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# The 2019 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 3

New Zealand Fisheries Assessment Report 2020/42

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## EXECUTIVE SUMMARY

**Webber, D.N.; Roberts, J.; Rudd, M.B.; Starr, P.J.; Large, K. (2020). The 2019 stock assessment of rock lobsters (*Jasus edwardsii*) in CRA 3.**

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This document describes the 2019 stock assessment of red rock lobsters (*Jasus edwardsii*) in CRA 3. This length-structured stock assessment used the lobster stock dynamics (LSD) model. Data inputs and technical decisions were reviewed by the Rock Lobster Fishery Assessment Working Group (RLFAWG), who oversaw this stock assessment.

The model was fitted to standardised catch per unit effort (CPUE) indices, size frequency, sex ratio, and tag-recapture observations. This document describes the procedures used to find acceptable base case models and shows the model fits. Uncertainty about growth rates resulted in two base case models fitted to different sets of the tag-recapture growth increment observations. Several sensitivity trials tested the assumptions of the base case models.

Model inference for this assessment was based on maximum *a posteriori* (MAP) fits and Markov chain Monte Carlo (MCMC) simulations. This document describes the diagnostics for each and shows the results of MAP and MCMC sensitivity trials.

The stock assessment depicts a stock that declined rapidly between 1960 and 1970, followed by a plateau until about 1980. Since 1980 the stock size has oscillated over roughly a 10-year cycle, with the stock increasing slightly after 1980 and then steadily declining until 1992. From there it increased until 1998, declined until 2004, and then increased again to 2013. Since 2013, the stock has declined and is projected to further decline at current levels of catch and assuming recent recruitment patterns. However, at no point did the spawning stock biomass fall below the soft limit (the default of 20%  $SSB_0$ ). This is due, in part, to the small size at maturity in CRA 3.

## 1. INTRODUCTION

This work addresses Objective 4 of the Fisheries New Zealand contract CRA2018-01. This one-year contract, which began in April 2019, was awarded to New Zealand Rock Lobster Industry Council Ltd. (NZ RLIC Ltd.), who sub-contracted Objective 4 to the New Zealand rock lobster stock assessment team.

*Objective 4 - Stock assessment: To estimate biomass and sustainable yields for rock lobster stocks.*

The National Rock Lobster Management Group (NRLMG) decided that CRA 1 and CRA 3 should be assessed in 2019. Data for both stocks were compiled by a team comprising Paul Starr (Starrfish), D'Arcy Webber (Quantifish Limited), Merrill Rudd (Scaleability), Kath Large (NIWA), and Jim Roberts (independent consultant). CRA 1 (Figure 1) was then assessed by Merrill Rudd and Kath Large, and CRA 3 (Figure 1) was assessed by D'Arcy Webber and Jim Roberts, with Paul Starr supporting both teams. Decisions on data and modelling choices were discussed and approved by the Rock Lobster Fishery Assessment Working Group (RLFAWG).



**Figure 1: The CRA 3 Quota Management Area (QMA) which is located off the northern coast of the North Island. The QMA boundaries are shown in the left panel. The statistical area boundaries within CRA 3 are shown in the right panel.**

This document describes a new stock assessment for CRA 3. All of the tables referred to in this document can be found in Section 6 and the majority of the figures in Section 7. This CRA 3 stock assessment used the lobster stock dynamics (LSD) model (Webber et al. 2018a) and assumed a multi-area stock. The stock was split into two regions: statistical areas 909+910 combined, and the separate area 911. The justification for adopting a multi-area model and the data used in this stock assessment are presented by Starr et al. (2020).

The CRA 3 commercial fishery is a trap or pot fishery operating in shallow water, fished by small boats on day trips. From 2010 (the 2010–11 fishing year<sup>1</sup>) to 2018, the CRA 3 total allowable commercial catch (TACC) was set using a management procedure (MP), based on the offset-year catch per unit effort (CPUE). The stock assessment that was scheduled for 2019 has been completed and is presented in this report. However, a new MP has not been developed in 2019. Because of changes to the collection of compulsory catch and effort data (see below), this form of management has been temporarily discontinued.

Allowances are added by the Minister for the non-commercial fisheries to produce a total allowable catch (TAC). Other management measures include protection of ovigerous (berried) females, a different minimum legal size (MLS) for each sex, and escape gaps in pots that allow small lobster to egress. The current MLS is 54 mm tail width (TW) for males and 60 mm TW for females for both the commercial and recreational fisheries, except for commercially caught males in statistical areas 909 and 910 from June to August, where it is 52 mm TW.

Beginning with the 1993–94 fishing year, the CRA 3 fishery was closed, by regulation, to all users from September to the end of November and the male MLS was set to 52 mm from June to August. The commercial fishery was additionally shut for all of December up to 15 January as well as being closed for the month of May. These regulatory closures ended after 2001–02, except the May closure was retained until the end of the 2013–14 fishing year. After the regulatory closures ended in 2001–02, the fishing industry instituted a voluntary closure from 15 December to 15 January, beginning with the 2002–03 fishing year. From the 2008–09 fishing year, the voluntary closure was extended to start in September in statistical areas 909 and 910. Area 911 (Mahia) opted at that time to remain open in the spring-summer (SS) season and chose to impose a 54 mm MLS on all male lobster taken.

The CRA 3 fishery extends from East Cape south to the Wairoa River (Figure 1). The 2018–19 TAC of 366.86 tonnes comprises allowances of 20 tonnes for recreational catch, 20 tonnes for customary harvest, 89 tonnes for illegal removals, and a TACC of 237.86 tonnes distributed among 51 quota share owners. In the 2018 fishing year, 25 vessels reported at least 1 tonne of CRA 3 landings (Starr et al. 2020). There is significant iwi involvement in quota share ownership, and fishing and rock lobsters have great cultural significance to local Maori. The commercial harvest has an approximate landed value of \$18.7 million based on an average port price of \$84,500/tonne (D. Sykes, RLIC, pers. comm.). There are two processing plants in Gisborne and product is also shipped to Wellington, Tauranga, and Auckland for processing and export. CRA 3 rock lobsters are packed for live export from three locations in Auckland.

The stock assessment was completed in a workshop held in Wellington during September and October 2019 and was presented to the Fisheries New Zealand mid-year Plenary during November 2019 (Fisheries New Zealand 2019).

## 2. STOCK ASSESSMENT

The CRA 3 stock was previously assessed in 2014 (Haist et al. 2015) using the multi-stock length-based model (MSLM). The lobster stock dynamics model (LSD, Webber et al. 2018a) was used for the 2019 assessment. This model is coded in Stan (Stan Development Team 2016, 2017). Maximum *a posteriori* (MAP) estimation and Markov chain Monte Carlo (MCMC) were used to make inference about the CRA 3 stock. A series of MAP sensitivity trials were explored and several of these were extended to a full Bayesian implementation using MCMC.

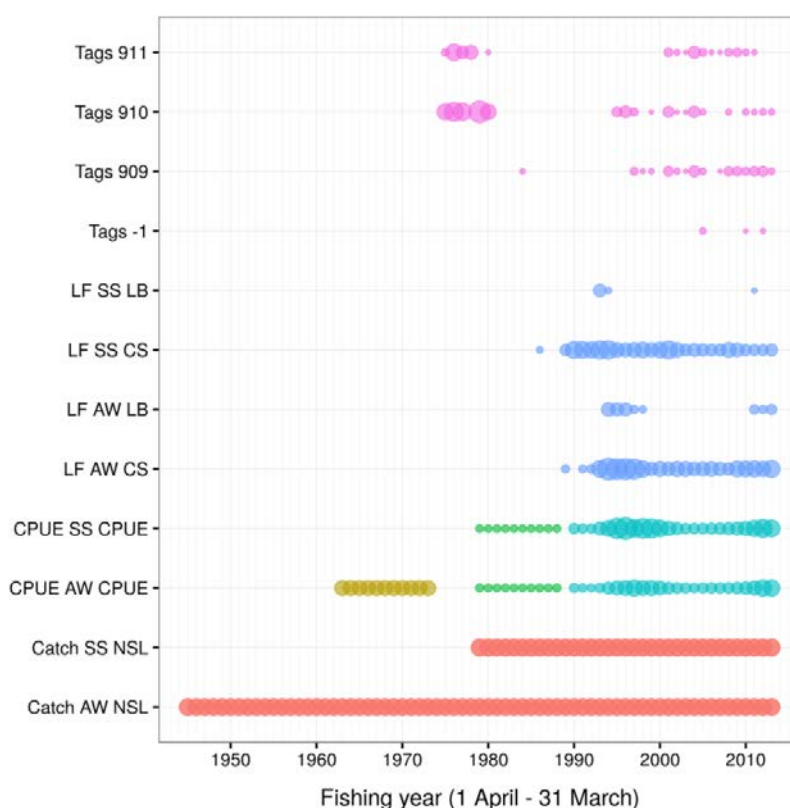
Uncertainty associated with the consequences of a change in the collection of compulsory commercial catch and effort data, moving from paper forms to electronic monitoring and on-board data processing, prevented the development of a new MP based on the outcome of this stock assessment. This resulted in the loss of using MPs to set the TACC over the next few years. Instead, we have explored multiple options for setting interim catch levels without a MP, including a range of projections based on current

<sup>1</sup> Fishing years extend from 1 April to 31 March and are designated with the first year of the pair.

catch levels and identifying the fixed level of catch that maintains current vulnerable biomass. We present projections based on current catch levels in this document.

## 2.1 Data

All data (catch, CPUE, length frequency, and tagging) were allocated to one of two regions, with one region defined by combining statistical areas 909 and 910 (Figure 1) and the second region consisting of statistical area 911 (see Starr et al. 2020 for full documentation). This procedure was straightforward beginning with 1979 because the statistical area definitions have been consistent since that year. Reconstruction of the catch before 1979 was more problematic because the early spatial data, which only spanned the years 1963 to 1973, used alternative statistical area definitions and the remaining years had no spatial data, thus were filled by interpolation (Starr et al. 2020). Length frequency data collection began in 1986 and tagging data collection began in 1975, but the early tag release information could be assigned to a statistical area. There was some movement of tags between statistical areas, so the area of release was used to allocate tags to either region. The temporal extent of the data is illustrated in Figure 2.



**Figure 2:** Temporal extent of data for each fishing year used in the CRA 3 stock assessment. The sizes of the bubbles respectively represent the relative number of recaptured tags, the effective sample size for length frequency distributions, the standard deviation for CPUE series, and a fixed size for catch. The different bubble colours represent different data sets (e.g., for CPUE, the CR, FSU, and CELR series). The tags coded ‘Tags -1’ were not used in this stock assessment because these tags were not assigned to a statistical area. The codes are: SS=spring/summer, AW=autumn/winter, LB=logbook, CS=catch sampling, NSL=non size limited.

Following the example of the most recent CRA 2 and CRA 6 stock assessments (Webber et al. 2018b, Rudd et al. 2019), a vessel explanatory variable was included in the CPUE standardisation procedure (see Starr et al. 2020) and CPUE was split into three series:

- The catch rate (CR) series is a non-seasonal un-standardised daily catch rate from 1963 to 1973. This series is available for 909+910 only. Catchability ( $q$ ) is assumed constant over this period.

- The Fisheries Statistics Unit (FSU) series is a seasonal (spring/summer or autumn/winter) standardised index from 1979 to 1988, with a separate time series for each region (i.e., the series for each region was standardised in different models). The standardisation model includes year, month, and statistical area explanatory variables, but no vessel effect. Catchability ( $q$ ) is assumed constant over this period, but a different  $q$  is estimated for each region.
- The Catch Effort Landing Return (CELR) series is a seasonal standardised time series from 1989 to 2018 with different series for each region derived within the same model (therefore estimates of CPUE between each region are relative to each other). A vessel explanatory variable is used in this model (using a subset of ‘core’ vessels that fished CRA 3 for at least five years). Catchability ( $q$ ) is assumed to increase over time at a constant rate, with the rate of change estimated in the model by the  $q_{drift}$  parameter. The same  $q$  is used for both 909+910 and 911 because the two series were estimated within the same standardisation model and therefore were relative to each other. These assumptions were discussed and agreed by the RLFAG.

This assessment combined observations from lobsters tagged and recaptured by commercial operators in CRA 3 and tagging data from inside the Te Tapuwae o Rongokako Marine Reserve, which is in the 910 statistical area (Figure A3-1, Freeman 2008). Initial model exploration suggested that individuals recaptured multiple times may have slower growth rates. However, it was decided that this was a second-order effect compared with the differences in estimated growth rates when sub-setting the tag data to account for the effects of a moulting bias. Therefore, tags with multiple recaptures were included in the stock assessment. Because tag releases for males tended to immediately precede moulting, a large proportion of these tags had been at liberty for less than a year. Consequently, it was thought that this effect could bias the estimation of growth (which does not explicitly account for moulting). For CRA 3, this hypothesis was supported by a preliminary analysis of the mark-recapture data (outside the assessment model), which obtained faster growth from individuals recaptured after less than one year at liberty for both sexes (Appendix 1, Figure A1-7). When the LSD model was run using different subsets of the tagging data (i.e., using all data, or a subset excluding all recaptures within one year of the date of release), the estimated growth rates were very different, and it was unclear which subset of the tags should be used. As such, the RLFAG agreed that the assessment should include both tag data sets in all model runs.

The 2014 CRA 3 stock assessment estimated two growth stanzas, one from 1945 to 1981 and the second from 1995 to 2013 (using interpolated growth from 1982 to 1994). The 2019 stock assessment did not repeat this approach. The justification for this change is presented in Appendices 1 and 2, coupled with the concern that tags that had been at liberty for less than a year showed faster growth rates. The faster growth rates present a potential bias which may have contributed to the decision to estimate separate growth stanzas because much of the early tag data had been at liberty for less than one year (i.e., mean number of days at liberty before 1986 is 189 days whereas the mean number of days at liberty between 1995 and 2014 is 330 days).

Puerulus settlement data were available for CRA 3, obtained from collectors located along the coast immediately to the north of Gisborne (Forman et al. 2018). A standardised annual puerulus index for CRA 3 was estimated for all years from 1987–88 to 2018–19 (see table 12, Fisheries New Zealand 2019), showing variable puerulus settlement through time. However, this index was found to be uninformative to recruitment by the previous CRA 3 stock assessment (Haist et al. 2015). There was insufficient time to revisit the settlement index while the assessment work was proceeding, resulting in no attempt to include a puerulus index in this stock assessment. However, raw observations from early (pre-1980) dive survey length frequency sampling of juvenile lobsters were used to derive the growth rates of juvenile lobsters (analysis in Appendix 1).

In 1945 and 1946, there was no MLS for rock lobster in New Zealand. In 1947, an MLS restriction was implemented for rock lobster based on a measurement of total length (total length from tip of rostrum to tip of tail) in inches. This form of MLS regulation was the only restriction up to 1952 when a minimum tail length of 5.75 inches was additionally introduced (raised to 6 inches in 1959). The

total length MLS was retained until 1969. The tail length measurement standard was subject to some abuse because tails could be stretched, although this MLS measurement standard was necessary because a significant fraction of the catch came from Fiordland where it was permissible to tail lobsters at sea. MLS was changed to a width measurement (in mm) across the spines of the second abdominal segment (called tail width or TW) in 1988 for all New Zealand red rock lobster (except for CRA 7), necessitating the conversion of the pre-1988 regulations into equivalent TW measurements for use in the stock assessment model (see Breen et al. 1988 for equations and supporting analyses) (Table 1).

Handling mortality was assumed to be 10% for all lobsters returned to the sea before 1990 and 5% from 1990 to present. This reduction in handling mortality was agreed by the RLFAWG in recognition of the start of the live export market and the introduction of rock lobster into the QMS. Handling mortality was applied to undersized lobsters of both sexes taken in either season by the size-limited (SL) fishery as well as to mature females taken in the AW SL fishery. It was assumed that there were no discards in the non-size-limited (NSL) fishery.

## 2.2 Model

The LSD model allows stock assessments for individual stocks to be split into two or more regions (e.g., groupings of statistical areas), allowing differences in some estimated parameters among regions. This stock assessment splits the CRA 3 stock into two regions with statistical areas 909 and 910 being one region and 911 the other. This was done in response to differences in the CPUE and size composition of sampled individuals among the three statistical areas (see Starr et al. 2020 observer catch sampling and logbook length frequency data). The stock assessment could not be split into three regions, because data were limited in the 909 statistical area.

The first fishing year in the model was set to 1945 because this was the year that the commercial fishery data began. The model assumes an unfished population before 1945. The last year in the model is 2018, because this was the last full year with data. The model includes two six-month seasons within a fishing year: autumn-winter (AW, April through September) and spring-summer (SS, October through March) from April 1979 to the end of March 2019. Data from 1945 to 1978 are combined into 12-month (January-December) calendar years because of the lack of seasonal data from 1945 to 1962 and from 1974 to 1978. Data from the months of January-March 1979 are added to the 1978 calendar year to ensure all catches are included. The model tracks the numbers of immature females, mature females, and males in 31 2-mm TW bins (i.e., {[30, 32), [32, 34), ..., [90, ∞)}). In summary, the model dimensions are:

- Fishing years: 1945–2018 (i.e., ending with the 2018–19 fishing year), with a sensitivity starting in 1979 (see sensitivities in Section 2.5.3)
- Two seasons: AW and SS during each fishing year from 1979 onwards, one season from 1945 to 1978
- Three sex categories: immature females, mature females, males
- Tail width bins: 31 2-mm wide bins from 30 mm to 90 mm tail width (last bin is a plus bin)

Commercial and recreational lobster fishing is not permitted within the Te Tapuwae o Rongokako Marine Reserve, which is located within CRA 3, approximately 15 km north of Gisborne (Figure A3-1). The reserve was implemented in 1999, and the previous CRA 3 stock assessment model accounted for the reserve by excluding 10% of recruitment after 1999 and reducing the population size by 10% in 1999 (Haist et al. 2015). This value of 10% was chosen because it approximated the proportion of the historical annual CRA 3 catch that had been taken annually within the marine reserve boundaries. In this stock assessment, a more quantitative representation of the percentage of excluded recruitment represented by the reserve was developed, based on reef area (Appendix 3). On this basis, the percentage of recruitment assumed to be within the reserve was updated to 3.2%, which is the amount by which recruitment was decremented after 1999.

## 2.3 Parameters and priors

A list of all estimated model parameters is given in Table 5. All priors and bounds used for these parameters are provided in Table 6 and are plotted in Figures 14–16. Wide uniform priors were specified for average recruitment ( $R_0$ ) and the catchability coefficients ( $q$ ) for each CPUE series. Beta priors were used for all parameters constrained to be between 0 and 1, including: the growth parameter  $G_{diff}$ ; the vulnerability parameters ( $vuln$ ); and, when applicable, the initial exploitation rate ( $U_0$ ), and density-dependent growth parameter ( $G_{dd}$ ). An informative lognormal prior was specified for natural mortality ( $M$ ) and an informative prior based on an unpublished meta-analysis was specified for  $GCV$ . An informative prior was also specified for the  $Galpha$  parameter and is based on the growth rates of juvenile lobsters described in Appendix 1. Uninformative normal prior distributions were specified for all other model parameters. These uninformative normal priors do not influence the outcome of the stock assessment, but they are used to improve MCMC mixing in Stan by restricting the amount of time the algorithm is likely to spend exploring extremely unlikely parameter values.

The vulnerability parameters, which estimate the relative vulnerability of each seasonal sex category, were assumed to be different within each region. The previous CRA 3 stock assessment estimated different vulnerability parameters for females during the AW. In the 2019 assessment in both regions, the vulnerability of immature females and mature females during the AW was assumed to be the same and the vulnerability of immature females and mature females during the SS was also assumed to be the same. This simplification helped reduce the number of model parameters and had little impact on the stock assessment because so few immature females are caught and therefore are unavailable to inform a separate vulnerability from mature females. The three vulnerability parameters for each region were estimated relative to the vulnerability of males during the AW (which is fixed to 1) because males during AW have the highest fishing mortality among the six available sex/season categories (Table 8).

## 2.4 Assessment indicators

Stock assessment indicators requested by Fisheries New Zealand and the RLFAWG are summarised in Table 9. These included several based on vulnerable biomass, such as current biomass ( $B_{2019}$ ) and the minimum of the vulnerable biomass trajectory ( $B_{MIN}$ ). Vulnerable biomass is defined as start-of-season AW biomass, which does not include mature females. Vulnerable biomass takes MLS, selectivity, and sex/seasonal vulnerability into account and is the biomass available to the fishery. Vulnerable reference biomass is calculated by applying the MLS and selectivity from the final model year to all previous years, including those years where alternative regulations applied.

There is no agreed reference biomass indicator ( $B_{REF}$ ) for CRA 3. The estimated biomass that enables the stock to deliver the maximum sustainable yield ( $B_{MSY}$ ) is sensitive to growth and mortality estimates and the assumptions under which it is estimated. The RLFAWG and the 2019 Plenary concluded that more work was needed to evaluate how this quantity should be calculated for rock lobsters. Consequently MSY-related quantities are not reported here.

Spawning stock biomass (SSB) is defined as the biomass of all mature females at the start of AW.  $SSB_0$  is defined as the spawning stock biomass at unfished equilibrium with  $R_0$ . The soft and hard limits are set at the default 20%  $SSB_0$  and 10%  $SSB_0$ , respectively.  $H_{2018}$  and  $H_{2023}$  are the model estimate of the amount (in tonnes) of handling mortality in the final model year (2018) and final projected years (2023).

In addition to the reference point indicators, the RLFAWG requested the posterior distributions of several ratios (e.g., the ratio of current biomass to  $B_0$  and  $B_{MIN}$ ), as well as the probability of each ratio being below specific levels important for management. These indicators were calculated from the MCMC posterior samples.

## 2.5 Maximum *a posteriori* (MAP) inference

Maximum *a posteriori* inference was used for exploring potential model options without committing the computing time required for Bayesian inference. Two base case models were developed, and sensitivities were used to test several of the base case model assumptions.

### 2.5.1 Matching previous multi-stock length-based model to current LSD model

Because the previous CRA 3 stock assessment used the multi-stock length-based model (MLSM), developing the 2019 base case models first involved replicating the previous assessment model in LSD before moving on to new base case models. This process involved fitting to data up to and including the 2013 fishing year and specifying settings to be as similar as possible to the previous assessment, to obtain the best match possible between the old and the new model. A reasonable match was achieved and this model run was named *1\_base2014* (Table 2, Figure 3).

Following this initial match, data assembled for the 2019 assessment, and other improvements to the modelling of rock lobster stocks that have been incorporated into recent assessments, were iteratively added until the model had the desired attributes of a new base case, but was still based on data up to the end of 2013 (Table 2, Figure 4). Several of the changes to the data and model assumptions resulted in a mixture of increased and decreased estimates of unfished biomass. For example, the model runs *2\_handling*, *3\_splitCPUE*, and *4\_maturity* all altered the unfished biomass, whereas the biomass since 1990 was very similar in all of these runs (Figure 4). Conversely, the models runs *5\_tagfile*, *6\_catch*, and *7\_cpue* had different biomass trajectories since 1990 (Figure 4).

### 2.5.2 MAP base case

After completing the model runs described in the previous section (Table 2), the model was ready to be extended to include data up to the end of the 2018 fishing year. Searching for a base case beyond the *7\_cpue* model run involved:

- Determining LF bins for fitting;
- Checking the season and sex used to set the vulnerability to 1 to ensure that no estimated sex- and seasonal-specific vulnerability was on the upper bound of 1;
- Adjusting dataset weights iteratively until the SDNRs were close to 1 and/or the MARs were close to 0.67 (except for tagging data which are self-weighting and length frequencies which are weighted using Francis iterative re-weighting; Francis 2011); then
- Comparing models with different subsets of the tagging data, i.e., excluding the tag data from within the marine reserve and excluding all tags that had been at liberty for less than 1 year.

Major model options and choices included:

- **Length-weight:** general North Island length-weight parameters used (Table 7)
- **Recruitment size:** mean 32 mm with standard deviation 2 mm
- **Mature females:** allowed to be landed in SS but not in AW
- **Likelihoods:**
  - o lognormal for three CPUE series (CR, FSU, and CELR)
  - o robust normal for tags
  - o multinomial for LFs, fitted to proportions for males, immature females, and mature females, with each sex category normalised separately
  - o multinomial for sex ratio
- **Data weighting:** determined iteratively. There is no re-weighting of tag data because these data are self-weighting through estimation of an observation error parameter (*Gobs*)
- **Fishing mortality dynamics:** instantaneous using the Newton-Raphson algorithm (Press et al. 2007) with 3 iterations to iteratively solve the Baranov catch equation
- **Growth model:** Schnute-Francis
- **Recruitment deviations (*Rdevs*) estimated:** 1945–2016 (final two years are set to the 2016 estimate given the lack of information in the data for recent recruitment)
- **Selectivity:** “double-normal” with right-hand limb parameter fixed at 200. One selectivity period for males in 909+910, one selectivity period for males and females in 911, and two



selectivity periods for females in 909+910 (1945–1992 and 1993 onwards) (informed by the analysis of seasonal fishing patterns in Appendix 2)

- **Handling mortality:** two periods (10% from 1945 to 1989 and 5% from 1990 to 2018)
- **Stock-recruitment:** off
- **Density-dependent growth:** off
  - o Explored a sensitivity with density-dependence on (see sensitivities in Section 2.5.3)
- **Three CPUE series with four estimated catchability coefficients ( $q$ ):**
  - o The catch rate (CR) series is a non-seasonal unstandardised daily catch rate from 1963 to 1973 and applies to 909+910 only. Catchability ( $q$ ) is assumed constant over this period
  - o The Fisheries Statistics Unit (FSU) series is a seasonal standardised index from 1979 to 1988. The standardisation model includes year, month, and statistical area explanatory variables but no vessel effect (however a vessel effect was explored and the result was no different). Catchability ( $q$ ) is assumed constant over this period with a different  $q$  for each region
  - o The CELR series is a seasonal standardised series from 1989 to 2018 with a vessel explanatory variable (vessels required to have fished CRA 3 for least 5 years). A single catchability coefficient was estimated/used for both regions
- **$qdrift$  parameter:** estimated annual proportional increase of the CPUE  $q$  for CELR series
  - o Sensitivity test explored fixing  $qdrift = 0$
- **Catch from 1945 to 2018:** as documented by Starr et al. (2020); note that illegal catch from 1981 to the present was set at 20% of the total 1981–2018 commercial catch, with annual catches allocated uniformly by year
  - o Sensitivity test explored the illegal catch from 1981 to present set at 10% of the commercial catch based on the pattern of CPUE

Parameter estimates, likelihoods, and indicators for the base case are given in Table 10 to Table 15, which also report the sensitivity runs. Parameter estimates were checked against the estimates from the previous CRA 3 stock assessment and other rock lobster stock assessments, and all seemed to be consistent with previous estimates, or changed predictably. Diagnostic plots for both of the base case model runs were checked in detail. These diagnostics consisted of model predictions relative to observed data or the standardised residuals of the model fits to the data. We do not present MAP diagnostics in this document, though these were very similar to the MCMC diagnostics.

The vulnerable reference biomass of the two base case model runs was compared with the previous CRA 3 stock assessment (Figure 5). The two new base case models predicted a lower vulnerable biomass in most years. The unfished biomass in the two new base cases was considerably lower than in the 2014 model. The two new base case models are reasonably different in that:

- $r1\_qdrift$  has smaller male growth increments for smaller individuals than  $r2\_qdrift$  as indicated by the  $Galpha$  parameter which is 7.47 for  $r1\_qdrift$  and 10.23 for  $r2\_qdrift$ . However, this relationship is reversed for larger individuals as indicated by the  $Gbeta$  parameter which is 2.65 and 1.28 for  $r1\_qdrift$  and  $r2\_qdrift$ , respectively. The same pattern is observed for females.
- $r1\_qdrift$  has a higher natural mortality ( $M$ ) of 0.231 compared with 0.175 for  $r2\_qdrift$  (Table 12 and Table 13).
- $r1\_qdrift$  always estimates a lower vulnerable reference biomass compared with the  $r2\_qdrift$  model, this is particularly obvious from 1945 to 1960 (Figure 5).

### 2.5.3 MAP sensitivity trials

Nine sensitivity trials were done as single variants relative to the base case models (Table 3). These included sensitivities relating to the catchability, data set weighting, growth, model start year, and changes to the illegal catch data. Although the results of the sensitivity tests span a range of relative spawning stock biomass and recruitment, most of these runs did not have large impacts on the stock trajectories, particularly in recent years. A comparison of the vulnerable reference biomass for all

model runs is presented in Figure 6 and for a subset of these runs in Figure 7. Figure 8 and Figure 9 compare the relative spawning stock biomass for all/some sensitivity runs with the equivalent base case. Figure 10 and Figure 11 compare the recruitment trends for all/some sensitivity runs.

We summarise the results for sensitivity tests relative to the *r1\_qdrift* and *r2\_qdrift* model runs:

- **No qdrift**
  - o *r1\_no\_qdrift*: vulnerable reference biomass slightly lower in initial years and slightly higher in final years. Relative spawning stock biomass is nearly equivalent to base case throughout the time series. Recruitment is very similar. Natural mortality is slightly higher at 0.239 (compared with 0.231 for the *r1\_qdrift* model run, Table 12).
  - o *r2\_no\_qdrift*: vulnerable reference biomass higher in initial years and slightly higher in final years. Relative spawning stock biomass is nearly equivalent to base case throughout the time series. Recruitment is very similar. Natural mortality is slightly lower at 0.162 (compared with 0.175 for the *r2\_qdrift* model run, Table 13).
- **Down-weighting CPUE**
  - o *r1\_dwnCPUE*: vulnerable reference biomass is slightly higher throughout the series and recruitment is lower.
  - o *r2\_dwnCPUE*: very similar to the base model.
- **Down-weighting LFs**
  - o *r1\_dwnLF*: similar to *r1\_dwnSR* and the equivalent *r2\_dwnLF* model runs with a higher initial vulnerable biomass throughout the series compared with the base case.
  - o *r2\_dwnLF*: similar to *r2\_dwnSR* and the equivalent *r1\_dwnLF* model runs with a higher initial vulnerable biomass throughout the series compared with the base case.
- **Down-weighting sex-ratios**
  - o *r1\_dwnSR*: similar to the *r1\_dwnLF* model run.
  - o *r2\_dwnSR*: similar to the *r2\_dwnLF* model run.
- **Density-dependent growth**
  - o *r1\_gdd*: almost no difference between this run and *r1\_qdrift*.
  - o *r2\_gdd*: almost no difference between this run and *r2\_qdrift*.
- **Fix Gshape to 3**
  - o *r1\_gshape3*: similar to the *r1\_no\_qdrift* model run with vulnerable reference biomass slightly lower in initial years and slightly higher in final years, relative spawning stock biomass is nearly equivalent, and similar recruitment.
  - o *r2\_gshape3*: vulnerable reference biomass is much higher in initial years and similar in final years, relative spawning stock biomass is no longer similar, and similar recruitment with the pulses in recruitment tending to happen 1 year earlier.
- **No tag likelihood**
  - o *r1\_notag*: vulnerable reference biomass is lower in all years, relative spawning stock biomass is about the same, and recruitment is higher in all years.
  - o *r2\_notag*: vulnerable reference biomass is much lower in all years, relative spawning stock biomass is no longer the same, and recruitment is much higher in all years with several additional recruitment pulses that were not present in the base case.
- **Start in 1979**
  - o *r1\_start\_1979*: similar to the base case but with a slightly higher recruitment and vulnerable reference biomass in the first few years. In this model the initial exploitation rate is 0.096 in 909+910 and 0.608 in 911. Such a low value in 909+910 is probably not feasible given the catch history and the state of the fishery in 1979 (inferred from other model runs).
  - o *r2\_start\_1979*: similar to the base case but with higher recruitment and vulnerable reference biomass in the first few years. In this model the initial exploitation rate is 0.037 in 909+910 and 0.307 in 911. Again, such a low value in 909+910 is probably not feasible given the catch history and the state of the fishery in 1979 (inferred from other model runs).
- **Catch**
  - o *r1\_illegal10*: slightly lower initial biomass compared with the *r1\_qdrift* run, but otherwise very similar.
  - o *r2\_illegal10*: slightly lower initial biomass compared with the *r2\_qdrift* run, but otherwise very similar.

Vulnerable biomass in the model runs that do not fit to tag-recapture observations (*r1\_notag* and *r2\_notag*) are consistently lower than all other model runs suggesting that the tag-recapture increments indicate a higher growth rate than the length-frequency observations (Figure 7). Other than these runs, there are few consistent patterns between the *r1* and *r2* model runs.

## 2.6 Bayesian inference using Markov chain Monte Carlo (MCMC)

Bayesian inference was used to estimate parameter uncertainty in this stock assessment. LSD uses Stan to run MCMC simulations using the Hamiltonian Monte Carlo (HMC) algorithm, starting with the MAP estimates (Table 12 and Table 13). For the base case and each selected sensitivity run (Table 4), we explored the posterior distributions with a total of 1000 samples across four chains, each with a warm-up phase of 250 iterations followed by 250 samples, retaining every sample.

### 2.6.1 MCMC base case

MCMC was used to obtain samples from the posterior distribution for the two base case models described in Section 2.5.2. Diagnostic trace plots are shown for estimated parameters in Figure 12, Figure 13, Figure 14, and Figure 15. Density plots of the priors and posterior distributions of estimated parameters and important derived quantities are shown in Figure 16, Figure 17, and Figure 18. Posterior distributions of parameter estimates and derived quantities are summarised in Table 16.

Traces for important estimated parameters such as  $M$  and  $R_0$  show reasonable stability. MCMC chains for most parameters stayed away from parameter bounds. Trace plots indicate that MCMC chains are well-mixed. The posteriors updated the priors considerably in most cases; the only posterior that is similar to the prior is the *Mat95* parameter which is of little concern and poorly estimated (Figure 16).

A set of base case MCMC diagnostic plots consisting of the posterior distributions of model predictions relative to the observed data, or the standardised residuals of model fits to the data, can be found in Figure 19 through to Figure 47:

- Fit to the CPUE series (Figure 19);
- Residuals of the fits to the CPUE series (Figure 20);
- Fits to the observer and logbook LF data by sex (Figure 21 to Figure 35);
- Residuals to the LF fits by region, size, and data source (observer or logbook) (Figure 36);
- Residuals of the LF fits by region, year, and data source (observer or logbook) (Figure 37);
- Estimated and observed sex ratios, by region, season, sex, year, and data source (Figure 38);
- Residuals of the sex-ratio fits by region, season, sex, year, and data source (Figure 39);
- Predicted growth increments, with standard deviation, at length, and sex (Figure 40);
- Residuals of the growth increments by statistical area and sex (Figure 41);
- Residuals of the growth increments by statistical area, size, and sex (Figure 42);
- Residuals of the growth increments by sex and year (Figure 43);
- Residuals of the growth increments by re-recapture (Figure 44);
- Selectivity curve by selectivity period and sex (Figure 45);
- Estimated female maturity function (Figure 46); and
- Catchability by year for the CELR CPUE series (Figure 47).

Overall the model fits the CPUE time series reasonably well, with acceptable residual patterns (Figure 19 and Figure 20). It is most important that the model produces good fits to the CELR series; the fits during the AW season are excellent, with the exception of the final few years in 909+910 and the final year in 911. The fits to the CELR series during the SS are not as good. These CPUE fits were

similar to the equivalent MAP fits. The *qdrift* parameters for each base case were estimated to be 1–2% (0.012 [90% CI = 0.004–0.020] for *r1\_qdrift* and 0.016 [90% CI = 0.009–0.024] for *r2\_qdrift*; Table 16). This converts to an increase in the CELR *q* of 43% for *r1\_qdrift* and 61% for *r2\_qdrift* over the 30-year period of the CELR series (1989–2018). The credibility of this increase is unknown.

Model fits to the LF data are acceptable, with good agreement with the logbook and catch sampling observations (Figure 21 to Figure 35). The fit to the proportions-at-sex showed agreement with most of the observations (Figure 38 and Figure 39). However, the logbook and catch sampling data appear to suggest inconsistent sex ratios in different years. Because the logbook data are given much higher weight in the model, these fits tend to look much better than the fits to the catch sampling data.

This stock assessment estimated five selectivity curves, one for each sex/region and an additional selectivity for females in 909+910, which specified early and late selectivity periods (i.e., 1945–1992 and 1993–2018, Figure 45). The splitting of female selectivity in 909+910 into two time periods was justified by a major shift in the seasonality of lobster sampling in 910 (Figure A2-2), coincident with the implementation of a seasonal closure in 1993/94 (see discussion in Appendix 2). Note that the seasonal pattern of fishing effort and lobster sampling was largely unaffected by the termination of the seasonal closure in 2001/02, i.e., the biggest change in fishing patterns and lobster sampling occurred in 1993 (Figure A2-2). Fishery selectivity for males was always smaller than for females and the second selectivity period for females selected much larger individuals.

Maturation was estimated to be well below the female MLS with the 50% of females maturing at around 40 mm TW in all model runs (Table 16, Figure 46).

Three strong recruitment periods are estimated in both regions and in both base case models. The first and biggest recruitment occurs in the mid-1970s, the second during the 1990s, and the most recent in the late 2000s (Figure 49). Recent (2007–2016) mean recruitment is estimated to be below  $R_0$  in the *r1\_qdrift* model in both regions, but, in the *r2\_qdrift* model run, recent recruitment is above  $R_0$  in 909+910 and below  $R_0$  in 911 (Table 16).

Fishing mortality was relatively low in the initial years of this fishery and has since fluctuated with the biggest peaks occurring in the size-limited fishery during the SS of the early 1990s and late 2000s (Figure 50).

Vulnerable biomass decreased, slowly at first, and then rapidly from the early 1960s, dropping to low levels in the early 1990s (Figure 51). Vulnerable biomass has since fluctuated with roughly a 10-year period. The vulnerable biomass of 909+910 was historically much higher than 911. In the most recent years, the vulnerable biomass in 909+910 and 911 is roughly the same. The *r1\_qdrift* model predicts a lower vulnerable biomass in the early years compared with the *r2\_qdrift* model. A similar trend is seen for the spawning stock biomass (Figure 52). Due to the small size at maturity, the SSB never approaches the soft limit.

Current (2018) spawning stock biomass is estimated to be at 79% or 82% of  $SSB_0$  in 909+910 respectively for the *r1\_qdrift* and *r2\_qdrift* model runs, and 82% or 77% of  $SSB_0$  in 911. Overall the stock is at 80% of  $SSB_0$  in both base case models ( $SSB_{2018}/SSB_0 = 0.80$  [90% credible interval (CI) for *r1\_qdrift* is 0.72–0.91 and for *r2\_qdrift* is 0.74–0.89]; Table 16). This assessment indicates zero probability of the base run being below the soft limit (20%  $SSB_0$ ) and 100% probability of being above  $B_{MIN}$  (Table 16).

## 2.6.2 MCMC sensitivity trials

A reduced number of sensitivity trials was chosen to be simulated using MCMC (Table 4). These runs represented plausible alternative hypotheses or differed in the parameter space (i.e., biomass trajectories) being investigated. All sensitivity runs had acceptable MCMC diagnostics.

Removing the *qdrift* parameter in the *r1\_no\_qdrift* and *r2\_no\_qdrift* model runs had little impact on the historical biomass but did alter the recent biomass. The *r1\_no\_qdrift* run predicts a higher terminal

year biomass than the base case and is very similar to the *r2\_qdrift* terminal year biomass (Figure 53). The *r2\_no\_qdrift* model run predicts an even higher terminal biomass.

Both base cases and both sensitivity runs evaluated in Table 4 resulted in there being zero probability of the stock being below the soft limit (20%  $SSB_0$ ) and 100% probability of it being above  $B_{MIN}$  (Table 16).

## 2.7 Projections

Five-year projections were done using the posterior samples for the MCMC base case and sensitivity trials. Projections extend from 2019 to 2023 with simulated recruitment from 2017 to 2023 (i.e., the final two years recruitment deviations that were fixed at the 2016 recruitment deviation estimate during MAP estimation were overwritten). Recruitment deviations were simulated from a normal distribution with mean and standard deviation calculated from the last 10 years of estimated recruitment deviations (2007–2016). Recruitment autocorrelation was calculated from the 1986–2016 recruitment deviations (1986 is the first year for which there is a length-frequency observation).

Projections assumed 2018 catch levels (135.78 t commercial, 6.06 t recreational, 11.32 t customary, and 34.46 t illegal in 909+910 and 104.18 t commercial, 4.66 t recreational, 8.68 t customary, and 26.44 t illegal in 911) and the current MLS regime. The proportion of the catch taken during AW was simulated from a logit regression of AW CPUE (assuming normally distributed error in logit-space) with parameters estimated from the relationship between the observed proportion of catch taken during AW and the AW CPUE from 1993 to 2018 (Figure 48). Unlike most other CRA QMAs, there is very little signal in this relationship, indicating that the AW CPUE is a poor predictor of the AW/SS seasonal split.

Projections indicate that, at current levels of removals with the current MLS regime, the CRA 3 population is expected to decline over the next 5 years.

## 3. DISCUSSION

This stock assessment represents the first formal multi-area rock lobster stock assessment. This new multi-area model better represents the differences in catch, MLS, and productivity between the two regions, given the differences in data between the two regions.

The assessment model fits well to the data, although, precisely how representative the estimated life history parameters are of the underlying population is not readily determined from the available data (see below). Some suggestions for addressing this are provided in Section 3.2.

### 3.1 Limitations of this assessment

Red rock lobsters are known to undergo seasonal migrations that can change the bathymetric distribution of different demographic groups (e.g., by sex or breeding status) (MacDiarmid 1991). As such, where fishing effort is concentrated within a particular season or depth range, the growth information from tagging data may not be fully representative of the wider population.

Much of the CRA 3 fishery is also relatively shallow (~80% of effort over reefs shallower than 20 m depth) compared with other North Island QMAs and has primarily operated during the winter in recent years (see discussion in Appendix 2). Consequently, the fishery will be relatively selective of mature lobsters that migrate up to shallow reefs prior to moulting and mating (Annala & Bycroft 1988, MacDiarmid 1991). Thus, the concentrated nature of fishing, and the resulting sampling in CRA 3, may have produced a biased sample for estimating population life history parameters by the assessment model. For example: overly representing pre-breeders could bias the estimation of maturity-at-size or growth; and over-representation of pre-moulters could also bias the estimation of growth, if most lobsters are caught again after short times at liberty.

The estimation of growth parameters by the model is primarily informed by the tagging data and (to an unknown, though presumably, lesser extent) by fitting to length-frequency and other data. In the case of CRA 3, this also may be biased by the timing of the tag and recapture events relative to moulting (see Appendix 1), given that the tagging tends to be done opportunistically around the commercial fishery.

Dive survey length-frequency observations of pre-recruit lobsters (up to 30 mm TW) were used to obtain a prior for the growth increment at 30 mm TW (*Galpha*), the smallest lobster size used by the model. As such, the prior used should have been high relative to true growth at 30 mm TW. The model posteriors for male and female *Galpha* were near the centre of the prior (although high for males when using the full set of tagging data), which indicates that model estimates of growth are still likely to be biased high for newly recruited lobsters, possibly due to the parameterisation of the growth model. Initial model explorations not using the revised *Galpha* (i.e., almost entirely based on tagging data) obtained implausibly high growth at smaller sizes, given the diver survey derived estimates. This highlights the value of using additional sources of growth information beyond tagging data.

The inclusion of the revised *Galpha* prior affected the shape of growth-at-size, though, ultimately, had minimal effect on the stock status quantities used for management. This was presumably because of concurrent changes in *M* that resulted in largely unchanged fits to the LF data. Thus, biased growth appears to be a trivial issue for the purposes of estimating a future TACC, although this highlights a wider issue of a lack of information for ground-truthing life history parameters (such as growth and *M*) that appear to be confounded in the CRA 3 assessment model.

### 3.2 Future research

- Exploration of the estimation of growth parameters exploiting new methods for the direct ageing of red rock lobsters based on growth rings in gastric mills (e.g., Leland & Bucher 2017). This would require the acquisition and destructive sampling of lobsters across a range of sizes, and ideally include known-age individuals for validation purposes, for a range of ages. This would also ideally use existing expertise to ensure consistency of methods and estimates.
- Consideration of fishery-independent sampling of lobsters across a range of depths and seasons. This would have the objective of ground-truthing model estimates of life history parameters, which could otherwise be biased by the concentrated bathymetric and seasonal distribution of effort and catch sampling in CRA 3.
- Obtaining length-weight parameters specific to CRA 3.
- Growth meta-analysis and simulation study that considers moulting as well as growth increments and explore different growth models.

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## 6. TABLES

**Table 1: Minimum legal size (MLS) limits for males and females by region used in the CRA 3 stock assessment model. Units are in mm tail width (TW). The values used before 1988 represent conversions from tail length in inches to TW in mm. The values used in the stock assessment are slightly different to the real MLS limits because the model has a 6-month time step.**

| 909+910                |       |         | 911                    |       |         |
|------------------------|-------|---------|------------------------|-------|---------|
| Period                 | Males | Females | Period                 | Males | Females |
| 1945–1949 <sup>1</sup> | –     | –       | 1945–1949 <sup>1</sup> | –     | –       |
| 1950–1951              | 47    | 49      | 1950–1951              | 47    | 49      |
| 1952–1958              | 51    | 53      | 1952–1958              | 51    | 53      |
| 1959–1987              | 53    | 58      | 1959–1987              | 53    | 58      |
| 1988–1991              | 54    | 58      | 1988–1991              | 54    | 58      |
| 1992                   | 54    | 60      | 1992                   | 54    | 60      |
| 1993–2018 AW           | 52    | 100     | 1993–2006 AW           | 52    | 100     |
| 1993–2018 SS           | 54    | 60      | 1993–2018 SS           | 54    | 60      |
|                        |       |         | 2007–2018 AW           | 54    | 100     |

<sup>1</sup> the 1947–1949 total length MLS regulation was not implemented in the CRA 3 model

**Table 2: List of model runs used to iteratively update the 2014 assessment of CRA 3.**

| Model name         | Model description                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Outcome                                                                                                                               |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| <i>1_base2014</i>  | Mimics the 2014 assessment model: <ul style="list-style-type: none"> <li>Catch and CPUE used in 2014 assessment (up to and including the 2013 fishing year)</li> <li>LF from the new data extract (due to formatting differences from the MLSM model in 2014), only including years used in the 2014 assessment</li> <li>Tag data used in 2014 assessment</li> <li>FSU and CELR CPUE series linked with single catchability coefficient (<math>q</math>)</li> </ul> | MAP estimates of vulnerable reference biomass match reasonably well (Figure 3)                                                        |
| <i>2_handling</i>  | Changed the handling mortality from 10% to 5% from 1990 onwards                                                                                                                                                                                                                                                                                                                                                                                                     | Very similar vulnerable reference biomass to the <i>1_base2014</i> run with a slightly higher unfished biomass (Figure 4)             |
| <i>3_splitCPUE</i> | Split the FSU and CELR CPUE series and therefore estimated separate catchability parameters for each of the 3 series (CR, FSU, CELR)                                                                                                                                                                                                                                                                                                                                | Similar vulnerable reference biomass with a higher unfished biomass (Figure 4)                                                        |
| <i>4_maturity</i>  | Estimated the maturation curve which was fixed in the previous CRA 3 assessment                                                                                                                                                                                                                                                                                                                                                                                     | Very similar vulnerable reference biomass (Figure 4)                                                                                  |
| <i>5_tagfile</i>   | Included new tag data that include all tags up to 2019 and Debbie Freeman’s marine reserve tags.                                                                                                                                                                                                                                                                                                                                                                    | Vulnerable reference biomass is reduced in all years compared with the <i>1_base2014</i> run with a lower unfished biomass (Figure 4) |
| <i>6_catch</i>     | Used new catch time series up to 2013 which included the 20% illegal series                                                                                                                                                                                                                                                                                                                                                                                         | Very similar vulnerable reference biomass (Figure 4)                                                                                  |
| <i>7_cpue</i>      | Used the new CELR CPUE indices up to 2013                                                                                                                                                                                                                                                                                                                                                                                                                           | Very similar vulnerable reference biomass except from 1970 to 1989 where the biomass is higher (Figure 4)                             |



**Table 3: List of CRA 3 maximum *a posteriori* (MAP) sensitivity runs. Two sets of nine sensitivities were run for each of the two reference cases.**

| Type               | Model name                        | Model description                                                                            |
|--------------------|-----------------------------------|----------------------------------------------------------------------------------------------|
| Base               | <i>r1_qdrift, r2_qdrift</i>       | Reference base case models: 1=all tag-recaptures dataset, 2=subset of tag-recaptures dataset |
| No qdrift          | <i>r1_no_qdrift, r2_no_qdrift</i> | Turn off the <i>qdrift</i> parameter                                                         |
| Data set weighting | <i>r1_dwnCPUE, r2_dwnCPUE</i>     | Down-weight all CPUE series to 10% of their original weight                                  |
|                    | <i>r1_dwnLF, r2_dwnLF</i>         | Down-weight LF data to 10% of its original weight                                            |
|                    | <i>r1_dwnSR, r2_dwnSR</i>         | Down-weight sex-ratio data to 10% of its original weight                                     |
| Growth             | <i>r1_gdd, r2_gdd</i>             | Estimate density dependent growth parameter <i>Gdd</i>                                       |
|                    | <i>r1_gshape3, r2_gshape3</i>     | Fix the <i>Gshape</i> parameter to 3.0                                                       |
|                    | <i>r1_notag, r2_notag</i>         | Turn off the tag likelihood                                                                  |
| Start in 1979      | <i>r1_start1979, r2_start1979</i> | Start the model in 1979                                                                      |
| Catch              | <i>r1_illegal10, r2_illegal10</i> | Assume illegal catch is 10% of 1981–2018 commercial catch                                    |

**Table 4: List of CRA 3 Markov chain Monte Carlo (MCMC) models.**

| Model name          | Model description                                                                     |
|---------------------|---------------------------------------------------------------------------------------|
| <i>r1_qdrift</i>    | Reference case 1 with tags at liberty > 365 days and estimate <i>qdrift</i> parameter |
| <i>r1_no_qdrift</i> | Reference case 1 with tags at liberty > 365 days and no <i>qdrift</i> parameter       |
| <i>r2_qdrift</i>    | Reference case 2 with all tags and estimate <i>qdrift</i> parameter                   |
| <i>r2_no_qdrift</i> | Reference case 2 with all tags and no <i>qdrift</i> parameter                         |

**Table 5: Definitions of parameters used in the LSD model and discussed in this document.**

| Parameter     | Definition                                                                                    |
|---------------|-----------------------------------------------------------------------------------------------|
| $R_0$         | average numbers recruiting                                                                    |
| $U_0$         | initial exploitation rate (first year is in equilibrium using this estimate)                  |
| $M$           | instantaneous rate of natural mortality                                                       |
| $Rdevs$       | annual recruitment deviations                                                                 |
| $SigmaR$      | standard deviation of $Rdevs$                                                                 |
| $qCR$         | catchability coefficient (relationship between <i>Bvuln</i> and CR series)                    |
| $qFSU$        | catchability coefficient (relationship between <i>Bvuln</i> and FSU CPUE series)              |
| $qCELR$       | catchability coefficient (relationship between <i>Bvuln</i> and CELR CPUE series)             |
| <i>qdrift</i> | additive change in catchability coefficient each year                                         |
| <i>Mat50</i>  | size at which 50% of immature females become mature                                           |
| <i>Mat95</i>  | difference between <i>Mat50</i> and the size at which 95% of immature females become mature   |
| <i>Galpha</i> | annual growth increment at 30 mm TW                                                           |
| <i>Gbeta</i>  | annual growth increment at 80 mm TW                                                           |
| <i>Gdiff</i>  | the ratio of <i>Gbeta</i> to <i>Galpha</i>                                                    |
| <i>Gshape</i> | parameter for shape of growth curve: 1 implies vonB straight line; >1 implies concave upwards |
| <i>GCV</i>    | standard deviation of growth-at-size divided by growth-at-size                                |
| <i>Gobs</i>   | standard deviation of observation error for tag-recaptures                                    |
| <i>Gdd</i>    | density-dependent growth parameter                                                            |
| <i>SelL</i>   | shape of the left of the selectivity curve (as if it were a standard deviation)               |
| <i>SelM</i>   | size at maximum selectivity                                                                   |
| <i>SelR</i>   | shape of the right of the selectivity curve (as if it were a standard deviation)              |
| <i>vuln</i>   | relative vulnerability by sex category and season                                             |

**Table 6: Specifications for estimated parameters in the CRA 3 models including the upper and lower bounds, prior types, and prior parameters.**

| Sex    | Parameter | Bound    |         | type      | Prior |            |
|--------|-----------|----------|---------|-----------|-------|------------|
|        |           | lower    | upper   |           | par1  | par2       |
|        | $R_0$     | exp(1)   | exp(25) | uniform   |       |            |
|        | $Rdevs$   | -2.3     | 2.3     | normal    | 0     | $\sigma R$ |
|        | $M$       | 0.01     | 0.35    | lognormal | 0.12  | 0.4        |
|        | $qCR$     | exp(-25) | exp(0)  | uniform   |       |            |
|        | $qFSU$    | exp(-25) | exp(0)  | uniform   |       |            |
|        | $qCELR$   | exp(-25) | exp(0)  | uniform   |       |            |
|        | $Mat50$   | 10       | 80      | normal    | 50    | 50         |
|        | $Mat95$   | 1        | 60      | normal    | 10    | 10         |
|        | $Galpha$  | 1        | 15      | normal    | 5     | 3          |
|        | $Gdiff$   | 0.001    | 0.99    | beta      | 1     | 5          |
| Male   | $GCV$     | 0.01     | 2       | normal    | 0.59  | 1          |
| Female | $GCV$     | 0.01     | 2       | normal    | 0.82  | 1          |
|        | $Gobs$    | 0.0001   | 10      | normal    | 1.48  | 1          |
|        | $Gdd$     | 0        | 1       | beta      | 1     | 1          |
|        | $SelL$    | 1        | 50      | normal    | 20    | 100        |
|        | $SelM$    | 30       | 90      | normal    | 50    | 50         |
|        | $vuln$    | 0.01     | 1       | beta      | 3     | 3          |
|        | $U_0$     | 0        | 0.99    | beta      | 1     | 1          |
|        | $qdrift$  | -0.08    | 0.08    | normal    | 0     | 1          |

**Table 7: Fixed quantities used in the CRA 3 stock assessment models.**

| quantity                        | value    | quantity                                       | value     |
|---------------------------------|----------|------------------------------------------------|-----------|
| <b>Projected catches</b>        |          | <b>Fixed parameters</b>                        |           |
| commercial (909+910)            | 135.78 t | $\sigma R$                                     | 0.4       |
| commercial (911)                | 104.18 t | $Gshape$                                       | 5.0       |
| recreational (909+910)          | 6.06 t   | $Gmin$                                         | 0.5       |
| recreational (911)              | 4.66 t   | $\alpha$ (for $Galpha$ )                       | 30 mm     |
| illegal (909+910)               | 34.46 t  | $\beta$ (for $Gbeta$ )                         | 80 mm     |
| illegal (911)                   | 26.44 t  | $SelR$                                         | 200       |
| customary (909+910)             | 11.32 t  | <b>Length-weight</b>                           |           |
| customary (911)                 | 8.68 t   | male length-weight $a$                         | 4.16e-6   |
| <b>Handling mortality rates</b> |          | male length-weight $b$                         | 2.9354    |
| handling mortality (1945-1989)  | 0.10     | female length-weight $a$                       | 1.30 e-5  |
| handling mortality (1990-2017)  | 0.05     | female length-weight $b$                       | 2.5452    |
| <b>Other</b>                    |          | <b>Recruitment</b>                             |           |
| Newton-Raphson iterations       | 3        | last year of estimated $Rdevs$                 | 2016      |
| Tail compression: male bins     | 4 to 23  | years for estimating $Rdev$ 's for projections | 2007-2016 |
| Tail compression: female        | 4 to 17  | years for estimating autocorrelation           | 1986-2016 |
| Tail compression: female mature | 4 to 24  | recruitment size mean                          | 32 mm     |
|                                 |          | recruitment size SD                            | 2 mm      |

**Table 8: Mapping of the vulnerability ( $vuln$ ) parameters in the CRA 3 stock assessment models. Vulnerability for males in AW is fixed at 1 in both regions, all other  $vuln$  parameters are estimated relative to the vulnerability of males during AW.**

| Sex             | 909+910 |         | 911     |         |
|-----------------|---------|---------|---------|---------|
|                 | AW      | SS      | AW      | SS      |
| Male            | 1       | $vuln1$ | 1       | $vuln4$ |
| Immature female | $vuln2$ | $vuln3$ | $vuln5$ | $vuln6$ |
| Mature female   | $vuln2$ | $vuln3$ | $vuln5$ | $vuln6$ |

**Table 9: Reference points, performance indicators, and stock status probabilities produced from the CRA 3 stock assessment.**

| <i>Type</i>                   | <i>Description</i>                                                   |
|-------------------------------|----------------------------------------------------------------------|
| <b>Reference Points</b>       |                                                                      |
| $B_0$                         | beginning of season AW vulnerable biomass before fishing (1945)      |
| $B_{vuln}$                    | start-of-season AW biomass available to be caught legally            |
| $B_{2019}$                    | vulnerable biomass at start of AW 2019                               |
| $SSB_0$                       | female AW spawning stock biomass before fishing began (1945)         |
| $B_{0now}$                    | equilibrium vulnerable biomass using mean 2007–2016 recruitment      |
| $SSB_{0now}$                  | equilibrium female spawning biomass using mean 2007–2016 recruitment |
| $B_{0TOT}$                    | equilibrium total biomass                                            |
| $B_{MIN}$                     | the lowest beginning AW vulnerable biomass in the series             |
| $B_{2018}$                    | beginning of season AW vulnerable biomass for 2018                   |
| $B_{2022}$                    | beginning of season AW vulnerable biomass for 2022                   |
| $SSB_{2018}$                  | female spawning stock biomass at beginning of 2018 AW season         |
| $SSB_{2022}$                  | female spawning stock biomass at beginning of 2022 AW season         |
| $B_{2018TOT}$                 | beginning of season AW total biomass for 2018                        |
| $CPUE_{2018}$                 | AW CPUE at beginning of 2018 (in kg/potlift)                         |
| $CPUE_{2022}$                 | AW CPUE at beginning of 2022 (in kg/potlift)                         |
| $H_{2018}$                    | total handling mortality for 2018 (tonnes)                           |
| $H_{2023}$                    | total handling mortality for 2023 (tonnes)                           |
| <b>Performance indicators</b> |                                                                      |
| $B_{2018} / B_0$              | ratio of $B_{2018}$ to $B_0$                                         |
| $B_{2022} / B_0$              | ratio of $B_{2022}$ to $B_0$                                         |
| $B_{2022} / B_{2018}$         | ratio of $B_{2022}$ to $B_{2018}$                                    |
| $SSB_{2018} / SSB_0$          | ratio of $SSB_{2018}$ to $SSB_0$                                     |
| $SSB_{2022} / SSB_0$          | ratio of $SSB_{2022}$ to $SSB_0$                                     |
| $SSB_{2022} / SSB_{2018}$     | ratio of $SSB_{2022}$ to $SSB_{2018}$                                |
| $B_{2018TOT} / B_{0TOT}$      | ratio of $B_{2018TOT}$ to $B_{0TOT}$                                 |
| $B_{2022TOT} / B_{0TOT}$      | ratio of $B_{2022TOT}$ to $B_{0TOT}$                                 |
| $B_{2022TOT} / B_{2018TOT}$   | ratio of $B_{2022TOT}$ to $B_{2018TOT}$                              |
| <b>Probabilities</b>          |                                                                      |
| $P(B_{2018} > B_{MIN})$       | probability $B_{2018}$ is greater than $B_{MIN}$                     |
| $P(SSB_{2018} < 20\% SSB_0)$  | probability $SSB_{2018}$ is less than 20% $SSB_0$                    |
| $P(SSB_{2018} < 10\% SSB_0)$  | probability $SSB_{2018}$ is less than 10% $SSB_0$                    |

**Table 10: CRA MAP: reference base case and sensitivity trial results for Reference case 1 (for tags at liberty > 365 days) including *likelihoods*, *standardised normalised residuals*, *median of absolute residuals and weightings*. Growth increment values in mm TW, biomass values in tonnes, and  $R_0$  in numbers. Fixed input values are indicated by grey shading. Values by region indicated by: region 1=909+910, and region 2=911. The different sensitivity runs are defined in Table 3.**

|                           | <i>qdrift</i> | <i>no_qdrift</i> | <i>dwnCPUE</i> | <i>dwnLF</i> | <i>dwnSR</i> | <i>gdd</i> | <i>gshape3</i> | <i>start1979</i> | <i>illegal10</i> | <i>notag</i> |
|---------------------------|---------------|------------------|----------------|--------------|--------------|------------|----------------|------------------|------------------|--------------|
| <u><i>Likelihoods</i></u> |               |                  |                |              |              |            |                |                  |                  |              |
| Total                     | 21 671        | 22 137           | 22 504         | 6 285        | 19 664       | 21 852     | 22 156         | 22 565           | 22 133           | 20 080       |
| Prior                     | -19.2         | -21.2            | -64.4          | -19.3        | -14.8        | -18.8      | -19.1          | 31.3             | -19.4            | -24.3        |
| tag                       | 2 015         | 2 015            | 1 998          | 1 985        | 2 006        | 2 016      | 2 022          | 2 007            | 2 013            | –            |
| sexr                      | 2 530         | 2 726            | 2 739          | 2 712        | 281          | 2 655      | 2 731          | 2 639            | 2 726            | 2 722        |
| LF                        | 17 295        | 17 559           | 17 530         | 1 775        | 17 540       | 17 348     | 17 567         | 17 968           | 17 554           | 17 538       |
| CR                        | -19.2         | -19.2            | 1.3            | -19.4        | -19.5        | -19.2      | -19.1          | -7.8             | -19.1            | -19.8        |
| FSU region 1              | -32.2         | -34.3            | 6.8            | -39          | -36.4        | -32.6      | -34.7          | -28.1            | -33.7            | -37.7        |
| FSU region 2              | -31.7         | -31.7            | 7.4            | -31.4        | -31.1        | -30.9      | -32.7          | -44.7            | -31.7            | -31.9        |
| CELR                      | -67.2         | -56.7            | 287.1          | -78.4        | -61.4        | -65.4      | -58.7          | –                | -56.2            | -65.7        |
| <u><i>sdnr</i></u>        |               |                  |                |              |              |            |                |                  |                  |              |
| tag                       | 1.226         | 1.224            | 1.297          | 1.260        | 1.257        | 1.218      | 1.204          | 1.215            | 1.226            | –            |
| sexr                      | 0.964         | 0.988            | 1.044          | 0.933        | 0.406        | 0.978      | 1.005          | 0.982            | 0.988            | 0.974        |
| LF                        | 1.803         | 1.867            | 2.220          | 0.916        | 2.167        | 1.849      | 1.939          | 1.715            | 1.843            | 1.559        |
| CR                        | 1.008         | 1.014            | 0.230          | 0.993        | 0.979        | 1.013      | 1.021          | 0.996            | 1.018            | 0.952        |
| FSU region 1              | 1.033         | 1.062            | 0.776          | 0.795        | 0.949        | 1.061      | 1.039          | 1.078            | 1.088            | 0.876        |
| FSU region 2              | 1.000         | 0.999            | 0.514          | 1.017        | 1.031        | 0.987      | 0.947          | 1.006            | 0.998            | 0.990        |
| CELR                      | 1.178         | 1.103            | 1.487          | 0.913        | 1.063        | 1.187      | 1.087          | –                | 1.106            | 1.037        |
| <u><i>MAR</i></u>         |               |                  |                |              |              |            |                |                  |                  |              |
| tag                       | 0.679         | 0.681            | 0.704          | 0.685        | 0.685        | 0.680      | 0.680          | 0.671            | 0.674            | –            |
| sexr                      | 0.497         | 0.505            | 0.550          | 0.446        | 0.178        | 0.507      | 0.524          | 0.503            | 0.507            | 0.464        |
| LF                        | 0.023         | 0.023            | 0.022          | 0.008        | 0.023        | 0.023      | 0.022          | 0.023            | 0.023            | 0.023        |
| CR                        | 0.596         | 0.610            | 0.190          | 0.546        | 0.575        | 0.604      | 0.620          | 0.604            | 0.625            | 0.556        |
| FSU region 1              | 0.818         | 0.853            | 0.761          | 0.656        | 0.787        | 0.840      | 0.714          | 0.556            | 0.863            | 0.828        |
| FSU region 2              | 0.609         | 0.621            | 0.393          | 0.646        | 0.746        | 0.604      | 0.692          | 0.564            | 0.637            | 0.575        |
| CELR                      | 0.605         | 0.629            | 1.106          | 0.632        | 0.580        | 0.692      | 0.614          | –                | 0.637            | 0.565        |
| <u><i>Weightings</i></u>  |               |                  |                |              |              |            |                |                  |                  |              |
| sexr                      | 14.00         | 15.10            | 15.10          | 15.10        | 1.51         | 14.70      | 15.10          | 14.60            | 15.10            | 15.10        |
| LF region 1               | 4.35          | 4.38             | 4.38           | 0.44         | 4.38         | 4.34       | 4.38           | 4.50             | 4.38             | 4.38         |
| LF region 2               | 13.87         | 14.23            | 14.23          | 1.42         | 14.23        | 14.00      | 14.23          | 14.50            | 14.23            | 14.23        |
| CR                        | 3.56          | 3.56             | 0.36           | 3.56         | 3.56         | 3.56       | 3.56           | –                | 3.56             | 3.56         |
| FSU region 1              | 2.10          | 2.40             | 0.24           | 2.40         | 2.40         | 2.20       | 2.40           | 0.60             | 2.40             | 2.40         |
| FSU region 2              | 2.00          | 2.00             | 0.20           | 2.00         | 2.00         | 1.90       | 2.00           | 1.80             | 2.00             | 2.00         |
| CELR                      | 1.90          | 1.60             | 0.16           | 1.60         | 1.60         | 1.90       | 1.60           | 1.30             | 1.60             | 1.60         |

**Table 11: CRA 3 MAP: reference base case and sensitivity trial results for Reference case 2 (all tags datasets), including *likelihoods*, *standardised normalised residuals*, *median of absolute residuals* and *weightings*. Growth increment values in mm TW, biomass values in tonnes and  $R_0$  in numbers. Fixed input values are indicated in grey shading. Values by region indicated by: region 1=909+910, and region 2=911. The different sensitivity runs are defined in Table 3.**

|                    | <i>qdrift</i> | <i>no_qdrift</i> | <i>dwnCPUE</i> | <i>dwnLF</i> | <i>dwnSR</i> | <i>gdd</i> | <i>gshape3</i> | <i>start1979</i> | <i>illegal10</i> | <i>notag</i> |
|--------------------|---------------|------------------|----------------|--------------|--------------|------------|----------------|------------------|------------------|--------------|
| <i>Likelihoods</i> |               |                  |                |              |              |            |                |                  |                  |              |
| Total              | 25 387        | 26 909           | 27 218         | 10 914       | 24 423       | 26 627     | 27 009         | 27 307           | 26 904           | 20 081       |
| Prior              | -19.4         | -9.4             | -64.8          | -11.2        | -10.1        | -15.8      | -2.2           | 20.2             | -7.1             | -22.6        |
| tag                | 6 665         | 6 666            | 6 632          | 6 565        | 6 661        | 6 675      | 6 742          | 6 651            | 6 663            | –            |
| sexr               | 2 537         | 2 727            | 2 741          | 2 712        | 283          | 2 663      | 2 739          | 2 656            | 2 726            | 2 722        |
| LF                 | 16 334        | 17 657           | 17 606         | 1 815        | 17 619       | 17 435     | 17 662         | 18 038           | 17 653           | 17 538       |
| CR                 | -19.6         | -19.6            | 1.3            | -19.6        | -19.7        | -19.6      | -19.7          | -0.7             | -19.6            | -19.8        |
| FSU region 1       | -32.9         | -38.9            | 5.2            | -41.0        | -37.9        | -32.6      | -38.9          | -26.0            | -38.6            | -40.0        |
| FSU region 2       | -30.9         | -29.9            | 7.1            | -30.6        | -27.9        | -30.3      | -23.7          | -31.1            | -29.4            | -31.9        |
| CELR               | -45.8         | -43.2            | 291.5          | -75.0        | -44.8        | -46.7      | -50.2          | –                | -44.0            | -65.3        |
| <i>sdnr</i>        |               |                  |                |              |              |            |                |                  |                  |              |
| tag                | 5.669         | 5.639            | 6.363          | 6.049        | 6.119        | 5.585      | 6.327          | 6.113            | 5.751            | –            |
| sexr               | 0.997         | 0.989            | 1.054          | 0.933        | 0.428        | 1.010      | 1.054          | 1.053            | 0.993            | 0.974        |
| CR                 | 0.966         | 1.010            | 0.236          | 0.968        | 0.961        | 0.973      | 0.963          | 1.321            | 0.969            | 0.953        |
| FSU region 1       | 0.980         | 0.994            | 0.873          | 0.864        | 1.034        | 1.057      | 0.984          | 1.175            | 0.997            | 0.919        |
| FSU region 2       | 1.091         | 1.044            | 0.488          | 1.056        | 1.183        | 1.022      | 1.357          | 1.099            | 1.114            | 0.989        |
| CELR               | 1.186         | 1.176            | 1.509          | 0.934        | 1.175        | 1.297      | 1.135          | –                | 1.180            | 1.041        |
| <i>MAR</i>         |               |                  |                |              |              |            |                |                  |                  |              |
| tag                | 0.721         | 0.720            | 0.729          | 0.733        | 0.735        | 0.719      | 0.738          | 0.730            | 0.722            | –            |
| sexr               | 0.493         | 0.521            | 0.580          | 0.451        | 0.194        | 0.517      | 0.564          | 0.578            | 0.482            | 0.461        |
| CR                 | 0.543         | 0.592            | 0.190          | 0.548        | 0.492        | 0.573      | 0.452          | 1.222            | 0.555            | 0.564        |
| FSU region 1       | 0.605         | 0.792            | 0.855          | 0.612        | 0.855        | 0.868      | 0.588          | 0.722            | 0.652            | 0.813        |
| FSU region 2       | 0.636         | 0.644            | 0.339          | 0.638        | 0.860        | 0.596      | 0.914          | 0.705            | 0.713            | 0.582        |
| CELR               | 0.797         | 0.732            | 1.108          | 0.665        | 0.770        | 0.801      | 0.739          | –                | 0.800            | 0.584        |
| <i>Weightings</i>  |               |                  |                |              |              |            |                |                  |                  |              |
| sexr               | 14.00         | 15.10            | 15.10          | 15.10        | 1.51         | 14.70      | 15.10          | 14.60            | 15.10            | 15.10        |
| LF region 1        | 4.30          | 4.38             | 4.38           | 0.44         | 4.38         | 4.34       | 4.38           | 4.50             | 4.38             | 4.38         |
| LF region 2        | 12.20         | 14.23            | 14.23          | 1.42         | 14.23        | 14.00      | 14.23          | 14.50            | 14.23            | 14.23        |
| CR                 | 3.70          | 3.56             | 0.36           | 3.56         | 3.56         | 3.56       | 3.56           | –                | 3.56             | 3.56         |
| FSU region 1       | 2.10          | 2.40             | 0.24           | 2.40         | 2.40         | 2.20       | 2.40           | 0.60             | 2.40             | 2.40         |
| FSU region 2       | 2.00          | 2.00             | 0.20           | 2.00         | 2.00         | 1.90       | 2.00           | 1.80             | 2.00             | 2.00         |
| CELR               | 1.60          | 1.60             | 0.16           | 1.60         | 1.60         | 1.90       | 1.60           | 1.30             | 1.60             | 1.60         |

**Table 12: CRA 3 MAP: reference base case and sensitivity trial results for Reference case 1 (for tags at liberty > 365 days), including parameters. Growth increment values in mm TW, biomass values in tonnes and  $R_0$  in numbers. Values by region indicated by: region 1=909+910, and region 2=911. The different sensitivity runs are defined in Table 3.**

|                               | <i>qdrift</i> | <i>no_qdrift</i> | <i>dwnCPUE</i> | <i>dwnLF</i> | <i>dwnSR</i> | <i>gdd</i> | <i>gshape3</i> | <i>start1979</i> | <i>illegal10</i> | <i>notag</i> |
|-------------------------------|---------------|------------------|----------------|--------------|--------------|------------|----------------|------------------|------------------|--------------|
| <i>Parameters</i>             |               |                  |                |              |              |            |                |                  |                  |              |
| $R_0$ region 1                | 1 415 430     | 1 502 280        | 849 578        | 1 110 940    | 1 083 610    | 1 480 050  | 1 891 790      | 1 309 720        | 1 348 070        | 1 916 730    |
| $R_0$ region 2                | 811 741       | 865 374          | 477 142        | 621 222      | 629 975      | 851 126    | 1 091 070      | 974 209          | 772 305          | 1 078 790    |
| M                             | 0.231         | 0.239            | 0.138          | 0.207        | 0.196        | 0.238      | 0.243          | 0.216            | 0.232            | 0.304        |
| Galpha male                   | 7.47          | 7.46             | 8.10           | 9.80         | 7.70         | 7.45       | 5.13           | 8.20             | 7.53             | 6.87         |
| Galpha female                 | 7.55          | 7.65             | 6.21           | 8.23         | 6.56         | 7.63       | 4.92           | 7.87             | 7.56             | 8.94         |
| Gbeta male                    | 2.65          | 2.63             | 2.29           | 1.57         | 2.56         | 2.67       | 2.27           | 2.38             | 2.61             | 4.97         |
| Gbeta female                  | 0.75          | 0.76             | 0.74           | 0.72         | 0.89         | 0.76       | 0.56           | 0.67             | 0.75             | 0.87         |
| GCV male                      | 0.78          | 0.79             | 0.79           | 0.74         | 0.78         | 0.79       | 0.80           | 0.79             | 0.79             | 0.40         |
| GCV female                    | 1.27          | 1.26             | 1.27           | 1.12         | 1.21         | 1.26       | 1.22           | 1.30             | 1.27             | 1.07         |
| Gobs                          | 0.154         | 0.152            | 0.171          | 0.670        | 0.159        | 0.140      | 0.172          | 0.113            | 0.154            | 1.464        |
| Gdd                           | —             | —                | —              | —            | —            | 0.0010     | —              | —                | —                | —            |
| Mat50                         | 40.84         | 40.48            | 48.90          | 42.57        | 46.76        | 40.52      | 45.48          | 40.03            | 40.81            | 37.87        |
| Mat95                         | 19.48         | 18.99            | 31.48          | 15.16        | 26.78        | 18.75      | 24.72          | 17.02            | 19.99            | 13.13        |
| SelL male region 1            | 4.66          | 4.64             | 4.84           | 4.77         | 4.71         | 4.65       | 4.51           | 4.70             | 4.66             | 4.50         |
| SelL female region 1 period 1 | 15.16         | 14.97            | 17.85          | 10.84        | 13.21        | 14.68      | 12.32          | 18.83            | 15.15            | 14.54        |
| SelL female region 1 period 2 | 6.23          | 6.21             | 6.95           | 5.73         | 6.21         | 6.17       | 5.62           | 7.25             | 6.33             | 6.17         |
| SelL male region 2            | 5.69          | 5.63             | 5.23           | 6.46         | 5.66         | 5.70       | 5.48           | 5.50             | 5.63             | 5.25         |
| SelL female region 2          | 6.35          | 6.35             | 6.76           | 5.82         | 6.25         | 6.35       | 5.98           | 6.51             | 6.35             | 6.53         |
| SelM male region 1            | 54.63         | 54.63            | 54.71          | 53.73        | 54.63        | 54.64      | 54.56          | 54.50            | 54.56            | 54.64        |
| SelM female region 1 period 1 | 77.62         | 77.21            | 82.96          | 65.17        | 74.12        | 76.44      | 72.34          | 86.68            | 77.64            | 75.76        |
| SelM female region 1 period 2 | 58.36         | 58.40            | 59.94          | 53.85        | 58.54        | 58.25      | 57.54          | 60.90            | 58.60            | 58.18        |
| SelM male region 2            | 59.64         | 59.55            | 57.84          | 60.70        | 59.28        | 59.72      | 59.33          | 58.90            | 59.46            | 58.92        |
| SelM female region 2          | 65.88         | 65.91            | 66.86          | 63.58        | 65.85        | 65.91      | 64.90          | 65.91            | 65.81            | 66.35        |
| vuln1                         | 0.952         | 0.924            | 0.807          | 0.949        | 0.920        | 0.949      | 0.939          | 0.960            | 0.924            | 0.946        |
| vuln2                         | 0.074         | 0.074            | 0.071          | 0.043        | 0.088        | 0.070      | 0.074          | 0.109            | 0.078            | 0.051        |
| vuln3                         | 0.264         | 0.250            | 0.212          | 0.134        | 0.457        | 0.249      | 0.265          | 0.381            | 0.267            | 0.177        |
| vuln4                         | 0.926         | 0.902            | 0.574          | 0.915        | 0.947        | 0.928      | 0.916          | 0.841            | 0.900            | 0.915        |
| vuln5                         | 0.416         | 0.425            | 0.560          | 0.370        | 0.442        | 0.416      | 0.444          | 0.432            | 0.428            | 0.358        |
| vuln6                         | 0.904         | 0.900            | 0.792          | 0.851        | 0.878        | 0.902      | 0.916          | 0.882            | 0.900            | 0.796        |
| qCR                           | 0.175         | 0.185            | 0.114          | 0.157        | 0.152        | 0.181      | 0.188          | 0.002            | 0.189            | 0.215        |
| qFSU region 1                 | 0.002         | 0.003            | 0.003          | 0.002        | 0.002        | 0.003      | 0.003          | 0.006            | 0.003            | 0.003        |
| qFSU region 2                 | 0.003         | 0.004            | 0.004          | 0.003        | 0.003        | 0.004      | 0.004          | 0.006            | 0.004            | 0.004        |
| qCELR                         | 0.005         | 0.006            | 0.263          | 0.005        | 0.006        | 0.006      | 0.006          | —                | 0.006            | 0.009        |
| qdrift                        | 0.012         | —                | —              | —            | —            | —          | —              | —                | —                | —            |
| $U_0$ region 1                | —             | —                | —              | —            | —            | —          | —              | 0.096            | —                | —            |
| $U_0$ region 2                | —             | —                | —              | —            | —            | —          | —              | 0.608            | —                | —            |

**Table 13: CRA 3 MAP: reference base case and sensitivity trial results for Reference case 2 (all tags datasets), including *parameters*. Growth increment values in mm TW, biomass values in tonnes and  $R_0$  in numbers. Values by region indicated by: region 1=909+910, and region 2=911. The different sensitivity runs are defined in Table 3.**

|                      | <i>qdrift</i> | <i>no_qdrift</i> | <i>dwnCPUE</i> | <i>dwnLF</i> | <i>dwnSR</i> | <i>qdd</i> | <i>gshape3</i> | <i>start1979</i> | <i>illegal10</i> | <i>notaq</i> |
|----------------------|---------------|------------------|----------------|--------------|--------------|------------|----------------|------------------|------------------|--------------|
| <i>Parameters</i>    |               |                  |                |              |              |            |                |                  |                  |              |
| $R_0$ region 1       | 861 679       | 826 315          | 646 885        | 787 968      | 724 047      | 873 389    | 766 018        | 688 468          | 761 338          | 1 886 090    |
| $R_0$ region 2       | 488 543       | 443 572          | 361 993        | 429 504      | 421 898      | 495 637    | 405 095        | 485 856          | 407 922          | 1 060 020    |
| M                    | 0.175         | 0.162            | 0.111          | 0.156        | 0.153        | 0.177      | 0.134          | 0.124            | 0.158            | 0.301        |
| Galpha male          | 10.23         | 10.23            | 10.52          | 11.44        | 10.32        | 10.19      | 7.16           | 10.32            | 10.24            | 6.89         |
| Galpha female        | 7.58          | 7.50             | 6.37           | 7.96         | 6.67         | 7.63       | 3.97           | 6.69             | 7.32             | 8.87         |
| Gbeta male           | 1.28          | 1.29             | 1.10           | 0.47         | 1.29         | 1.33       | 0.84           | 1.24             | 1.29             | 4.97         |
| Gbeta female         | 0.49          | 0.49             | 0.54           | 0.36         | 0.60         | 0.50       | 0.43           | 0.52             | 0.50             | 0.87         |
| GCV male             | 0.72          | 0.72             | 0.73           | 0.71         | 0.71         | 0.71       | 0.73           | 0.72             | 0.72             | 0.40         |
| GCV female           | 1.32          | 1.33             | 1.32           | 1.24         | 1.28         | 1.32       | 1.24           | 1.34             | 1.33             | 1.09         |
| Gobs                 | 0.002         | 0.002            | 0.002          | 0.002        | 0.002        | 0.002      | 0.002          | 0.003            | 0.002            | 0.002        |
| Gdd                  | —             | —                | —              | —            | —            | 0.0002     | —              | —                | —                | —            |
| mat50                | 41.87         | 42.65            | 49.71          | 43.89        | 49.32        | 41.60      | 52.70          | 47.33            | 43.59            | 37.80        |
| mat95                | 22.54         | 23.63            | 32.90          | 15.13        | 29.38        | 21.81      | 31.06          | 31.14            | 25.59            | 13.64        |
| selL male region 1   | 4.85          | 4.84             | 5.02           | 4.84         | 4.88         | 4.83       | 4.62           | 4.89             | 4.86             | 4.50         |
| selL female region 1 |               |                  |                |              |              |            |                |                  |                  |              |
| period 1             | 17.67         | 10.61            | 20.31          | 10.84        | 15.37        | 16.60      | 8.58           | 20.23            | 10.55            | 14.30        |
| selL female region 1 |               |                  |                |              |              |            |                |                  |                  |              |
| period 2             | 6.71          | 5.86             | 7.28           | 6.17         | 6.53         | 6.59       | 5.76           | 7.84             | 5.88             | 6.12         |
| selL male region 2   | 5.92          | 5.82             | 5.15           | 7.24         | 5.79         | 5.96       | 5.44           | 5.57             | 5.83             | 5.26         |
| selL female region 2 | 6.48          | 6.53             | 7.05           | 6.06         | 6.58         | 6.51       | 6.27           | 6.76             | 6.54             | 6.55         |
| selM male region 1   | 53.80         | 53.74            | 54.06          | 52.81        | 53.82        | 53.78      | 53.77          | 53.75            | 53.68            | 54.64        |
| selM female region 1 |               |                  |                |              |              |            |                |                  |                  |              |
| period 1             | 80.56         | 62.40            | 86.35          | 63.15        | 77.01        | 77.95      | 60.00          | 88.59            | 62.27            | 75.03        |
| selM female region 1 |               |                  |                |              |              |            |                |                  |                  |              |
| period 2             | 57.80         | 53.74            | 59.89          | 52.44        | 57.68        | 57.44      | 54.55          | 61.56            | 53.72            | 57.95        |
| selM male region 2   | 58.80         | 58.48            | 56.48          | 61.10        | 58.28        | 58.94      | 57.95          | 57.69            | 58.44            | 58.93        |
| selM female region 2 | 65.39         | 65.43            | 67.02          | 63.52        | 65.92        | 65.51      | 64.77          | 65.90            | 65.38            | 66.41        |
| vuln1                | 0.952         | 0.972            | 0.801          | 0.963        | 0.936        | 0.959      | 0.980          | 0.966            | 0.973            | 0.939        |
| vuln2                | 0.080         | 0.028            | 0.069          | 0.035        | 0.092        | 0.073      | 0.027          | 0.107            | 0.029            | 0.049        |
| vuln3                | 0.280         | 0.104            | 0.201          | 0.107        | 0.503        | 0.262      | 0.102          | 0.396            | 0.106            | 0.168        |
| vuln4                | 0.891         | 0.884            | 0.502          | 0.923        | 0.938        | 0.908      | 0.929          | 0.833            | 0.887            | 0.917        |
| vuln5                | 0.455         | 0.452            | 0.604          | 0.375        | 0.449        | 0.460      | 0.467          | 0.454            | 0.455            | 0.363        |
| vuln6                | 0.928         | 0.926            | 0.770          | 0.841        | 0.907        | 0.933      | 0.935          | 0.907            | 0.927            | 0.808        |
| qCR                  | 0.141         | 0.131            | 0.100          | 0.131        | 0.126        | 0.143      | 0.107          | 0.001            | 0.134            | 0.214        |
| qFSU region 1        | 0.002         | 0.002            | 0.003          | 0.001        | 0.002        | 0.002      | 0.002          | 0.004            | 0.002            | 0.003        |
| qFSU region 2        | 0.002         | 0.003            | 0.004          | 0.002        | 0.002        | 0.003      | 0.002          | 0.005            | 0.003            | 0.004        |
| qCELR                | 0.004         | 0.004            | 0.202          | 0.004        | 0.005        | 0.004      | 0.005          | —                | 0.005            | 0.009        |
| qdrift               | 0.016         | —                | —              | —            | —            | —          | —              | —                | —                | —            |
| $U_0$ region 1       | —             | —                | —              | —            | —            | —          | —              | 0.037            | —                | —            |
| $U_0$ region 2       | —             | —                | —              | —            | —            | —          | —              | 0.307            | —                | —            |

**Table 14: CRA 3 MAP: base cases and sensitivity trial results for Reference case 1 (for tags at liberty > 365 days) including derived quantities. Growth increment values in mm TW, biomass values in tonnes and  $R_0$  in numbers. Values by region indicated by:  $r_1=909+910$ ,  $r_2=911$ , and  $r_3$ =Total. The different sensitivity runs are defined in Table 3.**

|                                                  | <i>qdrift</i> | <i>no_qdrift</i> | <i>dwnCPUE</i> | <i>dwnLF</i> | <i>dwnSR</i> | <i>gdd</i> | <i>gshape3</i> | <i>start1979</i> | <i>illegal10</i> | <i>notaq</i> |
|--------------------------------------------------|---------------|------------------|----------------|--------------|--------------|------------|----------------|------------------|------------------|--------------|
| <i>Reference points</i>                          |               |                  |                |              |              |            |                |                  |                  |              |
| $R_{\text{mean}} r1$                             | 1 302 950     | 1 416 210        | 798 302        | 1 070 560    | 1 026 110    | 1 393 660  | 1 732 430      | 1 172 750        | 1 240 950        | 1 716 330    |
| $R_{\text{mean}} r2$                             | 738 445       | 817 423          | 415 672        | 671 996      | 581 071      | 805 695    | 1 007 540      | 763 268          | 718 265          | 1 048 860    |
| $H_{2018} r1$                                    | 7.28          | 6.87             | 6.56           | 6.55         | 7.05         | 6.90       | 6.78           | 6.72             | 6.88             | 6.97         |
| $H_{2018} r2$                                    | 2.67          | 2.55             | 2.46           | 2.44         | 2.39         | 2.54       | 2.57           | 2.45             | 2.55             | 2.42         |
| $H_{2018}$                                       | 9.94          | 9.42             | 9.03           | 8.99         | 9.44         | 9.44       | 9.35           | 9.17             | 9.43             | 9.39         |
| $MSY r1$                                         | 188.9         | 192.9            | 185.7          | 198.6        | 177.0        | 192.3      | 198.2          | 207.0            | 192.4            | 193.7        |
| $MSY r2$                                         | 112.6         | 115.5            | 111.3          | 118.9        | 100.7        | 114.9      | 115.9          | 171.1            | 116.0            | 118.6        |
| $MSY$                                            | 301.4         | 308.3            | 297.0          | 317.5        | 277.7        | 307.2      | 314.2          | 378.1            | 308.4            | 312.3        |
| $B_{\text{tot0male}} / B_{\text{tot0female}} r1$ | 1.754         | 1.715            | 2.363          | 1.831        | 2.038        | 1.725      | 1.733          | 1.819            | 1.753            | 1.674        |
| $B_{\text{tot0male}} / B_{\text{tot0female}} r2$ | 1.754         | 1.715            | 2.363          | 1.831        | 2.038        | 1.725      | 1.733          | 1.819            | 1.753            | 1.674        |
| $B_{\text{male}} / B_{\text{female}} r1$         | 0.796         | 0.833            | 0.644          | 0.790        | 0.799        | 0.827      | 0.945          | 0.779            | 0.835            | 0.831        |
| $B_{\text{male}} / B_{\text{female}} r2$         | 1.109         | 1.135            | 1.074          | 1.188        | 1.110        | 1.131      | 1.205          | 1.168            | 1.136            | 1.098        |
| $B_0 r1$                                         | 1 885.0       | 1 830.0          | 3 612.1        | 2 131.9      | 2 177.4      | 1 844.3    | 1 799.9        | 2 168.9          | 1 789.2          | 1 665.0      |
| $B_0 r2$                                         | 958.2         | 929.5            | 1 935.6        | 1 039.3      | 1 156.6      | 934.6      | 916.0          | 1 457.7          | 909.7            | 851.9        |
| $B_0$                                            | 2 843.1       | 2 759.5          | 5 547.7        | 3 171.2      | 3 334.1      | 2 778.9    | 2 715.9        | 3 626.6          | 2 698.9          | 2 516.9      |
| $B_{\text{now}} r1$                              | 1 729.1       | 1 718.2          | 3 387.6        | 2 030.0      | 2 056.6      | 1 730.2    | 1 653.9        | 1 942.0          | 1 640.5          | 1 494.8      |
| $B_{\text{now}} r2$                              | 868.7         | 874.5            | 1 682.6        | 1 107.0      | 1 064.0      | 881.5      | 849.0          | 1 142.1          | 842.7            | 830.7        |
| $B_{\text{now}}$                                 | 2 597.8       | 2 592.7          | 5 070.2        | 3 137.0      | 3 120.7      | 2 611.7    | 2 502.9        | 3 084.1          | 2 483.2          | 2 325.5      |
| $B_{\text{min}} r1$                              | 117.7         | 114.2            | 93.1           | 124.3        | 109.1        | 112.1      | 113.9          | 116.5            | 111.5            | 93.2         |
| $B_{\text{min}} r2$                              | 48.2          | 48.1             | 49.0           | 64.0         | 48.0         | 48.3       | 49.7           | 48.5             | 45.1             | 36.9         |
| $B_{\text{min}}$                                 | 165.9         | 162.3            | 142.0          | 188.3        | 157.1        | 160.5      | 163.6          | 165.1            | 156.7            | 130.2        |
| $B_{2018} r1$                                    | 248.3         | 286.9            | 284.1          | 382.8        | 241.8        | 281.2      | 295.7          | 299.5            | 273.1            | 220.1        |
| $B_{2018} r2$                                    | 232.2         | 264.5            | 331.8          | 348.1        | 249.9        | 260.0      | 261.2          | 363.2            | 253.6            | 226.7        |
| $B_{2018}$                                       | 480.6         | 551.4            | 615.9          | 730.9        | 491.7        | 541.1      | 556.9          | 662.7            | 526.8            | 446.8        |
| $B_{2018} / B_0 r1$                              | 0.132         | 0.157            | 0.079          | 0.180        | 0.111        | 0.152      | 0.164          | 0.138            | 0.153            | 0.132        |
| $B_{2018} / B_0 r2$                              | 0.242         | 0.285            | 0.171          | 0.335        | 0.216        | 0.278      | 0.285          | 0.249            | 0.279            | 0.266        |
| $B_{2018} / B_0$                                 | 0.169         | 0.200            | 0.111          | 0.231        | 0.147        | 0.195      | 0.205          | 0.183            | 0.195            | 0.178        |
| $SSB_0 r1$                                       | 1 419.5       | 1 442.2          | 1 608.1        | 1 363.5      | 1 215.2      | 1 436.6    | 1 392.3        | 1 463.4          | 1 346.8          | 1 434.8      |
| $SSB_0 r2$                                       | 814.1         | 830.8            | 903.1          | 762.4        | 706.5        | 826.2      | 803.0          | 1 088.5          | 771.6            | 807.6        |
| $SSB_0$                                          | 2 233.6       | 2 273.0          | 2 511.3        | 2 125.9      | 1 921.7      | 2 262.8    | 2 195.2        | 2 551.9          | 2 118.4          | 2 242.4      |
| $SSB_{\text{now}} r1$                            | 1 255.6       | 1 305.0          | 1 467.8        | 1 260.6      | 1 112.6      | 1 298.9    | 1 229.6        | 1 310.3          | 1 191.4          | 1 223.4      |
| $SSB_{\text{now}} r2$                            | 711.6         | 753.3            | 764.3          | 791.3        | 630.1        | 750.9      | 715.1          | 852.8            | 689.6            | 747.6        |
| $SSB_{\text{now}}$                               | 1 967.2       | 2 058.3          | 2 232.0        | 2 051.8      | 1 742.7      | 2 049.8    | 1 944.7        | 2 163.1          | 1 880.9          | 1 971.0      |
| $SSB_{2018} r1$                                  | 1 069.0       | 1 129.8          | 1 176.6        | 1 098.0      | 893.9        | 1 121.6    | 1 092.7        | 1 126.1          | 1 030.8          | 1 091.8      |
| $SSB_{2018} r2$                                  | 630.2         | 672.9            | 609.5          | 658.3        | 558.7        | 670.3      | 652.5          | 767.4            | 620.8            | 645.4        |
| $SSB_{2018}$                                     | 1 699.2       | 1 802.7          | 1 786.1        | 1 756.2      | 1 452.6      | 1 791.9    | 1 745.2        | 1 893.5          | 1 651.5          | 1 737.2      |
| $SSB_{2018} / SSB_0 r1$                          | 0.753         | 0.783            | 0.732          | 0.805        | 0.736        | 0.781      | 0.785          | 0.770            | 0.765            | 0.761        |
| $SSB_{2018} / SSB_0 r2$                          | 0.774         | 0.810            | 0.675          | 0.863        | 0.791        | 0.811      | 0.813          | 0.705            | 0.805            | 0.799        |
| $SSB_{2018} / SSB_0$                             | 0.761         | 0.793            | 0.711          | 0.826        | 0.756        | 0.792      | 0.795          | 0.742            | 0.780            | 0.775        |
| $B_{\text{tot0}} r1$                             | 4 621.2       | 4 639.9          | 6 288.1        | 4 499.1      | 4 558.1      | 4 633.6    | 5 051.5        | 4 874.3          | 4 385.8          | 4 550.1      |
| $B_{\text{tot0}} r2$                             | 2 650.3       | 2 672.8          | 3 531.5        | 2 515.8      | 2 649.9      | 2 664.6    | 2 913.4        | 3 625.7          | 2 512.6          | 2 560.9      |
| $B_{\text{tot0}}$                                | 7 271.5       | 7 312.7          | 9 819.6        | 7 014.9      | 7 208.1      | 7 298.3    | 7 964.9        | 8 500.0          | 6 898.5          | 7 111.1      |
| $B_{\text{tot0now}} r1$                          | 4 219.5       | 4 336.3          | 5 881.0        | 4 302.2      | 4 289.9      | 4 326.4    | 4 569.1        | 4 364.6          | 4 004.5          | 4 017.3      |
| $B_{\text{tot0now}} r2$                          | 2 391.4       | 2 502.9          | 3 062.2        | 2 700.5      | 2 429.3      | 2 501.1    | 2 657.3        | 2 840.6          | 2 317.8          | 2 455.0      |
| $B_{\text{tot0now}}$                             | 6 610.8       | 6 839.2          | 8 943.2        | 7 002.7      | 6 719.2      | 6 827.5    | 7 226.3        | 7 205.2          | 6 322.2          | 6 472.3      |



**Table 15: CRA 3 MAP: base cases and sensitivity trial results for Reference case 2 (all tag data) including derived quantities. Growth increment values in mm TW, biomass values in tonnes and  $R_0$  in numbers. Values by region indicated by: 1=909+910, 2=911, and 3=Total. The different sensitivity runs are defined in Table 3.**

|                                                  | <i>qdrift</i> | <i>no_qdrift</i> | <i>dwnCPUE</i> | <i>dwnLF</i> | <i>dwnSR</i> | <i>gdd</i> | <i>gshape3</i> | <i>start1979</i> | <i>illegal10</i> | <i>notag</i> |
|--------------------------------------------------|---------------|------------------|----------------|--------------|--------------|------------|----------------|------------------|------------------|--------------|
| <i>Reference points</i>                          |               |                  |                |              |              |            |                |                  |                  |              |
| $R_{\text{mean}} r1$                             | 822 036       | 839 035          | 628 954        | 788 547      | 734 449      | 882 240    | 782 667        | 689 850          | 732 671          | 1 691 910    |
| $R_{\text{mean}} r2$                             | 407 662       | 427 052          | 310 867        | 476 457      | 379 222      | 453 668    | 362 704        | 355 013          | 368 017          | 1 030 210    |
| $H_{2018} r1$                                    | 6.62          | 6.84             | 6.46           | 6.04         | 6.61         | 6.36       | 6.66           | 6.15             | 6.68             | 6.97         |
| $H_{2018} r2$                                    | 2.66          | 2.82             | 2.58           | 2.48         | 2.45         | 2.62       | 2.66           | 2.53             | 2.66             | 2.42         |
| $H_{2018}$                                       | 9.28          | 9.66             | 9.04           | 8.52         | 9.05         | 8.98       | 9.32           | 8.68             | 9.33             | 9.39         |
| MSY $r1$                                         | 174.8         | 176.4            | 177.2          | 182.2        | 165.2        | 178.3      | 158.7          | 178.1            | 176.3            | 192.9        |
| MSY $r2$                                         | 100.0         | 104.3            | 107.1          | 108.3        | 94.9         | 105.5      | 87.9           | 141.0            | 102.5            | 118.0        |
| MSY                                              | 274.8         | 280.7            | 284.3          | 290.5        | 260.1        | 283.8      | 246.6          | 319.1            | 278.8            | 310.9        |
| $B_{\text{tot0male}} / B_{\text{tot0female}} r1$ | 2.035         | 1.983            | 2.390          | 1.910        | 2.216        | 1.977      | 2.347          | 2.318            | 2.078            | 1.688        |
| $B_{\text{tot0male}} / B_{\text{tot0female}} r2$ | 2.035         | 1.983            | 2.390          | 1.910        | 2.216        | 1.977      | 2.347          | 2.318            | 2.078            | 1.688        |
| $B_{\text{male}} / B_{\text{female}} r1$         | 0.651         | 0.669            | 0.514          | 0.659        | 0.681        | 0.716      | 0.659          | 0.597            | 0.651            | 0.829        |
| $B_{\text{male}} / B_{\text{female}} r2$         | 1.040         | 1.040            | 0.999          | 1.118        | 1.011        | 1.075      | 1.033          | 1.018            | 1.039            | 1.099        |
| $B_0 r1$                                         | 2 309.0       | 2 567.6          | 4 072.3        | 2 499.8      | 2 536.7      | 2 304.6    | 3 001.4        | 3 503.2          | 2 501.1          | 1 678.3      |
| $B_0 r2$                                         | 1 199.9       | 1 278.7          | 2 198.8        | 1 215.2      | 1 383.5      | 1 196.7    | 1 503.1        | 2 354.8          | 1 247.4          | 858.4        |
| $B_0$                                            | 3 508.9       | 3 846.3          | 6 271.2        | 3 715.0      | 3 920.2      | 3 501.3    | 4 504.6        | 5 857.9          | 3 748.5          | 2 536.7      |
| $B_{\text{now}} r1$                              | 2 208.1       | 2 510.7          | 3 829.2        | 2 374.3      | 2 528.7      | 2 291.4    | 2 968.3        | 3 510.2          | 2 365.3          | 1 509.3      |
| $B_{\text{now}} r2$                              | 1 026.1       | 1 151.2          | 1 820.9        | 1 261.3      | 1 218.2      | 1 074.3    | 1 299.5        | 1 720.6          | 1 102.2          | 836.7        |
| $B_{\text{now}}$                                 | 3 234.2       | 3 661.8          | 5 650.1        | 3 635.5      | 3 747.0      | 3 365.7    | 4 267.8        | 5 230.8          | 3 467.6          | 2 345.9      |
| $B_{\text{min}} r1$                              | 137.8         | 126.4            | 104.9          | 132.1        | 125.0        | 126.9      | 119.0          | 131.1            | 121.6            | 92.7         |
| $B_{\text{min}} r2$                              | 63.3          | 63.5             | 68.4           | 75.8         | 61.5         | 63.9       | 60.6           | 61.4             | 59.0             | 36.9         |
| $B_{\text{min}}$                                 | 201.1         | 189.9            | 173.3          | 207.8        | 186.5        | 190.7      | 179.6          | 192.5            | 180.6            | 129.6        |
| $B_{2018} r1$                                    | 297.0         | 335.0            | 306.7          | 415.2        | 292.7        | 353.6      | 298.9          | 357.9            | 312.3            | 219.7        |
| $B_{2018} r2$                                    | 261.2         | 298.0            | 393.2          | 375.9        | 285.3        | 299.5      | 263.4          | 363.9            | 282.3            | 225.8        |
| $B_{2018}$                                       | 558.3         | 632.9            | 699.9          | 791.1        | 578.0        | 653.1      | 562.2          | 721.8            | 594.6            | 445.5        |
| $B_{2018} / B_0 r1$                              | 0.130         | 0.129            | 0.075          | 0.166        | 0.115        | 0.153      | 0.100          | 0.102            | 0.125            | 0.131        |
| $B_{2018} / B_0 r2$                              | 0.233         | 0.218            | 0.179          | 0.309        | 0.206        | 0.250      | 0.175          | 0.155            | 0.226            | 0.263        |
| $B_{2018} / B_0$                                 | 0.165         | 0.159            | 0.112          | 0.213        | 0.147        | 0.187      | 0.125          | 0.123            | 0.159            | 0.176        |
| $SSB_0 r1$                                       | 1 392.5       | 1 310.1          | 1 723.4        | 1 409.4      | 1 172.1      | 1 316.6    | 1 282.2        | 1 541.7          | 1 311.1          | 1 423.8      |
| $SSB_0 r2$                                       | 747.5         | 742.8            | 964.4          | 768.3        | 683.0        | 747.1      | 678.0          | 1 088.0          | 702.5            | 800.2        |
| $SSB_0$                                          | 2 139.9       | 2 052.9          | 2 687.8        | 2 177.7      | 1 855.0      | 2 063.7    | 1 960.2        | 2 629.7          | 2 013.6          | 2 224.1      |
| $SSB_{\text{now}} r1$                            | 1 335.1       | 1 228.7          | 1 611.7        | 1 350.0      | 1 146.4      | 1 281.1    | 1 273.3        | 1 544.8          | 1 216.4          | 1 217.0      |
| $SSB_{\text{now}} r2$                            | 662.1         | 625.4            | 796.6          | 815.7        | 591.9        | 658.7      | 590.1          | 795.0            | 611.0            | 741.0        |
| $SSB_{\text{now}}$                               | 1 997.1       | 1 854.0          | 2 408.3        | 2 165.8      | 1 738.3      | 1 939.8    | 1 863.3        | 2 339.8          | 1 827.4          | 1 958.0      |
| $SSB_{2018} r1$                                  | 1 137.9       | 1 027.6          | 1 258.8        | 1 160.4      | 892.3        | 1 079.8    | 1 065.9        | 1 213.8          | 1 037.6          | 1 085.1      |
| $SSB_{2018} r2$                                  | 571.4         | 543.6            | 624.5          | 649.5        | 527.5        | 578.1      | 506.4          | 637.8            | 532.1            | 639.0        |
| $SSB_{2018}$                                     | 1 709.2       | 1 571.2          | 1 883.3        | 1 810.0      | 1 419.8      | 1 657.9    | 1 572.3        | 1 851.6          | 1 569.7          | 1 724.1      |
| $SSB_{2018} / SSB_0 r1$                          | 0.817         | 0.784            | 0.730          | 0.823        | 0.761        | 0.820      | 0.831          | 0.787            | 0.791            | 0.762        |
| $SSB_{2018} / SSB_0 r2$                          | 0.764         | 0.732            | 0.648          | 0.845        | 0.772        | 0.774      | 0.747          | 0.586            | 0.757            | 0.799        |
| $SSB_{2018} / SSB_0$                             | 0.799         | 0.765            | 0.701          | 0.831        | 0.765        | 0.803      | 0.802          | 0.704            | 0.780            | 0.775        |
| $B_{\text{tot0}} r1$                             | 4 766.7       | 4 430.4          | 6 566.6        | 4 640.1      | 4 492.9      | 4 438.8    | 5 287.7        | 5 852.4          | 4 571.4          | 4 535.0      |
| $B_{\text{tot0}} r2$                             | 2 558.8       | 2 511.9          | 3 674.6        | 2 529.2      | 2 618.0      | 2 519.0    | 2 796.3        | 4 130.1          | 2 449.3          | 2 548.8      |
| $B_{\text{tot0}}$                                | 7 325.5       | 6 942.2          | 10 241.2       | 7 169.4      | 7 110.9      | 6 957.7    | 8 084.0        | 9 982.4          | 7 020.7          | 7 083.7      |
| $B_{\text{tot0now}} r1$                          | 4 684.8       | 4 263.1          | 6 217.0        | 4 498.8      | 4 500.3      | 4 436.3    | 5 268.2        | 5 864.1          | 4 344.6          | 4 012.0      |
| $B_{\text{tot0now}} r2$                          | 2 323.3       | 2 169.8          | 3 072.8        | 2 718.3      | 2 323.7      | 2 281.2    | 2 441.4        | 3 017.8          | 2 182.3          | 2 442.9      |
| $B_{\text{tot0now}}$                             | 7 008.1       | 6 432.9          | 9 289.8        | 7 217.1      | 6 824.0      | 6 717.5    | 7 709.6        | 8 881.9          | 6 526.8          | 6 454.9      |

**Table 16: CRA 3 MCMC: reference case runs (see Table 4 for run descriptions) MCMC outputs, reporting the 5<sup>th</sup>, 50<sup>th</sup> (median, highlighted in yellow), and 95<sup>th</sup> quantiles of the posterior distributions. Growth increment values in mm TW, biomass values in tonnes,  $R_0$  in numbers of individuals, handling mortality ( $H$ ) in tonnes, and CPUE in kg/potlift. ‘—’: not applicable. Model runs are defined in Table 3. [Continued on next 3 pages]**

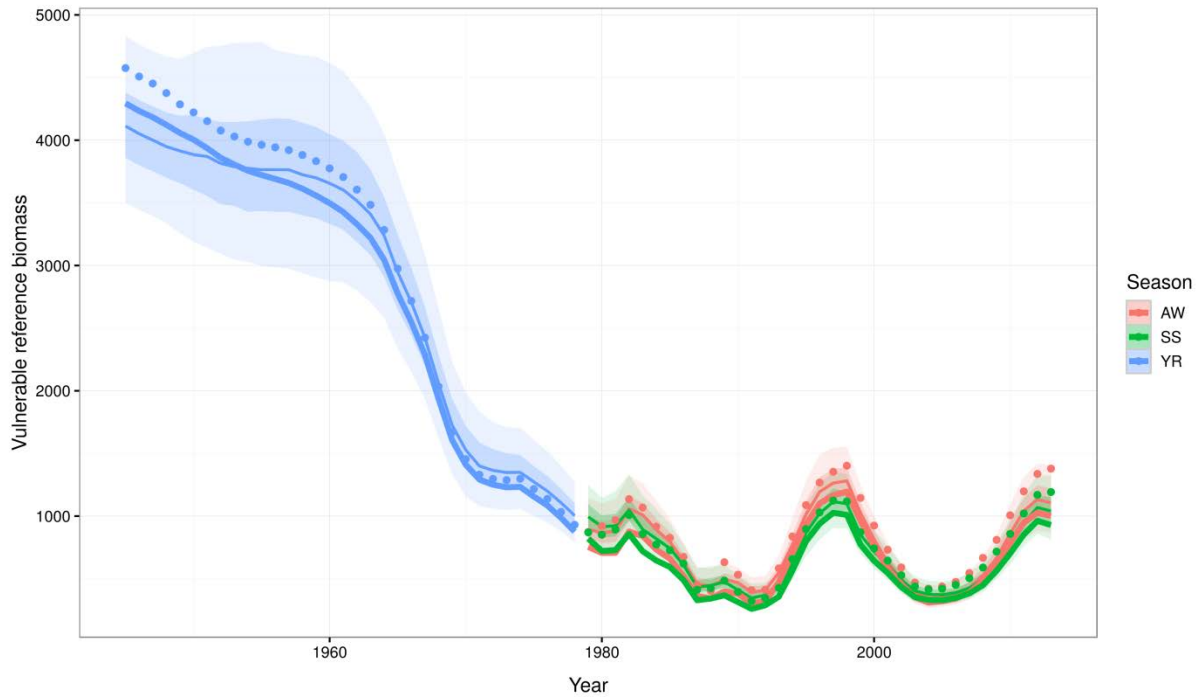
|                                                       | reduced tag data set |           |           |           |           |           | full tag data set |          |          |           |          |           |
|-------------------------------------------------------|----------------------|-----------|-----------|-----------|-----------|-----------|-------------------|----------|----------|-----------|----------|-----------|
|                                                       | r1_qdrift            |           |           | no_qdrift |           |           | r2_qdrift         |          |          | no_qdrift |          |           |
|                                                       | 5%                   | 50%       | 95%       | 5%        | 50%       | 95%       | 5%                | 50%      | 95%      | 5%        | 50%      | 95%       |
| <b>Likelihoods</b>                                    |                      |           |           |           |           |           |                   |          |          |           |          |           |
| Total                                                 | 21 744.0             | 21 758.9  | 21 774.9  | 22 210.4  | 22 224.7  | 22 241.9  | 25 461.1          | 25 475.2 | 25 490.4 | 26 980.9  | 26 995.9 | 27 011.4  |
| Prior                                                 | 20.8                 | 35.0      | 48.2      | 20.5      | 33.3      | 47.7      | 22.0              | 34.6     | 49.7     | 23.5      | 35.7     | 49.6      |
| tag                                                   | 2 008.5              | 2 016.7   | 2 025.7   | 2 007.9   | 2 016.4   | 2 025.4   | 6 653.8           | 6 668.3  | 6 684.4  | 6 659.8   | 6 674.7  | 6 692.5   |
| sexratio                                              | 2 526.4              | 2 532.9   | 2 540.8   | 2 722.6   | 2 729.2   | 2 737.3   | 2 532.2           | 2 539.9  | 2 549.9  | 2 728.4   | 2 737.2  | 2 747.0   |
| LFs                                                   | 17 297.2             | 17 309.4  | 17 324.4  | 17 560.7  | 17 573.8  | 17 588.4  | 16 329.9          | 16 349.2 | 16 367.1 | 17 641.6  | 17 659.3 | 17 679.5  |
| CPUE[CR]                                              | -19.3                | -18.2     | -15.8     | -19.3     | -18.0     | -15.3     | -19.6             | -18.7    | -16.3    | -19.5     | -18.6    | -16.2     |
| CPUE[FSU-909+910]                                     | -33.9                | -29.8     | -24.6     | -36.0     | -31.9     | -25.9     | -34.9             | -30.8    | -25.6    | -38.2     | -33.7    | -27.8     |
| CPUE[FSU-911]                                         | -32.4                | -29.8     | -25.7     | -32.6     | -29.7     | -24.7     | -32.2             | -29.2    | -24.7    | -31.9     | -28.8    | -23.7     |
| CPUE[CELR]                                            | -68.7                | -58.6     | -47.3     | -59.6     | -49.9     | -38.8     | -51.1             | -39.9    | -27.5    | -43.1     | -32.1    | -20.1     |
| <b>Standard deviation normalised residuals (SDNR)</b> |                      |           |           |           |           |           |                   |          |          |           |          |           |
| tag                                                   | 1.17                 | 1.22      | 1.26      | 1.17      | 1.22      | 1.27      | 5.29              | 5.54     | 5.78     | 5.25      | 5.48     | 5.72      |
| sexratio                                              | 0.94                 | 0.98      | 1.02      | 0.97      | 1.00      | 1.04      | 0.97              | 1.00     | 1.05     | 0.99      | 1.03     | 1.08      |
| CPUE[CR]                                              | 0.98                 | 1.07      | 1.24      | 0.98      | 1.08      | 1.27      | 1.00              | 1.06     | 1.22     | 0.97      | 1.03     | 1.21      |
| CPUE[FSU-909+910]                                     | 0.92                 | 1.12      | 1.34      | 0.96      | 1.15      | 1.39      | 0.86              | 1.07     | 1.30     | 1.00      | 1.21     | 1.44      |
| CPUE[FSU-911]                                         | 0.95                 | 1.07      | 1.25      | 0.94      | 1.08      | 1.29      | 0.96              | 1.10     | 1.30     | 0.97      | 1.12     | 1.33      |
| CPUE[CELR]                                            | 1.16                 | 1.23      | 1.32      | 1.08      | 1.15      | 1.24      | 1.13              | 1.22     | 1.30     | 1.17      | 1.26     | 1.34      |
| <b>Mean absolute residual (MAR)</b>                   |                      |           |           |           |           |           |                   |          |          |           |          |           |
| tag                                                   | 0.65                 | 0.68      | 0.71      | 0.65      | 0.68      | 0.70      | 0.70              | 0.72     | 0.73     | 0.70      | 0.72     | 0.73      |
| sexratio                                              | 0.46                 | 0.51      | 0.56      | 0.46      | 0.52      | 0.57      | 0.49              | 0.53     | 0.57     | 0.50      | 0.54     | 0.59      |
| CPUE[CR]                                              | 0.42                 | 0.71      | 1.11      | 0.43      | 0.72      | 1.13      | 0.40              | 0.66     | 1.03     | 0.38      | 0.66     | 1.03      |
| CPUE[FSU-909+910]                                     | 0.62                 | 0.89      | 1.13      | 0.61      | 0.90      | 1.18      | 0.56              | 0.80     | 1.05     | 0.64      | 0.92     | 1.21      |
| CPUE[FSU-911]                                         | 0.49                 | 0.70      | 0.93      | 0.51      | 0.72      | 0.95      | 0.50              | 0.73     | 0.97     | 0.52      | 0.76     | 1.01      |
| CPUE[CELR]                                            | 0.61                 | 0.71      | 0.81      | 0.58      | 0.69      | 0.79      | 0.68              | 0.76     | 0.87     | 0.72      | 0.83     | 0.94      |
| <b>Parameters</b>                                     |                      |           |           |           |           |           |                   |          |          |           |          |           |
| $R_0$ [909+910]                                       | 1 173 200            | 1 422 330 | 1 749 880 | 1 247 740 | 1 493 570 | 1 826 450 | 734 761           | 845 445  | 981 710  | 758 325   | 874 071  | 1 008 070 |
| $R_0$ [911]                                           | 672 448              | 814 417   | 1 024 670 | 710 963   | 865 970   | 1 072 800 | 410 541           | 481 193  | 562 359  | 426 205   | 494 822  | 581 814   |
| $R_{2007-2016}$ [909+910]                             | 1 158 150            | 1 368 720 | 1 642 220 | 1 265 270 | 1 480 150 | 1 779 780 | 771 264           | 865 708  | 981 717  | 822 021   | 925 365  | 1 034 450 |
| $R_{2007-2016}$ [911]                                 | 630 441              | 783 201   | 1 010 260 | 690 451   | 865 528   | 1 123 610 | 370 070           | 442 804  | 533 574  | 396 925   | 475 174  | 573 169   |
| M                                                     | 0.213                | 0.235     | 0.262     | 0.219     | 0.242     | 0.268     | 0.162             | 0.179    | 0.197    | 0.167     | 0.183    | 0.202     |
| Galpha[909+910]                                       | 6.81                 | 7.35      | 7.89      | 6.76      | 7.33      | 7.88      | 9.91              | 10.16    | 10.39    | 9.87      | 10.13    | 10.37     |
| Galpha[911]                                           | 7.08                 | 7.59      | 8.11      | 7.15      | 7.69      | 8.16      | 7.20              | 7.65     | 8.10     | 7.29      | 7.74     | 8.17      |
| Gbeta[909+910]                                        | 2.41                 | 2.61      | 2.82      | 2.38      | 2.60      | 2.81      | 1.17              | 1.27     | 1.37     | 1.21      | 1.31     | 1.41      |
| Gbeta[911]                                            | 0.64                 | 0.74      | 0.86      | 0.65      | 0.75      | 0.86      | 0.42              | 0.49     | 0.56     | 0.43      | 0.49     | 0.56      |
| GCV[909+910]                                          | 0.750                | 0.795     | 0.844     | 0.756     | 0.801     | 0.846     | 0.703             | 0.724    | 0.744    | 0.702     | 0.722    | 0.743     |
| GCV[911]                                              | 1.14                 | 1.26      | 1.40      | 1.12      | 1.25      | 1.39      | 1.22              | 1.32     | 1.43     | 1.22      | 1.32     | 1.44      |
| Gobs                                                  | 0.0298               | 0.2740    | 0.6724    | 0.0262    | 0.2696    | 0.6471    | 0.0012            | 0.0091   | 0.0269   | 0.0009    | 0.0095   | 0.0263    |
| Mat50                                                 | 35.4                 | 40.2      | 43.4      | 34.9      | 39.9      | 43.1      | 36.6              | 41.1     | 44.5     | 35.8      | 40.6     | 43.7      |
| Mat95                                                 | 9.4                  | 20.9      | 34.2      | 10.3      | 20.6      | 34.6      | 11.9              | 23.2     | 36.4     | 11.0      | 22.5     | 36.0      |
| selL(M[909+910])                                      | 4.5                  | 4.6       | 4.8       | 4.5       | 4.6       | 4.8       | 4.7               | 4.8      | 5.0      | 4.6       | 4.8      | 5.0       |
| selL(F[909+910]epoch2)                                | 13.3                 | 15.8      | 18.1      | 13.5      | 15.6      | 18.3      | 15.6              | 18.3     | 20.9     | 14.4      | 17.5     | 20.1      |

|                                                | reduced tag data set |         |         |           |         |         | full tag data set |         |         |           |         |         |
|------------------------------------------------|----------------------|---------|---------|-----------|---------|---------|-------------------|---------|---------|-----------|---------|---------|
|                                                | r1 qdrift            |         |         | no qdrift |         |         | r2 qdrift         |         |         | no qdrift |         |         |
|                                                | 5%                   | 50%     | 95%     | 5%        | 50%     | 95%     | 5%                | 50%     | 95%     | 5%        | 50%     | 95%     |
| selL(M[911])                                   | 5.3                  | 5.7     | 6.1     | 5.3       | 5.6     | 6.0     | 5.5               | 6.0     | 6.5     | 5.5       | 5.9     | 6.4     |
| selL(F[911])                                   | 5.9                  | 6.3     | 6.8     | 5.9       | 6.3     | 6.8     | 6.0               | 6.5     | 6.9     | 6.0       | 6.5     | 7.0     |
| selL(F[909+910]epoch1)                         | 5.2                  | 6.7     | 8.9     | 5.2       | 6.7     | 8.7     | 5.3               | 7.2     | 9.6     | 5.3       | 7.1     | 9.5     |
| selM(M[909+910])                               | 54.3                 | 54.6    | 55.0    | 54.2      | 54.6    | 55.0    | 53.5              | 53.8    | 54.1    | 53.5      | 53.8    | 54.1    |
| selM (F[909+910]epoch2)                        | 73.7                 | 79.7    | 86.1    | 73.7      | 79.4    | 86.2    | 76.4              | 82.9    | 88.8    | 72.8      | 80.7    | 87.3    |
| selM (M[911])                                  | 58.9                 | 59.7    | 60.5    | 58.9      | 59.6    | 60.4    | 58.0              | 58.9    | 60.0    | 57.9      | 58.8    | 59.7    |
| selM (F[911])                                  | 64.9                 | 65.8    | 66.8    | 64.9      | 65.8    | 66.8    | 64.4              | 65.3    | 66.3    | 64.4      | 65.3    | 66.3    |
| selM (F[909+910]epoch1)                        | 56.6                 | 59.5    | 64.4    | 56.7      | 59.6    | 63.9    | 55.6              | 58.9    | 63.4    | 55.2      | 58.5    | 63.0    |
| vuln1(M/SS[909+910])                           | 0.89                 | 0.94    | 0.98    | 0.85      | 0.91    | 0.96    | 0.88              | 0.94    | 0.98    | 0.86      | 0.92    | 0.97    |
| vuln2(F/AW[909+910])                           | 0.06                 | 0.09    | 0.14    | 0.06      | 0.09    | 0.13    | 0.06              | 0.09    | 0.14    | 0.05      | 0.09    | 0.13    |
| vuln3(F/SS[909+910])                           | 0.21                 | 0.30    | 0.47    | 0.20      | 0.29    | 0.43    | 0.22              | 0.32    | 0.46    | 0.19      | 0.29    | 0.42    |
| vuln4(M/SS[911])                               | 0.86                 | 0.91    | 0.96    | 0.83      | 0.89    | 0.95    | 0.82              | 0.88    | 0.94    | 0.82      | 0.87    | 0.94    |
| vuln5(F/AW[911])                               | 0.34                 | 0.42    | 0.51    | 0.34      | 0.42    | 0.52    | 0.37              | 0.45    | 0.55    | 0.38      | 0.46    | 0.56    |
| vuln6(F/SS[911])                               | 0.78                 | 0.89    | 0.96    | 0.77      | 0.89    | 0.96    | 0.82              | 0.91    | 0.98    | 0.83      | 0.92    | 0.98    |
| qCPUE[CR]                                      | 0.13815              | 0.17356 | 0.21772 | 0.14523   | 0.18223 | 0.23275 | 0.11508           | 0.14264 | 0.17450 | 0.11860   | 0.14732 | 0.18587 |
| qCPUE[FSU-909+910]                             | 0.00178              | 0.00222 | 0.00283 | 0.00189   | 0.00235 | 0.00293 | 0.00152           | 0.00191 | 0.00239 | 0.00163   | 0.00197 | 0.00240 |
| qCPUE[FSU-911]                                 | 0.00250              | 0.00314 | 0.00394 | 0.00260   | 0.00334 | 0.00428 | 0.00198           | 0.00239 | 0.00300 | 0.00210   | 0.00253 | 0.00311 |
| qCPUE[CELR]                                    | 0.00433              | 0.00501 | 0.00581 | 0.00534   | 0.00595 | 0.00662 | 0.00313           | 0.00359 | 0.00410 | 0.00400   | 0.00439 | 0.00483 |
| qdrift                                         | 0.00469              | 0.01240 | 0.01958 | —         | —       | —       | 0.00859           | 0.01612 | 0.02374 | —         | —       | —       |
| <b>Derived parameters: vulnerable biomass</b>  |                      |         |         |           |         |         |                   |         |         |           |         |         |
| B <sub>0</sub> [909+910]                       | 1 549                | 1 765   | 1 991   | 1 507     | 1 713   | 1 956   | 1 896             | 2 139   | 2 426   | 1 876     | 2 122   | 2 389   |
| B <sub>0</sub> [911]                           | 780                  | 896     | 1 014   | 762       | 870     | 998     | 973               | 1 111   | 1 261   | 964       | 1 098   | 1 244   |
| B <sub>0</sub> [CRA 3]                         | 2 367                | 2 658   | 2 940   | 2 308     | 2 590   | 2 928   | 2 929             | 3 257   | 3 635   | 2 903     | 3 226   | 3 567   |
| B <sub>0now</sub> [909+910]                    | 1 457                | 1 690   | 1 952   | 1 455     | 1 694   | 1 954   | 1 905             | 2 155   | 2 455   | 1 931     | 2 207   | 2 509   |
| B <sub>0now</sub> [911]                        | 713                  | 850     | 1 014   | 728       | 868     | 1 031   | 839               | 998     | 1 183   | 868       | 1 027   | 1 210   |
| B <sub>0now</sub> [CRA 3]                      | 2 219                | 2 551   | 2 919   | 2 247     | 2 568   | 2 920   | 2 795             | 3 154   | 3 577   | 2 869     | 3 237   | 3 639   |
| B <sub>min</sub> [909+910]                     | 109                  | 118     | 128     | 106       | 116     | 126     | 126               | 138     | 150     | 119       | 131     | 142     |
| B <sub>min</sub> [911]                         | 44                   | 50      | 57      | 43        | 50      | 57      | 56                | 65      | 74      | 57        | 66      | 76      |
| B <sub>min</sub> [CRA 3]                       | 155                  | 168     | 182     | 152       | 166     | 181     | 185               | 202     | 219     | 181       | 196     | 214     |
| B <sub>2019</sub> [909+910]                    | 208                  | 257     | 323     | 237       | 299     | 377     | 238               | 307     | 403     | 282       | 368     | 462     |
| B <sub>2019</sub> [911]                        | 186                  | 240     | 310     | 212       | 278     | 354     | 201               | 266     | 340     | 234       | 308     | 384     |
| B <sub>2019</sub> [CRA 3]                      | 419                  | 501     | 602     | 489       | 578     | 689     | 476               | 575     | 706     | 557       | 675     | 806     |
| B <sub>2023</sub> [909+910]                    | 109                  | 266     | 511     | 145       | 328     | 587     | 149               | 346     | 637     | 204       | 434     | 768     |
| B <sub>2023</sub> [911]                        | 47                   | 126     | 250     | 60        | 161     | 296     | 45                | 126     | 273     | 63        | 168     | 336     |
| B <sub>2023</sub> [CRA 3]                      | 209                  | 400     | 673     | 284       | 499     | 779     | 254               | 489     | 798     | 359       | 619     | 963     |
| B <sub>2019</sub> /B <sub>0</sub> [909+910]    | 0.11                 | 0.15    | 0.19    | 0.14      | 0.18    | 0.22    | 0.11              | 0.14    | 0.19    | 0.13      | 0.17    | 0.22    |
| B <sub>2019</sub> /B <sub>0</sub> [911]        | 0.20                 | 0.27    | 0.36    | 0.24      | 0.32    | 0.41    | 0.18              | 0.24    | 0.31    | 0.21      | 0.28    | 0.36    |
| B <sub>2019</sub> /B <sub>0</sub> [CRA 3]      | 0.15                 | 0.19    | 0.23    | 0.18      | 0.22    | 0.27    | 0.14              | 0.18    | 0.22    | 0.17      | 0.21    | 0.26    |
| B <sub>2023</sub> /B <sub>0</sub> [909+910]    | 0.06                 | 0.15    | 0.29    | 0.08      | 0.19    | 0.35    | 0.07              | 0.16    | 0.30    | 0.10      | 0.20    | 0.36    |
| B <sub>2023</sub> /B <sub>0</sub> [911]        | 0.05                 | 0.14    | 0.28    | 0.07      | 0.18    | 0.35    | 0.04              | 0.11    | 0.24    | 0.06      | 0.15    | 0.31    |
| B <sub>2023</sub> /B <sub>0</sub> [CRA 3]      | 0.08                 | 0.15    | 0.26    | 0.11      | 0.19    | 0.31    | 0.08              | 0.15    | 0.25    | 0.11      | 0.19    | 0.30    |
| B <sub>2023</sub> /B <sub>2019</sub> [909+910] | 0.47                 | 1.03    | 1.85    | 0.53      | 1.08    | 1.82    | 0.53              | 1.10    | 1.91    | 0.65      | 1.19    | 1.88    |
| B <sub>2023</sub> /B <sub>2019</sub> [911]     | 0.23                 | 0.52    | 0.90    | 0.26      | 0.58    | 0.98    | 0.20              | 0.47    | 0.90    | 0.23      | 0.54    | 0.97    |
| B <sub>2023</sub> /B <sub>2019</sub> [CRA 3]   | 0.45                 | 0.80    | 1.25    | 0.53      | 0.86    | 1.28    | 0.47              | 0.83    | 1.29    | 0.57      | 0.91    | 1.34    |

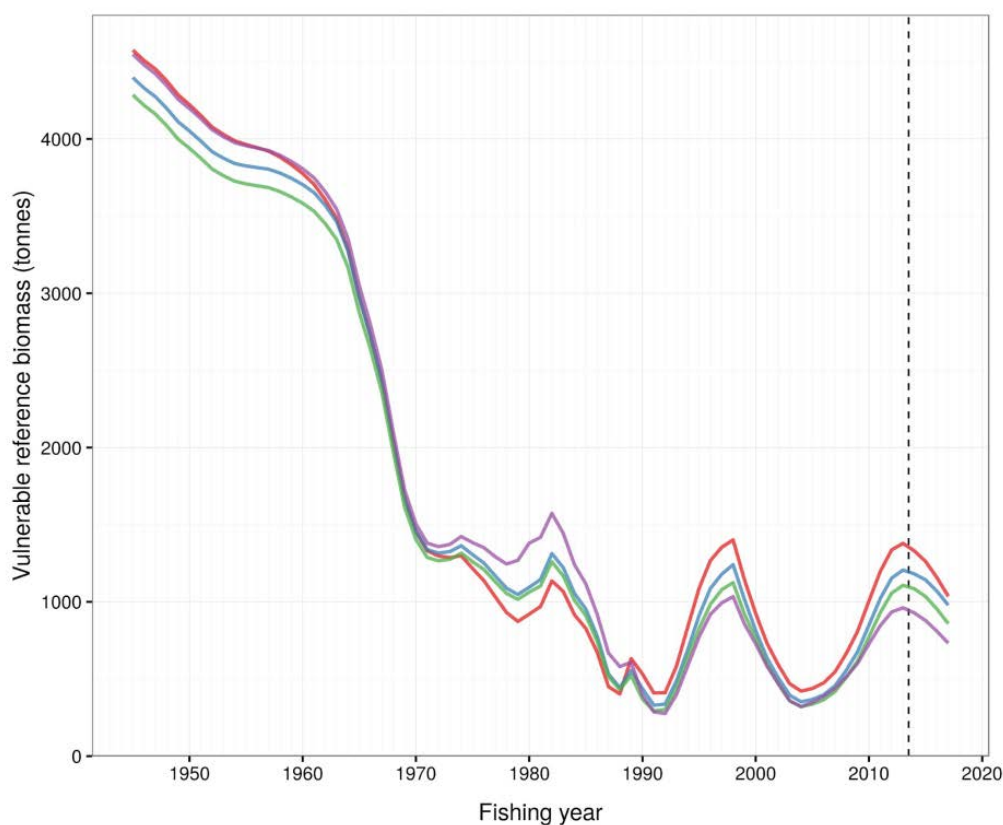
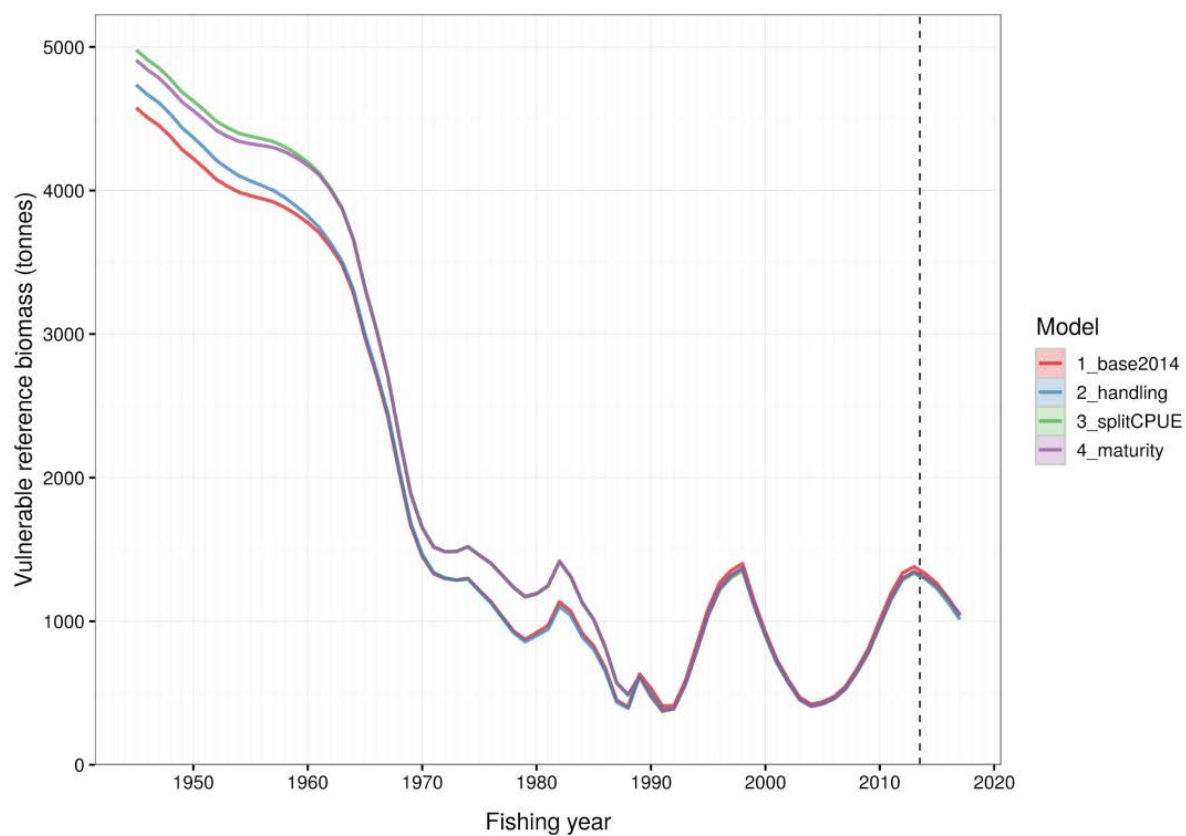
|                                                            | reduced tag data set |       |       |           |       |       | full tag data set |       |       |           |       |       |
|------------------------------------------------------------|----------------------|-------|-------|-----------|-------|-------|-------------------|-------|-------|-----------|-------|-------|
|                                                            | r1_qdrift            |       |       | no_qdrift |       |       | r2_qdrift         |       |       | no_qdrift |       |       |
|                                                            | 5%                   | 50%   | 95%   | 5%        | 50%   | 95%   | 5%                | 50%   | 95%   | 5%        | 50%   | 95%   |
| <b>Derived parameters: spawning biomass (females only)</b> |                      |       |       |           |       |       |                   |       |       |           |       |       |
| SSB <sub>0</sub> [909+910]                                 | 1 243                | 1 394 | 1 546 | 1 263     | 1 412 | 1 592 | 1 149             | 1 254 | 1 397 | 1 150     | 1 265 | 1 387 |
| SSB <sub>0</sub> [911]                                     | 718                  | 802   | 910   | 732       | 820   | 922   | 643               | 713   | 787   | 649       | 720   | 792   |
| SSB <sub>0</sub> [CRA 3]                                   | 2 002                | 2 198 | 2 419 | 2 032     | 2 233 | 2 471 | 1 829             | 1 974 | 2 130 | 1 843     | 1 984 | 2 145 |
| SSB <sub>0now</sub> [909+910]                              | 1 168                | 1 289 | 1 446 | 1 202     | 1 345 | 1 510 | 1 131             | 1 240 | 1 363 | 1 171     | 1 287 | 1 421 |
| SSB <sub>0now</sub> [911]                                  | 636                  | 741   | 871   | 670       | 790   | 929   | 544               | 632   | 739   | 574       | 665   | 774   |
| SSB <sub>0now</sub> [CRA 3]                                | 1 840                | 2 029 | 2 262 | 1 924     | 2 137 | 2 373 | 1 712             | 1 878 | 2 044 | 1 801     | 1 953 | 2 133 |
| SSB <sub>2018</sub> [909+910]                              | 958                  | 1 099 | 1 306 | 1 009     | 1 161 | 1 393 | 935               | 1 036 | 1 162 | 982       | 1 094 | 1 228 |
| SSB <sub>2018</sub> [911]                                  | 546                  | 659   | 804   | 579       | 706   | 882   | 480               | 551   | 646   | 507       | 587   | 690   |
| SSB <sub>2018</sub> [CRA 3]                                | 1 560                | 1 765 | 2 047 | 1 642     | 1 874 | 2 187 | 1 452             | 1 589 | 1 755 | 1 538     | 1 681 | 1 844 |
| SSB <sub>2023</sub> [909+910]                              | 898                  | 1 144 | 1 452 | 957       | 1 231 | 1 548 | 896               | 1 083 | 1 312 | 949       | 1 152 | 1 408 |
| SSB <sub>2023</sub> [911]                                  | 460                  | 623   | 835   | 496       | 675   | 900   | 374               | 498   | 650   | 407       | 535   | 706   |
| SSB <sub>2023</sub> [CRA 3]                                | 1 464                | 1 781 | 2 162 | 1 572     | 1 910 | 2 320 | 1 338             | 1 590 | 1 863 | 1 440     | 1 696 | 1 995 |
| SSB <sub>2018</sub> /SSB <sub>0</sub> [909+910]            | 0.69                 | 0.79  | 0.92  | 0.71      | 0.83  | 0.98  | 0.73              | 0.82  | 0.92  | 0.77      | 0.86  | 0.97  |
| SSB <sub>2018</sub> /SSB <sub>0</sub> [911]                | 0.69                 | 0.82  | 1.00  | 0.71      | 0.86  | 1.05  | 0.67              | 0.77  | 0.90  | 0.70      | 0.82  | 0.95  |
| SSB <sub>2018</sub> /SSB <sub>0</sub> [CRA 3]              | 0.72                 | 0.80  | 0.91  | 0.75      | 0.84  | 0.96  | 0.74              | 0.80  | 0.89  | 0.77      | 0.85  | 0.93  |
| SSB <sub>2023</sub> /SSB <sub>0</sub> [909+910]            | 0.65                 | 0.82  | 1.04  | 0.69      | 0.87  | 1.09  | 0.70              | 0.86  | 1.05  | 0.75      | 0.91  | 1.11  |
| SSB <sub>2023</sub> /SSB <sub>0</sub> [911]                | 0.59                 | 0.78  | 1.02  | 0.62      | 0.82  | 1.08  | 0.53              | 0.70  | 0.91  | 0.57      | 0.75  | 0.98  |
| SSB <sub>2023</sub> /SSB <sub>0</sub> [CRA 3]              | 0.67                 | 0.81  | 0.96  | 0.71      | 0.86  | 1.02  | 0.68              | 0.80  | 0.94  | 0.73      | 0.86  | 1.00  |
| SSB <sub>2023</sub> /SSB <sub>2018</sub> [909+910]         | 0.87                 | 1.02  | 1.22  | 0.89      | 1.03  | 1.23  | 0.90              | 1.02  | 1.18  | 0.91      | 1.04  | 1.20  |
| SSB <sub>2023</sub> /SSB <sub>2018</sub> [911]             | 0.78                 | 0.94  | 1.12  | 0.79      | 0.94  | 1.13  | 0.74              | 0.89  | 1.06  | 0.76      | 0.91  | 1.07  |
| SSB <sub>2023</sub> /SSB <sub>2018</sub> [CRA 3]           | 0.88                 | 0.99  | 1.13  | 0.89      | 1.00  | 1.14  | 0.88              | 0.98  | 1.09  | 0.89      | 0.99  | 1.11  |
| <b>Derived parameters: total biomass</b>                   |                      |       |       |           |       |       |                   |       |       |           |       |       |
| Btot <sub>0</sub> [909+910]                                | 4 051                | 4 487 | 4 877 | 4 065     | 4 484 | 4 941 | 3 826             | 4 186 | 4 644 | 3 823     | 4 197 | 4 601 |
| Btot <sub>0</sub> [911]                                    | 2 327                | 2 576 | 2 866 | 2 358     | 2 605 | 2 894 | 2 152             | 2 382 | 2 605 | 2 158     | 2 385 | 2 619 |
| Btot <sub>0</sub> [CRA 3]                                  | 6 524                | 7 051 | 7 585 | 6 570     | 7 109 | 7 696 | 6 103             | 6 582 | 7 090 | 6 136     | 6 575 | 7 055 |
| Btot <sub>0now</sub> [909+910]                             | 3 879                | 4 276 | 4 723 | 3 995     | 4 409 | 4 889 | 3 874             | 4 236 | 4 680 | 3 990     | 4 373 | 4 826 |
| Btot <sub>0now</sub> [911]                                 | 2 132                | 2 448 | 2 836 | 2 208     | 2 575 | 3 006 | 1 872             | 2 163 | 2 504 | 1 947     | 2 259 | 2 608 |
| Btot <sub>0now</sub> [CRA 3]                               | 6 161                | 6 723 | 7 381 | 6 390     | 7 015 | 7 669 | 5 907             | 6 414 | 6 994 | 6 124     | 6 644 | 7 230 |
| Btot <sub>2018</sub> [909+910]                             | 2 063                | 2 522 | 3 101 | 2 238     | 2 749 | 3 413 | 1 803             | 2 115 | 2 518 | 1 947     | 2 287 | 2 702 |
| Btot <sub>2018</sub> [911]                                 | 1 377                | 1 708 | 2 168 | 1 460     | 1 866 | 2 383 | 1 080             | 1 314 | 1 628 | 1 164     | 1 428 | 1 758 |
| Btot <sub>2018</sub> [CRA 3]                               | 3 631                | 4 264 | 5 030 | 3 922     | 4 606 | 5 562 | 3 028             | 3 441 | 4 001 | 3 252     | 3 720 | 4 262 |
| Btot <sub>2023</sub> [909+910]                             | 2 017                | 2 643 | 3 565 | 2 150     | 2 881 | 3 829 | 1 683             | 2 247 | 2 938 | 1 840     | 2 459 | 3 121 |
| Btot <sub>2023</sub> [911]                                 | 1 168                | 1 585 | 2 209 | 1 231     | 1 757 | 2 464 | 825               | 1 156 | 1 635 | 899       | 1 271 | 1 742 |
| Btot <sub>2023</sub> [CRA 3]                               | 3 449                | 4 248 | 5 388 | 3 727     | 4 670 | 5 883 | 2 763             | 3 410 | 4 301 | 3 041     | 3 730 | 4 574 |
| Btot <sub>2018</sub> /Btot <sub>0</sub> [909+910]          | 0.46                 | 0.56  | 0.69  | 0.50      | 0.61  | 0.77  | 0.42              | 0.50  | 0.61  | 0.06      | 0.46  | 0.55  |
| Btot <sub>2018</sub> /Btot <sub>0</sub> [911]              | 0.54                 | 0.67  | 0.85  | 0.57      | 0.72  | 0.91  | 0.45              | 0.55  | 0.69  | 0.08      | 0.49  | 0.60  |
| Btot <sub>2018</sub> /Btot <sub>0</sub> [CRA 3]            | 0.52                 | 0.61  | 0.71  | 0.56      | 0.65  | 0.77  | 0.45              | 0.52  | 0.61  | 0.05      | 0.49  | 0.57  |
| Btot <sub>2023</sub> /Btot <sub>0</sub> [909+910]          | 0.44                 | 0.59  | 0.80  | 0.48      | 0.64  | 0.85  | 0.40              | 0.53  | 0.71  | 0.10      | 0.44  | 0.59  |
| Btot <sub>2023</sub> /Btot <sub>0</sub> [911]              | 0.46                 | 0.62  | 0.84  | 0.48      | 0.67  | 0.94  | 0.35              | 0.48  | 0.69  | 0.11      | 0.38  | 0.53  |
| Btot <sub>2023</sub> /Btot <sub>0</sub> [CRA 3]            | 0.49                 | 0.60  | 0.76  | 0.52      | 0.66  | 0.83  | 0.41              | 0.52  | 0.65  | 0.07      | 0.46  | 0.57  |
| Btot <sub>2023</sub> /Btot <sub>2018</sub> [909+910]       | 0.86                 | 1.04  | 1.32  | 0.87      | 1.05  | 1.30  | 0.87              | 1.05  | 1.30  | 0.89      | 1.06  | 1.30  |
| Btot <sub>2023</sub> /Btot <sub>2018</sub> [911]           | 0.78                 | 0.92  | 1.12  | 0.78      | 0.93  | 1.14  | 0.72              | 0.87  | 1.07  | 0.73      | 0.89  | 1.07  |
| Btot <sub>2023</sub> /Btot <sub>2018</sub> [CRA 3]         | 0.87                 | 1.00  | 1.18  | 0.87      | 1.00  | 1.18  | 0.86              | 0.98  | 1.16  | 0.87      | 1.00  | 1.16  |

|                                                         | reduced tag data set |       |      |           |       |      | full tag data set |       |      |           |       |      |
|---------------------------------------------------------|----------------------|-------|------|-----------|-------|------|-------------------|-------|------|-----------|-------|------|
|                                                         | r1_qdrift            |       |      | no_qdrift |       |      | r2_qdrift         |       |      | no_qdrift |       |      |
|                                                         | 5%                   | 50%   | 95%  | 5%        | 50%   | 95%  | 5%                | 50%   | 95%  | 5%        | 50%   | 95%  |
| <b>other derived parameters</b>                         |                      |       |      |           |       |      |                   |       |      |           |       |      |
| H <sub>2018</sub> [909+910]                             | 6.4                  | 7.2   | 8.2  | 6.1       | 6.8   | 7.7  | 5.9               | 6.8   | 7.7  | 5.6       | 6.3   | 7.2  |
| H <sub>2018</sub> [911]                                 | 2.3                  | 2.7   | 3.0  | 2.2       | 2.5   | 2.9  | 2.4               | 2.8   | 3.2  | 2.3       | 2.7   | 3.0  |
| H <sub>2018</sub> [CRA 3]                               | 9.0                  | 9.9   | 10.9 | 8.5       | 9.3   | 10.3 | 8.7               | 9.6   | 10.7 | 8.2       | 9.0   | 9.9  |
| H <sub>2023</sub> [909+910]                             | 4.6                  | 8.3   | 25.7 | 4.0       | 6.8   | 16.0 | 3.7               | 6.7   | 17.2 | 3.3       | 5.4   | 10.1 |
| H <sub>2023</sub> [911]                                 | 2.9                  | 5.1   | 15.9 | 2.7       | 4.4   | 9.8  | 3.3               | 5.7   | 21.0 | 2.9       | 4.6   | 11.3 |
| H <sub>2023</sub> [CRA 3]                               | 8.7                  | 14.3  | 34.2 | 7.5       | 11.8  | 25.5 | 8.2               | 13.3  | 31.2 | 7.2       | 10.6  | 18.9 |
| B <sub>0M</sub> /B <sub>0F</sub> [909+910]              | 1.60                 | 1.71  | 1.83 | 1.58      | 1.68  | 1.78 | 1.85              | 1.94  | 2.05 | 1.84      | 1.93  | 2.03 |
| B <sub>0M</sub> /B <sub>0F</sub> [911]                  | 1.60                 | 1.71  | 1.83 | 1.58      | 1.68  | 1.78 | 1.85              | 1.94  | 2.05 | 1.84      | 1.93  | 2.03 |
| B <sub>tot2019M</sub> /B <sub>tot2018F</sub> [909+910]  | 0.73                 | 0.81  | 0.89 | 0.77      | 0.85  | 0.92 | 0.60              | 0.69  | 0.78 | 0.65      | 0.74  | 0.83 |
| B <sub>tot2019M</sub> /B <sub>tot2018F</sub> [911]      | 1.06                 | 1.11  | 1.16 | 1.09      | 1.14  | 1.19 | 0.97              | 1.05  | 1.13 | 1.01      | 1.09  | 1.16 |
| CPUE <sub>2018</sub> [909+910]                          | 1.13                 | 1.36  | 1.63 | 1.07      | 1.32  | 1.61 | 1.11              | 1.35  | 1.67 | 1.00      | 1.23  | 1.49 |
| CPUE <sub>2018</sub> [911]                              | 1.23                 | 1.56  | 1.97 | 1.18      | 1.48  | 1.83 | 1.12              | 1.43  | 1.81 | 1.02      | 1.27  | 1.54 |
| CPUE <sub>2023</sub> [909+910]                          | 0.16                 | 1.31  | 2.78 | 0.38      | 1.34  | 2.58 | 0.42              | 1.51  | 3.03 | 0.59      | 1.44  | 2.62 |
| CPUE <sub>2023</sub> [911]                              | 0.12                 | 0.71  | 1.44 | 0.19      | 0.73  | 1.45 | 0.07              | 0.62  | 1.36 | 0.17      | 0.61  | 1.20 |
| <b>Probabilities</b>                                    |                      |       |      |           |       |      |                   |       |      |           |       |      |
| P(B <sub>2019</sub> >B <sub>min</sub> )[909+910]        |                      | 1     |      |           | 1     |      |                   | 1     |      |           | 1     |      |
| P(B <sub>2019</sub> >B <sub>min</sub> )[911]            |                      | 1     |      |           | 1     |      |                   | 1     |      |           | 1     |      |
| P(B <sub>2019</sub> >B <sub>min</sub> )[CRA 3]          |                      | 1     |      |           | 1     |      |                   | 1     |      |           | 1     |      |
| P(SSB <sub>2018</sub> <20%SSB <sub>0</sub> )[909+910]   |                      | 0     |      |           | 0     |      |                   | 0     |      |           | 0     |      |
| P(SSB <sub>2018</sub> <20%SSB <sub>0</sub> )[911]       |                      | 0     |      |           | 0     |      |                   | 0     |      |           | 0     |      |
| P(SSB <sub>2018</sub> <20%SSB <sub>0</sub> )[CRA 3]     |                      | 0     |      |           | 0     |      |                   | 0     |      |           | 0     |      |
| P(SSB <sub>2018</sub> <10%SSB <sub>0</sub> )[909+910]   |                      | 0     |      |           | 0     |      |                   | 0     |      |           | 0     |      |
| P(SSB <sub>2018</sub> <10%SSB <sub>0</sub> )[911]       |                      | 0     |      |           | 0     |      |                   | 0     |      |           | 0     |      |
| P(SSB <sub>2018</sub> <10%SSB <sub>0</sub> )[CRA 3]     |                      | 0     |      |           | 0     |      |                   | 0     |      |           | 0     |      |
| P(B <sub>tot2023</sub> >B <sub>tot2018</sub> )[909+910] |                      | 0.611 |      |           | 0.717 |      |                   | 0.611 |      |           | 0.640 |      |
| P(B <sub>tot2023</sub> >B <sub>tot2018</sub> )[911]     |                      | 0.268 |      |           | 0.160 |      |                   | 0.138 |      |           | 0.267 |      |
| P(B <sub>tot2023</sub> >B <sub>tot2018</sub> )[CRA 3]   |                      | 0.493 |      |           | 0.498 |      |                   | 0.444 |      |           | 0.505 |      |
| P(B <sub>2023</sub> >B <sub>2019</sub> )[909+910]       |                      | 0.527 |      |           | 0.575 |      |                   | 0.606 |      |           | 0.708 |      |
| P(B <sub>2023</sub> >B <sub>2019</sub> )[911]           |                      | 0.028 |      |           | 0.042 |      |                   | 0.023 |      |           | 0.037 |      |
| P(B <sub>2023</sub> >B <sub>2019</sub> )[CRA 3]         |                      | 0.204 |      |           | 0.264 |      |                   | 0.268 |      |           | 0.340 |      |
| P(SSB <sub>2023</sub> >SSB <sub>2018</sub> )[909+910]   |                      | 0.588 |      |           | 0.637 |      |                   | 0.604 |      |           | 0.681 |      |
| P(SSB <sub>2023</sub> >SSB <sub>2018</sub> )[911]       |                      | 0.253 |      |           | 0.289 |      |                   | 0.149 |      |           | 0.170 |      |
| P(SSB <sub>2023</sub> >SSB <sub>2018</sub> )[CRA 3]     |                      | 0.470 |      |           | 0.500 |      |                   | 0.382 |      |           | 0.463 |      |

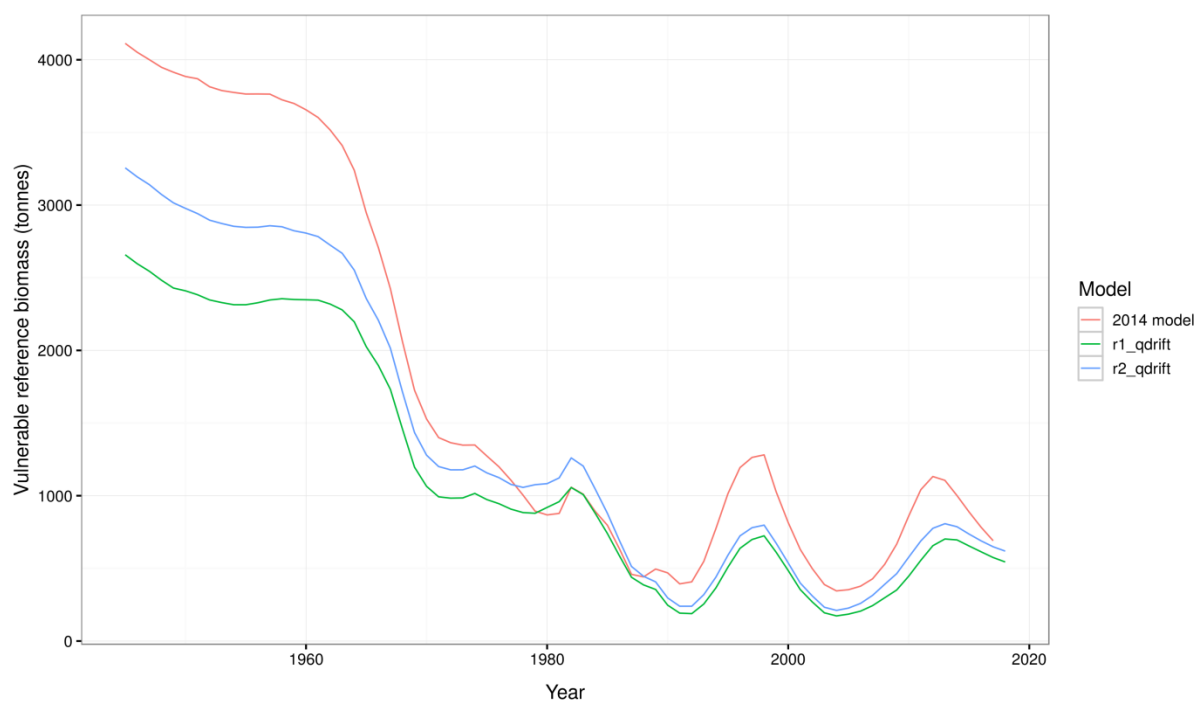
## 7. FIGURES



**Figure 3:** CRA 3 MAP 1\_base2014: comparison with 2014 assessment showing the vulnerable reference biomass (tonnes) by fishing year and season. The thick solid line is the MAP for the 2019 model mimic of the 2014 model using LSD, the dotted line is the previous model's MAP using MLSM in 2014, and the thin solid line and shaded areas are 50% and 90% credible interval of the 2014 model's posterior distribution.

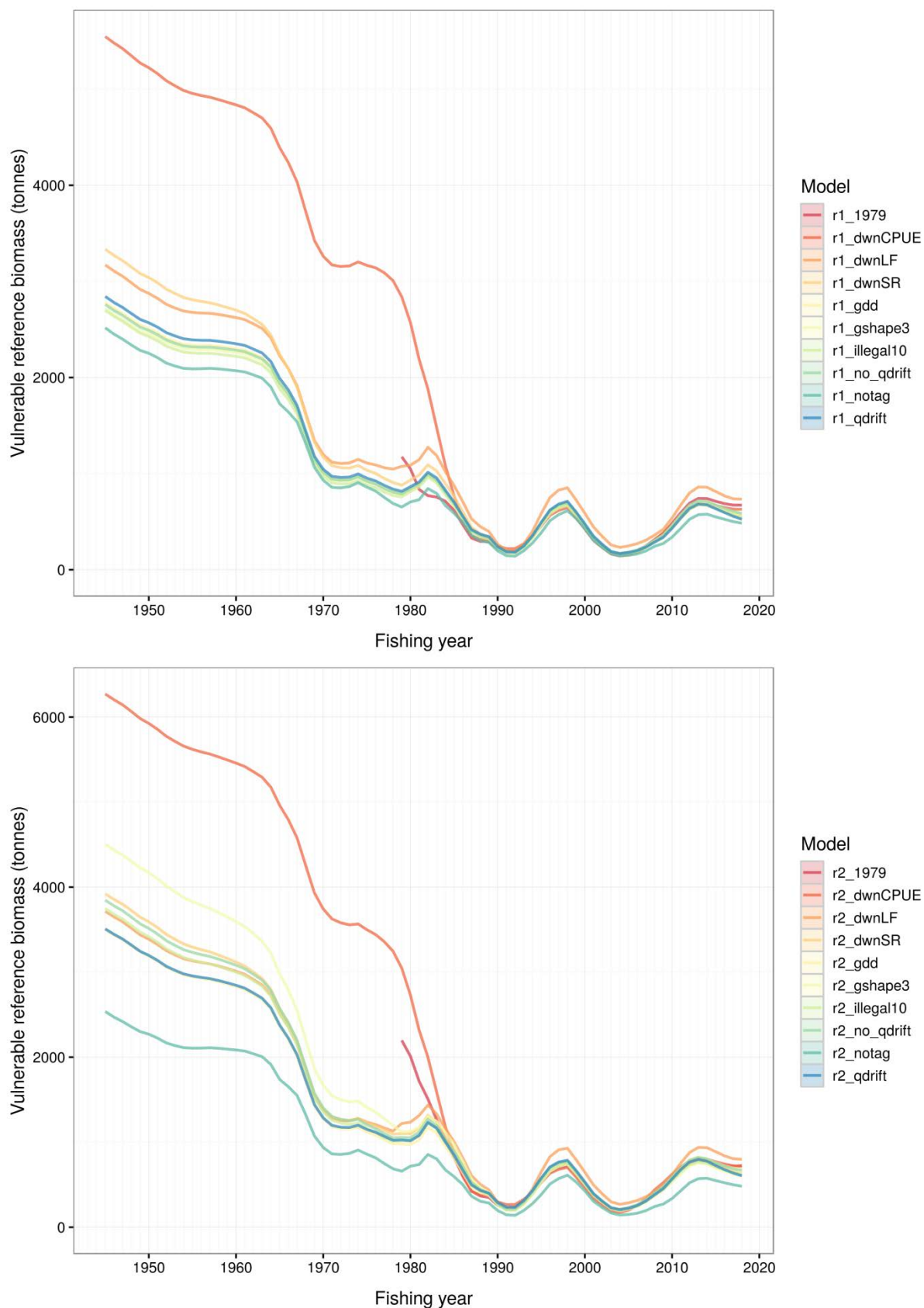


**Figure 4:** CRA 3 MAP: vulnerable reference biomass (tonnes). Comparison of 2019 model mimic of the 2014 model (1\_base2014) and progressive changes to the assessment model including changing the handling mortality (2\_handling), splitting the FSU and CELR CPUE series (3\_splitCPUE), estimating maturation (4\_maturity), updating the tag-recapture data (5\_tagfile), updating the catch (6\_catch), and updating the CPUE (7\_cpue).

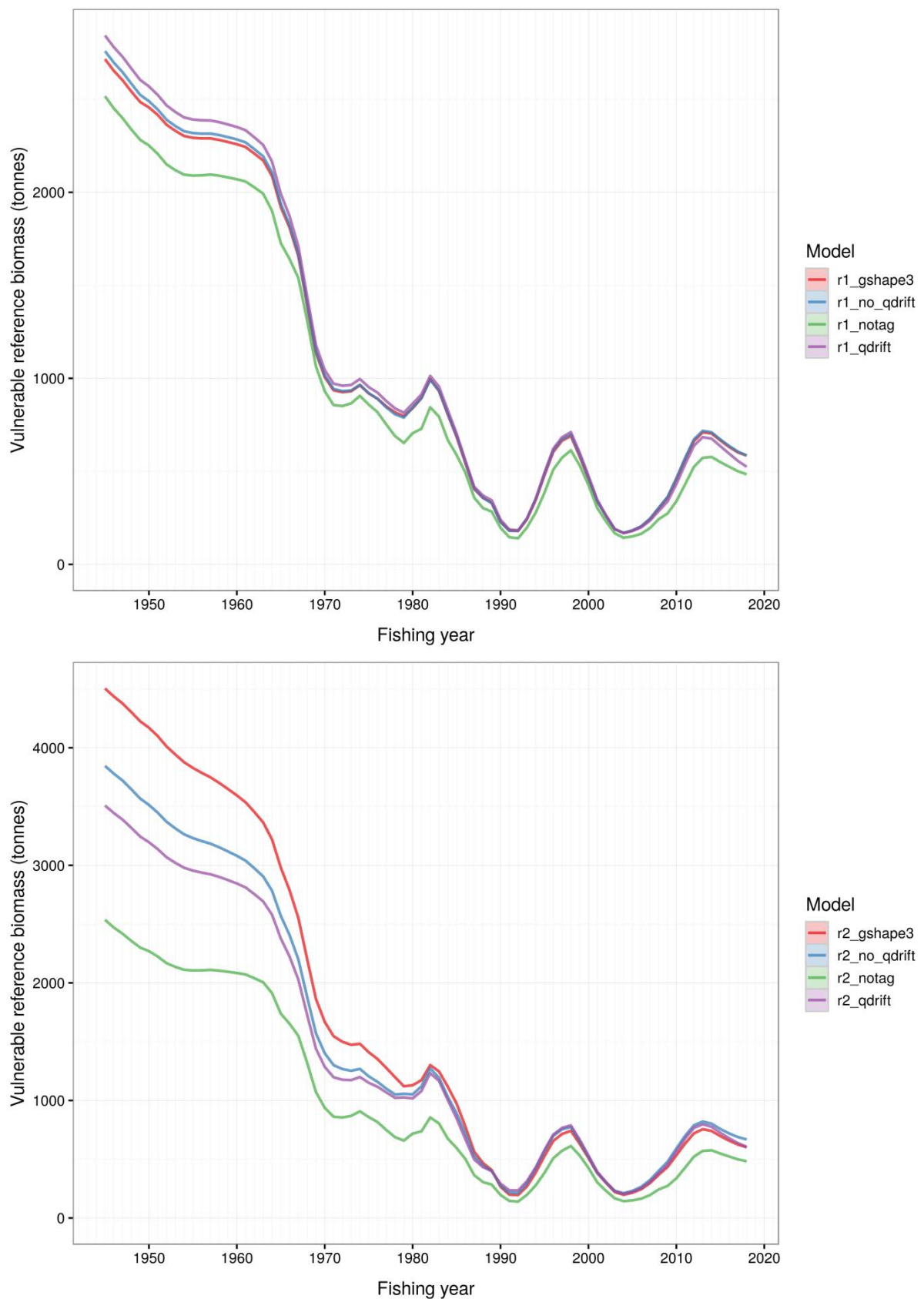


**Figure 5: CRA 3 MAP: trajectory of vulnerable reference biomass. Comparison of mimicked 2014 assessment model and the *r1\_qdrift* and *r2\_qdrift* models.**

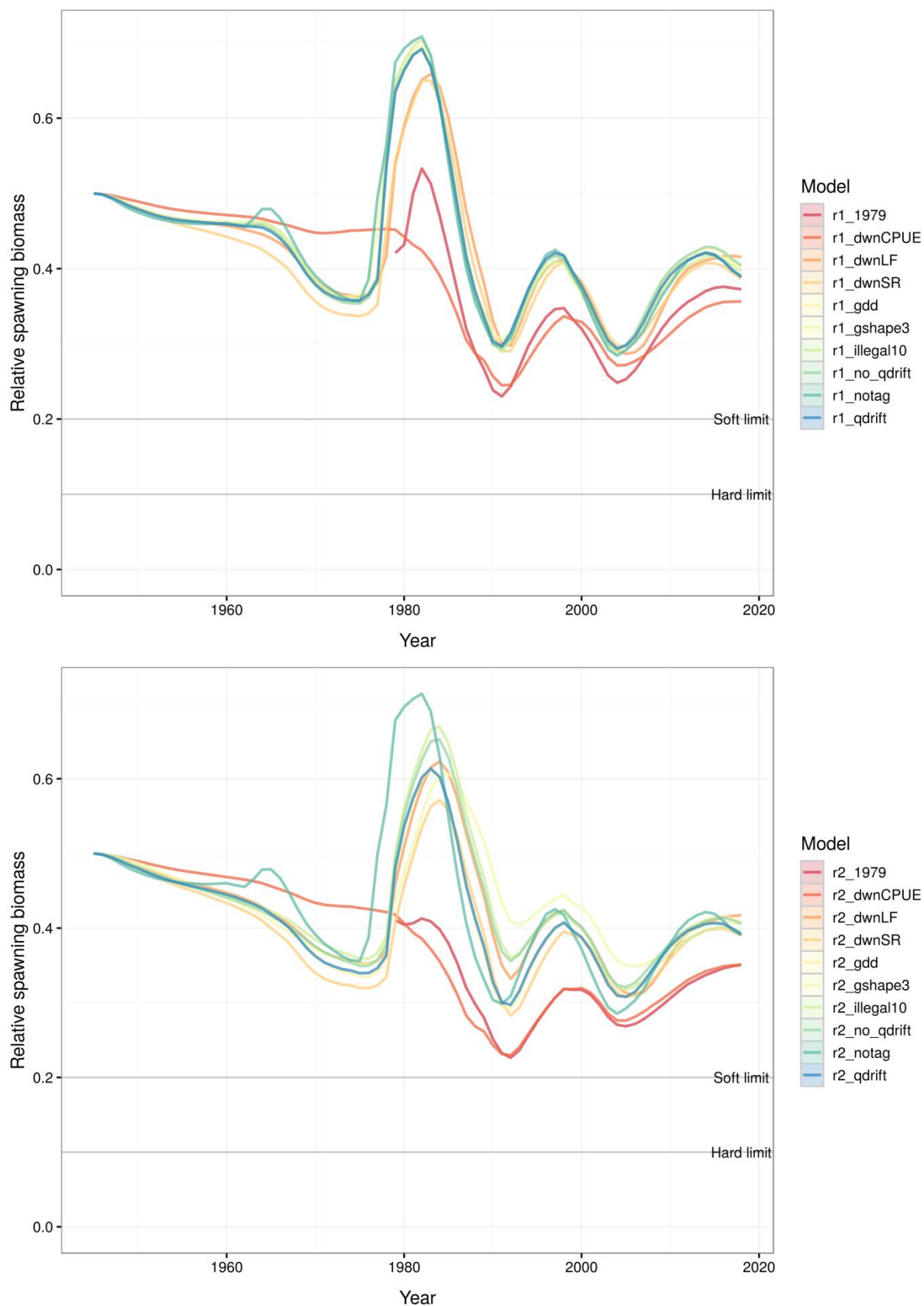




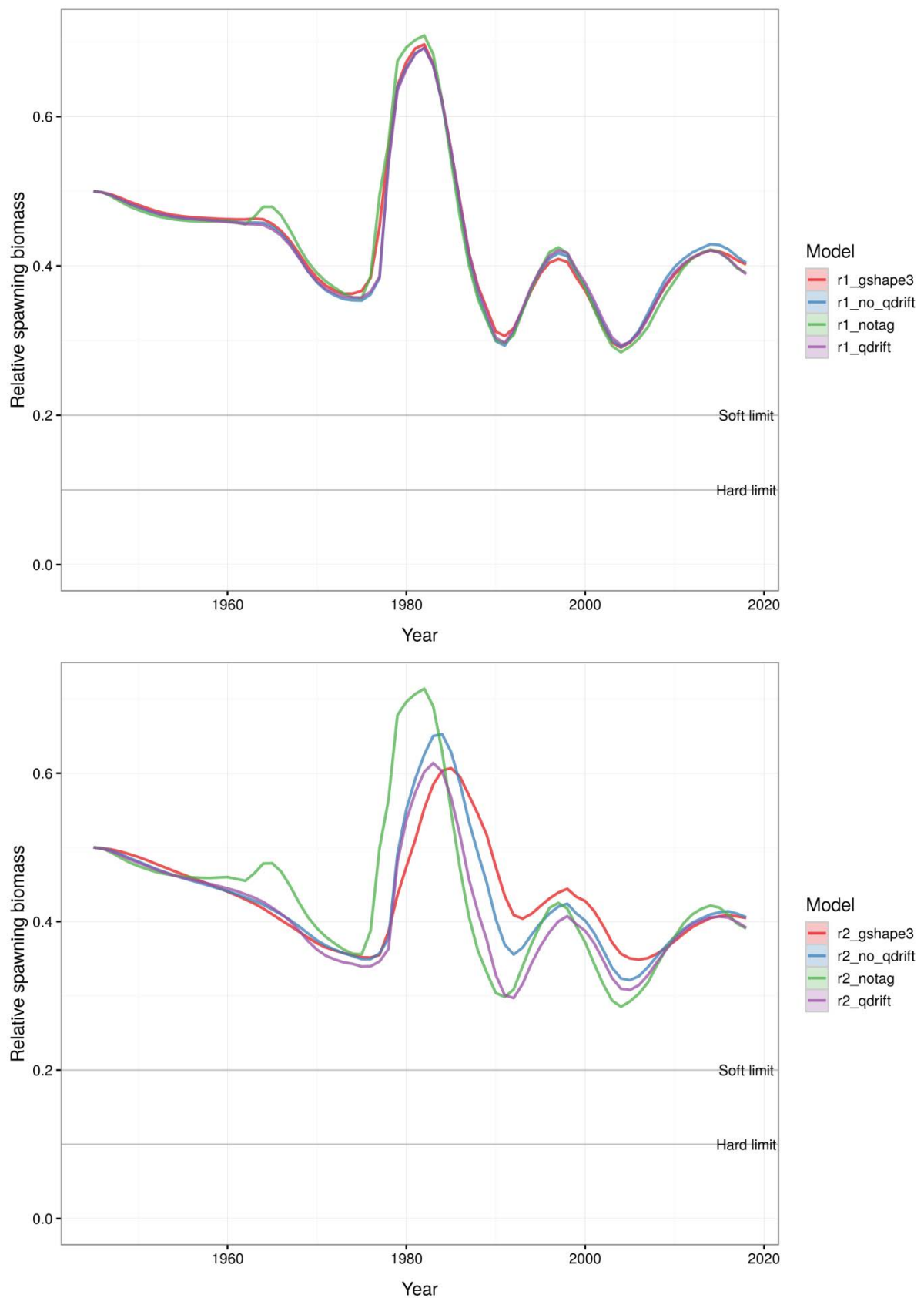
**Figure 6: CRA 3 MAP *r1\_qdrift* (top) and *r2\_qdrift* (bottom): vulnerable reference biomass (tonnes) for all MAP sensitivities.**



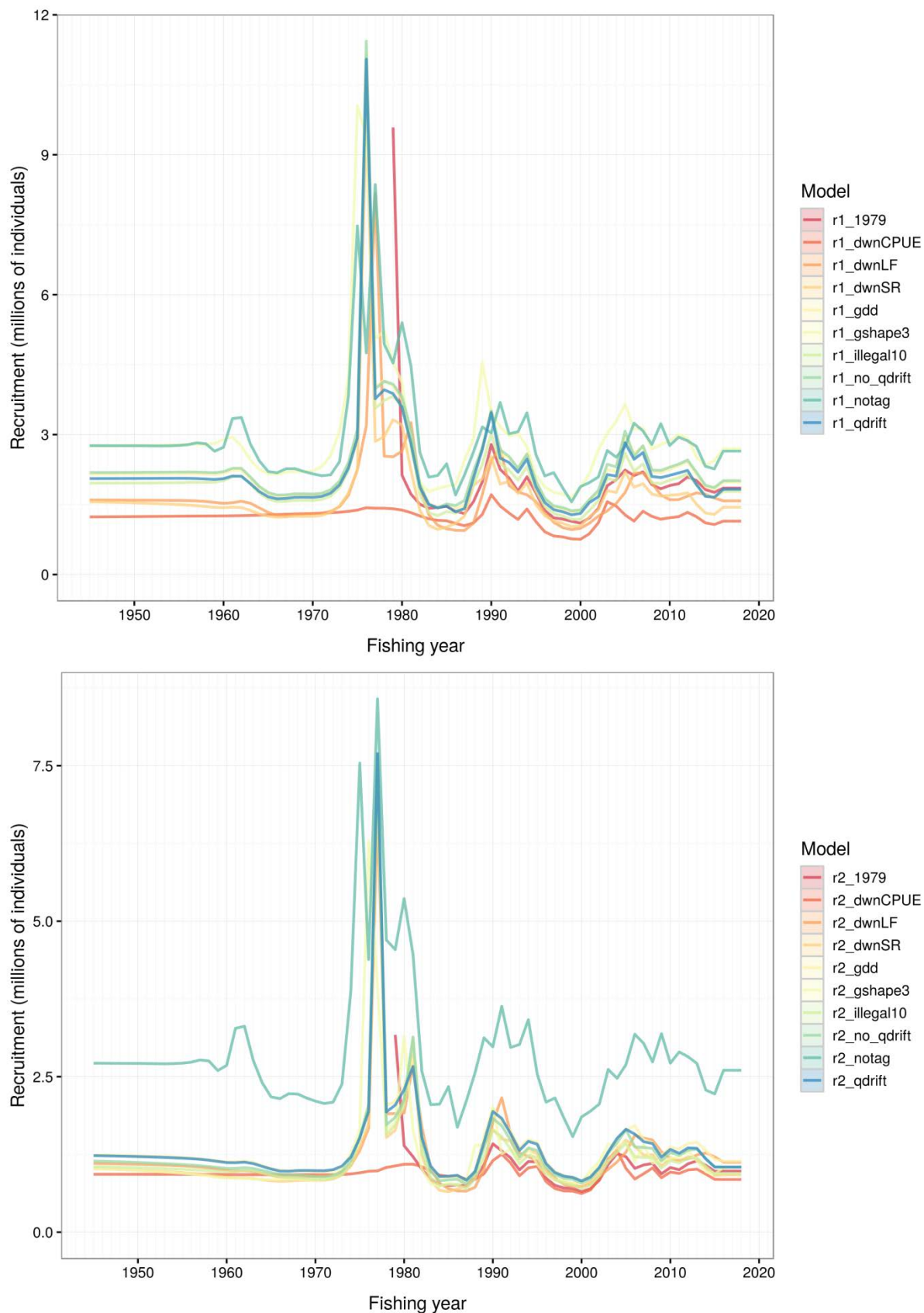
**Figure 7: CRA 3 MAP *r1\_qdrift* (top) and *r2\_qdrift* (bottom): vulnerable reference biomass (tonnes) for a subset of the more important MAP sensitivities.**



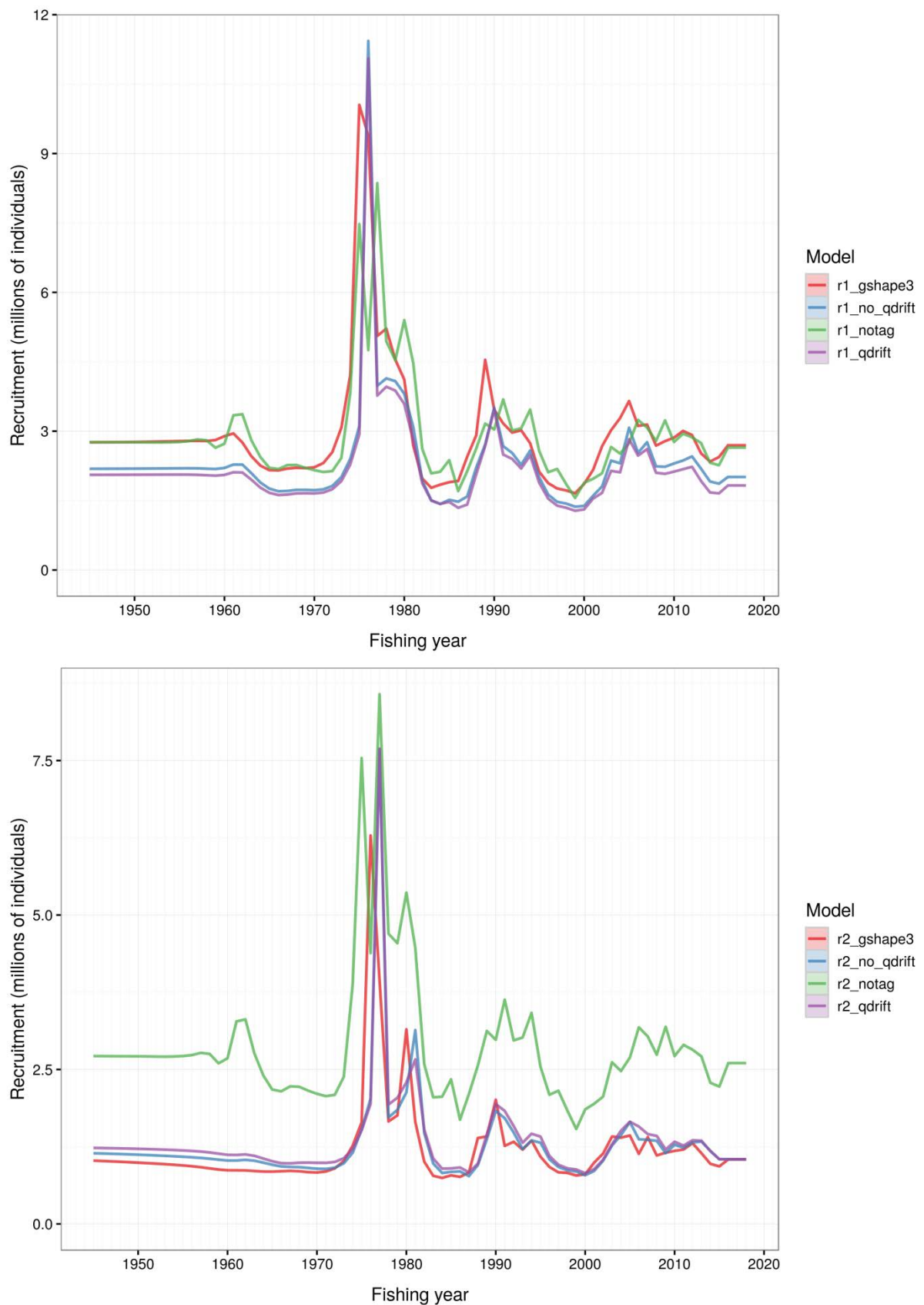
**Figure 8: CRA 3 MAP *r1\_qdrift* (top) and *r2\_qdrift* (bottom): relative spawning stock biomass for all MAP sensitivities.**



**Figure 9: CRA 3 MAP *r1\_qdrift* (top) and *r2\_qdrift* (bottom): relative spawning stock biomass for a subset of the more important MAP sensitivities.**

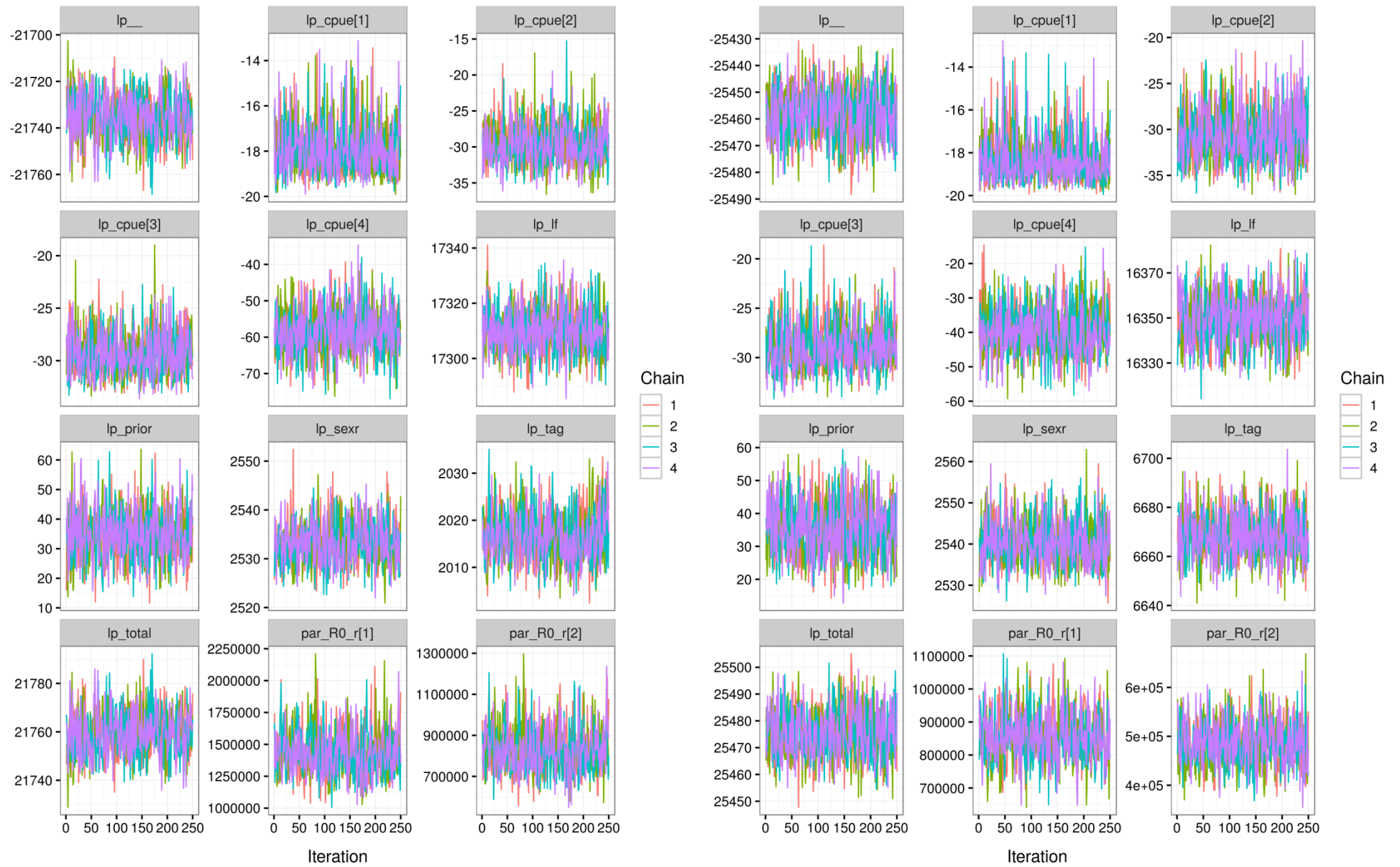


**Figure 10: CRA 3 MAP *r1\_qdrift* (top) and *r2\_qdrift* (bottom): recruitment (millions of individuals) for all MAP sensitivities.**

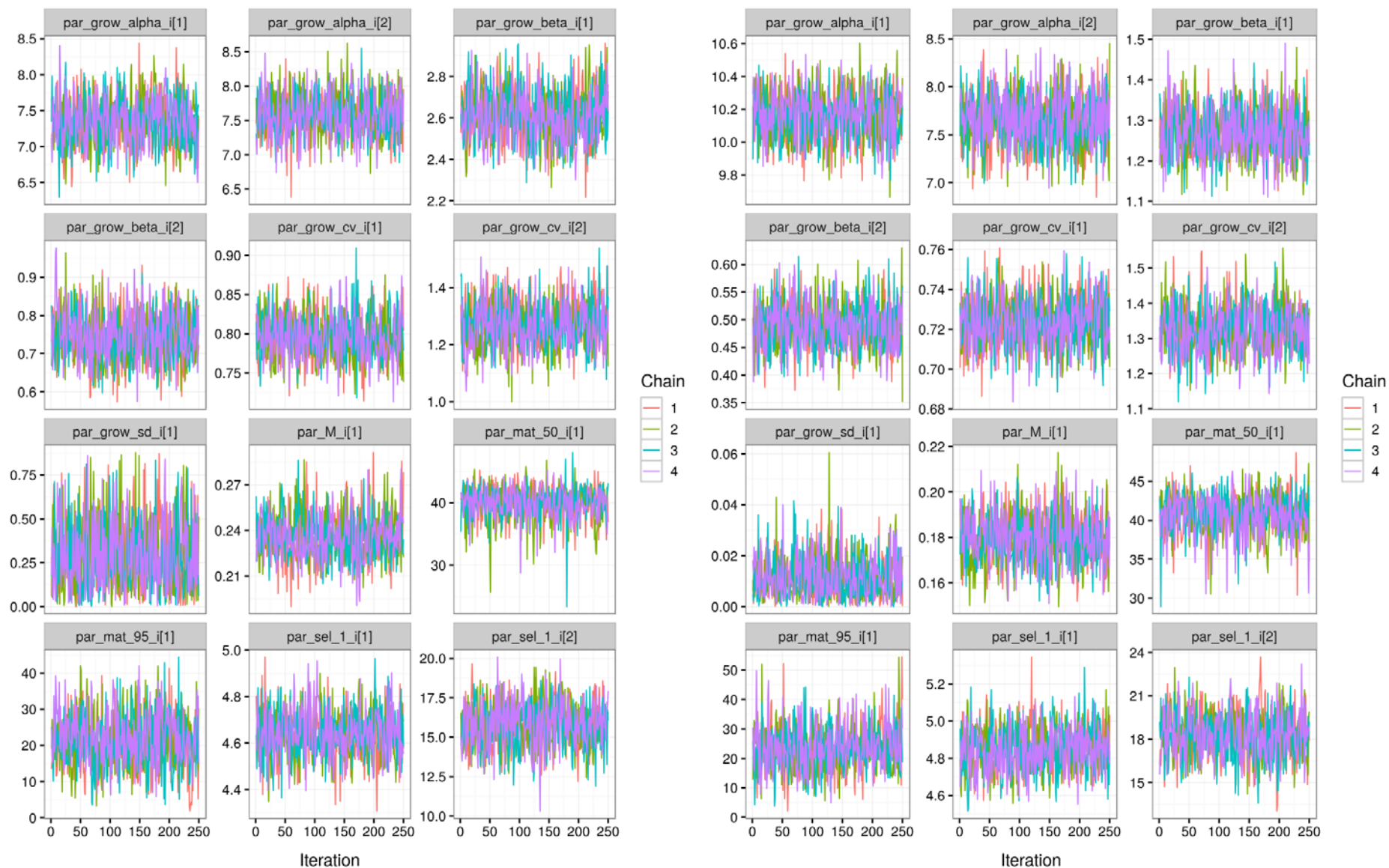


**Figure 11: CRA 3 MAP *r1\_qdrift* (top) and *r2\_qdrift* (bottom): recruitment (millions of individuals) for a subset of the more important MAP sensitivities.**



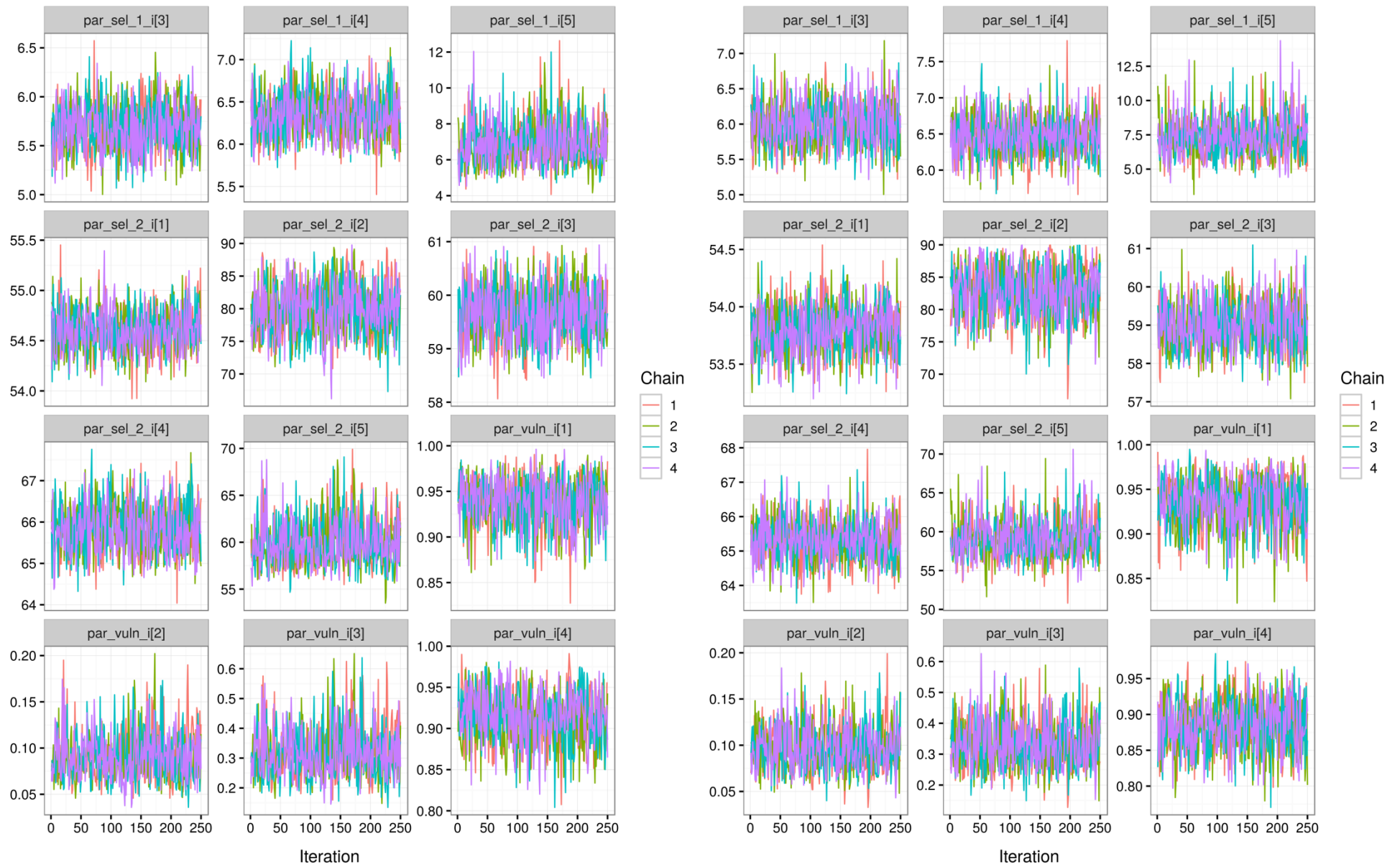


**Figure 12: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): trace plots by independent chain for likelihood components and  $R_0$  parameters.**

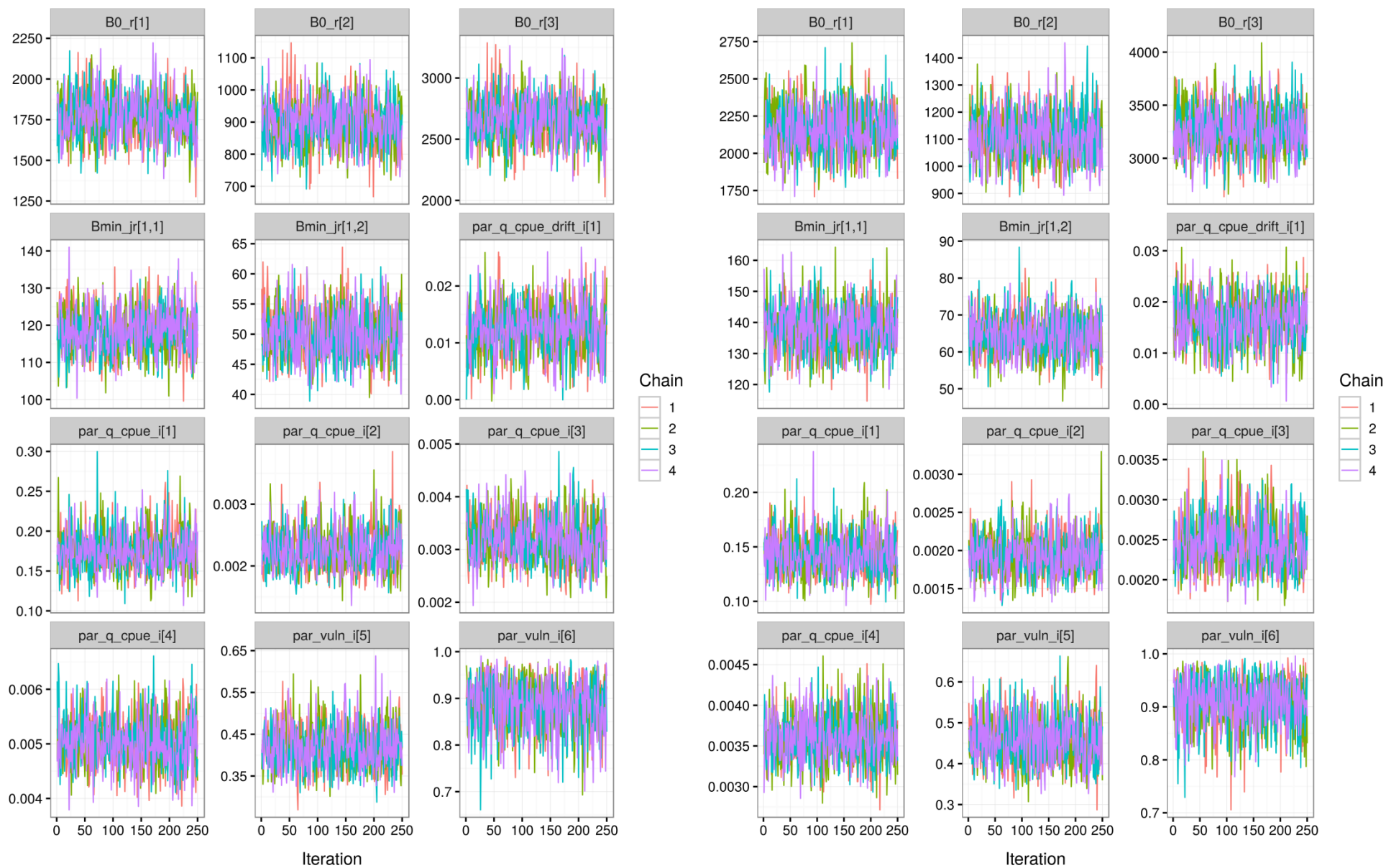


**Figure 13: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): trace plots by independent chain for growth and maturity, natural mortality ( $M$ ), and selectivity parameters.**

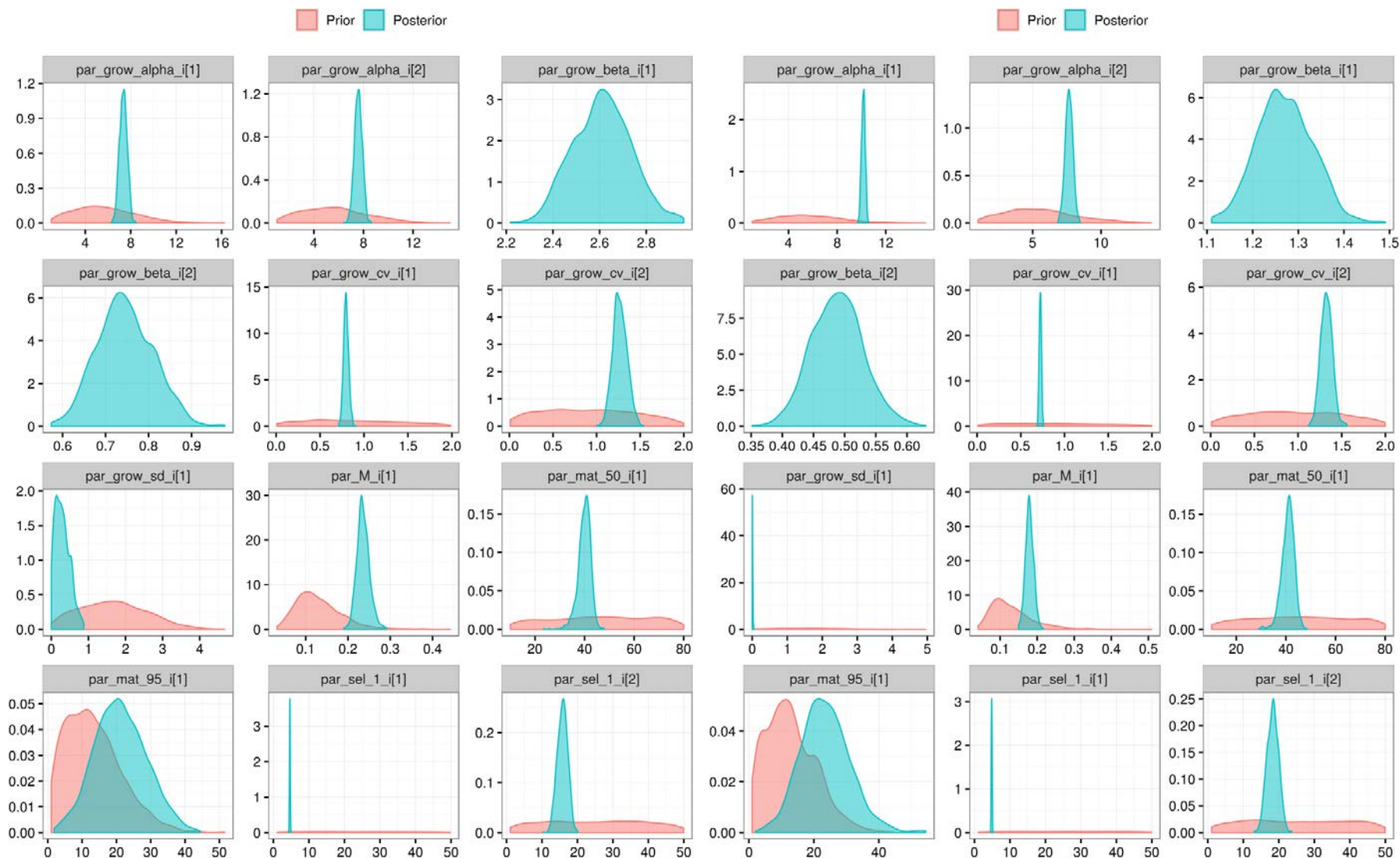




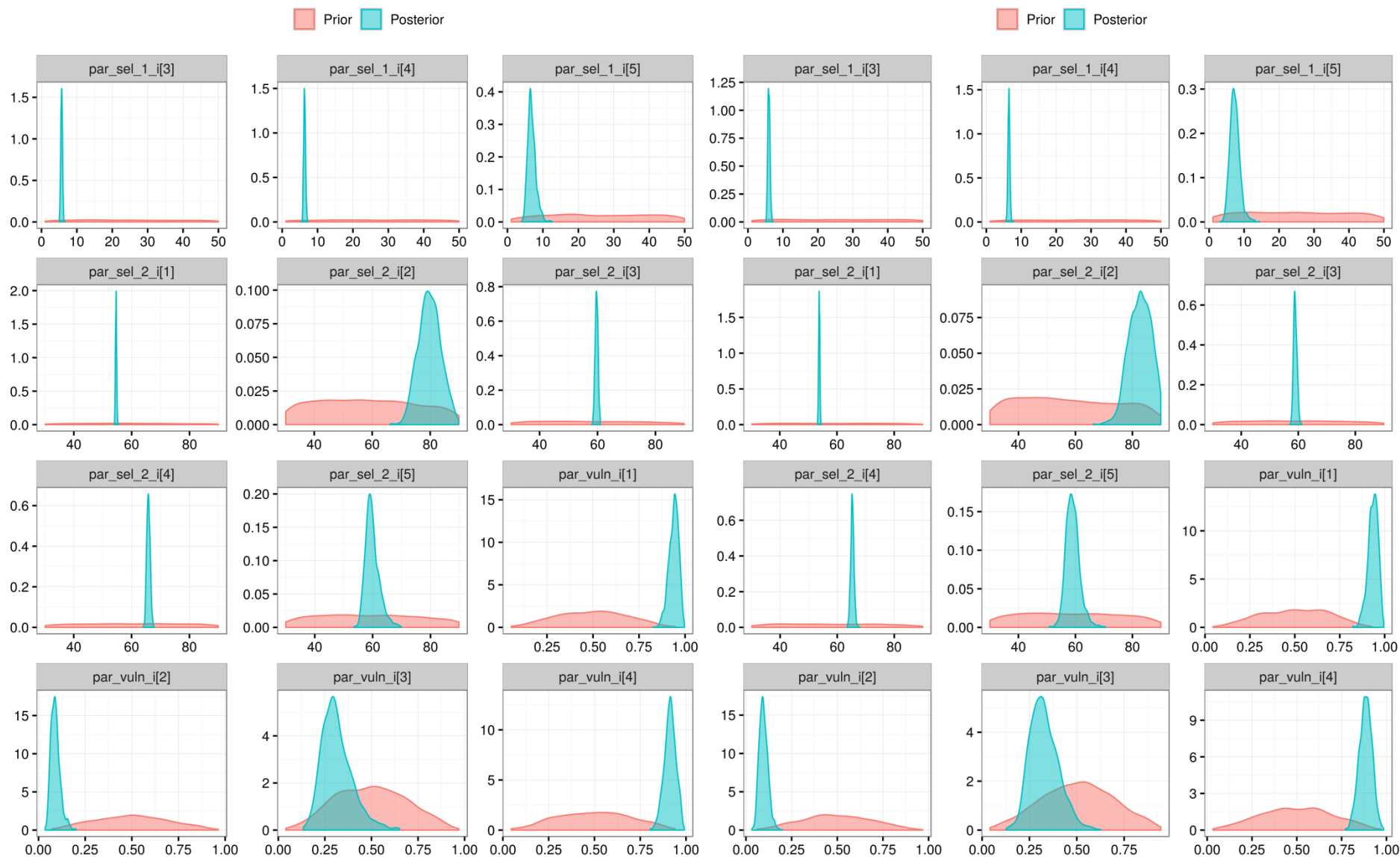
**Figure 14: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): trace plots by independent chain for selectivity and vulnerability parameters.**



**Figure 15: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): trace plots by independent chain for catchability ( $q$ ) and vulnerability parameters.**

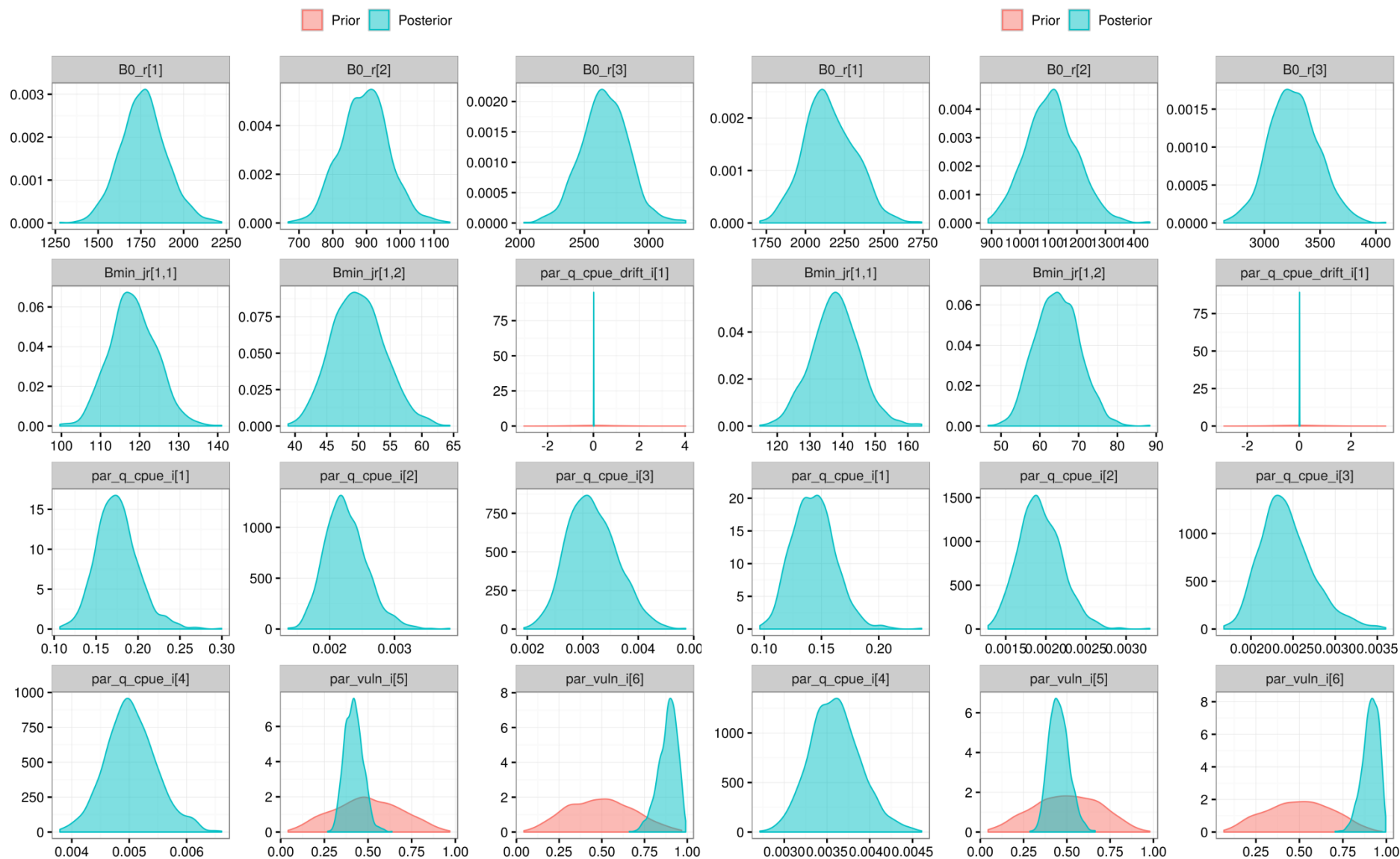


**Figure 16: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): density plots showing prior (red) and posterior distributions (blue) for growth, natural mortality, maturation, and selectivity parameters.**

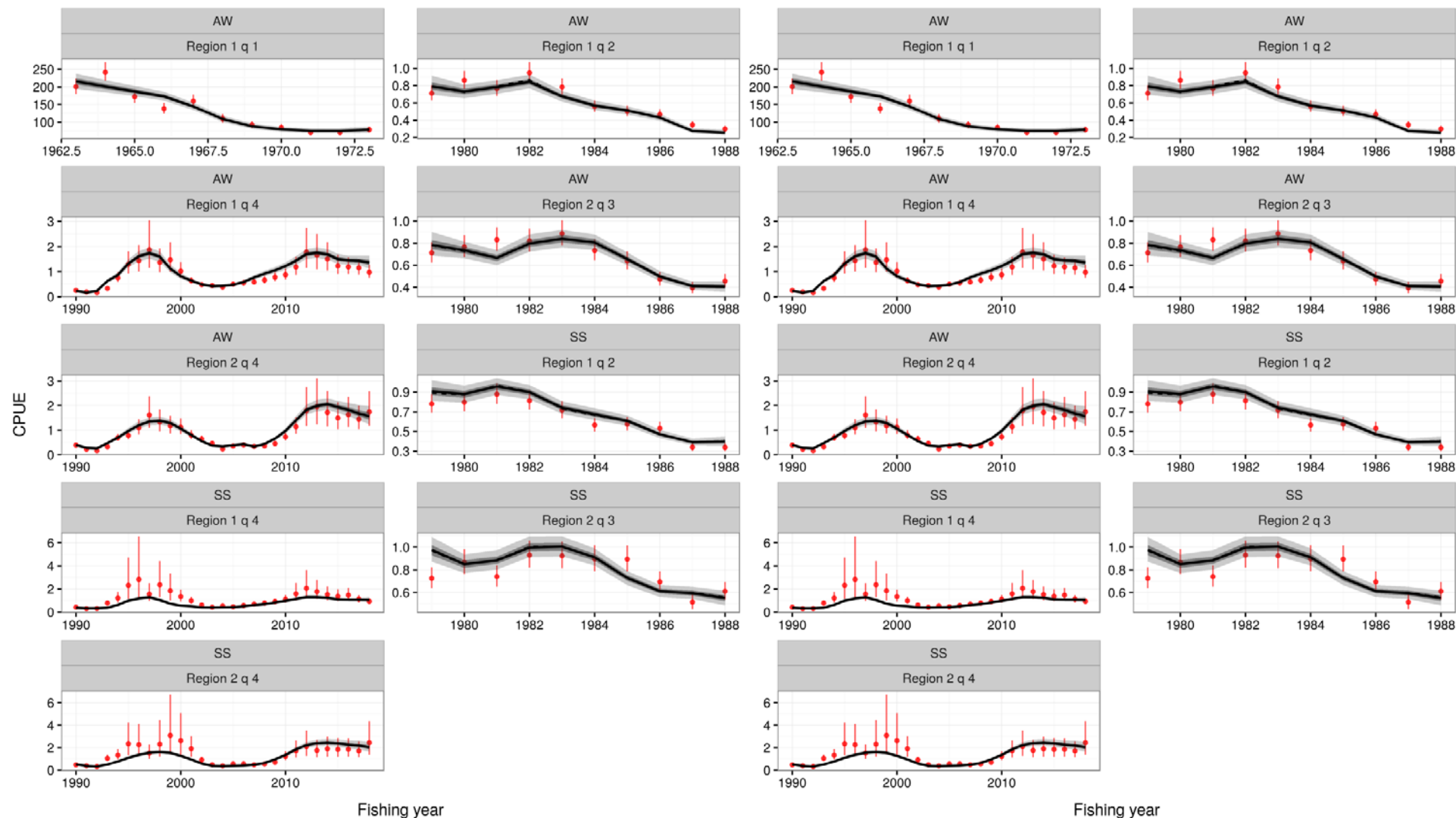


**Figure 17: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): density plots showing prior (red) and posterior distributions (blue) selectivity and vulnerability parameters.**

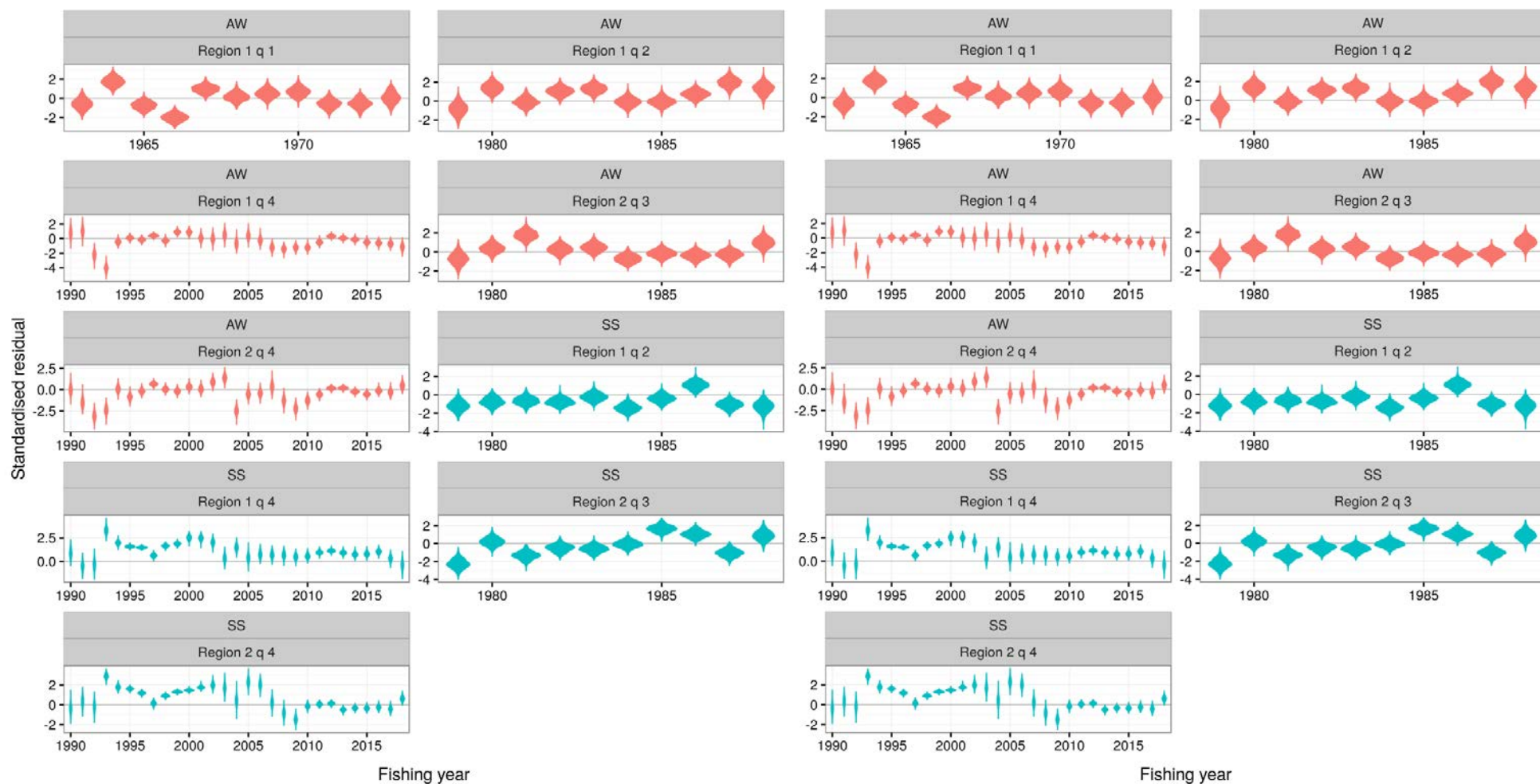




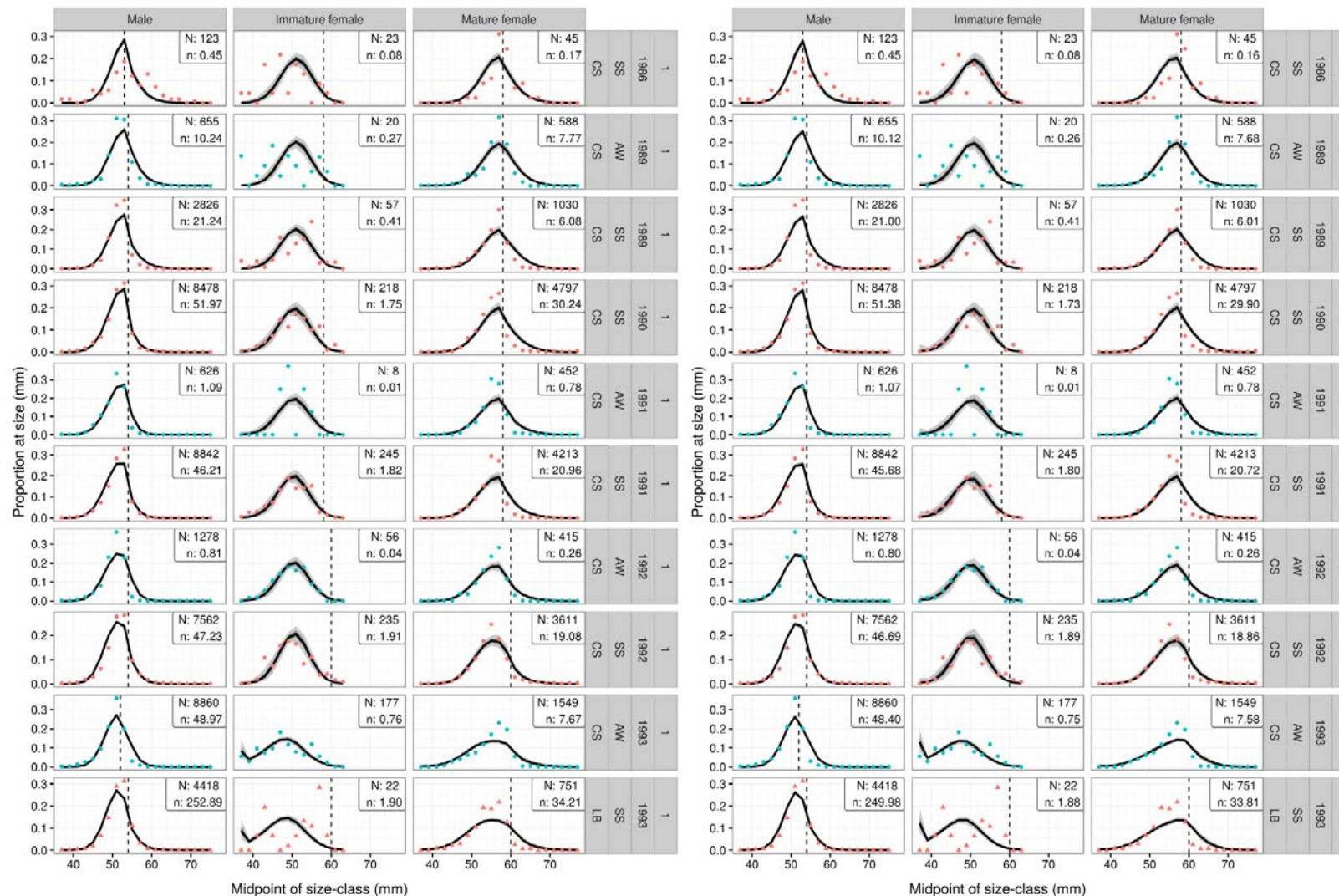
**Figure 18: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): density plots showing prior (red) and posterior distributions (blue) for catchability and vulnerability parameters.**



**Figure 19: CRA 3  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior of predicted CPUE by season. Region 1 includes statistical areas 909+910 and region two is statistical area 911. q1 is the CR fit; q2 and q3 are FSU fit; and q4 is the CELR fit. The solid line indicates the posterior median and grey shading with variable intensity indicates the 50% and 90% credible intervals. The dashed line (often not visible as it is covered by the median line) indicates the corresponding MAP estimates.**

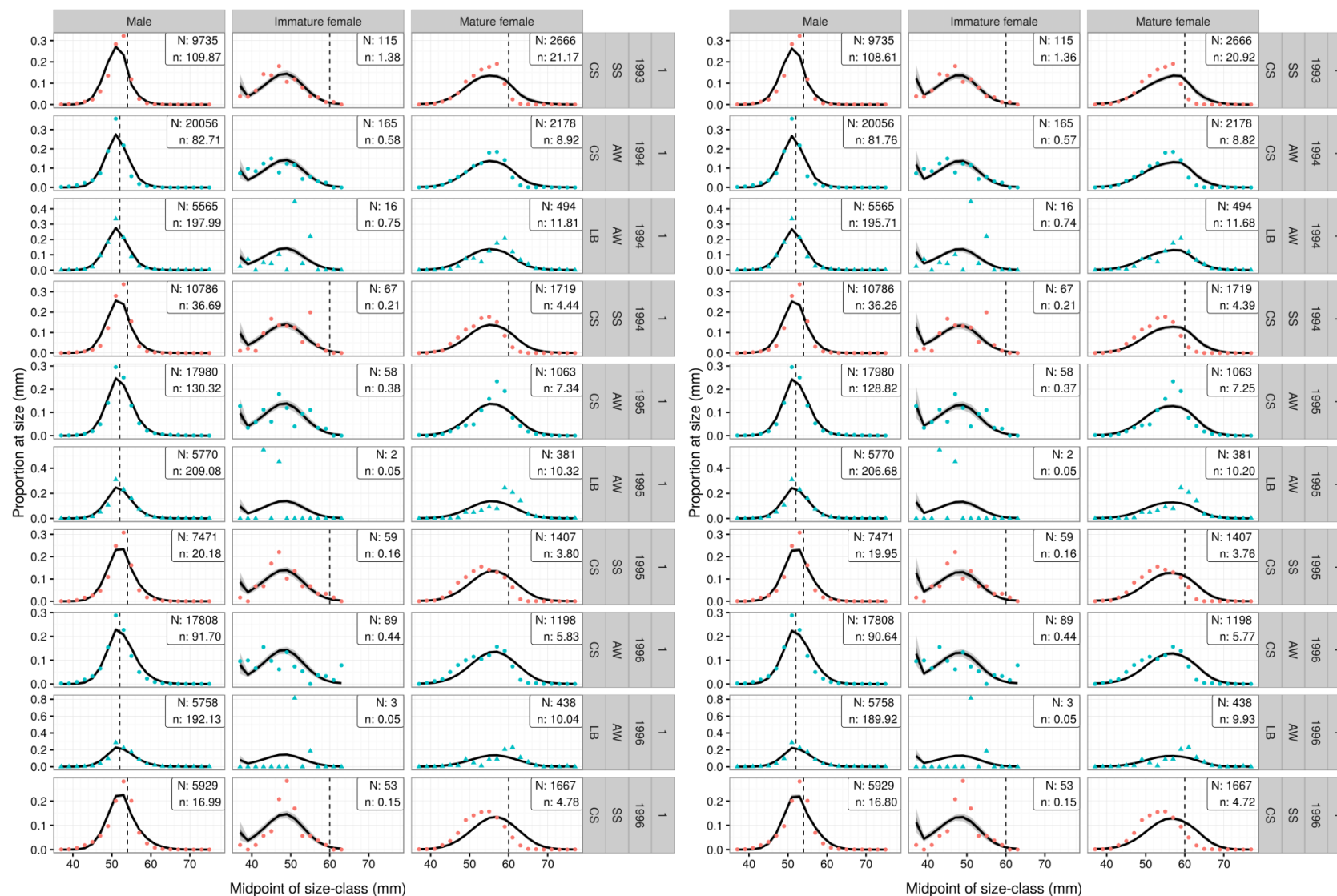


**Figure 20: CRA 3 *r1\_qdrift* (left) and *r2\_qdrift* (right): distribution of standardised residuals between the predicted CPUE and observed CPUE by season for each sample from the posterior distribution. Region 1 includes statistical areas 909+910 and region two is statistical area 911. q1 is the CR fit; q2 and q3 are FSU fit; and q4 is the CELR fit.**

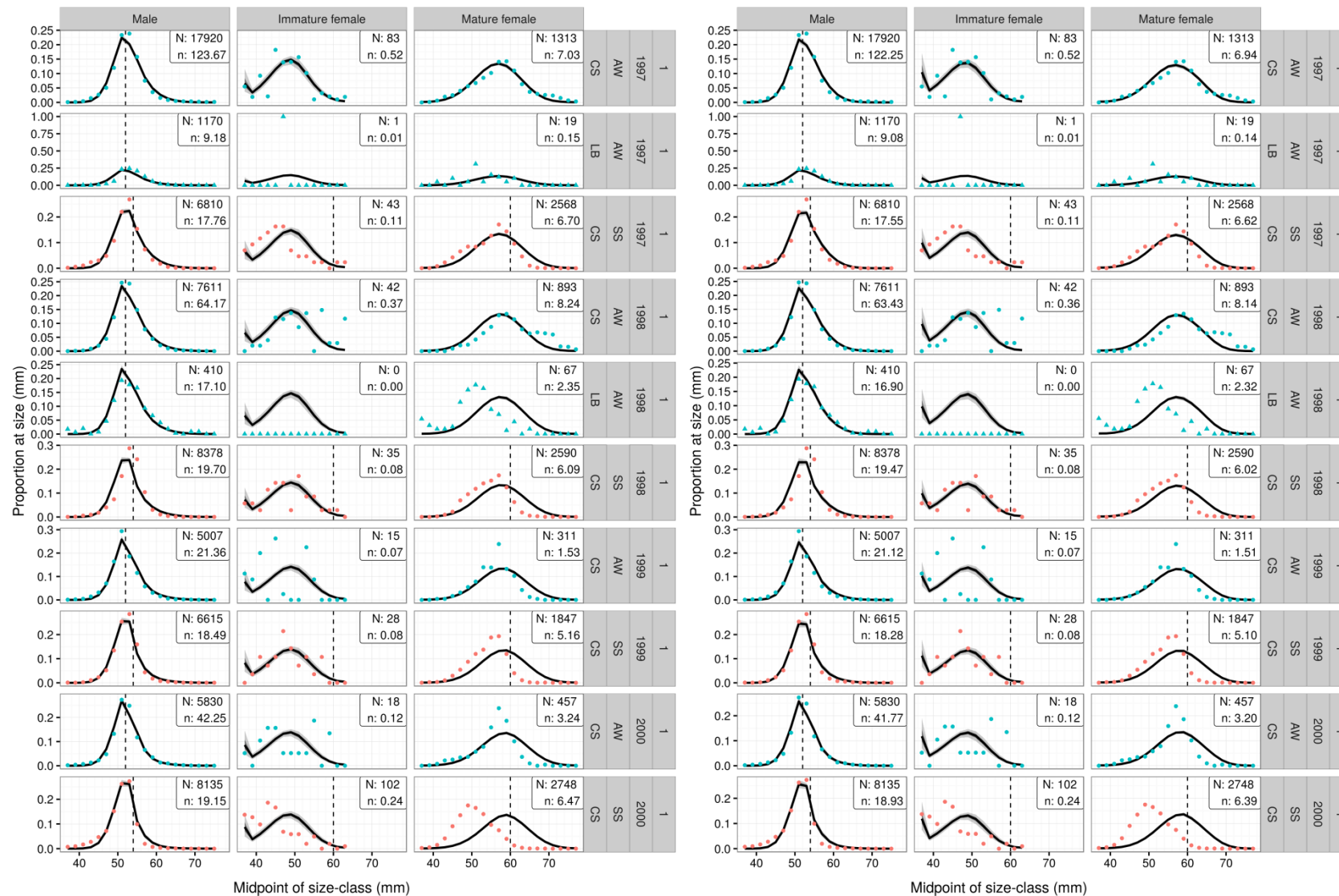


**Figure 21: CRA 3 MCMC *r1\_qdrift* (left) and *r2\_qdrift* (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

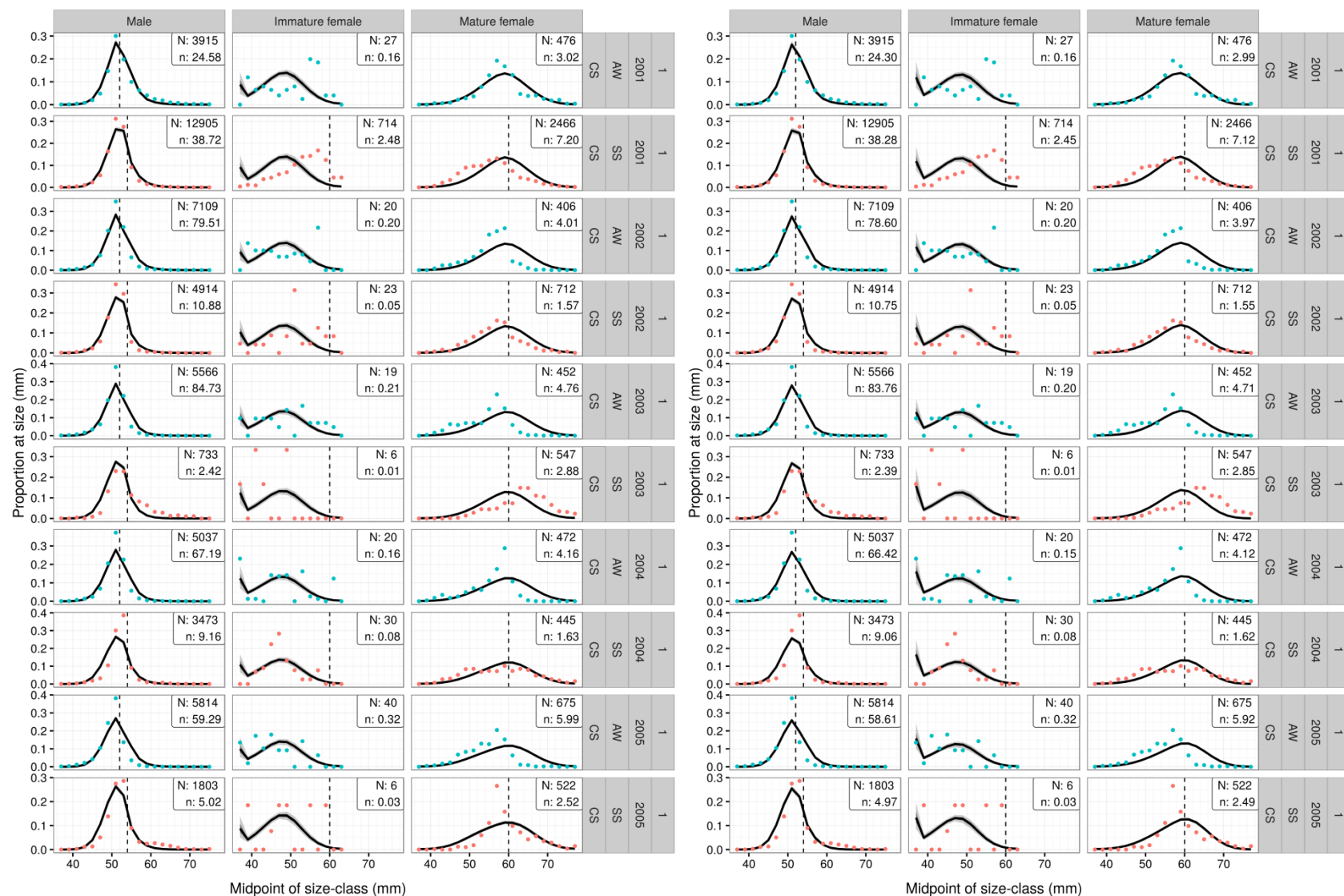




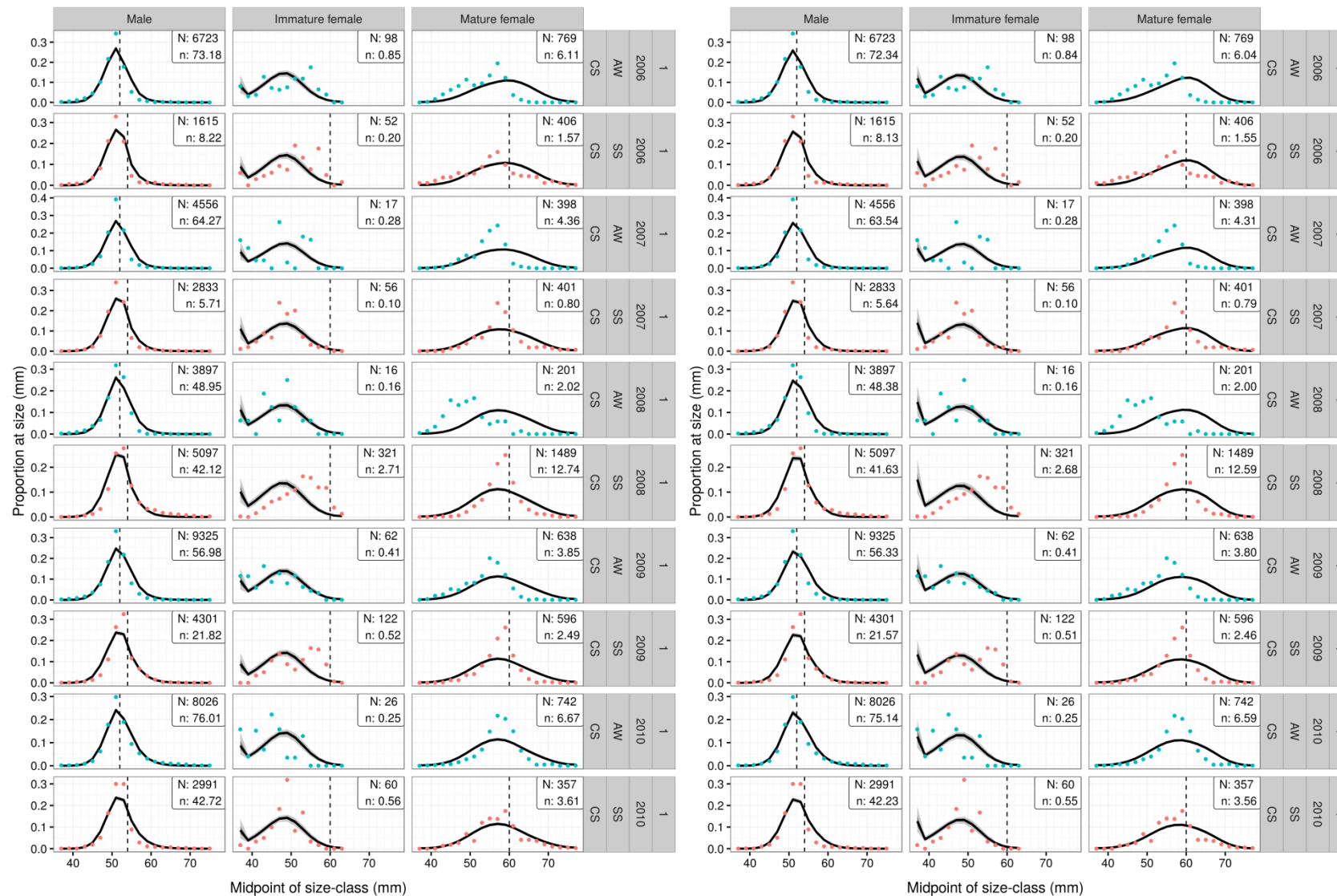
**Figure 22: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**



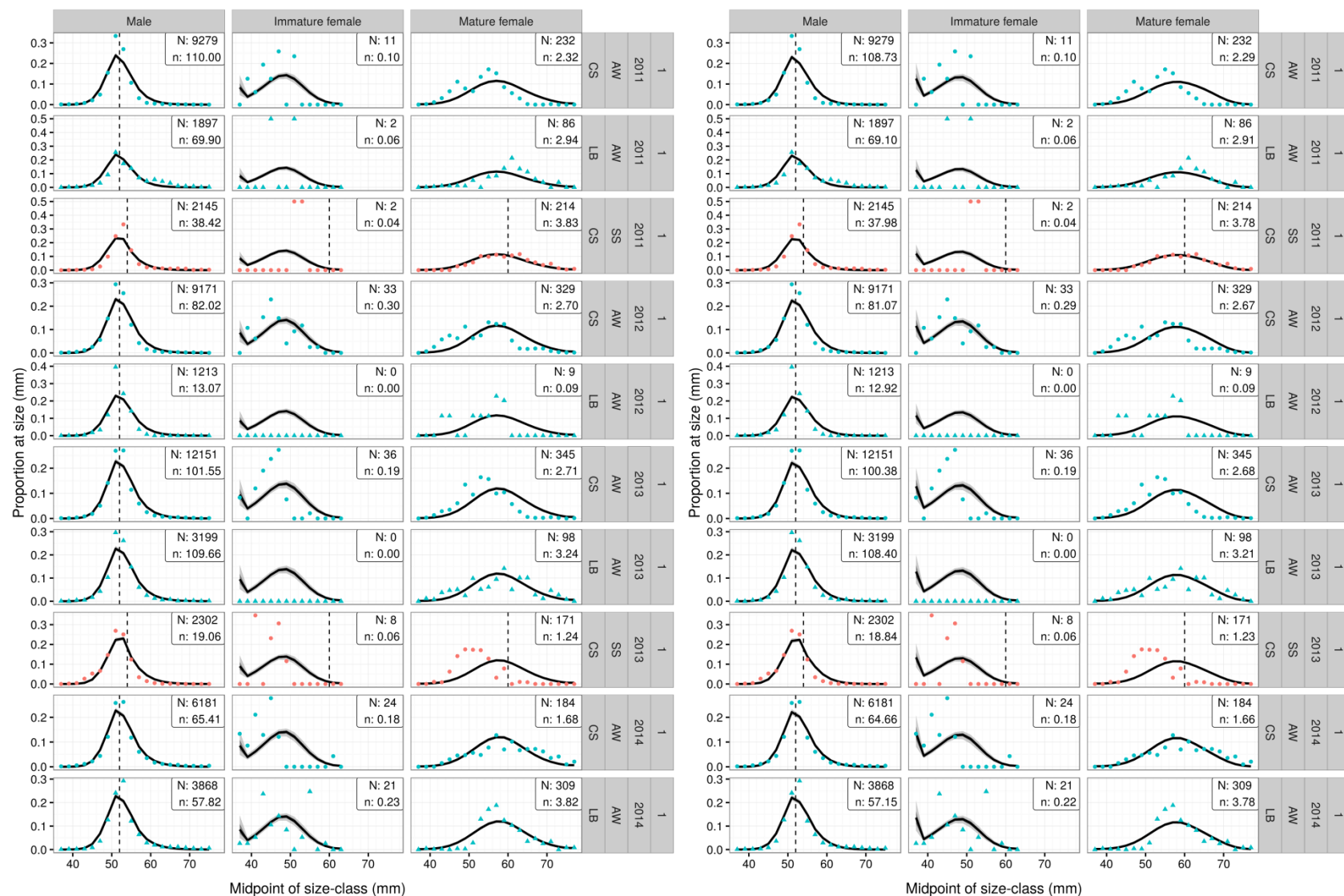
**Figure 23: CRA 3 MCMC *r1\_qdrift* (left) and *r2\_qdrift* (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**



**Figure 24: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

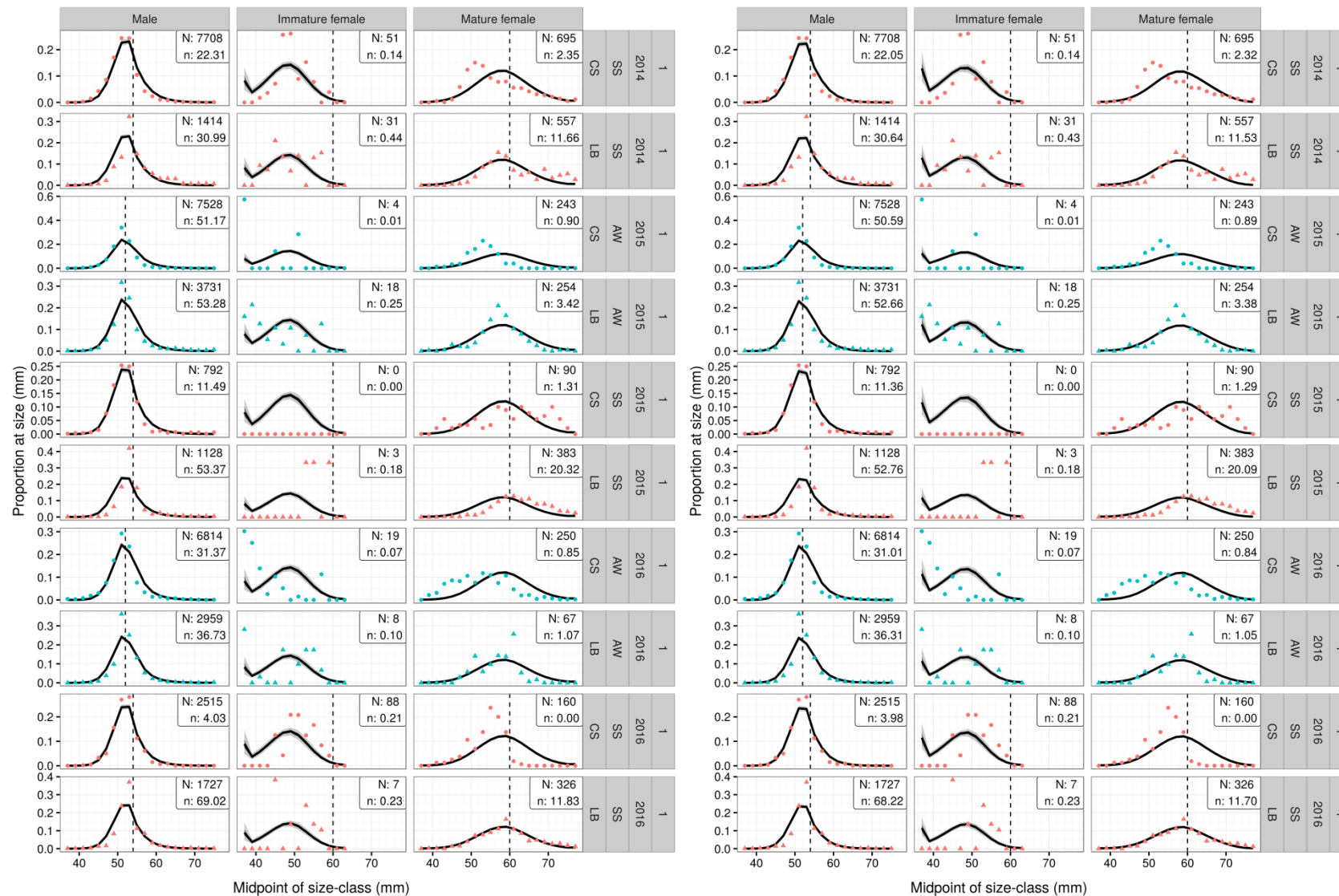


**Figure 25: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

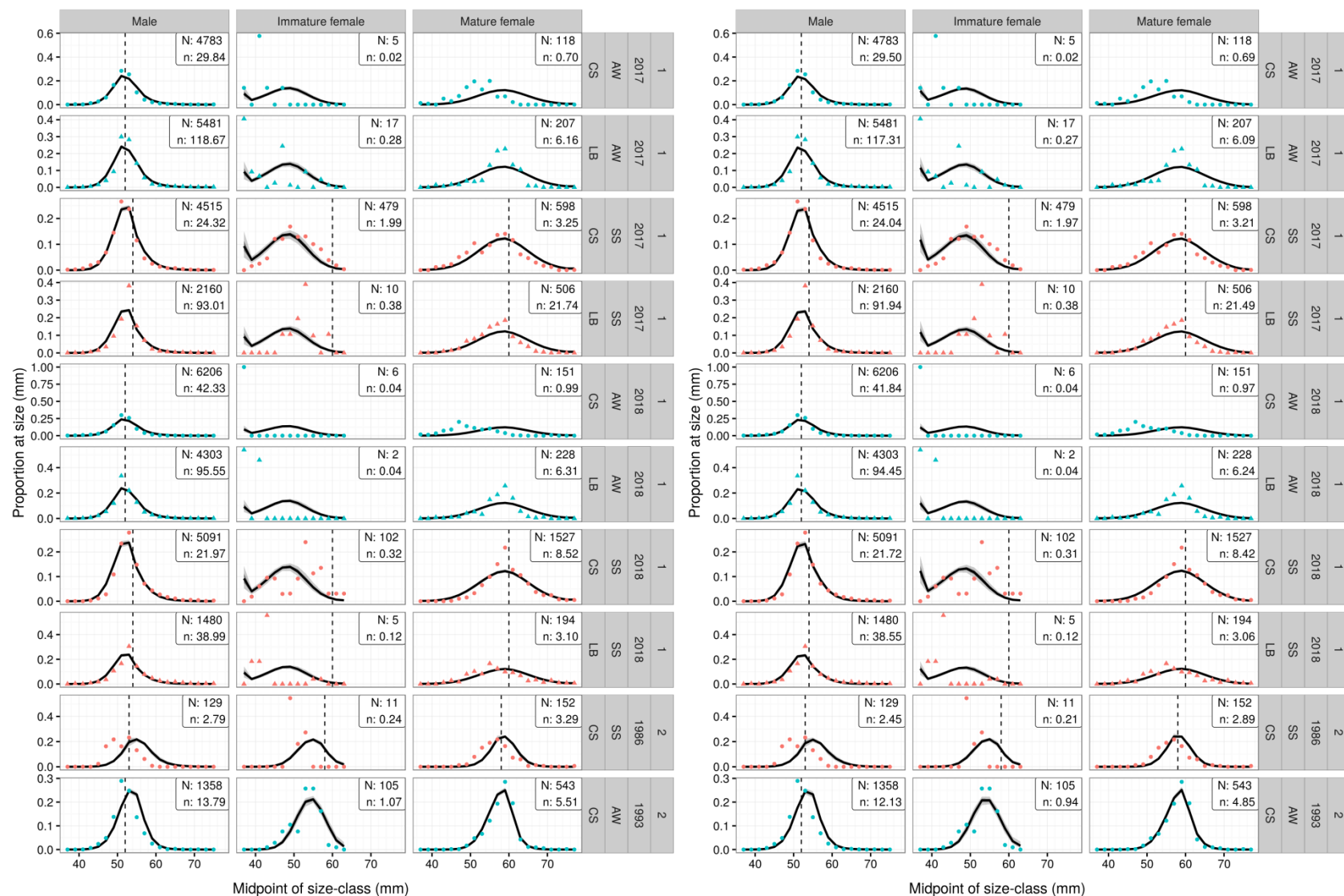


**Figure 26: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

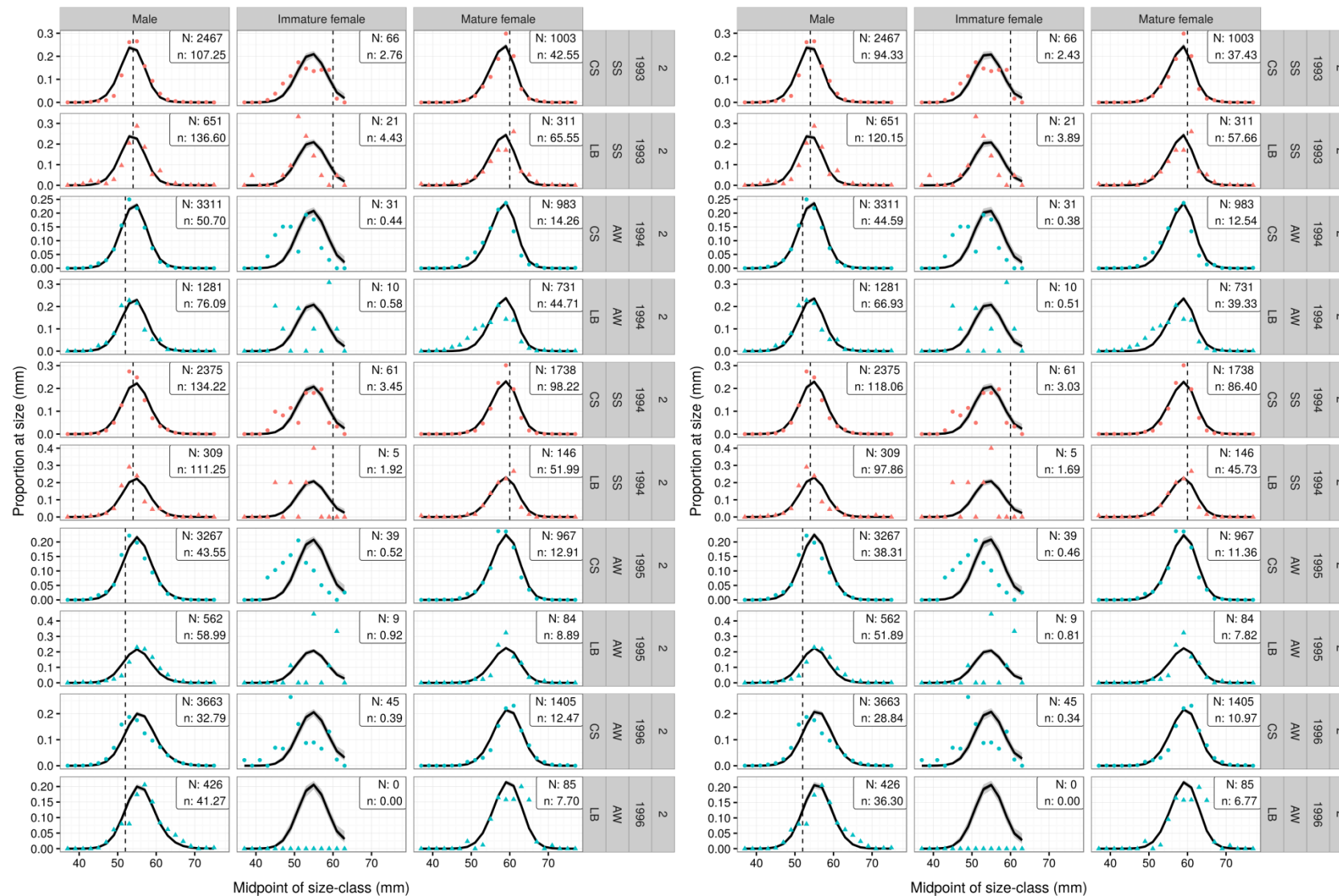




**Figure 27: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

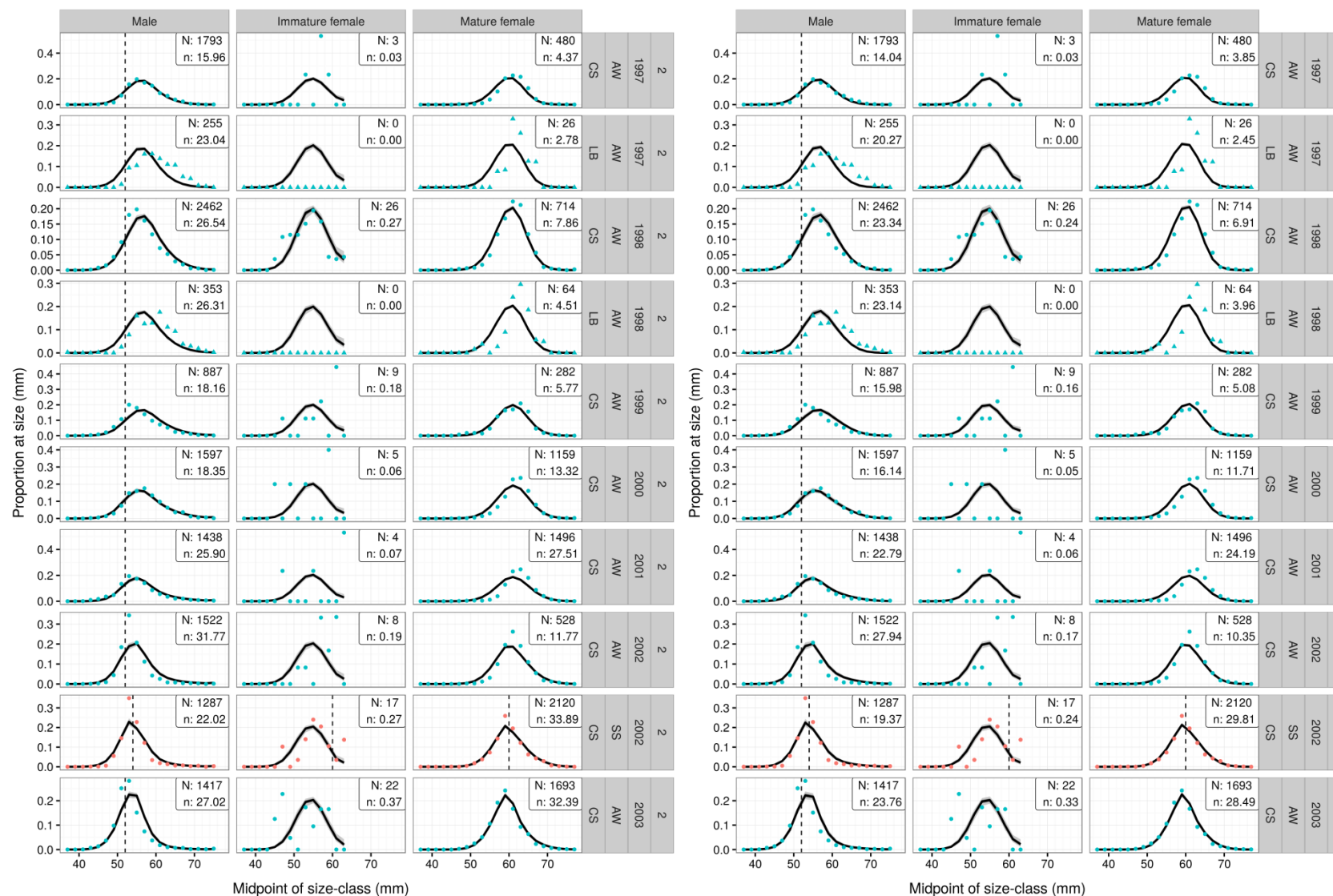


**Figure 28: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

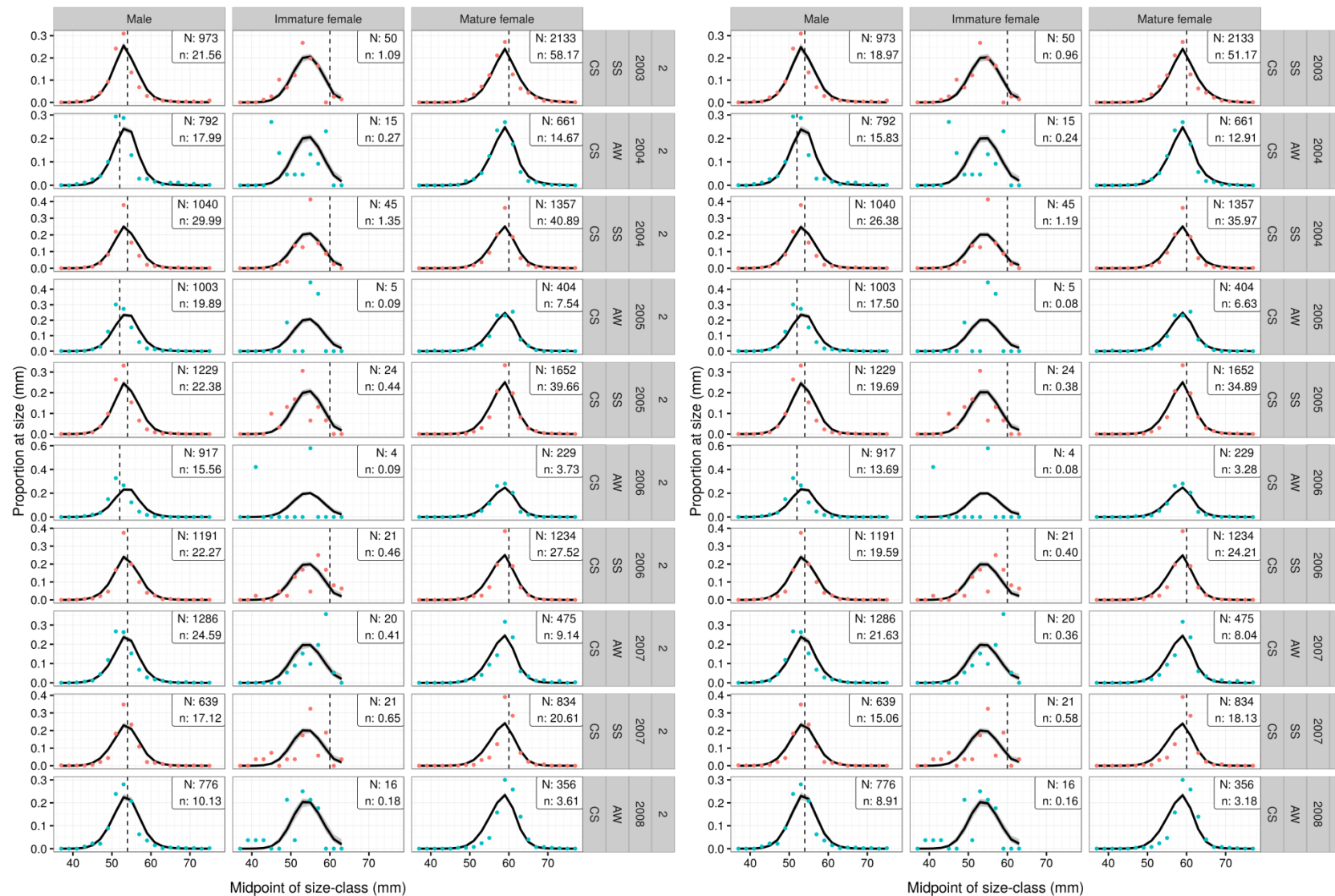


**Figure 29: CRA 3 MCMC *r1\_qdrift* (left) and *r2\_qdrift* (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

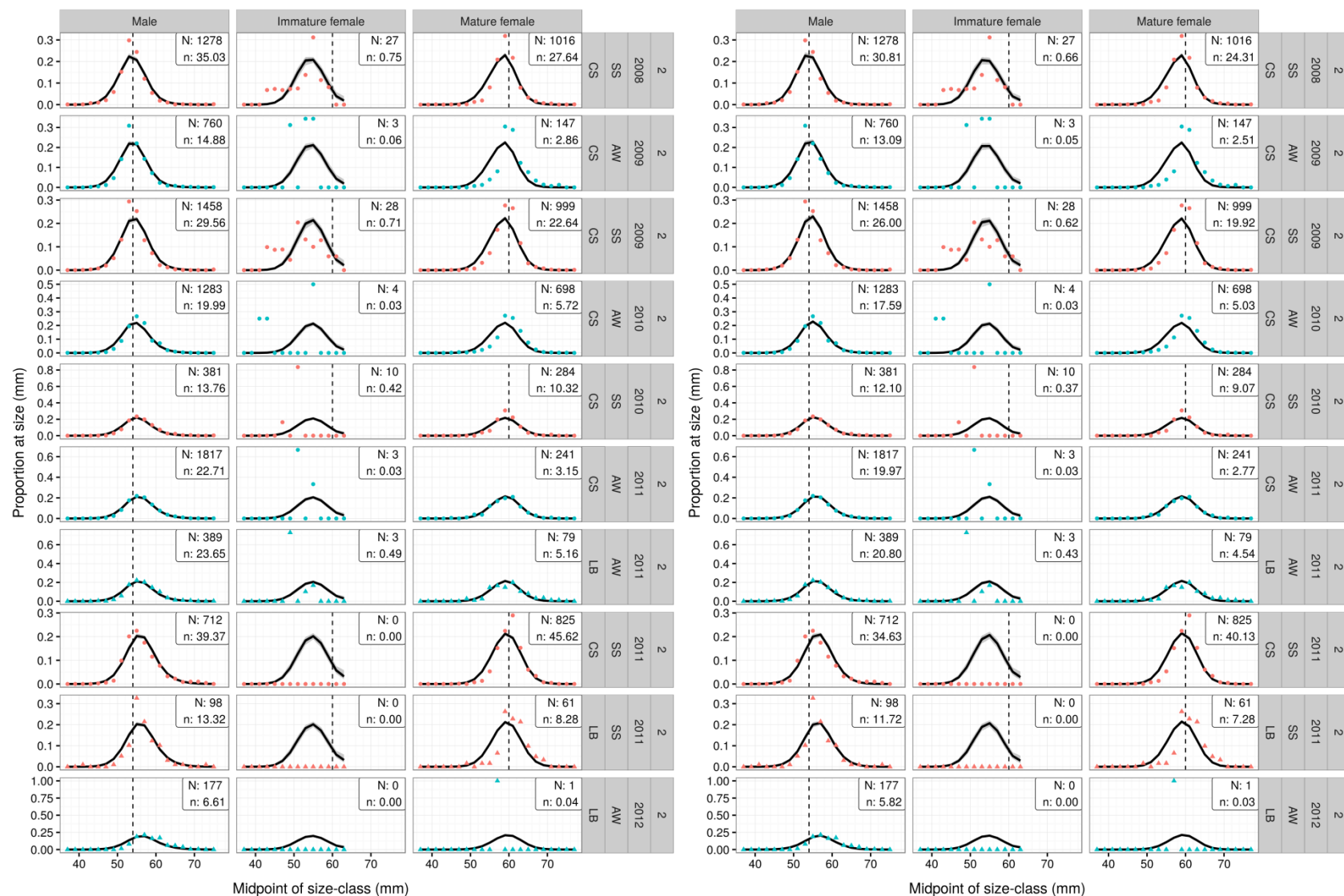




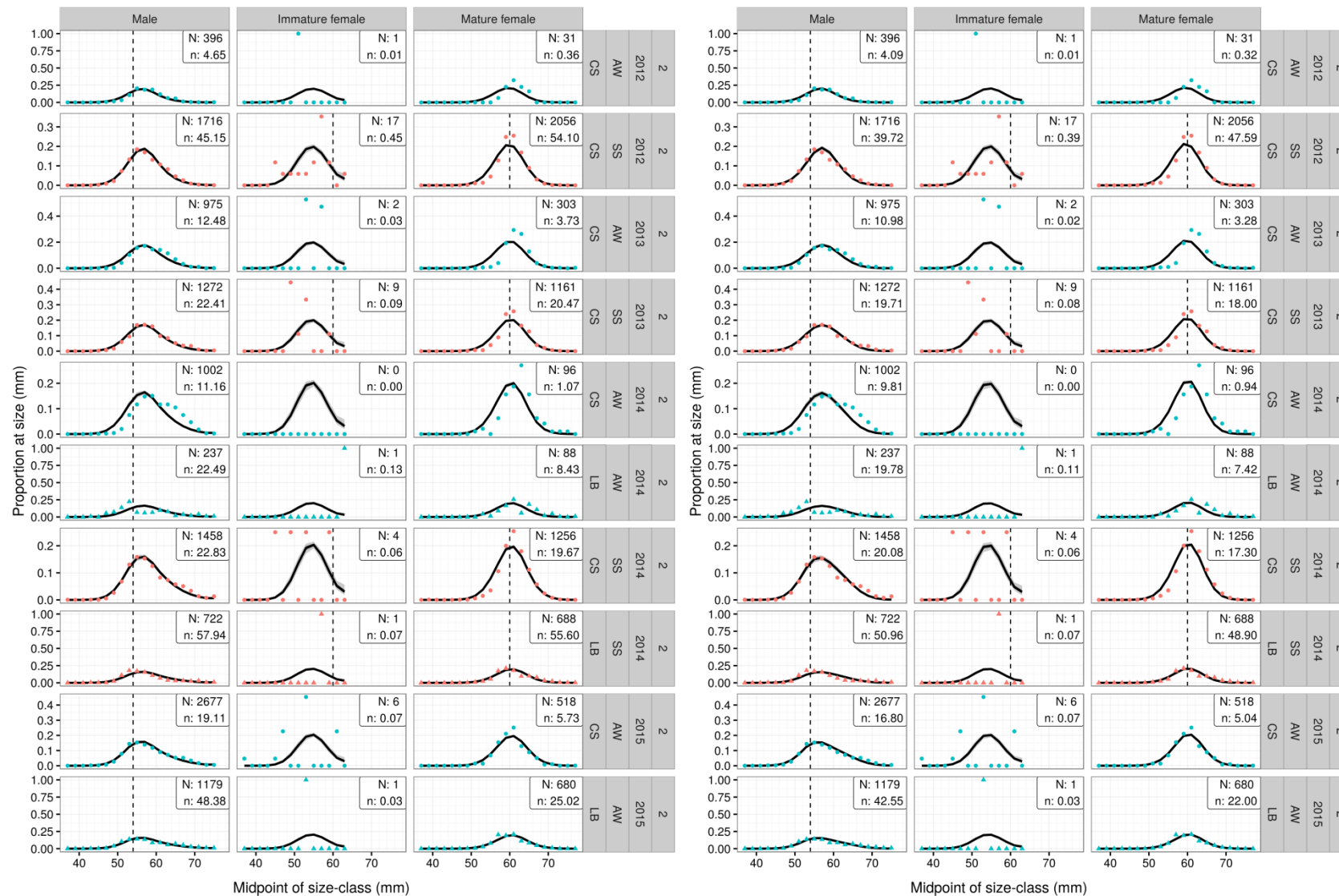
**Figure 30: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**



**Figure 31: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

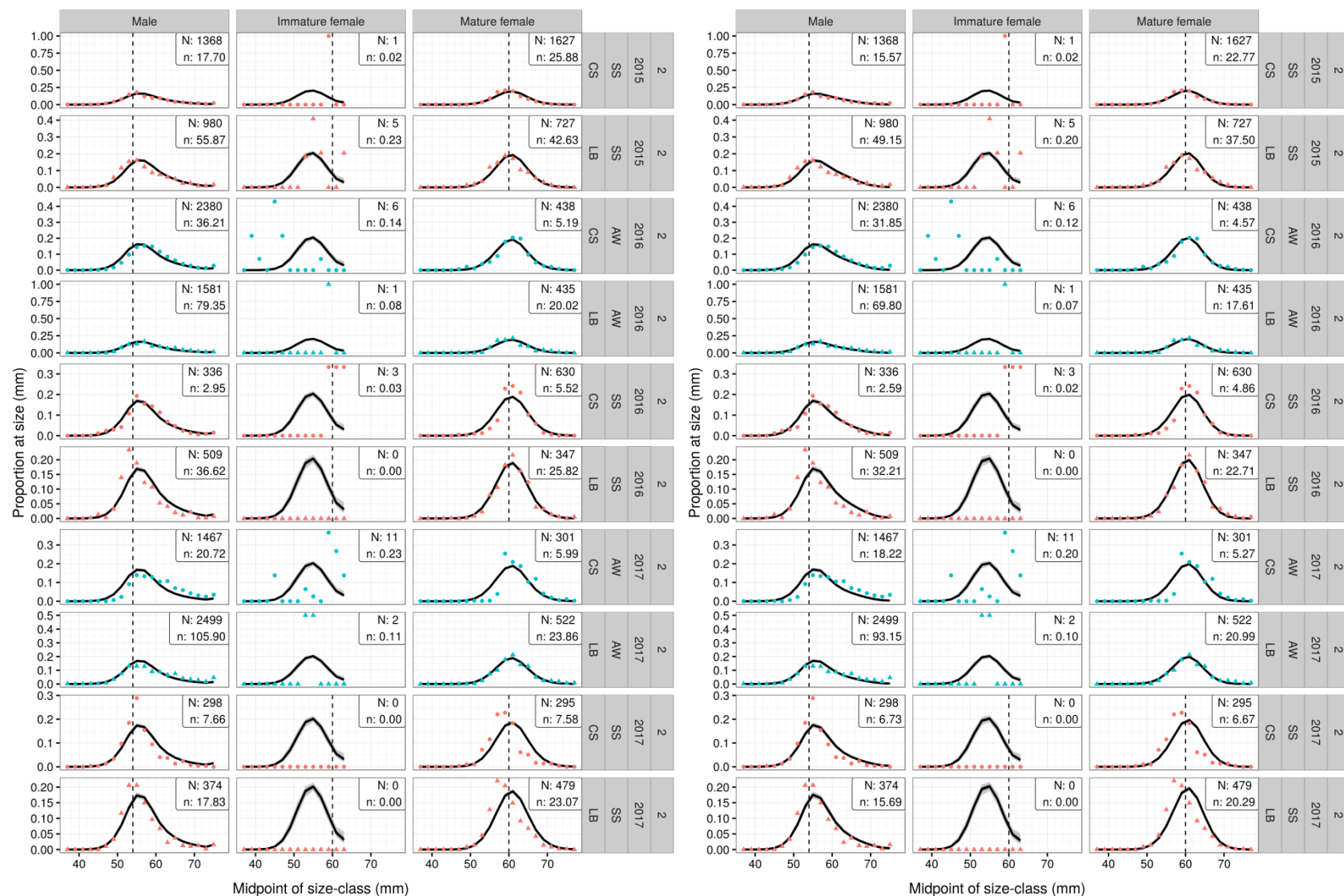


**Figure 32: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

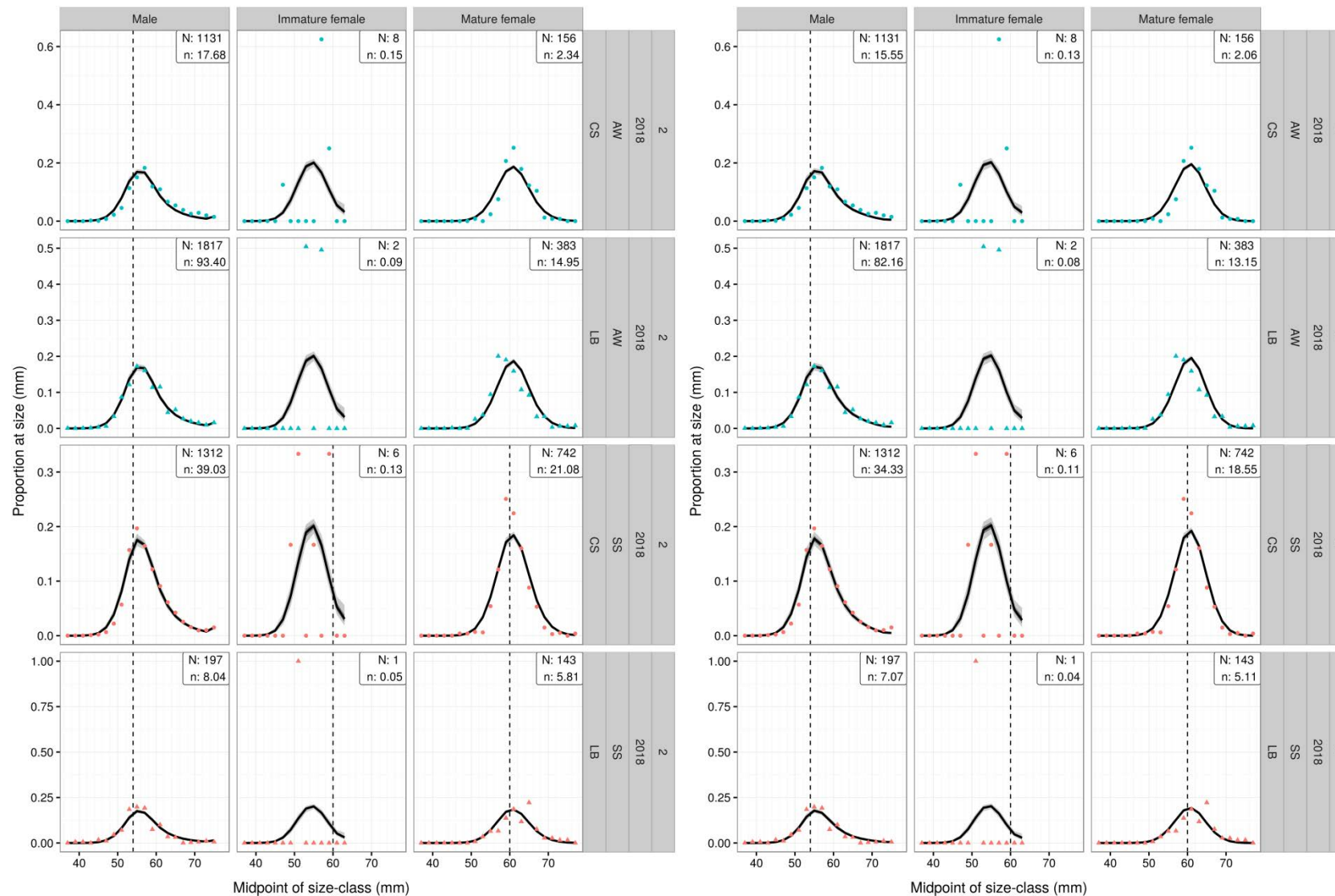


**Figure 33: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

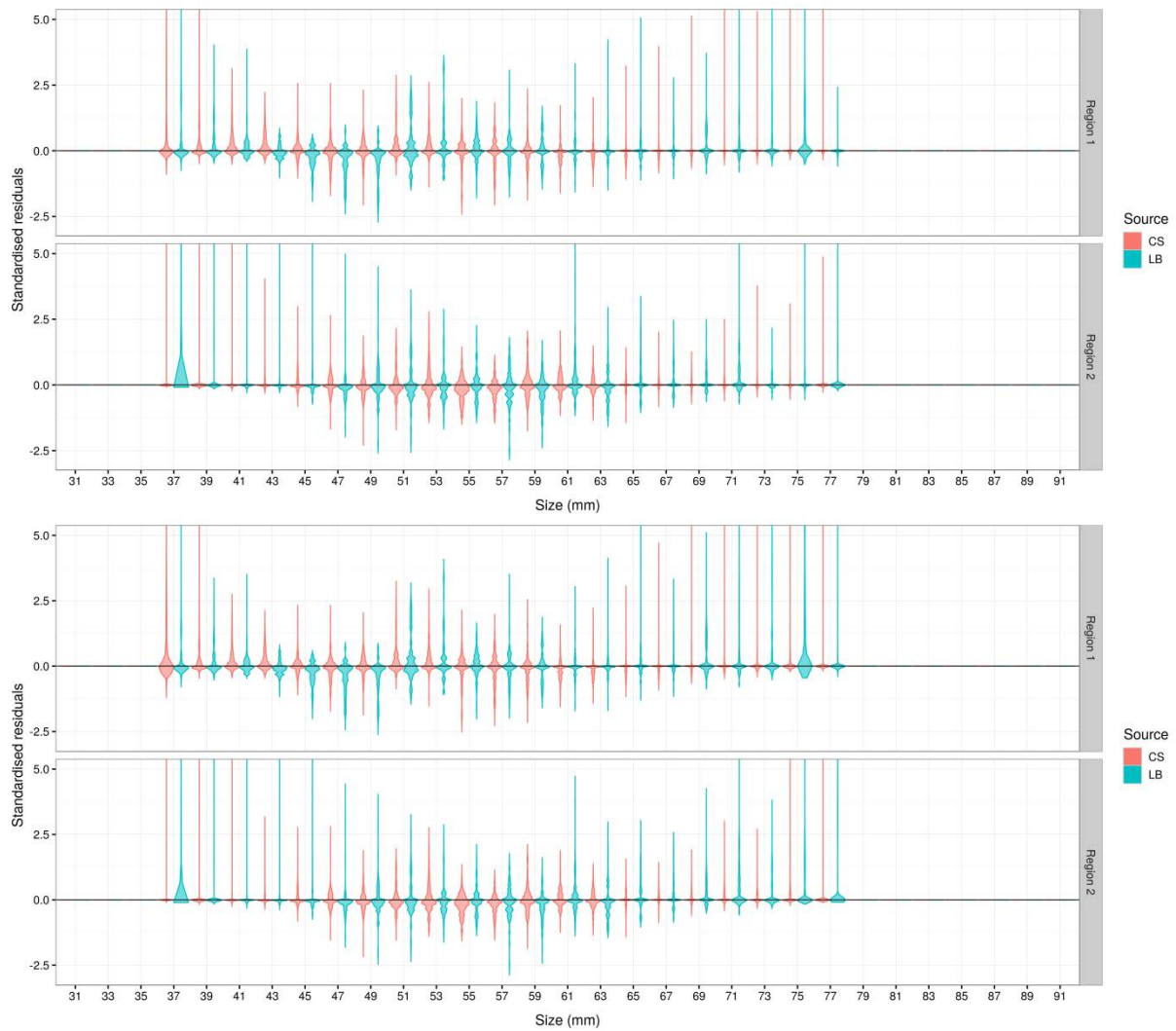




**Figure 34: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

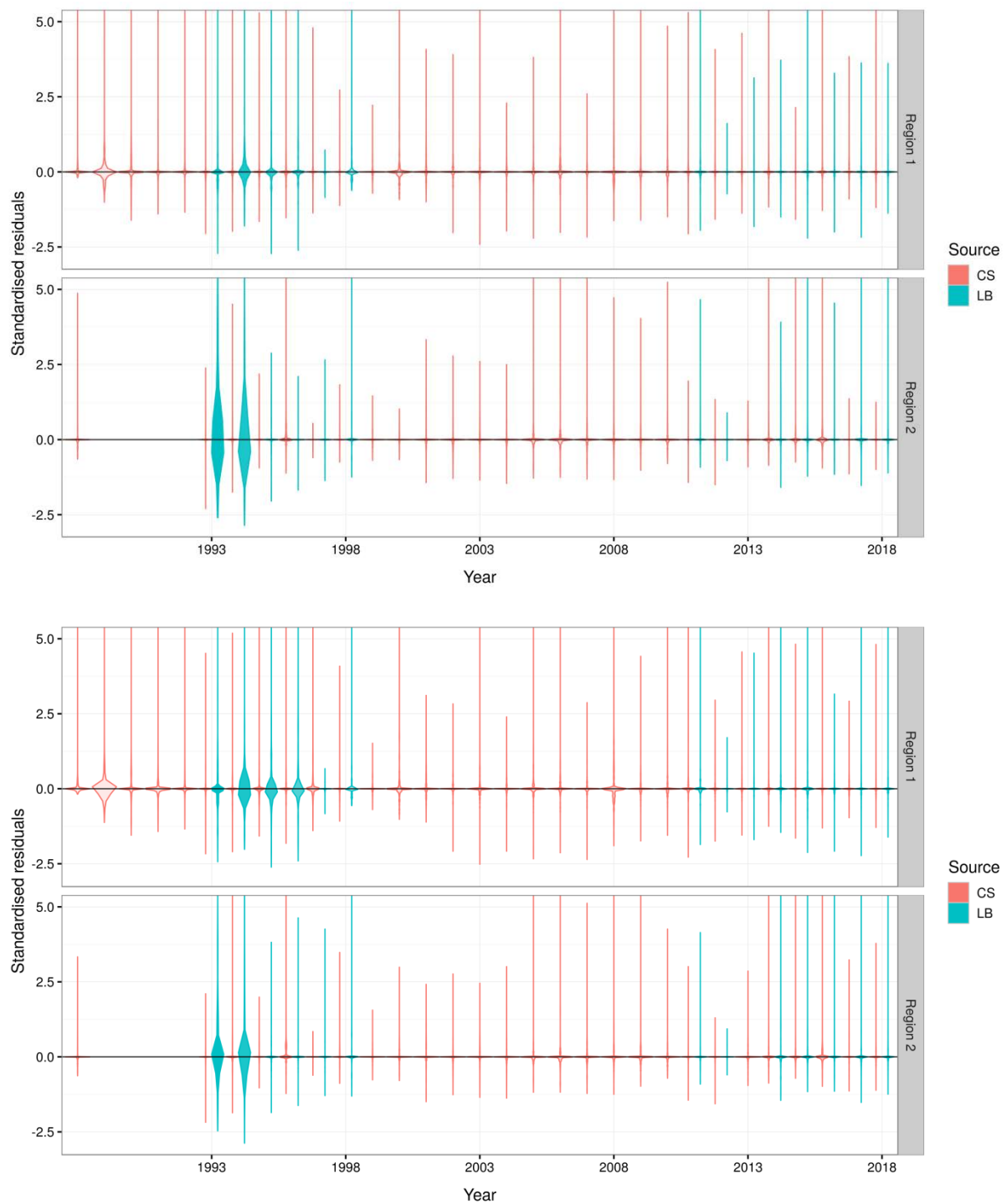


**Figure 35: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): posterior and observed LFs by region, fishing year, season, data source and sex (1=909+910, 2=911, AW=autumn/winter, SS=spring/summer, LB=logbook, CS=catch sampling). The points are the data (blue=AW, red=SS), solid line indicates the posterior median and grey shading indicates the 50% and 90% credible interval, the vertical dashed line is the MLS, N is the number of lobsters measured and n is the effective sample size.**

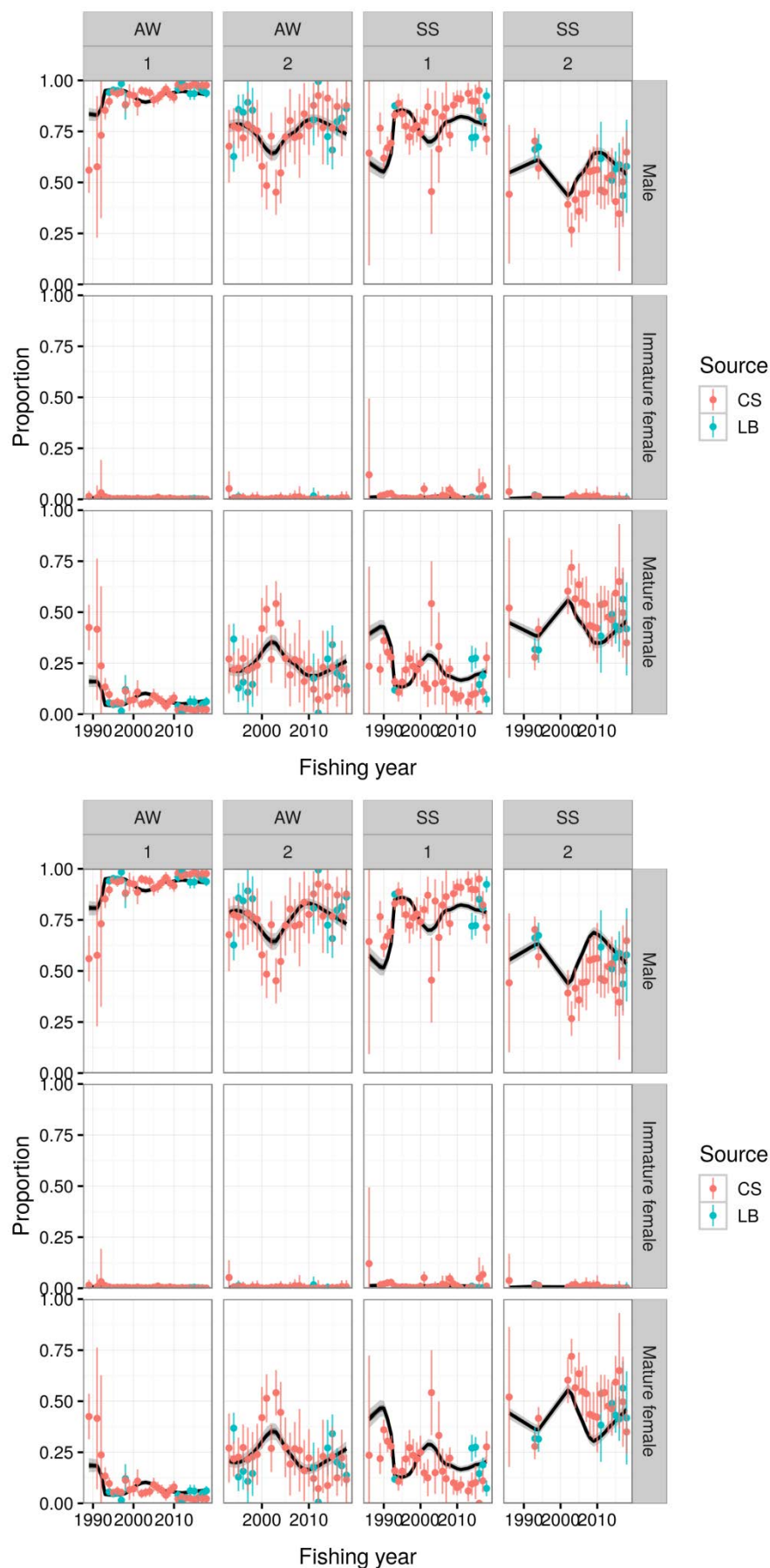


**Figure 36: CRA 3  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): distribution of standardised residuals between the predicted LF distributions and LF data for each sample from the posterior distribution, showing residuals by region, 2 mm size bin, and sampling source. Shading intensity varies with number of observations.**

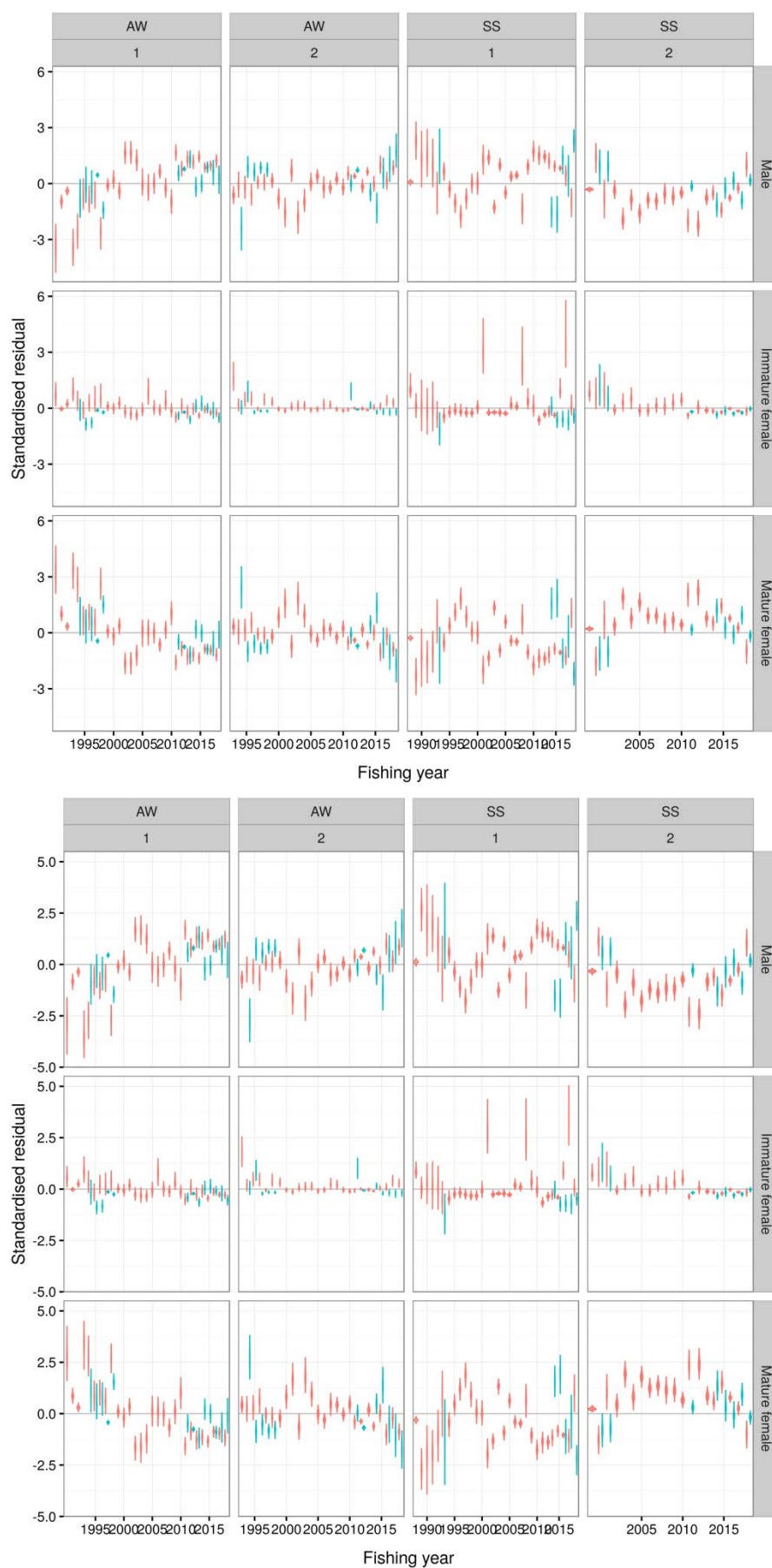




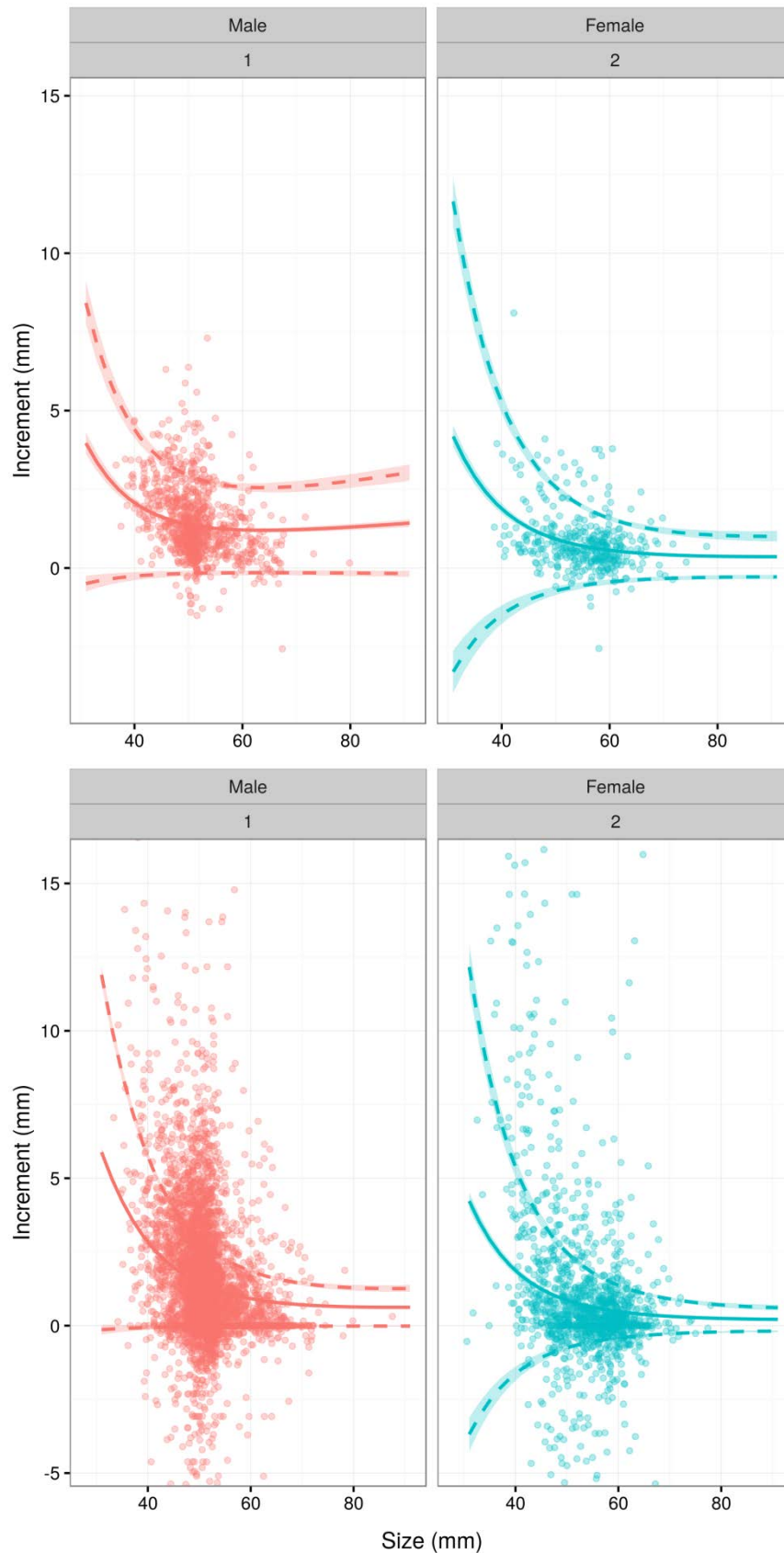
**Figure 37: CRA 3  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): distribution of standardised residuals between the predicted LF distributions and LF data for each sample from the posterior distribution, showing residuals by region, year, and sampling source. Shading intensity varies with number of observations.**



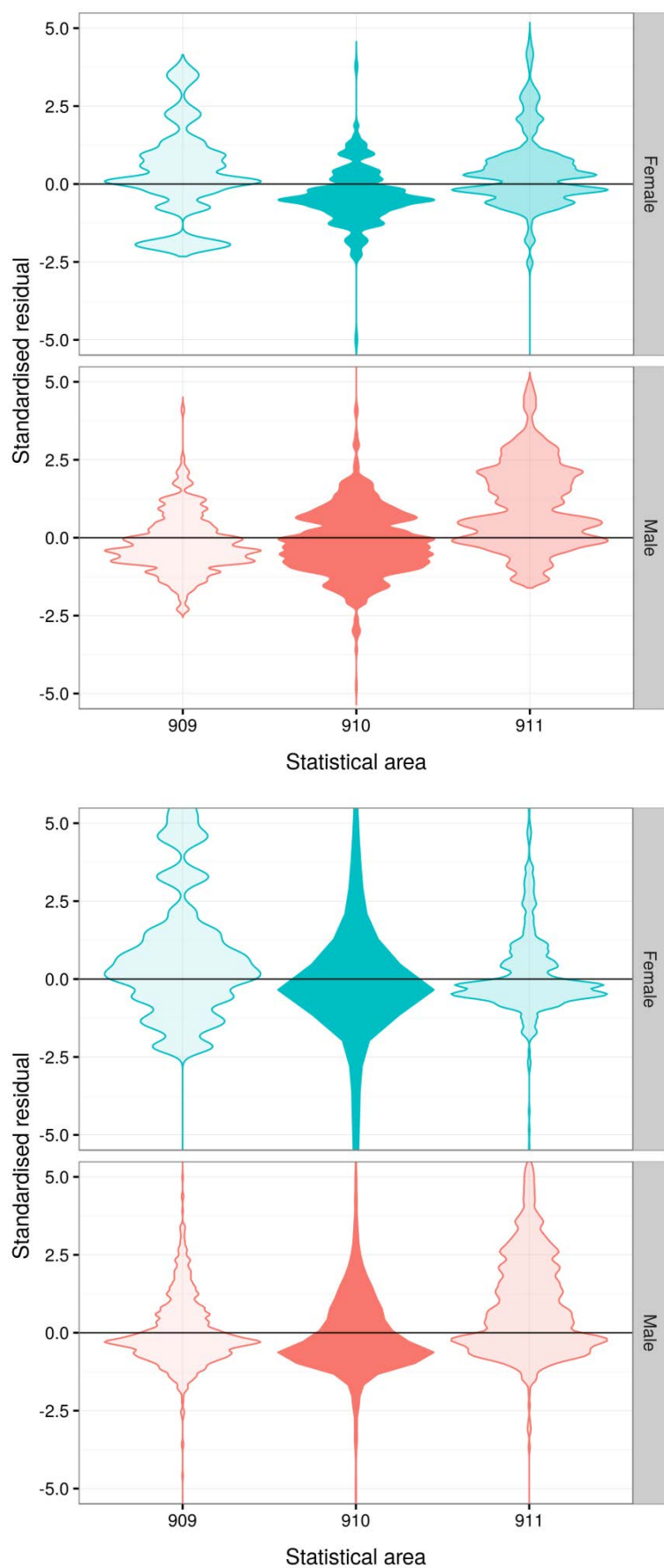
**Figure 38: CRA 3  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): model fit to sex ratios by year and data source for each season in each region. The solid line indicates the posterior median and grey shading indicates the 90% credible interval.**



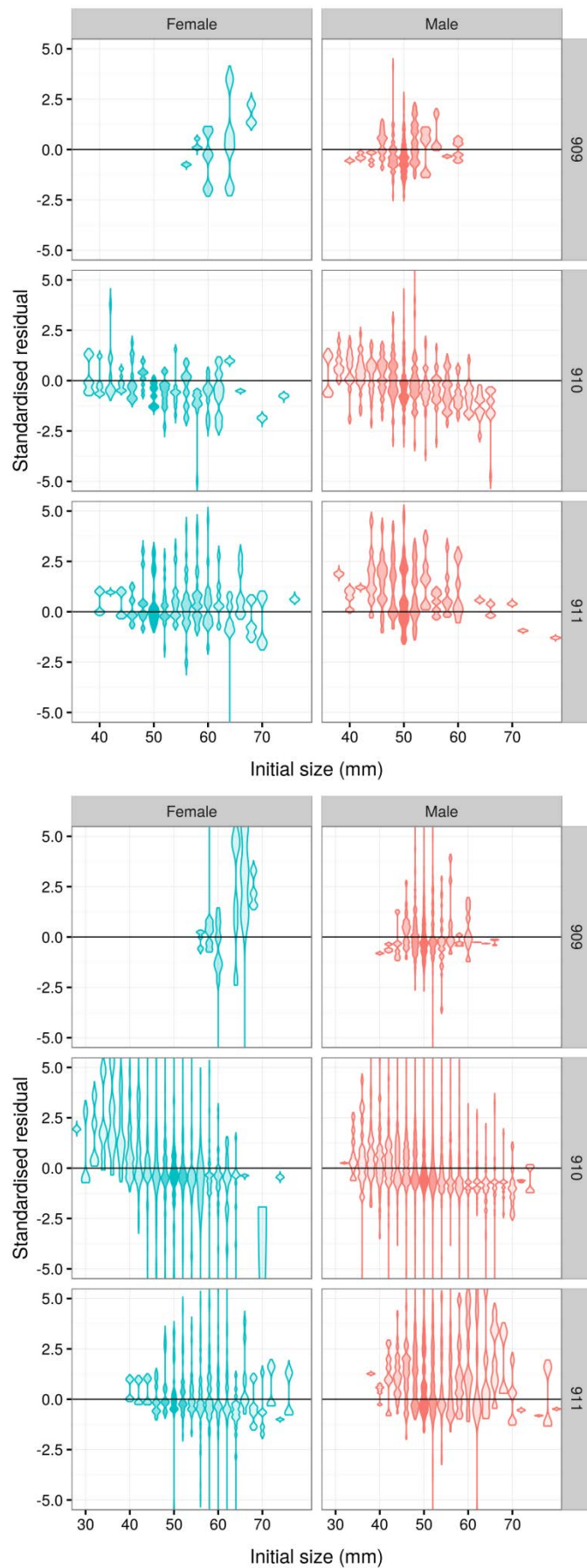
**Figure 39: CRA 3  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): distribution of standardised residuals between predicted and observed sex ratios by year and data source for each season in each region.**



**Figure 40: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): predicted increments-at-length by sex (showing the observed recoveries) and  $\pm 1$  standard deviation (dashed coloured lines), with the solid line indicating the posterior median and the shaded bands showing the 90% credible intervals.**

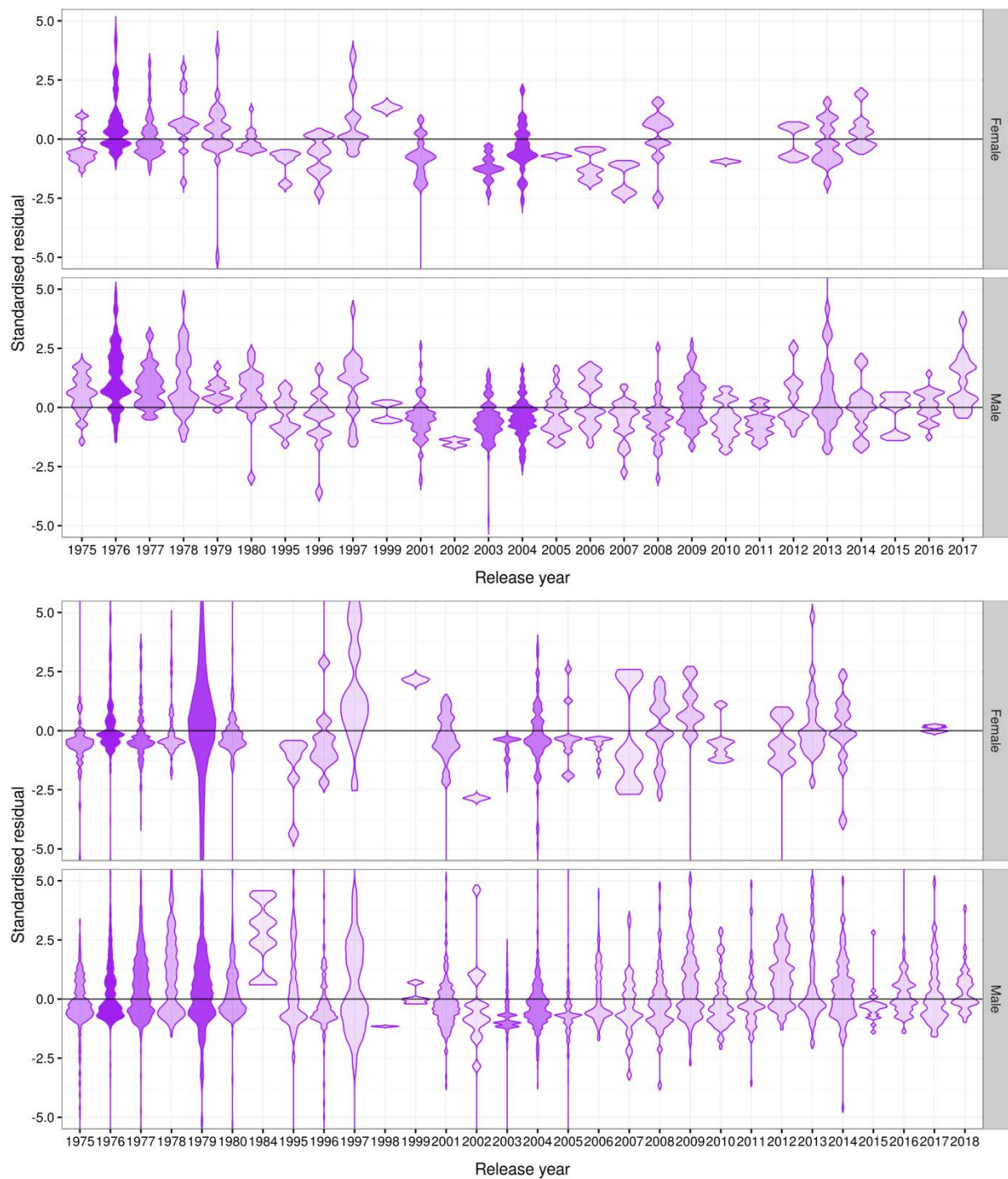


**Figure 41: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): distribution of tag residuals by sex and statistical area of release for each sample from the posterior distribution. Shading intensity varies with number of observations.**



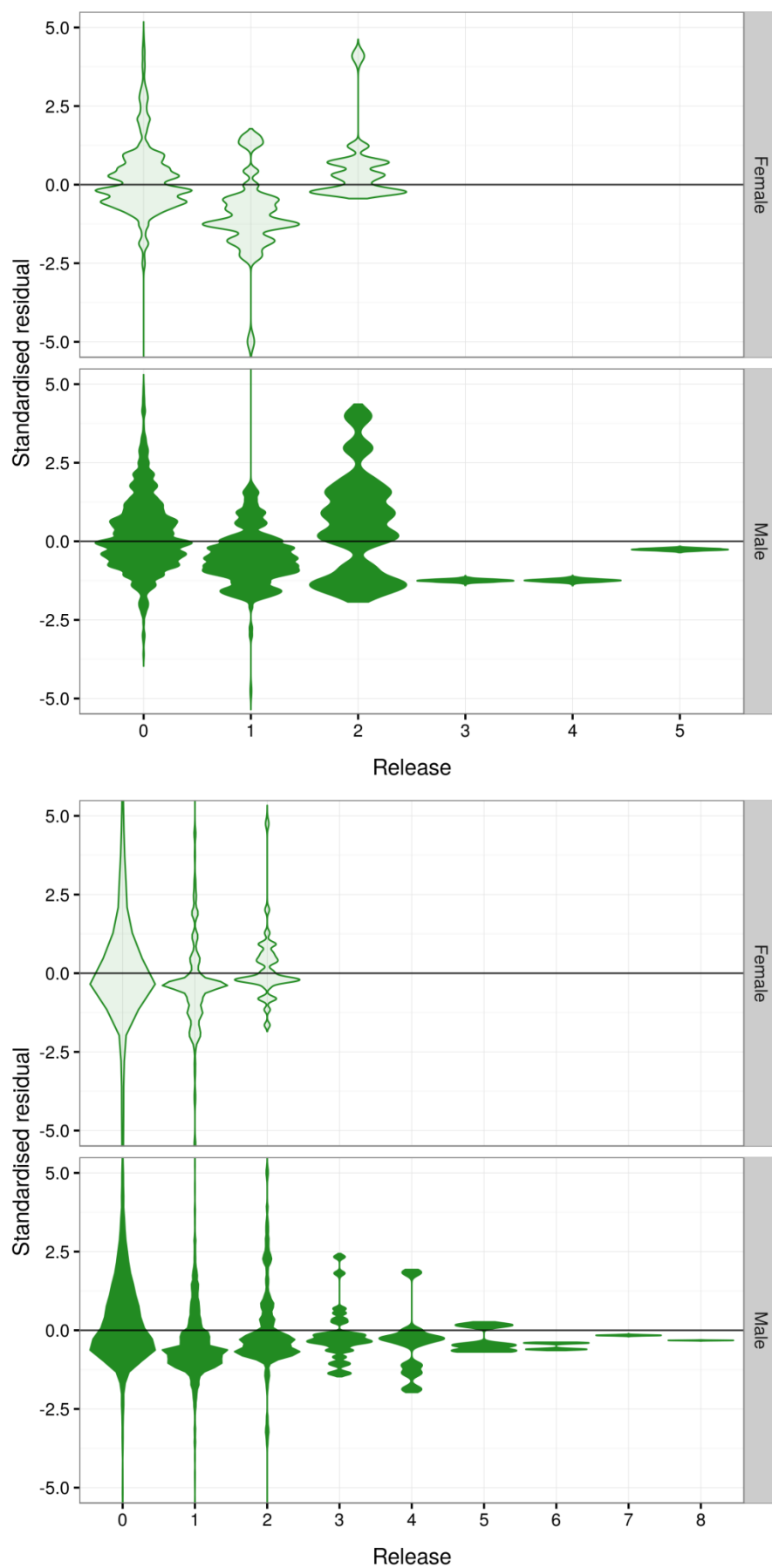
**Figure 42: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): distribution of tag residuals by sex, statistical area of release, and TW bin for each sample from the posterior distribution. Shading intensity varies with number of observations.**



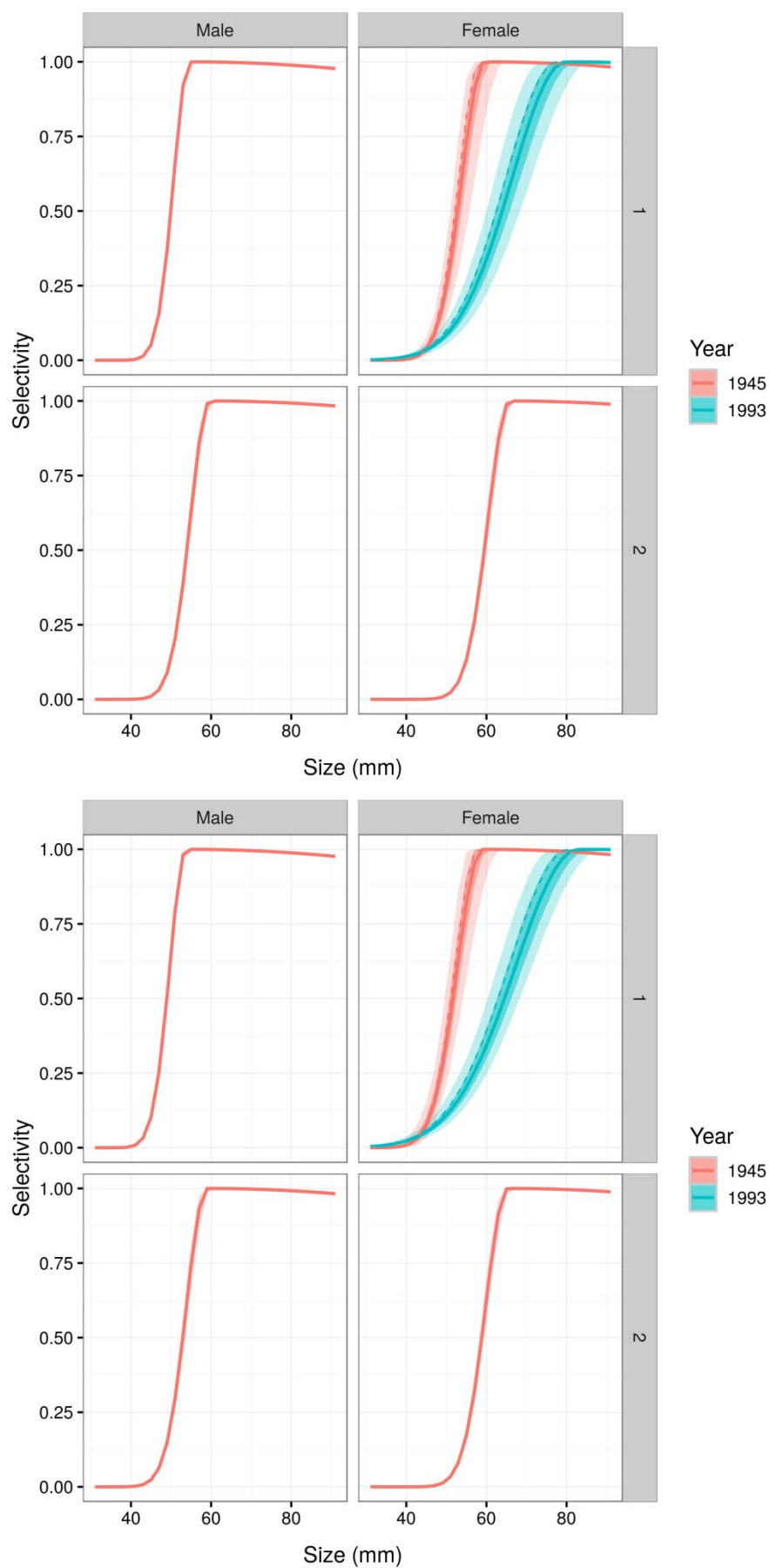


**Figure 43: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): distribution of tag residuals by sex and year of release for each sample from the posterior distribution. Shading intensity varies with number of observations.**

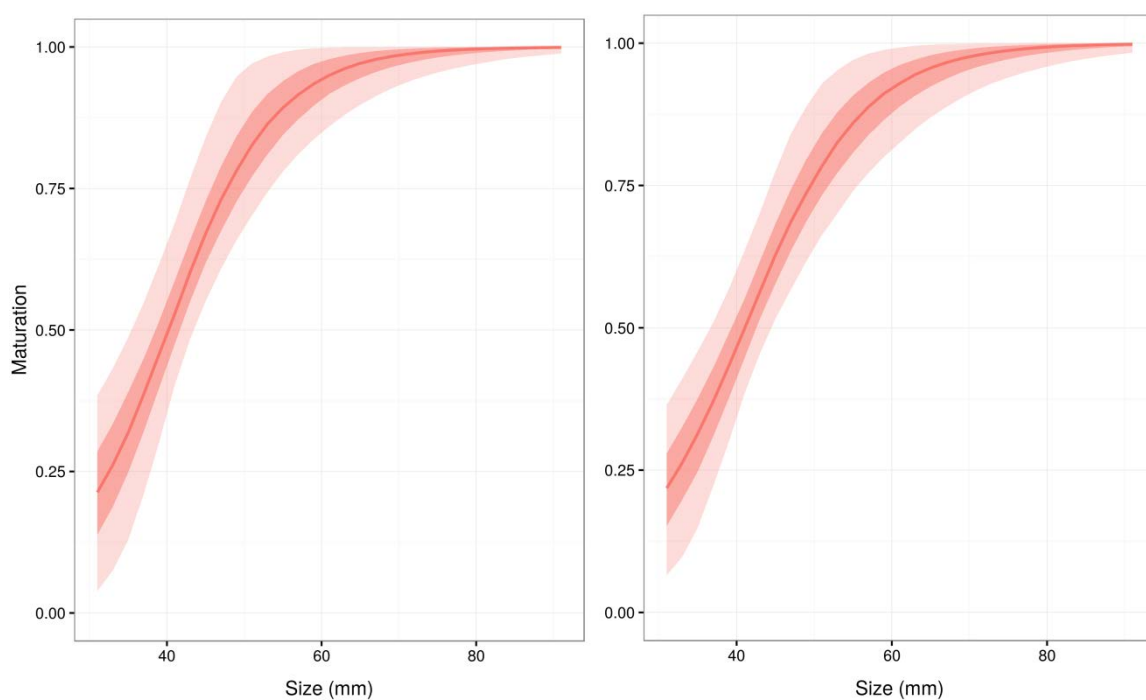




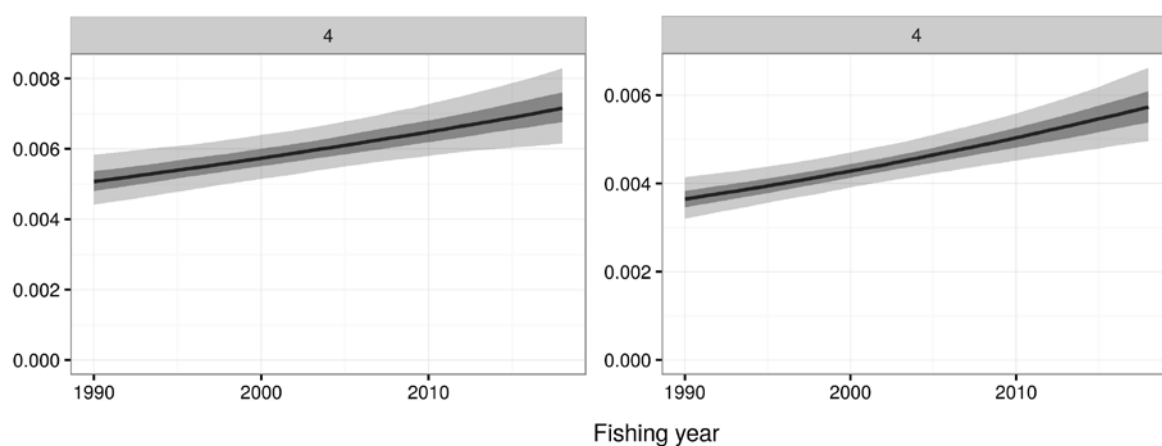
**Figure 44: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): distribution of tag residuals by sex at release for each sample from the posterior distribution. Shading intensity varies with number of observations.**



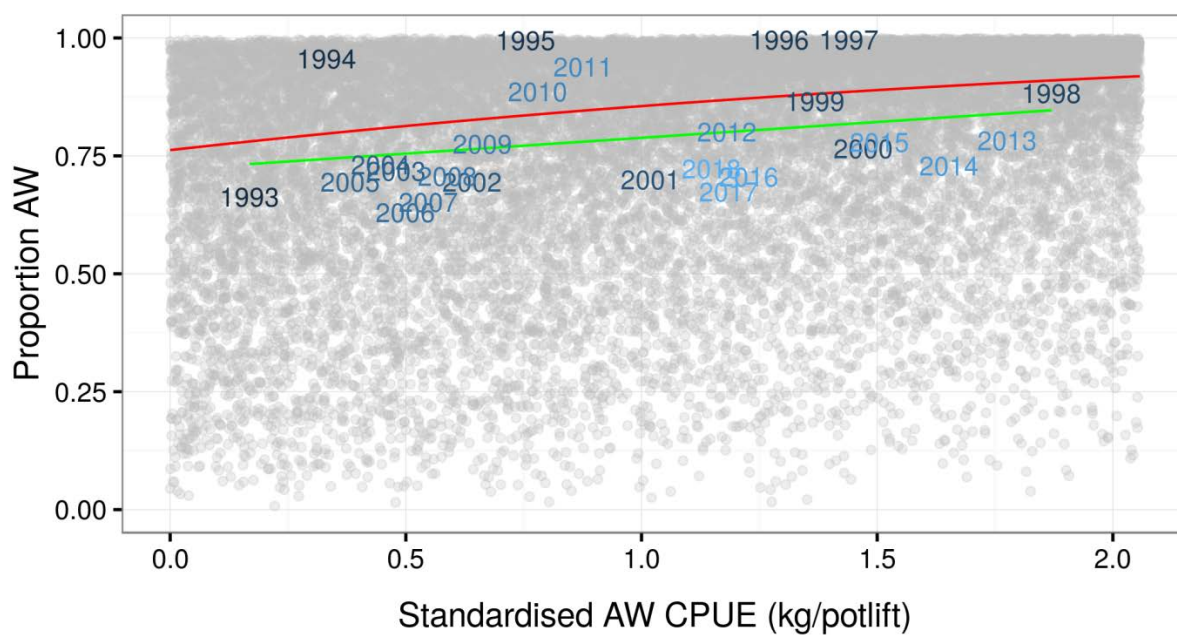
**Figure 45: CRA 3 *r1\_qdrift* (top) and *r2\_qdrift* (bottom): selectivity by sex, region and period, with the solid line indicating the posterior median and the variable intensity coloured bands showing the 50% and 90% credible intervals. The dashed lines indicate the corresponding MAP estimates.**



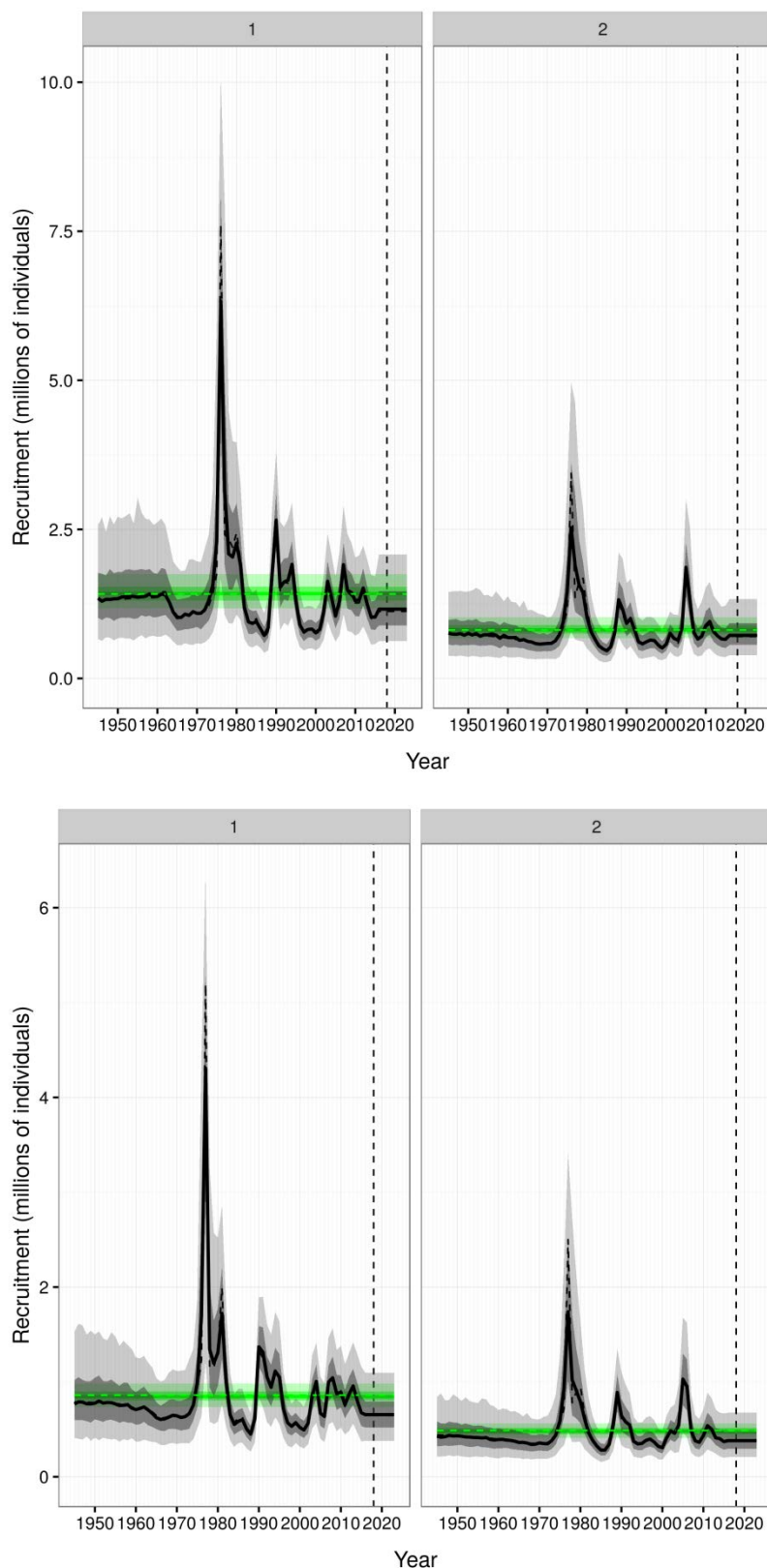
**Figure 46: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): female maturation curve, where the solid line indicates the posterior median and shaded regions with variable intensity indicates the 50% and 90% credible intervals.**



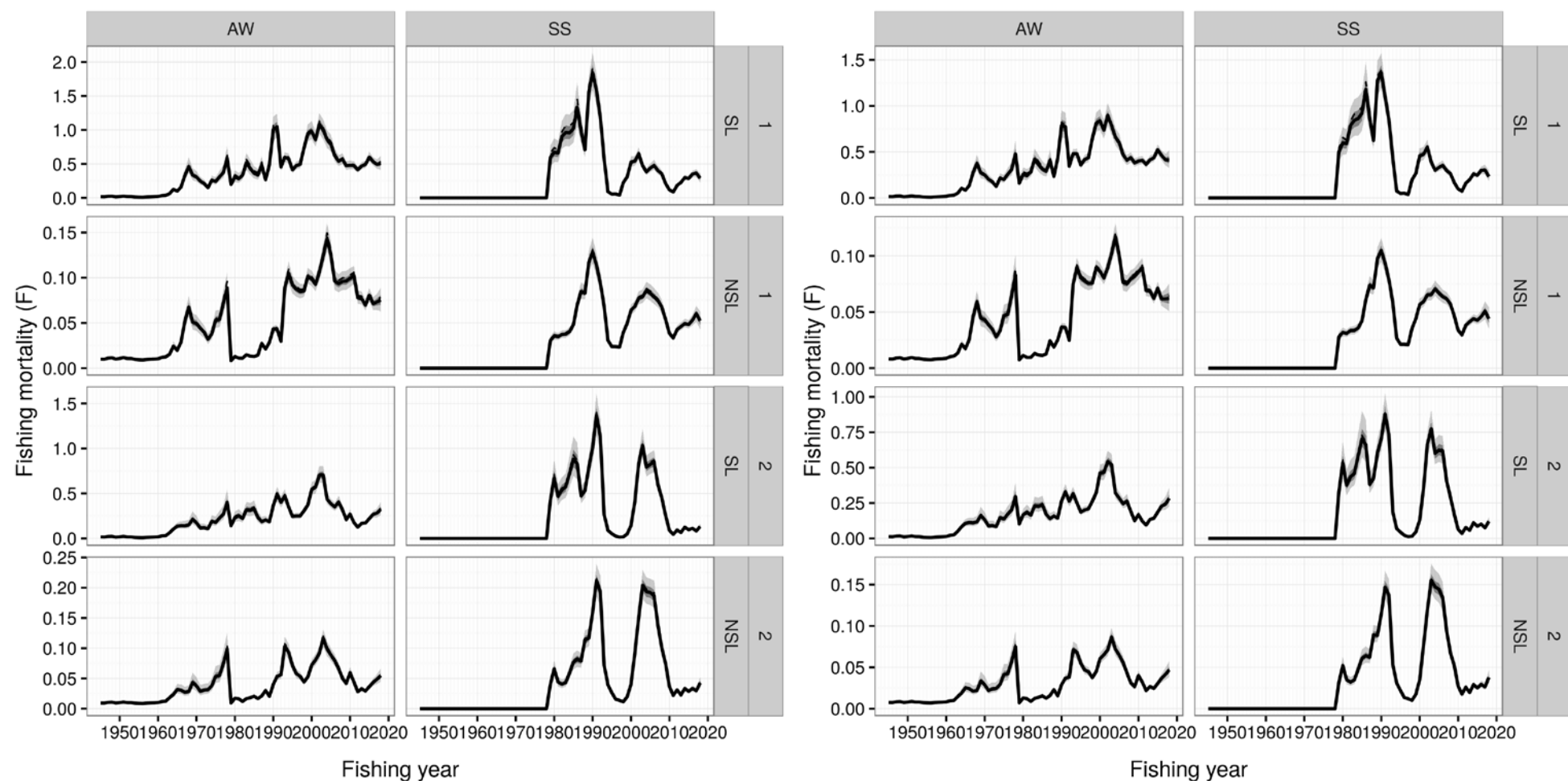
**Figure 47: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): catchability coefficient ( $q$ ) for the CELR CPUE series by fishing year, with the solid line indicating the posterior median and the variable intensity grey bands showing the 50% and 90% credible intervals.**



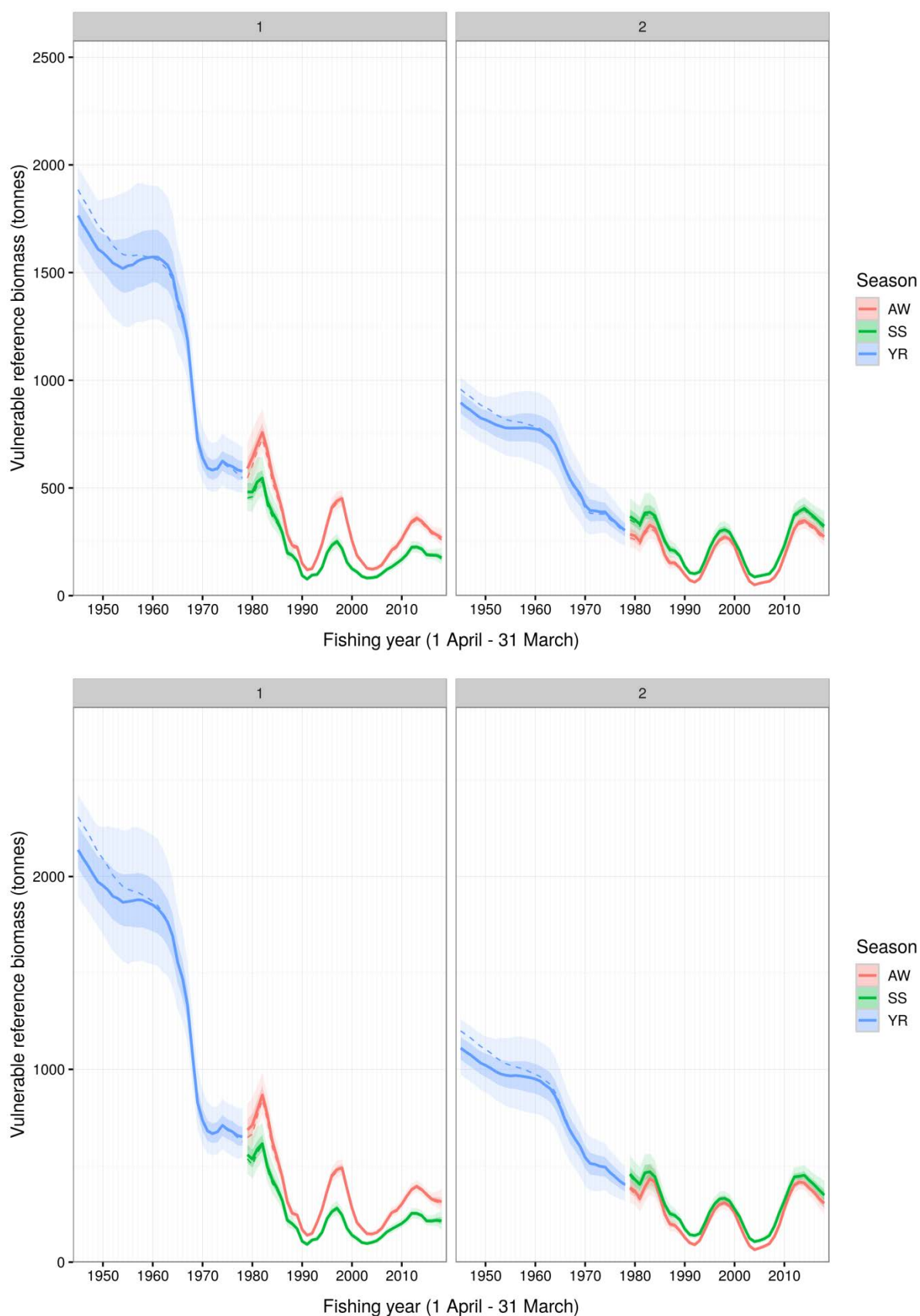
**Figure 48:** Relationship between the observed proportion of catch taken during the AW season and the standardised AW CPUE. The red line shows a predictive logistic regression ( $r^2 = 0.04$ ) and the grey points are simulations from the logistic regression. The green line shows the predictive linear regression for comparison.



**Figure 49: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): recruitment in millions of individuals, where the dashed black line indicates the MAP, the solid black line indicates the median of the posterior, and variable shading intensity indicates the 50% and 90% credible intervals. The horizontal solid green line is the median of the posterior for  $R_0$  with green shading indicating the 50% and 90% credible intervals for  $R_0$ , and the dashed green line is the MAP for  $R_0$ . The vertical dashed line is the final year of the reconstruction period. Projection recruitments (plotted to the right of the vertical dashed line) are based on the mean and standard deviation of the 2007–2016 recruitment and the 1945–2016 estimated autocorrelation.**

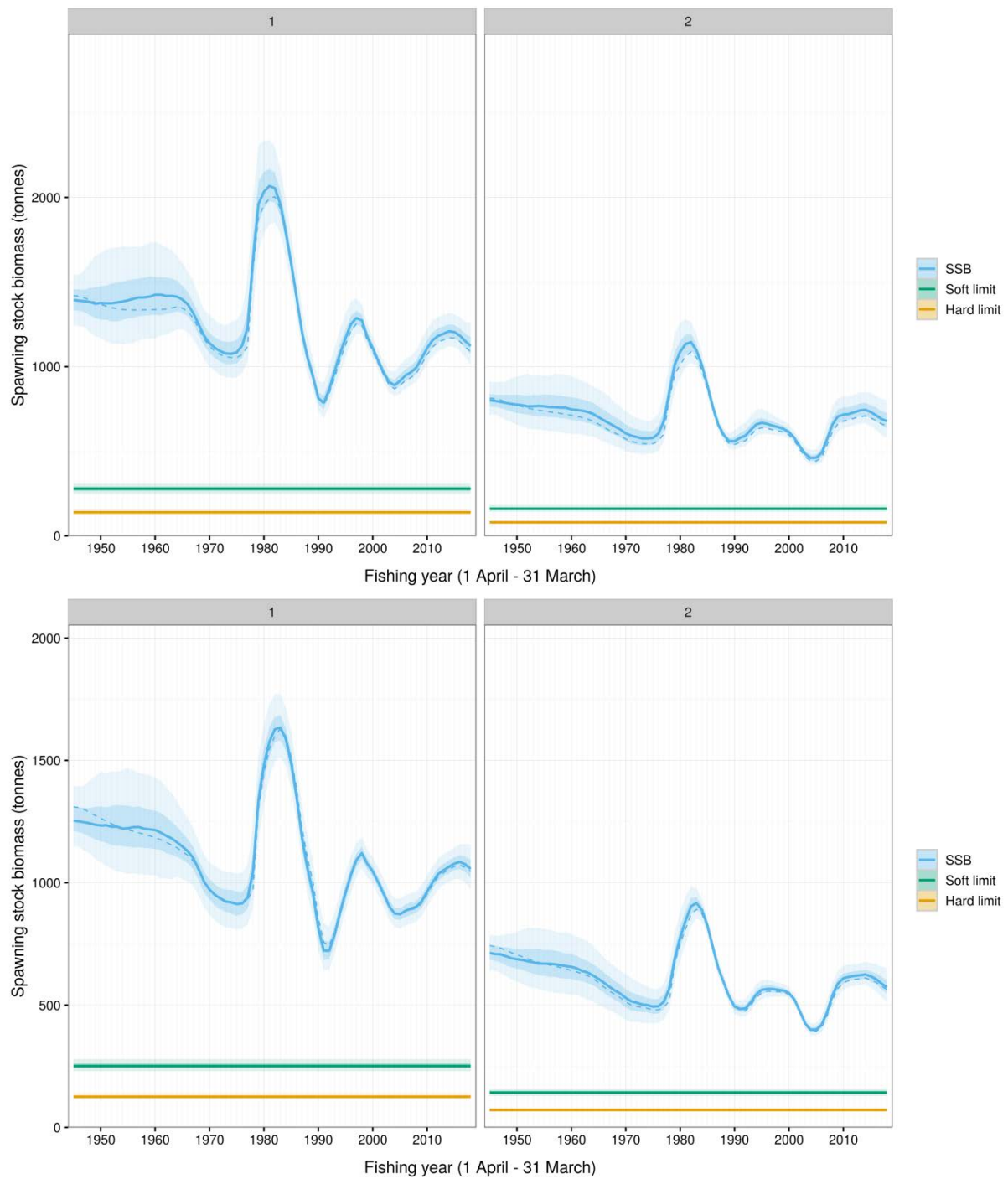


**Figure 50: CRA 3 MCMC  $r1\_qdrift$  (left) and  $r2\_qdrift$  (right): fishing mortality by year, season, region (1 = 909+910, 2 = 911), and fishery (SL = size limited, NSL = non size limited), with the dashed black line (not visible) indicating the MAP, the solid black line indicating the median of the posterior and variable shading intensity indicating the 50% and 90% credible intervals.**

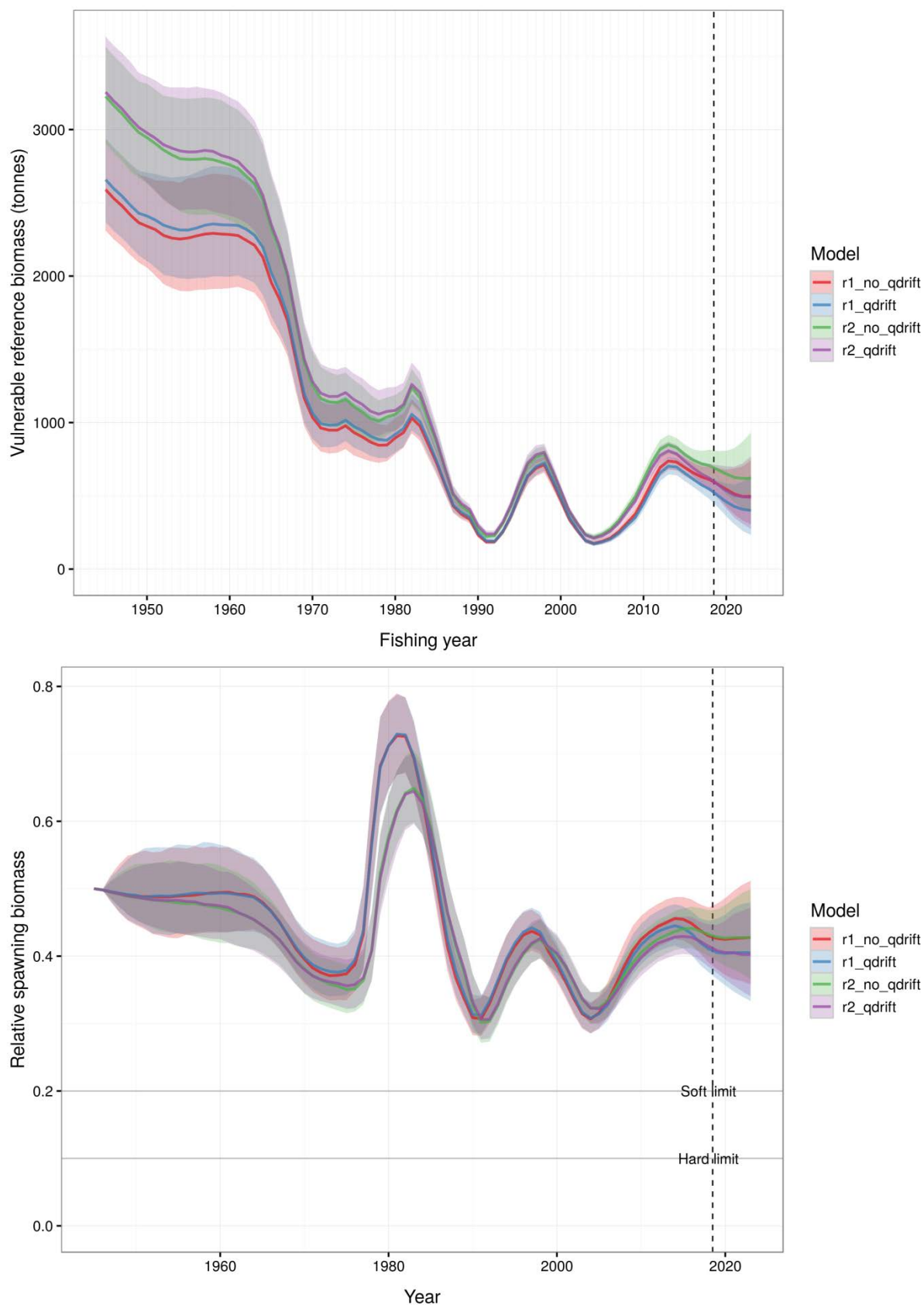


**Figure 51: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): posterior distribution of the vulnerable reference biomass by region (1=909+910, 2=911), season, and year with dashed lines indicating the equivalent MAP estimates. Variable shading intensity indicates the 50% and 90% credible intervals.**

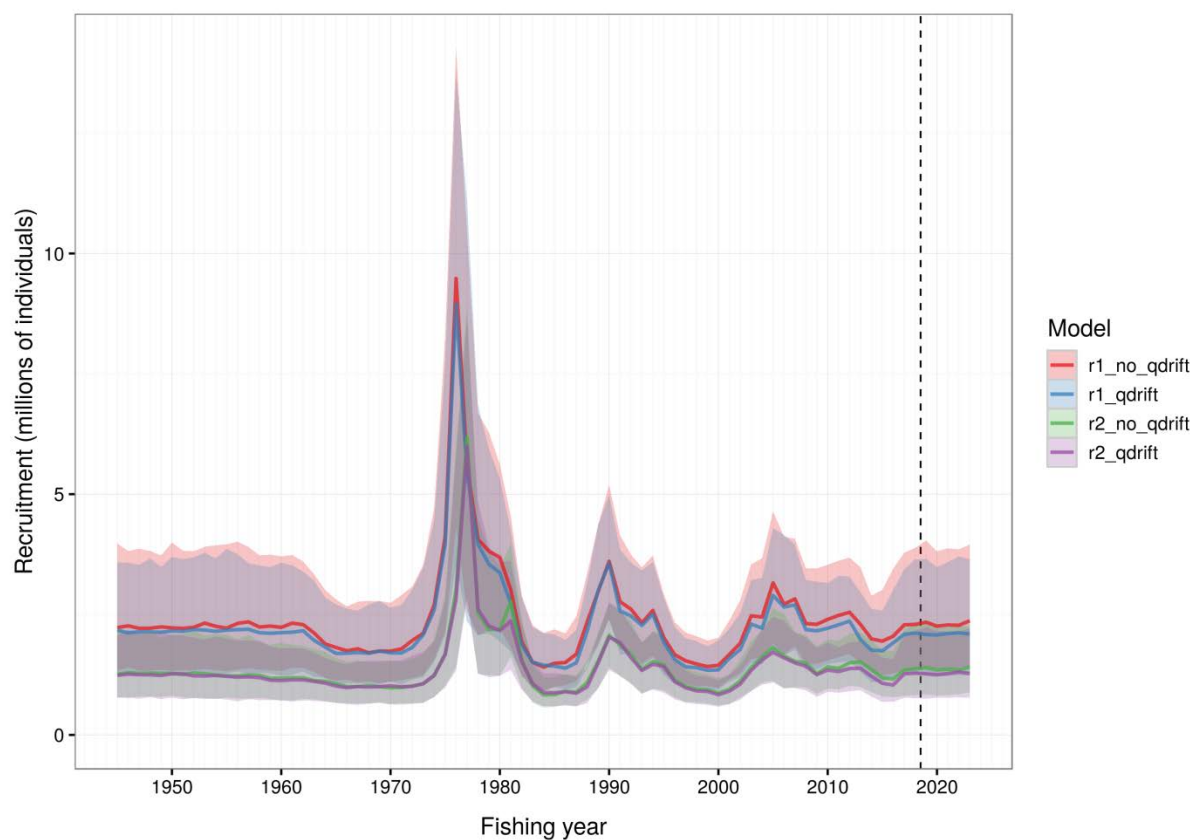




**Figure 52: CRA 3 MCMC  $r1\_qdrift$  (top) and  $r2\_qdrift$  (bottom): posterior distribution of spawning stock biomass (SSB) by region (1=909+910, 2=911), with dashed lines indicating the equivalent MAP estimates. Variable shading intensity indicates the 50% and 90% credible intervals.**



**Figure 53: CRA 3 projection: vulnerable reference biomass (top) and relative spawning stock biomass (bottom) trajectories including projections beyond the dashed vertical line.**



**Figure 54: CRA 3 projection: comparison of recruitment trajectories between the base run and the MCMC sensitivities including projections beyond the dashed vertical line.**

## APPENDIX 1 – EXPLORATION OF A POTENTIAL SOURCE OF BIAS IN GROWTH ESTIMATES

### Background

Red rock lobster stock assessment model estimates of growth-at-size are primarily informed by tag-based growth increment data (Fisheries New Zealand 2019). Since 2006, all assessments have assumed continuous growth. All assessments since 2015 have used all recaptures with at least one day at liberty, i.e. essentially all first-time recaptures were included in growth estimates, regardless of how long they had been at liberty. This facilitates the estimation of observation error (*Gobs*) by the stock assessment model, which can be informed by repeated measurements of the same individual across short time periods.

However, when models assume continuous growth (i.e. they do not account for seasonal moulting) and the bulk of recaptures occur after a short time at liberty, biased estimates of growth can manifest (e.g. Gardner & Mills 2013). When the timing of tag release occurs immediately prior to moulting and recaptures occur shortly after, growth rates could be overestimated. Conversely, we may underestimate growth if tag release and recapture both occur pre- or post-moulting. Previous assessments of red rock lobster growth in Tasmania have addressed these issues by using an appropriate subset of observations to ensure that moulting had occurred (e.g. Buxton et al. 2006).

Also, following the recommendation of Punt et al. (1997), recent New Zealand red rock lobster assessments have only used first-time recaptures (i.e. they have excluded subsequent release-recaptures of individual lobsters). Punt et al. (1997) reasoned that slower growth from subsequent recaptures occurred because the first recapture would be more likely to be under the minimum legal size and would consequently be more likely to be slower growing individuals. Figure 44 demonstrates this effect for this assessment, with negative growth residuals for all males in subsequent recaptures and for females using the *r2* (all tags) data set (there are very few female recoveries in the *r1* data set).

The analysis presented here starts with an assessment of juvenile growth rate from length-frequency data, which can be used to ‘sanity-check’ growth rate estimates using tagging data. It then examines the potential for biased estimates of growth rate in red rock lobsters, focussing on CRA 1 and CRA 3. Recommendations were then made to account for potential bias.

### Juvenile growth from dive survey length-frequency sampling in CRA 3

Juvenile length-frequency observations were collected by dive surveys under Gisborne Wharf from February 1976 to October 1979 (McKoy & Esterman 1981). The length-frequency observations for each survey month were extracted from bar plots of the observations presented in Figure 2 of McKoy & Esterman (1981). Normal and mixture distributions were then fitted to the observations to identify the mean size of individual cohorts. A linear growth model was then fitted to the mean carapace length (CL) estimates of each respective cohort and used to estimate the growth rate of juvenile lobsters.

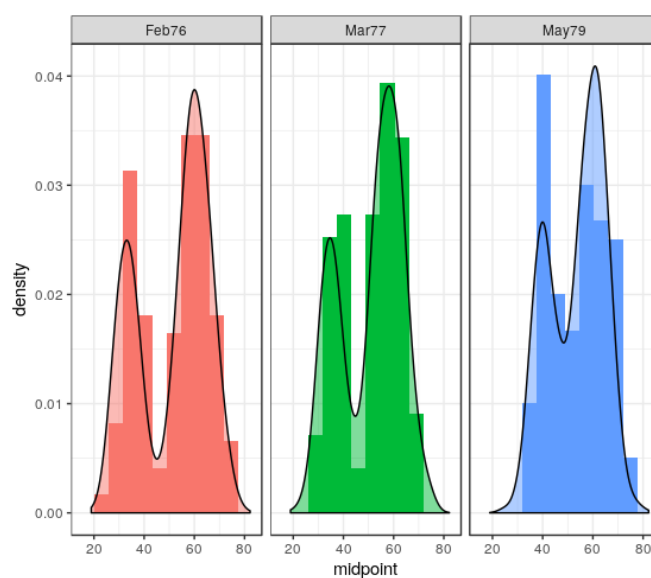
Normal and mixture distribution models produced good fits to length frequency observations (Figure A1-1 and A1-2). The mean values of each fitted distribution were then assigned to one of four clearly-definable cohorts for which a clear progression in size across the study period (Figure A1-3). Good fits were then obtained for the linear growth model to the estimated means of each cohort (Figure A1-3).

The growth model produced an annual growth increment estimate of 15.9 mm CL for juveniles from 25-60 mm CL. This annual growth is within the range of estimates from other studies on juvenile *J. edwardsii*, for example:

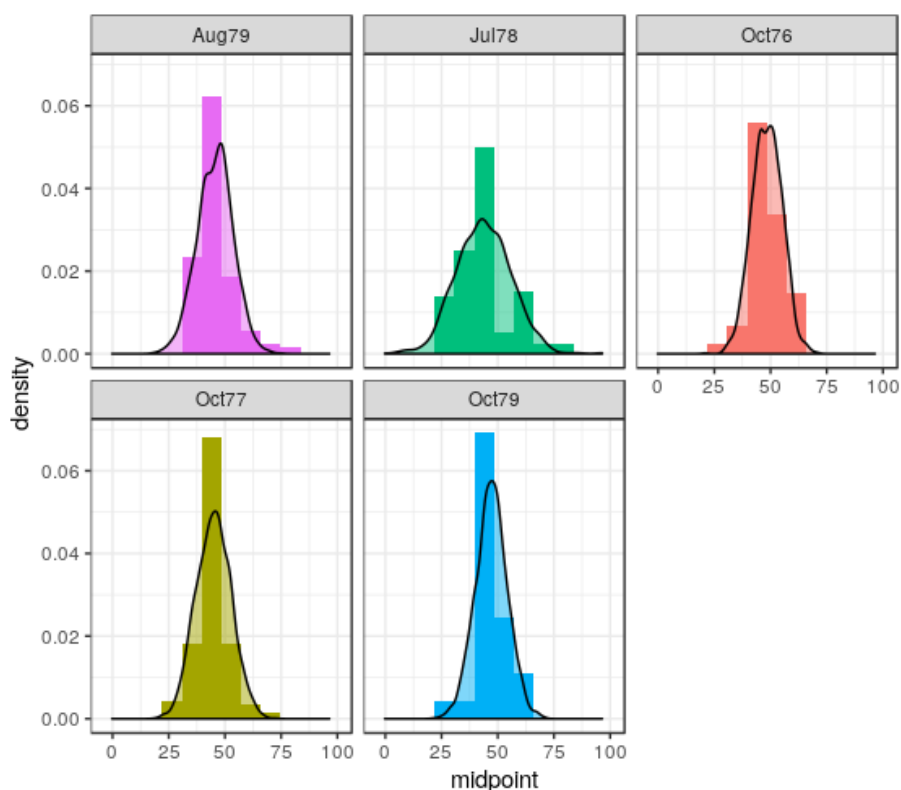
- At Gisborne Wharf (using the same data as the analysis above), where males and females combined grew ~20 mm CL between ages 1-2 years post settlement as pueruli (McKoy & Esterman 1981);

- At Stewart Island, where males grew  $\sim 35$  mm in CL and females grew  $\sim 33.5$  mm in CL between ages 1-3 years post-settlement as puereli, or  $\sim 17$  mm CL  $\text{yr}^{-1}$  (Annala & Bycroft 1985);
- Across the species' range in Australia, from  $16.8\text{-}19.7$  CL  $\text{yr}^{-1}$  for males and  $10.0\text{-}14.1$  CL  $\text{yr}^{-1}$  for females, both at 60 mm CL (Linnane et al. 2011).

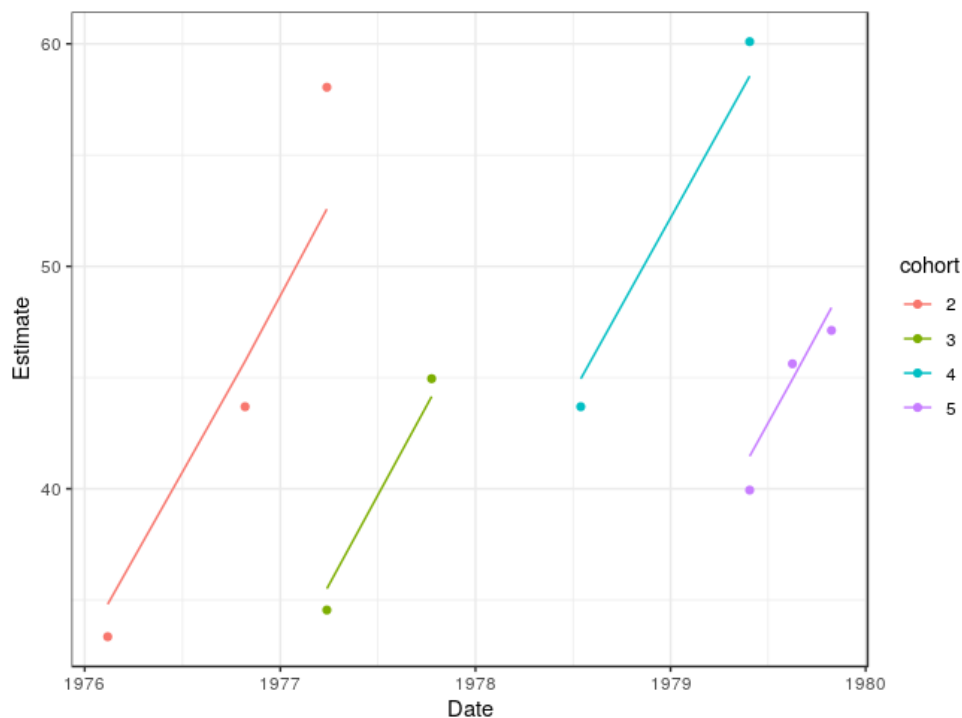
Since carapace length is close to double the tail width (TW) measurement for red rock lobsters, the annual growth of 15.9 mm CL approximates to an annual growth of 8 mm TW for individuals up to 30 mm TW, the size at which lobsters recruit to the stock assessment model. Previous research indicates that lobsters reach 30 mm TW ( $\sim 60$  mm CL) between 2-3 years post-settlement as pueruli (Annala & Bycroft 1985; McKoy & Esterman 1981).



**Figure A1-1: Mixture model fits (curves) to carapace length frequency observations (bars) for survey months with two modal groups.**



**Figure A1-2: Normal model fits (curves) to carapace length frequency observations (bars) for survey months with a single modal group.**



**Figure A1-3: Comparison of model estimated carapace lengths of cohorts (lines) and the mean carapace lengths of modal groups estimated by normal and mixture models (points). A separate colour is used for each cohort.**

### Timing of moulting relative to tag release and recapture

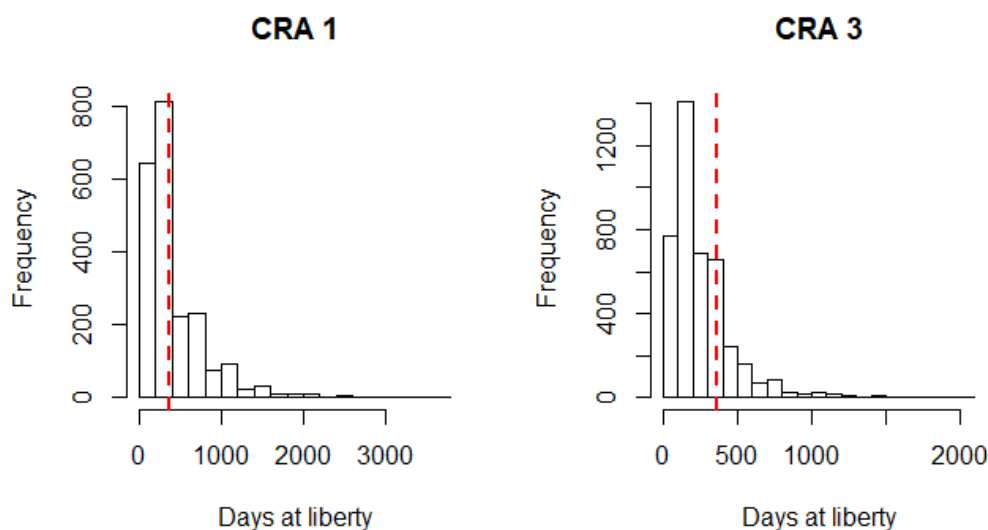
Previous research in New Zealand and Australia indicated that mature females moult approximately once each year. Depending on location, females moult between January and June (Gardner & Mills 2013; Freeman 2008; MacDiarmid 1991; McKoy & Esterman 1981). For females, moulting typically occurs less than a month prior to mating (MacDiarmid 1989).

Mature males frequently moult more than once each year, and moult frequency appears to decrease with increasing body size. For example, in CRA 3, males of 80-89 mm carapace length (CL) moulted around 1.6 times per year, compared with 1.3 to 1.5 times per year at 90-99 mm CL (depending on location) (McKoy & Esterman 1981). Regardless of size and location, Annala & Bycroft (1988) deduced that most males moult in winter, from June to August, although it was suggested that June may be too early for the start of the male winter moult, which may in fact be later in this period (Daryl Sykes, NZRLIC, pers. comm.). Smaller males may also undergo an additional spring/summer moult, which typically occurs from September-November in CRA 3 (Saila et al. 1979; McKoy & Esterman 1981; Annala & Bycroft 1988). Freeman (2008) found that males in the Te Tapuwae o Rongokako marine reserve in CRA 3 moulted from August-September. Regardless of frequency, moulting by males in CRA 3 appears to occur during an extended period from the middle of winter to the end of spring.

In both CRA 1 and CRA 3, at least half of tag releases were in the period from July to October (Table A1-1). The mean number of days at liberty for recaptures in CRA 1 and CRA 3 are 408 and 258 days, respectively (Figure A1-4). The percentage of tagged lobsters recaptured within one year of liberty was 61.3 % in CRA 1 and 78.0 % in CRA 3.

**Table A1-1: Number and proportion of tag recaptures and releases by month for CRA 1 and CRA 3. Proportions sum to 1.0 by column. At least 50% of tags were released from July to October in both CRA1 and CRA3.**

| Month | CRA 1    |            |             |            | CRA 3    |            |             |            |
|-------|----------|------------|-------------|------------|----------|------------|-------------|------------|
|       | Numbers  |            | Proportions |            | Numbers  |            | Proportions |            |
|       | Releases | Recaptures | Releases    | Recaptures | Releases | Recaptures | Releases    | Recaptures |
| Jan   | 1        | 68         | 0.00        | 0.03       | 117      | 350        | 0.03        | 0.08       |
| Feb   | 41       | 49         | 0.02        | 0.02       | 243      | 260        | 0.06        | 0.06       |
| Mar   | 129      | 14         | 0.06        | 0.01       | 362      | 181        | 0.09        | 0.04       |
| Apr   | 288      | 251        | 0.13        | 0.12       | 110      | 77         | 0.03        | 0.02       |
| May   | 37       | 139        | 0.02        | 0.06       | 286      | 125        | 0.07        | 0.03       |
| Jun   | 119      | 55         | 0.06        | 0.03       | 236      | 452        | 0.06        | 0.11       |
| Jul   | 414      | 211        | 0.19        | 0.10       | 1483     | 625        | 0.35        | 0.15       |
| Aug   | 184      | 389        | 0.09        | 0.18       | 152      | 334        | 0.04        | 0.08       |
| Sep   | 474      | 405        | 0.22        | 0.19       | 146      | 145        | 0.03        | 0.03       |
| Oct   | 354      | 422        | 0.16        | 0.20       | 607      | 307        | 0.14        | 0.07       |
| Nov   | 84       | 119        | 0.04        | 0.06       | 370      | 591        | 0.09        | 0.14       |
| Dec   | 38       | 41         | 0.02        | 0.02       | 76       | 741        | 0.02        | 0.18       |

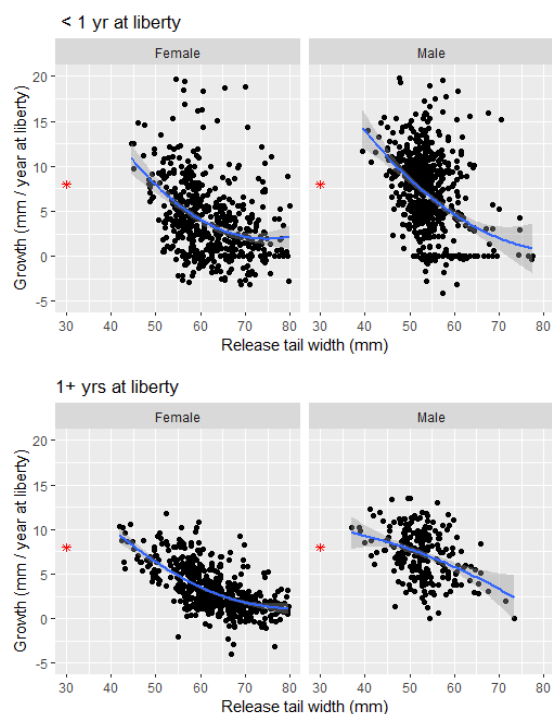


**Figure A1-4: Frequency of tag recaptures by days at liberty for CRA 1 (left) and CRA 3 (right). One year at liberty highlighted by red dashed line.**

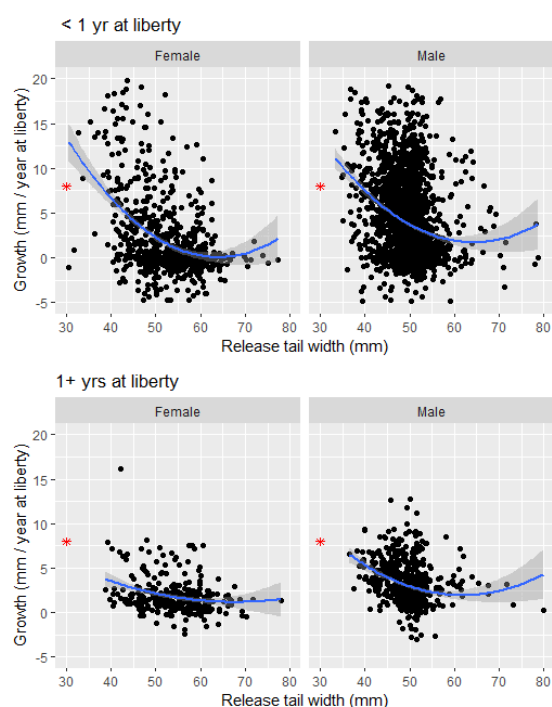
### Growth from recaptures at different periods at liberty

An exploration of the mark-recapture-based growth information was undertaken to assess the effect of alternative periods at liberty on size based growth estimates. Annualised growth (at-size) was greater for individuals that spent less than 1 year at liberty compared with 1+ years at liberty (Figures A1-5 and A1-7). This was the case for males and females in both CRA 1 and CRA 3. By limiting the data to the subset of recaptures which spent at least 1 year at liberty, estimated growth rates at smaller sizes (i.e. less than 50 mm tail width) were more consistent with the juvenile growth estimated from the preliminary analysis of juvenile length-frequency data (~8 mm TW increment at 30 mm TW) (see Figures A1-5 and A1-6).





**Figure A1-5:** Annualised growth increments for females (left) and males (right) from mark recaptures in CRA 1, spending less than (top) or at least (bottom) one year at liberty. The blue line is a loess smooth, and the associated shaded area is within 1 standard error of this smooth. The red star represents the annual growth rate at 30 mm tail width approximated from juvenile length-frequency data.



**Figure A1-6:** Annualised growth increments for females (left) and males (right) from mark-recaptures in CRA 3, spending less than (top) or at least (bottom) one year at liberty. The blue line is a loess smooth, and the associated shaded area is within 1 standard error of this smooth. The red star represents the annual growth rate at 30 mm tail width approximated from juvenile length-frequency data.

## Conclusions for stock assessment

A large number of recaptures in both CRA 1 and CRA 3 had less than one year at liberty (Figure A1-4). The bulk of tagging in these areas was in winter and early spring, at or prior to moulting for both males and females (which takes place in winter/spring [males] and late summer [females]). Because tag releases for males tended to immediately precede moulting in these two QMAs, including tags which have been at liberty for less than a year could lead to biased estimates of growth. For CRA 3, this was supported by a preliminary analysis of the mark-recapture data, which obtained faster growth from individuals recaptured after less than 1 year at liberty, for both sexes.

Unpublished simulations found that uneven tag releases (relative to moulting) can lead to a positive bias in growth parameter estimates. However, eliminating tag recaptures with a shorter time period at liberty can greatly decrease the precision of growth parameter estimates (Paul Breen, unpublished data).

Dropping tags that had been at liberty for less than one year had little impact on the estimates of growth at small sizes in CRA 1. Preliminary model runs for this stock produced almost identical estimates of growth-at-size when using either the full tag dataset, or excluding recaptures within 1 year of release. Whereas for CRA 3, initial model runs obtained a reduced growth rate at smaller tail widths when excluding recaptures within 1 year of release.

Due to this potential for biased growth estimates in CRA 3, stock assessment model runs excluding recaptures of less than one year at liberty were proposed for this stock. This would allow the completion of an annual moult cycle for each tagged individual, and would exclude growth information from individuals that moult and are then recaptured within a few days of release.

With respect to the usage of growth information after the first recapture (termed ‘subsequent’ recaptures), Punt et al. (1997) recommended not using these on the basis that this will over-represent slow growing individuals, because they were more likely to be at sub-legal size at first recapture. It is suggested that model runs initially use the full set of recaptures, and that subsequent recaptures are then removed if model residual patterns for the subsequent recapture categories consistently show slower growth.

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## APPENDIX 2 – DISCUSSION OF FISHING PATTERNS IN CRA 3 TO INFORM MODEL PARAMETERISATION

### Background

Logbook records (see Starr et al. 2020 for a description of these data) were obtained for 2288 pot lifts in CRA 3 from 2010 to 2018. Comparison of the depth range of these observations with other QMAs indicated that effort in CRA 3 tended to be shallow relative to other QMAs. Approximately 80% of pot lifts in the CRA 3 logbook sample were at depths less than 20 m, compared with ~20% in CRA 1, ~65% in CRA 2, and ~50% in CRA 4. The shallow nature of the fishery in CRA 3 has also been corroborated from anecdotal reports by fishers operating in CRA 3, which also indicated that pre-moulting males are the primary target.

This analysis considers some of the potential issues for the CRA 3 stock assessment that may result from the particular fishing patterns in this QMA. It also explores some of the model fitting issues that could result from changes in fishing patterns through time, and some options for addressing these issues in the stock assessment model.

The analysis begins with a description of seasonal moulting migrations of the lobsters and how these relate to seasonal patterns of effort in the fishery through time.

### Annual moulting and spawning migrations

Previous research at Leigh indicated that mature *Jasus edwardsii* of both sexes migrate into shallow reef areas to moult (< 10 m depth for females and < 17 m depth for males) (MacDiarmid 1991). Most mature males moult in winter (Annala & Bycroft 1988), which is when they are likely to be most abundant over shallow reef areas (MacDiarmid 1991). In addition, males may also undergo an additional spring/summer moult, which typically occurs from September–November in CRA 3 (Annala & Bycroft 1988). Mature females moult between January and June (Gardner & Mills 2013; Freeman 2008; MacDiarmid 1991; McKoy & Esterman 1981).

### Seasonal patterns in fishing effort

The temporal pattern of fishing effort is very similar across all statistical areas of CRA 3, with respect to changes in the distribution of effort by month since 1979–80 (Figure A2-1). The general pattern is as follows:

- From 1979–80 to 1992–93, the peak in fishing effort was from Oct–Jan;
- From 1993–94 to 2001–02, the peak in fishing effort moved to Jun–Aug, in response to a seasonal closure from 1 September to 15 January, along with a winter reduction in the MLS for males from 54 to 52 mm TW. This reduction was made to encourage fishing of smaller males in the winter months;
- From 2002–03 to 2008–09 (2009–10 in statistical area 911), there a peak in fishing effort remained in Jun–Aug, although fishing recommenced in Sep–Jan in response to the removal of the seasonal fishing restriction; and
- From 2009–10 (2010–11 in statistical area 911) to 2018–19, effort was relatively even across all months, except for Sep–Dec in statistical areas 909 and 910, which had few pot lifts.

The seasonal pattern of catch sampling through time (in terms of the number of lobsters sampled) approximately follows the pattern in fishing effort, though with greater variability between years resulting from uneven lobster sampling relative to fishing effort (Figure A2-2). One major difference was additional contracted lobster sampling in November in statistical area 910 from 1993–94 to 2001–02 when the seasonal closure was in place. With this exception, there was a shift in the seasonal timing of lobster sampling from spring/summer to autumn in response to the seasonal fishery closure from 1993–94 to 2001–02. This shift in sampling effort was the direct result of the design of this programme, which was to monitor the length distribution of the catch.

The autumn peak in fishing effort and catch sampling since 1993–94 coincides with the period when mature males have migrated into shallow reef areas to moult. As such, fishery-dependent lobster data collected since then would tend to over-represent mature males, relative to the wider population. Prior to 1993–94, a much greater proportion of fishing effort occurred later in the fishing year and could thus reasonably have had a greater proportion of females and immature individuals in the catch (Figure A2-1).

### Temporal patterns in stock assessment model residuals

Initial model runs for the current CRA 3 assessment obtained the following temporal patterns in model residuals:

- Size-based growth increments are consistent with a reduction in growth rate across the period over which the tagging data are informative (from 1975–76 to 2017–18);
- The size composition of mature females was poorly estimated in all years and seasons prior to 1994–95.

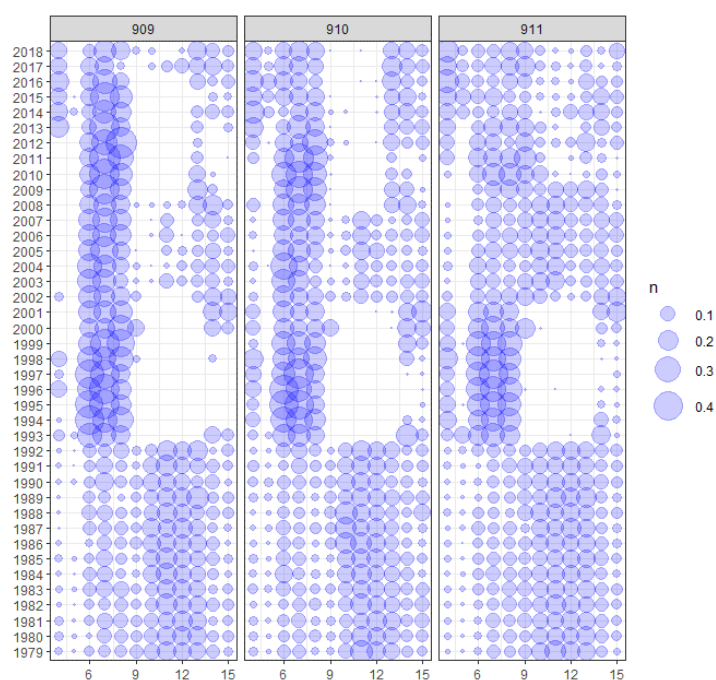
The abrupt changes in residual patterns in model fits to sex ratio and female size composition data coincide with a shift in seasonal fishing patterns since 1993–94. The increased proportion of females in the catch prior to 1993–94 may be explained by the relatively high proportion of fishing effort in later summer and autumn (Figure A2-1), outside of the period when most males move to shallow waters prior to moulting (MacDiarmid 1989 and 1991). The apparent shifts in mature female size composition are not so readily explainable, but may also relate to the seasonality of fishing relative to the timing of females moulting and reproductive cycles, which appear to vary with size (McKoy & Esterman 1981), or to active avoidance by the fishery of mature (ovigerous) females.

### Conclusions for stock assessment

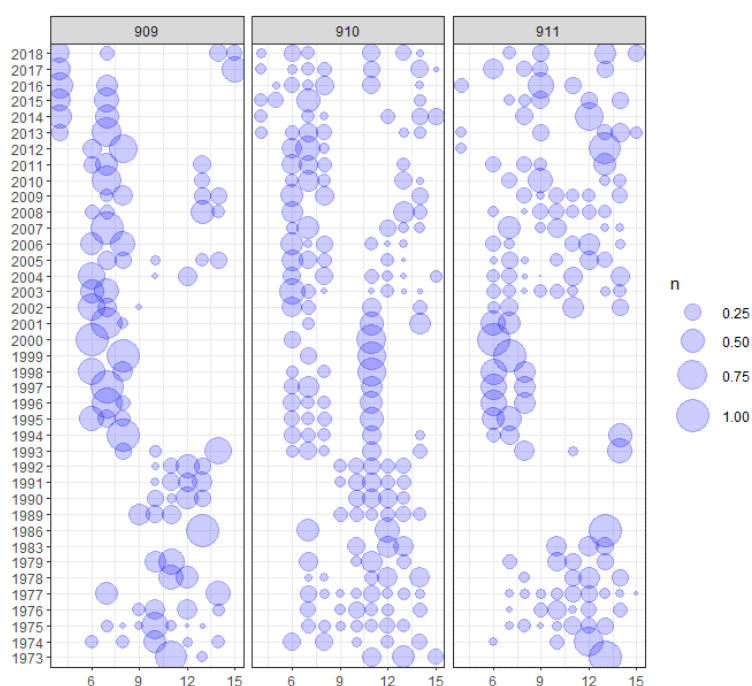
Based on the review of the information presented above, a number of modifications to the CRA 3 stock assessment model structure were trialled:

- Trends in tag-based growth increment residuals suggest a decrease in growth rate across the time series. Previous CRA 3 stock assessments have estimated growth rate separately for different year periods (termed growth ‘stanzas’) (Haist et al. 2015). However, the residual patterns may be explained by the shift in seasonal fishing patterns and catch sampling since 1993–94 (and an associated shift in the moult or maturity stage of the lobster being captured), rather than any true shift in growth rate. As such, the updated CRA 3 assessment did not estimate growth parameters separately for different year periods.
- Poor fits to the catch size composition samples of mature females in the early part of the time series may be explained by different fishing patterns in the period prior to 1993–94 or possible active avoidance of mature females. As such, the updated CRA 3 assessment trialled separate female selectivity parameters for the period prior to 1993–94. Future assessments could consider the development of standardised length-frequency time series.
- Early model runs obtained an implausible maturation-at-length ogive for females (more than 90% becoming mature at 40 mm tail width). Logbook records indicate that fishing in statistical areas 909 and 910 (Region 1 of the current assessment) catches a lower proportion of females than in statistical area 911 (Region 2), and that ~ 80% of effort is shallower than 20 m depth (RLFAWG, unpublished data) at the depth range that mature females congregate prior to moulting (MacDiarmid 1991). As a measure to generate more plausible female maturation-at-length ogives, female selectivity ogives were estimated separately for Region 1 and Region 2 in the current assessment.

The shift in model catch sex ratio residuals (also since 1993–94) may also be better explained by the abrupt shift in fishing patterns at that time, rather than a shift in the sex ratio of the underlying population. There may be other issues for stock assessment model fitting associated with the narrow seasonal period of fishery-dependent data. For example, the tag-based growth information could be biased if it is disproportionately representative of mature individuals relative to the underlying population. Some of these issues could be addressed by alternative model parameterisations, where this is supported by other information (e.g. changes in seasonal or bathymetric fishing patterns).



**Figure A2-1: Monthly potlifts as a proportion of total for the fishing year, by statistical area for CRA 3 (FSU and CELR records). Note that fishing months Jan-Mar (at the end of the fishing year) are labelled 13 to 15, respectively.**



**Figure A2-2: Monthly lobsters sampled as a proportion of the total for the fishing year, by statistical area for CRA 3 (rlcs records). Note that fishing months Jan-Mar (at the end of the fishing year) are labelled 13 to 15, respectively.**

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## APPENDIX 3 – PERCENTAGE OF CRA 3 PRODUCTIVITY WITHIN THE TE TAPUWAE O RONGOKAKO MARINE RESERVE

### Background

Commercial and recreational lobster fishing is not permitted within the Te Tapuwae o Rongokako Marine Reserve located within CRA 3 (Figure A3-1). The previous CRA 3 stock assessment model accounted for the reserve by excluding 10% of the recruitment, based on the proportion of the catch historically taken within the reserve (Fisheries New Zealand 2018, Haist et al. 2015).

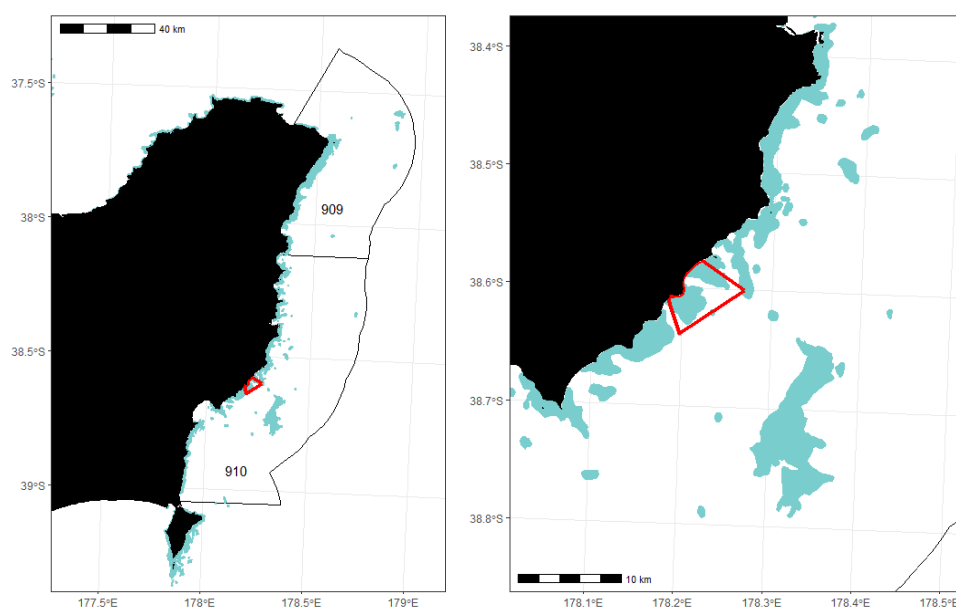
A more quantitative representation would be to base this on the relative size of rocky reef area (the preferred habitat of red rock lobsters), rather than on an approximation based on undocumented historical catch, which may also vary in response to spatial population status, accessibility, or the economics of the fishery.

### Reef habitat within the marine reserve

The Department of Conservation (DOC) provided (on 11 October, 2019) a shapefile “Rocky\_reef\_National\_NZ” that maps areas of predicted rocky reef habitat (shallower than 50 m), based on expert knowledge and the analysis of hydrographic faring sheets (DOC unpublished data) (Figure A3-1). The 50 m extent of this shapefile should encompass the majority of rock lobster habitat that is associated with CRA 3 recruitment.

The revised CRA 3 stock assessment has a separate recruitment time series for statistical areas 909 and 910 (Region 1), and statistical area 911 (Region 2). We require the percentage of reef area across Region 1 that is within the reserve. This was obtained using the “st\_area” function in R package “sf”, which returns the spatial extent of a polygon in m<sup>2</sup> (Pebesma 2018; R Core Team 2019). The total rocky reef habitat area in CRA 3 (shallower than 50 m) was 420.19 km<sup>2</sup>, of which 13.48 km<sup>2</sup> (3.21%) was inside the marine reserve.

Based on this analysis, the CRA 3 stock assessment decremented the estimated recruitment for Region 1 by 3.2%, beginning in 1999.



**Figure A3-1: Location of the Te Tapuwae o Rongokako Marine Reserve (red box), and spatial extent of rocky reef habitat (blue shaded polygons).**

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