p.

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

Wynne-Jones, J.; Gray, A.; Heinemann, A.; Hill, L; Walton, L. (2019). National Panel Survey of Marine Recreational Fishers 2017–2018. *New Zealand Fisheries Assessment Report 2019/24*. 104 p.

Appendix A. LOGBOOK CPUE DIAGNOSTICS

Table A.1: Summary of logbook (LB) sampling effort in CRA 4 by fishing year and season (‘AW’ = autumn/winter, ‘SS’ = spring/summer) in terms of: the number of vessels, the number of pots, and the number of lobsters measured. Fishing years shaded grey were not included in the LB CPUE model.

Fishing	Vessels			Pots			Lobsters measured		
year	AW	SS	Total	AW	SS	Total	AW	SS	Total
1997	1	1	1	201	8	209	1 349	47	1 396
1998	3	2	3	94	80	174	732	374	1 106
1999	1	–	1	119	–	119	239	–	239
2000	1	–	1	23	–	23	244	–	244
2002	1	1	1	176	24	200	240	40	280
2003	1	1	1	324	50	374	1 073	196	1 269
2004	1	1	1	248	30	278	798	76	874
2005	2	1	2	432	66	498	1 659	197	1 856
2006	2	1	2	390	62	452	952	81	1 033
2007	1	1	1	181	96	277	302	241	543
2008	1	–	1	146	–	146	322	–	322
2009	1	2	2	130	10	140	472	68	540
2010	5	6	8	486	226	712	1 284	911	2 195
2011	11	4	11	517	193	710	2 178	1 225	3 403
2012	6	5	6	348	401	749	1 946	1 742	3 688
2013	4	4	4	316	232	548	944	921	1 865
2014	6	9	9	491	634	1 125	1 990	2 225	4 215
2015	9	10	11	759	1 062	1 821	1 850	2 651	4 501
2016	12	12	14	614	1 637	2 251	919	3 529	4 448
2017	6	11	12	329	860	1 189	761	1 963	2 724
2018	6	10	11	386	1 114	1 500	952	2 439	3 391
2019	8	8	10	407	582	989	1 185	1 986	3 171
2020	6	6	7	451	425	876	1 804	1 503	3 307
2021	7	6	9	510	219	729	2 179	1 009	3 188
2022	7	6	7	456	263	719	2 033	1 144	3 177
2023	3	4	4	267	119	386	1 296	664	1 960

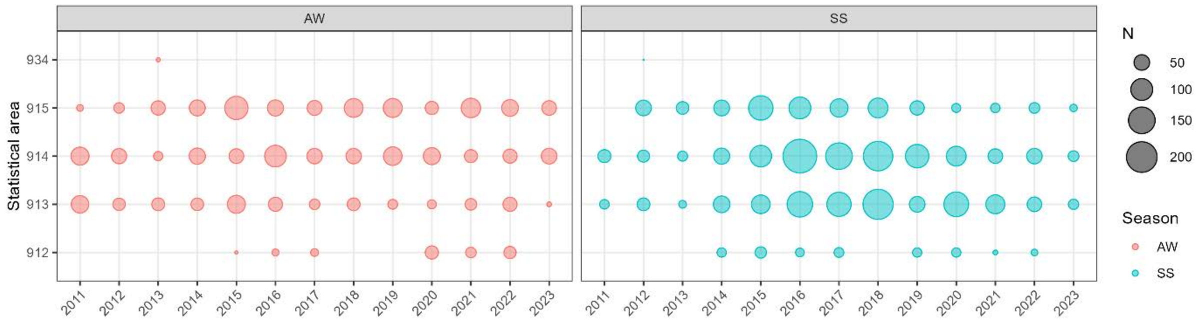


Figure A.1: Bubble plot of logbook (LB) effort by fishing year, season, and statistical area, including only the fishing years included in the LB CPUE model.

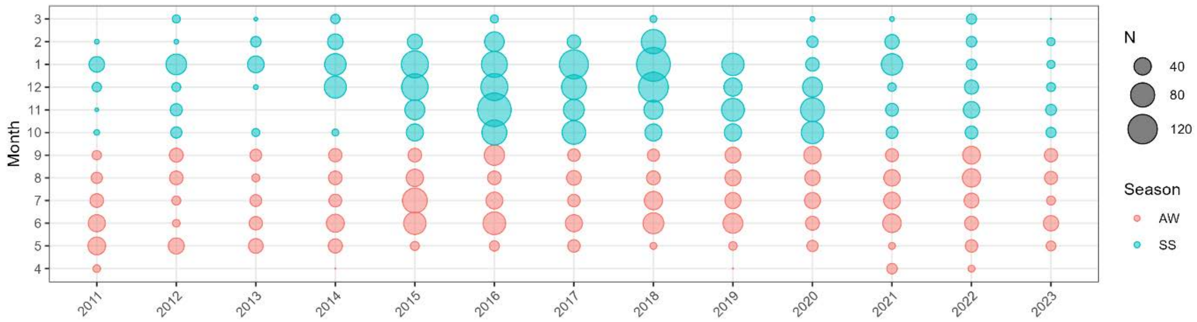


Figure A.2: Bubble plot of logbook (LB) effort by fishing year, season, and month, including only the fishing years included in the LB CPUE model.

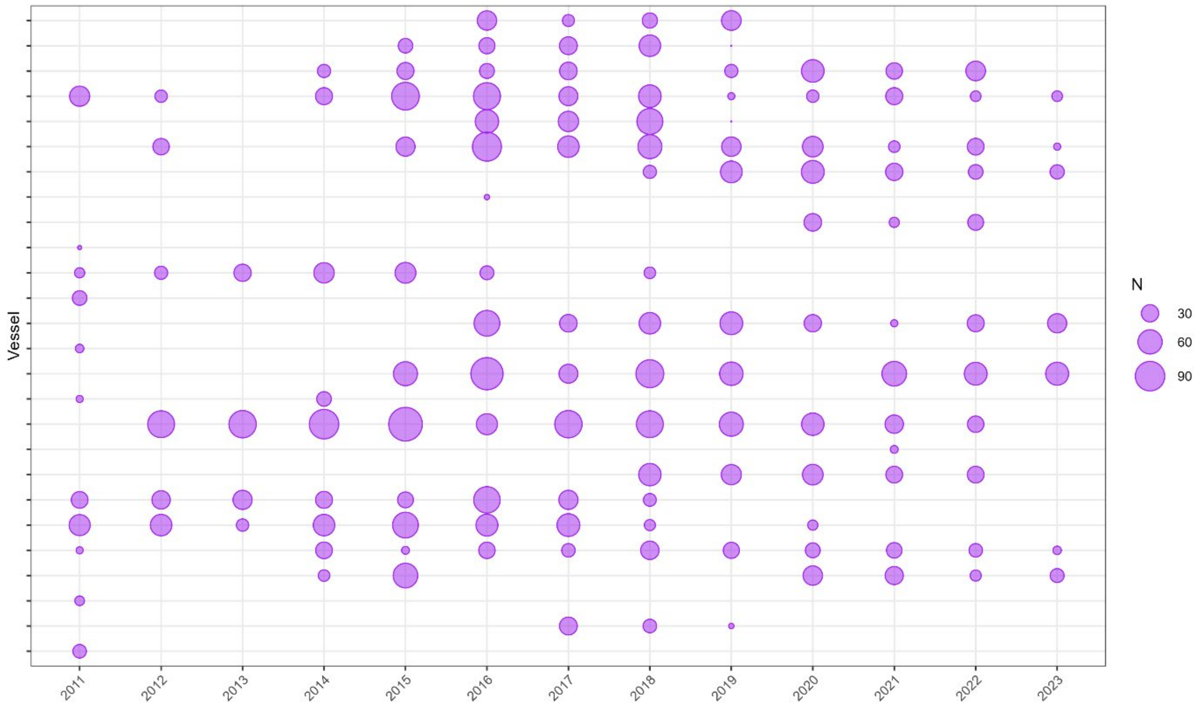


Figure A.3: Bubble plot of logbook (LB) effort by fishing year, season, and vessel, including only the fishing years included in the LB CPUE model.

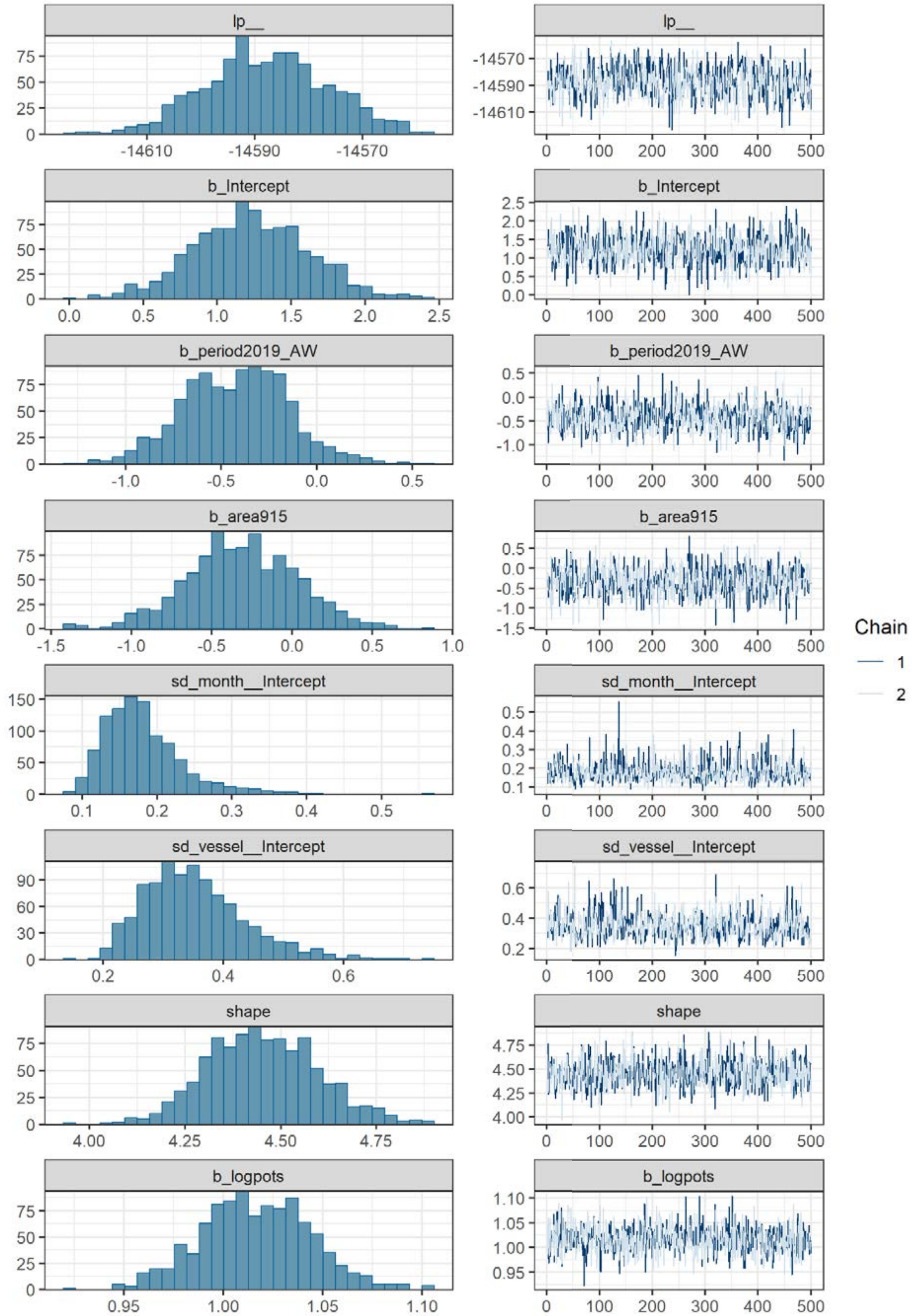


Figure A.4: Posterior densities (left) and MCMC trace plots (right) for a subset of model parameters from the logbook CPUE model.

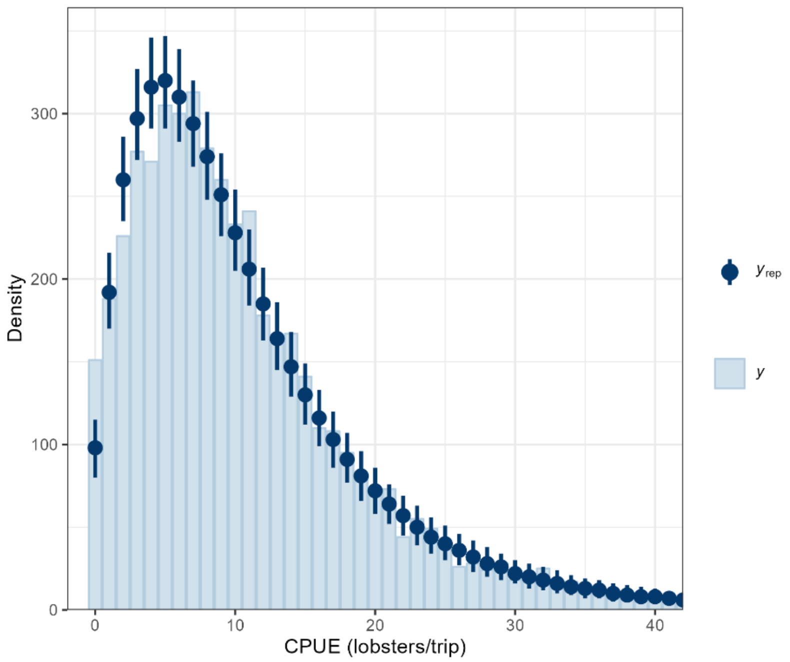


Figure A.5: Logbook CPUE model posterior predictive density overlay. In this plot, *y* is the density of the data (solid blue line) and *yrep* is the density of 100 draws of data from the posterior predictive distribution (points are medians and bars are the 50th percentiles).

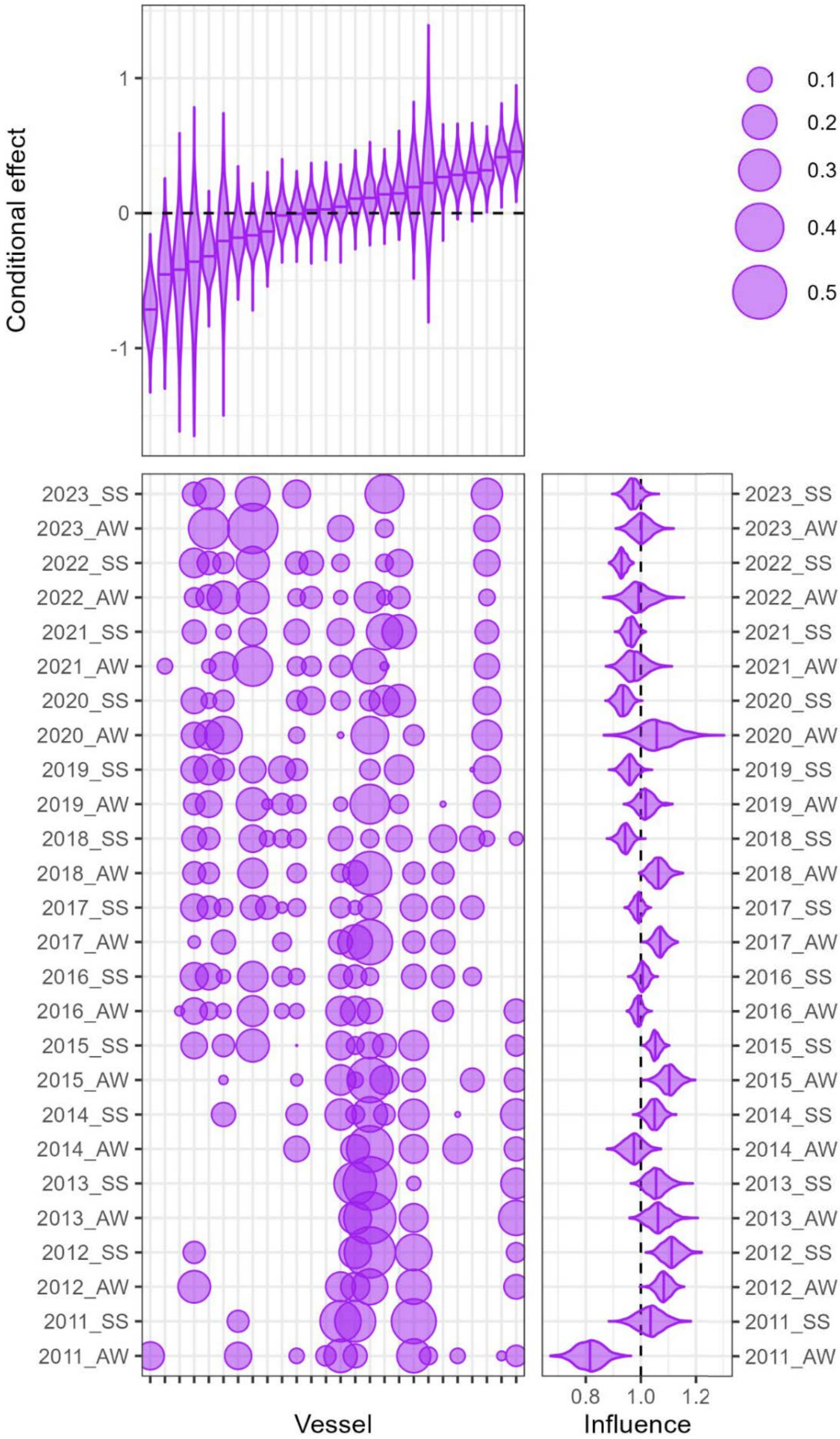


Figure A.6: Coefficient distribution influence plot for the explanatory variable vessel for the logbook CPUE model.

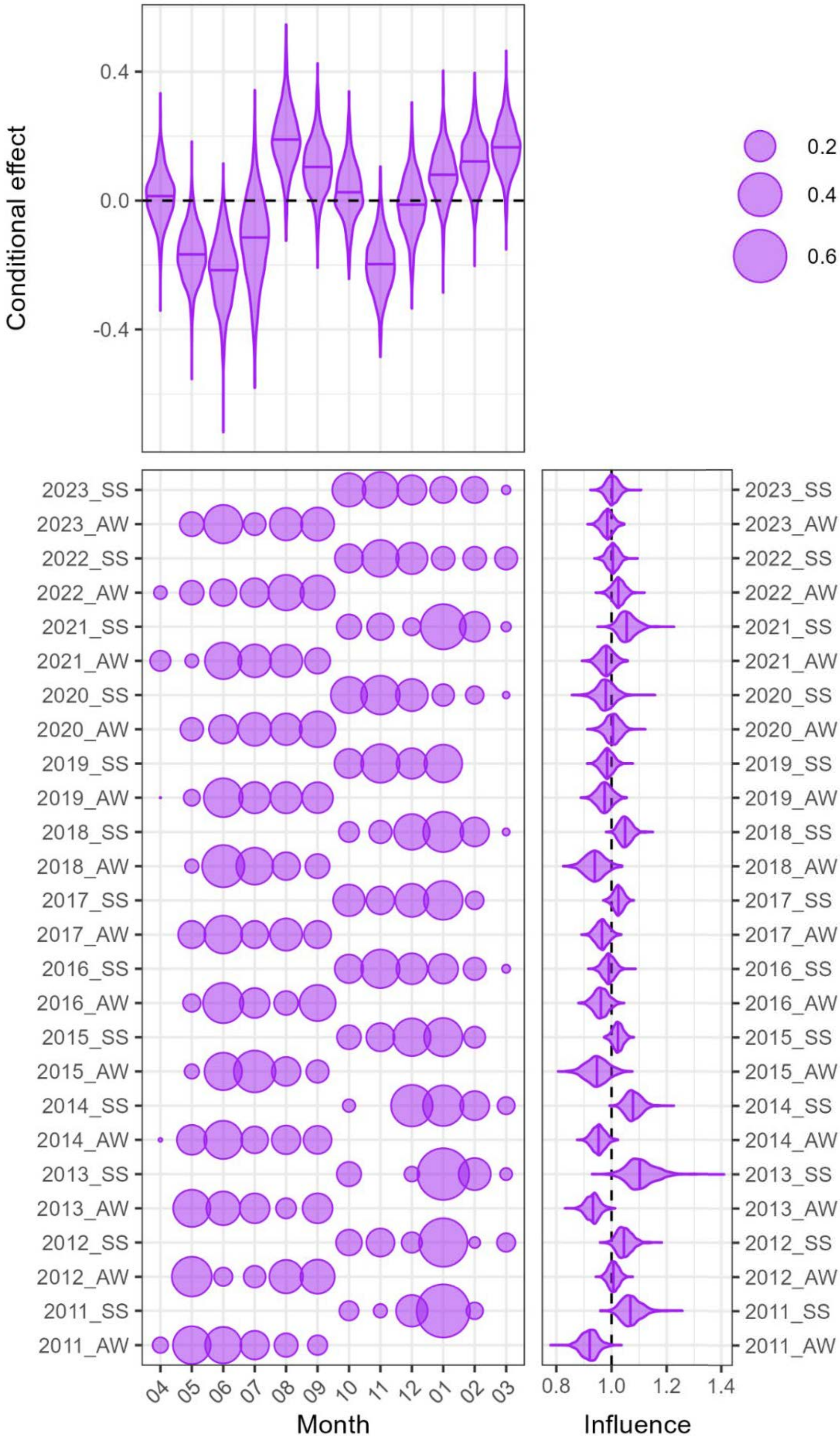


Figure A.7: Coefficient distribution influence plot for the explanatory variable month for the logbook CPUE model.

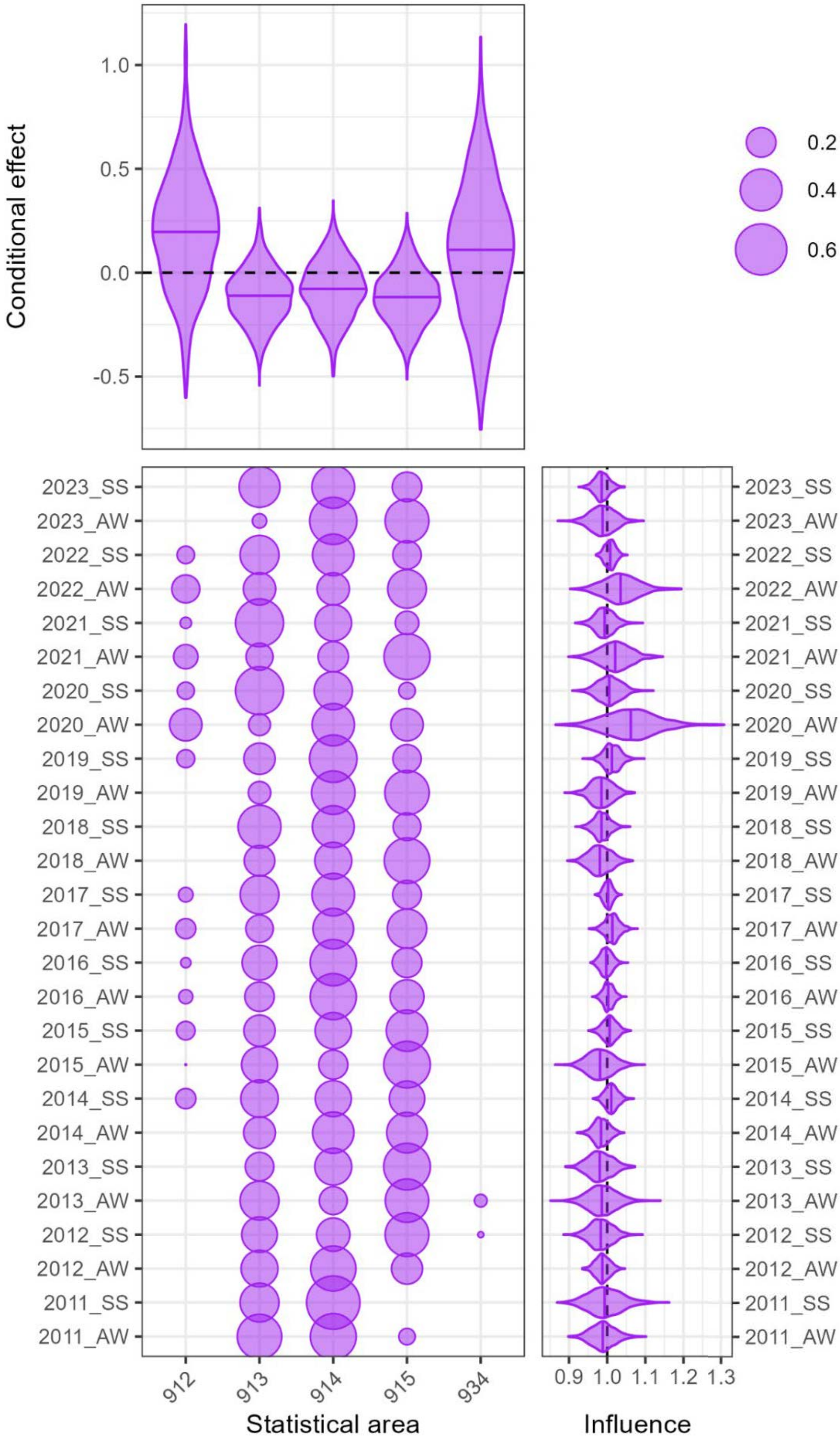


Figure A.8: Coefficient distribution influence plot for the explanatory variable statistical area for the logbook CPUE model.

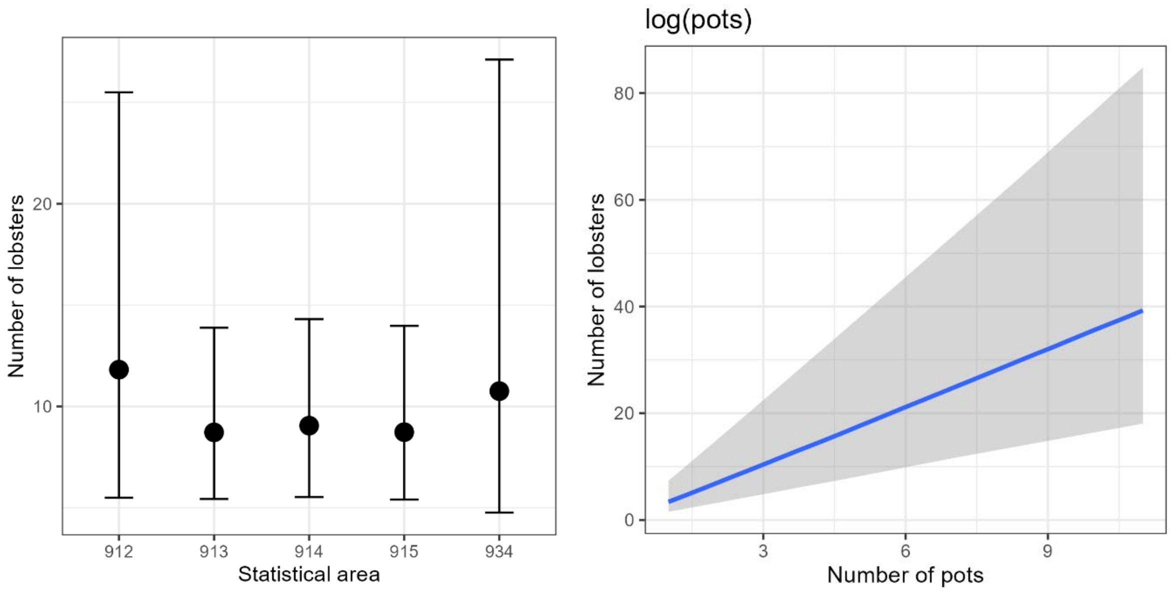


Figure A.9: Logbook CPUE model plot of the predicted number of lobsters in response to statistical area (left) and the number of pots (right). The prediction is represented by closed points (left) and the blue line (right); the 95% credible interval is represented by bars (left) and shaded area (right).

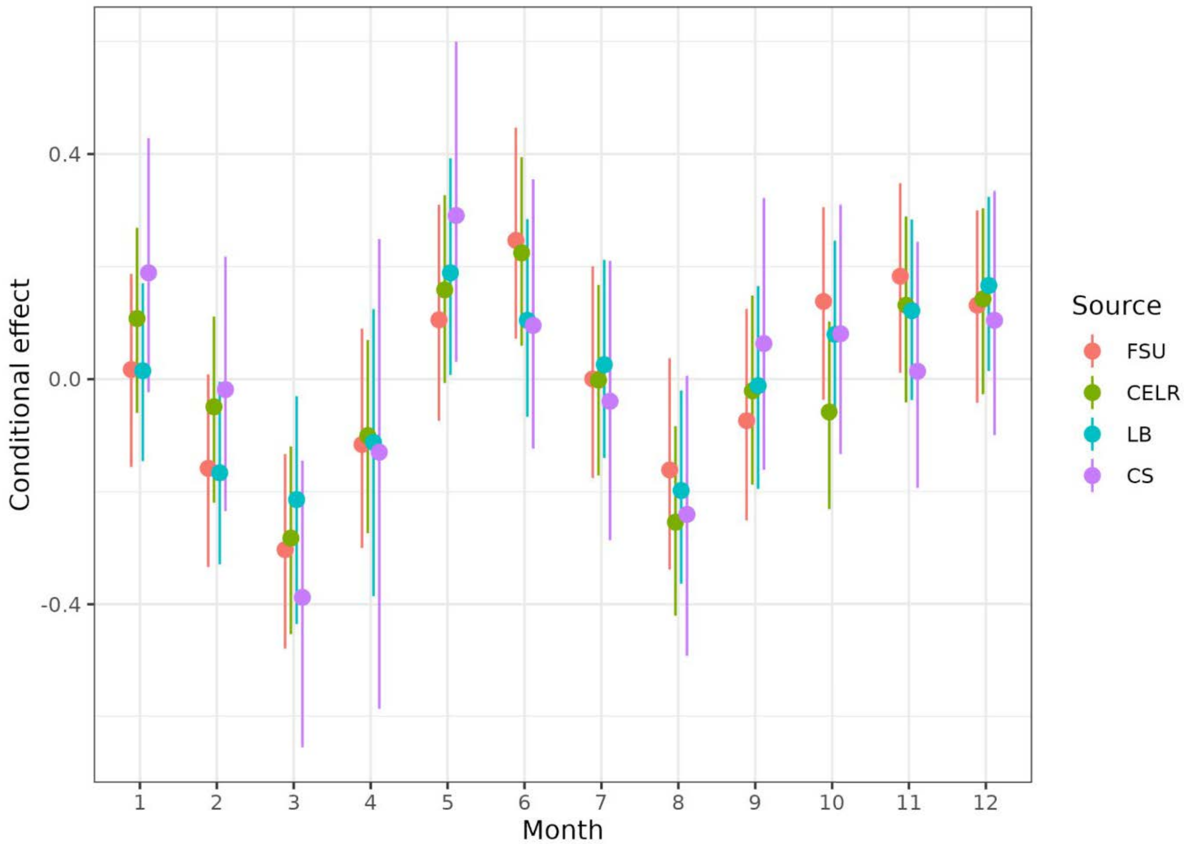


Figure A.10: The conditional effect of month comparing the FSU, CELR, logbook (LB), and catch sampling (CS) CPUE models. The prediction is represented by closed points; the 95% credible interval is represented by bars.

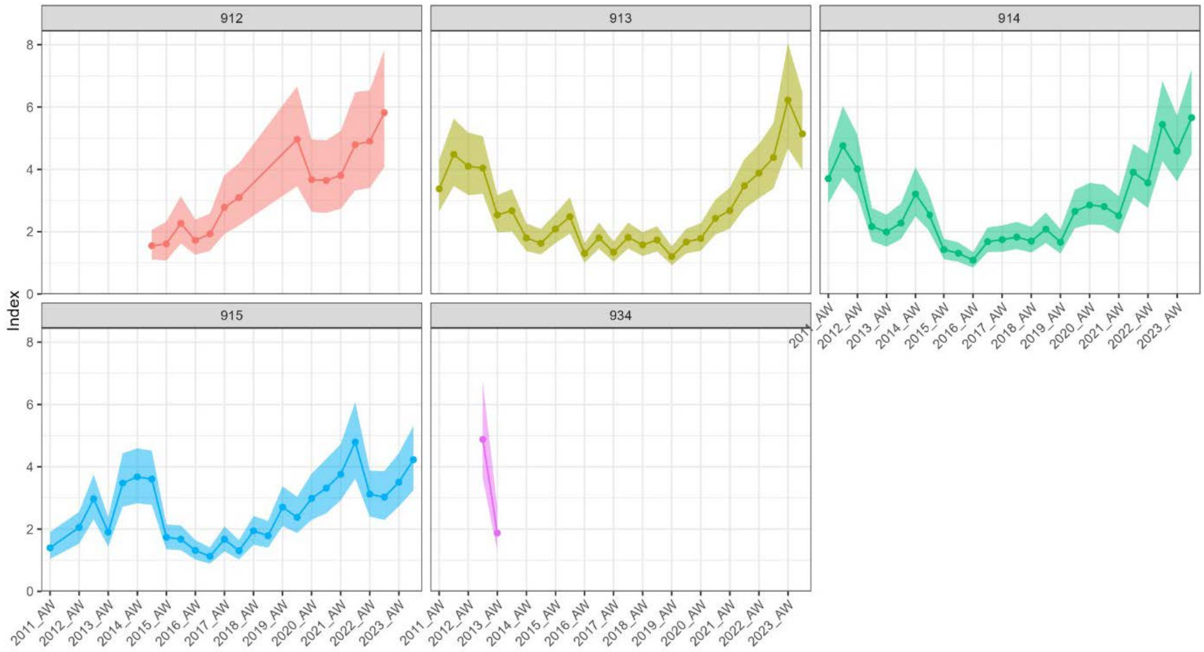


Figure A.11: Plot of the predicted CPUE index of the logbook CPUE model by statistical area. The prediction is represented by closed points; the 95% credible interval is represented by the shaded area.

Appendix B. CATCH SAMPLING CPUE DIAGNOSTICS

Table B.1: Summary of catch sampling (CS) effort in CRA 4 by fishing year and season ('AW' = autumn/winter, 'SS' = spring/summer) in terms of: the number of vessels, the number of pots, and the number of lobsters measured. Fishing years shaded grey were not included in the CS CPUE model.

	Vessels			Pots			Lobsters measured		
	SS	AW	Total	SS	AW	Total	SS	AW	Total
1986	2	–	2	177	–	177	552	–	552
1987	2	2	2	844	436	1 280	2 763	1 234	3 997
1988	3	4	4	432	848	1 280	1 910	2 873	4 783
1989	4	3	5	1 220	1 422	2 642	4 440	3 735	8 175
1990	5	3	5	2 662	1 459	4 121	17 185	7 682	24 867
1991	3	1	3	1 949	335	2 284	15 572	3 043	18 615
1992	2	2	3	2 001	202	2 203	15 588	1 556	17 144
1993	2	1	2	1 973	112	2 085	9 605	1 120	10 725
1994	3	1	4	1 055	195	1 250	4 605	2 640	7 245
1995	4	1	4	1 428	206	1 634	7 483	2 428	9 911
1996	–	5	5	–	711	711	–	4 631	4 631
1997	–	12	12	–	4 220	4 220	–	34 479	34 479
1998	–	11	11	–	3 053	3 053	–	18 873	18 873
1999	–	10	10	–	2 538	2 538	–	12 303	12 303
2000	–	11	11	–	2 717	2 717	–	17 487	17 487
2001	5	13	13	776	3 077	3 853	3 596	16 822	20 418
2002	4	14	17	627	3 707	4 334	2 939	17 586	20 525
2003	5	16	19	659	3 702	4 361	3 473	15 107	18 580
2004	9	15	17	1 447	2 772	4 219	9 024	13 337	22 361
2005	14	10	16	3 570	1 840	5 410	16 876	9 557	26 433
2006	13	10	15	3 304	2 361	5 665	13 848	8 755	22 603
2007	13	9	16	2 537	2 481	5 018	12 185	7 506	19 691
2008	15	7	17	2 944	1 047	3 991	16 154	4 345	20 499
2009	10	8	13	2 175	1 743	3 918	11 954	6 230	18 184
2010	10	12	14	1 681	2 162	3 843	9 631	8 025	17 656
2011	10	12	14	1 798	2 220	4 018	7 227	11 626	18 853
2012	10	13	17	2 096	3 055	5 151	10 206	12 717	22 923
2013	11	12	15	3 019	2 601	5 620	14 171	8 429	22 600
2014	12	7	14	2 222	2 120	4 342	7 770	8 283	16 053
2015	14	8	14	3 104	1 818	4 922	9 071	5 994	15 065
2016	14	10	17	2 679	1 296	3 975	8 348	3 720	12 068
2017	14	7	16	3 050	1 101	4 151	13 321	2 976	16 297
2018	14	10	18	2 718	1 716	4 434	8 920	4 969	13 889
2019	12	7	16	2 688	1 141	3 829	11 668	3 389	15 057
2020	13	7	17	3 343	1 580	4 923	16 181	5 509	21 690
2021	14	6	17	3 493	1 100	4 593	18 266	5 176	23 442
2022	9	10	15	2 325	1 810	4 135	17 430	11 675	29 105
2023	7	6	10	2 884	1 108	3 992	16 617	5 136	21 753

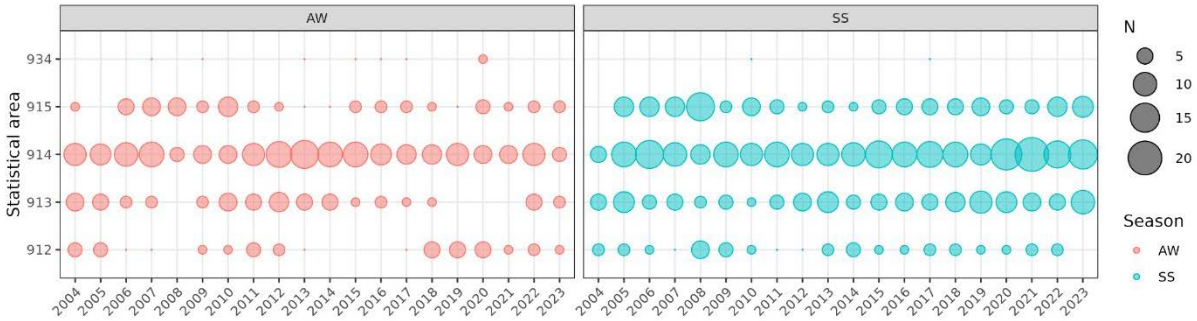


Figure B.1: Bubble plot of catch sampling (CS) effort by fishing year, season, and statistical area, including only the fishing years included in the CS CPUE model.

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

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

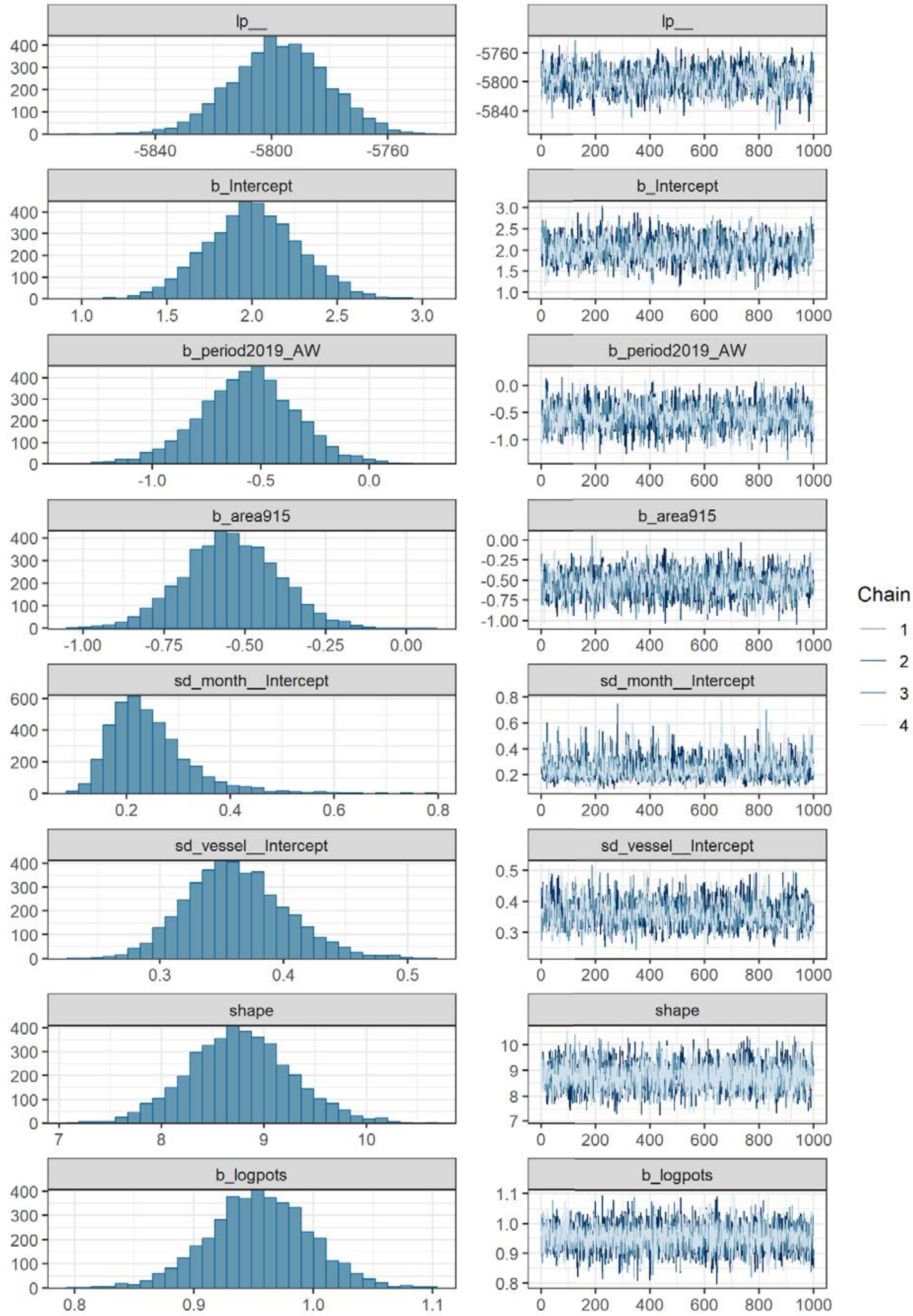


Figure B.4: Posterior densities (left) and MCMC trace plots (right) for a subset of model parameters from the catch sampling CPUE model.

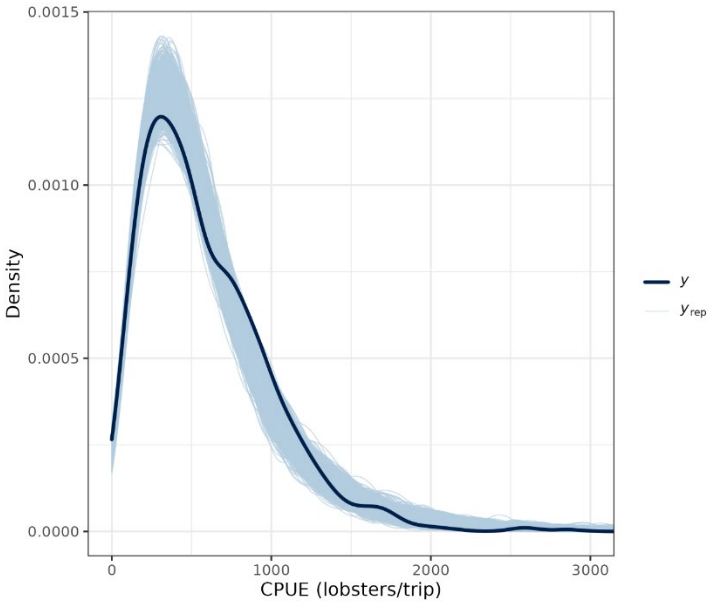


Figure B.5: Catch sampling CPUE model posterior predictive density overlay. In this plot, *y* is the density of the data (solid blue line) and *yrep* is the density of 100 draws of data from the posterior predictive distribution.

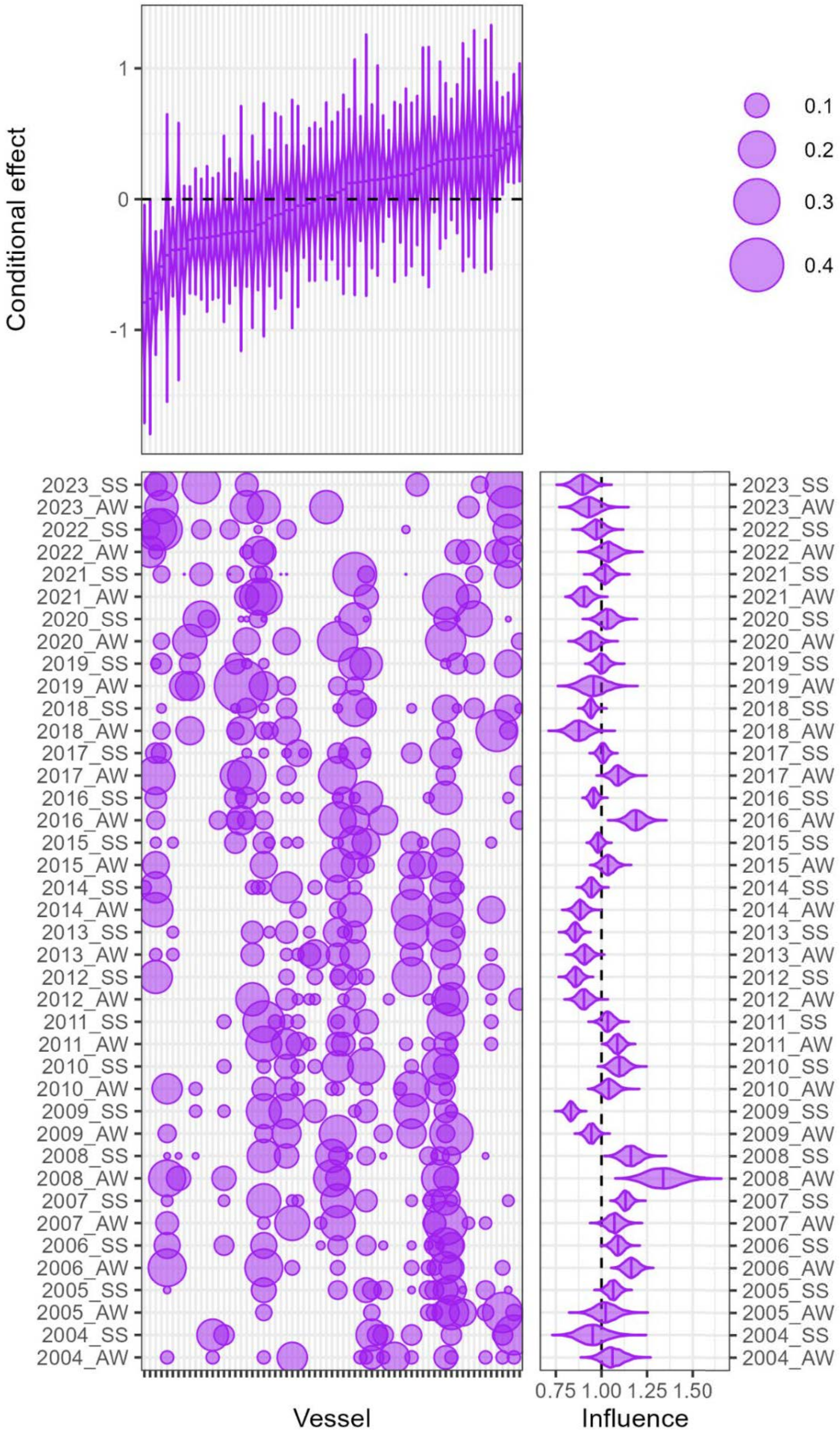


Figure B.6: Coefficient distribution influence plot for the explanatory variable vessel for the catch sampling CPUE model.

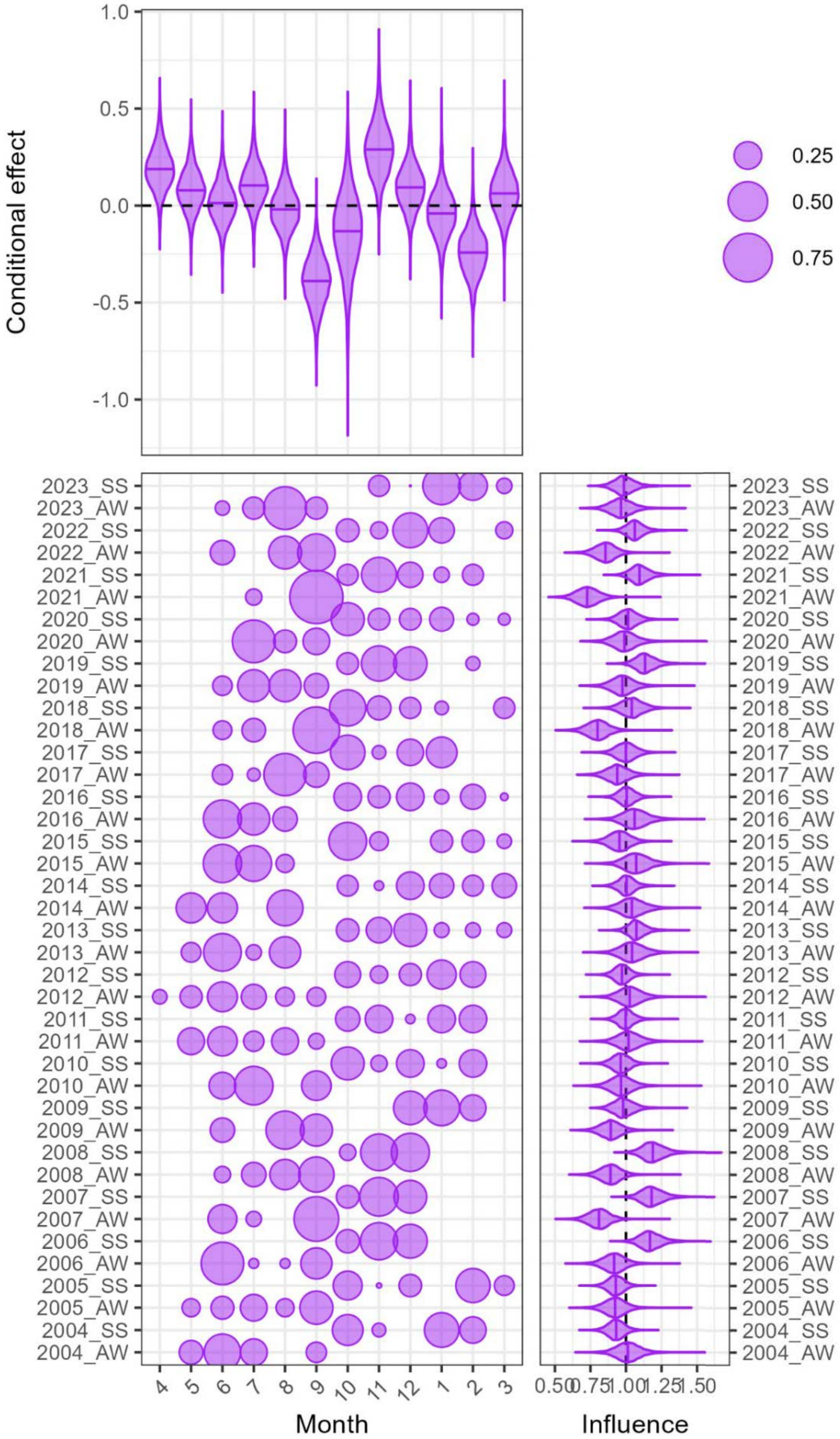


Figure B.7: Coefficient distribution influence plot for the explanatory variable month for the catch sampling CPUE model.

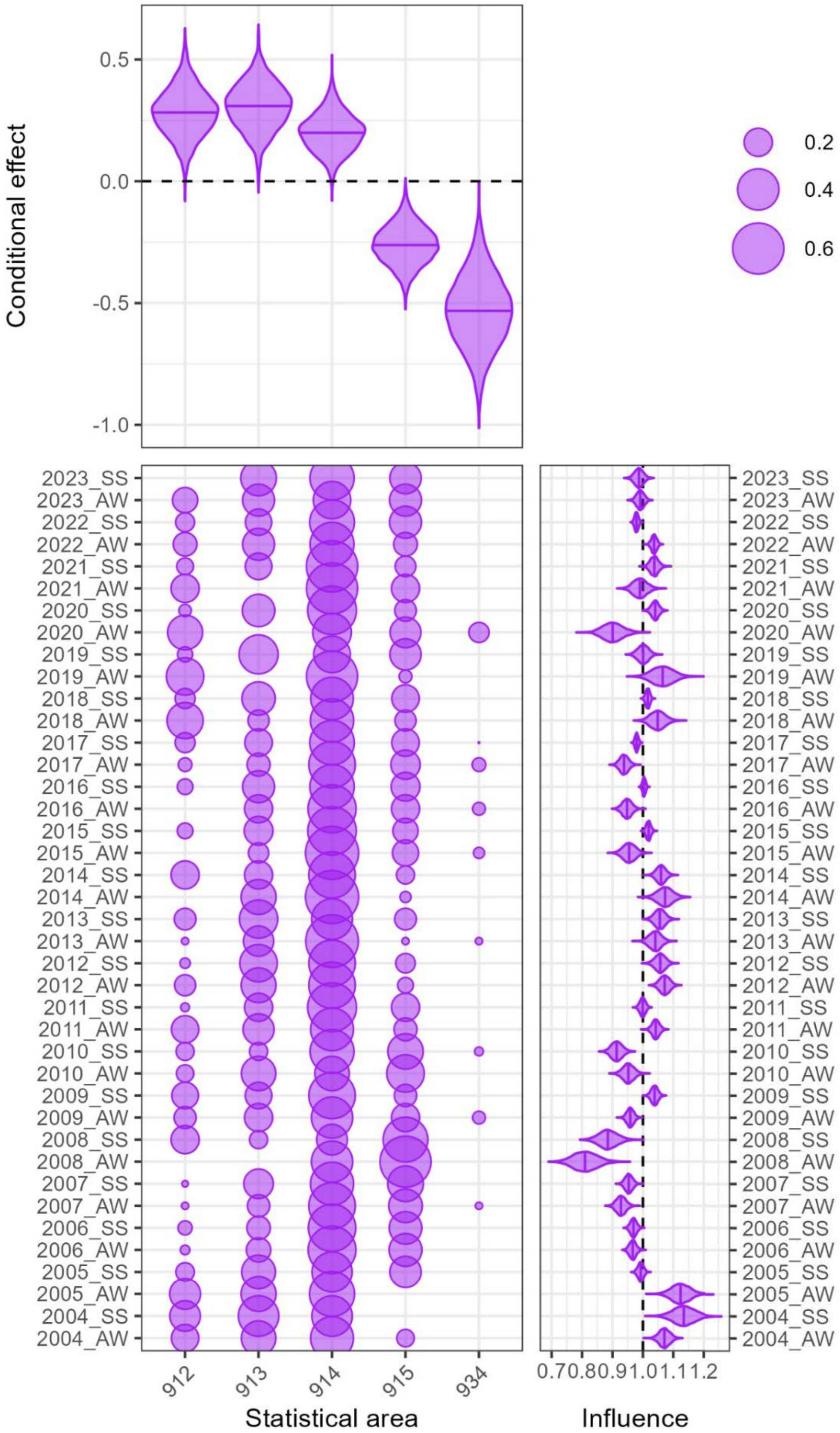


Figure B.8: Coefficient distribution influence plot for the explanatory variable statistical area for the catch sampling CPUE model.

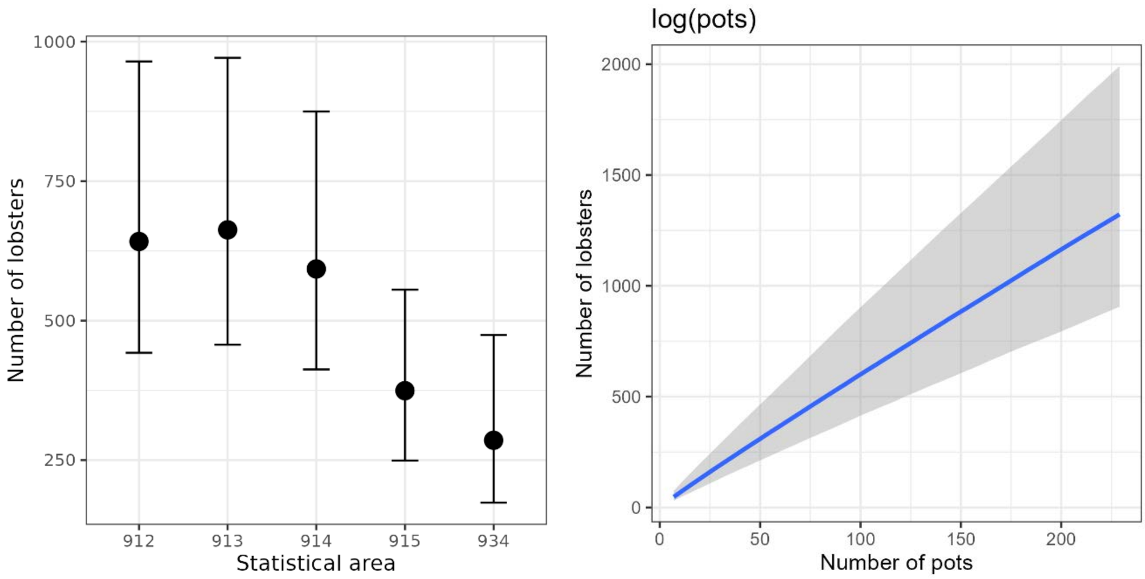


Figure B.9: Catch sampling CPUE model plot of the predicted number of lobsters in response to statistical area (left) and the number of pots (right). The prediction is represented by closed points (left) and the blue line (right); the 95% credible interval is represented by bars (left) and shaded area (right).

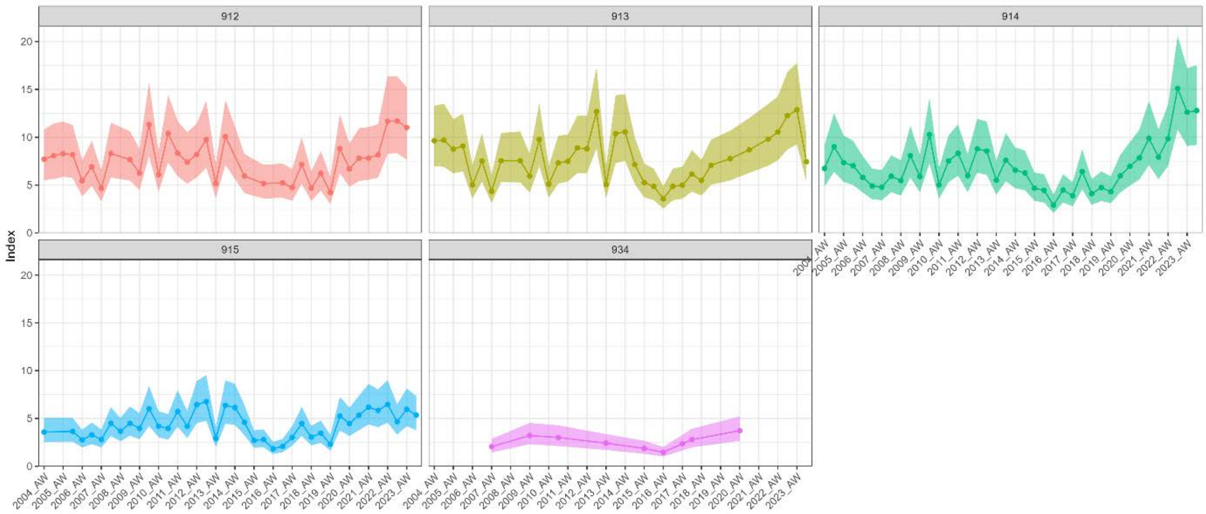


Figure B.10: Plot of the predicted CPUE index of the catch sampling CPUE model by statistical area. The prediction is represented by closed points; the 95% credible interval is represented by the shaded area.

Appendix C. CATCH COMPOSITION ANALYSIS

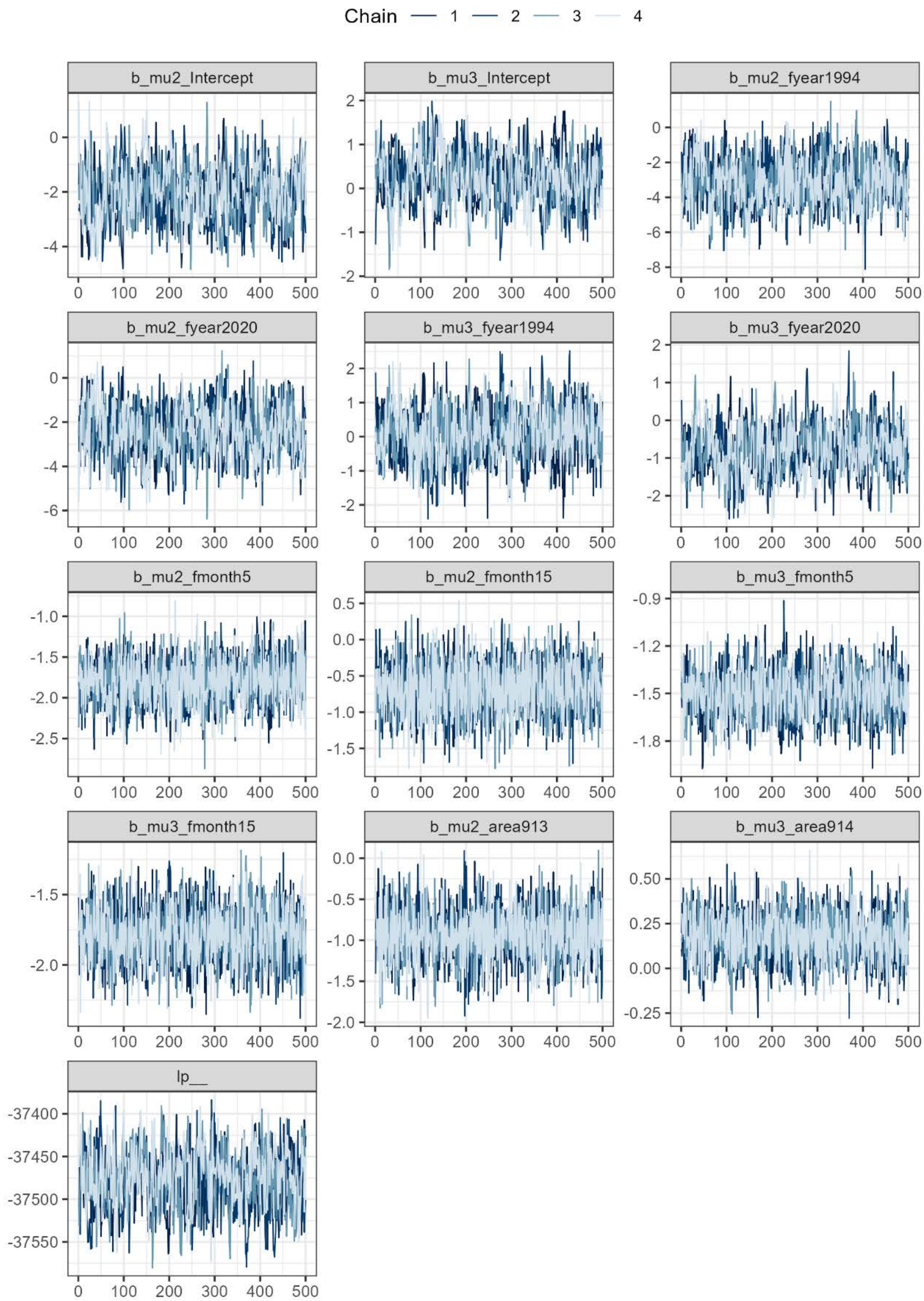


Figure C.1: MCMC trace plots for a subset of model parameters from the sex ratio model.

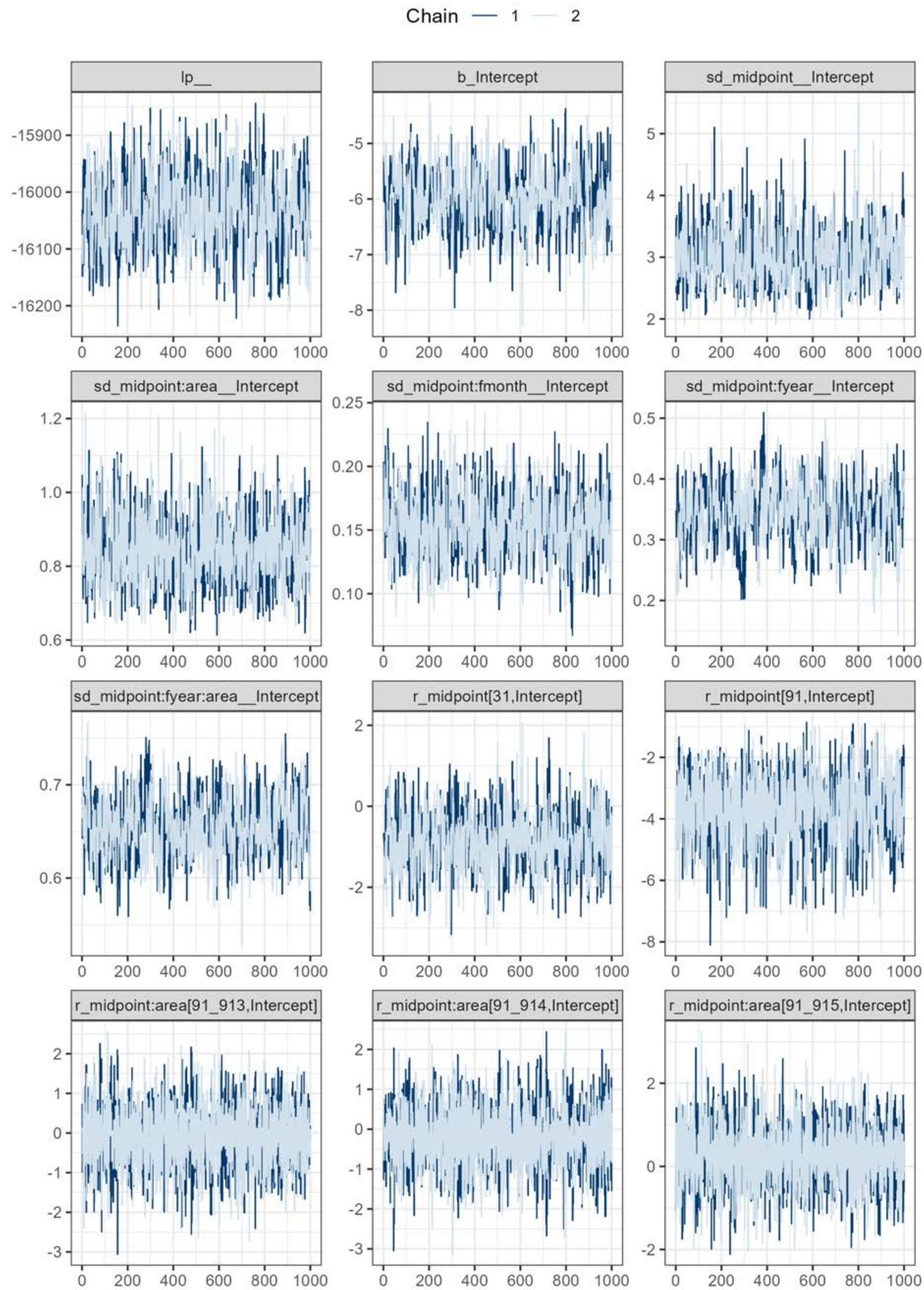


Figure C.2: MCMC trace plots for a subset of model parameters from the immature female LF model.

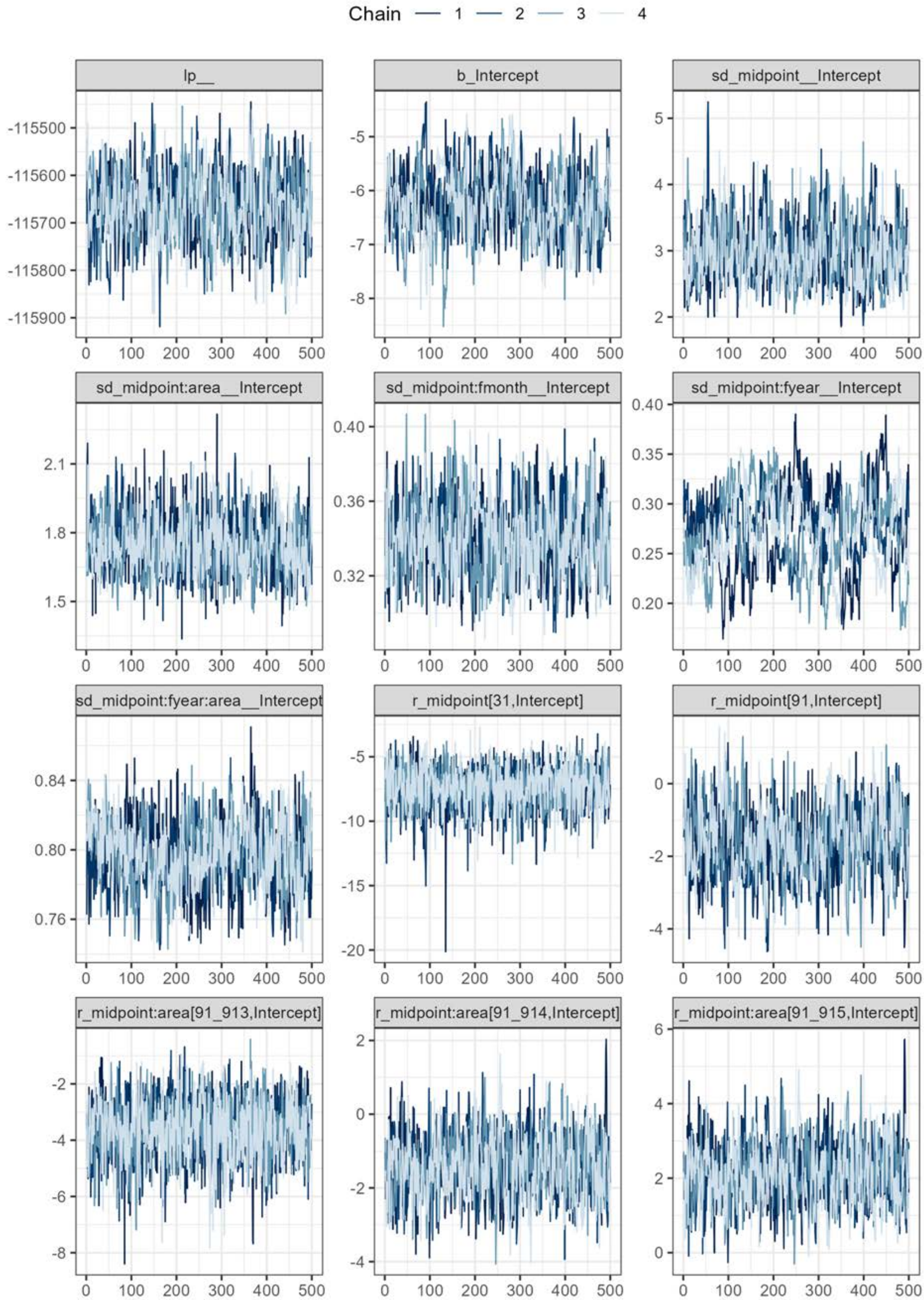


Figure C.3: MCMC trace plots for a subset of model parameters from the mature female LF model.

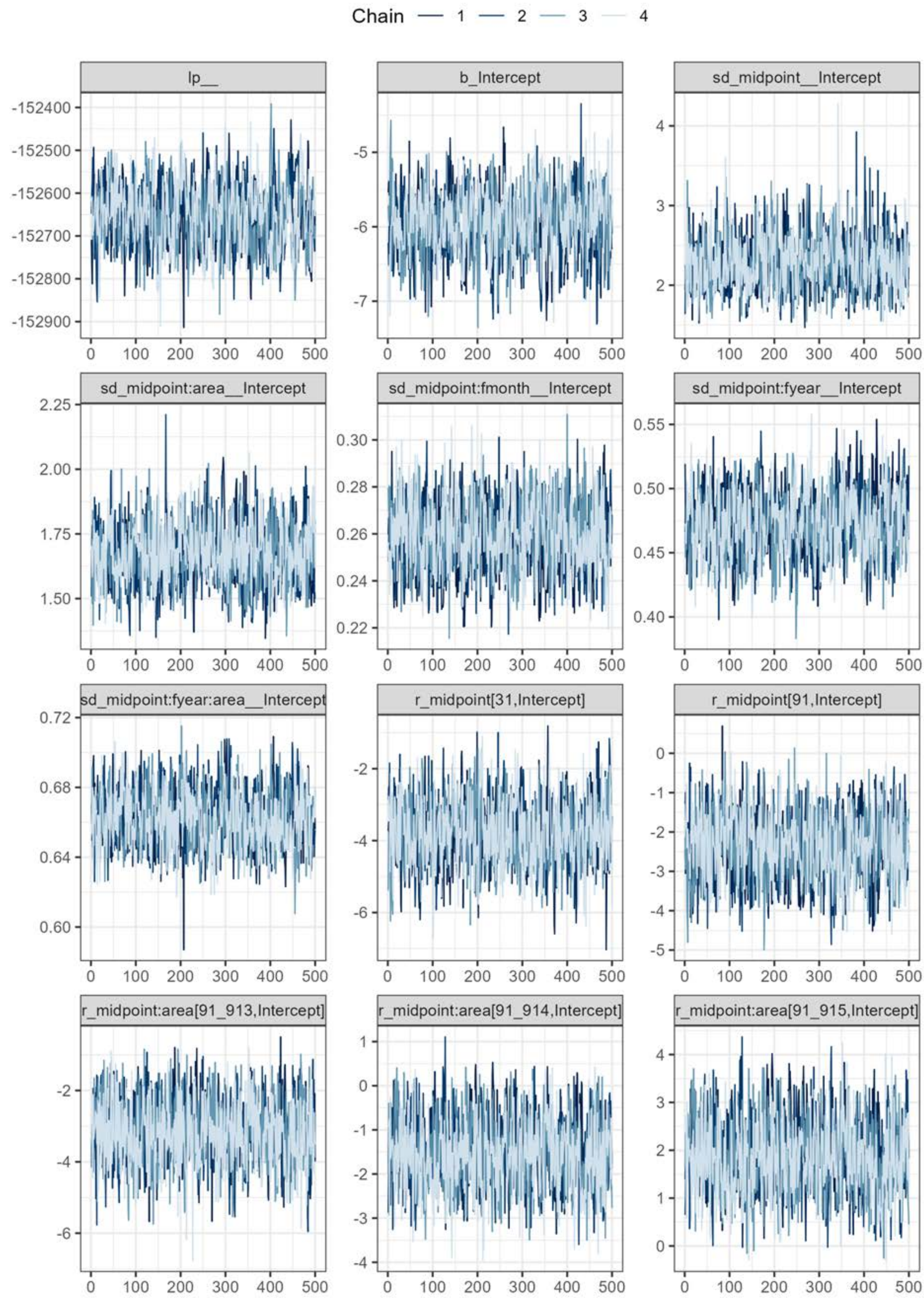


Figure C.4: MCMC trace plots for a subset of model parameters from the male LF model.

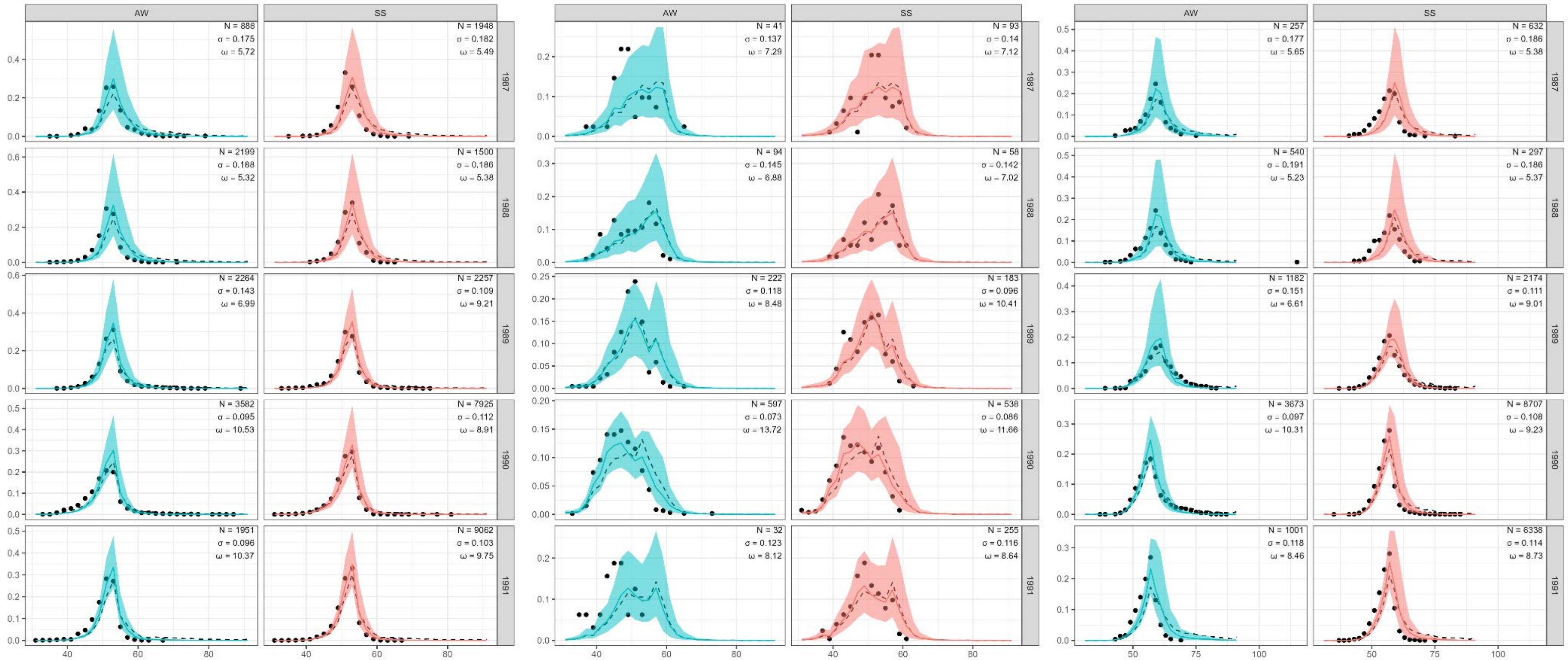


Figure C.5: CRA 4 LFs by fishing year (from 1987 to 1991), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.

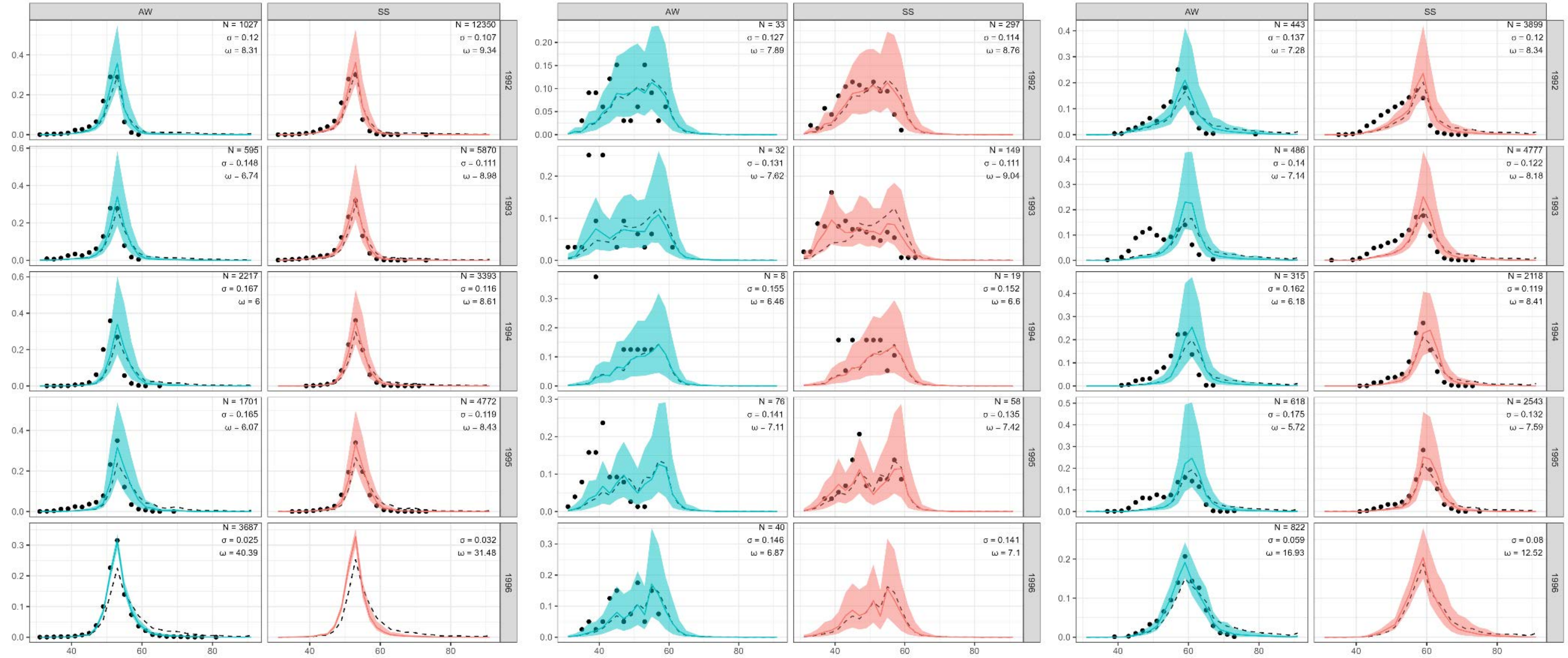


Figure C.6: CRA 4 LFs by fishing year (from 1992 to 1996), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.

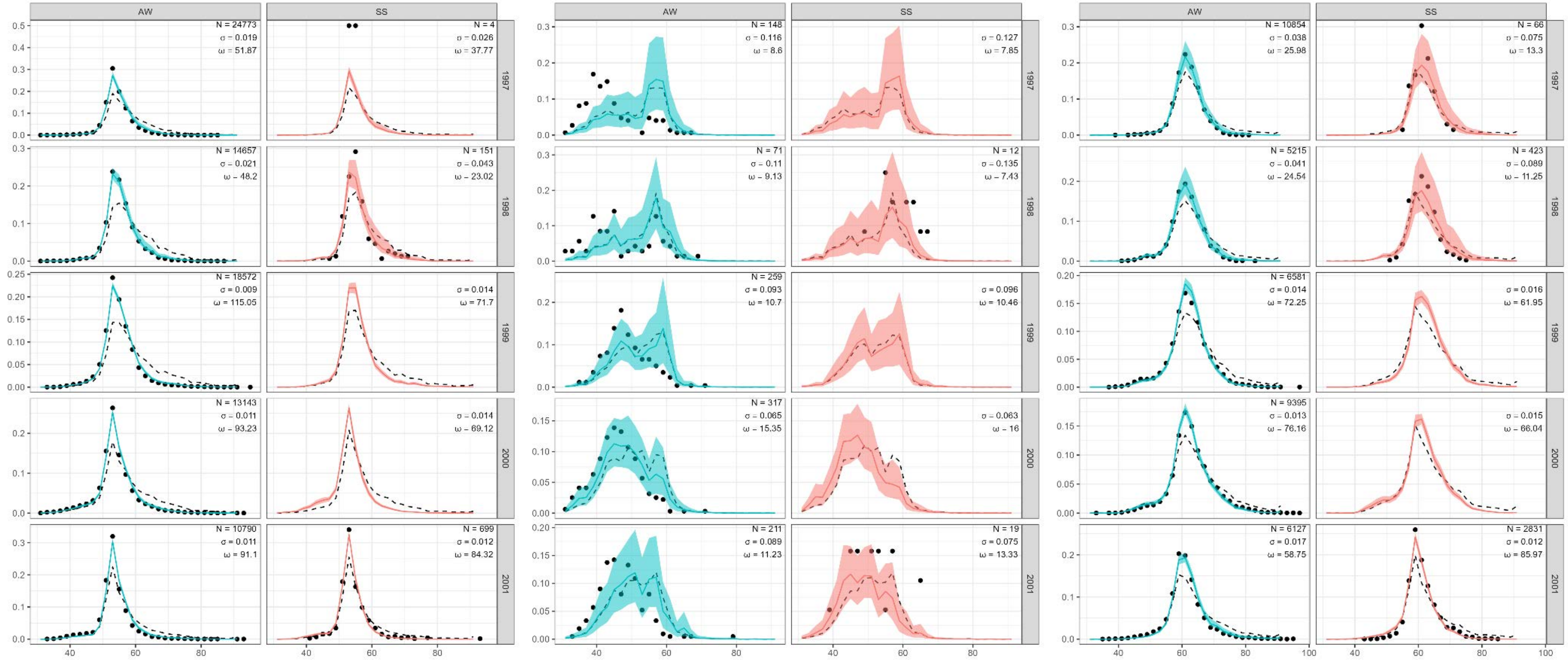


Figure C.7: **CRA 4 LFs by fishing year (from 1997 to 2001), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.**

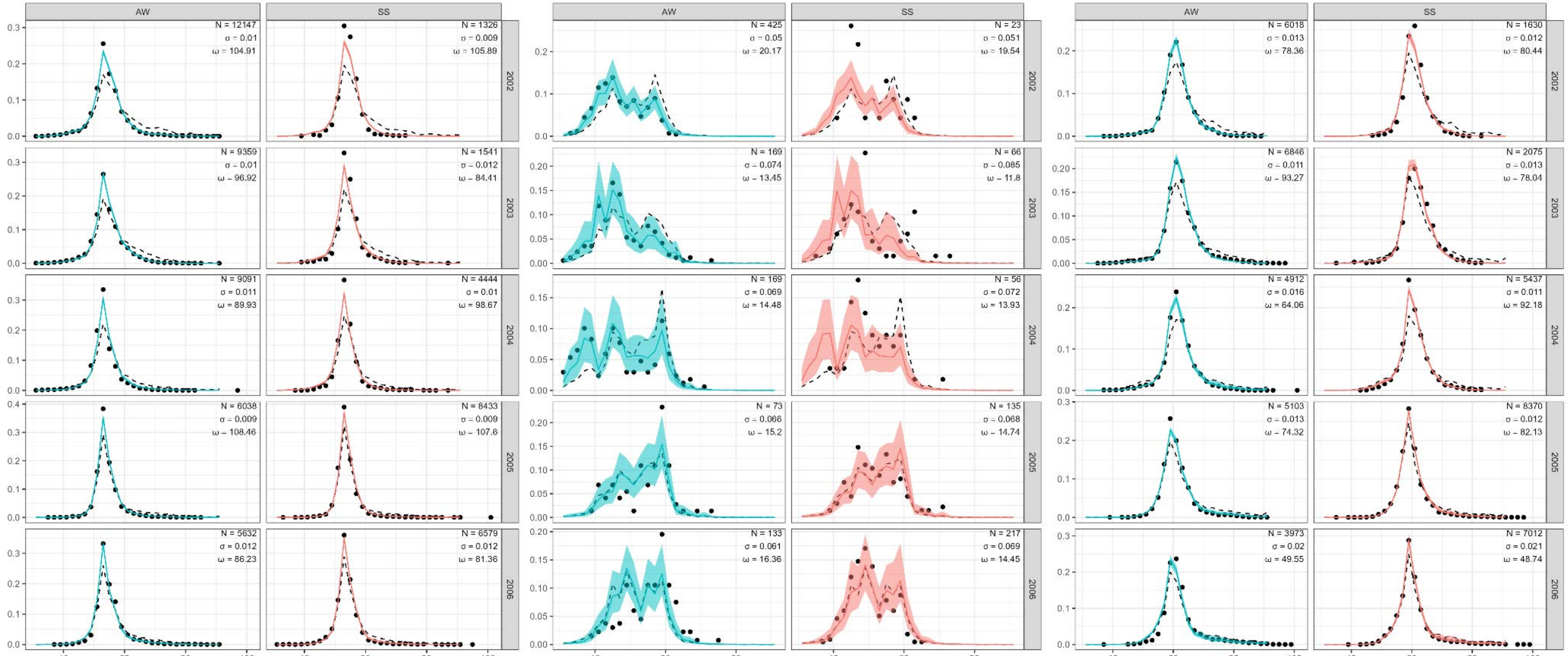


Figure C.8: CRA 4 LFs by fishing year (from 2002 to 2006), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.

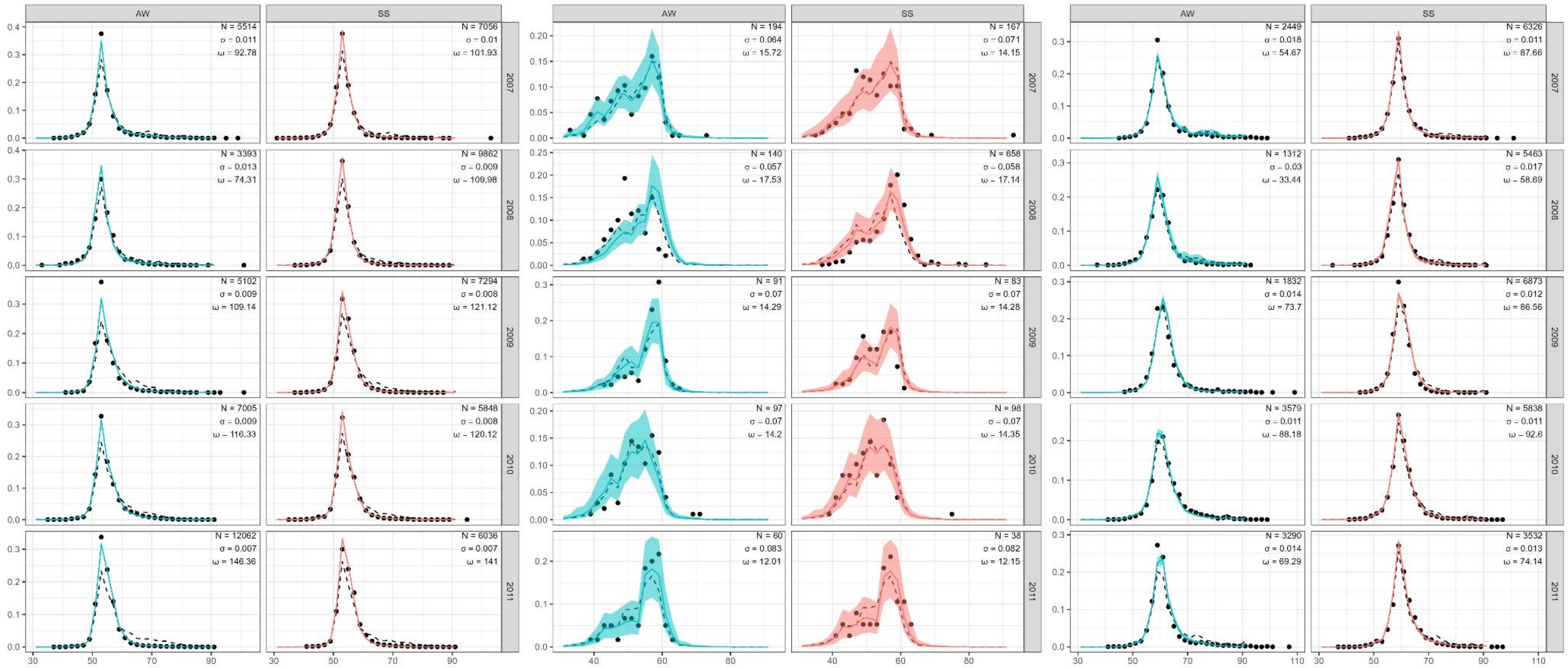


Figure C.9: CRA 4 LFs by fishing year (from 2007 to 2011), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.

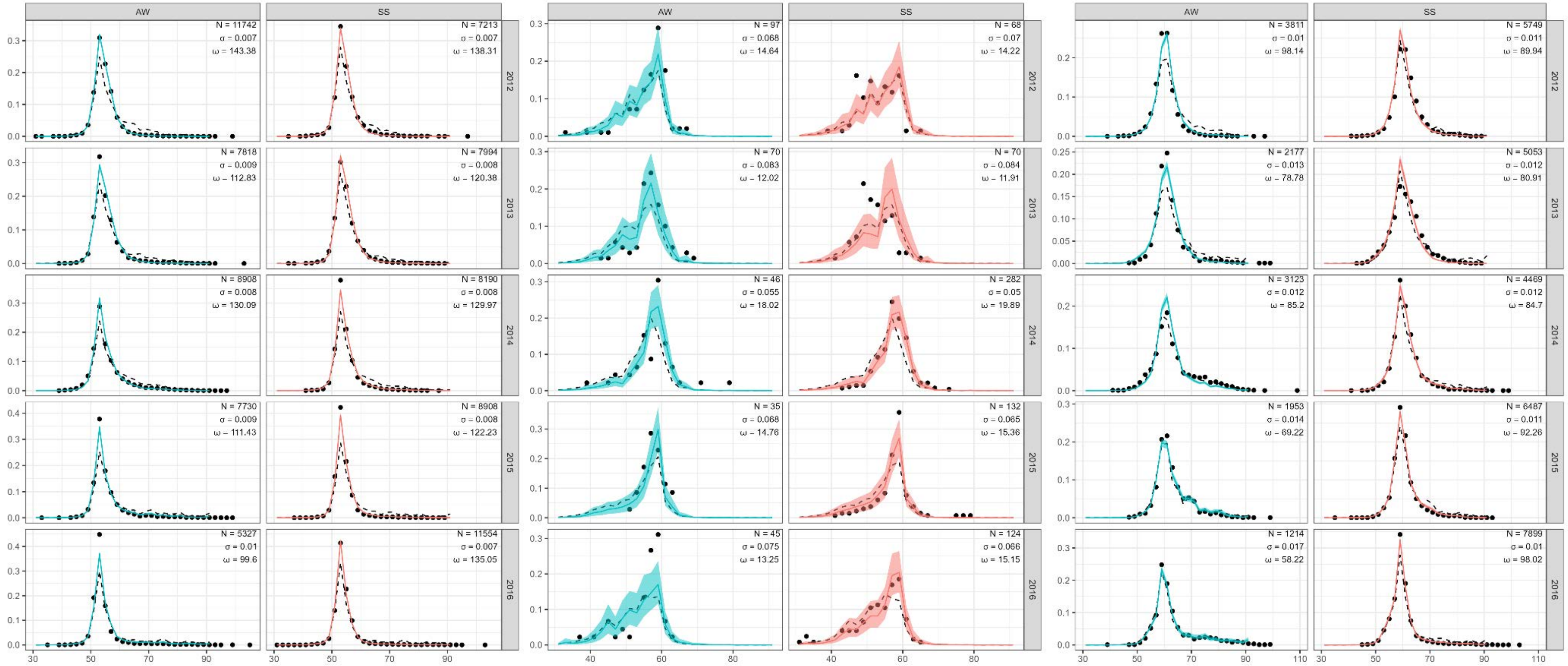


Figure C.10: CRA 4 LFs by fishing year (from 2012 to 2016), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.

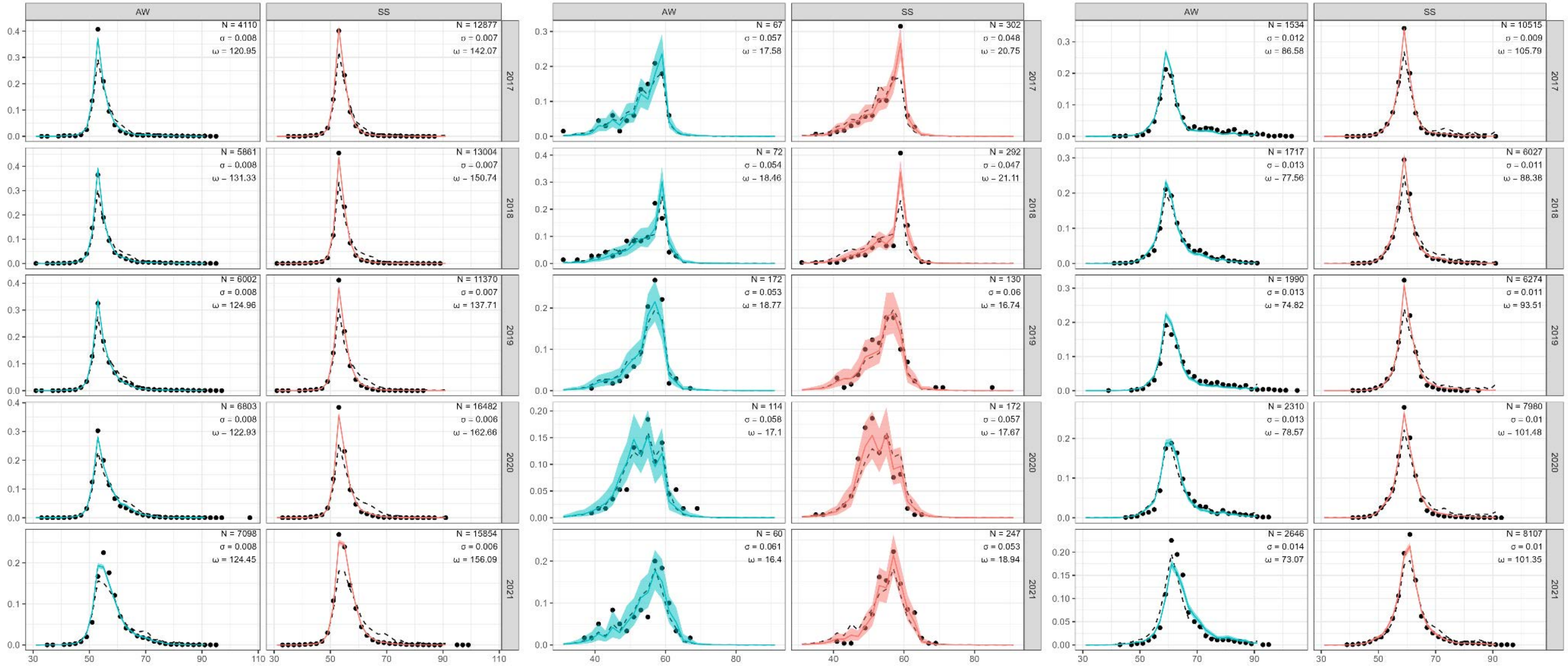


Figure C.11: CRA 4 LFs by fishing year (from 2017 to 2021), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.

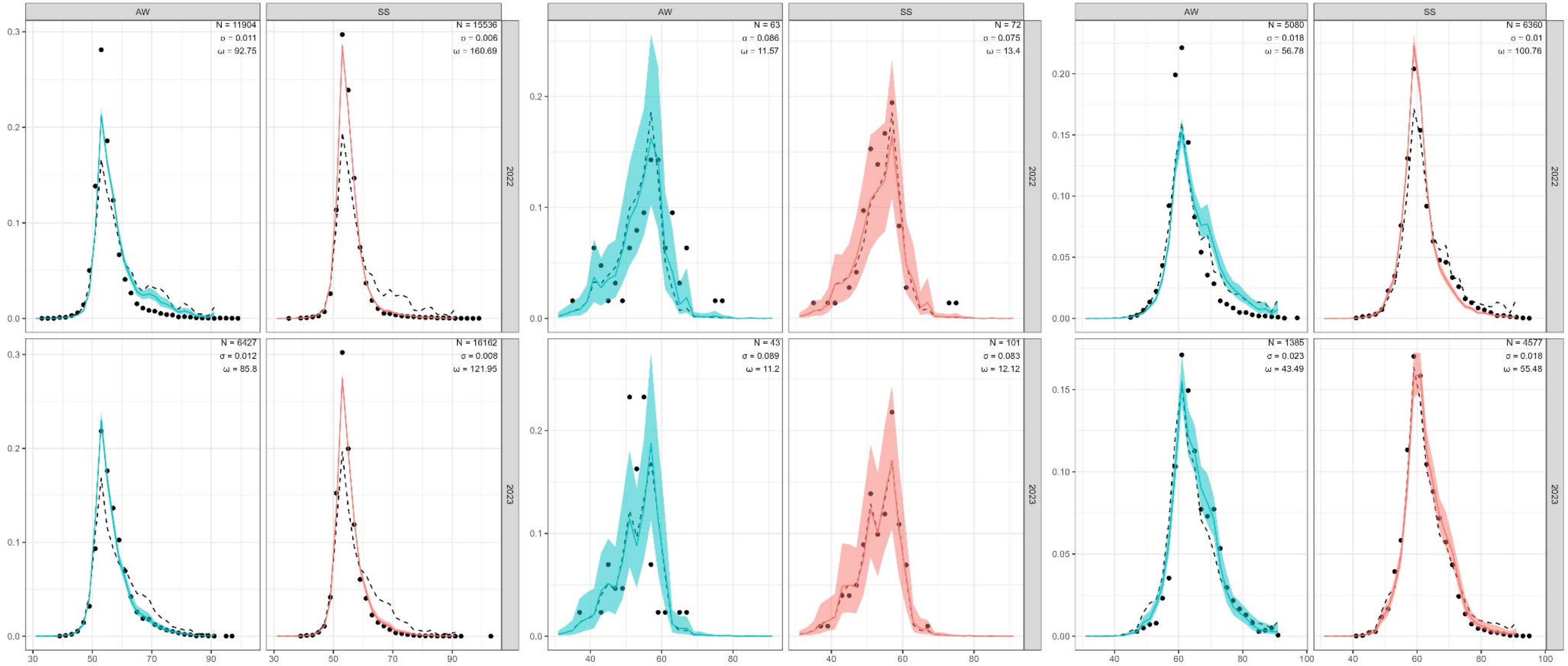


Figure C.12: CRA 4 LFs by fishing year (from 2022 to 2023), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex (males left panel, immature females middle panel, and mature females right panel). The solid line is the mean and the shaded region is the 95% credible interval of the scaled LF distributions. The aggregated data (points) and unscaled predictions of the LF (dashed line) for the same stratum are also shown. Each panel also includes text which provides: the number of lobsters measured; the SD of the predicted LF for each stratum; and the data set weight for each stratum.

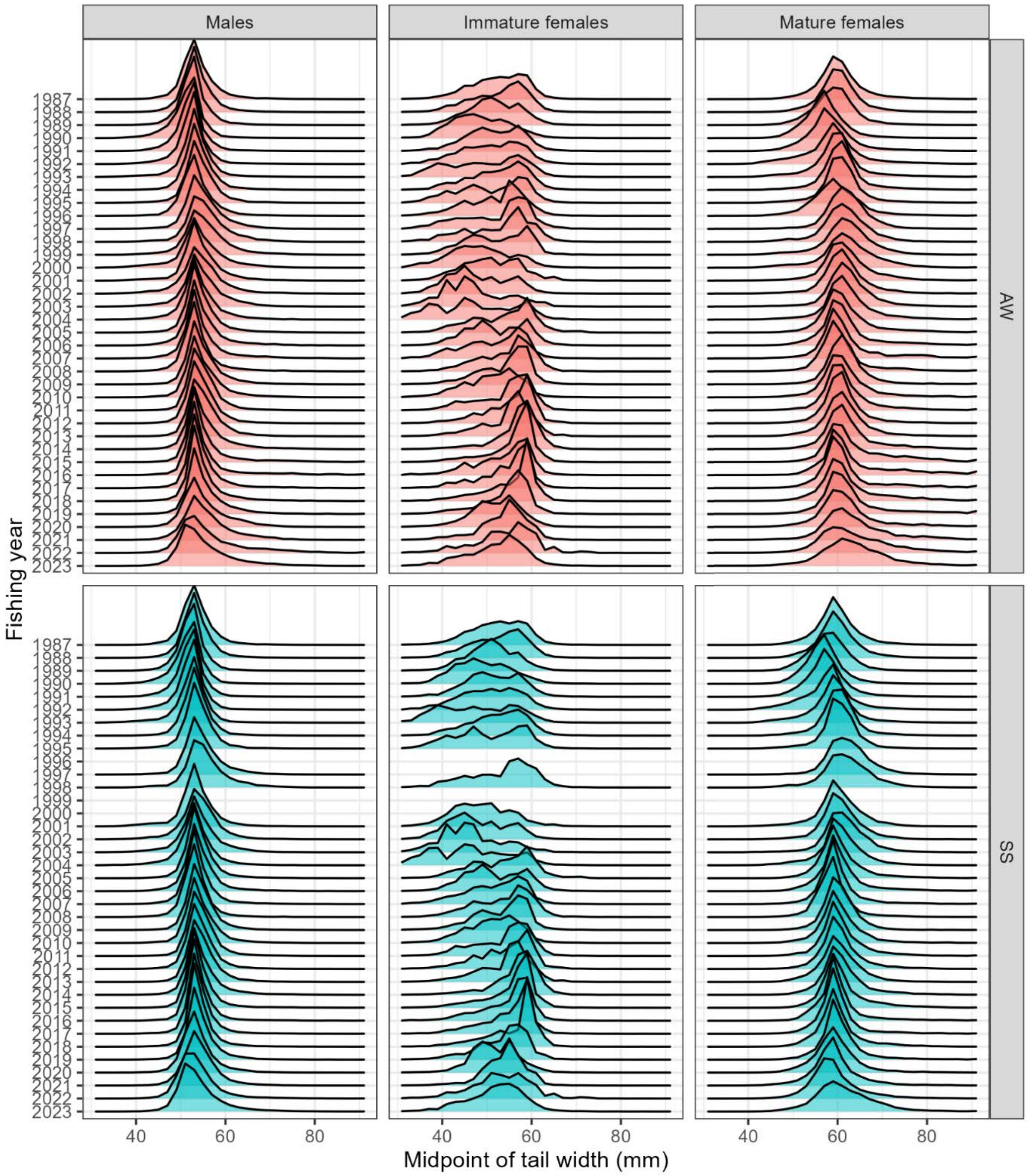


Figure C.13: Expected standardised LFs using the uncorrected TW data, by fishing year (from 1987 to 2023), season (AW = autumn/winter, SS = spring/summer), TW bin, and sex.

Appendix D. TAG RECAPTURE DATA

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

Project ID	Previous	Current	Difference
CRA_Akaroa	227	227	–
CRA_CCampb	44	44	–
CRA_Gis70s	2240	2240	–
CRA_Gisb	48	48	–
CRA_ReefPt	573	573	–
CRA_StewIs	1614	1614	–
CRA01Gisb	1179	1179	–
CRA1_TAG	1647	1694	47
CRA2_EBOP	5	5	–
CRA2_TAG	4776	4840	64
CRA2_WBOP	268	268	–
CRA3_TAG	2190	2184	-6
CRA4_TAG	3138	3137	-1
CRA4_Wair	10	10	–
CRA5_Kaik	1176	1176	–
CRA5_TAG	6107	6107	–
CRA6_TAG	250	270	20
CRA7_TAG	703	722	19
CRA7rs	202	202	–
CRA8_Fiord	1714	1714	–
CRA8_TAG	7419	7393	-26
CRA8rs	233	233	–
CRA9_TAG	127	127	–
Total	35 890	36 007	117

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

Calendar year	Previous	Current	Difference	Calendar year	Previous	Current	Difference
1966	53	53	–	1999	2 486	2 486	–
1967	28	28	–	2000	1 585	1 585	–
1968	7	7	–	2001	1 377	1 377	–
1969	2	2	–	2002	1 571	1 571	–
1971	1	1	–	2003	1 121	1 121	–
1975	115	115	–	2004	2 079	2 079	–
1976	1 268	1 268	–	2005	2 386	2 386	–
1977	2 091	2 091	–	2006	975	975	–
1978	886	886	–	2007	482	481	-1
1979	1 081	1 081	–	2008	366	366	–
1980	1 112	1 112	–	2009	304	304	–
1981	593	593	–	2010	237	237	–
1982	332	332	–	2011	548	548	–
1983	273	273	–	2012	425	425	–
1984	1 071	1 071	–	2013	510	510	–
1985	394	394	–	2014	778	778	–
1986	76	76	–	2015	875	875	–
1987	18	18	–	2016	525	525	–
1988	4	4	–	2017	565	565	–
1989	2	2	–	2018	363	363	–
1991	1	1	–	2019	203	203	–
1992	1	1	–	2020	271	275	4
1994	39	39	–	2021	254	225	-29
1995	72	72	–	2022	140	240	100
1996	423	423	–	2023	19	60	41
1997	2 558	2 558	–	2024	–	2	2
1998	2 944	2 944	–				
				Total	35 890	36 007	117

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

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

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

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

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

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

Table D.6: Number of tag recaptures by calendar year of <u>release</u> and sex for each statistical area in CRA 4 and CRA 5. 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.

Release year	CRA 4 statistical area of release					CRA 5 statistical area of release					Sex		
	912	913	914	915	934	916	917	918	933	Un-known	Females	Males	Total
1974	–	–	–	–	–	–	–	2	–	–	–	2	2
1975	–	–	–	–	–	–	–	51	–	–	19	32	51
1976	–	–	–	–	–	–	–	117	–	–	75	42	117
1977	–	–	–	–	–	–	–	10	–	–	8	2	10
1978	–	–	–	–	–	–	–	–	–	–	–	–	–
1979	–	–	–	–	–	–	–	14	–	–	11	3	14
1980	–	–	–	–	–	–	–	16	–	–	10	6	16
1981	–	–	–	–	–	–	–	28	–	–	21	7	28
1982	–	10	–	–	–	–	1	–	–	–	3	8	11
1983	–	–	–	–	–	42	983	–	–	52	208	869	1 077
1984	–	–	–	–	–	1	10	–	–	116	10	117	127
1985	–	–	–	–	–	2	–	–	–	12	3	11	14
1986	–	–	–	–	–	–	–	–	–	2	–	2	2
…	–	–	–	–	–	–	–	–	–	–	–	–	–
1996	–	–	–	–	–	734	–	–	–	–	229	505	734
1997	–	–	–	–	–	136	372	–	221	–	280	449	729
1998	178	146	381	–	–	20	83	–	40	–	262	586	848
1999	123	134	154	52	–	8	328	–	91	–	439	451	890
2000	32	66	15	65	1	428	122	–	29	–	178	580	758
2001	–	4	1	–	–	446	247	–	231	–	240	689	929
2002	–	–	1	3	–	157	83	–	82	–	46	280	326
2003	–	–	–	6	–	83	44	–	25	–	43	115	158
2004	–	–	–	2	–	612	201	–	141	–	266	690	956
2005	–	21	65	108	–	290	70	–	27	–	132	449	581
2006	–	16	11	67	–	60	18	–	6	–	50	128	178
2007	11	5	69	64	–	5	6	–	1	–	42	119	161
2008	1	2	–	1	–	–	1	–	-	–	2	3	5
2009	29	3	41	1	–	–	–	–	–	–	17	57	74
2010	12	265	5	4	–	–	–	–	–	–	10	276	286
2011	–	50	2	–	–	–	–	–	–	–	1	51	52
2012	–	6	–	–	–	26	119	–	181	–	190	142	332
2013	–	–	–	–	–	2	21	–	15	–	16	22	38
2014	–	36	426	28	1	–	8	–	14	–	78	435	513
2015	–	225	96	2	1	–	3	–	13	–	40	300	340
2016	–	66	8	5	–	48	80	–	5	2	56	158	214
2017	–	18	4	–	–	2	50	–	1	–	31	44	75
2018	–	5	3	–	–	75	38	–	–	–	34	87	121
2019	–	1	–	–	–	–	3	–	–	–	2	2	4
2020	–	–	1	–	–	–	–	–	–	–	1	–	1
2021	–	–	–	–	–	–	–	–	–	–	–	–	–
2022	–	–	–	–	–	–	–	–	–	–	–	–	–
2023	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	386	1 079	1 283	408	3	3 177	2 891	238	1 123	184	3 053	7 719	10 772

Table D.7: Number of tag recaptures by calendar year of <u>recapture</u> and sex for each statistical area in CRA 4 and CRA 5. 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.

	CRA 4 statistical area of release					CRA 5 statistical area of release					Sex		
Release year	912	913	914	915	934	916	917	918	933	Un-known	Females	Males	Total
1975	–	–	–	–	–	–	–	2	–	–	1	1	2
1976	–	–	–	–	–	–	–	113	–	–	68	45	113
1977	–	–	–	–	–	–	–	59	–	–	30	29	59
1978	–	–	–	–	–	–	–	5	–	–	2	3	5
1979	–	–	–	–	–	–	–	4	–	–	3	1	4
1980	–	–	–	–	–	–	–	21	–	–	15	6	21
1981	–	–	–	–	–	–	–	31	–	–	25	6	31
1982	–	–	–	–	–	–	–	3	–	–	–	3	3
1983	–	5	–	–	–	20	355	–	–	20	69	331	400
1984	–	4	–	–	–	18	537	–	–	134	107	586	693
1985	–	1	–	–	–	5	78	–	–	22	35	71	106
1986	–	–	–	–	–	1	21	–	–	6	11	17	28
1987	–	–	–	–	–	1	3	–	–	–	2	2	4
…	–	–	–	–	–	–	–	–	–	–	–	–	–
1996	–	–	–	–	–	60	–	–	–	–	4	56	60
1997	–	–	–	–	–	625	56	–	1	–	212	470	682
1998	–	–	26	–	–	139	276	–	162	–	196	407	603
1999	170	125	360	1	–	34	85	–	72	–	261	586	847
2000	160	190	92	49	–	16	295	–	116	–	374	544	918
2001	3	31	42	35	1	351	120	–	20	–	188	415	603
2002	–	2	14	13	–	497	253	–	237	–	237	779	1016
2003	–	1	14	23	–	243	129	–	70	–	150	330	480
2004	–	–	4	7	–	89	56	–	75	–	103	128	231
2005	–	5	31	55	–	724	171	–	104	–	239	851	1090
2006	–	19	40	45	–	173	77	–	24	–	109	269	378
2007	–	7	57	100	–	23	36	–	13	–	92	144	236
2008	9	9	14	25	–	4	16	–	–	–	28	49	77
2009	1	7	3	9	–	1	2	–	–	–	8	15	23
2010	24	127	31	8	–	-	2	–	–	–	20	172	192
2011	9	169	15	2	–	-	1	–	–	–	9	187	196
2012	10	25	2	–	–	9	11	–	101	–	74	84	158
2013	–	1	–	1	–	13	84	–	37	–	71	65	136
2014	–	20	297	–	–	4	22	–	29	–	67	305	372
2015	–	142	195	23	2	1	17	–	33	–	65	348	413
2016	–	145	31	9	–	37	24	–	21	2	52	217	269
2017	–	11	7	–	–	10	103	–	5	–	61	75	136
2018	–	31	6	2	–	73	35	–	1	–	40	108	148
2019	–	2	–	1	–	6	24	–	1	–	20	14	34
2020	–	–	1	–	–	–		–	–	–	1	–	1
2021	–	–	–	–	–	–		–	–	–	–	–	–
2022	–	–	1	–	–	–	2	–	1	–	4	–	4
2023	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	386	1 079	1 283	408	3	3 177	2 891	238	1 123	184	3 053	7 719	10 772

Table D.8: Number of tag releases by sex, release month, and release statistical area for CRA 4 and CRA 5.

Release month	CRA 4 statistical area of release					CRA 5 statistical area of release					Sex		
	912	913	914	915	934	916	917	918	933	Un-known	Females	Males	Total
Jan	9	72	206	23	–	1048	3	19	5	11	347	1 049	1 396
Feb	1	55	202	101	–	2	360	23	6	7	149	608	757
Mar	–	–	–	25	–	13	1	2	1	33	15	60	75
Apr	10	4	1	1	–	127	64	–	13	4	64	160	224
May	9	70	23	2	–	576	486	–	195	48	366	1 043	1 409
Jun	32	116	355	10	1	779	346	–	83	20	334	1 408	1 742
Jul	12	253	41	9	–	114	55	39	48	–	99	472	571
Aug	5	11	121	88	–	44	274	37	31	2	267	346	613
Sep	1	5	70	120	2	113	323	42	524	2	494	708	1 202
Oct	11	9	44	18	–	306	756	63	107	8	547	775	1 322
Nov	1	158	49	6	–	1	121	13	107	21	142	335	477
Dec	295	326	171	5	–	54	102	-	3	28	229	755	984
Total	386	1079	1283	408	3	3177	2891	238	1123	184	3 053	7 719	10 772

Table D.9: Number of tag recaptures by release and recovery statistical areas for CRA 4 and CRA 5 releases, summed across all years. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

	Unknown	912	913	914	915	916	917	918	919	920	921	933	934	Total
Unknown	183	–	–	–	–	–	–	–	–	–	–	1	–	184
912	–	386	–	–	–	–	–	–	–	–	–	–	–	386
913	10	–	1 042	6	21	–	–	–	–	–	–	–	–	1 079
914	1	–	6	1 222	52	1	–	–	–	–	–	1	–	1 283
915	–	–	–	6	396	–	–	–	–	–	–	5	1	408
934	–	–	–	–	–	–	–	–	–	–	–	–	3	3
916	4	–	–	2	–	3 157	3	–	–	–	–	11	–	3 177
917	998	–	–	–	–	–	1 892	–	–	–	–	1	–	2 891
918	–	–	–	–	–	–	–	231	1	5	1	–	–	238
933	1	–	–	–	–	4	3	–	–	–	–	1 115	–	1 123
Total	1 197	386	1 048	1 236	469	3 162	1 898	231	1	5	1	1 134	4	10 772

Table D.10: Days-at-liberty statistics for recaptures of CRA 4 and CRA 5 releases. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

Statistical area of release	Sex	N	Minimum	5%	Median	95%	Maximum
Unknown	Males	172	1	4	56	320	659
	Females	12	13	25	74	308	313
912	Males	333	1	6	195	552	1 047
	Females	53	37	176	300	808	1 071
913	Males	968	1	5	189	559	1 633
	Females	111	10	19	313	1 095	2 141
914	Males	963	1	6	165	555	1 325
	Females	320	1	19	216	1 283	2 007
915	Males	172	2	51	251	670	1 026
	Females	236	1	10	263	1 242	1 821
916	Males	2782	1	3	216	718	2 033
	Females	395	1	18	256	1 141	3 427
917	Males	1610	1	9	227	720	2 523
	Females	1281	1	20	334	1 395	3 371
918	Males	94	2	9	291	557	909
	Females	144	7	13	105	498	773
933	Males	623	1	6	253	715	2 182
	Females	500	1	17	313	1 461	3 532
934	Males	2	45	61	203	345	361
	Females	1	396	396	396	396	396
CRA 4&5	Males	7719	1	4	201	693	2 523
	Females	3053	1	16	280	1 297	3 532

Table D.11: Number of tag re-releases in CRA 4 and CRA 5, by sex and statistical area of release. Re-release event code = 0 means the first release-recapture event.

Re-release event	912		913		914		915		916		917		918		933		934		Unknown		CRA 4 & 5	
	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop	N	Cum Prop
Males																						
0	262	0.79	641	0.66	677	0.70	155	0.90	1 901	0.68	1 322	0.82	81	0.86	392	0.63	1	0.50	0	0.00	5 432	0.70
1	48	0.93	204	0.87	170	0.88	12	0.97	570	0.89	164	0.92	9	0.96	143	0.86	1	1.00	107	0.62	1 428	0.89
2	17	0.98	81	0.96	64	0.95	3	0.99	201	0.96	67	0.96	3	0.99	54	0.95	0	1.00	34	0.82	524	0.96
3	5	1.00	28	0.99	29	0.98	2	1.00	73	0.99	27	0.98	1	1.00	22	0.98	0	1.00	11	0.88	198	0.98
4	1	1.00	9	0.99	12	0.99	0	1.00	22	0.99	13	0.99	0	1.00	7	0.99	0	1.00	6	0.92	70	0.99
5	0	1.00	3	1.00	6	0.99	0	1.00	8	1.00	6	0.99	0	1.00	2	1.00	0	1.00	5	0.95	30	1.00
6	0	1.00	1	1.00	2	1.00	0	1.00	4	1.00	4	1.00	0	1.00	2	1.00	0	1.00	3	0.97	16	1.00
7	0	1.00	1	1.00	2	1.00	0	1.00	2	1.00	1	1.00	0	1.00	1	1.00	0	1.00	2	0.98	9	1.00
8	0	1.00	0	1.00	1	1.00	0	1.00	1	1.00	1	1.00	0	1.00	0	1.00	0	1.00	1	0.98	4	1.00
9	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	1	0.99	2	1.00
10	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	1	0.99	2	1.00
11	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	1	1.00	2	1.00
12	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00
13	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00
Females																						
0	51	0.96	100	0.90	263	0.82	217	0.92	349	0.88	992	0.77	131	0.91	386	0.77	1	1.00	0	0.00	2 490	0.82
1	2	1.00	11	1.00	37	0.94	13	0.97	40	0.98	192	0.92	12	0.99	87	0.95	0	1.00	8	0.67	402	0.95
2	0	1.00	0	1.00	9	0.97	3	0.99	5	1.00	67	0.98	1	1.00	20	0.99	0	1.00	4	1.00	109	0.98
3	0	1.00	0	1.00	4	0.98	2	1.00	1	1.00	23	0.99	0	1.00	6	1.00	0	1.00	0	1.00	36	0.99
4	0	1.00	0	1.00	3	0.99	1	1.00	0	1.00	5	1.00	0	1.00	1	1.00	0	1.00	0	1.00	10	1.00
5	0	1.00	0	1.00	2	0.99	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	0	1.00	3	1.00
6	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	0	1.00	2	1.00
7	0	1.00	0	1.00	1	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00

Table D.12: Statistics for tail width growth increments (mm) for recaptures of CRA 4 and CRA 5 releases. Recaptures were considered valid if there was a valid growth increment, regardless of the location of recapture.

Statistical area of release	Sex	N	Minimum	5%	Median	95%	Maximum
Unknown	Males	172	-2.91	-0.15	0.05	4.36	8.27
	Females	12	-0.72	-0.68	-0.04	2.47	4.86
912	Males	333	-9.9	-0.94	0.4	3.74	8.3
	Females	53	-6	-3.78	-0.4	4.54	17.4
913	Males	968	-7	-1	0.9	4.2	12.86
	Females	111	-9.6	-2.45	0.7	4.05	10.1
914	Males	963	-9.4	-1	1	5.49	15.9
	Females	320	-18.7	-1.9	1.1	5.6	13.9
915	Males	172	-5.7	0	2.8	9.78	17.9
	Females	236	-9.5	-1.43	1.6	9.38	22.3
916	Males	2 782	-8.2	-1	1	5.7	21.1
	Females	395	-30	-2.06	0.73	5	31
917	Males	1 610	-30	-0.1	2.95	10.3	34.5
	Females	1 281	-14.2	-0.6	2.1	10.2	30.2
918	Males	94	-2.47	-0.29	2.26	7.28	10.95
	Females	144	-4.46	-1.44	0.38	7.35	14.19
933	Males	623	-10	-0.97	3	10.87	20
	Females	500	-14.7	-1	1.9	9.5	31.3
934	Males	2	0	0.41	4.05	7.7	8.1
	Females	1	1.1	1.1	1.1	1.1	1.1
CRA 4 &	Males	7 719	-30	-1	1.2	7.39	34.5
CRA 5	Females	3 053	-30	-1.1	1.5	9.04	31.3

Table D.13: The number and proportion of recaptured tag releases by time period at liberty category and by QMA.

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

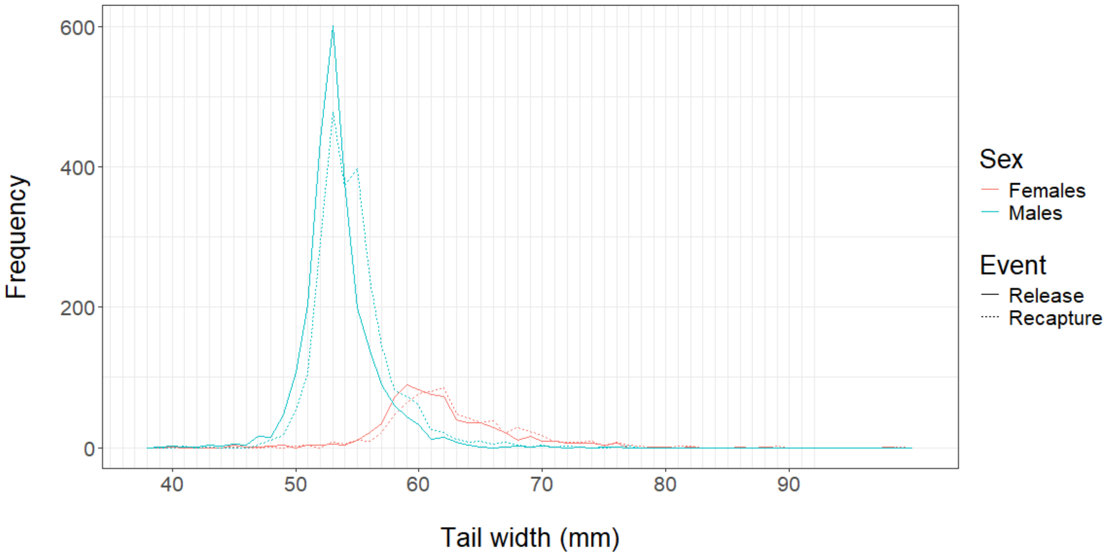


Figure D.1: CRA 4 size at release (solid lines) and recapture (dashed lines) distributions by sex. A bin width of 1 mm was used.

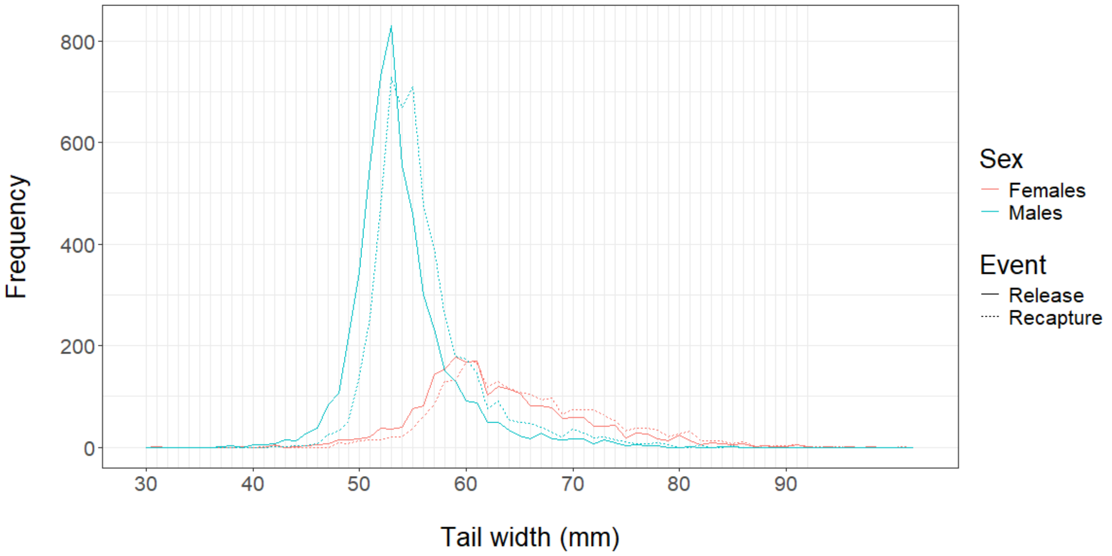


Figure D.2: CRA 5 size at release (solid lines) and recapture (dashed lines) distributions by sex. A bin width of 1 mm was used.

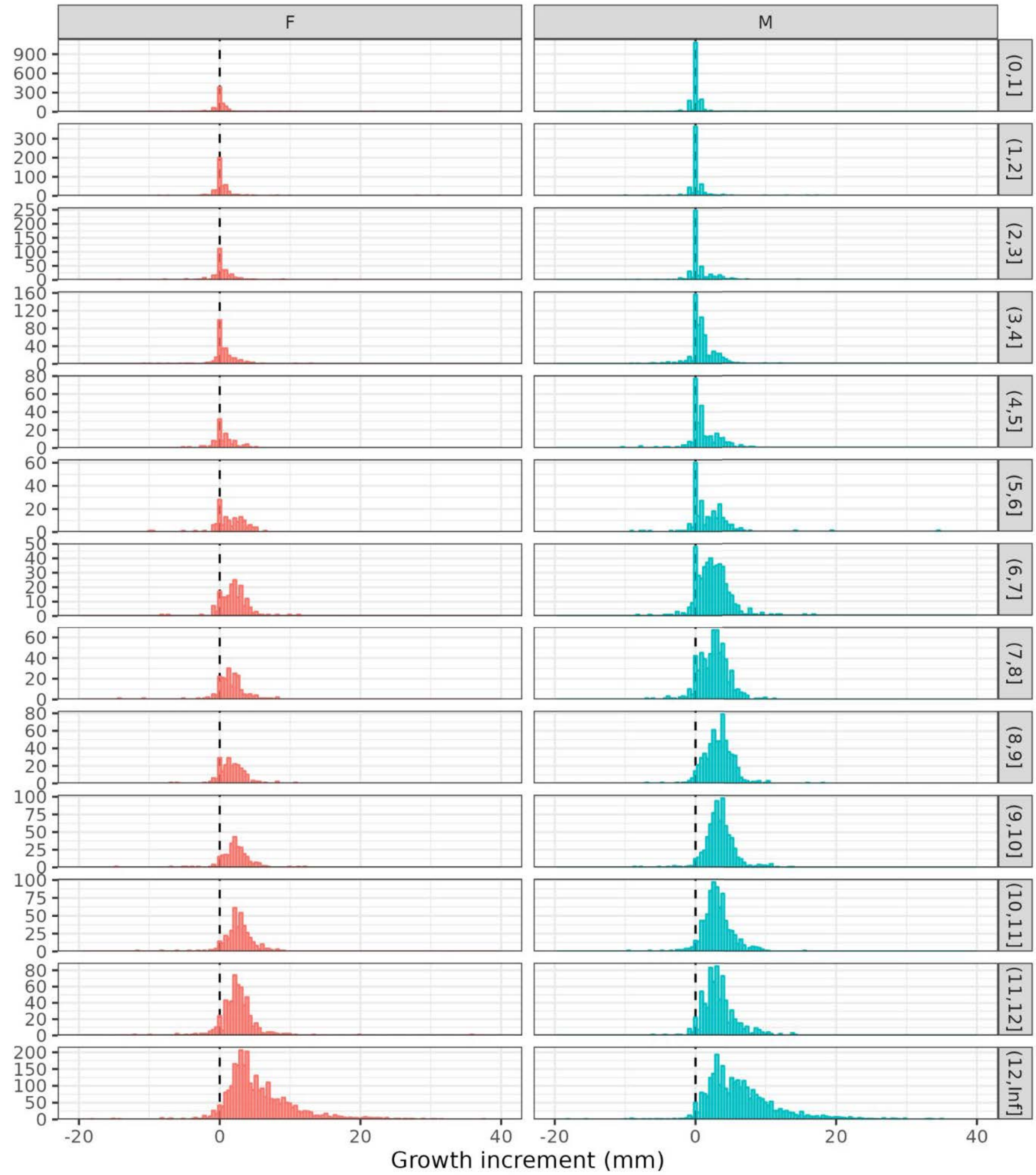


Figure D.3: Growth increment distribution (in terms of tail-width) of lobsters across all QMAs by sex ('M' = males, and 'F' = females) and time at liberty (e.g., '(0,1]' = up to 1 month at liberty, and '(1, 2]' = from 1 to 2 months at liberty), etc. The vertical dashed line represents the zero-growth increment.

Appendix E. PROPORTION IN BERRY ANALYSIS

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

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

Table E.2: Summary of parameter estimates of final model for predicting the proportion of mature females in berry (*fit10*). This tables excludes parameters relating to interaction terms.

Parameter label	Mean	SD	2.50%	Median	97.50%
b_Intercept	-0.706	0.897	-2.409	-0.738	1.012
sd_area__Intercept	1.431	0.242	1.027	1.403	1.935
sd_fmonth__Intercept	3.176	0.710	2.115	3.054	4.922
sd_fmonth:area__Intercept	1.798	0.087	1.635	1.797	1.974
sd_fyear__Intercept	0.134	0.088	0.005	0.125	0.328
sd_fyear:area__Intercept	1.355	0.046	1.270	1.355	1.446
Intercept	-0.706	0.897	-2.409	-0.738	1.012
r_area[901,Intercept]	-0.437	0.665	-1.759	-0.439	0.822
r_area[902,Intercept]	-0.559	0.766	-2.013	-0.572	0.940
r_area[903,Intercept]	1.713	0.725	0.314	1.687	3.173
r_area[904,Intercept]	-0.141	0.807	-1.752	-0.167	1.512
r_area[905,Intercept]	-0.802	0.612	-1.997	-0.805	0.427
r_area[906,Intercept]	-0.380	0.580	-1.585	-0.373	0.741
r_area[907,Intercept]	-0.991	0.599	-2.151	-1.007	0.155
r_area[908,Intercept]	0.248	0.590	-0.858	0.236	1.427
r_area[909,Intercept]	-2.187	0.674	-3.496	-2.194	-0.958
r_area[910,Intercept]	-1.933	0.647	-3.229	-1.951	-0.686
r_area[911,Intercept]	1.771	0.615	0.629	1.779	2.979
r_area[912,Intercept]	-1.068	0.710	-2.466	-1.047	0.337
r_area[913,Intercept]	-0.921	0.651	-2.196	-0.898	0.357
r_area[914,Intercept]	-0.899	0.597	-2.053	-0.871	0.235
r_area[915,Intercept]	0.578	0.614	-0.571	0.580	1.787
r_area[916,Intercept]	0.338	0.584	-0.809	0.327	1.482
r_area[917,Intercept]	1.253	0.584	0.145	1.247	2.322
r_area[918,Intercept]	0.960	0.663	-0.297	0.981	2.262
r_area[920,Intercept]	-3.721	1.179	-6.183	-3.712	-1.406

Parameter label	Mean	SD	2.50%	Median	97.50%
r_area[922,Intercept]	0.425	0.944	-1.512	0.461	2.239
r_area[923,Intercept]	1.473	0.805	-0.141	1.488	3.039
r_area[924,Intercept]	2.266	0.597	1.107	2.270	3.406
r_area[925,Intercept]	1.948	0.948	0.114	1.932	3.820
r_area[926,Intercept]	1.054	0.549	-0.057	1.075	2.071
r_area[927,Intercept]	-0.337	0.563	-1.402	-0.324	0.764
r_area[928,Intercept]	0.857	0.596	-0.322	0.881	2.041
r_area[930,Intercept]	-0.824	0.840	-2.570	-0.787	0.828
r_area[931,Intercept]	0.711	0.584	-0.376	0.701	1.835
r_area[932,Intercept]	0.558	1.312	-1.905	0.576	3.296
r_area[933,Intercept]	-0.182	0.565	-1.264	-0.175	0.900
r_area[934,Intercept]	0.043	0.940	-1.905	0.057	1.907
r_area[935,Intercept]	0.686	0.646	-0.552	0.658	1.986
r_area[936,Intercept]	1.163	0.674	-0.065	1.130	2.536
r_area[937,Intercept]	-0.173	1.140	-2.391	-0.161	2.004
r_area[939,Intercept]	-1.104	0.684	-2.552	-1.081	0.203
r_area[940,Intercept]	-0.283	0.617	-1.517	-0.266	0.898
r_area[941,Intercept]	0.289	0.597	-0.912	0.287	1.463
r_area[942,Intercept]	-0.643	0.631	-1.927	-0.686	0.605
r_area[943,Intercept]	-0.745	0.695	-2.152	-0.737	0.599
r_fmonth[4,Intercept]	-2.232	0.961	-4.188	-2.219	-0.488
r_fmonth[5,Intercept]	1.054	0.934	-0.788	1.090	2.763
r_fmonth[6,Intercept]	4.007	0.936	2.172	4.029	5.727
r_fmonth[7,Intercept]	4.375	0.920	2.626	4.399	6.136
r_fmonth[8,Intercept]	3.683	0.930	1.930	3.703	5.475
r_fmonth[9,Intercept]	1.647	0.930	-0.166	1.705	3.401
r_fmonth[10,Intercept]	-0.199	0.921	-2.030	-0.215	1.506
r_fmonth[11,Intercept]	-1.522	0.924	-3.265	-1.508	0.217
r_fmonth[12,Intercept]	-2.928	0.951	-4.832	-2.882	-1.121
r_fmonth[13,Intercept]	-3.482	0.926	-5.348	-3.459	-1.748
r_fmonth[14,Intercept]	-3.629	0.936	-5.389	-3.655	-1.790
r_fmonth[15,Intercept]	-3.017	0.959	-4.936	-3.023	-1.201
r_fyear[1993,Intercept]	-0.067	0.145	-0.432	-0.038	0.186
r_fyear[1994,Intercept]	-0.005	0.132	-0.301	-0.001	0.280
r_fyear[1995,Intercept]	0.085	0.147	-0.140	0.048	0.438
r_fyear[1996,Intercept]	0.069	0.151	-0.186	0.028	0.439
r_fyear[1997,Intercept]	-0.014	0.144	-0.373	-0.003	0.268
r_fyear[1998,Intercept]	-0.028	0.137	-0.365	-0.008	0.218
r_fyear[1999,Intercept]	-0.107	0.168	-0.521	-0.056	0.126
r_fyear[2000,Intercept]	0.061	0.145	-0.205	0.030	0.405
r_fyear[2001,Intercept]	-0.057	0.146	-0.416	-0.025	0.194
r_fyear[2002,Intercept]	0.083	0.160	-0.174	0.040	0.474
r_fyear[2003,Intercept]	-0.018	0.134	-0.310	-0.008	0.265
r_fyear[2004,Intercept]	0.117	0.172	-0.116	0.064	0.551
r_fyear[2005,Intercept]	0.061	0.142	-0.174	0.026	0.413
r_fyear[2006,Intercept]	-0.033	0.136	-0.371	-0.007	0.205

Parameter label	Mean	SD	2.50%	Median	97.50%
r_fyear[2007,Intercept]	0.062	0.141	-0.182	0.032	0.410
r_fyear[2008,Intercept]	0.012	0.130	-0.270	0.002	0.308
r_fyear[2009,Intercept]	0.093	0.163	-0.134	0.048	0.527
r_fyear[2010,Intercept]	0.024	0.128	-0.227	0.005	0.326
r_fyear[2011,Intercept]	-0.054	0.135	-0.403	-0.026	0.182
r_fyear[2012,Intercept]	-0.091	0.148	-0.443	-0.050	0.135
r_fyear[2013,Intercept]	-0.030	0.132	-0.325	-0.017	0.222
r_fyear[2014,Intercept]	-0.033	0.131	-0.329	-0.014	0.239
r_fyear[2015,Intercept]	0.083	0.140	-0.109	0.044	0.424
r_fyear[2016,Intercept]	-0.013	0.120	-0.280	-0.007	0.244
r_fyear[2017,Intercept]	0.005	0.125	-0.261	0.000	0.268
r_fyear[2018,Intercept]	-0.055	0.132	-0.392	-0.032	0.182
r_fyear[2019,Intercept]	0.016	0.127	-0.235	0.005	0.293
r_fyear[2020,Intercept]	-0.036	0.129	-0.357	-0.013	0.223
r_fyear[2021,Intercept]	-0.067	0.132	-0.380	-0.038	0.154
r_fyear[2022,Intercept]	-0.085	0.148	-0.462	-0.054	0.148
r_fyear[2023,Intercept]	0.029	0.118	-0.180	0.011	0.313

Table E.3: Summary of posteriors of predicted proportion of mature females in berry by stock assessment QMA/Region and season (*fit10*).

Season	QMA/Region	Mean	SD	2.5%	Median	97.5%
Autumn/Winter	CRA 1	0.739	0.094	0.570	0.736	0.901
	CRA 2	0.779	0.085	0.516	0.781	0.917
	CRA 3_R1	0.768	0.124	0.490	0.790	0.952
	CRA 3_R2	0.843	0.087	0.627	0.848	0.965
	CRA 4	0.794	0.083	0.593	0.806	0.920
	CRA 5_R1	0.934	0.036	0.840	0.944	0.981
	CRA 5_R2	0.863	0.058	0.735	0.865	0.971
	CRA 6	0.841	0.094	0.614	0.855	0.970
	CRA 7&8_Fiordland	0.750	0.108	0.488	0.761	0.920
	CRA 7&8_Southland	0.609	0.113	0.375	0.614	0.807
	CRA 9	0.843	0.078	0.635	0.849	0.951
Spring/Summer	CRA 1	0.198	0.091	0.079	0.175	0.432
	CRA 2	0.189	0.102	0.067	0.152	0.389
	CRA 3_R1	0.009	0.025	0.000	0.002	0.060
	CRA 3_R2	0.442	0.263	0.013	0.455	0.859
	CRA 4	0.069	0.054	0.013	0.053	0.208
	CRA 5_R1	0.218	0.090	0.066	0.210	0.403
	CRA 5_R2	0.091	0.071	0.020	0.066	0.311
	CRA 6	0.086	0.047	0.026	0.075	0.195
	CRA 7&8_Fiordland	0.245	0.111	0.090	0.213	0.483
	CRA 7&8_Southland	0.560	0.180	0.160	0.584	0.814
	CRA 9	0.263	0.144	0.046	0.269	0.535

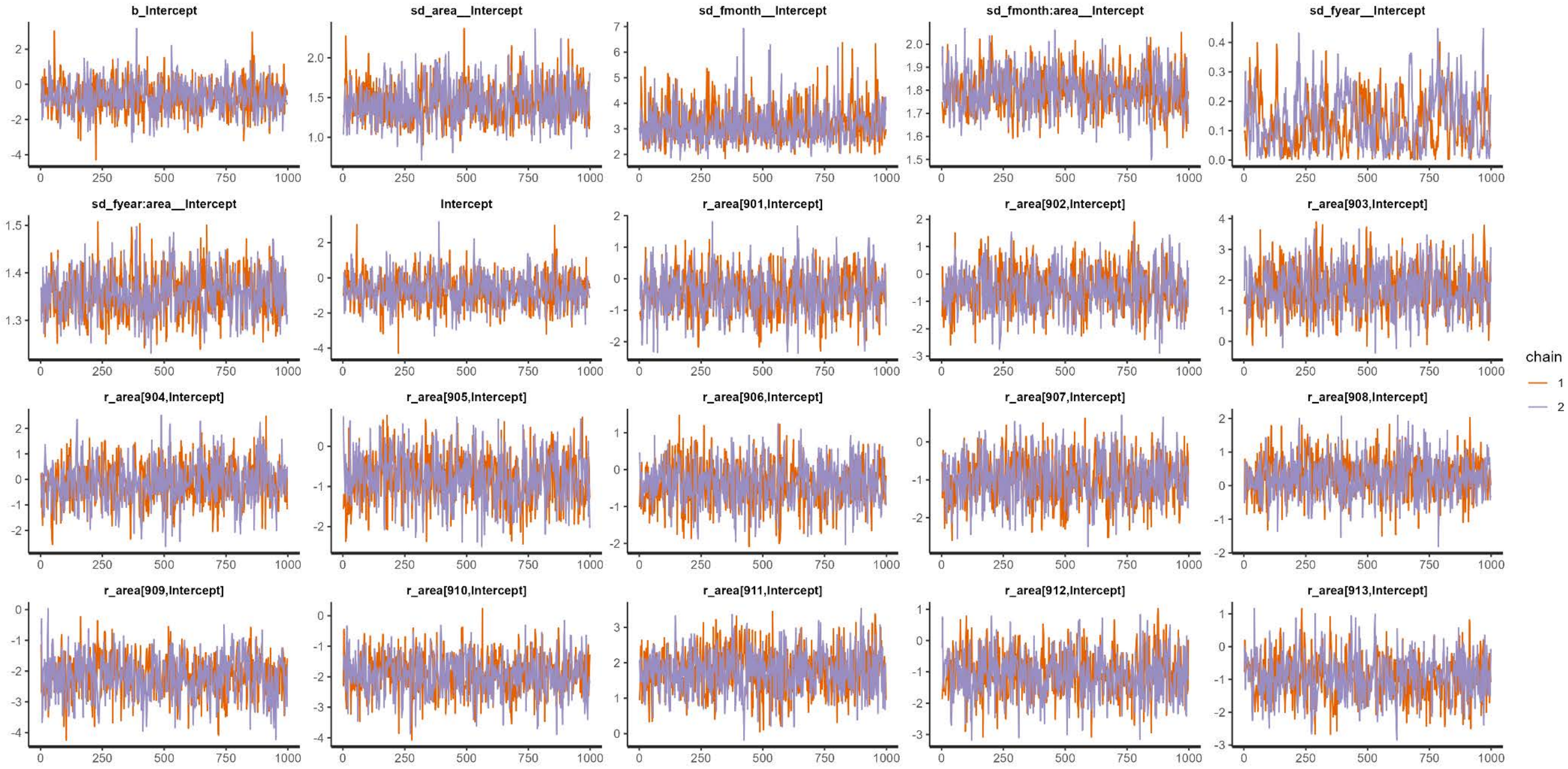


Figure E.1: MCMC traces of a sample of estimated parameters of the final model used to predict the proportion of mature females in berry (*fit10*).

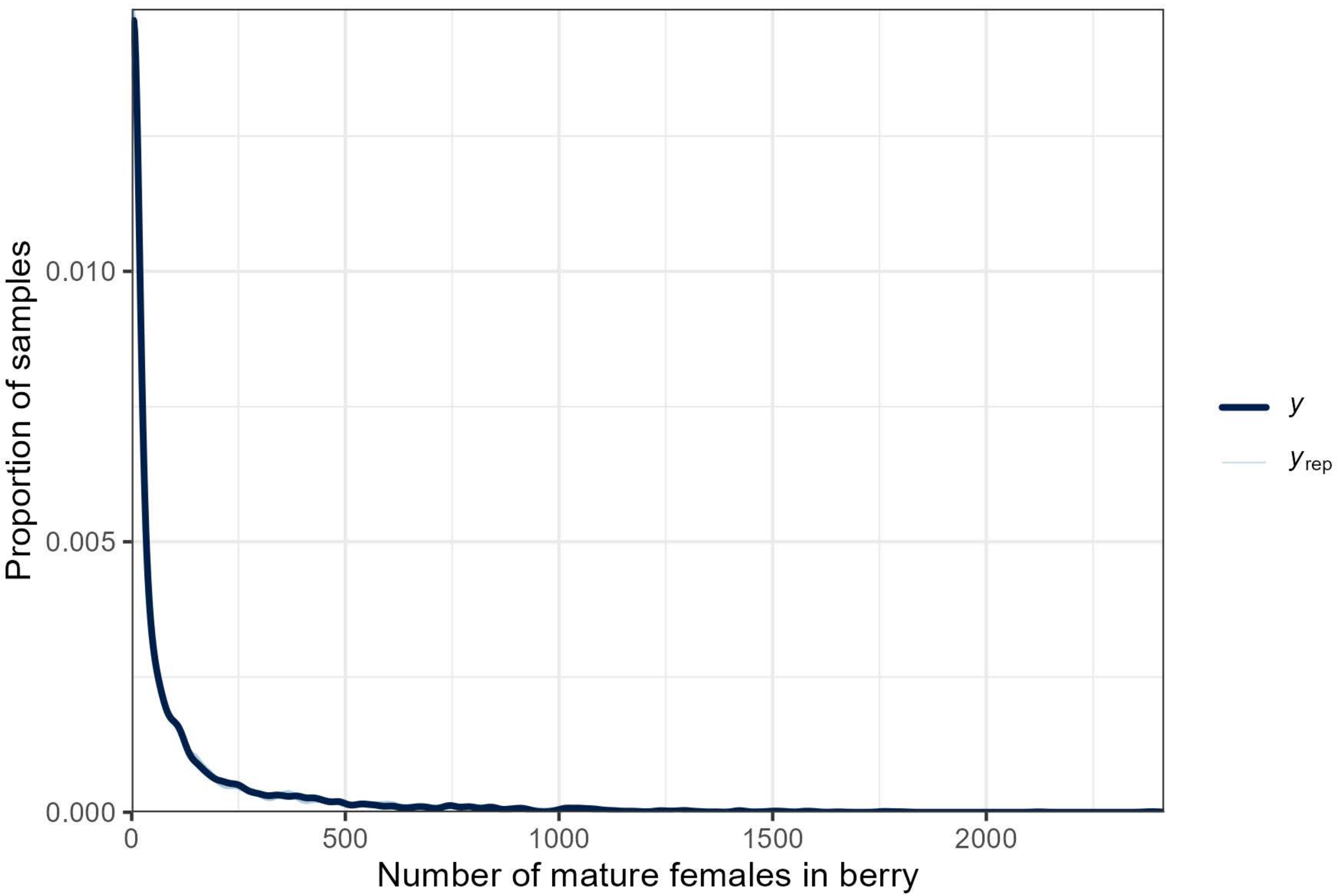


Figure E.2: Comparison of observed (dark blue line) versus predicted (light blue lines) density of the number of mature females in berry from the posterior predictive distribution of the final model used to predict the proportion of mature females in berry (*fit10*).

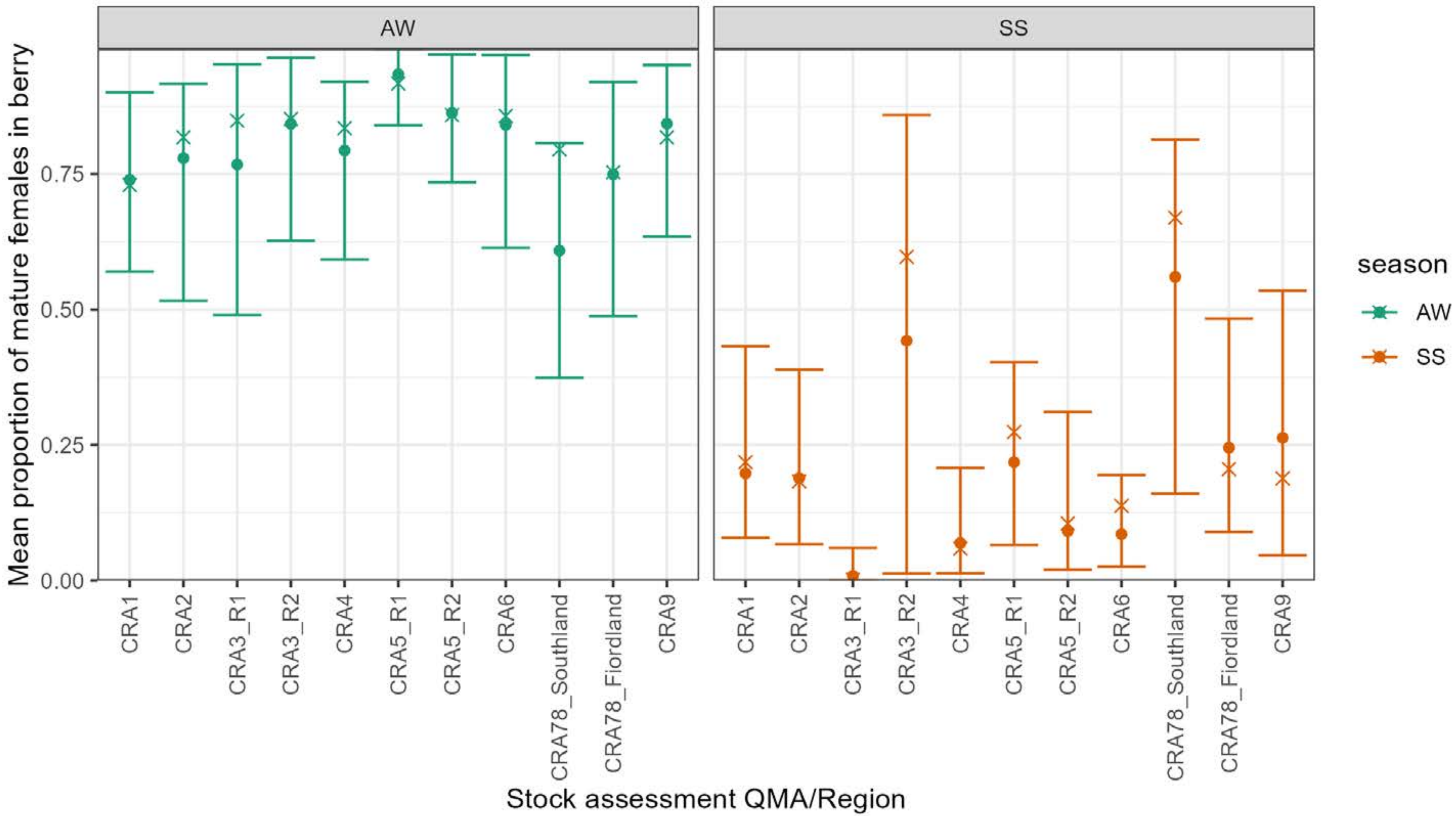


Figure E.3: Catch-weighted posterior of the proportion of mature females in berry by stock assessment QMA/region and season from the final model (*fit10*). Closed points are mean values; bars are the 95% credible intervals; and the non-catch-weighted proportions are represented by crosses.

Appendix F. BASE CASE DIAGNOSTICS

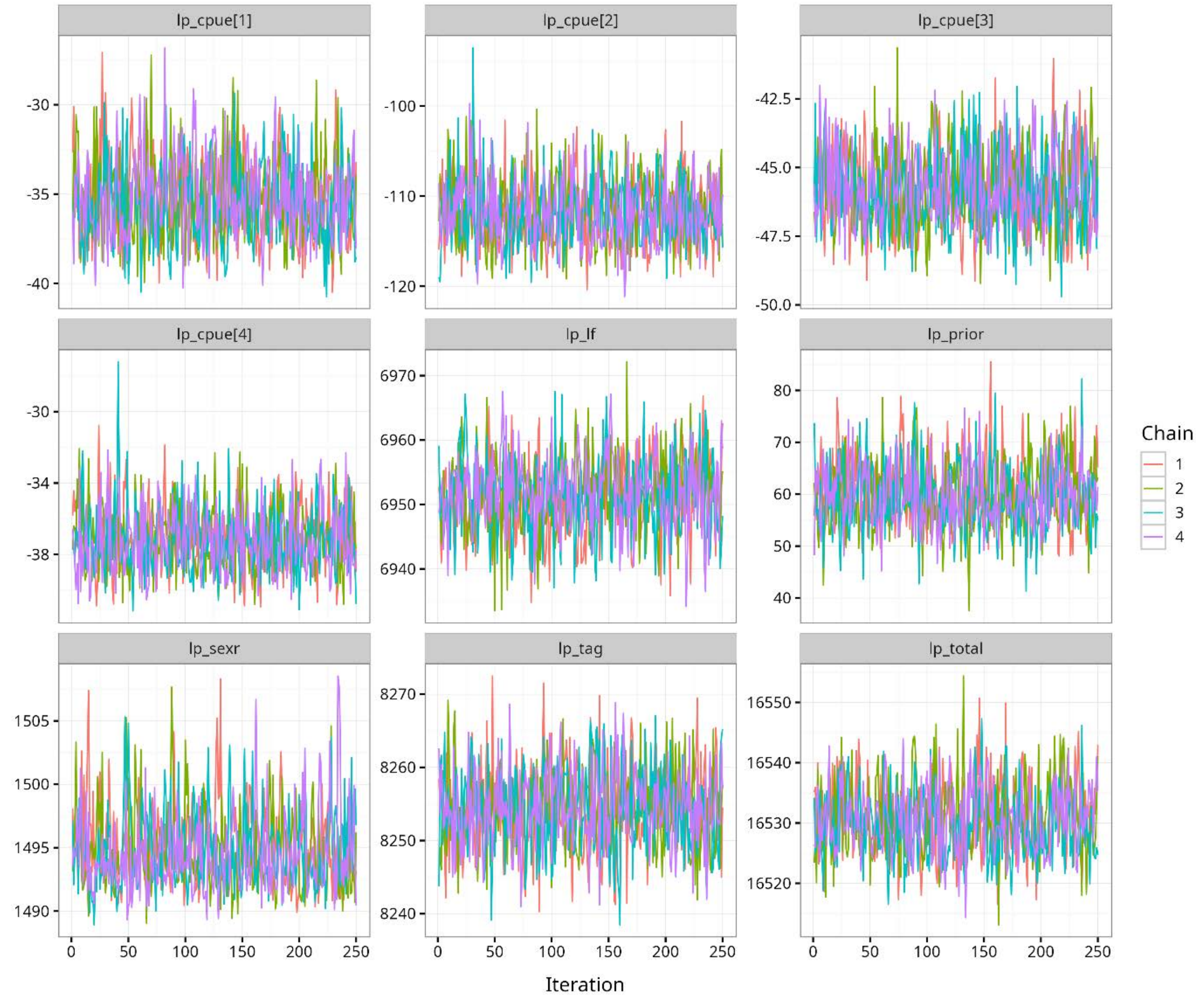


Figure F.1: MCMC trace plots by independent chain for likelihood components for the base2 model run.

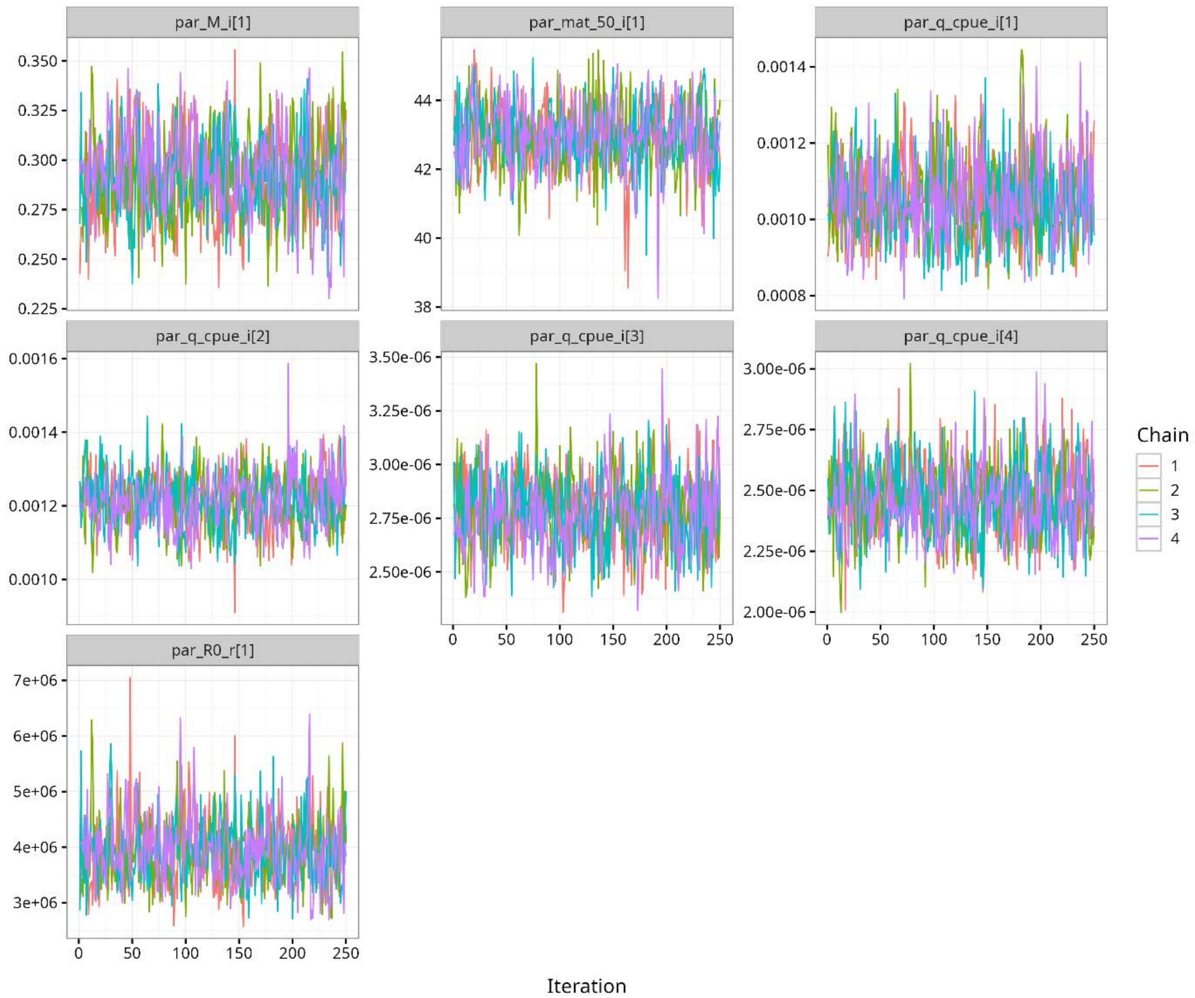


Figure F.2: MCMC trace plots by independent chain for *M*, R_0, maturation, and CPUE parameters for the base2 model run.

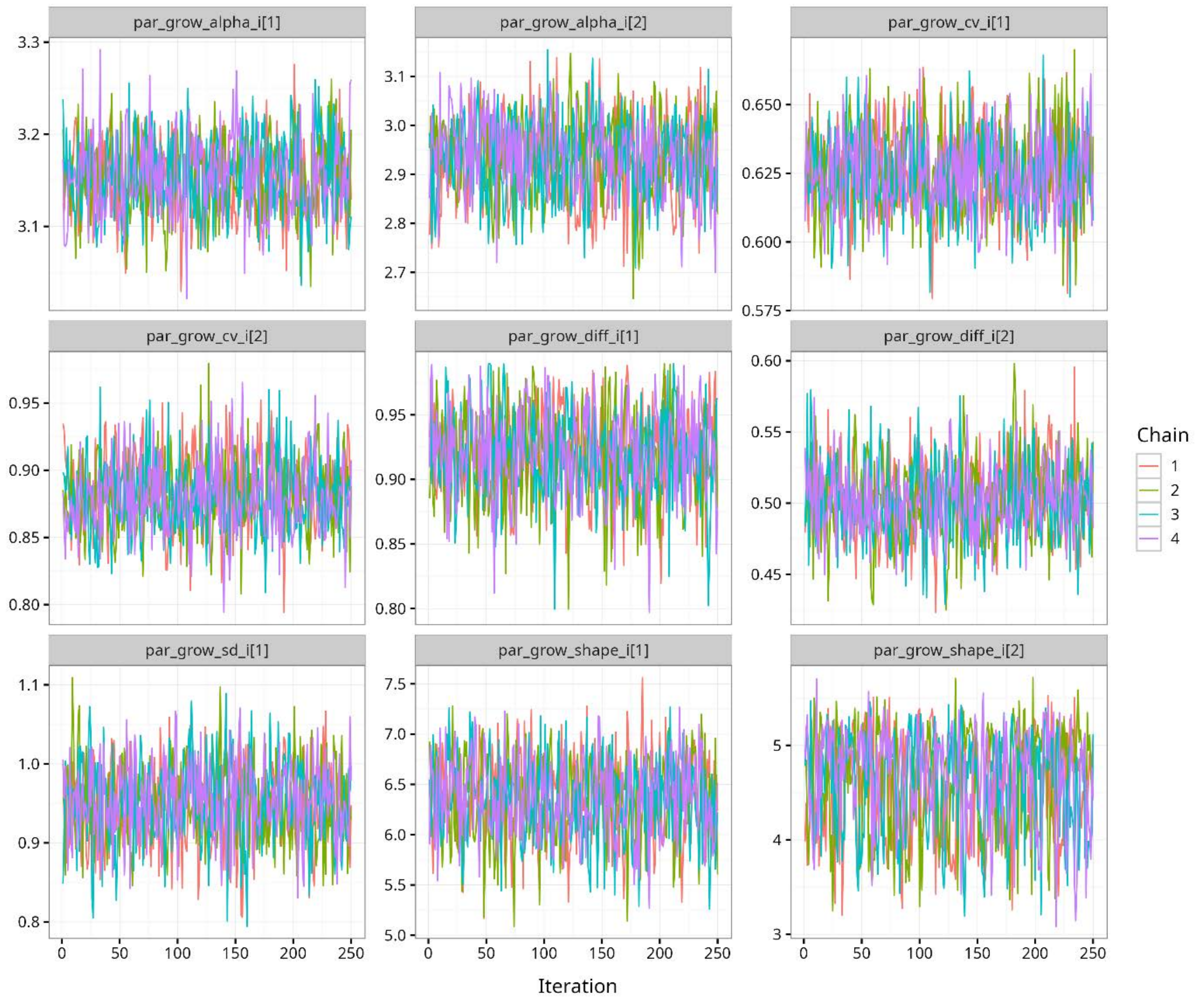


Figure F.3: MCMC trace plots by independent chain for growth parameters for the base2 model run.

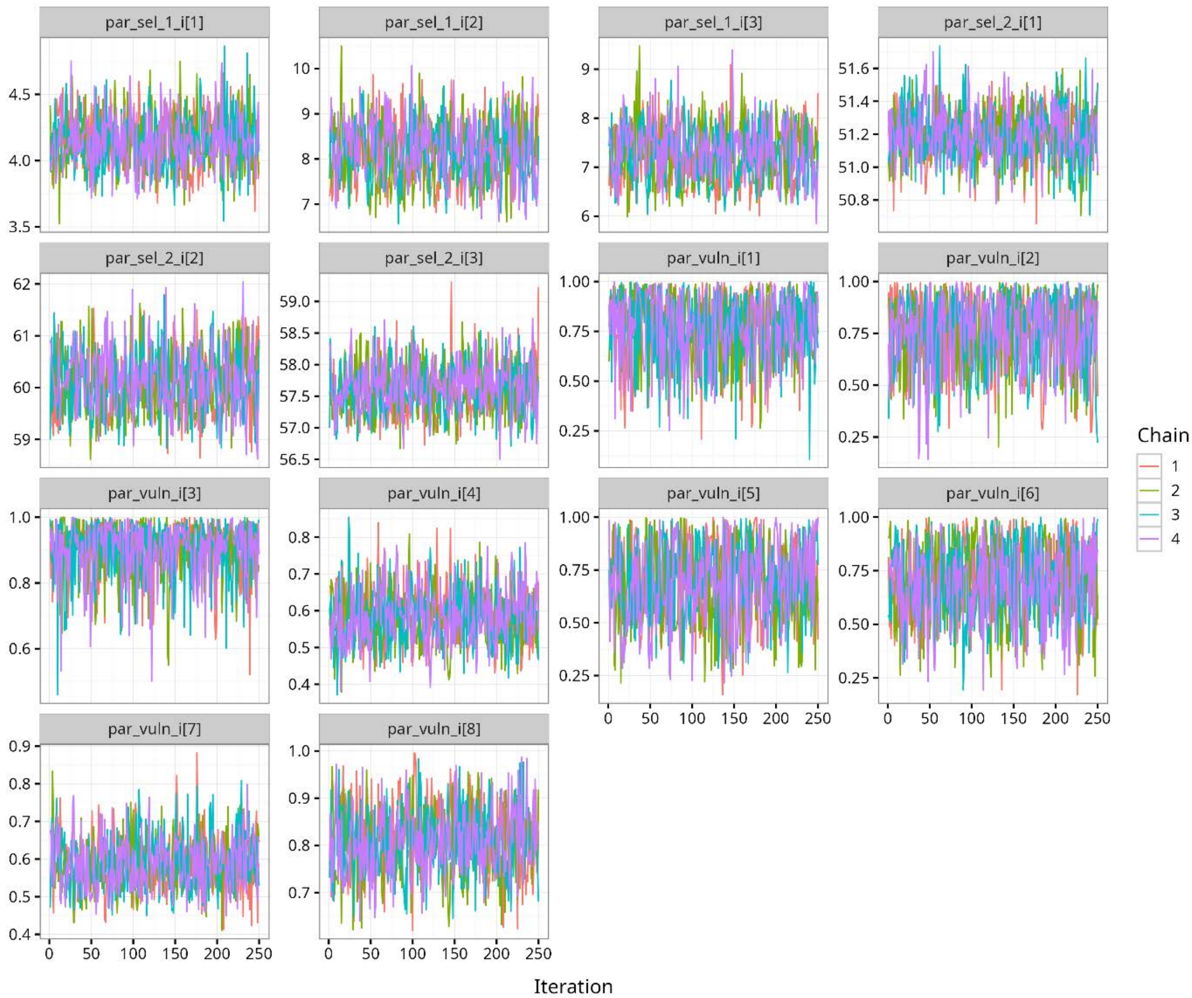


Figure F.4: MCMC trace plots by independent chain for selectivity and vulnerability parameters for the base2 model run.

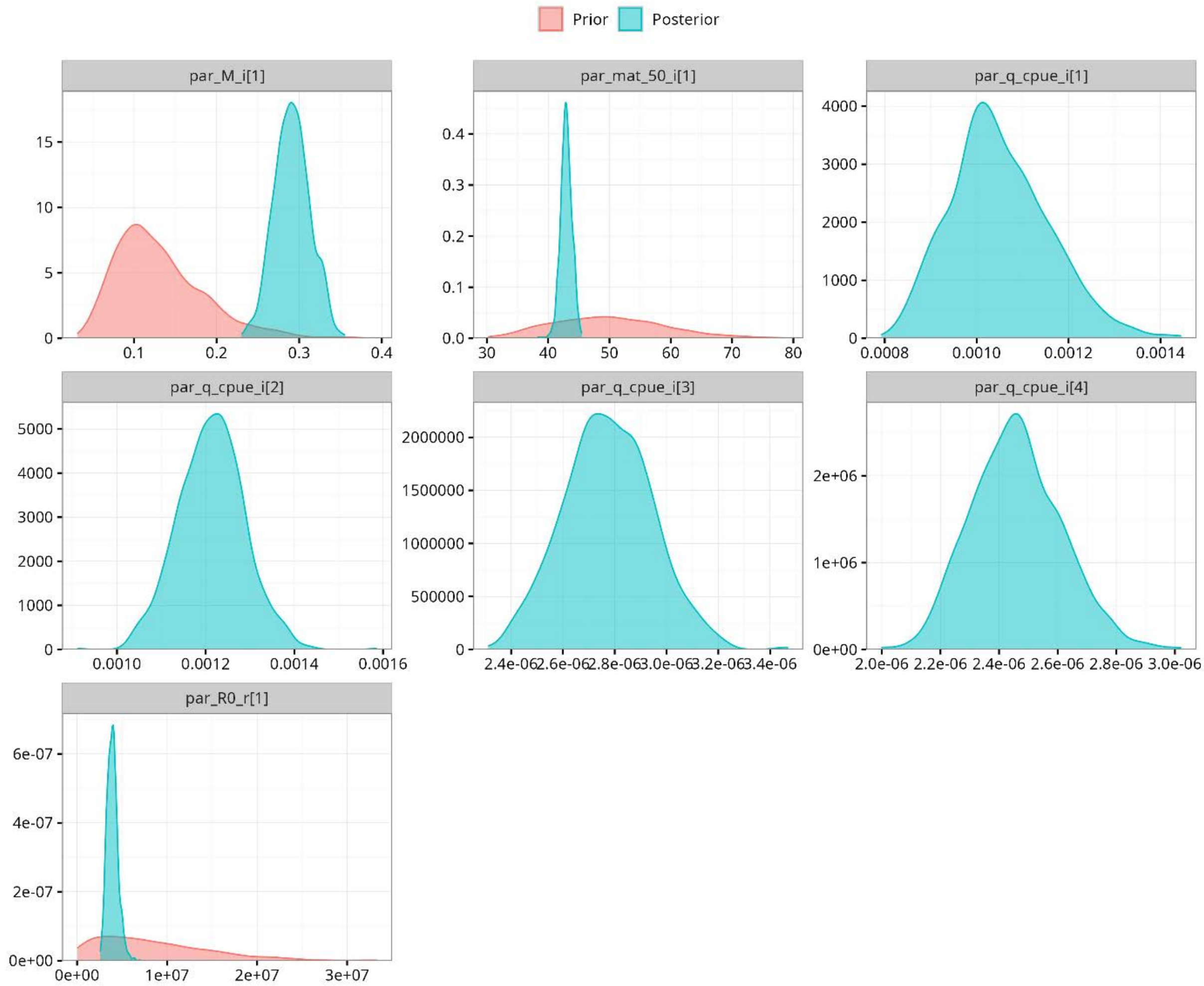


Figure F.5: Density plots showing prior (red) and posterior distributions (blue) for natural mortality (*M*), the R_0 parameter, maturation, and CPUE parameters for the base2 model run.

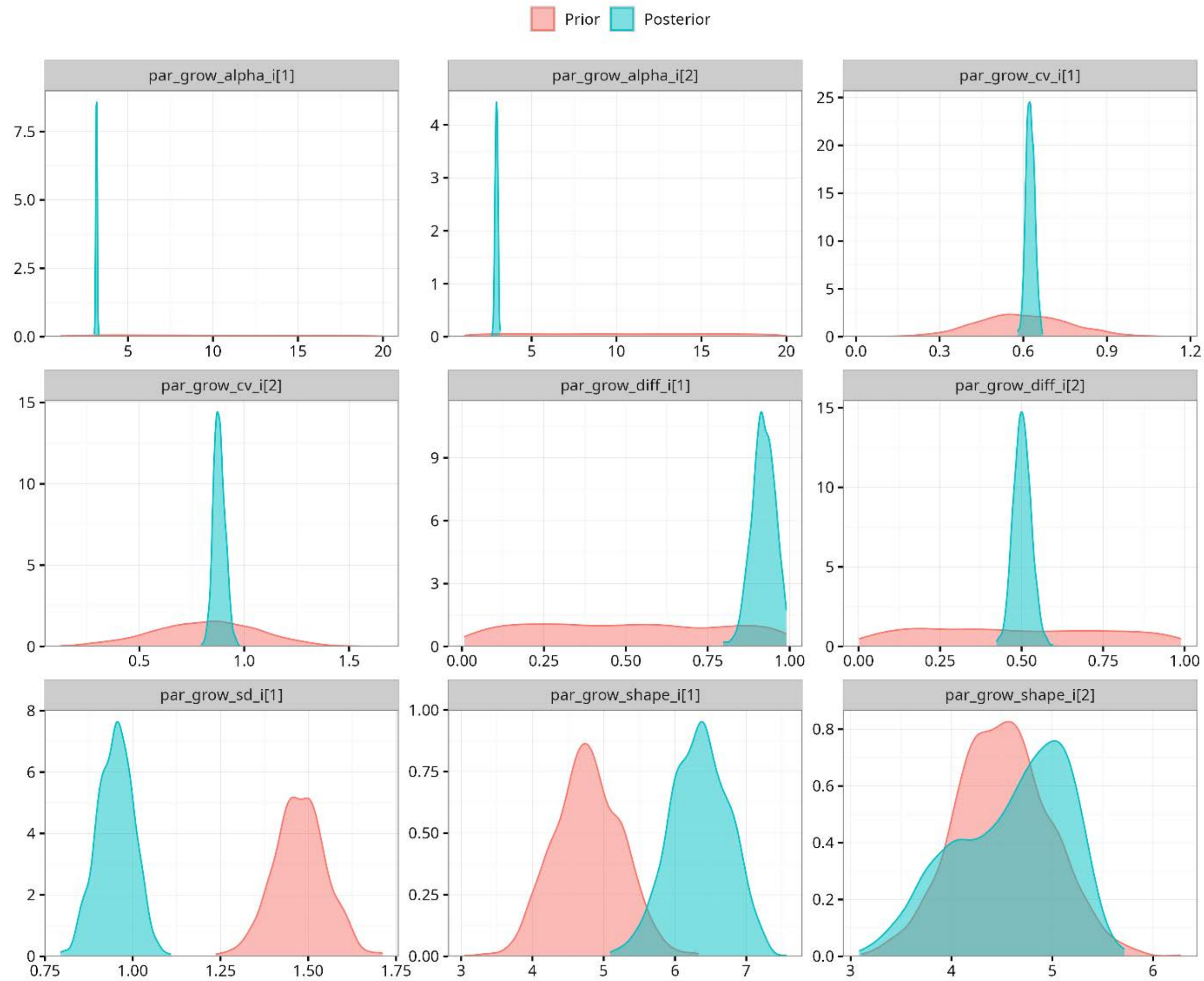


Figure F.6: Density plots showing prior (red) and posterior distributions (blue) for growth parameters for the base2 model run.

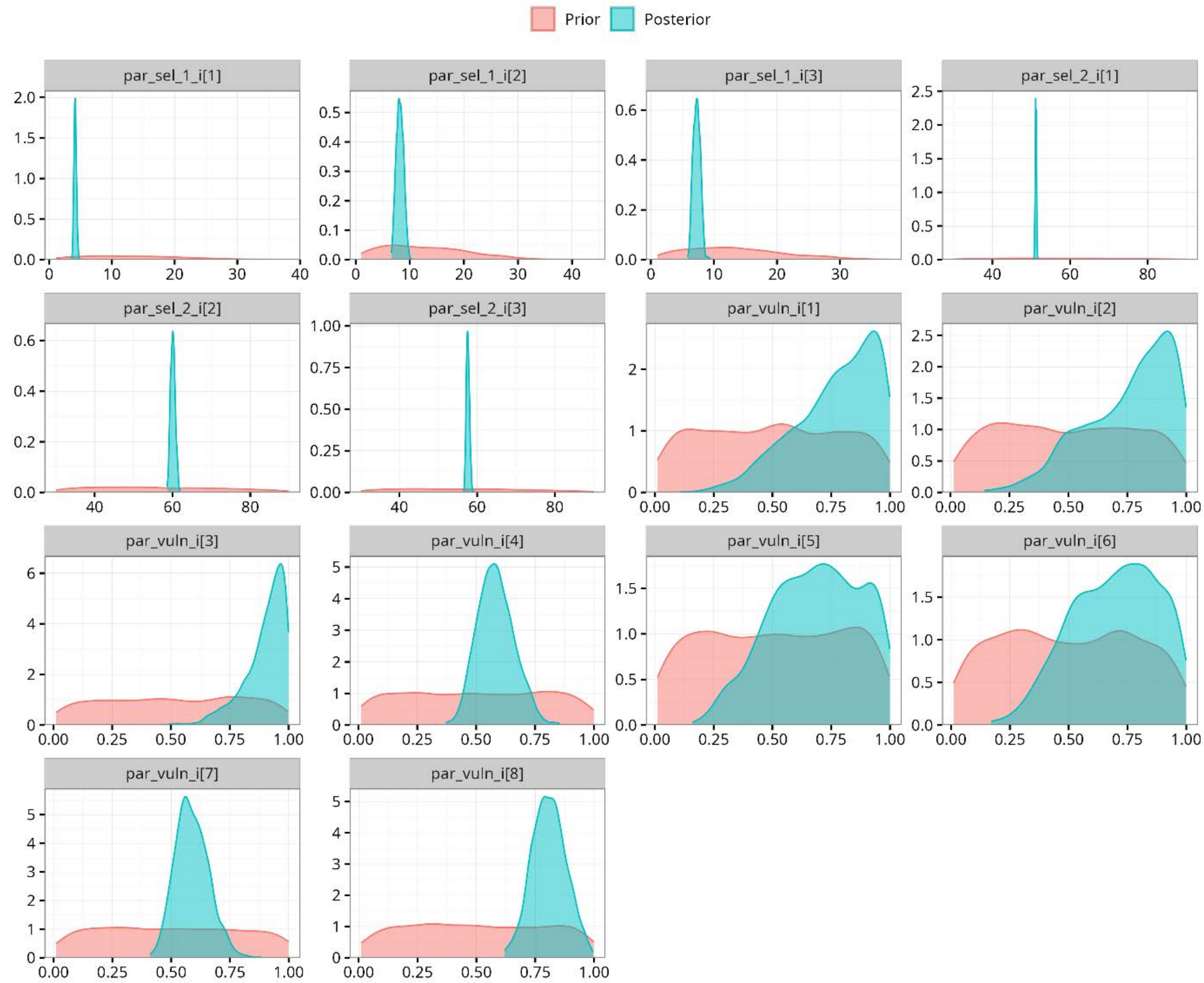


Figure F.7: Density plots showing prior (red) and posterior distributions (blue) for selectivity and vulnerability parameters for the base2 model run.

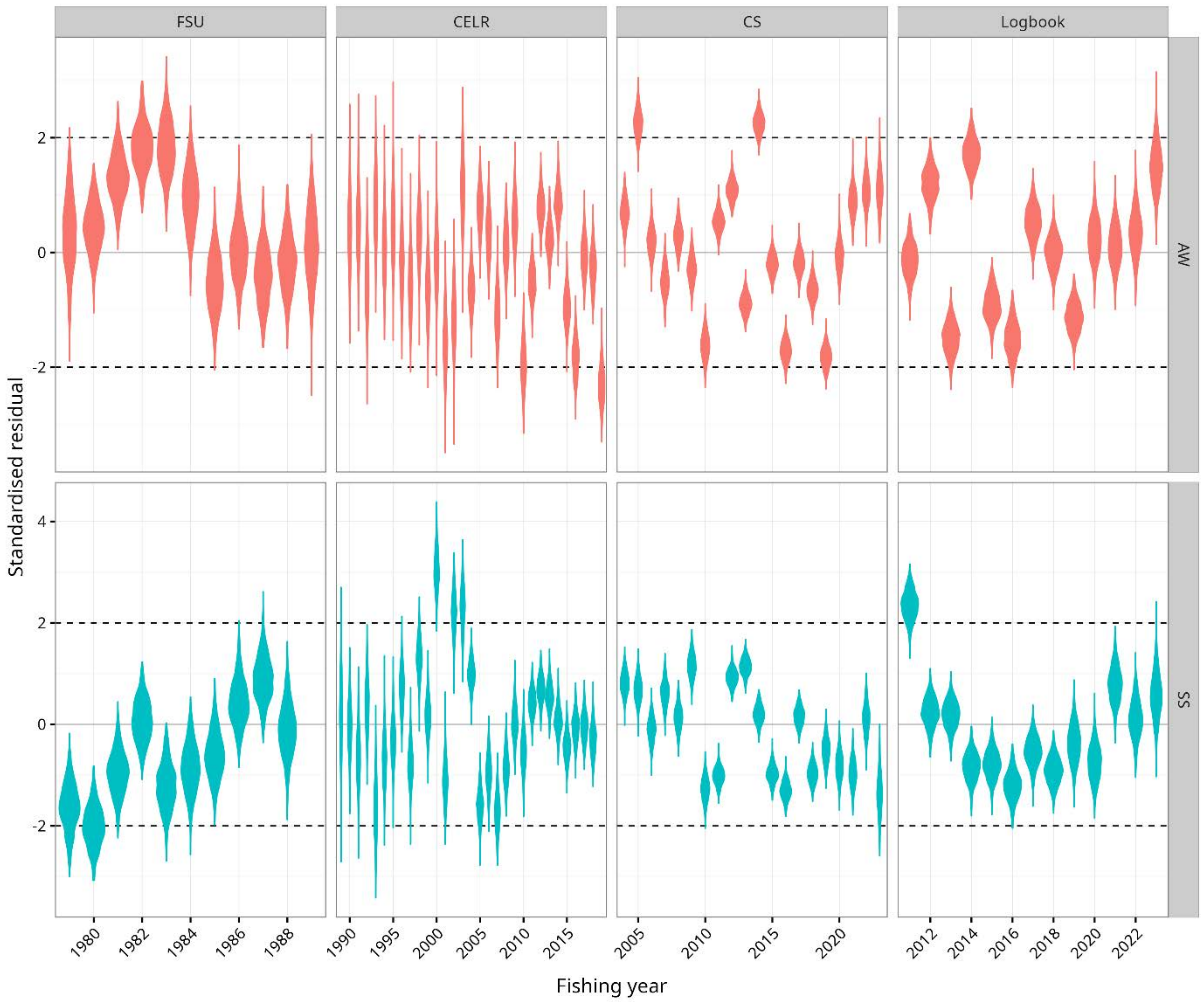


Figure F.8: CPUE residuals for the CR, FSU, CELR, and logbook series by fishing year and season in the base2 model run.

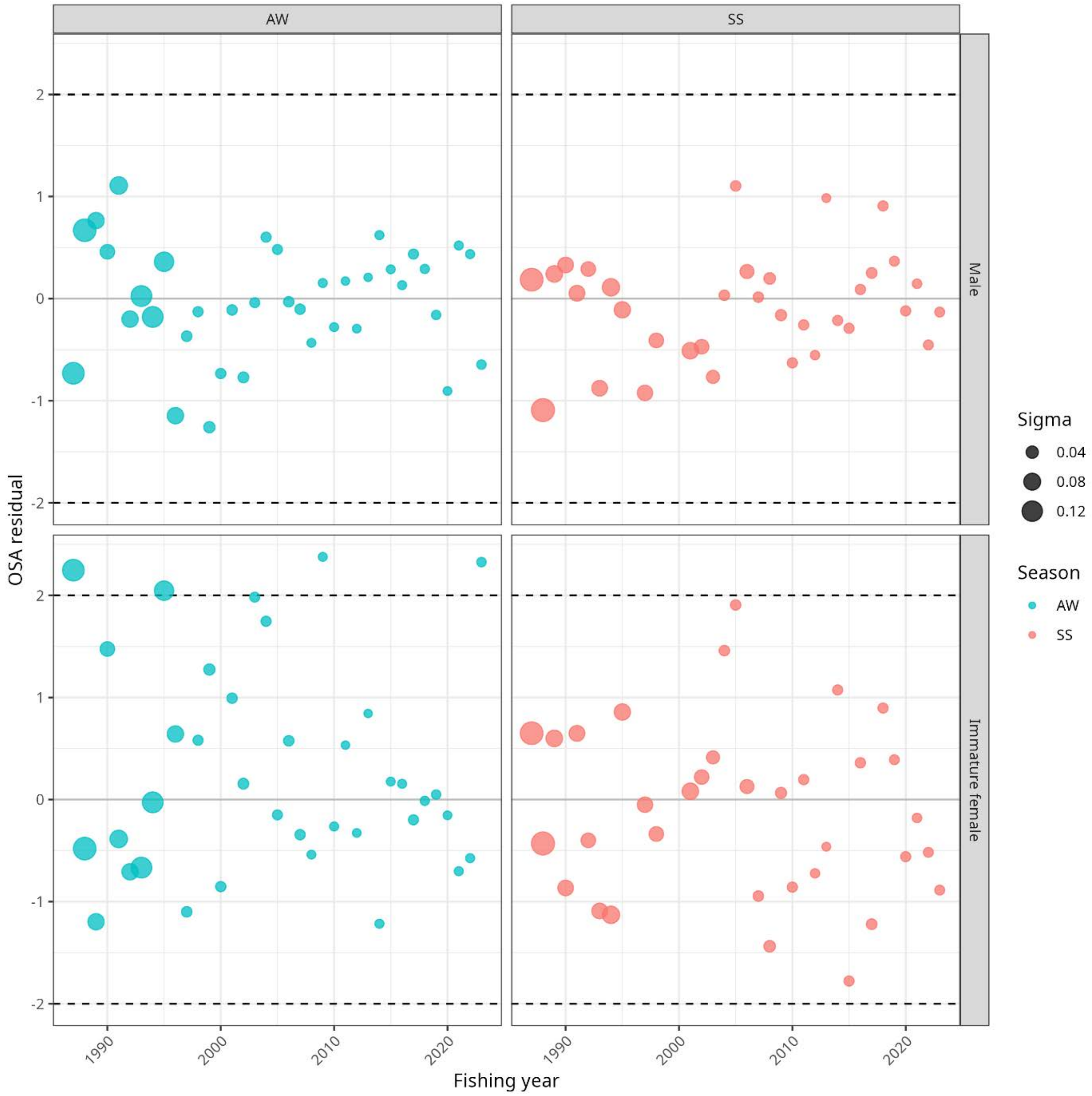


Figure F.9: **Median of the OSA residuals of the sex ratios by fishing year, season (AW = autumn/winter, SS = spring/summer) and sex, in the base2 model run.**

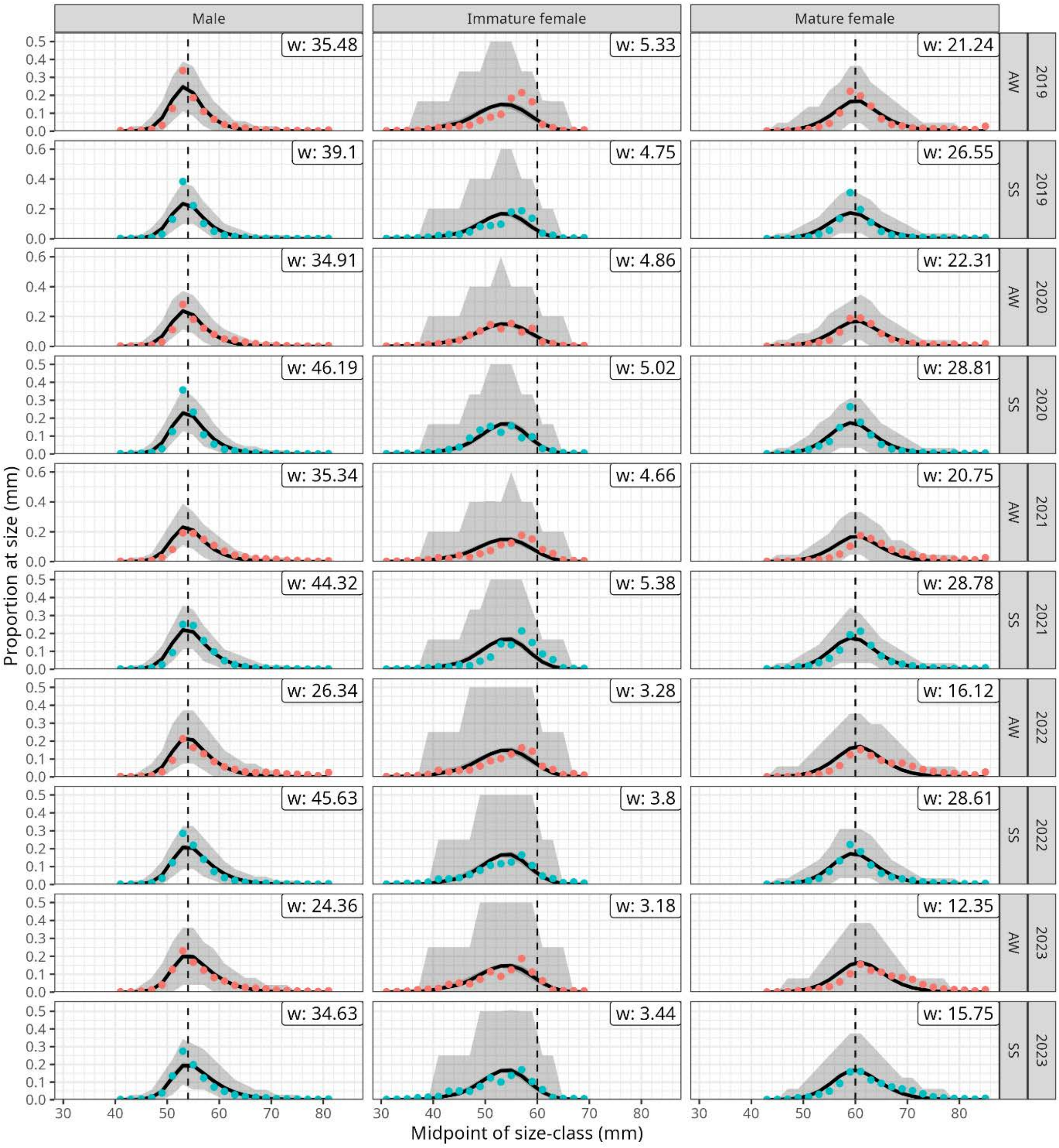


Figure F.10: Posterior distribution of the LFs compared with the observed LFs by fishing year, season (AW = autumn/winter, SS = spring/summer), and sex category in the <u>base2</u> model run. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. In each panel 'w' is the effective sample size.

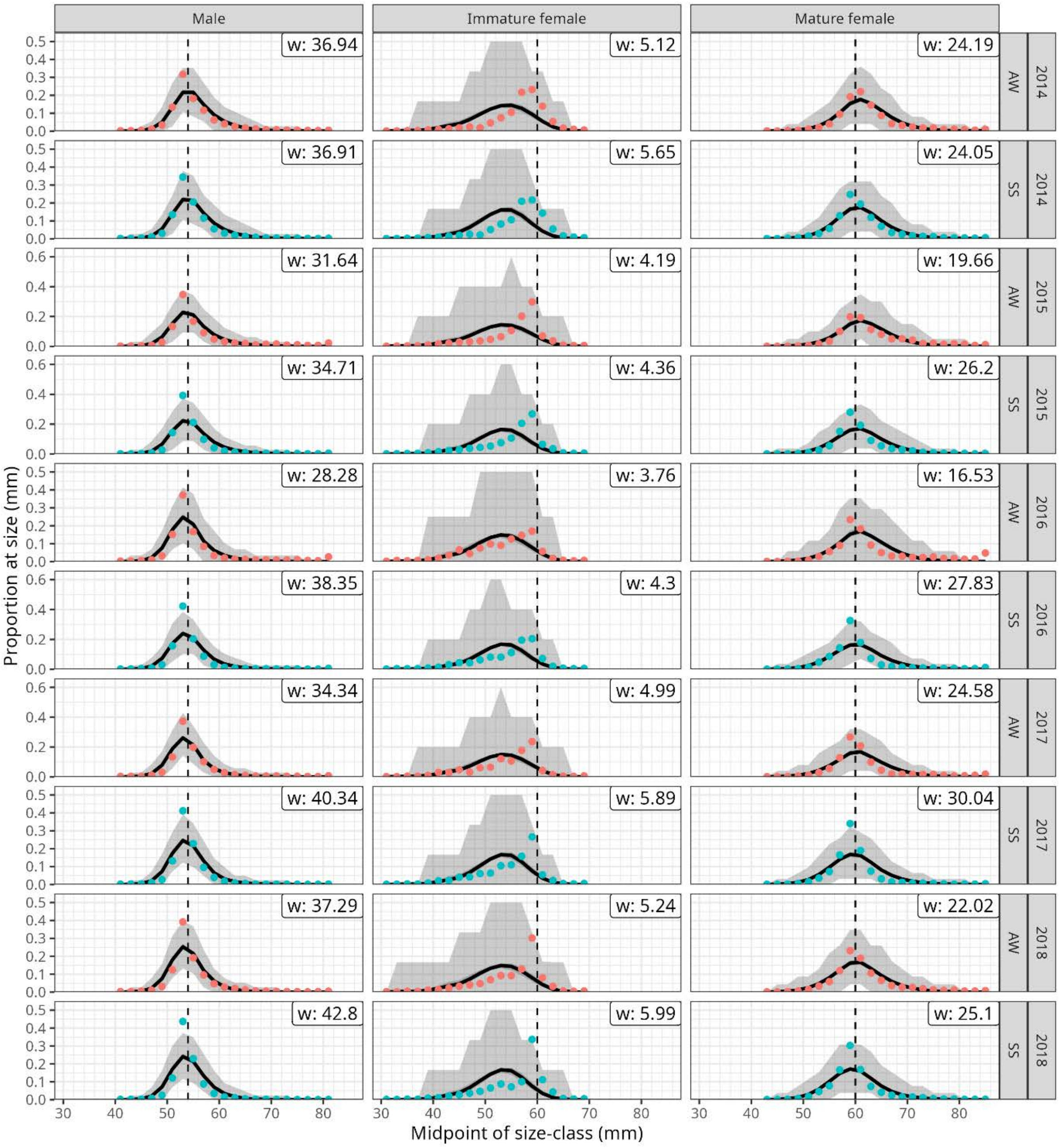


Figure F.10: (cont.):

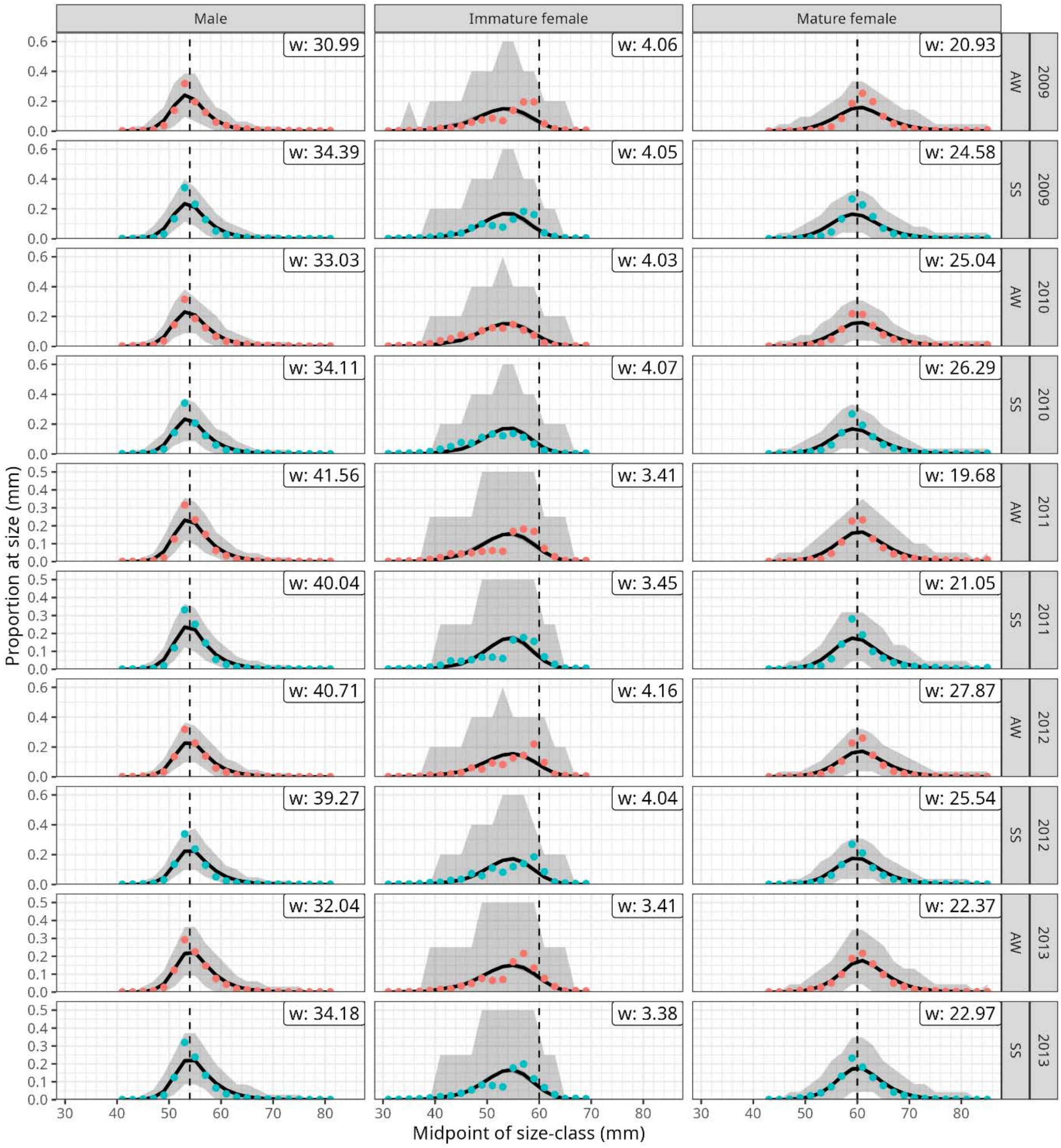


Figure F.10 (cont.)

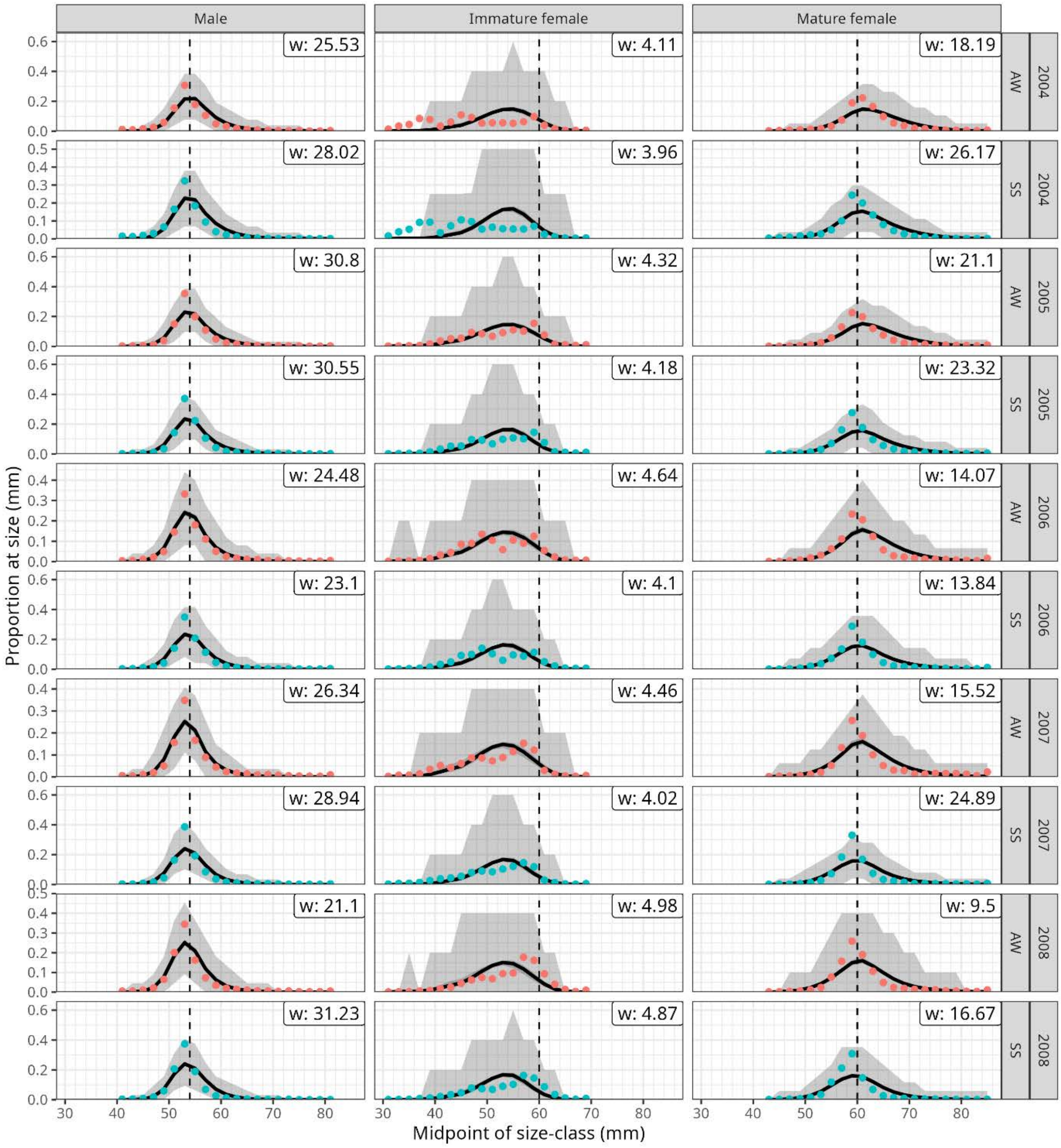


Figure F.10 (cont.)

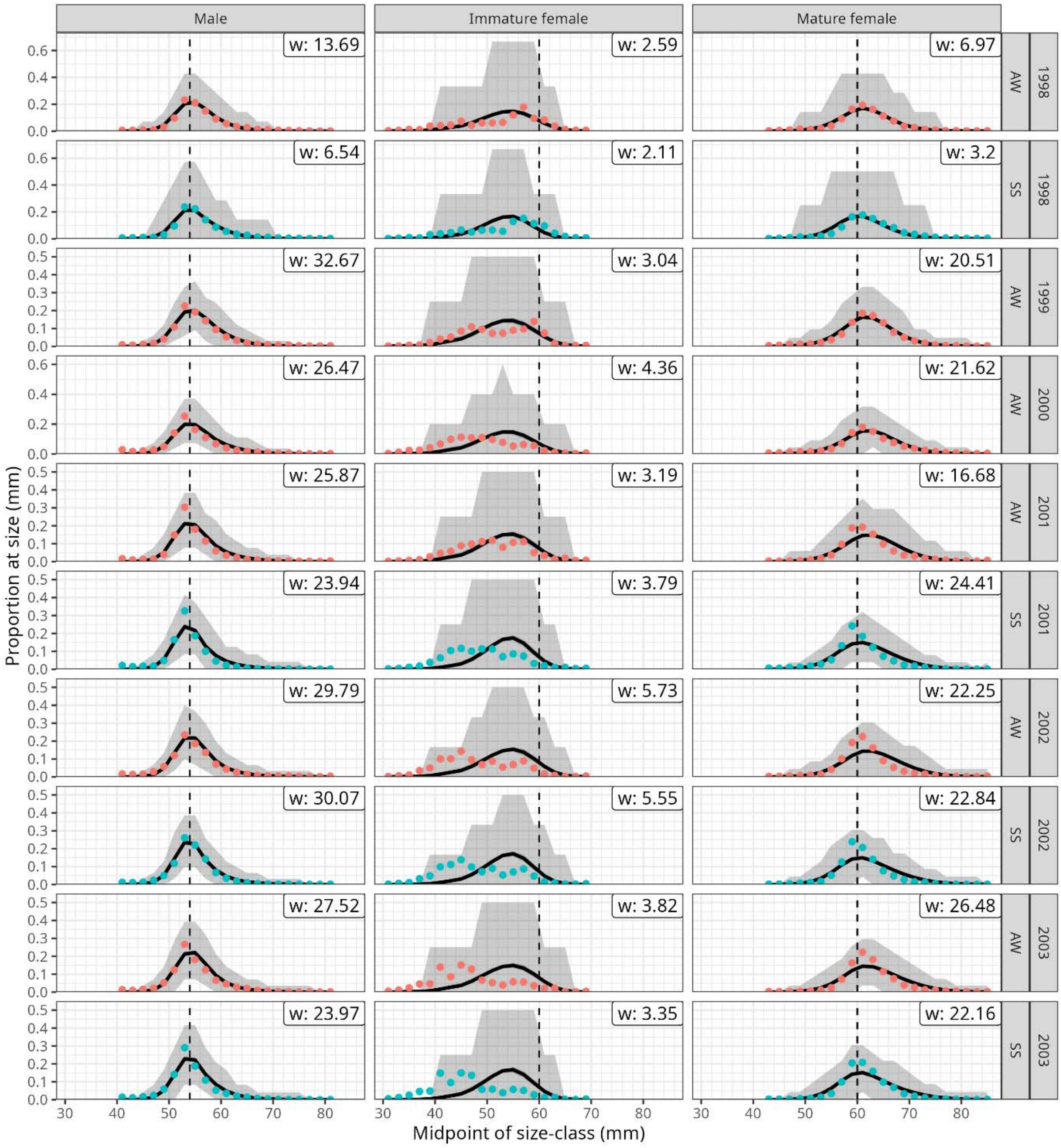


Figure F.10 (cont.)

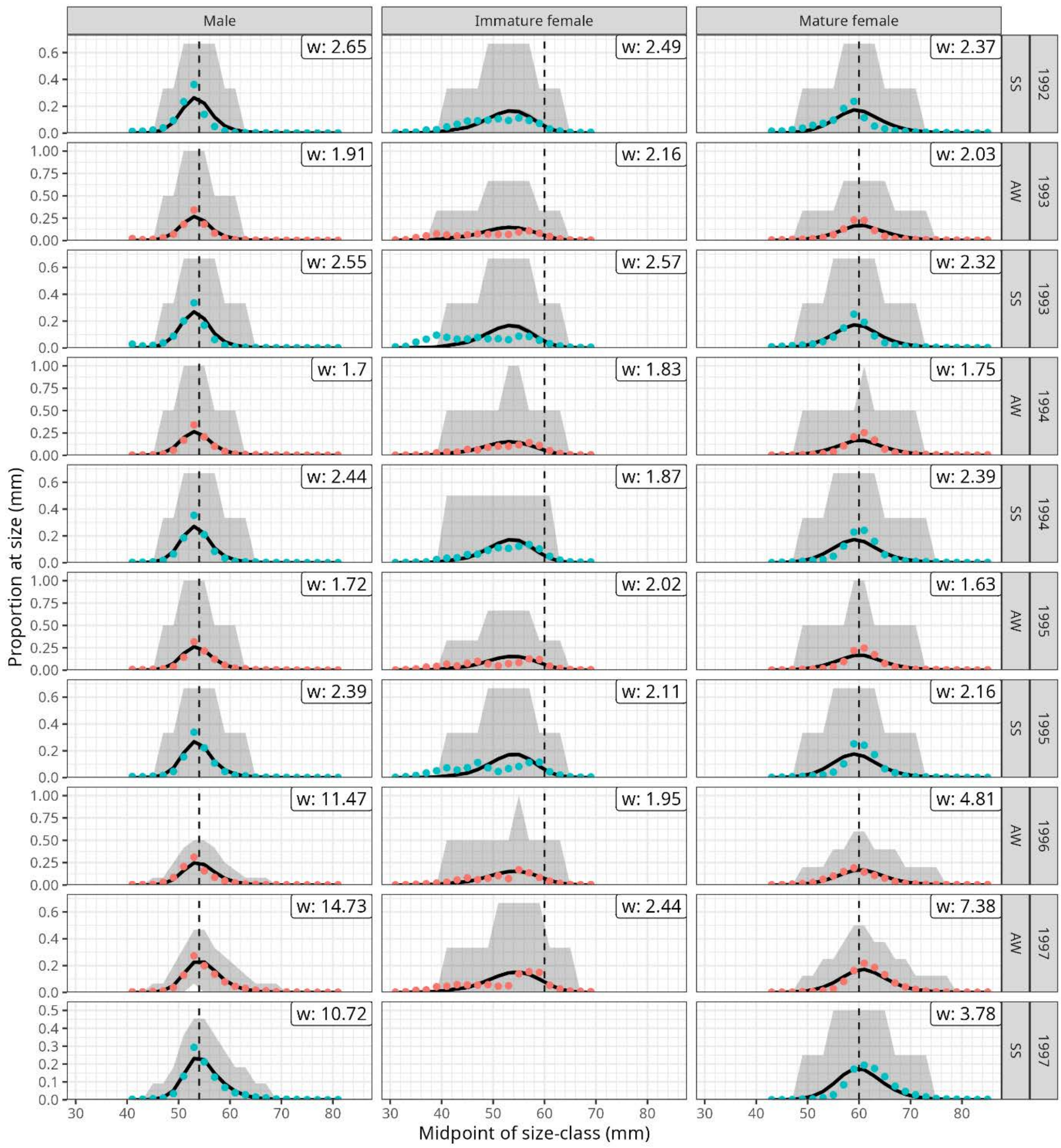


Figure F.10 (cont.)

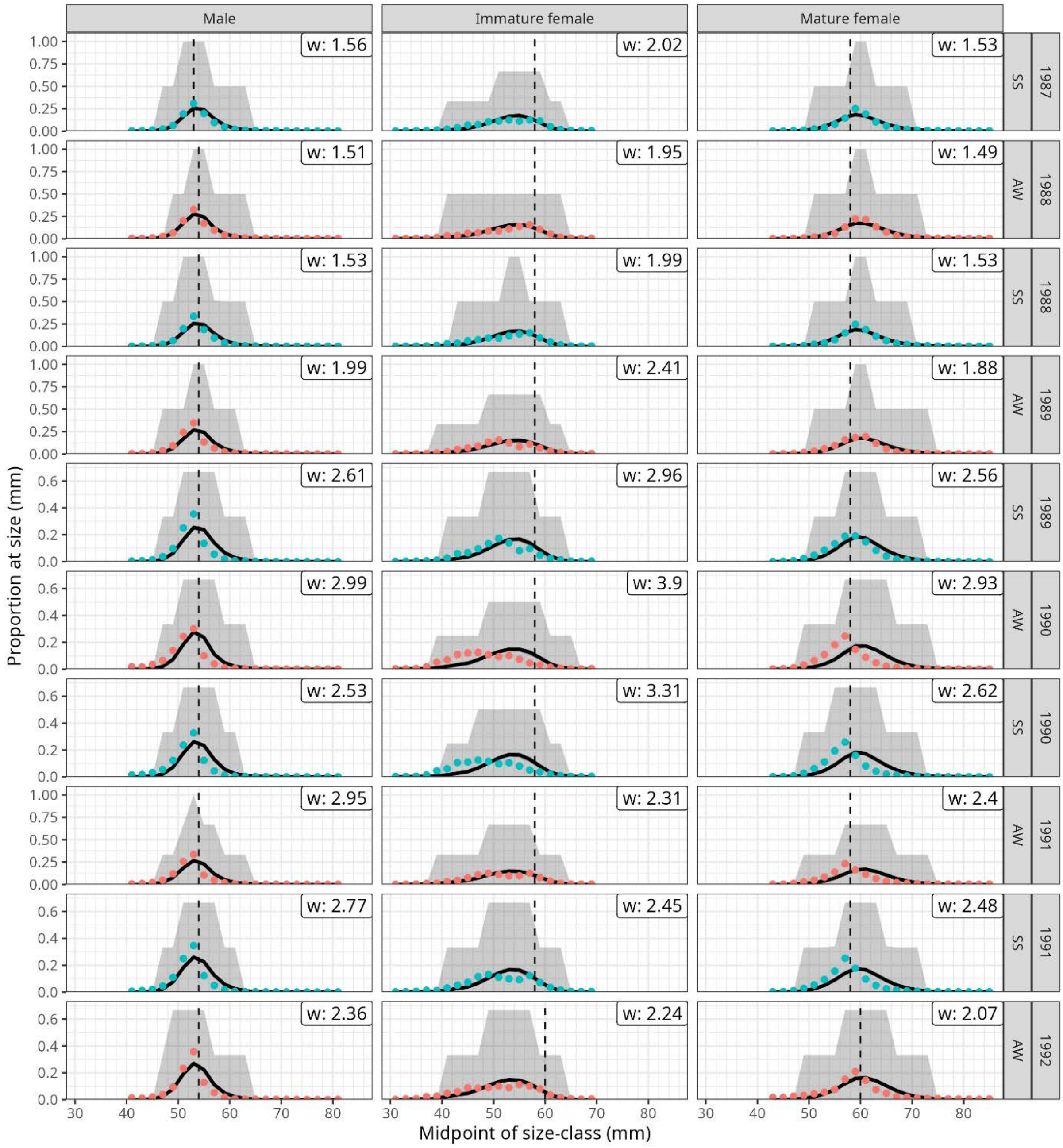
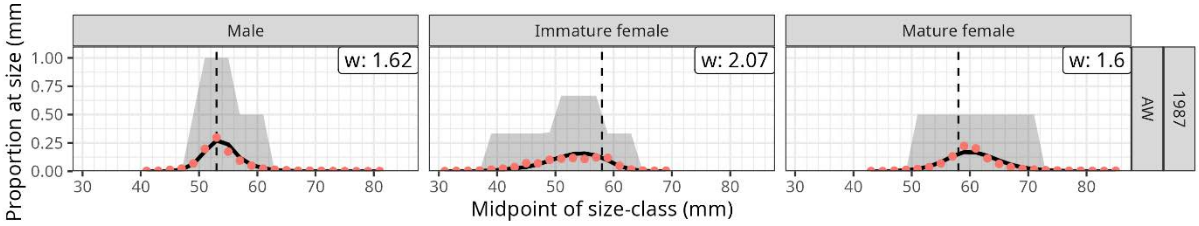


Figure F.10 (cont.)



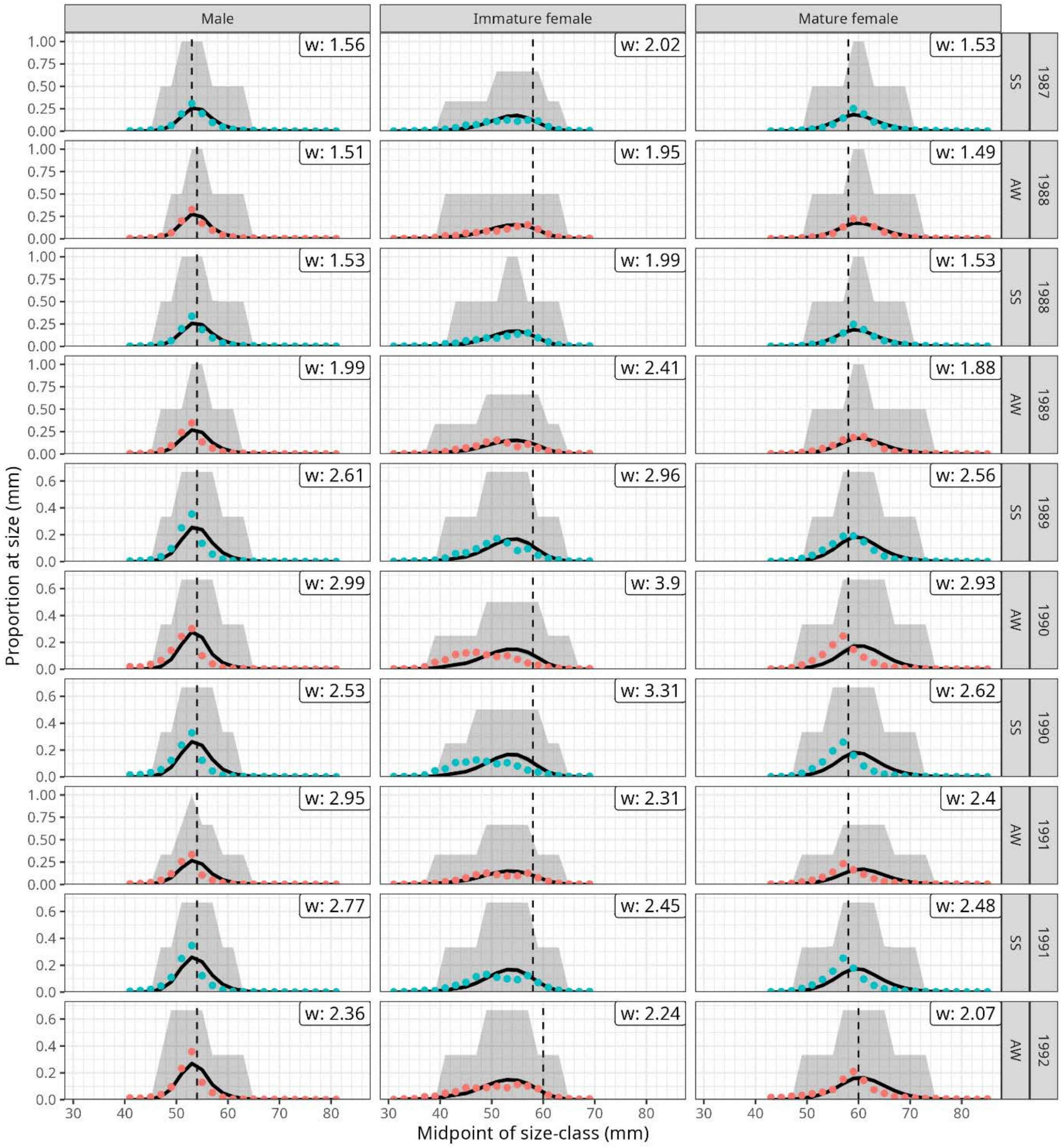


Figure F.10 (cont.)

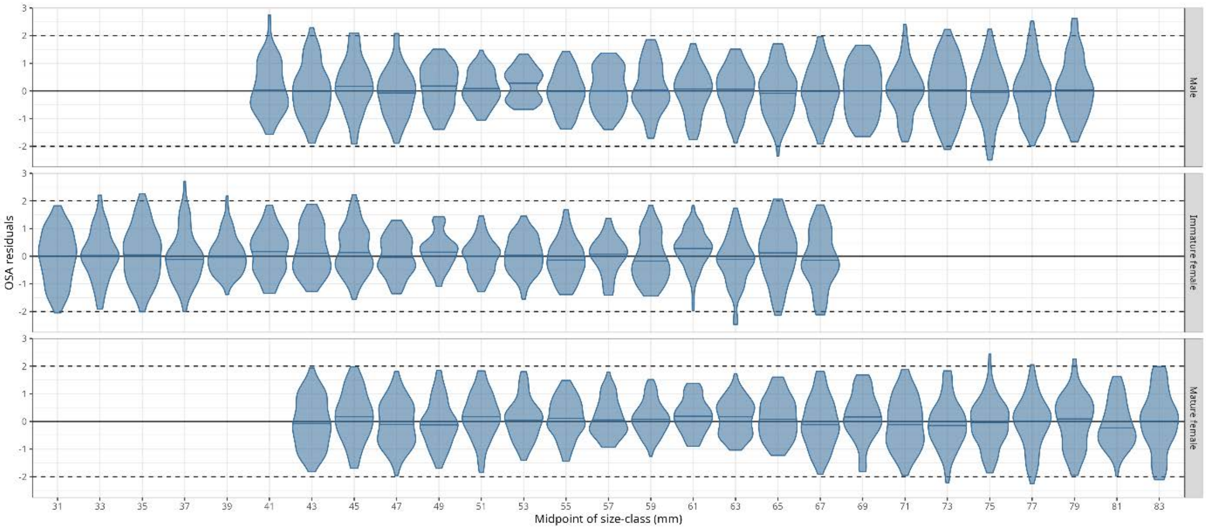


Figure F.11: Posterior distribution of OSA residuals from fits to the LF data by sex and 2 mm TW bin.

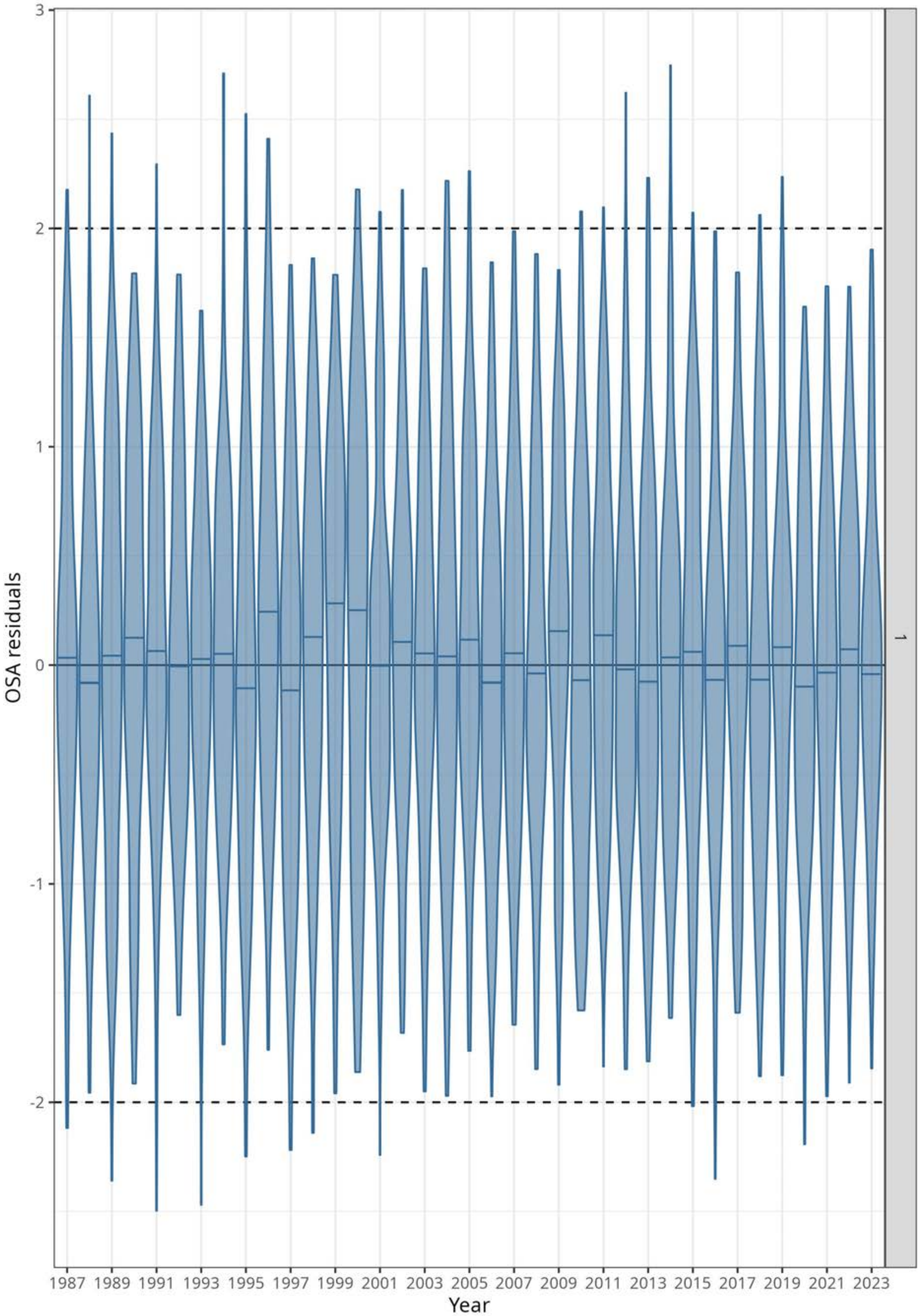


Figure F.12: Posterior distribution of OSA residuals from fits to the LF data by sex and fishing year.

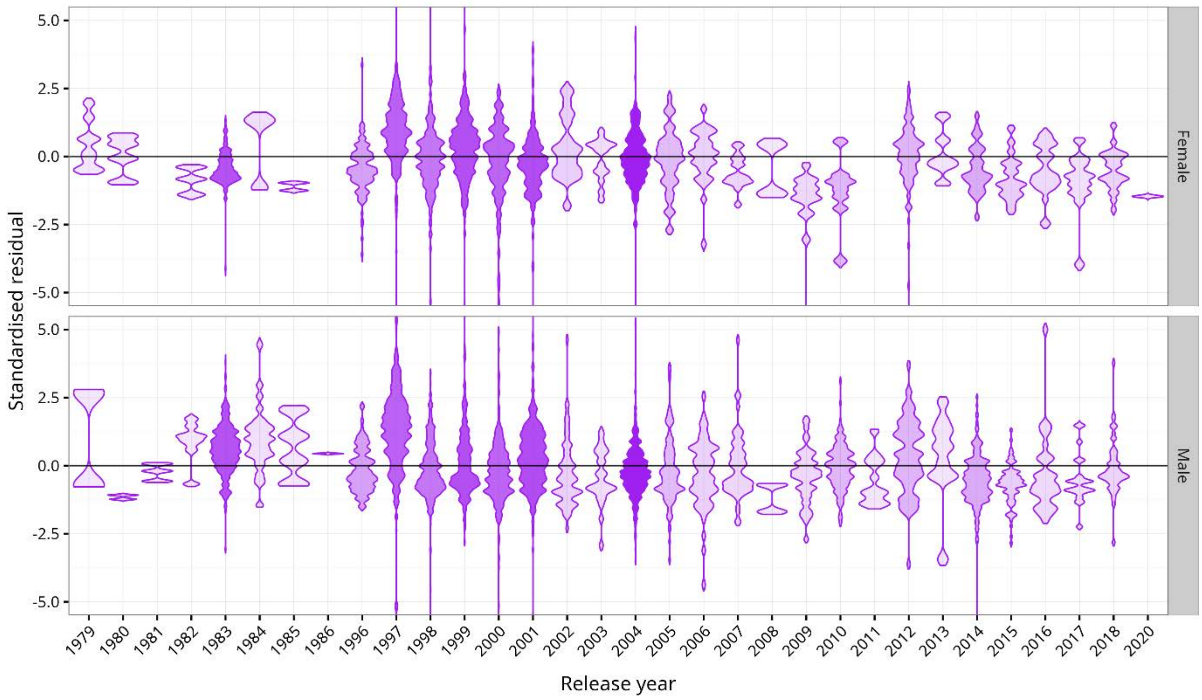


Figure F.13: Posterior distribution of standardised residuals from model fit to the tag data by fishing year of release and sex in the base2 model run. Shading intensity varies with number of observations.

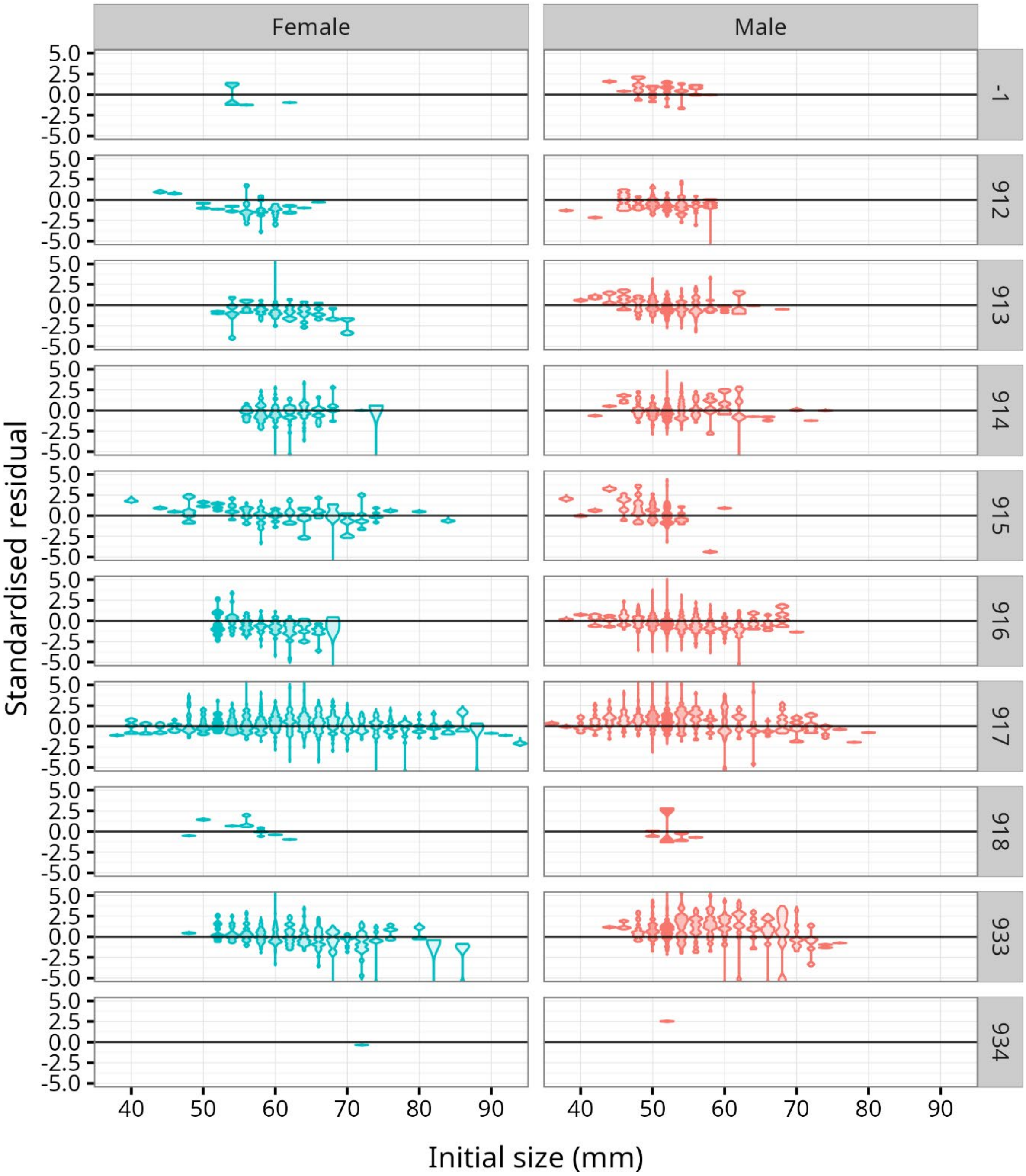


Figure F.14: Posterior distribution of standardised residuals from model fit to the tag data by statistical area of release, initial size, and sex in the <u>base2</u> model run. Shading intensity varies with number of observations.