2020 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Executive Summary

1. Stock: species/area.
Southern Tanner crab (*Chionoecetes bairdi*) in the eastern Bering Sea (EBS).

2. Catches: trends and current levels.
Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The NPFMC annually determines the overfishing limit (OFL) and acceptable biological catch (ABC) levels for Tanner crab in the EBS, while the Alaska Department of Fish and Game (ADFG) determines the total allowable catch (TAC) separately for areas east and west of 166ºW longitude in the Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J. Following rationalization of the Bering Sea and Aleutian Islands (BSAI) crab fisheries in 2005/06, the directed fishery for Tanner crab was open through 2009/10, after which time it was determined that the stock was overfished in the EBS and directed fishing was closed. Prior to the closure, the retained catch averaged 770 t per year between 2005/06-2009/10. The directed fishery was re-opened in 2013/14 following determinations by NMFS in 2012 that the stock was rebuilt and no longer overfished and by ADFG that the stock met state harvest guidelines for opening the fishery. ADFG set the TAC at 1,645,000 lbs (746 t) for the area west of 166º W and at 1,463,000 lbs (664 t) for the area east of 166º W. On closing, 79.6% (594 t) of the TAC was taken in the western area while 98.6% (654 t) was taken in the eastern area.

TACs were steadily increased for the next two years, with concomitant increasing harvests. In 2014/15, TAC was set at 6,625,000 lbs (2,329 t) for the area west of 166º W and at 8,480,000 lbs (3,829 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. In 2015/16, TAC was set at 8,396,000 lbs (3,808 t) for the western area and 11,272,000 lbs (5,113 t) for the eastern area. On closing, essentially 100% of the TAC was taken in both areas (8,373,493 lbs [3,798 t] in the western area, 11,268,885 lbs [5,111 t] in the eastern area based on the 5/20/2016 in-season catch report).

Although the NPFMC determined an OFL of almost 60,000,000 lbs (~25,000 t) based on the 2016 assessment (Stockhausen, 2016), mature female Tanner crab biomass fell below the threshold set in the State of Alaska's harvest strategy for opening the fishery; consequently, the fishery was closed and the TAC was set to 0. Thus, no directed harvest occurred in 2016/17. In 2017/18, ADFG determined that a directed fishery could occur in the area west of 166ºW longitude. The TAC was set at 2,500,200 lbs (1,130 t), of which 100% was taken. A similar situation occurred in 2018/19, with only the area west of 166ºW open to directed fishing. The TAC for 2018/19 was 2,439,000 lbs (1,106 t), with slightly more actually harvested (2,441,201 lbs [1,107 t]). Mature female biomass again fell below State of Alaska's threshold for opening the 2019/20 Tanner crab fishery (The 2019/20 OFL was 63,620,000 lbs [28,860 t]) and no directed occurred in 2019/20.

In addition to legal-sized males, females and sub-legal males are taken in the directed fishery as bycatch and must be discarded. Discarding of legal-sized males also occurs, primarily because the minimum size preferred by processors is larger than the minimum legal size but also because “old shell” crab can be less desirable than “new shell” males. No bycatch occurred in the directed fishery in 2019/20, of course, because it was closed. The average bycatch over the last five years the fishery was open (i.e., since 2013/14) in the directed fishery was 1,396 t. Tanner crab are also taken as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a very minor extent, in the scallop fishery. Over the last five years, the snow crab fishery has been the major source of Tanner crab bycatch among these fisheries, averaging ~1,900 t for the 5-year period 2015/16-2019/20. Bycatch in the snow crab fishery in 2019/20 was 1,018 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 229 t. Bycatch in the groundfish fisheries in 2019/20 was 148 t. Excluding the scallop fishery, the Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 134 t over the 5-year time period. In 2019/20, this fishery accounted for only 18 t of Tanner crab bycatch.

In order to account for mortality of discarded crab, handling mortality rates are assumed to be 32.1% for Tanner crab discarded in the crab fisheries, 50% for Tanner crab in the groundfish fisheries using fixed gear, and 80% for Tanner crab discarded in the groundfish fisheries to account for differences in gear and handling procedures used in the various fisheries.

3. Stock biomass: trends and current levels relative to virgin or historic levels
For EBS Tanner crab, spawning stock biomass is expressed as mature male biomass (MMB) at the time of mating (mid-February). From the author’s preferred model (20.07), estimated MMB for 2019/20 was 56.1 thousand t (Table 30). MMB has been on a declining trend since 2014/15 when it peaked at 131.7 thousand t, and it is approaching the very low levels seen in the mid-1990s to early 2000s (1993 to 2003 average: 55.1 thousand t).

4. Recruitment: trends and current levels relative to virgin or historic levels.
From the author’s preferred model (20.07), the estimated total recruitment for 2020 (the number of crab entering the population on July 1) is 274.5 million crab (Table 33). However, this estimate is uninformed by data because the 2020 NMFS EBS shelf bottom trawl survey was canceled due to safety concerns associated with the COVID-19 pandemic. As such, it is highly uncertain. More believable, but still fairly uncertain, last year’s estimated recruitment of 1193.6 million crab was the highest since 2008. Average recruitment over the previous 10 years is 398 million crab, which is slightly above the longterm (1982+) mean of 370 million crab.

5. Management performance
Historical status and catch specifications for eastern Bering Sea Tanner crab, with 2020/21 values based on the author’s recommended model, 20.07, and MCMC results.

(a) in 1000’s t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	14.58	77.96	0.00	0.00	1.14	25.61	20.49
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.31	56.15	0.00	0.00	0.54	28.86	23.09
2020/21		35.31				20.88	16.70

(b) in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	32.15	171.87	0.00	0.00	2.52	56.46	45.17
2017/18	33.40	95.49	2.50	2.50	5.22	56.03	44.83
2018/19	45.27	182.09	2.44	2.44	4.18	46.01	36.82
2019/20	40.36	123.77	0.00	0.00	1.20	63.62	50.89
2020/21		77.84				46.02	36.82

Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for retained catch and total catch mortality.

6. Basis for the OFL

a) in 1000's t.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY}	F_{OFL} (yr^{-1})	Years to define B_{MSY}	Natural Mortality (yr^{-1})
2016/17	3a	25.65	45.34	1.77	0.79	1982-2016	0.23
2017/18	3a	29.17	47.04	1.49	0.75	1982-2017	0.23
2018/19	3a	21.87	23.53	1.08	0.93	1982-2018	0.23
2019/20	3b	41.07	39.55	0.96	1.08	1982-2019	0.23
2020/21	3b	36.62	35.31	0.96	0.93	1982-2019	0.23

b) in millions lbs.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY}	F_{OFL} (yr^{-1})	Years to define B_{MSY}	Natural Mortality (yr^{-1})
2016/17	3a	56.54	99.95	1.77	0.79	1982-2016	0.23
2017/18	3a	64.30	103.70	1.49	0.75	1982-2017	0.23
2018/19	3a	48.21	51.87	1.08	0.93	1982-2018	0.23
2019/20	3b	90.53	87.18	0.96	1.08	1982-2019	0.23
2020/21	3b	80.72	77.84	0.96	0.93	1982-2019	0.23

Notes: Values are calculated from the assessment reviewed by the Crab Plan Team in 20XX of 20XX/(XX+1) or based on the author's preferred model for 2020/21. Values for natural mortality are nominal. Actual rates used in the assessment are estimated and may be different.

Current male spawning stock biomass (MMB), as projected for 2020/21, is estimated at 35.31 thousand t. B_{MSY} for this stock is calculated to be 36.62 thousand t, so MSST is 18.31 thousand t. Because current MMB > MSST, **the stock is not overfished**. Total catch mortality (retained + discard mortality in all fisheries, using a discard mortality rate of 0.321 for pot gear and 0.8 for trawl gear) in 2019/20 was 0.54

thousand t, which was less than the OFL for 2019/20 (28.86 thousand t); consequently, **overfishing did not occur**. The OFL for 2020/21, based on the author's preferred model (20.07), is 20.88 thousand t. The ABC_{max} for 2020/21, based on the p^* ABC, is 20.87 thousand t. In 2014, the SSC adopted a 20% buffer to calculate ABC for Tanner crab to incorporate concerns regarding model uncertainty for this stock. Based on this buffer, the ABC would be 16.70 thousand t.

7. Rebuilding analyses summary.
The EBS Tanner crab stock was found to be above MSST (and B_{MSY}) in the 2012 assessment (Rugolo and Turnock, 2012b) and was subsequently declared rebuilt. The stock remains not overfished. Consequently, no rebuilding analyses were conducted.

A. Summary of Major Changes

1. Changes (if any) to the management of the fishery.
The SOA's harvest control rule (HCR) for setting TAC in the directed Tanner crab fisheries has undergone three revisions in the past 6 years (Daly et al., 2020). In 2015, the minimum preferred harvest size used to compute TAC for the area east of 166ºW longitude was changed from 140 mm CW (5.5 inches; including the lateral spines) to 127 mm CW (5.0 inches), the preferred size used to compute TAC for the area west of 166ºW longitude. In 2017, the criteria used to determine mature female biomass (MFB) was changed from an area-specific one based on carapace width to one based on morphology (the same as that used by the NMFS EBS shelf bottom trawl survey), the definition of 'long-term average' for calculating average mature biomass was changed from 1975-2010 to 1982-2016, the spatial range for calculating average MFB was expanded to include the entire NMFS EBS shelf bottom trawl survey area, and a so-called 'error band system' was introduced to account for survey uncertainty such that the exploitation rate on industry-preferred males used to calculate was gradually reduced when the lower 95% confidence interval of the point estimate of MFB fell below 40% of the long-term average (replacing a requirement to close the fisheries when MFB fell below the 40% threshold; ADF&G, 2017; Daly et al., 2020). In March 2020, the harvest control rule was again changed based on results from an extensive management strategy evaluation (MSE) conducted with input from industry stakeholders, NMFS and academic scientists, and ADF&G managers (Daly et al., 2020). The current HCR (HCR 4_1 in Daly et al., 2020) defines the period for calculating average mature biomass as 1982-2018 and implements sliding scales for exploitation rates on mature males which are functions of the ratios of MMB and MFB to their longterm averages.

The directed Tanner crab fishery east of 166ºW longitude has been closed since 2016/17 because mature female Tanner crab biomass in the area has failed to meet the criteria defined in the SOA's harvest strategy to open the fishery. The directed fishery west of 166ºW longitude was also closed in 2016/17, but was prosecuted in 2017/18 and 2018/19. It was closed, as well, in 2019/20.

2. Changes to the input data
Due to safety concerns associated with the COVID-19 pandemic, the 2020 NMFS EBS shelf bottom trawl survey was cancelled. In addition, the directed fisheries for Tanner crab were closed by SOA regulation (estimated mature female biomass failed to meet the criteria for opening the fisheries). Thus, the changes to the input data to the assessment consisted mainly of finalized catch data for 2018/19 and new bycatch data for 2019/20. However, estimated bycatch abundance and biomass in the groundfish fisheries for 2016/17-2018/19 also changed because AKFIN updated the algorithms it uses to calculate the estimate to match those the NMFS Alaska Regional Office uses to calculate Prohibited Species Catch (PSC) estimates. The following table summarizes data sources that have been updated for this assessment:

Updated data sources.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	no 2020 survey	NMFS
	size compositions	1975-2019	no 2020 survey	
	male maturity data	2006+	no new data	
NMFS/BSFRF	molt-increment data	2015-17, 2019	no new data	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	no new data	BSFRF
	size compositions	2013-17	no new data	
Directed fishery	historical retained catch (numbers, biomass)	1965/66-1996/97	not updated	2018 assessment
	historical retained catch size compositions	1980/81-2009/10	not updated	2018 assessment
	retained catch (numbers, biomass)	2005/06-2018/19	fisheries closed 2019/20	ADFG
	retained catch size compositions	2013/14-2018/19	fisheries closed 2019/20	ADFG
	total catch (abundance, biomass)	1991/92-2018/19	fisheries closed 2019/20	ADFG
	total catch size compositions	1991/92-2018/19	fisheries closed 2019/20	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Groundfish Fisheries (all gear types)	historical total bycatch (abundance, biomass)	1973/74-1990/91	not updated	2018 assessment
	hostorical total bycatch size compositions	1973/74-1990/91	not updated	
	total bycatch (abundance, biomass)	1991/92-2019/20	now using AKRO algorithm for 2016/17+	NMFS/AKFIN
	total bycatch size compositions	1991/92-2019/20		

3. Changes to the assessment methodology.

The assessment model framework, TCSAM02, is described in detail in Appendix 1. The model accepted for the 2019 assessment, “19.03” (referred to as M19F03 in the 2019 SAFE chapter), differed rather substantially from the 2017 and 2018 assessment models by: 1) adding a likelihood component to fit annual male maturity ogives determined from chela height-to-carapace width ratios in the NMFS survey; 2) eliminating fits to survey biomass and size composition data for male crab classified as mature/immature based on a maturity ogive determined outside the model; and 3) instead fitting to time series of undifferentiated male survey biomass, abundance, and size compositions. In addition, this scenario fit revised time series data for retained and total catch biomass since 1990/91 provided by ADFG for the directed Tanner crab, snow crab and Bristol Bay red king crab fisheries. The model scenario 19.03(2020) is the base model for this assessment, and represents last year’s assessment model, 19.03, with the addition of fishery data for 2019/20.

The additional uncertainty introduced into the assessment due to the lack of a 2020 NMFS EBS shelf bottom trawl survey was evaluated (Appendix 2) for 19.03 and 19.03(2020) using: 1) retrospective analyses in which the terminal year was sequentially dropped from the 19.03 dataset, re-run, and compared with results from the same model run without NMFS survey data in the terminal year and 2) model runs with simulated 2020 survey biomass data that bracketed the range of the value expected if the survey had been conducted.

The author-preferred scenario for this assessment is Scenario 20.07, which builds on 19.03 by incorporating BSFRF trawl survey data from its cooperative “side-by-side” (SBS) catch comparison studies with the NMFS EBS shelf bottom trawl survey in order to better fix the scale of the NMFS survey data. Empirical availability curves for the BSFRF were determined outside the assessment model (Appendix 3). These were used in the model to relate the BSFRF estimates of absolute abundance (at spatial scales smaller than the stock distribution) and the stock abundance estimated by the assessment model.

4. Changes to the assessment results
Changes in the assessment results are relatively minor, but this may reflect the absence of data from the cancelled NMFS EBS shelf bottom trawl survey. Average recruitment (1982-2019) was estimated at 394 million in last year's assessment, but it is slightly lower at 370 million from the author's preferred model this year. F_{MSY} is smaller this year (0.96 yr^{-1} this year vs. 1.18 yr^{-1} last year), as is B_{MSY} (36.62 thousand t vs. 40.75 thousand t). The stock remains in Tier 3b because the ratio of projected MMB to B_{MSY} is below 1 (as it was last year). Because both average recruitment and F_{MSY} were estimated somewhat smaller than last year, this year's OFL ended up being smaller than that for 2019/20 by 28%.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets (May/June 2020, September/October 2019) of SSC and CPT comments on assessments in general. [Note: for continuity with the previous assessment, the following may include comments prior to the most recent two sets.]

June 2020 SSC Meeting
SSC Comment: The SSC reminds all stock assessment authors to implement the guidelines for model numbering for consistency and easier version tracking over time, and emphasizes how important this is for SSC review.
Response (9/20): The SSC numbering convention is followed in this chapter (having finally been implemented for Tanner crab in May 2020).

May 2020 CPT Meeting
CPT Comment: Should no survey occur, the CPT recommends that stock assessment authors roll over last year's accepted model, incorporating updated fishery data when possible, and projecting OFL/ABCs based on our understanding of stock trends from surveys to 2019.
Response (9/20): The 2020 NMFS EBS Shelf bottom trawl survey was indeed cancelled. Model runs were conducted with last year's accepted model, updated with fishery data for 2019/20 (Scenario 19.03(2020)). Additional runs were made that included simulated 2020 survey data which bracketed the survey biomass for 2020 predicted by 19.03(2020) by 25% of expected variation. The results of these runs are discussed in Appendix 2 but the variability had little effect on the resulting OFL because other quantities exhibited offsetting changes.

Oct 2019 SSC Meeting
SSC Comment: The SSC reminds authors to use the model numbering protocols that allows the SSC to understand the year in which a particular version of the model was first introduced.
Response (5/20): The requested numbering protocols have been implemented, with the 2019 assessment model "backdated" and referred here as 19.03 (where it was referred to 19F03 during the 2019 assessment).

SSC Comment: the SSC requests that the CPT consider developing a standard approach for projecting the upcoming year's biomass that does not include removing the entire OFL for stocks where recent mortality has been substantially below the OFL. This may appreciably change the projected biomass levels for stocks such as Tanner crab, where actual catch mortality has been less than 10% of the OFL .
Response (updated 9/20): The CPT has not yet developed a standard approach for doing so, but will discuss ideas at the September 2020 meeting for implementation prior to the May 2021 CPT meeting.

SSC Comment: the SSC encouraged authors to work together to create a standard approach for creating priors on selectivity and catchability from these (BSFRF/NMFS side-by-side trawl) data for use in the respective assessments. A hierarchical comparison of all species pooled, separated species, and separated sexes may be helpful for understanding where statistically supported differences exist. Where sample sizes are modest (e.g., snow crab), bootstrapping, or a sample size-weighted estimate rather than a raw average may be useful for aggregating across years.
Response (updated 9/20): An option to use such priors has also been added to the Tanner crab assessment model code, but has not yet been utilized. Results from a preliminary attempt to develop priors on sex/size-specific catchability (q *x* selectivity) and availability were presented for Tanner crab in the May 2020 CPT Report. Further work estimating catchability outside the assessment model using catch ratio analysis of the BSFRF/NMFS side-by-side trawl data using GAMMs is underway but incomplete (see Appendix 4 for an interim report). A model scenario (20.10) using the "best" estimates (from a limited, preliminary set of candidate models) of sex-specific catchability from this analysis is presented in this chapter, however, the estimated catchability curves are used as "known" in the assessment model rather than as priors partly because the uncertainty associated with the curves has not yet been adequately characterized and partly because assuming the curves are known reduces the complexity of the model. The suggested hierarchical comparison is an intriguing suggestion, and can be addressed in future research.

September 2019 Crab Plan Team Meeting
No new general comments.

October 2018 SSC Meeting
SSC Comment: The SSC encourages authors (using VAST estimates of survey biomass) to consider whether or not the apparent reduction in uncertainty in survey biomass is appropriately accounted for with their models.
Updated response (09/20): At its May 2020 meeting, the CPT suggested authors not use VAST estimates in assessment models until the estimates could be better validated.

Updated response (05/20): Two model scenarios fitting VAST estimates of survey biomass were included in this report: one which fit the estimates without adjusting the variance estimates and one which estimated parameters describing "extra" uncertainty (i.e., re-inflating the uncertainty of the VAST estimates). While the model fit without estimating "extra" uncertainty was "worse" from a strictly likelihood perspective (larger z-scores) compared to that from the same model fit to the standard design-based estimates, the predicted values "fit" the VAST estimates better from a visual standpoint (i.e., on a scale unweighted by the uncertainty). Unfortunately, the attempt to compensate for the possible over-shrinkage of uncertainty in the VAST estimates by estimating parameters related to "extra" uncertainty failed because the model converged to with the parameters at their upper bounds (equivalent to "extra" CVs of 270%).

2. Responses to the most recent two sets (May/June 2020, September/October 2019) of SSC and CPT comments specific to the assessment. [Note: for continuity with the previous assessment, the following includes comments prior to the most recent two sets of comments.]

June 2020 SSC Meeting
SSC Comment: The SSC requested that, for the next assessment, models be reparametrized, simplified, or have parameter bounds adjusted such that no parameters remain at the bounds after estimation.
Response (9/20): Several attempts so far to do so have not been successful. Model scenario 20.10 considered here reduced the number of parameters at bounds from 12 to 5, but was unsatisfactory for other reasons. It appears that reparameterizing selectivity functions from using logistic functions to using half-normal functions may eliminate several such parameters. It is also apparent that three parameters related to estimates of fully-selected retention can be eliminated. A simplified male-only model including

only the directed and snow crab fisheries as source of fishing mortality is being investigated, as well as whether bycatch in the BBRKC fishery is small enough to be dropped post-2004 (at least for females). As such, a number of avenues are being explored but work continues on this topic.

SSC Comment: Provide additional information on data weighting. Specifically, identify standardized residuals appreciably greater than would be expected by chance (e.g., values of four and larger), report mean input and harmonic mean effective sample sizes by source for evaluation of model fit, and consider basing input sample sizes on the number of trips/hauls sampled rather than the number of individual crab measured.
Response (9/20): Information is not currently provided to base input sample sizes on the number of trips/hauls sampled for fishery-related size compositions, and the sample sizes in the survey are limited to 200 in order to avoid numerical issues (the number of hauls would typically be 375 in any survey year post-1987, and would never be as low as 200 in any case). Geometric mean, not harmonic mean, effective sample sizes based on the McAllister-Ianelli method are provided for all size composition data. Large standardized residuals are not specifically flagged as part of the assessment model output. This capability will be added in the future.

SSC Comment: The SSC reiterated its previous recommendation on analysis of the BSFRF data. The SSC encouraged authors to work together to create a standard approach for creating priors on selectivity and catchability from these data for use in the respective assessments. A hierarchical comparison of all species pooled, separated species, and separated sexes may be helpful for understanding where statistically supported differences exist. Where sample sizes are modest (e.g., snow crab), bootstrapping, or a sample size-weighted estimate rather than a raw average may be useful for aggregating across years.
Response: This needs to be highlighted as a request to the CPT to add this topic as an agenda item to its January 2021 meeting, if possible. It seems like the best avenue forward at the moment is for individual authors to continue to develop the best analysis for their own stock. These can be compared in January and perhaps the best of these can be used as the basis for an hierarchical model, as the SSC recommends. Off hand, it seems likely that the differing morphological characteristics of *Chionoecetes* and *Paralithodes* crab, as well as the different environmental conditions they experience across the EBS shelf, will affect catchability differently and produce statistically-supported differences among the stocks.

May 2020 CPT Meeting

CPT Comment: Therefore, the CPT recommends that model 20.07 be identified as a preliminary base model for September. The CPT discussed a refinement to model 20.07 (here denoted model 20.07b), in which the empirical availability curves are input as data vectors with specified uncertainty, rather than assumed known. If Model 20.07b turns out to be straightforward to implement, as we expect, then Model 20.07b could be regarded as the preliminary base model rather than Model 20.07.
Response: Given the current model code, Model 20.07b would be possible to implement, once the empirical curves and associated uncertainty were developed. Empirical curves (smooth functions of size) were developed by fitting the ratio of observed survey abundance in the side-by-side study area to that from the entire survey area on an annual basis for 2013-2017 using the same size bins as in the assessment model (Appendix 3). However, it is unclear what the appropriate measure of uncertainty should be. Estimates of uncertainty from fitting the empirical curves seem to be too small, while ones developed previously from bootstrapping (May 2020 CPT Tanner Crab Report) seem to be too large. With more pressing issues (characterizing the uncertainty associated with the missing 2020 NMFS EBS shelf bottom trawl survey), it was not possible to further resolve this one. The author looks forward to recommendations to move forward.

CPT Comment: Consider ways to remove any additional complexity in the Tanner crab assessment that does not add to our understanding of stock dynamics.
Response (9/20): A male-only model including only the directed and snow crab fisheries is in development as a simplified baseline for adding further complexity (e.g., bycatch in the groundfish and BBRKC fisheries). A model that starts in 1982, after the survey gear change, is under consideration for development. Its implementation would require new code to parameterize the initial size compositions; this approach would be substantially different from the way the model is initialized at present.

CPT Comment: Evaluate potential conflicts between data sets in the assessment using likelihood profiles and other approaches.
Response (9/20): This is a good suggestion, but ADMB's likelihood profiling does not appear to be adequate to address this request because it does not report individual components to the likelihood. Thus, some specialized software needs to be developed in order to proceed.

CPT Comment: Further work is needed to incorporate empirical estimates of catchability in the assessment. Quantifying uncertainty in catchability is critical. Uncertainty estimates should consider year-to-year variation catchability either as a random effect or as a level of a hierarchical model.
Response: Survey catchability for the NMFS EBS shelf bottom trawl survey was estimated outside the assessment model using BSFRF-NMFS side-by-side (paired tows) data in a catch-comparison analysis (Appendix 4). The catchability curves were estimated using GAMs with haul as a random effect. The analysis of models with year as a random effect, as well as the addition of potential environmental covariates, is pending. The curves were used in Scenario 20.10 as "known" values without any uncertainty. The author welcomes more-specific recommendations on how best to quantify the uncertainty, as well as how to include it in the assessment model.

October 2019 SSC Meeting
SSC comment: The SSC requested that for the next assessment, models be reparameterized, simplified, or have parameter bounds adjusted such that no parameters remain at the bounds after estimation.
Response: See response above.

SSC comment: Use the standard model numbering approach.
Response: Done.

SSC comment: In next year's assessment, project biomass using a mortality level consistent with recent years, rather than the full OFL (see general CPT comments).
Response: See response above.

SSC comment: Provide a retrospective analysis for future assessments.
Response (9/20): Retrospective analyses are now provided.

SSC comment: Add the 2018 BSFRF/NMFS side-by-side data for all future analyses of that time-series.
Response (9/20): BSFRF has not provided this data, although it has been promised.

SSC comment: Report the values for natural mortality actually used for calculation of reference points in the appropriate table(s).
Response (9/20): The values for natural mortality actually used for calculation of reference points are now reported in tables in the Introduction to the SAFE and are updated by the CPT.

SSC comment: Provide additional information on data weighting. Specifically, identify standardized residuals appreciably greater than would be expected by chance (e.g., values of 4 and larger), report mean input and harmonic mean effective sample sizes by source for evaluation of model fit, and consider basing input sample sizes on the number of trips/hauls sampled rather than number of individual crab measured..
Response: See response above.

September 2019 CPT Meeting
The CPT suggested exploring appropriate values for catchability. For example, runs that fit to the BSFRF data and fix availability to empirical estimates to contrast the outcomes with runs in which availability is estimated could be informative for what is driving the small estimates of catchability in the author-preferred model.
Response (9/20): Empirical estimates of availability and selectivity were developed from BSFRF and NMFS side-by-side (SBS) selectivity study data for Tanner crab and presented in the May 2020 CPT Report. These were used in several model scenarios.

The CPT suggested exploring the relationship between natural mortality, growth, and overestimates of large crab. For example, estimate growth outside the model to attempt to address the overestimates of large crab.
Response (9/20): Model scenarios have been run where growth is estimated outside the model. This does not seem to solve this issue. Software to perform a likelihood profile on male growth parameters is under development and the results of the profile will hopefully shed some light on this issue.

The CPT suggested exploring maturity states for growth increment data and make recommendations for directions for growth model development.
Response (9/20): Except for the 2019 data, there seems to be little information on whether or not a molt was considered terminal.

Response (5/20): Work is in progress to address this issue.

The CPT requested include the data to which the models are fit for the survey biomasses figures in the presentation.
Response (5/20): The data was dropped for clarity of comparison among model predictions of survey biomass. The data will be included in future plots of this sort.

The CPT requested that if 'catchability' is to be used for something similar to 'fully-selected fishing mortality', perhaps translate it to a 0-1 scale and distinguish it from survey catchability so that it is clear that there is mortality associated with it.
Response (5/20): The term "catchability" was used to describe the rate at which "fully-selected" crab are captured in a fishery. Because some discards are assumed to survive, this is not equivalent to "fully-selected fishing mortality" (if discard mortality were 0, there would be *no* mortality associated with capture in a bycatch fishery). Perhaps "capturability" would cause less confusion?

The CPT requested that the author explore ways to provide a retrospective analysis of the assessment model.
Updated Response (9/20): A substantial effort was made to add the capability to perform a retrospective analysis to the assessment model. Retrospective analyses are provided here for several model scenarios.

June 2019 SSC Meeting
The SSC endorsed the CPT suggestions from its May meeting.
Response: none.

The SSC requested an evaluation of all parameters estimated to be at or very near bounds, or substantially limited by priors (unless those priors can be logically defended).
Original response (9/19): Two tables of parameters estimated at or near their bounds are provided (Tables 18 and 19). These parameters are estimated at their bounds in all (or nearly all) of the scenarios examined here. The parameters include one related to peak retention in the directed fishery prior to 1997 (at its upper bound on the logit scale, implying full retention of large legal males) and two related to the probability of undergoing terminal molt (effectively 1 for males in the largest model size bin and 0 for females in the smallest model size bin). These could be fixed in future models (the latter two are in several scenarios here). Survey catchability parameters for the 1975-1981 time period were also estimated at their lower bound (0.5). This might not be unreasonable given the reduced areal coverage of these surveys relative to later surveys and the spatial limits of the Tanner crab stock. However, it would be worthwhile to explore the effect of reducing these bounds. The remaining parameters are related to selectivity functions describing the size-specific capture efficiency of the fisheries and surveys. Two at their lower bounds are probably inconsequential (pS2[10] and pS4[1]) and are related to the ascending and descending slopes of the dome-shaped selectivity describing male bycatch in the snow crab fishery prior to 1997. A double-normal is used to describe the dome shape, but an alternative function (e.g., a single normal) might have better estimation properties. The size at 50% selected was estimated at its upper bound (90 mm CW) for NMFS survey selectivity in the 1975-1981 time period pS1[1]). This results in an almost linear function, rather than asymptotic, across the size range. This result may reflect the changing interaction between the areas surveyed (availability) and the gear selectivity in this time period as the survey gradually extended from the southeast shelf and Bristol Bay where adult males were prevalent to the north and west where more immature males would be encountered, effectively "seeing" relatively more large males than small males. Two other survey-related selectivity parameters, describing the size difference between crab at 50% and 95% selected) were estimated at their upper bounds for the both males and females in the NMFS EBS trawl survey in the 1982-present time period (pS2[2] and pS2[4]). The selectivity functions are assumed to be logistic, with the other estimated parameter being the size at 95% selected. The practical consequence of this is that small crab (females in particular) are described as fairly well-selected (> 50% for females) relative to fully-selected (sex-specific) large crab. This result may reflect conflicts from between the model assumption of equal sex ratios for recruitment in the 25-40 mm CW range, apparent equal abundances and spatial patterns for males and females at small sizes in the NMFS EBS survey, and assumed logistic selectivity. The selectivity parameter describing the size at 50% selected for males in the groundfish fisheries during 1987-1996 was estimated in all scenarios at its lower bound (40 mm CW), probably a consequence of fairly substantial catches of small crab in some years (e.g., 1993, Figure 12). Finally, three parameters at their upper bounds (pS1[23], pS1[24], and pS1[27]) are related to the size at 95% selected in the BBRKC fishery in the 1997-2004 (males) and 2005+ (males and females) time periods. The upper bounds (180 for males, 140 for females) were selected to reflect the largest possible sizes reasonably expected in the model, so the resulting selectivity functions are essentially positively-sloped linear functions with values fixed at 0.95 at the parameter bound because the other estimated logistic parameter estimates a large size at 50% selected (see selectivity curves in Figure 46).

May2019 Crab Plan Team Meeting
CPT comment: Compare trends in largest crab to fishing pressure and area occupied by stock.
Original response (9/19): This is a good suggestion that, time permitting, will be addressed before the January 2021 CPT meeting.

CPT comment: Compare the maximum sizes seen in the fishery to the survey.
Original response (9/19): Another good suggestion that, time permitting, will be addressed before the January 2021 CPT meeting.

CPT comment: Consider blocking for estimation of growth and probability of maturing.
Original response (9/19): This has been on the "to do" list for a while now, but with relatively low priority. The problem is that the principal data which the model relies on for estimating both processes is, except for size compositions, only available (from a practical standpoint) since 2006 for male maturity ogives and since 2015 for (both sexes) molt increment data. The ability of the model to reliably estimate changes in these processes is thus somewhat doubtful.

CPT comment: Provide retrospective analysis and calculate Mohn's rho for MMB
Updated response (9/20): This has been done and results are presented in this chapter.

C. Introduction

1. Scientific name.
Chionocoetes bairdi. Tanner crab is one of five species in the genus *Chionoecetes* (Rathbun, 1924). The common name "Tanner crab" for *C. bairdi* (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" had also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

2. Description of general distribution
Tanner crabs are found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a), where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit (Fig. 1). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although males less than the industry-preferred size (>125 mm CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, *C. opilio,* in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 60°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

3. Evidence of stock structure
Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998). Clinal differences across the EBS shelf in some biological characteristics such as mean mature size exist across the range of the unit stock, leading some authors to argue for a division into eastern and western stocks in the EBS (Somerton 1981b, Zheng 2008, Zheng and Pengilly 2011). However, it was not generally recognized at the time of these analyses that this species undergoes a terminal molt at maturity (Tamone et al. 2007), nor were the implications of ontogenetic movement considered. Thus, biological characteristics estimated using comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time, may be confounded as a result and do not provide definitive evidence of stock structure.

Simulated patterns of larval dispersal suggest that Tanner crab in Bristol Bay may be somewhat isolated from other areas on the shelf, and that this component of the stock relies heavily on local retention of larvae for recruitment, suggesting that Tanner crab on the shelf may exist as a metapopulation of weakly-connected sub-stocks (Richar et al. 2015). However, recent genetic analysis has failed to distinguish multiple non-intermixing, non-interbreeding sub-stocks on the EBS shelf (Johnson 2019), suggesting that Tanner crab in the EBS form a single unit stock.

4. Life history characteristics

a. Molting and Shell Condition
Tanner crabs, like all crustaceans, normally exhibit a hard exoskeleton of chitin and calcium carbonate. This hard exoskeleton requires individuals to grow through a process referred to as molting, in which the individual sheds its current hard shell, revealing a new, larger exoskeleton that is initially soft but which rapidly hardens over several days. Newly-molted crab in this "soft shell" phase can be vulnerable to predators because they are generally torpid and have few defenses if discovered. Subsequent to hardening, an individual's shell provides a settlement substrate for a variety of epifaunal "fouling" organisms such as

barnacles and bryozoans. The degree of hard-shell fouling was once thought to correspond closely to post-molt age and led to a classification of Tanner crab by shell condition (SC) in survey and fishery data similar to that described in the following table (NMFS/AFSC/RACE, unpublished):

Shell Condition Class	Description
0	pre-molt and molting crab
1	carapace soft and pliable
2	carapace firm to hard, clean
3	carapace hard; topside usually yellowish brown; thoracic sternum and underside of legs yellow with numerous scratches; pterygostomial and bronchial spines worn and polished; dactyli on meri and metabranchial region rounded; epifauna (barnacles and leech cases) usually present but not always.
4	carapace hard, topside yellowish-brown to dark brown; thoracic sternum and undersides of legs data yellow with many scratches and dark stains; pterygostomial and branchial spines rounded with tips sometimes worn off; dactyli very worn, sometimes flattened on tips; spines on meri and metabranchial region worn smooth, sometimes completely gone; epifauna most always present (large barnacles and bryozoans).
5	conditions described in Shell Condition 4 above much advanced; large epifauna almost completely covers crab; carapace is worn through in metabranchial regions, pterygostomial branchial spines, or on meri; dactyli flattened, sometimes worn through, mouth parts and eyes sometimes nearly immobilized by barnacles.

Although these shell classifications continue to be applied to crab in the field, it has been shown that there is little real correspondence between post-molt age and shell classifications SC 3 through 5, other than that they indicate that the individual has probably not molted within the previous year (Nevisi et al, 1996). In this assessment, crab classified into SCs 3-5 have been aggregated as “old-shell” crab, indicating that these are crab likely to have not molted within the previous year. In a similar fashion, crab classified in SCs 0-2 have been combined as “new shell” crab, indicating that these are crab have certainly (SCs 0 and 1), or are likely to have (SC 2), molted within the previous year.

b. Growth

Work by Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of Tanner crab in survey data assuming no terminal molt at maturity. Somerton’s approach did not directly measure molt increments and his findings are constrained by not considering that the progression of modal lengths between years was biased because crab ceased growing after their terminal molt to maturity.

Growth in immature Tanner crab larger than approximately 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). Rugolo and Turnock (2012a) derived growth relationships for male and female Tanner crab used as priors for estimated growth parameters in this (and previous) assessments from data on observed growth in males to approximately 140 mm carapace width (CW) and in females to approximately 115 mm CW that were collected near Kodiak Island in the Gulf of Alaska (Munk, unpublished.; Donaldson et al. 1981). Rugolo and Turnock (2010) compared the resulting growth per molt (gpm) relationships with those of Stone et al. (2003) for Tanner crab in southeast Alaska in terms of the overall pattern of gpm over the size range of crab and found that the pattern of gpm for both males and females was characterized by a higher rate of growth to an intermediate size (90-100 mm CW) followed by a decrease in growth rate from that size thereafter. Similarly-shaped growth curves were found by Somerton (1981a) and Donaldson et al. (1981), as well.

Molt increment data was collected for Tanner crab in the EBS during 2015, 2016, 2017 and 2019 in cooperative research between NMFS and the Bering Sea Research Foundation (R. Foy and E. Fedewa, NMFS, pers. comm.s). Previous analysis of the data suggests it is not substantially different from that obtained near Kodiak Island (Stockhausen, 2017). The EBS molt increment data is incorporated in the assessment model to inform inferred growth trajectories in all of the alternative models evaluated in this assessment.

c. Weight at Size

Weight-at-size relationships used in this assessment were revised in 2014 based on a comprehensive re-evaluation of data from the NMFS EBS Bottom Trawl Survey (Daly et al., 2014). Weight-at-size is described by a power-law model of the form $w = a \cdot z^b$, where w is weight in kg and z is size in mm CW (Daly et al., 2016; table below). Parameter values are presented in the following table:

sex	maturity	a	b
males		0.000270	3.022134
females	immature (non-ovigerous)	0.000562	2.816928
	mature (ovigerous)	0.000441	2.898686

d. Maturity and Reproduction

It is now generally accepted that both Tanner crab males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo a terminal molt to maturity, as in most majid crabs. Maturity in females can be determined visually rather unambiguously from the relative size of the abdomen. Females usually undergo their terminal molt from their last juvenile, or pubescent, instar while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding the female's clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using sperm stored in the spermathacae (Adams and Paul 1983, Paul and Paul 1992). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to self-fertilize the new clutch (Paul 1982, Adams and Paul 1983), although egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically, but is not as easily determined as with females. Physiological maturity refers to the presence or absence of spermataphores in the gonads whereas morphometric maturity refers to the presence or absence of a large claw (Brown and Powell 1972). During the molt to morphometric maturity, there is a disproportionate increase in the size of the chelae in relation to the carapace (Somerton 1981a). The ratio of chela height (CH) to carapace width (CW) has been used to classify male Tanner crab as to morphometric maturity. While many earlier studies on Tanner crabs assumed that morphometrically mature male crabs continued to molt and grow, there is now substantial evidence supporting a terminal molt for males (Otto 1998, Tamone et al. 2007). A consequence of the terminal molt in male Tanner crab is that a substantial portion of the population may never achieve legal size (NPFMC 2007). In this assessment, several model scenarios are considered in which size-specific annual proportions of mature, new shell male crab to all new shell male crab in the NMFS EBS bottom trawl survey, based on classification using CH:CW ratios, are fit to inform size-specific probabilities of terminal molt.

Although observations are lacking in the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous females in the Gulf of Alaska and Prince William Sound. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the EBS, egg condition for multiparous Tanner crabs assessed between April and July 1976 also suggested that hatching and extrusion of new clutches for this maturity state began in April and ended sometime in mid-June (Somerton 1981a).

e. Fecundity

A variety of factors affect female fecundity, including somatic size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004). Of these factors, somatic size is the most important, with estimates of 89 to 424 thousand eggs for females 75 to 124 mm CW, respectively (Haynes et al. 1976). Maturity status is another important factor affecting fecundity, with primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent females often carry small clutches or no eggs (i.e., are barren) suggesting that female crab reproductive output is a concave function of age (NMFS 2004).

f. Size at Maturity

Rugolo and Turnock (2012b) estimated size at 50% mature for females (all shell classes combined) from data collected in the NMFS bottom trawl survey at 68.8 mm CW, and 74.6 mm CW for new shell females. For males, Rugolo and Turnock (2012a) estimated classification lines using mixture-of-two-regressions analysis to define morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of 166ºW, based on chela height and carapace width data collected during the 2008 NMFS bottom trawl survey. These rules were then applied to historical survey data from 1990-2007 to apportion male crab as immature or mature based on size (Rugolo and Turnock, 2012b). Rugolo and Turnock (2012a) found no significant differences between the classification lines of the sub-stock components (i.e., east and west of 166ºW), or between the sub-stock components and that of the unit stock classification line. Size at 50% mature for males (all shell condition classes combined) was estimated at 91.9 mm CW, and at 104.4 mm CW for new shell males. By comparison, Zheng and Kruse (1999) used knife-edge maturity at >79 mm CW for females and >112 mm CW for males in development of the current SOA harvest strategy.

g. Mortality

Due to the lack of age information for crab, Somerton (1981a) estimated mortality separately for individual EBS cohorts of immature and adult Tanner crab. Somerton postulated that age five crab (mean CW = 95 mm) were the first cohort to be fully recruited to the NMFS trawl survey sampling gear and estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using this analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished stock to range from 0.20 to 0.28. When using CPUE data from the Japanese fishery, estimates of M ranged from 0.13 to 0.18. Somerton concluded that estimates of M from 0.22 to 0.28 obtained from models that used both the survey and fishery data were the most representative.

Rugolo and Turnock (2011a) examined empirical evidence for reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. They reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab, where longevity would be at least 20 years, given the close analogues in population dynamic and life-history characteristics (Turnock and Rugolo 2011a). Employing 20 years as a proxy for longevity and assuming that this age represented the upper 98.5th percentile of the distribution of ages in an unexploited population, M was estimated to be 0.23 based on Hoenig’s (1983) method. Alternatively, if 20 years was assumed to represent the 95% percentile of the distribution of ages in the unexploited stock, the estimate for M would be 0.15. Rugolo and Turnock (2011a) adopted M=0.23 for both male and female Tanner because the value corresponded with the range estimated by Somerton (1981a), as well as the value used in the analysis to estimate the overfishing definitions underlying Amendment 24 to the Crab Fishery Management Plan (NPFMC 2007).

5. Brief summary of management history.
A complete summary of the management history is provided in the ADFG Area Management Report appended to the annual SAFE. Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the EBS is managed under a federal Fishery Management Plan (FMP; NPFMC 2011). The plan defers certain management controls for Tanner crab to the State of Alaska (SOA), with federal oversight (Bowers et al. 2008). The SOA manages Tanner crab based on registration areas divided into districts. Under the FMP, the state can adjust districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 2011).

The Bering Sea District of Tanner crab Registration Area J (Figure 1) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36'N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173°W. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168°W and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008). In this report, the terms "east region" and "west region" are used in shorthand fashion to refer to the regions demarcated by 166ºW longitude.

In March 2011, the Alaska Board of Fisheries (BOF) approved a new minimum size limit harvest strategy for Tanner crab effective for the 2011/12 fishery. Prior to this change, the minimum legal size limit was 5.5" (140 mm CW, including lateral spines) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of 166º W. The minimum size limit for the fishery to the east of 166º W is now 4.8" (122 mm CW) and that to the west is 4.4" (112 mm CW), where the size measurement includes the lateral spines. For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas, and the SOA's harvest control rules (HCRs) used to determine total allowable catch (TAC) generally incorporate minimum industry-preferred sizes that are larger than the legal minimums. In 2011, these minimum preferred sizes were set at 5.5" (140 mm CW) in the east and 5" (127 mm CW) in the west, including the lateral spines (ADFG 2014). The harvest strategy also employed a minimum threshold that the mature female biomass (MFB) in the Eastern subdistrict be larger than 40% of its longterm (1975-2010) average in two subsequent years before the fisheries in either subdistrict could be opened. Minimum thresholds for opening the fishery in a subdistrict were also defined using the ratio subdistrict-specific MMB to its associated longterm average. Finally, the harvest strategy defined subdistrict-specific sloping harvest control rules to determine the maximum allowable exploitation rate on mature males in each subdistrict based on the ratio of MFB to average MFB, together with limits on the maximum exploitation rate (Figure 2).

Subsequently, the SOA's harvest strategy has undergone three revisions in the past 6 years (Daly et al., 2020). In 2015, the minimum preferred harvest size used to compute TAC for the area east of 166ºW longitude was changed from 140 mm CW (5.5 inches; including the lateral spines) to 127 mm CW (5.0 inches), the preferred size used to compute TAC for the area west of 166ºW longitude. In 2017, the criteria used to determine MFB was changed from an area-specific one based on carapace width to one based on morphology (the same as that used by the NMFS EBS shelf bottom trawl survey), the definition of 'long-term average' for calculating average mature biomass was changed from 1975-2010 to 1982-2016, the spatial range for calculating average MFB was expanded to include the entire NMFS EBS shelf bottom trawl survey area, and a so-called 'error band system' was introduced in the HCR to account for survey uncertainty such that the exploitation rate on industry-preferred males used to calculate was gradually reduced when the lower 95% confidence interval of the point estimate of MFB fell below 40% of the long-term average (replacing the requirement to close the fisheries when MFB fell below the 40% threshold; ADF&G, 2017; Daly et al., 2020).

Most recently, the harvest strategy was changed in March 2020 based on results from an extensive management strategy evaluation (MSE) conducted with input from industry stakeholders, NMFS and academic scientists, and ADF&G managers (Daly et al., 2020). The current HCR (Figure 3; HCR 4_1 in Daly et al., 2020) defines the period for calculating average mature biomass as 1982-2018 and implements sliding scales for exploitation rates on mature males which are functions of the ratios of MMB and MFB to their longterm averages. One particularly notable change is that there is no longer a threshold for opening the fisheries based on MFB.

Landings of Tanner crab in the Japanese pot and tangle net fisheries were reported in the period 1965-1978, peaking at 19.95 thousand t in 1969. The Russian tangle net fishery was prosecuted during 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s (Table 1; Figure 4). Foreign fishing for Tanner crab ended in 1980.

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; Figure 5). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery. Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand t in 1977/78. Landings fell sharply after the peak in 1977/78 through the early 1980s, and domestic fishing was closed in 1985/86 and 1986/87 due to depressed stock status. In 1987/88, the fishery re-opened and landings rose again in the late-1980s to a second peak in 1990/91 at 16.61 thousand t, and then fell sharply through the mid-1990s. The domestic Tanner crab fishery was closed between 1997/98 and 2004/05 as a result of conservation concerns regarding the depressed status of the stock. It re-opened in 2005/06 and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Tables 1 and 2). The SOA closed directed commercial fishing for Tanner crab during the 2010/11-2012/13 seasons because estimated female stock metrics fell below thresholds adopted in the state harvest strategy. However, these thresholds were met in fall 2013 and the directed fishery was opened in 2013/14. TAC was set at 1,645,000 lbs (746 t) for the area west of 166º W and at 1,463,000 lbs (664 t) for the area east of 166º W in the Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 79.6% (594 t) of the TAC had been taken in the western area while 98.6% (654 t) had been taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10. In 2014, TAC was set at 6,625,000 lbs (3,005 t) for the area west of 166º W and at 8,480,000 lbs (3,846 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. In 2015, TAC was set at 8,396,000 lbs (3,808 t) in the western area and 11,272,000 lbs (5,113 t) in the eastern area. On closing, essentially 100% of the TAC was taken in each area (3,798 t in the west, 5,111 t in the east). The total retained catch in 2015/16 (8,910 t) was the largest taken in the fishery since 1992/93 (Tables 1, 2; Figures **4** and 5). The directed fisheries in both areas were closed in 2016/17 because mature female biomass in the NMFS EBS Bottom Trawl Survey did not exceed the threshold set in the SOA's harvest strategy to allow them to open. Total retained catch was thus 0 in 2016/17. In 2017/18, the SOA allowed a limited directed fishery west of 166ºW longitude but closed the fishery east of 166ºW. Essentially, the entire TAC (1,130 t) was taken in 2017/18. The 2018/19 season followed a similar pattern, with the directed fishery closed in the eastern area and open in the western area (with a TAC of 1.106 thousand t). The entire TAC was again harvested in 2018/19. The directed fisheries in both subdistricts were again closed in 2018/19 because the threshold mature female biomass was not met.

Bycatch and discard losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Table 3; Figure 6). Within the assessment model, bycatch estimates are converted to discard mortality using assumed handling mortality rates of 32.1% for bycatch in the crab fisheries and 80% for bycatch in the groundfish fisheries. Bycatch was persistently high during the early-1970s; a subsequent peak occurred in the early-1990s. In the early-

1970s, the groundfish fisheries contributed substantially to total bycatch losses (although bycatch in the crab fisheries was undocumented at the time). From 1992/93 (when reliable crab fishery bycatch estimates are considered to be first available) to 2004/05, the groundfish fisheries accounted for the largest proportion of discard mortality. Since 2005/06, however, the crab fisheries have accounted for the largest proportion.

D. Data

Data incorporated into the Tanner crab assessment this year include: 1) annual abundance, biomass and size composition data collected by crab fishery observers for Tanner crab retained in the directed fisheries and taken as bycatch in the directed and other (snow crab, Bristol Bay red king crab) fisheries provided by ADFG; 2) annual abundance, biomass, and size composition data collected by groundfish fishery observers for bycatch in the groundfish fisheries provided by AFSC's Fisheries Monitoring and Analysis Division and the NMFS Alaska Regional Office (and hosted by AKFIN); 3) limited historical (pre-1990) data on annual abundance, biomass, and size compositions for Tanner crab retained in the foreign (1965-1980) and domestic (1968-1989) crab fisheries or taken as bycatch in the groundfish fisheries (1973-1990); 4) annual abundance, biomass and size composition data, as well as limited year-specific male maturity ogives, from the NMFS EBS shelf bottom trawl survey; 5) abundance, biomass, and size composition data from BSFRF/NMFS cooperative side-by-side trawl studies; and 6) molt increment data from NMFS/ADFG/ BSFRF cooperative studies.

1. Summary of new information

In general, incidental retained catch of Tanner crab in the snow crab and BBRKC fisheries has been very small compared with that from the directed fishery and continues to be "lumped" with that for the directed fishery. However, in 2019/20 the directed Tanner crab fisheries were closed by ADFG and incidentally-retained catch in the snow crab and BBRKC fisheries amounted to less than 50 kg—this small amount was not included in the assessment. ADFG also provided updated values for total catch of Tanner crab in the crab fisheries for 2018/19 and new values for 2019/20.

Tanner crab bycatch data in the groundfish fisheries (abundance, biomass, size compositions) were extracted for 1991/92-2018/19 from the groundfish observer and AKRO databases on AKFIN. Although the bycatch data in the groundfish fisheries is available by gear type, all model scenarios examined here fit the data aggregated over gear types. There were relatively small differences for estimates of total bycatch abundance and biomass between results provided by AKFIN last year and those provided this year for 2016/17, 2017/18, and 2018/19 due to a change in the algorithms AKFIN used to expand observed catch to total catch to align them with those used by the NMFS Alaska Regional Office to estimate Prohibited Species Catch (Figure 7). The effects of the changes were relatively minor, as shown in the following table:

Table. Comparison of management-related quantities to show the effects of the revised estimates for Tanner crab bycatch in the groundfish fisheries for 2016/17-2018/19.

case	average recruitment millions	Bmsy (1000's t)	current MMB (1000's t)	Fmsy per year	MSY (1000's t)	Fofl per year	OFL (1000's t)	projected MMB (1000's t)
19.03	393.84	41.64	82.61	1.18	19.49	1.12	29.51	39.73
19.03R	393.44	41.29	81.66	1.19	19.33	1.13	29.20	39.25

The scheduled 2020 NMFS EBS shelf bottom trawl survey was cancelled this year due to safety concerns associated with the COVID-19 pandemic. Thus, no new survey data was available. In addition, no new molt increment or maturity ogive data was available to incorporate into the assessment.

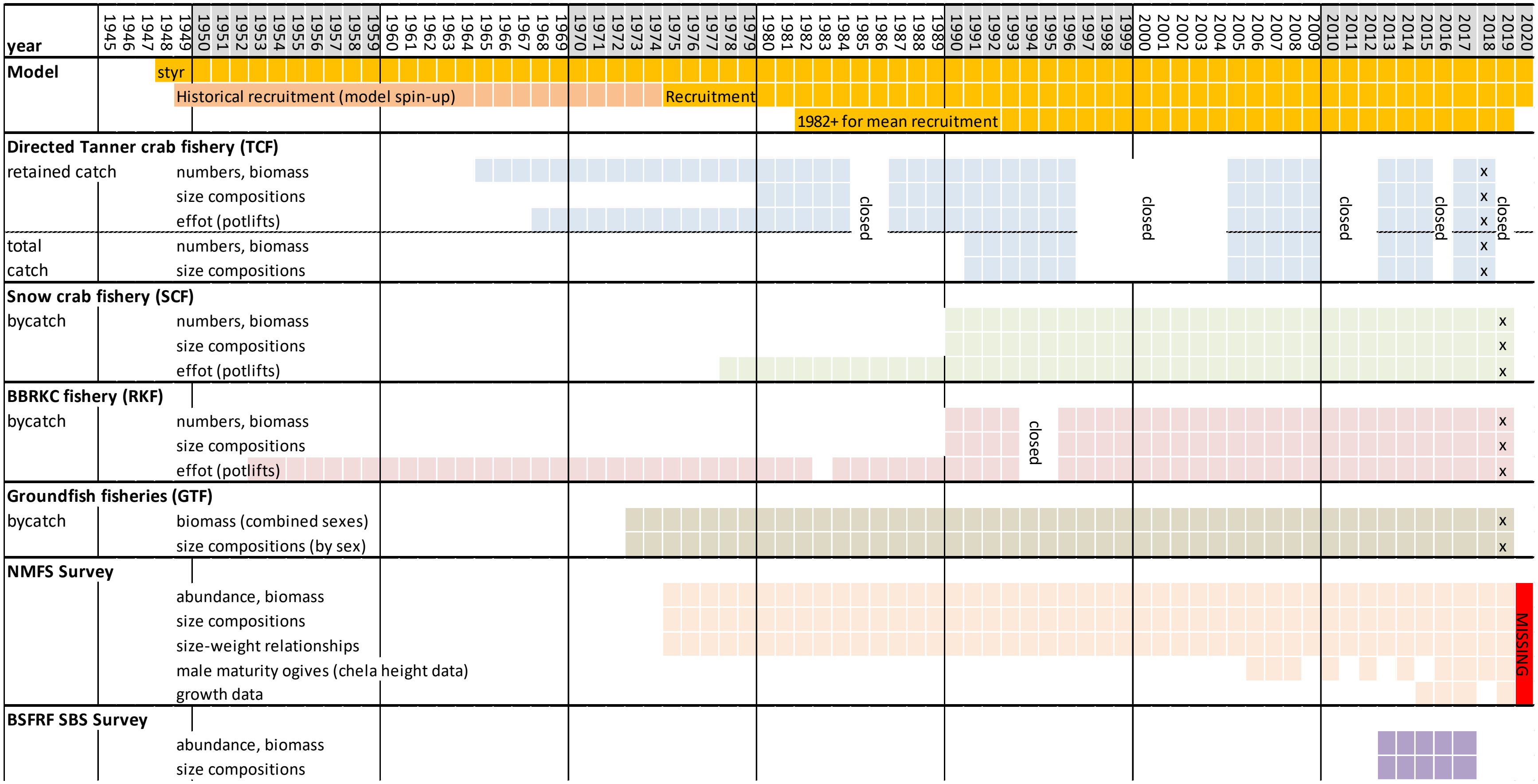
The following table summarizes data sources that have been updated for this assessment:

Table. Data sources updated for 2019/20.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	no 2020 survey	NMFS
	size compositions	1975-2019	no 2020 survey	
	male maturity data	2006+	no new data	
NMFS/BSFRF	molt-increment data	2015-17, 2019	no new data	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	no new data	BSFRF
	size compositions	2013-17	no new data	
Directed fishery	historical retained catch (numbers, biomass)	1965/66-1996/97	not updated	2018 assessment
	historical retained catch size compositions	1980/81-2009/10	not updated	2018 assessment
	retained catch (numbers, biomass)	2005/06-2018/19	fisheries closed 2019/20	ADFG
	retained catch size compositions	2013/14-2018/19	fisheries closed 2019/20	ADFG
	total catch (abundance, biomass)	1991/92-2018/19	fisheries closed 2019/20	ADFG
	total catch size compositions	1991/92-2018/19	fisheries closed 2019/20	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Groundfish Fisheries (all gear types)	historical total bycatch (abundance, biomass)	1973/74-1990/91	not updated	2018 assessment
	hostorical total bycatch size compositions	1973/74-1990/91	not updated	
	total bycatch (abundance, biomass)	1991/92-2019/20	now using AKRO algorithm for 2016/17+	NMFS/AKFIN
	total bycatch size compositions	1991/92-2019/20		

The following table summarizes the data coverage in the assessment:

Table. Data coverage in the assessment model (color shading highlights different model time periods and data components, x's denote new data).



2. Data presented as time series

For the data presented in this document, the convention is that ‘year’ refers to the year in which the NMFS bottom trawl survey was conducted (nominally July 1, yyyy), and fishery data are those subsequent to the survey (July 1, yyyy to June 30, yyyy+1)--e.g., 2015/16 indicates the 2015 bottom trawl survey and the winter 2015/16 fishery.

a. Retained catch

Retained catch in the directed fisheries for Tanner crab conducted by the foreign fisheries (Japan and Russia) and the domestic fleet, starting in 1965/66, is presented in Table 1 and Figures 4 and 5 by fishery year. More detailed information on retained catch in the directed domestic pot fishery is provided in Table 2, which lists total annual catches in numbers of crab and biomass (in lbs), as well as the SOA’s Guideline Harvest Level (GHL) or Total Allowable Catch (TAC) , number of vessels participating in the directed fishery, and the fishery season. Information from the Community Development Quota (CDQ) is included in the totals starting in 2005/06.

Directed fisheries for Tanner crab in the EBS began in 1965. Retained catch has followed a “boom-and-bust” cycle over the years, with the fishery experiencing periods of rapidly increasing catches followed by rapidly declining ones, after which it is closed for a time during which the stock partially recovers. Retained catch increased rapidly from 1965 to 1975, reaching ~ 25,000 t in 1970. It declined to ~13,000 t in 1973/74 coinciding with the termination of Russian fishing and the beginning of the domestic pot fishery. It increased again, this time to its highest level, in 1977/78 (~35,000 t) as the domestic fishery developed rapidly, but it subsequently declined and the fishery was closed in 1985/86 and 1986/87. In the late 1980s and early 1990s, the fishery experienced another, somewhat smaller, “boom” followed by a “bust” and closure of the fishery from 1997/98 to 2004/05. From 2005/06 to 2009/10, the fishery experienced its smallest boom-and-bust cycle, peaking at only ~1,000 t retained catch, and was closed again from 2010/11 to 2012/13. The fishery was re-opened in 2013/14, and retained catch increased each subsequent year until 2016/17 as TACs increased (Figures 2 and 3). The retained catch for 2015/16 (8,910 t) was the largest since 1992/1993 (15,920 t; Table 1). However, ADFG closed the directed fishery in both areas for the 2016/17 fishing season because mature female biomass in the 2016 NMFS EBS bottom trawl survey did not meet the SOA’s criteria for opening the fisheries. In 2017/18, ADFG allowed the fishery to commence in the western area (TAC was set at 1,130 t) but was closed in the eastern area. The directed fishery essentially caught the entire TAC. The 2018/19 fishery was similar to that in 2017/18 in that the eastern area was closed and the entire TAC (1,100 t) was taken west of 166ºW longitude. In 2019/20, the directed fisheries in both areas were closed because mature female biomass failed to exceed the threshold to open the fisheries.

b. Information on bycatch and discards

Total catch estimates for Tanner crab in the directed Tanner crab, the snow crab, and the BBRKC fisheries are provided in Table 4 and Figure 6 based on ADFG “at-sea” crab observer sampling starting in 1990/91. Annual bycatch in the groundfish fisheries, based on NMFS groundfish observer programs, is also available starting in 1973/74, but sex is undifferentiated. A value of 0.321 is used in the assessment model for “handling mortality” in the crab fisheries to convert observed bycatch to (unobserved) mortality (Stockhausen, 2014). For the groundfish fisheries, a value of 0.8 is used for handling mortality aggregated across gear types to reflect differences in groundfish gear effects and on-deck operations compared with the crab fleets. Mortality associated with the handling process can be estimated outside the assessment model for bycatch in the groundfish and non-directed crab fisheries (most or all Tanner crab bycatch is discarded), but estimates of “discard mortality” for males in the directed fishery obtained outside the assessment model are problematic if (due to sampling error) estimated total catch is less than reported retained catch.

Estimated bycatch mortality in the groundfish fisheries (without distinguishing gear type) was highest (~15,000 t) in the early 1970s, but it declined substantially by1977 to ~2,000 t with the curtailment of foreign fishing fleets (Stockhausen, 2017). It declined further in the 1980s (to ~500 t) but increased somewhat in the late 1980s to a peak of ~2,000 t in the early 1990s before undergoing another (gradual) decline until 2008, after which it has fluctuated annually below ~300 t to the present (~150 t in 2019/20).

In the crab fisheries, the largest component of bycatch occurs on males. In the early 1990s, female bycatch ranged between 6 and 40% of the bycatch in the directed and snow crab fisheries. Since the directed fishery re-opened in 2013/14, the fraction of bycatch that is female has ranged between 2% and 6% in the directed fishery, between 0.3 and 3% in the BBRKC fishery, and has been below 1% in the snow crab fishery. Estimates of total groundfish bycatch are not currently available by sex.

c. Catch-at-size for fisheries, bycatch, and discards

Retained (male) catch-at-size in the directed Tanner crab fishery from ADFG dockside observer sampling is shown in Figure 8 by fishery region and shell condition since rationalization of the crab fisheries in 20105/06. These indicate a shift to retaining somewhat smaller minimum sizes since 2013/14, compared with 2005/06-2009/10. As noted previously, the SOA changed its harvest strategy for calculating TACs to reflect a smaller minimum industry-preferred size of 125 mm CW east of 166ºW longitude. In addition, the proportion of old shell crab retained appears to have increased over the past few years and substantially exceeded that of new shell crab across the retained size range in 2018/19.

Normalized total catch (retained + discards) size compositions from at-sea crab fishery observer sampling are presented by fishery for males in Figure 9 and for females in Figure 10. The snow crab fishery, conducted primarily in the northern and western parts of the EBS shelf, catches predominantly small males while the BBRKC fishery, conducted to the south and east in Bristol Bay, predominantly catches large males. The size compositions in the snow crab fishery clearly reflect some sort of “dome-shaped” selectivity pattern (as assumed in the assessment model), with selectivity small for small and large males and highest for intermediate-sized males. In contrast, selectivity in the BBRKC fishery appears more consistent with asymptotic selection. The directed fishery, which extends across the shelf from west of the Pribilof Islands into Bristol Bay in the east catches primarily intermediate-sized males, with about half the new shell males caught larger than the industry-preferred size of 125 mm CW. Similar patterns are apparent for females, as well.

Sex-specific size compositions from observer sampling for bycatch in the groundfish fisheries, expanded to total bycatch, are shown in Figure 11 for 1991/92 to 2019/20. These fisheries, targeting a variety of groundfish stocks and using a variety of gear types, take a much larger size range of Tanner crab as bycatch than does the pot gear used in the crab fisheries—perhaps even providing support for recruitment events (see, e.g., the peaks in relative abundance at small sizes in the size compositions for 2003/04 and 2004/05; Figure 11).

Raw (number of individuals measured) and scaled sample sizes for size composition data from the various fisheries are presented in Tables 5-7.

d. Survey biomass estimates

Time series trends from the NMFS EBS bottom trawl survey suggest the Tanner crab stock in the EBS has undergone decadal-scale fluctuations (Tables 8-9, Figures12-13). Estimated biomass of male crab in the survey time series started at its maximum (295,000 t) in 1975, decreased rapidly to a low (15,000 t) in 1985, and rebounded quickly to a smaller peak (146,000 t) in 1991 (Table 8). After 1991, male survey biomass decreased again, reaching a minimum of 14,600 t in 1997. Recovery following this decline was slow and male survey biomass did not peak again until 2007 (104,000 t), after which it has fluctuated more rapidly—decreasing within two years by over 50% to a minimum in 2009 (47,000 t), followed by a doubling to a peak in 2014 (109,000 t). Since 2014 the trend has been a steady decline, with male biomass in 2019 at its lowest point (28,000 t) since 2000 (Table 8). Trends in the male and female components of survey biomass have primarily been in synchrony with one another, as have changes in the eastern and western management regions (east and west of 166ºW longitude), although the magnitudes differ (Figure 12). Preferred-size male survey biomass has been declining east of 166ºW (and in the EBS as a whole) since 2014, but was increasing up to 2016 in the west. In the west, it declined in 2017, remained essentially unchanged in 2018, and dropped by over 50% from 2018 to 2019 (Table 9, Figure 13). The ratio of new shell to old shell preferred-size males crab across the EBS has dropped dramatically since 2015, when the ratio was almost 1:1. In 2019, the ratio was almost 1:20 new shell to old shell crab biomass.

Data from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies are incorporated into several model scenarios in this assessment for the first time. During the SBS catchability studies, NMFS performed standard survey tows (e.g., 83-122 trawl gear, 30 minute tow duration) as part of its annual EBS bottom trawl survey while BSFRF performed parallel tows within 0.5 nm using a nephrops trawl and 5 minute tow duration. Because the nephrops trawl has better bottom-tending performance than the 83-112 gear, the BSFRF tows are hypothesized to catch all crab within the net path (i.e., to have selectivity equal to 1 at all crab sizes) and thus provide a measure of absolute abundance/biomass. The spatial footprints of the SBS studies for 2013-2017 are illustrated in Figure 14, while estimates of area-swept biomass for the study areas are compared in Figure 15 for the BSFRF and NMFS tows. Although the BSFRF gear is assumed to provide estimates of absolute abundance with the area surveyed, the relationship between these estimates and Tanner crab stock biomass is confounded by changes in the availability of Tanner crab to the BSFRF gear because the studies did not sample across the entire spatial extent of the population (in contrast to the full NMFS EBS bottom trawl survey).

e. Survey catch-at-length

Bubble plots of NMFS EBS bottom survey size compositions for Tanner crab by sex and fishery region are shown in Figure 16. Distinct recruitment events (late 1970s, early 1990s, mid-2000s, early 2010s and possibly late 2010s) and subsequent cohort progression are evident in the plots, particularly in the western area. The absence of small male crab in the 2010-2016 period is notable, although there is evidence for new recruitment in the western area in 2016-2109, with perhaps some spillover to the eastern area lagged by a year at slightly larger sizes.

Based on the total abundance size compositions from the BSFRF-NMFS SBS studies (Figure 17), the BSFRF nephrops gear is in general (as expected) more selective for Tanner crab, particularly at smaller sizes (< 60 mm CW), than is the NMFS 83-112 gear. However, the size-specific catch ratio of the BSFRF survey to the NMFS survey appears to vary substantially across years, which one would not expect if gear-specific selectivity were, in general, constant. It is worth noting that the nephrops gear appear to give a much better indication of recruitment than the 83-112 gear does (e.g., Figure 17, survey year 2017).

Observed sample sizes for the NMFS survey size compositions, aggregated to the EBS regional level used in the assessment, are presented in Table 10. Given the large number of individuals sampled, a sample size of 200 is used to fit survey size compositions in the assessment model to prevent convergence issues associated with using the actual sample sizes.

f. Other time series data.

Spatial patterns of abundance in the 2014-2019 NMFS bottom trawl surveys are shown in Figure 18 for males and females classified by maturity state. There has been some suggestions that an extensive cold pool in the middle region of the EBS shelf may act to diminish relative crab densities in this region, particularly for mature males. The cold pool on the EBS shelf was extensive during the 2017 survey and absent during the 2018 and 2019 surveys, but the distribution of mature males did not change remarkably.

Annual maturity ogives for new shell males, based on chela height collections from the NMFS EBS bottom trawl survey, are shown in Figure 19 for years in which chela heights were measured to 0.1 mm precision (i.e., since 2006). For each year, chela height:carapace width ratios for individual new shell crab were binned into 10 mm size bins, with the data split based on which management area (east or west of 166ºW longitude) it was collected in. The resulting histograms were analyzed to determine threshold sizes to discriminate mature from immature crab, and the fraction of mature crab was taken as the value of the resulting maturity ogive in the associated size bin (J. Richar, NMFS, pers. comm.). The area-specific ogives were combined to obtain one for the entire EBS by weighting each by the estimated abundance of new shell males in each area by size bin.

Annual effort in the snow crab and BBRKC fisheries is used in the model to "project" bycatch fishing mortality rates backward in time from the period when data on bycatch in these fisheries exists (1992-present). A table of annual effort (number of potlifts) is provided for the snow crab and BBRKC fisheries (Table 11).

3. Data which may be aggregated over time:

a. Growth-per-molt

Molt increment data collected for Tanner crab in the EBS in 2015-2017 and 2019 (Figure 20) is included in the parameter optimization for every model scenario considered in this assessment and is assumed to reflect growth rates over the entire model period.

b. Weight-at size

Weight-at-size relationships used in the assessment model for males, immature females, and mature females is depicted in Figure 21.

c. Size distribution at recruitment

The assumed size distribution for recruits to the population in the assessment model is presented in Figure 22.

4. Information on any data sources that were available, but were excluded from the assessment.

The 1974 NMFS trawl survey was dropped entirely from the standardized survey dataset in 2015 due to inconsistencies in spatial coverage with the standardized dataset. Molt increment data from the Kodiak area in the Gulf of Alaska were not included in the assessment given the current use of molt increment data from the EBS to inform growth estimates. BSFRF survey data focused on Tanner crab recruitment (size compositions) have not yet been incorporated into the assessment.

E. Analytic Approach

1. History of modeling approaches for this stock

Prior to the 2012 stock assessment, Tanner crab was managed as a Tier-4 stock using a survey-based assessment approach (Rugolo and Turnock 2011b). The Tier 3 Tanner Crab Stock Assessment Model (TCSAM) was developed by Rugolo and Turnock and presented for review in February 2011 to the Crab Modeling Workshop (Martel and Stram 2011), to the SSC in March 2011, to the CPT in May 2011, and to the CPT and SSC in September 2011. The model was revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model per recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was reviewed at a second Crab Modeling Workshop. Model revisions were made during the Workshop based on consensus recommendations. The model resulting from the Workshop was presented to the SSC in January 2012. Recommendations from the January 2012 Workshop and the SSC, as well as the authors' research plans, guided changes to the model. A model incorporating all revisions recommended by the CPT, the SSC and both Crab Modeling Workshops was presented to the SSC in March 2012.

In May 2012 and June 2012, respectively, the TCSAM was presented to the CPT and SSC to determine its suitability for stock assessment and the rebuilding analysis (Rugolo and Turnock 2012b). The CPT agreed that the model could be accepted for management of the stock in the 2011/12 cycle, and that the stock should be promoted to Tier-3 status. The CPT also agreed that the TCSAM could be used as the basis for rebuilding analyses to underlie a rebuilding plan developed in 2012. In June 2012, the SSC reviewed the model and accepted the recommendations of the CPT. The Council subsequently approved the SSC recommendations in June 2012. For 2011/12, the Tanner crab was assessed as a Tier-3 stock and the model was used for the first time to estimate status determination criteria and overfishing levels.

Modifications were to the TCSAM computer code to improve code readability, computational speed, model output, and user friendliness without altering its underlying dynamics and overall framework. A detailed description of the 2013 model (TCSAM2013) is presented in Appendix 3 of the 2014 SAFE chapter (Stockhausen, 2014). Following the 2014 assessment, the model code was put under version control using "git" software and is publicly available for download from the GitHub website[1].

The current model "framework", TCSAM02, was reviewed by the CPT and SSC in May/June 2017 and adopted for use in subsequent assessments as a transition to Gmacs. This framework is a completely-rewritten basis for the Tanner crab model: substantially different model scenarios can be created and run by editing model configuration files rather than modifying the underlying code itself. Most importantly, no time blocks are "hard-wired" into the code—any time blocks are defined in the configuration files. In addition, the framework has been used to incorporate new data types (molt increment data, male maturity ogives), new survey data (the BSFRF surveys), and new fishery data (bycatch in the groundfish fisheries by gear type). The framework also incorporates status determination and OFL calculations directly within a model run, so a follow-on, stand-alone projection model does not need to be run (as was the case with TCSAM2013). This approach has the added benefit of allowing a more complete characterization of model uncertainty in the OFL calculation, because the OFL calculations are now included in the Markov Chain Monte Carlo (MCMC) evaluation of a model's posterior probability distribution.

Most recently, the model code has been restructured to function in a management strategy evaluation (MSE) mode and allow retrospective analyses. The code for the TCSAM02 model framework is publicly available on GitHub[2].

2. Model Description

a. Overall modeling approach

TCSAM02 is a stage/size-based population dynamics model that incorporates sex (male, female), shell condition (new shell, old shell), and maturity (immature, mature) as different categories into which the overall stock is divided on a size-specific basis. For details of the model, the reader is referred to Appendix 1.

In brief, crab enter the modeled population as recruits following the size distribution in Figure 22. An equal (50:50) sex ratio is generally assumed at recruitment (although can be set otherwise or estimated), and all recruits begin as immature, new shell crab. Within a model year, new shell, immature recruits are added to the population numbers-at-sex/shell condition/maturity state/size remaining on July 1 from the previous year. These are then projected forward to Feb. 15 ($\delta t = 0.625$ yr) and reduced for the interim effects of natural mortality. Subsequently, the various fisheries that either target Tanner crab or catch

[1] https://github.com/wStockhausen/wtsTCSAM2013.git

[2] https://github.com/wStockhausen/wtsTCSAM02.git

them as bycatch are prosecuted as pulse fisheries (i.e., instantaneously). Catch by sex/shell condition/maturity state/size in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries is calculated based on fishery-specific stage/size-based selectivity curves and fully-selected fishing mortalities and removed from the population. The numbers of surviving immature, new shell crab that will molt to maturity are then calculated based on sex/size-specific probabilities of maturing, and growth (via molt) is calculated for all surviving new shell crab. Crab that were new shell, mature crab become old shell, mature crab (i.e., they don't molt) and old shell crab remain old shell. Population numbers are then adjusted for the effects of maturation, growth, and change in shell condition. Finally, population numbers are reduced for the effects of natural mortality operating from Feb. 15 to July 1 ($\delta t = 0.375$ yr) to calculate the population numbers (prior to recruitment) on July 1.

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components in the base model entering the likelihood include fits to mature survey biomass, survey size compositions, retained catch, retained catch size compositions, bycatch mortality in the bycatch fisheries, and bycatch size compositions in the bycatch fisheries.

b. Changes since the previous assessment.

The model code has been revised to facilitate retrospective analyses and to allow the user to specify the time period for calculating average recruitment. In addition, selectivity curves based on the normal or "double normal" have been implemented, as has the option to use fit selectivity curves using splines.

i. Methods used to validate the code used to implement the model

The TCSAM02 model framework was demonstrated to produce results that were exactly equivalent to those from the 2016 assessment model incorporating the changes listed in the previous table. TCSAM02 also underwent a review in July 2017 conducted by the Center for Independent Experts and has been further reviewed by the CPT in May 2017 and September 2017. Changes to model code are validated against results from the previous assessment model to ensure that modifications do not change the results of the previous assessment.

3. Model Selection and Evaluation

a. Description of alternative model configurations

The model selected for the 2019 assessment (Model 19F03 from Stockhausen 2019) provides the baseline model configuration for subsequent alternative model scenarios evaluated in this assessment. Here, the 2019 assessment model is referred to as "19.03" in accordance with SSC guidelines on model numbering. The following tables provide a summary of the baseline model configuration, 19.03, for this assessment.

Model 19.03: Description of model population processes and survey characteristics.

process	time blocks	description
Population rates and quantities		
Population built from annual recruitment		
Recruitment	1949-1974	ln-scale mean + annual devs constrained as AR1 process
	1975+	ln-scale mean + annual devs
Growth	1949+	sex-specific
		mean post-molt size: power function of pre-molt size
		post-molt size: gamma distribution conditioned on pre-molt size
Maturity	1949+	sex-specific
		size-specific probability of terminal molt
		logit-scale parameterization
Natural mortalty	1949-1979,	estimated sex/maturity state-specific multipliers on base rate
	1985+	priors on multipliers based on uncertainty in max age
	1980-1984	estimated "enhanced mortality" period multipliers
Surveys		
NMFS EBS trawl survey		
male survey q	1975-1981	ln-scale
	1982+	ln-scale w/ prior based on Somerton's underbag experiment
female survey q	1975-1981	ln-scale
	1982+	ln-scale w/ prior based on Somerton's underbag experiment
male selectivity	1975-1981	ascending logistic
	1982+	ascending logistic
female selectivity	1975-1981	ascending logistic
	1982+	ascending logistic

Model 19.03: Description of model fishery characteristics.

Fishery/process	time blocks	description
TCF	directed Tanner crab fishery	
capture rates	pre-1965	male nominal rate
	1965+	male ln-scale mean + annual devs
	1949+	ln-scale female offset
male selectivity	1949-1990	ascending logistic
	1991-1996	annually-varying ascending logistic
	2005+	annually-varying ascending logistic
female selectivity	1949+	ascending logistic
male retention	1949-1990, 1991-1996, 2005-2009, 2013-2015, 2017	ascending logistic
SCF	bycatch in snow crab fishery	
capture rates	pre-1978	nominal rate on males
	1979-1991	extrapolated from effort
	1992+	male ln-scale mean + annual devs
	1949+	ln-scale female offset
male selectivity	1949-1996	dome-shaped
	1997-2004	dome-shaped
	2005+	dome-shaped
female selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005+	ascending logistic
RKF	bycatch in BBRKC fishery	
capture rates	pre-1952	nominal rate on males
	1953-1991	extrapolated from effort
	1992+	male ln-scale mean + annual devs
	1949+	ln-scale female offset
male selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005+	ascending logistic
female selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005+	ascending logistic
GTF	bycatch in groundfish fisheries	
capture rates	pre-1973	male ln-scale mean from 1973+
	1973+	male ln-scale mean + annual devs
	1973+	ln-scale female offset
male selectivity	1949-1986	ascending logistic
	1987-1996	ascending logistic
	1997+	ascending logistic
female selectivity	1949-1986	ascending logistic
	1987-1996	ascending logistic
	1997+	ascending logistic

Model 19.03: Description of model likelihood components.

Name	Component	Type	included in optimization	Distribution	Likelihood
19.03	TCF: retained catch	abundance	no	lognormal	males only
		biomass	yes	norm2	males only
		size comp.s	yes	multinomial	males only
	TCF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	SCF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	RKF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	GTF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	NMFS "M" survey (males only, no maturity)	abundance	no	lognormal	all males
		biomass	yes	lognormal	all males
		size comp.s	yes	multinomial	all males
	NMFS "F" survey (females only, w/ maturity)	abundance	no	lognormal	by maturity classification
		biomass	yes	lognormal	by maturity classification
		size comp.s	yes	multinomial	by maturity classification
	growth data	EBS only	yes	gamma	by sex
	male maturity ogive data	EBS only	yes	binomial	males only

The NMFS “M” survey refers to a male-only “flavor” of the NMFS survey data in which maturity is not determined outside the model (males in the M survey have “undetermined” maturity). The NMFS “F” survey is simply the female portion of the NMFS survey data configured as a separate data file to accompany the NMFS “M” survey data file.

The following model scenarios are described as part of this assessment:

model scenario	number of parameters	objective function value	max gradient	Jitter runs	# runs converged to MLE	scenario description
19.03 (2019)	343	3,228.46	0.0001	--	--	2019 assessment model (M19F03)
19.03R	343	3,169.69	0.0004	--	--	19.03 with updated 2016/17-2018/19 groundfish bycatch data
19.03 (2020)	347	3,155.40	0.0003	400	24	19.03R with 2019/20 data
20.07	349	3,429.39	0.0003	400	47	19.03 + empirical SBS availability curves
20.10	341	3,747.27	0.0007	--	--	19.03 + empirical NMFS survey selectivity curves from SBS studies

Scenario 19.03R represents a check on the revised estimates for Tanner crab bycatch in the groundfish fisheries from 2016/17 to 2018/19. It does not include 2019/20 data and simply allows the incremental step associated with this change to be accounted for. Scenario 19.03(2020) updates the available data (bycatch in the snow crab, BBRKC, and groundfish fisheries) for the 2019/20 crab fishery year. Scenario 20.07 was recommended by the CPT as a scenario to consider basing the assessment upon after they reviewed results with 2019/20 data during the May 2020 CPT meeting. This scenario fits biomass and size composition estimates from the 2013-2017 BSFRF SBS catch ratio comparison studies along with

the standard NMFS EBS shelf bottom trawl survey data to try to better estimate NMFS survey catchability. Year-specific availability curves for the BSFRF data were determined outside the model using the ratio of expanded (area-swept) estimates of abundance-by-5 mm CW size classes derived from NMFS survey data at stations at which SBS tows were conducted to those derived from NMFS survey data for the entire survey grid (Figures 23 and 24; Appendix 3). Estimating the availability curves outside the model was reasonably straightforward and vastly reduced the number of model parameters that would otherwise be necessary.

Scenario 20.10 represents another approach suggested by the CPT to using the BSFRF SBS data (Appendix 4). In this case, size-specific catch ratio analysis is performed outside the model using the BSFRF and NMFS data from SBS tows to directly estimate the size-specific selectivity of the NMFS survey. The estimated curve(s) are then used directly in the assessment, rather than having to estimate survey selectivity (and fully-selected catchability) inside the model. For this scenario, sex-specific selectivity curves were estimated by evaluating the fits of a logistic curve and cubic splines of different degrees of freedom to the size-specific catch ratios from all SBS hauls and the selecting the "best" overall model, similar to that done by Somerton et al (2013, 2017) for snow crab. For females, the "best" model selected on the basis of BIC was a spline with 5 degrees of freedom (Figure 25). For males, the "best" model selected on the basis of BIC was a spline with 8 degrees of freedom (Figure 26). However, this analysis is incomplete (environmental factors such as depth and sediment type need to be incorporated into the analysis) and the selectivity curves used for this scenario are provisional, at best. As such, Scenario 20.10 should not be regarded as a viable candidate for status determination and OFL calculation.

The number of estimated parameters, the final value of the objective function for each converged scenario and the maximum gradient of the objective function at the converged solution are listed table above. However, the total objective function values can only be directly compared between scenarios 19.03(2020) and 10.07, because the other scenarios do not fit identical datasets. Convergence for the two scenarios under consideration for status determination and OFL-setting (19.03 and 20.07) was evaluated using parameter jittering, with a total of 400 runs initiated for each scenario. Of these runs, generally a large number failed to converge because initial starting values led to negative growth increments at some point in the search for the MLE solution, while a smaller number converged to local minima larger than the maximum likelihood (ML) solution (i.e., the global *minimum* of the objective function). About 5% of the runs found the (presumed) ML solution in 19.03(2020) and about 10% did so for 20.07. In the interest of time and computing resources, the other scenarios were not subjected to jittering.

Scenario 20.07 is the author's preferred scenario, as justified below.

b. Progression of results from the previous assessment to the preferred base model

The following table summarizes basic model results based on the MLE from the 2019 assessment model (19.03) and the 3 scenarios considered here in detail. The author's preferred scenario is 20.07.

case	average recruitment millions	Bmsy (1000's t)	current MMB (1000's t)	Fmsy per year	MSY (1000's t)	Fofl per year	OFL (1000's t)	projected MMB (1000's t)	status ratio
19.03	393.84	41.64	82.61	1.18	19.49	1.12	29.51	39.73	0.95
19.03(2020)	383.96	40.39	77.76	1.14	18.90	1.11	26.15	39.38	0.98
20.07	374.43	36.77	66.87	0.98	16.94	0.94	21.13	35.33	0.96
20.10	1,047.74	39.94	72.37	1.68	21.55	1.44	24.18	34.98	0.88

c. Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models.

Scenarios 20.07 and 20.10 represent simplifications to a "full" model (e.g., M19F05 from the 2019 assessment) that incorporated the BSFRF and NMFS SBS data simultaneously into the assessment to estimate NMFS survey selectivity but also required estimating size-specific annual availability in the SBS study areas at the cost of hundreds of additional parameters (~50 parameters for each year the SBS studies were conducted). In particular, 20.10 eliminated 6 parameters (4 selectivity parameters and 2 catchability parameters) used in 19.03(2020), but at a cost of ~600 likelihood units of worse overall fit.

In addition to these scenarios, a number of other models were evaluated in the interim between the May and September 2020 CPT meetings in an effort to identify a working model with reduced complexity but realistic dynamics. The simplest of these was a single-sex model which incorporated fits to catch data from only the directed and snow crab fisheries and re-parameterized logistic and double-logistic selectivity functions to normal and double-normal ones. Results from this (and several other) models indicated a strong confounding between estimated natural mortality rates and survey catchability, both of which affect (or are affected by) estimates of mean recruitment. The extent of this confounding needs to be characterized more fully in the future in order to better understand tradeoffs in the actual assessment model.

d. Convergence status and convergence criteria

As noted above, convergence in the two candidate scenarios (19.03[2020] and 20.07) for possible use to determine status and OFL was assessed by running each model 400 times with randomly-selected ("jittered") initial parameter values for each run. For both models, most of these jitter runs failed—primarily because the initial values eventually led to estimated growth parameters that resulted in negative mean molt increments. Of those that converged, the run with the smallest objective function value and smallest maximum gradient was selected as the "converged" model, if it was also possible to invert the associated hessian and obtain standard deviation estimates for parameter values. Theoretically, all gradients at a minimum of the objective function should be zero. However, because numerical methods have finite precision, the numerical search for the minimum is terminated after either achieving a minimum threshold for the maximum gradient or exceeding the maximum number of iterations. As noted previously, about 5% of jittered runs converged to the presumed MLE for scenario 19.03(2020) while 10% did so for 20.07.

e. Sample sizes assumed for the compositional data

Actual and input sample sizes used for compositional data are listed in Tables 5-7 for fishery-related size compositions. Actual samples sizes for survey size compositions are listed in Table 10. Input sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for fishery-related input sample sizes. Otherwise, input sample sizes were scaled as described in Stockhausen (2014, Appendix 5) using the formula:

$$SS_y^{inp} = \min\left(200, \frac{SS_y}{(\overline{SS}/200)}\right)$$

where $\overline{SS}$ is the mean sample size for all males from dockside sampling in the directed fishery.

f. Parameter sensibility

Limits were placed on all estimated parameters in all model scenarios primarily to provide ranges for jittering initial parameter values. Although these limits, for the most part, did not constrain parameter estimates in the converged models, some parameters were found to be at, or very close, to one of the bounds placed on them. These parameters are listed for the scenarios in Table 12. The CPT and SSC have both expressed concerns regarding parameters estimated at their bounds, as such results frequently violate assumptions regarding model convergence, parameter uncertainty estimates, and suggest that model suitability may be improved by widening the bounds or re-parameterizing the model. Estimates of parameter uncertainty based on inverting the model hessian and using the "delta" method were also obtained from each converged model's ADMB "std" file (Tables 13-23).

Of the scenarios considered in detail here, 19.03 and 19.03(2020) had the same 12 parameters estimated at a bound, 20.07 had 8 of these parameters estimated at a bound, as well as 3 others for 11 total, but 20.10 had only 5 parameters at bounds—and these were all at a bound in the other scenarios. The 5 parameters at a bound common among all these scenarios were: 1) a logit-scale parameter (pLgtRet[1]) at its upper bound (15) used to estimate maximum retention in the directed fishery prior to 1997; 2) two parameters (pS1[23], pS1[24]) at their upper bounds (180) describing the size at 95% selection for male bycatch in the BBRKC fishery during the periods 1997-2004 and 2005-2019, respectively; and 3) parameters (pS2[10] and pS4[1]) at their lower bounds (0.1) describing the ascending and descending slopes, respectively, of the double-logistic functions used to describe male bycatch selectivity in the snow crab fishery before 1997. Given the nature of these parameters, the first two of these may reflect reasonable structural limits in the fisheries: 1) large males in the directed fishery are highly prized and essentially always retained and 2) the larger mesh used in pots targeting BBRKC is such that selectivity for large male Tanner crab never reached an asymptote within the size range used in the model (25-185 mm CW) during the periods in question. The lower bound (0.1) for the two parameters characterizing the ascending and descending slopes of the double logistic selectivity function for males in the pre-1997 snow crab fishery should be decreased to allow greater "spread" in this function.

In scenarios 19.03(2020) and 20.07, the sex-specific parameters (pQ[1] and pQ[3]) were estimated at their lower bounds (ln(0.5)), as has been the case in almost all Tanner crab assessments to date. These parameters reflect ln-scale survey catchability during the 1975-1981 time period prior to the survey gear change to the 83-112 bottom trawl net. Previously, the chosen bounds seemed reasonable given the spatial limits of the Tanner crab stock and the reduced areal coverage of these pre-1982 surveys relative to those conducted after 1981 because an early estimate of fully-selected catchability using the 83-112 net was ~0.9 (Somerton et al. 1999). However, preliminary results from the BSFRF-NMFS SBS catch ratio studies suggest that fully-selected Q for Tanner crab in the current NMFS survey may be < 0.5 so the lower bounds on catchability during the pre-gear change time period should definitely be reduced. This is supported by results from Scenario 20.10, in which the lower bounds on these parameters were decreased and estimates were obtained that did not hit them (Table 13).

Another survey-related parameter, pS2[4] describing the size difference between female crab at 50% and 95% selected, was estimated at its upper bound in the post-gear change time period (1982-present) in both 19.03(2020) and 20.07. The resulting selectivity curve (see Figure 48) from 20.07 seems reasonable in that small crab are much less well-selected than larger females, but the curve from 19.03(2020) seems less so because it is relatively flat across all size ranges.

Scenarios 19.03(2020) and 20.07 also had a parameter describing the size-at-95% selectivity for females in the BBRKC fishery since 2005 at its upper bound (140 mm CW, which is larger than any seen in the NMFS survey). This may be the result of a simplifying assumption (that eliminates a number of extra parameters) that fully-selected fishing mortality on females in the BBRKC fishery is a scaled version of that on males. However, similar selectivity parameters applying to both males and females taken in the BBRKC fishery during different time periods were very poorly estimated, if not at a bound (pS1[23-27], Table 13).

Scenario 19.03(2020) estimated three additional parameters at bounds that 20.07 did not. These were the male size-at-50% selected in the NMFS survey prior to 1982 (pS1[1]) at its upper bound, the male size-at-50% selected in the groundfish fisheries during the 1987-1996 time period (pS1[20]) at its lower bound, and the difference between the sizes at 50%- and 95%-selected for males in the NMFS survey after 1981 (pS2[2]) at its upper bound. Scenario 20.07 was able to estimate all of these parameters reasonably well (Table 13). Conversely, the molt increment uncertainty parameter pGrBeta[1] (the scale factor for a gamma distribution) and the selectivity parameter pS1[4] (the size at 50% selected for females in the

NMFS survey in the 1982+ time period) were estimated at bounds in Scenario 20.07 but not in 19.03(2020), although the estimates of pS1[4] in 19.03(2020) were highly uncertain.

A few other parameters exhibited rather large uncertainties, as well. Among these, the logit-scale parameters that characterized fully-selected retention in the directed fishery (pLgtRet) exhibited large standard errors for all model scenarios (Table 13). The associated estimated values (~15) imply that fully-selected retention was essentially 1 in all time periods. In the future, these parameters will be fixed such that maximum retention is 1. Another notable parameter with large uncertainty across all scenarios was the estimated ln-scale recruitment deviation for recruits entering the population on July 1, 2020 (Table 15, last row). Clearly this is a result of the missing 2020 NMFS EBS survey, which is generally the only source of information on recruitment.

Although the overall likelihood cannot be compared across models here, individual components to the likelihood can be, if the underlying data is the same among the models. Data-related components to the likelihood are documented in Table 24; non-data components (penalties and priors) are documented in Table 25. Scenario 19.03(2020) fits the data better than Scenario 20.07 in six categories, while the reverse is true for two categories, and both fit similarly in 17 categories. Both scenarios exhibit similar likelihood penalties and prior likelihoods (Table 25), except the prior on the natural mortality multiplier for mature females (pDM1[3]) is much larger (~14 likelihood units) for Scenario 20.07 while the prior on fully-selected female catchability in the NMFS survey after 1981 (pQ[4]) is much larger ($55 likelihood units) for Scenario 19.03(2020).

Root mean square errors (RMSEs) for fits to biomass time series data are given in Table 26. Scenario 19.03(2020) generally had smaller RMSEs (better fits) across the data sources than 20.07 (17 out of 23 categories), but the differences were small. For size composition data, geometric means of effective sample sizes based on the McAllister-Ianelli method are presented in Table 27. For the most part, the effective N's for different data sources were very similar between 19.03(2020) and 20.07, although 20.07 had noticeably higher effective N's for male size compositions from the NMFS survey and retained catch size compositions, while 19.03(2020) had the higher N for male total catch size compositions in the directed fishery.

g. Criteria used to evaluate the model or to choose among alternative models

Scenarios 19.03(2020) and 20.07 are the two candidates on which to base status determination and OFL calculation—as noted previously, 20.01 should be considered a research scenario pending further development. These two models are not directly comparable on the basis of total likelihood because 20.07 includes the BSFRF SBS data in the model fitting whereas 19.03(2020) does not. However, one can look at individual components in the likelihood and summary statistics such as RMSEs and effective N's (discussed above). In this regard, 19.03(2020) appears to fit the data shared by both scenarios slightly better than 20.07, but this is understandable given that 20.07 is also constrained to fit the BSFRF data. More importantly, 20.07 does incorporate the BSFRF SBS data into the fitting procedure. These data are an important addition to the NMFS EBS bottom trawl data because it is assumed they provide estimates of absolute abundance within the SBS study areas and thus provide a measure of absolute scale lacking in the NMFS data. And this addresses one of the more fundamental problems with the assessment model, and that has been the sensitivity of estimates of fully-selected survey catchability to new data, leading to an annually changing baseline for status determination. Finally, neither scenario stands out from the other in regards to lack of sensible parameter values or biological realism.

h. Residual analysis

Standardized residuals to model fits were plotted and examined for all data components, including datasets that were not included (weighted 0) in the model objective function. Due to the large number of plots involved, these were created programmatically using the R package "rmarkdown" (R Core Team, 2020; Xie et al., 2020) and converted to pdf format. They are provided as appendices to the chapter. Standardized residuals for model fits to fishery data are given in Appendix 5, while standardized residuals for model fits to NMFS and BSFRF SBS data are given in Appendix 6. Standardized residuals for model fits to molt increment and male maturity ogive data are given in Appendix 7.

i. Evaluation of the model(s)

All scenarios fit the retained and total fishery catch biomass time series quite well (Figures 27-31). Z-scores for standardized residuals (Appendix 5) are all between -1 and 1, perhaps indicating a small tendency to overfit these data. The only concern is that the similar lack-of-fit to bycatch biomass in the groundfish fisheries during the early 1990s across all models indicates the possibility of an issue with the transition between historical datasets for bycatch in the groundfish fisheries and implementation of the Catch Accounting System in 1990 or a conflict with the bycatch data in the crab fisheries which starts in 1990 (Figure 32).

Normal distributions were assumed for all fishery catch biomass likelihoods in all model scenarios, with a standard deviation of 0.22 thousand t in order to fit the time series well. Consequently, the assumed sampling error is independent of catch size, which seems unlikely given the range of observed values across the fisheries, ranging from almost 0 to over 35 thousand t. Given the small levels of female bycatch observed in most of the fisheries, these data consequently have little effect on model convergence (which may be a worthwhile simplification considering that capture rates on fully-selected females are assumed to have the same temporal pattern as those for males). Using a lognormal assumption with fixed cv's as an alternative would align the error assumptions for fishery data with those made for survey data, but it would also reduce the relative influence of large catches over small ones—which may be undesirable in that it increases the arithmetic uncertainty associated with large removals from the population.

Except for the groundfish fisheries, catch abundance data is not fit in the model, but it does provide a diagnostic contrast to the fits to the biomass data. Comparison of model predictions with retained and total catch abundance in the fisheries are given in Appendix 5. All model scenarios over-predict the number of retained crab in the foreign fleets period prior to 1980. However, these data were based on IPHC reports and subject to considerable uncertainty. It seems likely that some sort of average retained male weight was used to convert biomass to abundance, in which case the average male retained prior to 1980 was heavier than those retained subsequently. Fits to total catch abundance from the fisheries seem remarkably good, considering that the data from the crab fisheries are not actually fit. However, the estimates of total catch biomass in the crab fisheries are converted from estimates of total catch abundance by applying annual mean weights based on size compositions. Therefore, the abundance and biomass data are redundant to one another.

Scenarios 19.03(2020) and 20.07 essentially fit the NMFS survey biomass time series data equally well (Figure 32), except for males in the 1975-1980 period. In this period, 19.03(2020) follows lower observations in 1976-78 while 20.07 follows higher observations in 1975 and 1980. A pattern both scenarios follow after 1990 is to underestimate the periods of high observed biomass and overestimate the periods of lower abundance. Z-scores (Appendix 6, Figures 19 and 20) reflect these observations, as well. While the biomass trajectories both scenarios follow are very similar in nature, the associated predicted survey abundance trajectories show a few more differences, with 20.07 exhibiting slightly less in the way of variability with respect to 19.03(2020). Scenario 20.07 also fits the BSFRF SBS survey biomass data well (Figure 33).

Both scenarios also fit the molt increment and maturity ogive data similarly (Figures 34 and 35, respectively). Both scenarios overpredict growth for females at small and large crab sizes, but underpredict growth at intermediate sizes (Figure 3 in Appendix 7,), which may be related to differences in growth of terminal molting crab. Also, both scenarios overpredict growth of male crab, with residuals increasing with pre-molt crab size (Figure 3 in Appendix 7). Results from fitting the molt increment data outside the model are similar for females to those from fitting the data inside the model, but not for males. There is no increasing bias with crab size when fitting the male data outside the model. Model runs have been conducted with growth fixed outside the model, but this gives rise to much poorer fits to size composition data. Fits to the maturity ogive data are similar for both scenarios (Figure 35 and Appendix 7).

Fits to retained catch size compositions are essentially identical and quite good for Scenarios 19.03(2020). and 20.07 (Figures 22-25 in Appendix 8). There are some slight (but identical) misfits in some years (e.g., 2005) when only one, but not both, of the directed fisheries was open. Fits could no doubt be slightly improved by allowing the retention curves to be estimated annually, rather than constant within a time block. Fits to total catch size compositions from the directed fishery (Figures 26-31 in Appendix 8) are also essentially identical among the scenarios, but more variable with respect to the data, with the fit in 1996 looking particularly poor (it was a year with very low sample sizes). Also, the predicted size compositions consistently overpredict larger size classes for males after 2013. This coincides with a relative increase in catch in the directed fishery west of 166ºW longitude, in which case the underlying selectivity pattern may have changed from an (assumed) asymptotic one (estimated as a logistic curve) to a dome-shaped one because larger males tend to be east of 166ºW longitude. Predicted bycatch size compositions for females in the directed fishery are also identical across scenarios and exhibit good fits to the data (Figures 29-31 in Appendix 8).

Predicted bycatch size compositions for the snow crab and BBRKC fisheries are likewise identical across scenarios (Figures 32-37 and 48-53, respectively, in Appendix 8). Fits to the male size composition data from the snow crab fishery are fairly poor in the early 1990s, with predictions overestimating the proportions small crab in the catch in 1992-1996, but the fits improve after 1997 for the most part (2002 and 2004 being notable exceptions with underpredicted proportions of small crab). Fits to female size composition data in the snow crab fishery are moderately good, with small variations in patterns of over- or under-prediction, but nothing dramatic. Fits to the male size composition data from the BBRKC fishery are also poor in the early 1990s, with predictions consistently overestimating the proportions small crab in the catch in 1990-1997. Then from 1999-2007, and from 2016-2019, the models overestimate the proportions of large crab taken. Somewhat unexpectedly, the fits to female size compositions from the BBRKC fishery seem to be more consistent than for males. However, sample sizes are generally very small (3 in 2019; Table 6) and trying to estimate a selectivity curve from this data may be futile (as evidenced by the associated parameters ending at bounds or exhibiting large uncertainty estimates).

Predicted bycatch size compositions for the groundfish fisheries are the most variable across the scenarios, although this is because Scenario 20.10 tends to be a bit different from the others (Figures 38-47 in Appendix 8). The fits to the data also tend to be the most variable among the fisheries, which may reflect the selectivity characteristics and relative importance to the total bycatch of different gear types that are currently lumped as “groundfish fisheries”.

Estimated capture rates in the directed fishery (Figure 36) follow the same temporal patterns in all scenarios, with the largest peak in 1979 or 1980 and a lesser peak in 1992. However, the relative levels vary among the scenarios, reflecting differences in recruitment (see below) rather than differences in estimated size-specific capture functions (Figures 37) or retention functions (Figure 38), which are essentially identical.

Estimated capture rates in the snow crab (Figure 39), BBRKC (Figure 41), and groundfish fisheries (Figure 43) also exhibited similar temporal patterns but with different scales across the scenarios. Estimated sex-specific bycatch selectivity functions in the snow crab and BRKC fisheries were essentially identical across the scenarios in the time periods for which they were defined (Figures 40 and 42). The selectivity curves for bycatch in the groundfish fisheries differed the most among the scenarios, but this amounted to a consistent shift of the male selectivity curves from 2019.03(2020) by ~10 mm CW to smaller sizes in 20.07 in each of the three time periods selectivity was estimated. Selectivity curves for females were similarly shifted, but by a lesser amount.

Overall, the most dramatic differences among the scenarios were exhibited for NMFS survey selectivity and fully-selected catchability estimates (Figures 45-48). The selectivity curves for males in the period before 1982 for Scenarios 19.03(2020) and 20.10 both had the small values in the smallest model size class (25 mm CW), but the curve for 19.03(2020) was essentially a linearly increasing function to 1 at 185 mm CW, whereas it approached it's asymptote of 1 at much smaller sizes (near 75 mm CW) for 20.10. The curve for 20.10 seems better estimated, given that the size at 95% selected parameter for this curve in 19.03(2020) was estimated at it upper bound. The selectivity curves for males in the 1982+ time period from the two scenarios are far more similar to each other. For females, the selectivity curves from the two scenarios are similar in the 1975-1981 period, but differ substantially in the 1982+ time period. For the latter time period, the selectivity curve from 19.03(2020) is almost flat across the model size range, suggesting that the survey is not size-selective for females, whereas it is more S-shaped for 20.01. When fully-selected catchability is applied (Figure 48), the catchability at small sizes is similar—but as crab size increases it essentially remains the same in Scenario 19.03(2020) while it increases across the size range in Scenario 20.07.

Parameter estimates for biological processes in the model (natural mortality, growth, and terminal molt) are generally similar for Scenarios 19.03(2020) and 20.07 (Figures 51-53), except in the case of natural mature male natural mortality in the "enhanced" mortality time block (1980-1984). In this case, "M" is estimated as 15% smaller in 20.07 compared with that in 19.03(2020).

The estimated recruitment time series exhibit the same basic fluctuations across the model time period, but the scale, and some of the fine details, differ among the scenarios (Figures 54 and 55). The time series estimated in Scenarios 19.03(2020) and 20.07 are very similar in the time period from 1980 to 2002, but differences are apparent before 1980 and after 2002 (Figure 54). However, estimated peaks in recruitment in 2008 and 2018 are almost identical, although estimates in the interim are somewhat different. One effect of the missing 2020 NMFS EBS shelf bottom trawl survey is not evident in the recruitment estimates shown in Figure 54 for 2019 (i.e., those that enter the population at the start of 2020): the estimated ln-scale rec dev for 2019 is 0 for all three 2020 model scenarios, but the estimate is also highly uncertain (~22 on the ln-scale!) because, without the survey data, there is nothing in the remaining data for 2019/20 to constrain the estimate.

Not surprisingly, then, estimates of the time series of mature biomass differ across the scenarios—again, the temporal variations are similar but the scales are different (Figure 56 and 57). "Current" MMB is about 15% smaller in Scenario 20.07 than in 19.03(2020).

The author's preferred model is 20.07 because it fits all of the datasets reasonably well and includes the BSFRF SBS data , which provides a measure of absolute scale for the NMFS EBS shelf bottom trawl survey data that the base model, 19.03(2020), does not.

4. Results (best model(s))

Scenario 20.10 was selected as the author's preferred model for the 2020 assessment.

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties.

Effective sample sizes for size composition data fit in the model are listed in Table 27. A weighting factor of 20 (corresponding to a standard deviation of 0.158) was applied to all fishery catch biomass likelihood components to achieve close fits to the catch biomass time series.

b. Tables of estimates:

i. All parameters

Parameter estimates and associated standard errors, based on inversion of the converged model's Hessian, are listed in Tables 13-23.

ii. Abundance and biomass time series, including spawning biomass and MMB.

Estimates for mature survey biomass are listed in Tables 28 and 29 for males and females, respectively. Estimates for mature biomass at mating are listed in Tables 30 and 31. Due to the size of the tables, the numbers at size for females and males by year in 5 mm CW size bins for scenario M19F03 are available online as zipped csv files (as noted in the caption for Table 32).

iii. Recruitment time series

The estimated recruitment time series from the scenarios are listed in Table 33.

iv. Time series of catch divided by biomass.

Time series of catch divided by biomass (i.e., exploitation rate) are listed in Table 34.

c. Graphs of estimates

Graphs of estimated quantities are shown in Figures 36-59 and have been discussed above in the "Model Selection" section.

i. Fishery and survey selectivities, molting probabilities, and other schedules depending on parameter estimates.

Graphs of estimated selectivity for the directed fishery are shown in Figure 37, for the snow crab fishery in Figure 40, for the BBRKC fishery in Figure 42, and for the groundfish fisheries in Figure 44. Estimated retention curves are shown in Figure 38. Graphs of selectivity and catchability curves for the NMFS survey are shown Figures 45-48 and graphs of the annual availability curves from the BSFRF-NMFS SBS studies (estimated outside the model) used in Scenario 20.07 are shown in Figures 49 and 50. Natural mortality estimates are shown in Figure 51, terminal molt probabilities are shown in Figure 52, and mean growth rates (molt increments) are shown in Figure 53.

iii. Estimated full selection F over time

Graphs of time series of estimated fully-selected F (total catch *capture rates*, not mortality) on males in the directed fishery and bycatch in the snow crab, BBRKC and groundfish fisheries are shown in Figures 36, 39, 41, and 43.

ii. Estimated male, female, mature male, total and effective mature biomass time series

Estimates of the time trends in population biomass for mature and immature components of the stock are shown by sex in Figure 58. Mature male and female biomass trends (MMB and MFB) are shown in Figures 56 and 57.

iv. Estimated fishing mortality versus estimated spawning stock biomass

Estimated fishing mortality is plotted against spawning stock biomass (MMB) for the author's preferred model, 20.07, in Figure 68.

v. Fit of a stock-recruitment relationship, if feasible.

Fits to a stock-recruit relationship were not evaluated.

e. Evaluation of the fit to the data:

i. Graphs of the fits to observed and model-predicted catches

Graphs of fits to observed catches are provided in Figures 27 and 28 for retained and total catch, respectively, in the directed fishery, as well as in Figures 29-31 for total catch in the snow crab, BBRKC, and groundfish fisheries. Fits to NMFS survey biomass are shown in Figure 32, while fits to the BSFRF SBS survey biomass are shown in Figure 33.

ii. Graphs of model fits to survey numbers

See Appendix 6 for graphs of observed and predicted survey abundance time series, including graphs of standardized residuals.

iii. Graphs of model fits to catch proportions by size class

Due to the large number of plots involved, these were created programmatically using the R package “rmarkdown” (RCore Team, 2020; Xie e tal., 2018) and converted to pdf format. They are provided as an appendix to the chapter. See Appendix 8 for model fits to annual catch proportions by size class for both fishery and survey data.

iv. Graphs of model fits to survey proportions by size class

Due to the large number of plots involved, these were created programmatically using the R package “rmarkdown” (RCore Team, 2020; Xie e tal., 2018) and converted to pdf format. They are provided as an appendix to the chapter. See Appendix 8 for model fits to annual survey proportions by size class.

v. Marginal distributions for the fits to the compositional data.

Due to the large number of plots involved, these were created programmatically using the R package “rmarkdown” (RCore Team, 2020; Xie e tal., 2018) and converted to pdf format. They are provided as appendices to the chapter. See Appendix 9 for marginal distributions of fits to the fishery compositional data. See Appendix 10 for marginal distributions of fits to the survey compositional data.

vi. Plots of implied versus input effective sample sizes and time-series of implied effective sample sizes.

See Appendix 9 for time-series of implied effective sample sizes for the fishery compositional data. See Appendix 10 for time-series of implied effective sample sizes for the survey compositional data.

vii. Tables of the RMSEs for the indices (and a comparison with the assumed values for the coefficients of variation assumed for the indices).

Root mean square error (RMSEs) for fits to various datasets are provided in Table 26, but no comparison is available with the cv’s assumed for the indices. The author requests guidance on how the cv’s for time series indices should be combined to compare with the RMSEs.

viii. Quantile-quantile (q-q) plots and histograms of residuals (to the indices and compositional data) to justify the choices of sampling distributions for the data.

Quantile-quantile (q-q) plots and histograms of residuals were not completed for this assessment.

f. Retrospective and historic analyses (retrospective analyses involve taking the “best” model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments).

i. Retrospective analysis (retrospective bias in base model or models).

Retrospective analyses were conducted for both 19.03(2020) and 20.10. The analysis for 19.03 used 9 “peels’ of annual data (2020-2011), with the model re-fit after each removal of the terminal year’s data. The analysis for 20.10 was limited to 2013-2020 because no BSFRF SBS surveys were available before 2013. For each scenario, time series plots of recruitment and MMB were made to identify potential patterns in how the terminal year's estimate for each peel differed from the model result using the complete dataset. Relative bias in the terminal year estimates was quantified using Mohn's rho (Mohn, 1999). The retrospective patterns don't indicate any apparent problems (Figures 60-63). Mohn's rho was 0.986 and 0.737 for the recruitment patterns and -0.0471 and 0.0187 for the MMB patterns for 19.03(2020) and 20.10, respectively.

ii. Historical analysis (plot of actual estimates from current and previous assessments).
Estimated recruitment and mature biomass time series from previous assessments (2017-2019) are compared with those from Scenario 20.20 in Figure 64. The temporal patterns are quite similar across the assessments, but the scale varies among them—with 20.20 exhibiting an overall scale intermediate between 2017 and 2018 (low) and 2019 (high).

g. Uncertainty and sensitivity analyses
MCMC runs were completed for scenario 19.03(2020) and 20.07 to explore model uncertainty. Prior MCMC runs with 10 million iterations per chain took over 3 days to complete each chain. Consequently, the models were run to create four chains, each with 1 million iterations and a thinning factor of 2,000 to reduce serial autocorrelation, yielding 400 samples per chain. Each chain took ~10 hours to complete. Unfortunately, trace plots (Figure 65, 67) and histograms (Figures 66, 68) of OFL-related quantities indicated mixing was insufficient for both models, although the situation seemed much worse for 19.03(2020).

F. Calculation of the OFL and ABC

1. Status determination and OFL calculation

EBS Tanner crab was elevated to Tier 3 status following acceptance of the TCSAM by the CPT and SSC in 2012. Based upon results from the model, the stock was subsequently declared rebuilt and not overfished. Consequently, EBS Tanner crab is assessed as a Tier 3 stock for status determination and OFL setting.

The (total catch) OFL for 2019/20 was 28.86 thousand t while the total catch mortality was 0.54 thousand t, based on applying mortality rates of 1.000 for retained catch, 0.321 to bycatch in the crab fisheries, and 0.800 to bycatch in the groundfish fisheries to the model-estimated catch by fleet for 2019/20. Therefore **overfishing did not occur**.

Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3. The OFL control rule for Tier 3 is (Figure 69):

B, $F_{35\%}$, $B_{35\%}$	3	a. $\frac{B}{B_{35\%^*}} > 1$	$F_{OFL} = F_{35\%}{}^*$	
		b. $\beta < \frac{B}{B_{35\%}{}^*} \le 1$	$F_{OFL} = F^*{}_{35\%} \frac{\frac{B}{B^*{}_{35\%}} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{35\%}{}^*} \le \beta$	Directed fishery F = 0 $F_{OFL} \le F_{MSY}$[†]	

and is based on an estimate of "current" spawning biomass at mating (B above, taken as the projected MMB at mating in the assessment year) and spawning biomass per recruit (SBPR)-based proxies for F_{MSY} and B_{MSY}. In the above equations, α=0.1 and β=0.25. For Tanner crab, the proxy for F_{MSY} is $F_{35\%}$, the fishing mortality that reduces the SBPR to 35% of its value for an unfished stock. Thus, if $\phi(F)$ is the SBPR at fishing mortality F, then $F_{35\%}$ is the value of fishing mortality that yields $\phi(F) = 0.35 \cdot \phi(0)$.

The Tier 3 proxy for B_{MSY} is $B_{35\%}$, the equilibrium biomass achieved when fishing at $F_{35\%}$, where $B_{35\%}$ is simply 35% of the unfished stock biomass. Given an estimate of average recruitment, $\bar{R}$, then $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2020/21 require estimates of B = $MMB_{2020/21}$ (the projected MMB at mating time for the coming year), $F_{35\%}$, spawning biomass per recruit in an unfished stock ($\phi(0)$), and $\bar{R}$. Current stock status is determined by the ratio $B/B_{35\%}$ for Tier 3 stocks. If the ratio is greater than 1, then the stock falls into Tier 3a and $F_{OFL} = F_{MSY} = F_{35\%}$. If the ratio is less than one but greater than β, then the stock falls into Tier 3b and F_{OFL} is reduced from $F_{35\%}$ following the descending limb of the control rule (Figure 69). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than ½ $B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

The OFL is calculated within the assessment model based on equilibrium calculations for F_{MSY} and projecting the state of the population at the end of the modeled time period one year forward assuming fishing mortality at F_{OFL}. Using MCMC, one can thus estimate the pdf of OFL (and related quantities of interest) and better characterize full model uncertainty.

To calculate F_{MSY}, the fishery capture rate for males in the directed fishery is adjusted until the longterm (equilibrium) MMB-at-mating is 35% of its unfished value (i.e., $B = 0.35 \cdot B_0 = B_{35\%} = B_{MSY}$). This calculation depends on the assumed bycatch F's on Tanner crab in the snow crab, BBRKC and groundfish fisheries. As with recent assessments, the average F over the last 5 years for each of the bycatch fisheries is used in these calculations (in previous years, a different approach was used to determine the F to use for the snow crab fishery—see e.g., Stockhausen, 2016). Fishery selectivity curves were set using the average curve over the last 5 years for each fishery, as in previous assessments (e.g., Stockhausen 2019).

The determination of $B_{MSY}=B_{35\%}$ for Tanner crab depends on the selection of an appropriate time period over which to calculate average recruitment ($\bar{R}$). Following discussion in 2012 and 2013, the SSC endorsed an averaging period of 1982+. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. This issue was revisited at the May 2018 CPT meeting with regard to whether or not the final year should be included in the calculation, but no definitive recommendations were made.

In previous assessments, average recruitment has been calculated by including the estimate for the terminal year. However, this was found to be problematic this year due to the absence of the 2020 NMFS EBS shelf bottom trawl survey, because the terminal year survey size composition is the only data providing information on the size of terminal year recruitment. In the absence of a terminal year survey, terminal year estimates of recruitment in a retrospective analysis were highly variable (and highly uncertain), leading to potentially large differences in estimated average recruitment depending on whether the model was fit with or without a terminal year survey. Consequently, average recruitment is calculated here by dropping the terminal year estimate and using the period 1982-2019 to compute the average.

The value of $\bar{R}$ for this period from MCMC runs of the author's preferred model is 369.64 million. This estimate of average recruitment is quite similar to that from the 2019 assessment model (373.96 million). The value of $B_{MSY}=B_{35\%}$ for $\bar{R}$ is 36.62 thousand t, which is somewhat smaller than that obtained in the 2019 assessment (41.07 thousand t).

Once F_{MSY} and B_{MSY} are determined, the (total catch) OFL can be calculated iteratively based on projecting the population forward one year assuming an F, calculating the catch and projected biomass B, comparing the stock's position on the harvest control rule's phase plane and adjusting F and recalculating the projected B until the point (F, B) lies on the control rule. In the absence of uncertainty, the OFL would then be the predicted total catch taken when fishing at $F = F_{OFL}$. When uncertainty (e.g. assessment uncertainty, variability in future recruitment) is taken into account, the OFL is taken as the median total catch mortality when fishing at $F = F_{OFL}$.

The total catch mortality (biomass), including all bycatch of both sexes from all fisheries, was estimated using

$$C = \sum_f \sum_x \sum_z \frac{F_{f,x,z}}{F_{.,x,z}} \cdot (1 - e^{-F_{.,x,z}}) \cdot w_{x,z} \cdot [e^{-M_x \cdot \delta t} \cdot N_{x,z}]$$

where C is total catch (biomass), $F_{f,x,z}$ is the fishing mortality in fishery f on crab in size bin z by sex (x), $F_{.,x,z} = \sum_f F_{f,x,z}$ is the total fishing mortality by sex on crab in size bin z, $w_{x,z}$ is the mean weight of crab in size bin z by sex, M_x is the sex-specific rate of natural mortality, δt is the time from July 1 to the time of the fishery (0.625 yr), and $N_{x,z}$ is the numbers by sex in size bin z on July 1, 2020 as estimated by the assessment model.

Assessment model uncertainty was included in the calculation of OFL using MCMC. Conceptually, a random draw from the assessment model's joint posterior distribution for the estimated parameters was taken, and the $\bar{R}$, B_0, F_{MSY}, B_{MSY}, F_{OFL}, OFL, and "current" MMB for 2020/21 were calculated based on the resulting parameter values. This should be repeated a large number of times to approximate the distribution of OFL given the full model uncertainty. For this assessment, four chains of 1 million MCMC steps each were generated from the author's preferred model (20.07), with the OFL and associated quantities calculated at each step. The chains were initialized from the converged model state using a "burn in" of 200,000 steps and subsequently thinned by a factor of 2,000 to reduce serial autocorrelation in the MCMC sampling. This resulted in about 1,600 MCMC samples with which to characterize the distribution of the OFL.

However, trace plots for the OFL and related quantities (Figures 63 and 64) indicate that the chains failed to achieve sufficient mixing, with subsequent samples in each chain highly autocorrelated when they should be independent. This may reflect the absence of a NMFS survey this year on model stability. Certainly, the mixing characteristics were as bad—actually much worse—or Scenario 19.03(2020) (Figures 61 and 62). **Despite the poor mixing characteristics of the MCMC sampling, the median value of across all chains was taken as the OFL for 2020/21. The median tends to be insensitive to outliers, and thus may perform better than, for example, a mean, under these circumstances. As such, the OFL for 2020/21 from the author's preferred scenario (20.07) is 20.88 thousand t** (Figure 66)**.**

The B_{MSY} proxy, $B_{35\%}$, from the author's preferred model is 36.62 thousand t, so MSST = 0.5 B_{MSY} = 18.31 thousand t. Because current projected B = 35.31 thousand t > MSST, **the stock is not overfished**. However, because current projected $B < B_{MSY}$, the **stock falls into Tier 3b**. The population state (directed F vs. MMB) is plotted for each year from 1965/66-2019/20 in Figure 67 against the Tier 3 harvest control rule.

2. ABC calculation

Amendments 38 and 39 to the Fishery Management Plan (NPFMC 2010) established methods for the Council to set Annual Catch Limits (ACLs). The Magnuson-Stevens Act requires that ACLs be established based upon an acceptable biological catch (ABC) control rule that accounts for scientific uncertainty in the OFL such that ACL=ABC and the total allowable catch (TAC) and guideline harvest levels (GHLs) be set below the ABC so as not to exceed the ACL. ABCs must be recommended annually by the Council's SSC.

Two methods for establishing the ABC control rule are: 1) a constant buffer where the ABC is set by applying a multiplier to the OFL to meet a specified buffer below the OFL; and 2) a variable buffer where the ABC is set based on a specified percentile (P*) of the distribution of the OFL that accounts for uncertainty in the OFL. P* is the probability that ABC would exceed the OFL and overfishing occur. In 2010, the NPFMC prescribed that ABCs for BSAI crab stocks be established at P*=0.49 (following Method 2). Thus, annual ACL=ABC levels should be established such that the risk of ovefishing, P[ABC>OFL], is 49%. In 2014, however, the SSC adopted a buffer of 20% on OFL for the Tanner crab stock for calculating ABC. Here, ABCs are provided based on both methods. However, because determining the P* ABC relies on an uncertainty distribution for the OFL derived from the MCMC results, its validity seems highly dubious this year.

For the author's preferred scenario, 20.07, the P* ABC (ABC_{max}) is 20.87 thousand t while the 20% Buffer ABC is 16.70 thousand t. As noted, the value for the P* ABC is questionable given the poor MCMC performance. In addition, the author remains concerned that the OFL calculation, based on $F_{35\%}$ as a proxy for F_{MSY}, is overly optimistic regarding the actual productivity of the stock. Fishery-related mortality similar to the P* ABC level has occurred only in the latter half of the 1970s and in 1992/93, coincident with collapses in stock biomass to low levels. This suggests that $F_{35\%}$ may not be a realistic proxy for F_{MSY} and/or that MMB may not be a good proxy for reproductive success, as are currently assumed for this stock. In addition, the estimates of survey catchability for this stock remain problematic and contribute to this year's inflated OFL recommendation (relative to last year's) despite a continued decline in survey biomass across the last few years. Given this uncertainty concerning the stock, **the author recommends using the 20% buffer previously adopted by the SSC for this stock to calculate ABC. Consequently, the author's recommended ABC is 16.70 thousand t**.

Given the poor MCMC results, the following tables summarize the OFL/ABC results for scenario 20.07 based on MLE results as well as the MCMC results:

Table: OFL/ABC results for scenario 20.07 based on MLE results.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	14.58	77.96	0.00	0.00	1.14	25.61	20.49
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.38	56.15	0.00	0.00	0.54	28.86	23.09
2020/21		35.33				21.13	16.90

Table: OFL/ABC results for scenario 20.07 based on MCMC results.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	14.58	77.96	0.00	0.00	1.14	25.61	20.49
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.31	56.15	0.00	0.00	0.54	28.86	23.09
2020/21		35.31				20.88	16.70

G. Rebuilding Analyses

Tanner crab is not currently under a rebuilding plan. Consequently no rebuilding analyses were conducted.

H. Data Gaps and Research Priorities

Information on growth-per-molt has been collected in the EBS on Tanner crab and incorporated into the assessment. It would be helpful to have more information on growth associated with the terminal molt, because it seems likely this has different characteristics than previous molts. Additionally, more data regarding temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock and potentially improve recruitment estimates. Information on temperature-dependent changes in crab movement and survey catchability would also be of value. In addition, it would be worthwhile to develop a “better” index of reproductive potential than MMB that can be calculated in the assessment model, as well as to revisit the issue of MSY proxies for this stock.

The characterization of fisheries in the assessment model needs to be carefully reconsidered. How, and whether or not, the differences in the directed fishery in areas east and west 166ºW longitude should be explicitly represented in the assessment model need to be addressed. The question of whether or not bycatch in the groundfish fisheries should be split into pot- and trawl-related components should be revisited. Also, the appropriate weight for male maturity ogives based on NMFS survey data in the model likelihood needs to be further explored.

Incorporating the BSFRF side-by-side (SBS) surveys into the assessment in the best way possible is also a matter for further exploration. Further catch ratio analysis using the SBS survey data outside the model (similar to what Somerton et al, 2013, did for snow crab) may eventually provide year-specific estimates of (or priors on) NMFS survey selectivity that account for variations in stock abundance across different depths and benthic substrates.

Development of a GMACS version of the Tanner crab model is also a priority and can proceed now that a GMACS model for snow crab has been developed. Further model development needs to continue the effort to eliminate parameters at bounds.

I. Ecosystem Considerations

Mature male biomass is currently used as the “currency” of Tanner crab spawning biomass for assessment purposes. However, its relationship to stock-level rates of egg production, a better measure of stock-level reproductive capacity, is unclear. Thus, use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health. Nor is it likely that mature female biomass has a clear relationship to annual egg production. For Tanner crab, the fraction of barren mature females by shell condition appears to vary at decadal time scales (Rugolo and Turnock, 2012), suggesting a climatic driver.

1. Ecosystem Effects on Stock

Time series trends in prey availability or abundance are generally unknown for Tanner crab because typical survey gear is not quantitative for Tanner crab prey. On the other hand, Pacific cod (*Gadus macrocephalus*) is thought to account for a substantial fraction of annual mortality on Tanner crab (Aydin et al., 2007). Total P. cod biomass is estimated to have been slowly declining from 1990 to 2008, during the time frame of a collapse in the Tanner crab stock, but has been increasing rather rapidly since 2008 (Thompson and Lauth, 2012). This suggests that the rates of “natural mortality” used in the stock assessment for the period post-1980 may be underestimates (and increasingly biased low if the trend in P. cod abundance continues). This trend is definitely one of potential concern.

2. Effects of Tanner crab fishery on ecosystem

Potential effects of the Tanner crab fishery on the ecosystem are considered in the following table:

Effects of Tanner crab fishery on ecosystem			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	salmon are unlikely to be trapped inside a pot when it is pulled, although halibut can be	unlikely to have substantial effects at the stock level	minimal to none
Forage (including herring, Atka mackerel, cod and pollock)	Forage fish are unlikely to be trapped inside a pot when it is pulled	unlikely to have substantial effects	minimal to none
HAPC biota	crab pots have a very small footprint on the bottom	unlikely to be having substantial effects post-rationalization	minimal to none
Marine mammals and birds	crab pots are unlikely to attract birds given the depths at which they are fished	unlikely to have substantial effects	minimal to none
Sensitive non-target species	Non-targets are unlikely to be trapped in crab pot gear in substantial numbers	unlikely to have substantial effects	minimal to none
Fishery concentration in space and time	substantially reduced in time following rationalization of the fishery	unlikely to be having substantial effects	probably of little concern
Fishery effects on amount of large size target fish	Fishery selectively removes large males	May impact stock reproductive potential as large males can mate with a wider range of females	possible concern
Fishery contribution to discards and offal production	discarded crab suffer some mortality	May impact female spawning biomass and numbers recruiting to the fishery	possible concern
Fishery effects on age-at-maturity and fecundity	none	unknown	possible concern

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Table captions

Figure captions

Tables

Table 1. Retained catch (males) in directed Tanner crab fisheries (1965/66-2000/01). Catch units are metric tons. ‘c’ appended to the year denotes a closure of the directed domestic fishery.

year	US	Japan	Russia	Total
1965	0	1,170	750	1,920
1966	0	1,690	750	2,440
1967	0	9,750	3,840	13,590
1968	460	13,590	3,960	18,010
1969	460	19,950	7,080	27,490
1970	80	18,930	6,490	25,500
1971	50	15,900	4,770	20,720
1972	100	16,800	0	16,900
1973	2,290	10,740	0	13,030
1974	3,300	12,060	0	15,360
1975	10,120	7,540	0	17,660
1976	23,360	6,660	0	30,020
1977	30,210	5,320	0	35,530
1978	19,280	1,810	0	21,090
1979	16,600	2,400	0	19,000
1980	13,426	0	0	13,426
1981	4,990	0	0	4,990
1982	2,390	0	0	2,390
1983	549	0	0	549
1984	1,429	0	0	1,429
1985c	0	0	0	0
1986c	0	0	0	0
1987	998	0	0	998
1988	3,180	0	0	3,180
1989	11,113	0	0	11,113
1990	18,189	0	0	18,189
1991	14,424	0	0	14,424
1992	15,921	0	0	15,921
1993	7,666	0	0	7,666
1994	3,538	0	0	3,538
1995	1,919	0	0	1,919
1996	821	0	0	821
1997c	0	0	0	0
1998c	0	0	0	0
1999c	0	0	0	0
2000c	0	0	0	0

Table 1 (cont.). Retained catch (males) in directed Tanner crab fisheries (2001/02-2018/19). Catch units are metric tons. Asterisks denote a closure of the directed domestic fishery; retained catch in these years represent incidentally retained Tanner crab in the snow crab and Bristol Bay red king crab fisheries.

year	US	Japan	Russia	Total
2001c	0	0	0	0
2002c	0	0	0	0
2003c	0	0	0	0
2004c	0	0	0	0
2005	432	0	0	432
2006	963	0	0	963
2007	956	0	0	956
2008	880	0	0	880
2009	603	0	0	603
2010c	1	0	0	1
2011c	2	0	0	2
2012c	1	0	0	1
2013	1,264	0	0	1,264
2014	6,216	0	0	6,216
2015	8,910	0	0	8,910
2016c	1	0	0	1
2017	1,133	0	0	1,133
2018	1,107	0	0	1,107
2019c	0	0	0	0

Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Community Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Total crab caught and total harvest include deadloss. The “Fishery Year” YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADFG year (in parentheses, if different from the “Fishery Year”) indicates the year ADFG assigned to the fishery season in compiled reports.

year (ADFG year)	Total Crab (no.)	Total Harvest (lbs)	GHL/TAC (millions lbs)	Vessels (no.)	Season
1968/69 (1969)	353,300	1,008,900			
1969/70 (1970)	482,300	1,014,700			
1970/71 (1971)	61,300	166,100			
1971/72 (1972)	42,061	107,761			
1972/73 (1973)	93,595	231,668			
1973/74 (1974)	2,531,825	5,044,197			
1974/75	2,773,770	7,028,378		28	
1975/76	8,956,036	22,358,107		66	
1976/77	20,251,508	51,455,221		83	
1977/78	26,350,688	66,648,954		120	
1978/79	16,726,518	42,547,174		144	
1979/80	14,685,611	36,614,315	28-36	152	11/01-05/11
1980/81 (1981)	11,845,958	29,630,492	28-36	165	01/15-04/15
1981/82 (1982)	4,830,980	11,008,779	12-16	125	02/15-06/15
1982/83 (1983)	2,286,756	5,273,881	5.6	108	02/15-06/15
1983/84 (1984)	516,877	1,208,223	7.1	41	02/15-06/15
1984/85 (1985)	1,272,501	3,036,935	3	44	01/15-06/15
1985/86 (1986)	----------	----------	---------closed	----------	----------
1986/87 (1987)	----------	----------	---------closed	----------	----------
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
1990/91	16,608,625	40,081,555	42.8	255	11/20-03/25
1991/92	12,924,102	31,794,382	32.8	285	11/15-03/31
1992/93	15,265,865	35,130,831	39.2	294	11/15-03/31
1993/94	7,235,898	16,892,320	9.1	296	11/01-11/10, 11/20-01/01
1994/95 (1994)	3,351,639	7,766,886	7.5	183	11/01-11/21
1995/96 (1995)	1,877,303	4,233,061	5.5	196	11/01-11/16
1996/97 (1996)	734,296	1,806,077	6.2	196	11/01-11/05, 11/15-11/27
1997/98-2004/05	----------	----------	---------closed	----------	----------
2005/06	443,978	952,887	1.7	49	10/15-03/31
2006/07	927,086	2,122,589	3.0	64	10/15-03/31
2007/08	927,164	2,106,655	5.7	50	10/15-03/31
2008/09	830,363	1,939,571	4.3	53	10/15-03/31
2009/10	485,676	1,327,952	1.3	45	10/15-03/31
2010/11	----------	----------	---------closed	----------	----------
2011/12	----------	----------	---------closed	----------	----------
2012/13	----------	----------	---------closed	----------	----------
2013/14	1,426,670	2,751,124	3.108	32	10/15-03/31
2014/15	7,442,931	13,576,105	15.105	100	10/15-03/31
2015/16	10,856,418	19,642,462	19.668	112	10/15-03/31
2016/17	----------	----------	---------closed	----------	----------
2017/18	1,340,394	2,497,033	2.500	34	10/15-03/31
2018/19	1,381,008	2,441,201	2.439	36	10/15-03/31
2019/20	----------	----------	---------closed	----------	----------

Table 3. Total catch (retained + discarded) of Tanner crab in various fisheries, as estimated from observer data. Units are 1000's t. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GTF: groundfish fisheries.

	TCF				SCF		RKF		GTF	Total
	West 166W		East 166W		all EBS		all EBS		all EBS	all EBS
year	male	female	male	female	male	female	male	female	all	all
1973	–	–	–	–	–	–	–	–	17.7355	17.7355
1974	–	–	–	–	–	–	–	–	24.4486	24.4486
1975	–	–	–	–	–	–	–	–	9.4075	9.4075
1976	–	–	–	–	–	–	–	–	4.6992	4.6992
1977	–	–	–	–	–	–	–	–	2.7760	2.7760
1978	–	–	–	–	–	–	–	–	1.8688	1.8688
1979	–	–	–	–	–	–	–	–	3.3974	3.3974
1980	–	–	–	–	–	–	–	–	2.1137	2.1137
1981	–	–	–	–	–	–	–	–	1.4742	1.4742
1982	–	–	–	–	–	–	–	–	0.4491	0.4491
1983	–	–	–	–	–	–	–	–	0.6713	0.6713
1984	–	–	–	–	–	–	–	–	0.6441	0.6441
1985c	–	–	–	–	–	–	–	–	0.3992	0.3992
1986c	–	–	–	–	–	–	–	–	0.6486	0.6486
1987	–	–	–	–	–	–	–	–	0.6396	0.6396
1988	–	–	–	–	–	–	–	–	0.4627	0.4627
1989	–	–	–	–	–	–	–	–	0.6713	0.6713
1990	–	–	–	–	7.0812	0.1057	3.7224	0.0356	0.9435	11.8885
1991	6.2206	0.4408	19.5967	1.4452	8.3602	0.1440	1.9703	0.0272	2.5432	40.7482
1992	7.3470	0.5996	29.6604	1.1040	2.4872	0.1625	1.3167	0.0190	2.7596	45.4561
1993	1.6439	0.1361	10.2100	0.8601	2.8744	0.4004	3.1308	0.1493	1.7580	21.1630
1994	0.3573	0.1124	6.9581	0.7293	1.3451	0.1942	–	–	2.0960	11.7924
1995	0.6503	0.1407	4.4152	0.9242	1.0210	0.1209	–	–	1.5249	8.7973
1996	0.0718	–	0.2286	0.0567	1.9607	0.1196	0.2700	0.0024	1.5945	4.3044
1997c	–	–	–	–	1.9637	0.0927	0.1601	0.0017	1.1800	3.3981
1998c	–	–	–	–	0.6559	0.0804	0.1152	0.0017	0.9350	1.7882
1999c	–	–	–	–	0.1318	0.0112	0.0751	0.0022	0.6306	0.8509
2000c	–	–	–	–	0.3128	0.0061	0.0664	0.0014	0.7415	1.1282

Table 3 (cont.). Total catch (retained + discarded) of Tanner crab in various fisheries, as estimated from observer data. Units are 1000's t. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GTF: groundfish fisheries.

	TCF				SCF		RKF		GTF	Total
	West 166W		East 166W		all EBS		all EBS		all EBS	all EBS
year	male	female	male	female	male	female	male	female	all	all
2001c	–	–	–	–	0.545308	0.020530	0.042200	0.000963	1.185191	1.794192
2002c					0.167178	0.013815	0.061253	0.001580	0.719068	0.962894
2003c	–	–	–	–	0.064743	0.007011	0.054937	0.001847	0.423801	0.552339
2004c					0.134619	0.039899	0.049761	0.001650	0.675058	0.900987
2005	0.684588	0.023750			1.162843	0.016258	0.041416	0.000991	0.621172	2.551018
2006	0.579229	0.072287	1.132145	0.048832	1.527248	0.085518	0.029515	0.001481	0.717134	4.193389
2007	0.679879	0.014809	1.779104	0.029297	1.861591	0.052063	0.060557	0.001422	0.694930	5.173652
2008	0.119145	0.001495	1.177782	0.006659	1.100270	0.024925	0.279901	0.002541	0.532864	3.245582
2009			0.664586	0.002270	1.559556	0.015674	0.186506	0.001139	0.374187	2.803918
2010c	–	–	–	–	1.453261	0.009179	0.031920	0.000553	0.231367	1.726280
2011c					2.141349	0.013272	0.017470	0.000072	0.203984	2.376147
2012c	–	–	–	–	1.564344	0.010297	0.042113	0.001314	0.153263	1.771331
2013	0.933101	0.011362	0.746213	0.012106	1.841754	0.015630	0.128942	0.001265	0.348367	4.038740
2014	3.057006	0.030467	5.306589	0.008767	5.330041	0.050675	0.305409	0.000997	0.435732	14.525683
2015	5.467550	0.029386	6.761436	0.028221	3.919177	0.016818	0.204958	0.005581	0.361220	16.794347
2016c	–	–	–	–	2.575704	0.016695	0.175692	0.004222	0.299052	3.071365
2017	1.362519	0.038489			1.081659	0.006841	0.183555	0.001433	0.160506	2.835002
2018	1.598424	0.034668			0.879726	0.008857	0.074017	0.000131	0.176189	2.772012
2019c	–	–	–	–	1.003315	0.015094	0.017965	0.000028	0.147583	1.183985

Table 4. Retained catch biomass in the directed Tanner crab (TCF), snow crab (SCF), and BBRKC (RKF) fisheries since 2005. The directed fishery was completely closed from 2010/11 to 2012/13, as well as in 2016/17 and 2019/20. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch.

	TCF						SCF		RKF	
	West 166W		East 166W		all EBS		all EBS		all EBS	
year	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)
2005	255,859	244,534	0	0	255,859	244,534	188,118	187,689	0	0
2006	164,719	155,532	583,650	633,937	748,369	789,469	175,904	171,439	1,830	1,883
2007	151,525	151,112	679,137	711,640	830,662	862,752	90,148	86,478	6,354	6,334
2008	48,171	47,157	760,166	809,022	808,337	856,179	3,300	2,535	18,732	21,068
2009	0	0	476,668	592,417	476,668	592,417	2,544	1,714	6,751	8,402
2010	0	0	0	0	0	0	1,689	1,154	6	3
2011	0	0	0	0	0	0	3,095	2,092	0	0
2012	0	0	0	0	0	0	1,643	1,111	4	3
2013	722,469	593,617	704,201	654,271	1,426,670	1,247,888	13,256	9,882	5,842	6,322
2014	3,121,442	2,368,693	4,378,199	3,829,288	7,499,641	6,197,981	19,512	14,458	3,691	3,792
2015	4,817,145	3,770,319	5,998,876	5,107,722	10,816,021	8,878,041	39,011	30,252	1,386	1,350
2016	0	0	0	0	0	0	1,733	1,177	33	21
2017	1,322,542	1,117,483	139	119	1,322,681	1,117,602	17,688	15,018	25	17
2018	1,376,977	1,103,903	0	0	1,376,977	1,103,903	4,013	3,409	18	12
2019	0	0	0	0	0	0	125	84	0	0

Table 5. Sample sizes for retained and total catch-at-size in the directed fishery. N = number of individuals. N' = scaled sample size used in assessment.

year	Retained catch		Total catch			
	Males		Males		Females	
	N	N'	N	N'	N	N'
1980/81	13,310	104.6	–	–	–	–
1981/82	11,311	88.9	–	–	–	–
1982/83	13,519	106.2	–	–	–	–
1983/84	1,675	13.2	–	–	–	–
1984/85	2,542	20.0	–	–	–	–
1988/89	12,380	97.3	–	–	–	–
1989/90	4,123	32.4	–	–	–	–
1990/91	120,676	200.0	–	–	–	–
1991/92	126,299	200.0	31,252	169.6	5,605	30.4
1992/93	125,193	200.0	54,836	172.5	8,755	27.5
1993/94	71,622	200.0	40,388	158.8	10,471	41.2
1994/95	27,658	198.8	5,792	41.6	2,132	15.3
1995/96	19,276	138.6	5,589	40.2	3,119	22.4
1996/97	4,430	31.8	352	2.5	168	1.2
2005/06	705	5.1	19,715	141.7	1,107	8.0
2006/07	2,940	21.1	24,226	169.1	4,432	30.9
2007/08	5,827	41.9	61,546	189.8	3,318	10.2
2008/09	3,490	25.1	29,166	195.7	646	4.3
2009/10	2,417	17.4	17,289	124.3	147	1.1
2013/14	4,553	32.7	17,291	124.3	710	5.1
2014/15	14,371	103.3	85,120	197.2	1,191	2.8
2015/16	24,320	174.8	119,843	197.3	1,624	2.7
2016/17	–	–	–	–	–	–
2017/18	3,470	24.9	18,785	135.1	1,721	12.4
2018/19	3,306	23.8	28,338	186.6	2,036	13.4
2019/20	–	–	–	–	–	–

Table 6. Sample sizes for total bycatch-at-size in the snow crab and Bristol Bay red king crab (BBRKC) fisheries, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	Snow crab fishery				Bristol Bay red king crab			
	Males		Females		Males		Females	
	N	N'	N	N'	N	N'	N	N'
1990/91	14,032	100.9	478	3.4	1,580	11.4	43	0.3
1991/92	11,708	84.2	686	4.9	2,273	16.3	89	0.6
1992/93	6,280	45.1	859	6.2	2,056	14.8	105	0.8
1993/94	6,969	50.1	1542	11.1	7,359	52.9	1,196	8.6
1994/95	2,982	21.4	1523	10.9	–	–	–	–
1995/96	1,898	13.6	428	3.1	–	–	–	–
1996/97	3,265	23.5	662	4.8	114	0.8	5	0.0
1997/98	3,970	28.5	657	4.7	1,030	7.4	41	0.3
1998/99	1,911	13.7	324	2.3	457	3.3	20	0.1
1999/00	976	7.0	82	0.6	207	1.5	14	0.1
2000/01	1,237	8.9	74	0.5	845	6.1	44	0.3
2001/02	3,113	22.4	160	1.2	456	3.3	39	0.3
2002/03	982	7.1	118	0.8	750	5.4	50	0.4
2003/04	688	4.9	152	1.1	555	4.0	46	0.3
2004/05	833	6.0	707	5.1	487	3.5	44	0.3
2005/06	9,807	70.5	368	2.6	983	7.1	70	0.5
2006/07	10,391	74.7	1256	9.0	746	5.4	68	0.5
2007/08	13,797	99.2	728	5.2	1,360	9.8	89	0.6
2008/09	8,455	60.8	722	5.2	3,797	27.3	121	0.9
2009/10	11,057	79.5	474	3.4	2,871	20.6	70	0.5
2010/11	12,073	86.8	250	1.8	582	4.2	28	0.2
2011/12	9,453	68.0	189	1.4	323	2.3	4	0.0
2012/13	11,004	79.1	270	1.9	618	4.4	48	0.3
2013/14	12,935	93.0	356	2.6	2,110	15.2	60	0.4
2014/15	24,878	178.9	804	5.8	3,110	22.4	32	0.2
2015/16	19,839	142.6	230	1.7	2,175	15.6	186	1.3
2016/17	16,369	117.7	262	1.9	3,220	23.1	246	1.8
2017/18	5,598	40.2	109	0.8	3,782	27.2	86	0.6
2018/19	6,145	44.2	233	1.7	1,283	9.2	6	0.0
2019/20	8,881	63.8	423	3.0	357	2.6	3	0.0

Table 7. Sample sizes for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. N = number of individuals. N` = scaled sample size used in the assessment.

year	Males		Females	
	N	N'	N	N'
1973/74	3,155	22.7	2,277	16.4
1974/75	2,492	17.9	1,600	11.5
1975/76	1,251	9.0	839	6.0
1976/77	6,950	50.0	6,683	48.0
1977/78	10,685	76.8	8,386	60.3
1978/79	18,596	115.3	13,665	84.7
1979/80	19,060	125.4	11,349	74.6
1980/81	12,806	92.1	5,917	42.5
1981/82	6,098	43.8	4,065	29.2
1982/83	13,439	96.6	8,006	57.6
1983/84	18,363	132.0	8,305	59.7
1984/85	27,403	133.1	13,771	66.9
1985/86	23,128	129.0	12,728	71.0
1986/87	14,860	106.8	7,626	54.8
1987/88	23,508	119.4	15,857	80.6
1988/89	10,586	76.1	7,126	51.2
1989/90	59,943	118.5	41,234	81.5
1990/91	23,545	135.5	11,212	64.5
1991/92	6,817	49.0	3,479	25.0
1992/93	3,128	22.5	1,175	8.4
1993/94	1,217	8.7	358	2.6
1994/95	3,628	26.1	1,820	13.1
1995/96	3,904	28.1	2,669	19.2
1996/97	8,306	59.7	3,400	24.4
1997/98	9,949	71.5	3,900	28.0
1998/99	12,105	87.0	4,440	31.9
1999/00	11,053	79.5	4,522	32.5
2000/01	12,895	92.7	3,087	22.2
2001/02	15,788	113.5	3,083	22.2
2002/03	15,401	110.7	3,249	23.4
2003/04	9,572	68.8	2,733	19.6
2004/05	13,844	99.5	4,460	32.1
2005/06	17,785	127.9	3,709	26.7
2006/07	15,903	114.3	3,047	21.9
2007/08	16,148	116.1	3,819	27.5
2008/09	26,171	172.1	4,235	27.9
2009/10	19,043	136.9	2,701	19.4
2010/11	15,666	112.6	2,604	18.7
2011/12	16,359	117.6	4,263	30.6
2012/13	13,186	94.8	3,103	22.3
2013/14	28,908	165.2	6,081	34.8
2014/15	39,276	180.4	4,262	19.6
2015/16	27,703	165.5	5,781	34.5
2016/17	18,731	134.7	4,430	31.8
2017/18	13,591	97.7	1,743	12.5
2018/19	7,701	55.4	1,485	10.7
2019/20	7,188	51.7	2,113	15.2

Table 8. Trends in Tanner crab biomass (metric tons) in the NMFS EBS summer bottom trawl survey, by sex and area.

		male			female	
year	W166	E166	all EBS	W166	E166	all EBS
1975	80,689	214,202	294,891	13,374	27,594	40,968
1976	55,092	101,958	157,050	12,140	25,420	37,560
1977	51,038	87,463	138,501	21,613	31,435	53,048
1978	25,394	72,913	98,308	14,167	18,406	32,574
1979	32,058	17,978	50,036	19,701	3,448	23,149
1980	103,505	48,979	152,484	64,420	12,883	77,303
1981	56,540	23,390	79,930	35,525	8,577	44,102
1982	49,255	16,602	65,856	57,757	8,107	65,864
1983	24,708	13,337	38,045	17,418	5,350	22,769
1984	18,490	12,020	30,510	12,358	4,800	17,158
1985	6,676	8,231	14,907	3,393	3,160	6,554
1986	11,986	9,625	21,612	2,570	3,504	6,074
1987	16,648	28,863	45,511	5,137	15,009	20,146
1988	41,093	58,130	99,223	12,668	22,885	35,553
1989	45,106	87,718	132,824	12,254	18,975	31,230
1990	55,539	76,879	132,418	22,532	25,022	47,554
1991	55,986	89,825	145,811	20,445	31,341	51,787
1992	37,674	89,918	127,592	16,857	11,358	28,215
1993	19,877	53,394	73,271	7,382	5,325	12,707
1994	16,032	32,303	48,335	5,716	5,332	11,048
1995	15,310	19,672	34,982	7,474	5,982	13,456
1996	10,790	19,979	30,770	4,470	6,548	11,019
1997	5,561	9,088	14,649	1,893	2,914	4,806
1998	6,604	8,404	15,008	2,489	1,752	4,241
1999	6,719	14,835	21,554	3,347	3,360	6,708
2000	6,903	16,429	23,332	2,999	3,613	6,613

Table 8 (cont). Trends in Tanner crab biomass (metric tons) in the NMFS EBS summer bottom trawl survey, by sex and area.

	male			female		
year	W166	E166	all EBS	W166	E166	all EBS
2001	13,089	16,231	29,320	6,989	3,931	10,920
2002	13,010	14,402	27,411	6,499	3,469	9,968
2003	20,661	17,164	37,825	10,297	2,795	13,092
2004	26,468	12,455	38,923	7,731	1,131	8,862
2005	46,313	17,443	63,756	17,469	4,493	21,962
2006	72,907	28,636	101,543	21,723	6,476	28,198
2007	76,285	27,938	104,223	12,465	6,612	19,076
2008	47,736	37,177	84,913	9,444	5,079	14,523
2009	32,653	14,786	47,439	6,495	4,553	11,048
2010	34,601	14,426	49,027	6,366	2,910	9,276
2011	39,321	23,390	62,712	9,190	6,615	15,805
2012	34,764	45,367	80,131	9,787	14,245	24,032
2013	38,839	64,580	103,420	10,866	13,398	24,264
2014	50,739	58,196	108,936	8,728	8,648	17,377
2015	39,158	35,093	74,251	7,574	5,304	12,878
2016	43,315	25,520	68,835	7,133	1,479	8,612
2017	29,685	23,952	53,637	6,274	2,144	8,418
2018	32,734	13,769	46,503	8,213	1,588	9,801
2019	17,503	10,790	28,293	7,452	2,133	9,585

Table 9. Trends in biomass for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (in metric tons).

	W166			E166			all EBS		
year	new shell	old shell	all	new shell	old shell	all	new shell	old shell	all
1975	56,181	2,509	58,691	152,683	6,522	159,205	208,864	9,032	217,896
1976	38,107	1,534	39,640	57,034	9,674	66,709	95,141	11,208	106,349
1977	26,511	6,808	33,319	50,855	7,543	58,399	77,366	14,351	91,717
1978	3,221	6,626	9,847	40,633	9,780	50,413	43,853	16,406	60,259
1979	4,115	3,745	7,860	9,767	3,426	13,192	13,882	7,171	21,052
1980	11,210	1,677	12,887	23,184	10,857	34,041	34,394	12,534	46,927
1981	5,884	2,167	8,050	3,445	11,286	14,731	9,329	13,452	22,781
1982	5,763	5,859	11,622	3,009	4,851	7,860	8,772	10,710	19,481
1983	2,416	3,240	5,655	5,151	2,082	7,233	7,566	5,322	12,889
1984	571	3,159	3,730	4,348	3,077	7,424	4,919	6,236	11,154
1985	588	870	1,458	4,055	1,046	5,101	4,642	1,917	6,559
1986	142	674	816	734	2,546	3,280	876	3,219	4,096
1987	3,505	658	4,163	4,911	3,473	8,385	8,416	4,132	12,548
1988	9,690	929	10,618	15,698	2,715	18,413	25,387	3,644	29,031
1989	13,758	2,741	16,499	37,364	3,740	41,104	51,122	6,481	57,603
1990	21,082	3,274	24,356	35,903	7,084	42,987	56,985	10,358	67,343
1991	13,386	8,430	21,816	32,973	14,476	47,449	46,359	22,906	69,265
1992	9,851	6,461	16,311	41,423	16,242	57,665	51,274	22,703	73,977
1993	3,716	2,596	6,312	22,942	11,990	34,932	26,658	14,586	41,244
1994	1,248	4,143	5,391	10,000	13,912	23,912	11,248	18,054	29,303
1995	370	5,392	5,761	1,241	13,516	14,757	1,611	18,907	20,518
1996	100	3,580	3,680	330	13,912	14,242	430	17,492	17,922
1997	163	958	1,121	316	4,245	4,561	478	5,203	5,681
1998	441	644	1,085	1,001	2,604	3,605	1,442	3,247	4,689
1999	256	356	612	1,645	1,838	3,483	1,902	2,194	4,095
2000	250	377	627	4,484	3,045	7,529	4,734	3,422	8,156

Table 9 (cont.). Trends in biomass for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (in metric tons).

	W166			E166			all EBS		
year	new shell	old shell	all	new shell	old shell	all	new shell	old shell	all
2001	418	1,361	1,780	4,473	3,600	8,073	4,892	4,961	9,853
2002	384	838	1,222	944	7,102	8,046	1,328	7,940	9,268
2003	434	2,227	2,661	1,558	6,433	7,991	1,992	8,660	10,652
2004	980	1,825	2,805	1,597	4,916	6,513	2,577	6,741	9,318
2005	8,776	5,062	13,839	2,368	5,822	8,190	11,145	10,884	22,029
2006	3,755	15,328	19,083	2,134	6,794	8,927	5,889	22,122	28,011
2007	8,523	7,757	16,281	4,143	5,314	9,457	12,666	13,071	25,737
2008	8,688	4,457	13,145	15,476	3,288	18,764	24,163	7,745	31,909
2009	6,657	4,156	10,812	2,644	5,139	7,783	9,300	9,295	18,595
2010	9,593	4,867	14,460	3,006	4,576	7,582	12,599	9,443	22,042
2011	9,023	6,637	15,660	1,513	6,987	8,500	10,536	13,624	24,160
2012	2,368	3,997	6,365	3,352	5,026	8,378	5,720	9,023	14,743
2013	5,383	2,837	8,220	10,871	3,527	14,397	16,254	6,364	22,618
2014	7,163	4,604	11,766	14,899	9,310	24,210	22,062	13,914	35,976
2015	8,380	5,925	14,306	9,084	10,217	19,301	17,464	16,143	33,607
2016	5,799	12,527	18,326	2,640	8,055	10,695	8,439	20,582	29,021
2017	894	11,659	12,553	1,629	10,841	12,470	2,523	22,500	25,024
2018	996	11,875	12,871	102	7,253	7,355	1,097	19,128	20,225
2019	202	4,799	5,001	315	4,455	4,769	517	9,254	9,771

Table 10. Sample sizes for NMFS survey size composition data. In the assessment model, an input sample size of 200 is used for all survey-related compositional data.

		females						males					
		immature		mature				immature		mature			
		new shell		new shell		old shell		new shell		new shell		old shell	
year	number of hauls	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab
1975	136	73	1,047	91	1,861	39	706	127	2,895	127	3,993	80	399
1976	214	88	1,097	91	1,304	39	311	130	2,023	130	2,469	47	242
1977	155	69	776	76	1,183	60	738	114	1,778	114	1,971	79	485
1978	230	88	1,949	82	638	65	1,307	147	2,957	147	1,570	104	700
1979	307	74	733	62	735	42	341	138	1,805	138	808	68	306
1980	320	103	1,491	95	1,471	49	570	164	4,602	164	2,359	71	569
1981	305	71	579	79	1,319	94	1,206	158	3,809	158	2,293	116	886
1982	342	87	823	72	457	103	2,384	181	1,751	181	1,371	147	2,082
1983	353	102	2,113	56	201	102	2,154	166	2,484	166	983	132	1,181
1984	355	135	1,879	53	284	94	1,531	171	1,965	171	490	126	1,399
1985	353	141	847	52	228	65	601	179	1,060	179	381	86	459
1986	353	162	1,588	64	191	68	331	213	2,141	213	528	115	468
1987	355	189	4,230	105	445	73	392	226	4,659	226	1,306	103	498
1988	370	206	3,735	149	1,753	100	530	252	5,627	252	2,210	101	475
1989	373	204	3,271	144	1,241	108	882	237	4,977	237	3,201	135	1,067
1990	370	198	3,114	155	1,502	126	1,511	247	5,107	247	3,149	151	1,342
1991	371	163	2,259	138	1,283	141	2,568	227	4,361	227	2,692	181	2,893
1992	355	107	1,494	119	820	123	2,205	215	2,958	215	2,047	177	1,924
1993	374	99	869	96	545	122	1,337	207	2,051	207	1,677	180	1,865
1994	374	97	921	52	148	104	1,293	175	1,281	175	724	174	1,827
1995	375	115	834	35	140	107	1,057	153	958	153	220	137	1,611
1996	374	115	883	57	109	98	963	148	1,069	148	222	134	1,414
1997	375	116	1,329	62	168	83	504	161	1,336	161	289	125	582
1998	374	146	1,710	53	160	73	344	176	2,032	176	396	128	624
1999	372	138	2,628	52	255	85	510	170	2,816	170	550	124	567
2000	371	142	2,249	61	242	55	345	188	2,836	188	628	133	653

Table10 (cont.). Sample sizes for NMFS survey size composition data. In the assessment model, an input sample size of 200 is used for all survey-related compositional data.

		females						males					
		immature		mature				immature		mature			
		new shell		new shell		old shell		new shell		new shell		old shell	
year	number of hauls	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab	number of nonzero hauls	number of crab
2001	374	164	3,678	83	364	72	644	211	4,036	211	629	145	817
2002	374	155	3,585	81	350	70	500	186	3,912	186	458	154	1,089
2003	375	153	2,834	111	923	83	752	203	4,754	203	900	153	1,349
2004	374	175	3,922	90	427	80	656	236	4,568	236	1,027	179	1,873
2005	372	201	3,352	103	634	74	928	254	4,496	254	1,280	185	1,753
2006	375	211	4,364	143	1,332	125	1,327	254	6,224	254	1,757	211	4,054
2007	375	186	2,430	138	1,311	136	1,396	261	4,697	261	1,982	201	2,907
2008	374	153	1,747	104	580	120	1,783	240	3,127	240	2,116	196	2,146
2009	375	171	2,408	75	363	115	1,317	216	2,879	216	1,144	187	1,954
2010	375	186	3,180	67	245	104	941	223	3,654	223	1,268	166	1,702
2011	375	193	5,044	90	471	102	705	210	6,095	210	1,115	167	1,941
2012	375	195	3,611	100	942	97	720	215	5,526	215	1,564	139	1,296
2013	375	163	2,917	116	1,417	101	1,002	207	5,592	207	2,675	137	1,344
2014	375	165	2,211	98	482	121	1,584	222	4,746	222	3,286	167	2,829
2015	375	118	1,455	60	445	94	1,363	225	2,737	225	1,859	200	2,817
2016	375	110	1,373	56	370	82	1,248	222	2,235	222	1,170	218	3,668
2017	375	131	2,033	50	213	99	1,125	186	2,241	186	424	205	3,541
2018	375	196	4,666	68	525	93	703	222	4,990	222	513	190	2,748
2019	375	181	3,810	85	649	55	541	208	4,216	208	522	169	1,175

Table 11. Effort data (potlifts) in the crab fisheries, by area. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery. Hyphens indicate years with no effort.

year	SCF all EBS	RKF all EBS
1953	–	30,083
1954	–	17,122
1955	–	28,045
1956	–	41,629
1957	–	23,659
1958	–	27,932
1959	–	22,187
1960	–	26,347
1961	–	72,646
1962	–	123,643
1963	–	181,799
1964	–	180,809
1965	–	127,973
1966	–	129,306
1967	–	135,283
1968	–	184,666
1969	–	175,374
1970	–	168,059
1971	–	126,305
1972	–	208,469
1973	–	194,095
1974	–	212,915
1975	–	205,096
1976	–	321,010
1977	–	451,273
1978	190,746	406,165
1979	255,102	315,226
1980	435,742	567,292
1981	469,091	536,646
1982	287,127	140,492
1983	173,591	–
1984	370,082	107,406
1985	542,346	84,443
1986	616,113	175,753
1987	747,395	220,971
1988	665,242	146,179
1989	912,718	205,528

Table 11 (cont.). Effort data (potlifts) in the crab fisheries, by area. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery. Hyphens indicate years with no effort.

		TCF		SCF	RKF
year	West 166W	East 166W	all EBS	all EBS	all EBS
1990	479	493,820	494,299	1,382,908	262,761
1991	140,050	360,864	500,914	1,278,502	227,555
1992	166,670	508,922	675,592	969,209	206,815
1993	40,100	286,620	326,720	716,524	254,389
1994	21,282	228,254	249,536	507,603	697
1995	46,454	201,988	248,442	520,685	547
1996	8,533	64,989	73,522	754,140	77,081
1997	–	–	–	930,794	91,085
1998	–	–	–	945,533	145,689
1999	–	–	–	182,634	151,212
2000	–	–	–	191,200	104,056
2001	–	–	–	326,977	66,947
2002	–	–	–	153,862	72,514
2003	–	–	–	123,709	134,515
2004	–	–	–	75,095	97,621
2005	6,346	–	6,346	117,375	116,320
2006	4,517	15,273	19,790	86,328	72,404
2007	7,268	26,441	33,709	140,857	113,948
2008	2,336	19,401	21,737	163,537	139,937
2009	–	6,635	6,635	137,292	119,261
2010	–	–	–	147,478	132,183
2011	–	–	–	270,602	45,784
2012	–	–	–	225,627	38,842
2013	23,062	16,613	39,675	225,245	46,589
2014	68,695	72,768	141,463	279,183	57,725
2015	84,933	130,302	215,235	202,526	48,763
2016	–	–	–	118,548	33,608
2017	19,284	11	19,295	114,673	49,169
2018	29,833	–	29,833	119,484	31,975
2019	–	–	–	188,958	35,033

Table 12.Parameters from all model scenarios that were estimated within 1% of bounds. TCF: Tanner crab fishery, SCF: snow crab fishery; RKF: BBRCK fishery; GF: groundfish fisheries. z50: size at 50% selected; z95: size at 95% selected.

case	category	name	parameter scale	min	max	which bound?	description
19.03_2020	selectivity	pS1[1]	ARITHMETIC	0	90	at upper bound	z50 for NMFS survey selectivity (males, pre-1982)
19.03_2020	selectivity	pS1[20]	ARITHMETIC	40	250	at lower bound	z50 for GF.AllGear selectivity (males, 1987-1996)
19.03_2020	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
19.03_2020	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
19.03_2020	selectivity	pS1[27]	ARITHMETIC	100	140	at upper bound	z95 for RKF selectivity (females, 2005+)
19.03_2020	selectivity	pS2[2]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (males, 1982+)
19.03_2020	selectivity	pS2[4]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (females, 1982+)
19.03_2020	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
19.03_2020	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
19.03_2020	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)
19.03_2020	surveys	pQ[1]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: males, 1975-1981
19.03_2020	surveys	pQ[3]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: females, 1975-1981
19.03	selectivity	pS1[1]	ARITHMETIC	0	90	at upper bound	z50 for NMFS survey selectivity (males, pre-1982)
19.03	selectivity	pS1[20]	ARITHMETIC	40	250	at lower bound	z50 for GF.AllGear selectivity (males, 1987-1996)
19.03	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
19.03	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
19.03	selectivity	pS1[27]	ARITHMETIC	100	140	at upper bound	z95 for RKF selectivity (females, 2005+)
19.03	selectivity	pS2[2]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (males, 1982+)
19.03	selectivity	pS2[4]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (females, 1982+)
19.03	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
19.03	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
19.03	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)
19.03	surveys	pQ[1]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: males, 1975-1981
19.03	surveys	pQ[3]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: females, 1975-1981
20.07	population	pGrBeta[1]	ARITHMETIC	0.5	1	at upper bound	growth distribution scale (both sexes)
20.07	selectivity	pS1[4]	ARITHMETIC	-50	69	at upper bound	z50 for NMFS survey selectivity (females, 1982+)
20.07	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
20.07	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
20.07	selectivity	pS1[27]	ARITHMETIC	100	140	at upper bound	z95 for RKF selectivity (females, 2005+)
20.07	selectivity	pS2[4]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (females, 1982+)
20.07	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
20.07	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
20.07	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)
20.07	surveys	pQ[1]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: males, 1975-1981
20.07	surveys	pQ[3]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: females, 1975-1981
20.1	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
20.1	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
20.1	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
20.1	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
20.1	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)

Table 13. All non-vector parameters. Parameters with phase > 0 are MLEs; otherwise, the values were fixed outside the model. Highlights indicate poorly-estimated parameters (large standard errors or estimates at bounds).

			19.03		19.03(2020)		20.07		20.10		
process	name	phase	est	stdv	est	stdv	est	stdv	est	stdv	label
fisheries	pDC2[1]	1	-2.202	0.225	-2.252	0.247	-1.999	0.240	-2.561	0.230	TCF: female offset
fisheries	pDC2[2]	2	-3.393	0.616	-3.451	0.617	-3.212	0.592	-3.672	0.610	SCF: female offset
fisheries	pDC2[3]	2	-1.002	0.083	-1.017	0.086	-0.850	0.076	-1.212	0.091	GTF: female offset
fisheries	pDC2[4]	2	-1.832	2.062	-1.757	2.156	-1.409	2.286	-2.133	1.844	RKF: female offset
fisheries	pHM[1]	-1	0.321	0.000	0.321	0.000	0.321	0.000	0.321	0.000	handling mortality for pot fisheries
fisheries	pHM[2]	-1	0.800	0.000	0.800	0.000	0.800	0.000	0.800	0.000	handling mortality for groundfish trawl fisheries
fisheries	pLgtRet[1]	3	14.999	4.757	14.999	4.872	14.999	4.089	14.999	4.945	TCF: logit-scale max retention (pre-1997)
fisheries	pLgtRet[2]	3	14.808	640.170	14.888	470.840	14.811	670.000	14.815	583.740	TCF: logit-scale max retention (2005-2009)
fisheries	pLgtRet[3]	3	14.984	66.684	14.978	85.510	14.972	112.400	14.988	47.896	TCF: logit-scale max retention (2013+)
fisheries	pLnC[1]	-1	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	TCF: base capture rate, pre-1965 (=0.05)
fisheries	pLnC[2]	1	-1.819	0.087	-1.803	0.087	-1.685	0.079	-1.788	0.078	TCF: base capture rate, 1965+
fisheries	pLnC[3]	-2	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	SCF: base capture rate, pre-1978 (=0.01)
fisheries	pLnC[4]	2	-3.732	0.116	-3.670	0.119	-3.512	0.106	-3.469	0.095	SCF: base capture rate, 1992+
fisheries	pLnC[5]	-2	-4.181	0.000	-4.181	0.000	-4.181	0.000	-4.181	0.000	DUMMY CAPTURE RATE
fisheries	pLnC[6]	2	-4.992	0.069	-4.999	0.070	-4.909	0.056	-4.827	0.057	GTF: base capture rate, ALL YEARS
fisheries	pLnC[7]	-2	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	RKF: base capture rate, pre-1953 (=0.02)
fisheries	pLnC[8]	2	-3.758	0.120	-3.793	0.121	-3.722	0.114	-3.549	0.111	RKF: base capture rate, 1992+
growth	pGrA[1]	4	32.741	0.292	32.697	0.292	32.553	0.251	30.496	0.253	males
growth	pGrA[2]	4	33.995	0.336	33.951	0.336	33.741	0.267	31.989	0.257	females
growth	pGrB[1]	4	166.566	0.921	166.561	0.930	168.825	0.917	169.604	1.075	males
growth	pGrB[2]	4	114.869	0.648	114.794	0.649	114.791	0.591	116.109	0.610	females
growth	pGrBeta[1]	5	0.904	0.114	0.889	0.113	1.000	0.000	0.944	0.125	gamma distribution scale parameter
natural mortality	pDM1[1]	4	0.984	0.051	0.984	0.052	1.041	0.044	1.710	0.039	multiplier for immature crab
natural mortality	pDM1[2]	4	1.292	0.040	1.295	0.040	1.272	0.038	1.527	0.035	multiplier for mature males
natural mortality	pDM1[3]	4	1.316	0.039	1.315	0.039	1.412	0.036	1.325	0.035	multiplier for mature females
natural mortality	pDM2[1]	4	2.230	0.215	2.294	0.225	1.986	0.181	2.362	0.224	1980-1984 multiplier for mature males
natural mortality	pDM2[2]	4	1.873	0.155	1.864	0.157	1.716	0.138	1.924	0.161	1980-1984 multiplier for mature females
natural mortality	pM[1]	-1	-1.470	0.000	-1.470	0.000	-1.470	0.000	-1.470	0.000	base ln-scale M
recruitment	pLnR[1]	1	6.301	0.476	6.300	0.476	6.229	0.451	7.410	0.482	historical recruitment period
recruitment	pLnR[2]	1	5.691	0.083	5.671	0.498	5.615	0.495	6.515	0.494	current recruitment period
recruitment	pRa[1]	-1	2.442	0.000	2.442	0.000	--	--	2.442	0.000	fixed value
recruitment	pRa[1]	5	--	--	--	--	2.105	0.043	--	--	fixed value
recruitment	pRb[1]	-1	1.386	0.000	1.386	0.000	--	--	1.386	0.000	fixed value
recruitment	pRb[1]	5	--	--	--	--	1.117	0.117	--	--	fixed value
recruitment	pRCV[1]	-1	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	full model period
recruitment	pRX[1]	-1	--	--	--	--	--	--	--	--	full model period
surveys	pQ[1]	5	-0.693	0.000	-0.693	0.000	-0.693	0.000	-1.477	0.091	NMFS trawl survey: males, 1975-1981
surveys	pQ[2]	5	-0.848	0.069	-0.817	0.069	-0.715	0.051	--	--	NMFS trawl survey: males, 1982+
surveys	pQ[3]	5	-0.693	0.001	-0.693	0.001	-0.693	0.002	-1.401	0.265	NMFS trawl survey: females, 1975-1981
surveys	pQ[4]	5	-1.437	0.105	-1.415	0.107	-0.669	0.050	--	--	NMFS trawl survey: females, 1982+

Table 14 (cont.). All non-vector parameters. Parameters with phase > 0 are MLEs; otherwise, the values were fixed outside the model. Highlights indicate poorly-estimated parameters (large standard errors or estimates at bounds).

				19.03		19.03(2020)		20.07		20.10		
category	process	name	phase	est	stdv	est	stdv	est	stdv	est	stdv	label
selectivity	selectivity	pS1[1]	1	90.000	0.000	90.000	0.000	51.378	1.816	58.921	2.330	z50 for NMFS survey selectivity (males, pre-1982)
selectivity	selectivity	pS1[10]	2	113.499	1.864	114.573	1.903	114.588	1.883	118.699	1.709	ascending z50 for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS1[11]	2	95.758	3.008	96.163	3.268	95.324	3.234	97.893	3.137	ascending z50 for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS1[12]	2	106.295	1.103	106.252	1.129	105.521	1.126	107.345	1.096	ascending z50 for SCF selectivity (males, 2005+)
selectivity	selectivity	pS1[13]	2	73.422	4.650	73.524	4.885	75.412	4.729	76.471	4.416	ascending z50 for SCF selectivity (females, pre-1997)
selectivity	selectivity	pS1[14]	2	76.348	4.447	76.416	4.651	77.232	4.551	77.678	4.392	ascending z50 for SCF selectivity (females, 1997-2004)
selectivity	selectivity	pS1[15]	2	79.972	3.937	79.247	3.879	80.286	3.790	80.886	3.616	ascending z50 for SCF selectivity (females, 2005+)
selectivity	selectivity	pS1[16]	2	57.537	2.499	57.530	2.620	54.155	1.796	65.138	2.300	z50 for GF.AllGear selectivity (males, pre-1987)
selectivity	selectivity	pS1[17]	2	68.392	5.326	67.344	5.648	58.585	4.946	103.954	10.079	z50 for GF.AllGear selectivity (males, 1987-1996)
selectivity	selectivity	pS1[18]	2	92.845	2.489	92.390	2.509	86.630	2.210	98.833	1.888	z50 for GF.AllGear selectivity (males, 1997+)
selectivity	selectivity	pS1[19]	2	41.452	1.663	41.086	1.727	43.691	1.510	47.952	1.741	z50 for GF.AllGear selectivity (males, pre-1987)
selectivity	selectivity	pS1[2]	1	46.968	5.617	48.015	5.608	49.498	2.982	--	--	z50 for NMFS survey selectivity (males, 1982+)
selectivity	selectivity	pS1[20]	2	40.000	0.000	40.000	0.000	41.517	1.924	74.902	11.957	z50 for GF.AllGear selectivity (males, 1987-1996)
selectivity	selectivity	pS1[21]	2	85.087	3.036	84.308	3.144	81.866	2.450	87.222	2.790	z50 for GF.AllGear selectivity (males, 1997+)
selectivity	selectivity	pS1[22]	3	151.025	4.078	149.898	4.259	149.585	4.425	149.829	4.020	z95 for RKF selectivity (males, pre-1997)
selectivity	selectivity	pS1[23]	3	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001	z95 for RKF selectivity (males, 1997-2004)
selectivity	selectivity	pS1[24]	3	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	z95 for RKF selectivity (males, 2005+)
selectivity	selectivity	pS1[25]	3	118.659	23.644	119.018	25.218	119.216	26.567	116.001	19.491	z95 for RKF selectivity (females, pre-1997)
selectivity	selectivity	pS1[26]	3	121.229	48.065	121.583	50.723	118.987	44.217	118.342	41.514	z95 for RKF selectivity (females, 1997-2004)
selectivity	selectivity	pS1[27]	3	140.000	0.103	140.000	0.097	140.000	0.166	135.743	45.470	z95 for RKF selectivity (females, 2005+)
selectivity	selectivity	pS1[28]	1	137.711	0.330	137.709	0.334	137.695	0.304	137.702	0.307	z50 for TCF retention (2005-2009)
selectivity	selectivity	pS1[29]	1	125.254	0.538	125.261	0.555	125.306	0.556	125.300	0.551	z50 for TCF retention (2013+)
selectivity	selectivity	pS1[3]	1	92.146	4.945	92.257	5.011	77.604	2.995	78.951	8.912	z50 for NMFS survey selectivity (females, pre-1982)
selectivity	selectivity	pS1[4]	1	-0.044	18.679	1.429	18.716	69.000	0.000	--	--	z50 for NMFS survey selectivity (females, 1982+)
selectivity	selectivity	pS1[5]	1	138.638	0.446	138.719	0.402	138.344	0.354	138.763	0.404	z50 for TCF retention (pre-1991)
selectivity	selectivity	pS1[6]	1	138.475	0.357	138.530	0.364	138.451	0.359	138.456	0.356	z50 for TCF retention (1991-1996)
selectivity	selectivity	pS1[8]	1	4.859	0.007	4.858	0.007	4.856	0.007	4.863	0.007	ln(z50) for TCF selectivity (males)
selectivity	selectivity	pS1[9]	1	95.205	2.202	94.500	2.606	94.726	2.469	94.411	2.281	z50 for TCF selectivity (females)

Table 15 (cont.). All non-vector parameters. Parameters with phase > 0 are MLEs; otherwise, the values were fixed outside the model. Highlights indicate poorly-estimated parameters (large standard errors or estimates at bounds).

				19.03		19.03(2020)		20.07		20.10		
category	process	name	phase	est	stdv	est	stdv	est	stdv	est	stdv	label
selectivity	selectivity	pS2[1]	1	92.629	7.617	93.604	7.842	21.515	2.678	25.996	3.125	z95-z50 for NMFS survey selectivity (males, pre-1982)
selectivity	selectivity	pS2[10]	2	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	ascending slope for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS2[11]	2	0.211	0.056	0.206	0.057	0.212	0.061	0.203	0.049	ascending slope for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS2[12]	2	0.182	0.013	0.183	0.013	0.185	0.014	0.186	0.012	ascending slope for SCF selectivity (males, 2005+)
selectivity	selectivity	pS2[13]	2	0.170	0.068	0.169	0.071	0.167	0.064	0.172	0.061	slope for SCF selectivity (females, pre-1997)
selectivity	selectivity	pS2[14]	2	0.264	0.126	0.263	0.131	0.261	0.122	0.265	0.117	slope for SCF selectivity (females, 1997-2004)
selectivity	selectivity	pS2[15]	2	0.193	0.058	0.199	0.060	0.199	0.056	0.205	0.053	slope for SCF selectivity (females, 2005+)
selectivity	selectivity	pS2[16]	2	0.093	0.010	0.093	0.011	0.121	0.012	0.098	0.008	slope for GF.AllGear selectivity (males, pre-1987)
selectivity	selectivity	pS2[17]	2	0.046	0.007	0.048	0.008	0.075	0.017	0.043	0.005	slope for GF.AllGear selectivity (males, 1987-1996)
selectivity	selectivity	pS2[18]	2	0.061	0.003	0.062	0.003	0.072	0.003	0.072	0.002	slope for GF.AllGear selectivity (males, 1997+)
selectivity	selectivity	pS2[19]	2	0.138	0.020	0.141	0.022	0.155	0.020	0.135	0.016	slope for GF.AllGear selectivity (females, pre-1987)
selectivity	selectivity	pS2[2]	1	100.000	0.000	100.000	0.000	59.152	6.865	--	--	z95-z50 for NMFS survey selectivity (males, 1982+)
selectivity	selectivity	pS2[20]	2	0.168	0.038	0.169	0.046	0.184	0.045	0.043	0.010	slope for GF.AllGear selectivity (females, 1987-1996)
selectivity	selectivity	pS2[21]	2	0.063	0.005	0.064	0.005	0.075	0.005	0.078	0.004	slope for GF.AllGear selectivity (females, 1997+)
selectivity	selectivity	pS2[22]	3	2.914	0.133	2.902	0.143	2.909	0.147	2.867	0.137	ln(z95-z50) for RKF selectivity (males, pre-1997)
selectivity	selectivity	pS2[23]	3	3.433	0.072	3.439	0.075	3.456	0.077	3.424	0.071	ln(z95-z50) for RKF selectivity (males, 1997-2004)
selectivity	selectivity	pS2[24]	3	3.408	0.035	3.408	0.036	3.429	0.037	3.390	0.034	ln(z95-z50) for RKF selectivity (males, 2005+)
selectivity	selectivity	pS2[25]	3	2.743	0.529	2.747	0.552	2.731	0.561	2.658	0.500	ln(z95-z50) for RKF selectivity (males, pre-1997)
selectivity	selectivity	pS2[26]	3	2.865	0.860	2.866	0.890	2.803	0.862	2.785	0.842	ln(z95-z50) for RKF selectivity (males, 1997-2004)
selectivity	selectivity	pS2[27]	3	3.026	0.201	3.022	0.210	2.995	0.206	2.967	0.386	ln(z95-z50) for RKF selectivity (males, 2005+)
selectivity	selectivity	pS2[28]	1	2.000	0.624	2.000	0.611	2.000	0.471	2.000	0.484	slope for TCF retention (2005-2009)
selectivity	selectivity	pS2[29]	1	0.565	0.100	0.566	0.104	0.565	0.104	0.564	0.103	slope for TCF retention (2013+)
selectivity	selectivity	pS2[3]	1	68.011	8.993	68.444	9.157	50.041	5.317	46.605	7.481	z95-z50 for NMFS survey selectivity (females, pre-1982)
selectivity	selectivity	pS2[4]	1	100.000	0.001	100.000	0.001	100.000	0.000	--	--	z95-z50 for NMFS survey selectivity (females, 1982+)
selectivity	selectivity	pS2[5]	1	0.689	0.116	0.725	0.117	0.750	0.122	0.734	0.120	slope for TCF retention (pre-1991)
selectivity	selectivity	pS2[6]	1	0.908	0.212	0.914	0.208	0.943	0.226	0.936	0.221	slope for TCF retention (1997+)
selectivity	selectivity	pS2[7]	1	0.116	0.006	0.117	0.007	0.117	0.007	0.126	0.007	slope for TCF selectivity (males, pre-1997)
selectivity	selectivity	pS2[8]	1	0.159	0.007	0.160	0.007	0.160	0.008	0.163	0.007	slope for TCF selectivity (males, 1997+)
selectivity	selectivity	pS2[9]	1	0.184	0.017	0.186	0.022	0.192	0.022	0.199	0.021	slope for TCF selectivity (females)
selectivity	selectivity	pS3[1]	2	3.515	0.135	3.432	0.144	3.361	0.140	3.392	0.157	ln(dz50-az50) for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS3[2]	2	3.836	0.148	3.815	0.163	3.825	0.159	3.799	0.163	ln(dz50-az50) for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS3[3]	2	3.509	0.060	3.502	0.063	3.522	0.061	3.490	0.063	ln(dz50-az50) for SCF selectivity (males, 2005+)
selectivity	selectivity	pS4[1]	2	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	descending slope for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS4[2]	2	0.168	0.103	0.162	0.104	0.162	0.103	0.174	0.122	descending slope for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS4[3]	2	0.196	0.025	0.193	0.025	0.195	0.025	0.197	0.027	descending slope for SCF selectivity (males, 2005+)

Table 16. Historical recruitment devs estimates (1949-1974) for all model scenarios.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	-1.341	1.620	-1.352	1.620	-1.404	1.598	-1.364	1.643
2	-1.338	1.476	-1.349	1.476	-1.400	1.453	-1.362	1.500
3	-1.332	1.338	-1.343	1.338	-1.393	1.314	-1.358	1.360
4	-1.320	1.207	-1.331	1.207	-1.379	1.182	-1.349	1.226
5	-1.301	1.085	-1.312	1.085	-1.357	1.061	-1.334	1.100
6	-1.271	0.976	-1.282	0.975	-1.322	0.952	-1.311	0.986
7	-1.225	0.882	-1.237	0.881	-1.270	0.860	-1.273	0.886
8	-1.158	0.806	-1.169	0.805	-1.193	0.786	-1.213	0.804
9	-1.057	0.750	-1.068	0.749	-1.077	0.732	-1.120	0.745
10	-0.904	0.714	-0.915	0.713	-0.901	0.698	-0.970	0.709
11	-0.667	0.697	-0.676	0.697	-0.626	0.682	-0.726	0.696
12	-0.285	0.698	-0.292	0.698	-0.180	0.685	-0.324	0.702
13	0.311	0.708	0.308	0.708	0.496	0.690	0.282	0.712
14	1.069	0.706	1.068	0.705	1.269	0.680	1.017	0.709
15	1.649	0.688	1.648	0.687	1.704	0.656	1.569	0.692
16	1.771	0.671	1.769	0.670	1.697	0.647	1.691	0.680
17	1.591	0.673	1.592	0.673	1.490	0.654	1.575	0.683
18	1.357	0.672	1.366	0.672	1.311	0.653	1.483	0.680
19	1.204	0.660	1.222	0.659	1.261	0.636	1.532	0.658
20	1.151	0.645	1.178	0.643	1.332	0.613	1.674	0.628
21	1.119	0.637	1.146	0.636	1.365	0.600	1.666	0.623
22	0.972	0.613	0.990	0.612	1.112	0.567	1.265	0.604
23	0.759	0.562	0.765	0.562	0.625	0.536	0.583	0.588
24	0.358	0.558	0.362	0.558	0.084	0.537	-0.043	0.594
25	-0.035	0.556	-0.022	0.555	-0.209	0.534	-0.324	0.586
26	-0.079	0.596	-0.065	0.595	-0.032	0.556	-0.265	0.659

Table 17. Current recruitment devs estimates (1975-2020) for all model scenarios. Note the large uncertainties in the last row (devs for recruits entering the population on July 1, 2020).

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	0.875	0.334	0.864	0.601	1.373	0.526	0.345	1.025
2	1.924	0.153	1.934	0.516	1.685	0.516	2.442	0.523
3	1.643	0.171	1.658	0.521	1.389	0.522	1.433	0.581
4	0.944	0.261	0.947	0.560	0.287	0.609	0.487	0.711
5	-0.067	0.430	-0.124	0.672	-0.373	0.684	-0.292	0.857
6	-0.578	0.517	-0.563	0.710	-0.578	0.675	-0.604	0.867
7	-0.109	0.264	-0.146	0.563	-0.050	0.552	-0.363	0.655
8	-0.253	0.243	-0.290	0.552	-0.107	0.549	-0.251	0.574
9	0.846	0.110	0.880	0.504	1.010	0.505	0.978	0.507
10	0.751	0.143	0.782	0.514	0.894	0.512	0.776	0.522
11	0.952	0.137	0.945	0.513	0.906	0.515	0.995	0.519
12	0.948	0.141	1.002	0.512	1.076	0.510	1.375	0.512
13	0.989	0.133	1.031	0.511	1.044	0.509	0.887	0.535
14	0.699	0.154	0.639	0.520	0.229	0.534	0.616	0.537
15	-0.172	0.211	-0.154	0.538	-0.278	0.538	-0.277	0.587
16	-1.323	0.410	-1.353	0.657	-1.747	0.772	-1.781	0.957
17	-1.424	0.321	-1.418	0.589	-1.302	0.574	-1.474	0.652
18	-1.391	0.258	-1.387	0.556	-1.421	0.565	-1.219	0.571
19	-1.482	0.274	-1.475	0.563	-1.283	0.551	-1.601	0.626
20	-1.256	0.246	-1.275	0.551	-1.271	0.554	-1.153	0.562
21	-0.723	0.174	-0.741	0.522	-0.628	0.521	-0.674	0.528
22	-1.012	0.233	-1.012	0.544	-0.786	0.537	-1.241	0.577
23	0.027	0.112	0.018	0.504	-0.006	0.506	0.092	0.506
24	-0.845	0.209	-0.851	0.535	-0.858	0.544	-0.787	0.547
25	0.419	0.104	0.425	0.503	0.583	0.502	0.449	0.505
26	-0.292	0.213	-0.292	0.536	-0.366	0.553	-0.208	0.545
27	0.935	0.098	0.940	0.501	0.934	0.503	0.968	0.505
28	-0.247	0.257	-0.249	0.555	-0.254	0.566	-0.049	0.567
29	1.030	0.108	1.011	0.504	1.109	0.502	0.981	0.509
30	0.842	0.117	0.864	0.505	0.467	0.514	0.987	0.509
31	-0.465	0.260	-0.463	0.557	-0.540	0.558	-0.933	0.699
32	-0.844	0.303	-0.842	0.579	-0.898	0.586	-1.194	0.704
33	-0.979	0.317	-0.955	0.585	-0.821	0.588	-0.784	0.604
34	-0.503	0.264	-0.487	0.558	0.246	0.541	-0.308	0.563
35	1.346	0.100	1.346	0.502	1.429	0.502	1.474	0.504
36	1.078	0.120	1.060	0.507	0.563	0.518	0.953	0.516
37	0.017	0.195	0.014	0.529	-0.281	0.533	-0.109	0.562
38	-1.552	0.460	-1.557	0.675	-1.610	0.662	-2.223	1.236
39	-0.535	0.175	-0.551	0.523	-0.498	0.512	-0.489	0.539
40	-1.018	0.221	-1.016	0.539	-1.237	0.547	-0.844	0.557
41	-1.309	0.257	-1.281	0.554	-0.738	0.525	-1.236	0.590
42	-0.926	0.231	-0.886	0.543	-0.713	0.549	-0.642	0.547
43	0.782	0.121	0.814	0.506	1.304	0.500	0.985	0.508
44	0.828	0.179	0.829	0.522	0.646	0.535	1.386	0.519
45	1.428	0.185	1.363	0.522	1.470	0.525	2.129	0.520
46	--	--	0.000	22.116	0.000	22.116	0.000	22.116

Table 18. Logit-scale parameters for the probability of terminal molt for all model scenarios. The probability of terminal molt is 0 at sizes less than, and 1 at sizes greater than, the indicated range.

	19.03		19.03(2020)		20.07		20.10		
index	est	stdv	est	stdv	est	stdv	est	stdv	label
1	-6.825	0.991	-6.845	0.997	-6.620	0.982	-6.426	0.942	females 50-105 mmCW (entire model period)
2	-5.053	0.452	-5.070	0.454	-4.891	0.444	-4.804	0.426	females 50-105 mmCW (entire model period)
3	-3.339	0.206	-3.350	0.207	-3.210	0.201	-3.221	0.199	females 50-105 mmCW (entire model period)
4	-1.794	0.115	-1.796	0.116	-1.689	0.112	-1.769	0.111	females 50-105 mmCW (entire model period)
5	-0.514	0.090	-0.514	0.091	-0.412	0.087	-0.534	0.087	females 50-105 mmCW (entire model period)
6	0.221	0.091	0.217	0.092	0.332	0.089	0.188	0.088	females 50-105 mmCW (entire model period)
7	0.545	0.101	0.542	0.102	0.621	0.098	0.509	0.099	females 50-105 mmCW (entire model period)
8	1.179	0.142	1.182	0.144	1.189	0.135	1.148	0.140	females 50-105 mmCW (entire model period)
9	2.263	0.251	2.259	0.253	2.344	0.247	2.272	0.255	females 50-105 mmCW (entire model period)
10	3.483	0.475	3.474	0.488	3.815	0.508	3.594	0.528	females 50-105 mmCW (entire model period)
11	4.776	0.989	4.763	1.015	5.371	1.071	4.996	1.092	females 50-105 mmCW (entire model period)
1	-2.909	0.281	-2.919	0.285	-3.237	0.313	-3.023	0.311	males 60-150 mmCW (entire model period)
2	-3.293	0.294	-3.298	0.296	-3.591	0.311	-3.337	0.307	males 60-150 mmCW (entire model period)
3	-2.861	0.248	-2.869	0.252	-3.106	0.268	-2.936	0.264	males 60-150 mmCW (entire model period)
4	-2.174	0.161	-2.178	0.163	-2.429	0.171	-2.239	0.171	males 60-150 mmCW (entire model period)
5	-1.659	0.138	-1.659	0.140	-1.908	0.145	-1.695	0.145	males 60-150 mmCW (entire model period)
6	-1.411	0.121	-1.413	0.123	-1.534	0.120	-1.378	0.126	males 60-150 mmCW (entire model period)
7	-0.855	0.107	-0.849	0.109	-0.934	0.104	-0.809	0.110	males 60-150 mmCW (entire model period)
8	-0.466	0.095	-0.452	0.097	-0.550	0.094	-0.466	0.099	males 60-150 mmCW (entire model period)
9	-0.320	0.096	-0.310	0.097	-0.433	0.094	-0.348	0.099	males 60-150 mmCW (entire model period)
10	-0.154	0.096	-0.154	0.097	-0.213	0.093	-0.176	0.099	males 60-150 mmCW (entire model period)
11	0.302	0.105	0.287	0.106	0.258	0.105	0.295	0.111	males 60-150 mmCW (entire model period)
12	0.904	0.134	0.882	0.134	1.024	0.142	1.013	0.159	males 60-150 mmCW (entire model period)
13	1.757	0.185	1.732	0.187	1.947	0.176	1.978	0.191	males 60-150 mmCW (entire model period)
14	3.110	0.305	3.071	0.301	3.328	0.282	3.370	0.282	males 60-150 mmCW (entire model period)
15	4.353	0.345	4.296	0.340	4.483	0.336	4.502	0.338	males 60-150 mmCW (entire model period)
16	6.116	0.733	6.043	0.721	6.067	0.727	5.955	0.727	males 60-150 mmCW (entire model period)
17	8.033	1.544	7.946	1.527	7.824	1.522	7.587	1.519	males 60-150 mmCW (entire model period)

Table 19. Availability parameters used in Scenario 20.07 (all fixed).

size bin	males					females				
(mm CW)	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
27	0.0553	0.0217	0.0204	0.0003	0.3022	0.0163	0.0151	0.0102	0.0000	0.4480
32	0.0579	0.0248	0.0252	0.0008	0.3438	0.0166	0.0185	0.0147	0.0000	0.4225
37	0.0606	0.0283	0.0311	0.0022	0.3929	0.0169	0.0225	0.0208	0.0117	0.4358
42	0.0635	0.0324	0.0383	0.0059	0.4536	0.0170	0.0269	0.0282	0.1017	0.5208
47	0.0667	0.0370	0.0470	0.0149	0.5308	0.0171	0.0315	0.0356	0.1102	0.6392
52	0.0703	0.0424	0.0576	0.0354	0.6163	0.0176	0.0361	0.0402	0.1390	0.6865
57	0.0744	0.0485	0.0704	0.0755	0.6806	0.0186	0.0393	0.0408	0.2271	0.6556
62	0.0791	0.0558	0.0864	0.1399	0.6844	0.0206	0.0395	0.0380	0.2123	0.6137
67	0.0848	0.0642	0.1061	0.2200	0.6168	0.0251	0.0376	0.0344	0.1391	0.6057
72	0.0915	0.0740	0.1281	0.2982	0.5299	0.0355	0.0357	0.0326	0.1454	0.6628
77	0.0994	0.0856	0.1495	0.3565	0.4680	0.0557	0.0355	0.0337	0.2528	0.7555
82	0.1087	0.0993	0.1659	0.3851	0.4554	0.0864	0.0383	0.0380	0.3893	0.7682
87	0.1199	0.1152	0.1751	0.3895	0.4842	0.1304	0.0486	0.0493	0.4249	0.6891
92	0.1333	0.1338	0.1777	0.3851	0.5309	0.2141	0.0826	0.0816	0.4314	0.6363
97	0.1497	0.1553	0.1757	0.3886	0.5659	0.3845	0.1815	0.1702	0.4860	0.5586
102	0.1696	0.1797	0.1715	0.4087	0.5696	0.6400	0.3785	0.3622	0.5985	0.2931
107	0.1936	0.2074	0.1679	0.4363	0.5588	0.8178	0.5978	0.6583	0.7664	0.0205
112	0.2218	0.2382	0.1677	0.4579	0.5560	0.6568	0.7107	0.9415	0.9329	0.0000
117	0.2543	0.2723	0.1736	0.4593	0.5797	0.0000	0.0000	1.0000	1.0000	0.0000
122	0.2902	0.3097	0.1873	0.4420	0.6195	0.0000	0.0000	0.9901	0.0000	0.0000
127	0.3276	0.3508	0.2109	0.4158	0.6464	0.0000	0.0000	0.0000	0.0000	0.0000
132	0.3634	0.3959	0.2479	0.3895	0.6277	0.0000	0.0000	0.0000	0.0000	0.0000
137	0.3927	0.4441	0.3015	0.3702	0.5651	0.0000	0.0000	0.0000	0.0000	0.0000
142	0.4076	0.4909	0.3688	0.3634	0.5026	0.0000	0.0000	0.0000	0.0000	0.0000
147	0.4007	0.5300	0.4411	0.3751	0.4737	0.0000	0.0000	0.0000	0.0000	0.0000
152	0.3692	0.5550	0.5020	0.4127	0.4601	0.0000	0.0000	0.0000	0.0000	0.0000
157	0.3213	0.5660	0.5353	0.4785	0.2592	0.0000	0.0000	0.0000	0.0000	0.0000
162	0.2681	0.5665	0.5288	0.5731	0.0394	0.0000	0.0000	0.0000	0.0000	0.0000
167	0.2174	0.5608	0.4785	0.6952	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000
172	0.1733	0.5518	0.3993	0.8448	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
177	0.1366	0.5410	0.3154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
182	0.1070	0.0000	0.2423	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 20. NMFS survey selectivity values used in Scenario 20.10. These were estimated outside the model.

size bin (mm CW)	males	females
27	0.0166	0.0073
32	0.0341	0.0152
37	0.0597	0.0283
42	0.0910	0.0458
47	0.1238	0.0657
52	0.1549	0.0854
57	0.1827	0.1034
62	0.2076	0.1191
67	0.2302	0.1335
72	0.2514	0.1487
77	0.2727	0.1658
82	0.2959	0.1841
87	0.3229	0.2026
92	0.3529	0.2200
97	0.3843	0.2348
102	0.4154	0.2455
107	0.4440	0.2511
112	0.4688	0.2521
117	0.4904	0.2494
122	0.5107	0.2441
127	0.5312	0.2371
132	0.5535	0.2293
137	0.5780	0.2293
142	0.6007	0.2293
147	0.6165	0.2293
152	0.6209	0.2293
157	0.6088	0.2293
162	0.5764	0.2293
167	0.5254	0.2293
172	0.4604	0.2293
177	0.3882	0.2293
182	0.3166	0.2293

Table 21. Ln-scale devs for annual deviations, starting in 1991/92, in the ln-scale size at 50% selected in the directed fishery.

	19.03		19.03(2020)		20.07		20.10		
index	est	stdv	est	stdv	est	stdv	est	stdv	label
1	0.090	0.010	0.090	0.011	0.090	0.011	0.087	0.010	ln(z50 devs) for TCF selectivity (males, 1991+)
2	0.038	0.010	0.037	0.010	0.037	0.010	0.039	0.009	ln(z50 devs) for TCF selectivity (males, 1991+)
3	0.112	0.012	0.113	0.013	0.115	0.012	0.106	0.011	ln(z50 devs) for TCF selectivity (males, 1991+)
4	0.066	0.017	0.065	0.017	0.072	0.017	0.061	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
5	0.005	0.024	0.012	0.024	0.022	0.023	0.011	0.021	ln(z50 devs) for TCF selectivity (males, 1991+)
6	0.161	0.036	0.161	0.037	0.164	0.036	0.146	0.033	ln(z50 devs) for TCF selectivity (males, 1991+)
7	-0.061	0.015	-0.061	0.016	-0.064	0.016	-0.060	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
8	-0.062	0.015	-0.063	0.016	-0.066	0.016	-0.057	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
9	-0.103	0.014	-0.103	0.015	-0.107	0.015	-0.101	0.014	ln(z50 devs) for TCF selectivity (males, 1991+)
10	0.030	0.013	0.029	0.013	0.028	0.013	0.027	0.012	ln(z50 devs) for TCF selectivity (males, 1991+)
11	0.195	0.014	0.193	0.015	0.193	0.015	0.184	0.014	ln(z50 devs) for TCF selectivity (males, 1991+)
12	-0.020	0.015	-0.021	0.015	-0.023	0.016	-0.023	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
13	-0.085	0.012	-0.085	0.012	-0.088	0.012	-0.080	0.011	ln(z50 devs) for TCF selectivity (males, 1991+)
14	-0.124	0.013	-0.123	0.013	-0.127	0.013	-0.111	0.011	ln(z50 devs) for TCF selectivity (males, 1991+)
15	-0.098	0.017	-0.099	0.018	-0.099	0.018	-0.093	0.017	ln(z50 devs) for TCF selectivity (males, 1991+)
16	-0.145	0.016	-0.144	0.016	-0.144	0.016	-0.135	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)

Table 22. Annual (1965+) ln-scale capture rate devs estimated for males taken in the directed fishery, for all model scenarios. Devs indexing skips years where the fishery was closed.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	-0.508	0.487	-0.509	0.488	-0.495	0.491	-0.532	0.483
2	-0.731	0.374	-0.732	0.374	-0.722	0.378	-0.751	0.368
3	0.491	0.328	0.490	0.329	0.490	0.337	0.497	0.321
4	0.352	0.307	0.348	0.308	0.344	0.312	0.370	0.300
5	0.532	0.296	0.525	0.297	0.532	0.301	0.527	0.297
6	0.375	0.291	0.365	0.293	0.385	0.300	0.307	0.298
7	0.169	0.276	0.155	0.278	0.174	0.291	0.007	0.284
8	0.001	0.242	-0.019	0.244	-0.023	0.259	-0.281	0.244
9	-0.220	0.185	-0.247	0.186	-0.304	0.195	-0.631	0.179
10	0.008	0.130	-0.024	0.130	-0.146	0.128	-0.507	0.121
11	0.281	0.104	0.246	0.104	0.083	0.097	-0.281	0.098
12	1.086	0.101	1.049	0.102	0.889	0.091	0.504	0.098
13	1.827	0.117	1.784	0.117	1.678	0.101	1.162	0.114
14	1.996	0.152	1.944	0.149	1.983	0.130	1.219	0.145
15	2.490	0.222	2.445	0.219	2.789	0.219	1.646	0.191
16	2.074	0.162	2.105	0.166	2.260	0.168	1.696	0.169
17	0.391	0.109	0.425	0.111	0.472	0.108	0.384	0.109
18	-0.640	0.122	-0.614	0.123	-0.607	0.122	-0.534	0.124
19	-1.707	0.248	-1.679	0.250	-1.696	0.248	-1.510	0.256
20	-0.714	0.176	-0.669	0.178	-0.725	0.174	-0.385	0.186
21	-1.119	0.213	-1.087	0.214	-1.144	0.215	-0.832	0.222
22	-0.223	0.104	-0.210	0.105	-0.282	0.105	0.050	0.108
23	0.998	0.078	1.003	0.079	0.909	0.079	1.274	0.084
24	1.669	0.082	1.679	0.084	1.619	0.084	1.981	0.092
25	1.827	0.116	1.817	0.118	1.795	0.117	2.047	0.124
26	1.875	0.109	1.853	0.109	1.848	0.106	2.104	0.113
27	1.428	0.136	1.439	0.137	1.480	0.134	1.675	0.136
28	0.697	0.151	0.698	0.150	0.800	0.151	0.926	0.146
29	0.205	0.161	0.253	0.165	0.361	0.168	0.497	0.158
30	-0.381	0.402	-0.369	0.408	-0.288	0.410	-0.156	0.393
31	-2.158	0.207	-2.151	0.207	-2.162	0.205	-1.974	0.210
32	-1.649	0.137	-1.644	0.138	-1.659	0.136	-1.449	0.140
33	-1.617	0.117	-1.608	0.118	-1.609	0.116	-1.447	0.119
34	-1.785	0.154	-1.781	0.154	-1.794	0.152	-1.596	0.156
35	-1.090	0.260	-1.109	0.262	-1.146	0.258	-0.983	0.261
36	-1.646	0.137	-1.644	0.137	-1.656	0.135	-1.439	0.138
37	-0.545	0.088	-0.534	0.088	-0.542	0.084	-0.295	0.090
38	-0.277	0.085	-0.262	0.085	-0.237	0.081	-0.023	0.086
39	-1.982	0.141	-1.966	0.141	-1.927	0.139	-1.746	0.142
40	-1.783	0.134	-1.764	0.135	-1.729	0.132	-1.522	0.135

Table 23. Annual (1992+) ln-scale capture rate devs for males caught in the snow crab fishery, for all model scenarios.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	0.512	0.104	0.525	0.104	0.540	0.104	0.544	0.104
2	0.807	0.097	0.828	0.097	0.866	0.097	0.856	0.097
3	0.242	0.179	0.268	0.179	0.310	0.179	0.308	0.179
4	0.199	0.234	0.231	0.233	0.276	0.234	0.305	0.233
5	1.099	0.140	1.131	0.140	1.175	0.140	1.242	0.141
6	0.901	0.161	0.892	0.168	0.886	0.165	0.921	0.164
7	-0.134	0.351	-0.125	0.349	-0.127	0.346	-0.074	0.344
8	-0.982	0.548	-0.968	0.546	-0.972	0.543	-0.922	0.548
9	-0.718	0.492	-0.701	0.488	-0.707	0.485	-0.654	0.486
10	-0.419	0.384	-0.407	0.382	-0.411	0.380	-0.372	0.377
11	-1.115	0.500	-1.106	0.499	-1.103	0.499	-1.099	0.492
12	-1.390	0.501	-1.387	0.500	-1.396	0.498	-1.394	0.494
13	-1.435	0.470	-1.435	0.469	-1.440	0.469	-1.461	0.462
14	-0.079	0.204	-0.098	0.203	-0.110	0.203	-0.125	0.201
15	0.069	0.163	0.048	0.163	0.028	0.163	-0.008	0.162
16	0.124	0.141	0.104	0.141	0.098	0.141	0.055	0.140
17	-0.494	0.206	-0.514	0.206	-0.524	0.205	-0.555	0.204
18	-0.085	0.159	-0.110	0.159	-0.124	0.159	-0.178	0.158
19	0.014	0.169	-0.010	0.168	-0.033	0.168	-0.070	0.167
20	0.568	0.128	0.543	0.129	0.514	0.129	0.504	0.128
21	0.215	0.161	0.192	0.161	0.168	0.161	0.166	0.160
22	0.101	0.142	0.079	0.142	0.059	0.142	0.077	0.141
23	1.005	0.089	0.982	0.089	0.970	0.089	0.971	0.089
24	0.773	0.096	0.754	0.096	0.766	0.096	0.720	0.096
25	0.548	0.115	0.531	0.115	0.547	0.115	0.490	0.115
26	-0.148	0.217	-0.157	0.215	-0.147	0.216	-0.171	0.214
27	-0.177	0.260	-0.183	0.257	-0.183	0.258	-0.174	0.256
28	0.000	0.000	0.095	0.236	0.076	0.235	0.098	0.235

Table 24. Annual (1992+) ln-scale capture rate devs for males caught in the BBRKC fishery, for all model scenarios. Devs indexing skips years where the fishery was closed.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	0.466	0.185	0.451	0.184	0.471	0.186	0.447	0.185
2	1.433	0.121	1.436	0.120	1.500	0.123	1.446	0.121
3	0.088	0.330	0.079	0.333	0.115	0.343	0.112	0.340
4	0.282	0.421	0.251	0.420	0.245	0.423	0.255	0.426
5	0.255	0.424	0.224	0.422	0.212	0.421	0.223	0.426
6	0.222	0.419	0.194	0.418	0.181	0.416	0.192	0.420
7	0.196	0.412	0.172	0.411	0.157	0.409	0.170	0.413
8	0.145	0.397	0.127	0.398	0.112	0.396	0.127	0.400
9	0.106	0.381	0.094	0.384	0.081	0.382	0.093	0.385
10	0.041	0.364	0.035	0.368	0.026	0.367	0.026	0.366
11	-0.053	0.344	-0.053	0.348	-0.070	0.346	-0.064	0.346
12	-0.128	0.326	-0.118	0.331	-0.131	0.329	-0.130	0.329
13	-0.233	0.309	-0.218	0.314	-0.228	0.313	-0.229	0.313
14	-0.278	0.299	-0.258	0.304	-0.265	0.303	-0.280	0.301
15	-0.195	0.282	-0.170	0.288	-0.173	0.287	-0.183	0.286
16	-0.306	0.280	-0.283	0.285	-0.283	0.285	-0.296	0.283
17	-0.361	0.290	-0.342	0.294	-0.343	0.294	-0.362	0.292
18	-0.274	0.304	-0.260	0.308	-0.264	0.307	-0.269	0.307
19	-0.189	0.314	-0.178	0.319	-0.184	0.317	-0.181	0.319
20	-0.174	0.306	-0.159	0.311	-0.165	0.309	-0.159	0.311
21	-0.175	0.280	-0.150	0.285	-0.158	0.284	-0.131	0.288
22	-0.302	0.277	-0.274	0.283	-0.268	0.284	-0.253	0.285
23	-0.266	0.286	-0.239	0.291	-0.225	0.294	-0.231	0.292
24	-0.156	0.301	-0.135	0.307	-0.122	0.310	-0.128	0.308
25	-0.145	0.319	-0.127	0.325	-0.120	0.327	-0.110	0.328
26	0.000	0.000	-0.100	0.339	-0.104	0.339	-0.085	0.343

Table 25. Annual (1973+) ln-scale capture rate devs for males caught in the groundfish fisheries, for all model scenarios.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	1.428	0.097	1.427	0.098	1.406	0.095	0.820	0.112
2	1.853	0.077	1.850	0.078	1.814	0.072	1.236	0.094
3	1.036	0.072	1.034	0.073	1.003	0.067	0.449	0.090
4	0.519	0.080	0.518	0.081	0.511	0.074	-0.020	0.097
5	0.203	0.100	0.203	0.101	0.233	0.096	-0.288	0.116
6	-0.070	0.131	-0.066	0.132	0.006	0.128	-0.499	0.144
7	0.520	0.095	0.531	0.096	0.667	0.089	0.139	0.112
8	0.132	0.121	0.156	0.121	0.305	0.120	-0.149	0.132
9	-0.058	0.156	-0.022	0.156	0.097	0.156	-0.219	0.162
10	-0.836	0.361	-0.797	0.364	-0.721	0.368	-0.888	0.360
11	-0.260	0.306	-0.209	0.309	-0.169	0.309	-0.236	0.311
12	-0.030	0.334	0.028	0.337	0.026	0.335	0.046	0.342
13	-0.452	0.446	-0.407	0.453	-0.417	0.453	-0.394	0.454
14	-0.254	0.331	-0.215	0.333	-0.219	0.336	-0.238	0.331
15	-0.363	0.329	-0.343	0.331	-0.404	0.331	-0.001	0.360
16	-0.769	0.379	-0.757	0.381	-0.818	0.379	-0.471	0.413
17	-0.560	0.301	-0.552	0.302	-0.611	0.301	-0.279	0.327
18	-0.252	0.233	-0.245	0.234	-0.296	0.232	0.027	0.259
19	0.405	0.069	0.418	0.072	0.358	0.066	0.764	0.144
20	0.666	0.066	0.682	0.069	0.644	0.062	1.003	0.140
21	0.291	0.082	0.310	0.084	0.286	0.078	0.628	0.145
22	0.821	0.071	0.842	0.073	0.825	0.067	1.166	0.137
23	0.758	0.080	0.782	0.081	0.770	0.076	1.123	0.141
24	0.877	0.083	0.904	0.084	0.874	0.080	1.295	0.145
25	1.445	0.080	1.471	0.080	1.466	0.079	1.555	0.084
26	1.348	0.089	1.377	0.090	1.367	0.088	1.477	0.093
27	0.729	0.136	0.760	0.137	0.749	0.136	0.862	0.139
28	0.729	0.127	0.759	0.128	0.744	0.126	0.861	0.130
29	0.863	0.100	0.893	0.101	0.893	0.099	0.979	0.104
30	0.140	0.160	0.167	0.160	0.158	0.159	0.242	0.162
31	-0.266	0.190	-0.240	0.191	-0.250	0.189	-0.172	0.192
32	0.025	0.127	0.051	0.128	0.055	0.126	0.104	0.130
33	-0.343	0.156	-0.318	0.156	-0.319	0.155	-0.268	0.158
34	-0.378	0.149	-0.353	0.149	-0.359	0.148	-0.310	0.151
35	-0.116	0.116	-0.092	0.117	-0.103	0.115	-0.061	0.119
36	-0.439	0.155	-0.418	0.155	-0.434	0.154	-0.407	0.157
37	-0.812	0.223	-0.791	0.224	-0.796	0.222	-0.795	0.225
38	-1.100	0.294	-1.078	0.295	-1.063	0.295	-1.055	0.296
39	-0.662	0.204	-0.639	0.205	-0.627	0.204	-0.577	0.207
40	-1.219	0.295	-1.196	0.296	-1.201	0.295	-1.117	0.299
41	-0.858	0.201	-0.833	0.201	-0.844	0.200	-0.764	0.203
42	-0.809	0.193	-0.782	0.194	-0.783	0.193	-0.741	0.196
43	-0.938	0.244	-0.911	0.245	-0.900	0.245	-0.886	0.247
44	-0.782	0.253	-0.787	0.261	-0.774	0.261	-0.762	0.262
45	-1.186	0.377	-1.186	0.385	-1.190	0.384	-1.159	0.387
46	-0.976	0.349	-1.008	0.364	-1.017	0.363	-1.009	0.365
47	0.000	0.000	-0.917	0.324	-0.943	0.322	-1.012	0.322

Table 26. Objective function values for all data components from the model scenarios. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. n.at.z: size compositions. Highlighted cells indicate best fits by > 5 likelihood units between Scenarios 19.03(2020) and 20.07.

				Model Scenarios			
category	fleet	data type	sex	19.03	19.03(2020)	20.07	20.1
surveys data	NMFS	biomass	male	54.22	49.34	65.33	56.88
		n.at.z		448.98	450.26	411.35	634.03
		biomass	female	137.41	136.39	139.92	147.29
		n.at.z		343.69	343.34	330.88	674.82
	SBS BSFRF	biomass	male	--	--	-1.02	--
		n.at.z		--	--	153.24	--
		biomass	female	--	--	-6.64	--
		n.at.z		--	--	146.29	--
fisheries data	TCF (RC)	biomass	male	7.35	7.06	8.13	7.64
		n.at.z	male	51.99	50.51	55.13	49.71
	TCF (TC)	biomass	female	9.96	9.72	9.28	9.69
			male	3.77	3.61	3.69	3.51
		n.at.z	female	18.16	13.65	13.74	13.41
			male	88.14	83.30	89.33	84.79
	SCF	biomass	female	1.92	1.91	1.91	1.86
			male	17.75	16.75	16.44	14.30
		n.at.z	female	15.69	14.71	14.57	14.36
			male	124.76	117.64	119.65	119.38
	RKF	biomass	female	0.07	0.07	0.06	0.07
			male	27.22	26.09	25.79	27.91
		n.at.z	female	3.06	2.85	2.91	2.80
			male	74.42	70.18	70.64	71.72
	GF All	abundance	all sexes	3.19	3.23	3.45	2.93
		biomass	all sexes	29.69	29.43	32.03	23.20
		n.at.z	female	274.47	254.72	262.14	270.42
			male	285.08	262.32	276.68	302.55
growth data	--	molt	female	252.27	251.13	252.78	251.06
		increment	male	287.61	287.34	296.49	284.59
maturity ogive data	--	male maturity ogives	male	95.41	94.90	107.27	89.50

Table 27. Objective function values for all non-data components from the model scenarios.

category	type	element	level	19.03	19.03(2020)	20.07	20.10	description
penalties	maturity	smoothness	1	0.9	0.9	0.8	0.7	male probability of terminal molt bby size
			2	0.9	0.9	1.1	0.9	male probability of terminal molt bby size
priors	fisheries	pDevsLnC	1	137.4	136.4	138.5	125.4	annual devs for directed fishery
			2	31.1	32.0	32.1	32.1	annual devs for snow crab fishery
			3	55.9	57.3	57.2	56.8	annual devs for groundfish fisheries
			4	147.8	152.8	153.4	153.0	annual devs for BBRKC fishery
	natural mortality	pDM1	1	0.0	0.0	0.0	98.8	multiplier for immature crab
			2	15.0	15.4	12.7	53.4	multiplier for mature males
			3	17.9	17.8	31.9	19.0	multiplier for mature females
	recruitment	pDevsLnR	1	48.0	48.0	48.3	48.6	prior to 1975 (devs are AR1 process)
			2	0.1	0.1	0.1	0.1	after 1975
	surveys	pQ	2	38.7	36.3	28.5	0.0	male fully-selected NMFS survey catchability, after 1982
			4	80.4	79.1	25.0	0.0	female fully-selected NMFS survey catchability, after 1982

Table 28. Root mean square errors (RMSE) for data components from the model scenarios. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. Abundance values were not included the model fits. Highlighted values indicate smallest RMSE between Scenarios 19.03(2020) and 20.07.

				Model Scenarios			
category	fleet	sex	data type	19.03	19.03(2020)	20.07	20.1
surveys data	NMFS	male	abundance	3.27	3.25	3.40	3.13
			biomass	2.50	2.46	2.60	2.53
		female	abundance	5.38	5.38	5.49	5.99
			biomass	4.97	4.96	4.99	5.05
	SBS BSFRF	male	abundance	--	--	1.73	--
			biomass	--	--	1.58	--
		female	abundance	--	--	2.98	--
			biomass	--	--	1.90	--
fisheries data	TCF (RC)	male	abundance	0.00	3.27	3.34	3.13
			biomass	2.05	2.06	2.12	1.99
	TCF (TC)	female	abundance	0.00	39.17	37.01	33.52
		male	abundance	0.00	1.07	1.08	1.04
		female	biomass	41.20	10.99	10.43	9.51
		male	biomass	1.69	1.68	1.69	1.67
	SCF	female	abundance	0.00	4.95	4.97	4.68
		male	abundance	0.00	2.60	2.63	2.71
		female	biomass	5.13	4.85	4.85	4.57
		male	biomass	3.35	3.37	3.40	3.52
	RKF	female	abundance	0.00	10.91	12.04	11.57
		male	abundance	0.00	27.58	27.65	27.38
		female	biomass	42.13	3.38	3.62	3.63
		male	biomass	30.08	31.95	31.95	31.79
	GF All	all sexes	abundance	0.53	0.57	0.58	0.58
		all sexes	biomass	1.02	1.03	1.04	1.00
growth data	--	female	molt increment	0.31	0.31	0.28	0.24
		male		0.55	0.55	0.56	0.50
maturity ogive data	--	male	male maturity ogives	17.75	17.52	19.35	17.97

Table 29. Geometric means of effective sample sizes used for size composition data. Effective sample sizes were estimated using the McAllister-Ianelli approach. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. Highlighted cells indicate "best" value between Scenarios 19.03(2020) and 20.07.

			Model Scenarios			
category	**fleet**	**sex**	**19.03**	**19.03(2020)**	**20.07**	**20.1**
surveys data	**NMFS**	**male**	**161.83**	**161.20**	172.72	**124.59**
		female	**79.49**	**79.48**	**82.05**	**55.35**
	SBS BSFRF	**male**	--	--	**60.82**	--
		female	--	--	**28.86**	--
fisheries data	TCF (RC)	male	232.58	234.09	244.83	232.71
	TCF (TC)	female	104.91	98.98	98.59	99.90
		male	299.03	292.50	281.16	**292.21**
	SCF	female	45.47	44.83	44.82	46.45
		male	146.18	148.35	149.62	151.59
	RKF	female	33.81	30.73	30.26	31.10
		male	44.98	46.51	46.50	45.90
	GF All	female	258.04	256.67	253.58	235.98
		male	278.61	273.60	267.68	241.33

Table 30. Comparison of observed and predicted (total) male survey biomass (in 1000's t) from the model scenarios.

	Observed	Scenario			
year	(1000's t)	19.03	19.03(2020)	20.07	20.10
1975	294.9	200.4	202.6	252.6	194.7
1976	157.0	171.9	173.6	211.4	157.3
1977	138.5	138.6	139.9	168.8	123.3
1978	98.3	111.0	111.7	137.2	101.2
1979	50.0	107.1	107.1	131.0	96.9
1980	152.5	114.5	113.7	127.4	97.9
1981	79.9	100.4	98.0	106.8	72.2
1982	65.9	87.9	87.5	82.2	109.9
1983	38.0	64.7	63.7	61.9	73.4
1984	30.5	47.1	45.9	46.8	49.0
1985	14.9	38.6	37.5	39.7	38.1
1986	21.6	47.0	46.4	48.2	49.3
1987	45.5	59.1	59.2	61.4	65.5
1988	99.2	72.1	72.9	76.1	83.8
1989	132.8	82.5	83.9	87.8	99.9
1990	132.4	85.4	87.1	90.8	106.1
1991	145.8	79.6	81.2	84.3	99.0
1992	127.6	71.8	72.9	74.9	88.0
1993	73.3	56.8	57.4	57.6	67.7
1994	48.3	44.7	45.0	44.8	51.9
1995	35.0	34.9	35.0	34.7	39.1
1996	30.8	27.9	27.9	27.7	30.0
1997	14.6	24.0	24.0	23.9	25.2
1998	15.0	22.0	21.9	21.9	22.9
1999	21.5	22.4	22.2	22.2	23.3
2000	23.3	24.3	24.2	24.3	25.8
2001	29.2	28.4	28.3	28.1	30.6
2002	27.4	33.2	33.1	33.1	36.8
2003	37.8	40.1	40.1	40.0	45.2
2004	38.9	48.7	48.7	48.5	55.6
2005	63.7	57.5	57.6	57.1	66.4
2006	101.5	65.3	65.4	65.1	76.0
2007	104.2	71.0	71.2	70.8	82.9
2008	84.9	72.7	73.0	72.9	85.2
2009	47.4	68.8	69.3	69.1	81.5
2010	49.0	62.1	62.5	62.0	72.8
2011	62.7	59.1	59.4	58.9	67.6
2012	80.1	63.3	63.5	63.3	71.1
2013	103.4	74.0	74.1	131.9	82.8
2014	108.9	81.0	81.0	163.4	91.7
2015	74.2	74.4	74.3	135.4	85.1
2016	69.6	60.1	60.0	133.4	68.1
2017	54.2	50.9	50.8	131.5	57.0
2018	47.1	44.3	44.3	43.9	49.7
2019	28.7	42.6	42.6	42.9	50.8
2020	--	--	47.0	49.2	61.2

Table 31. Comparison of observed and estimated mature female survey biomass (in 1000's t) from the model scenarios.

	Observed	Scenario			
year	(1000's t)	19.03	19.03(2020)	20.07	20.10
1975	31.4	43.5	43.8	48.3	52.6
1976	31.2	38.1	38.3	41.1	44.2
1977	38.6	32.7	32.9	34.1	36.4
1978	25.8	29.0	29.1	29.4	30.7
1979	19.3	28.8	28.7	28.3	28.6
1980	63.8	31.0	30.7	29.2	29.1
1981	42.6	26.1	25.9	24.5	22.9
1982	64.1	20.0	20.3	20.7	22.6
1983	20.4	14.2	14.3	14.8	15.3
1984	14.9	9.8	9.9	10.4	10.2
1985	5.6	7.5	7.5	7.9	7.3
1986	3.4	8.5	8.5	9.0	8.1
1987	5.1	10.5	10.5	11.4	9.9
1988	25.4	12.7	12.8	14.2	12.3
1989	19.4	14.9	15.0	16.8	14.9
1990	37.7	16.5	16.7	18.8	17.0
1991	44.8	17.1	17.3	19.7	17.7
1992	26.2	16.2	16.4	18.5	16.7
1993	11.6	13.9	14.0	15.7	14.5
1994	9.8	11.2	11.3	12.5	11.7
1995	12.4	8.9	8.9	9.7	9.2
1996	9.6	7.1	7.1	7.6	7.3
1997	3.4	5.8	5.8	6.1	6.0
1998	2.3	5.0	5.0	5.2	5.1
1999	3.8	4.7	4.6	4.8	4.6
2000	4.1	4.7	4.7	4.9	4.6
2001	4.6	5.1	5.1	5.3	4.9
2002	4.5	5.8	5.7	6.0	5.5
2003	8.4	6.8	6.7	7.2	6.4
2004	4.7	8.1	8.1	8.6	7.7
2005	11.6	9.7	9.6	10.3	9.2
2006	14.9	11.2	11.1	11.9	10.7
2007	13.4	12.7	12.6	13.5	12.1
2008	11.7	13.1	13.1	14.2	12.7
2009	8.5	12.0	11.9	13.0	11.8
2010	5.5	10.2	10.2	11.1	10.3
2011	5.4	9.4	9.3	9.9	9.4
2012	12.4	10.6	10.5	11.0	10.2
2013	17.8	13.2	13.1	23.2	12.3
2014	14.9	14.6	14.5	21.7	13.7
2015	11.2	13.7	13.6	21.1	13.2
2016	7.6	11.5	11.4	31.6	11.3
2017	7.1	9.5	9.4	34.8	9.4
2018	5.0	7.9	7.9	8.3	7.9
2019	4.8	7.0	7.0	7.4	7.2
2020	--	--	7.6	8.2	8.1

Table 32. Comparison of estimates of mature male biomass-at-mating by sex (in 1000's t) from the model scenarios.

	Scenario			
year	19.03	19.03(2020)	20.07	20.10
1948	0.0	0.0	0.0	0.0
1949	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.1
1951	0.4	0.4	0.1	0.6
1952	2.2	2.2	0.8	2.7
1953	7.3	7.1	3.8	8.0
1954	14.7	14.4	9.6	16.0
1955	21.4	20.9	15.4	23.6
1956	26.4	25.9	19.9	29.5
1957	30.2	29.7	23.3	33.8
1958	33.3	32.7	26.0	37.0
1959	36.1	35.4	28.3	39.7
1960	38.9	38.2	30.7	42.4
1961	42.2	41.4	33.3	45.6
1962	46.9	46.1	37.0	50.4
1963	55.2	54.2	43.2	59.5
1964	72.3	71.0	55.9	78.7
1965	108.4	106.7	82.9	118.7
1966	181.0	178.4	140.7	195.2
1967	280.3	276.6	221.2	297.6
1968	389.2	384.8	311.7	414.5
1969	457.3	453.2	367.3	503.3
1970	482.0	479.3	389.6	564.1
1971	479.4	478.7	394.8	611.0
1972	464.6	466.1	397.1	652.7
1973	441.2	444.6	397.2	678.2
1974	402.4	406.6	378.9	652.0
1975	358.6	362.6	342.8	576.9
1976	289.5	292.9	271.1	451.9
1977	209.9	212.6	187.3	321.7
1978	163.7	165.7	137.0	240.8
1979	142.6	143.3	105.9	202.0
1980	131.1	127.8	97.1	155.5
1981	131.6	126.0	103.2	129.2
1982	120.1	114.3	98.6	104.1
1983	91.7	86.3	77.5	70.9
1984	60.9	56.4	53.2	42.1
1985	55.2	51.2	48.1	38.4
1986	64.1	60.4	54.2	48.0
1987	80.7	77.5	67.8	64.9
1988	102.2	99.7	88.4	86.6
1989	112.9	110.8	97.6	99.7
1990	111.8	110.2	94.4	102.3
1991	116.6	115.6	99.0	109.7
1992	108.8	107.5	91.0	99.7
1993	100.1	98.1	82.0	89.1
1994	83.6	81.6	68.0	72.7
1995	65.7	64.0	53.2	55.2
1996	52.6	51.2	42.7	42.6
1997	43.3	42.0	35.4	34.2
1998	37.8	36.7	31.0	29.5
1999	36.2	35.0	29.7	28.3
2000	37.6	36.3	31.1	29.8
2001	42.1	40.7	34.7	33.9
2002	49.1	47.5	40.4	40.8
2003	58.7	56.9	48.5	50.0
2004	71.7	69.7	59.9	62.0
2005	87.0	84.7	71.6	75.9
2006	102.3	99.6	84.4	89.8
2007	116.9	113.6	95.5	102.7
2008	130.7	127.1	107.6	113.1
2009	128.2	125.2	106.7	111.3
2010	111.6	109.3	93.9	96.8
2011	95.5	93.5	80.4	81.8
2012	94.2	92.1	78.3	81.1
2013	114.8	111.7	94.5	97.7
2014	135.8	131.7	111.3	112.8
2015	131.9	127.6	105.6	108.8
2016	117.1	113.5	93.7	97.6
2017	96.4	93.3	77.2	78.9
2018	79.5	76.9	64.2	63.7
2019	–	66.1	56.1	55.5

Table 33. Comparison of estimates of mature female biomass-at-mating by sex (in 1000's t) from the model scenarios.

	Scenario					Scenario			
year	19.03	19.03(2020)	20.07	20.10	year	19.03	19.03(2020)	20.07	20.10
1948	0.0	0.0	0.0	0.0	1986	31.9	31.4	22.6	35.2
1949	0.0	0.0	0.0	0.0	1987	39.3	38.7	28.9	43.6
1950	0.1	0.1	0.0	0.1	1988	47.8	47.3	36.1	54.2
1951	0.5	0.4	0.1	0.7	1989	55.5	55.1	42.3	65.2
1952	1.9	1.8	0.8	2.5	1990	61.3	61.1	47.0	73.6
1953	4.3	4.2	2.4	5.7	1991	63.3	63.0	48.6	75.8
1954	7.0	6.8	4.3	9.3	1992	59.8	59.3	45.2	70.7
1955	9.2	9.0	6.0	12.5	1993	51.6	51.0	38.3	60.8
1956	10.9	10.7	7.3	15.0	1994	41.7	41.2	30.5	49.1
1957	12.2	12.0	8.3	16.9	1995	32.9	32.5	23.7	38.8
1958	13.4	13.1	9.1	18.5	1996	26.2	25.9	18.6	30.8
1959	14.5	14.2	9.9	20.0	1997	21.5	21.2	15.1	25.2
1960	15.7	15.4	10.7	21.6	1998	18.7	18.3	13.0	21.6
1961	17.3	16.9	11.8	23.7	1999	17.4	17.0	12.1	19.9
1962	19.8	19.4	13.5	27.1	2000	17.7	17.3	12.4	19.8
1963	24.6	24.2	16.7	33.8	2001	19.2	18.6	13.4	21.3
1964	35.1	34.5	23.6	48.2	2002	21.7	21.1	15.3	24.1
1965	56.8	55.9	38.8	76.5	2003	25.5	24.8	18.3	28.3
1966	93.8	92.4	65.7	122.9	2004	30.6	29.9	21.9	34.0
1967	140.1	138.2	100.1	181.7	2005	36.3	35.4	26.0	40.6
1968	180.5	178.7	130.3	238.7	2006	42.2	41.0	30.1	47.1
1969	203.7	202.3	147.8	282.3	2007	47.8	46.5	34.1	52.8
1970	210.3	209.6	153.9	312.9	2008	49.3	48.1	35.4	54.6
1971	207.4	207.6	154.7	337.0	2009	44.7	43.8	32.3	50.4
1972	200.6	201.7	154.9	355.3	2010	38.3	37.6	27.5	43.8
1973	190.4	192.0	152.4	358.3	2011	35.1	34.4	24.8	40.7
1974	175.8	177.6	143.2	337.3	2012	39.8	38.8	28.0	45.2
1975	158.3	159.9	127.8	296.9	2013	49.7	48.3	35.3	54.4
1976	137.8	139.2	108.1	248.0	2014	54.8	53.3	38.9	59.5
1977	118.2	119.3	89.5	204.0	2015	51.1	49.7	35.9	56.1
1978	106.3	106.9	78.0	174.6	2016	43.1	42.0	30.0	47.9
1979	107.1	106.9	75.3	165.8	2017	35.6	34.7	24.6	39.8
1980	98.8	98.2	68.4	142.3	2018	29.7	28.9	20.5	33.7
1981	82.3	81.8	57.3	110.2	2019	–	25.8	18.4	31.2
1982	63.4	63.2	44.3	79.8					
1983	44.8	44.6	31.4	53.7					
1984	31.1	30.8	22.0	35.7					
1985	27.9	27.5	19.7	31.1					

Table 34. Estimated population size (millions) on July 1 of year. from the model scenarios 19.03(2020) and 20.07.

<<Table too large: available online in the zip file "TannerCrab.PopSizeStructure.csv.zip".>>

Table 35. Comparison of estimates of recruitment (in millions) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

	Scenario					Scenario			
year	19.03	19.03(2020)	20.07	20.10	year	19.03	19.03(2020)	20.07	20.10
1948	142.7	140.8	124.7	422.6	1986	796.3	814.3	779.4	1639.1
1949	143.1	141.2	125.1	423.3	1987	595.9	550.3	345.0	1250.0
1950	144.0	142.1	126.0	425.3	1988	249.4	248.9	207.9	511.7
1951	145.7	143.8	127.8	429.0	1989	78.8	75.0	47.8	113.8
1952	148.5	146.6	130.7	435.3	1990	71.3	70.3	74.7	154.6
1953	153.0	151.0	135.2	445.8	1991	73.7	72.5	66.3	199.5
1954	160.1	158.0	142.5	463.0	1992	67.3	66.4	76.0	136.2
1955	171.3	169.0	153.9	491.3	1993	84.3	81.1	77.0	213.0
1956	189.5	187.0	172.8	539.5	1994	143.7	138.3	146.5	344.0
1957	220.8	218.0	206.1	626.5	1995	107.6	105.5	125.1	195.1
1958	279.9	276.8	271.4	800.2	1996	304.3	295.6	273.0	740.4
1959	410.0	406.5	423.9	1195.2	1997	127.2	124.0	116.3	307.3
1960	744.0	740.4	833.5	2191.4	1998	450.4	443.8	491.7	1057.9
1961	1587.8	1584.2	1804.6	4571.5	1999	221.1	216.7	190.4	548.1
1962	2837.5	2827.9	2787.9	7940.9	2000	754.2	743.5	698.7	1777.4
1963	3206.0	3193.7	2768.4	8966.4	2001	231.3	226.3	212.9	643.0
1964	2676.0	2675.2	2250.7	7983.0	2002	829.7	797.8	831.8	1799.7
1965	2119.0	2134.2	1882.1	7284.3	2003	687.4	688.9	438.0	1811.0
1966	1817.4	1848.0	1791.3	7647.8	2004	185.9	182.8	159.9	265.6
1967	1724.2	1767.7	1922.6	8821.1	2005	127.3	125.1	111.8	204.6
1968	1669.1	1712.1	1987.3	8745.8	2006	111.2	111.7	120.8	308.1
1969	1442.0	1465.2	1543.6	5858.4	2007	179.0	178.4	350.9	496.3
1970	1165.2	1170.2	948.0	2961.3	2008	1138.1	1115.6	1146.1	2947.0
1971	779.7	781.6	551.7	1583.3	2009	870.5	838.3	482.0	1750.1
1972	526.3	532.2	411.9	1196.1	2010	301.2	294.5	207.2	605.1
1973	504.0	509.9	491.5	1268.7	2011	62.7	61.2	54.9	73.1
1974	710.5	688.8	1083.3	953.4	2012	173.4	167.4	166.8	414.0
1975	2028.5	2008.1	1479.7	7757.5	2013	107.0	105.1	79.6	290.4
1976	1530.9	1524.2	1101.1	2828.1	2014	79.9	80.6	131.2	196.2
1977	761.0	748.2	365.6	1098.4	2015	117.3	119.7	134.6	355.2
1978	277.0	256.4	189.1	503.9	2016	647.0	655.1	1011.1	1807.3
1979	166.2	165.3	154.0	368.9	2017	677.6	665.0	523.8	2700.7
1980	265.6	250.9	261.1	469.5	2018	1234.9	1135.0	1193.6	5676.0
1981	229.9	217.2	246.6	525.4	2019	–	290.4	274.5	675.1
1982	690.0	700.1	753.2	1794.6					
1983	627.3	634.3	671.4	1467.3					
1984	767.4	746.6	679.3	1825.9					
1985	764.4	791.1	804.9	2669.6					

Table 36. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

	Scenario			
year	19.03	19.03(2020)	20.07	20.10
1948	–	–	--	--
1949	0.001	0.001	0.001	0.000
1950	0.001	0.001	0.001	0.001
1951	0.002	0.002	0.002	0.001
1952	0.003	0.003	0.003	0.002
1953	0.005	0.005	0.005	0.004
1954	0.008	0.008	0.008	0.006
1955	0.009	0.009	0.010	0.007
1956	0.010	0.010	0.011	0.008
1957	0.011	0.011	0.012	0.008
1958	0.011	0.011	0.012	0.008
1959	0.011	0.011	0.012	0.008
1960	0.010	0.010	0.011	0.008
1961	0.010	0.010	0.011	0.007
1962	0.009	0.009	0.010	0.006
1963	0.008	0.008	0.008	0.005
1964	0.007	0.007	0.008	0.004
1965	0.009	0.009	0.011	0.006
1966	0.009	0.009	0.011	0.006
1967	0.025	0.025	0.031	0.017
1968	0.029	0.029	0.034	0.020
1969	0.038	0.038	0.045	0.025
1970	0.036	0.036	0.042	0.023
1971	0.031	0.031	0.035	0.019
1972	0.028	0.028	0.032	0.019
1973	0.036	0.035	0.039	0.021
1974	0.049	0.048	0.053	0.029
1975	0.044	0.044	0.048	0.027
1976	0.071	0.070	0.079	0.043
1977	0.098	0.097	0.113	0.058
1978	0.076	0.075	0.095	0.043
1979	0.086	0.085	0.125	0.047
1980	0.058	0.059	0.081	0.039
1981	0.027	0.027	0.035	0.023
1982	0.014	0.014	0.018	0.013
1983	0.007	0.007	0.009	0.006
1984	0.015	0.016	0.019	0.013
1985	0.006	0.006	0.007	0.004
1986	0.007	0.007	0.008	0.005
1987	0.013	0.013	0.015	0.010
1988	0.020	0.020	0.023	0.016
1989	0.054	0.055	0.063	0.046
1990	0.091	0.093	0.106	0.082
1991	0.075	0.076	0.089	0.068
1992	0.096	0.097	0.115	0.089
1993	0.055	0.056	0.068	0.053
1994	0.039	0.039	0.048	0.038
1995	0.032	0.033	0.040	0.031
1996	0.019	0.020	0.024	0.019
1997	0.017	0.017	0.021	0.016
1998	0.011	0.012	0.014	0.011
1999	0.006	0.006	0.007	0.005
2000	0.006	0.006	0.007	0.005
2001	0.007	0.007	0.008	0.006
2002	0.004	0.004	0.004	0.003
2003	0.003	0.003	0.003	0.002
2004	0.003	0.003	0.004	0.003
2005	0.006	0.006	0.008	0.005
2006	0.009	0.009	0.011	0.008
2007	0.011	0.011	0.013	0.010
2008	0.008	0.008	0.010	0.008
2009	0.007	0.007	0.008	0.006
2010	0.003	0.003	0.004	0.003
2011	0.004	0.005	0.006	0.004
2012	0.003	0.003	0.004	0.003
2013	0.009	0.009	0.011	0.008
2014	0.031	0.032	0.039	0.031
2015	0.045	0.046	0.056	0.045
2016	0.006	0.006	0.007	0.006
2017	0.010	0.010	0.012	0.009
2018	0.011	0.011	0.013	0.009
2019	–	0.003	0.004	0.002

Table 37. Values required to determine Tier level and OFL for the models considered here. These values are presented only to illustrate the effect of incremental changes in the model scenarios.

case	average recruitment millions	Bmsy (1000's t)	current MMB (1000's t)	Fmsy per year	MSY (1000's t)	Fofl per year	OFL (1000's t)	projected MMB (1000's t)	status ratio
19.03	393.84	41.64	82.61	1.18	19.49	1.12	29.51	39.73	0.95
19.03(2020)	383.96	40.39	77.76	1.14	18.90	1.11	26.15	39.38	0.98
20.07	374.43	36.77	66.87	0.98	16.94	0.94	21.13	35.33	0.96
20.10	1,047.74	39.94	72.37	1.68	21.55	1.44	24.18	34.98	0.88

Figures

Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

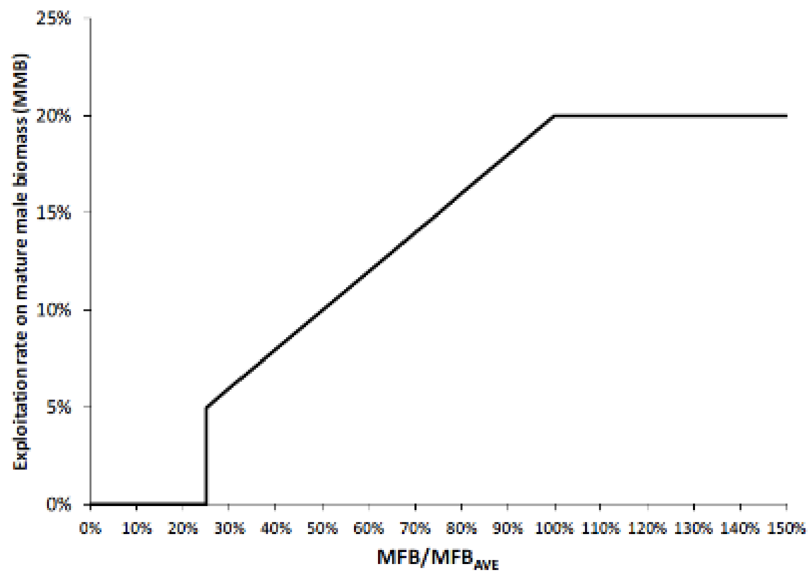


Figure 2. Sloping control rule used by ADFG from 2011 to 2019 as part of its TAC setting process to determine the maximum exploitation rate on mature male biomass as a function of the ratio of current mature female biomass (MFB) to MFB averaged over some time period.

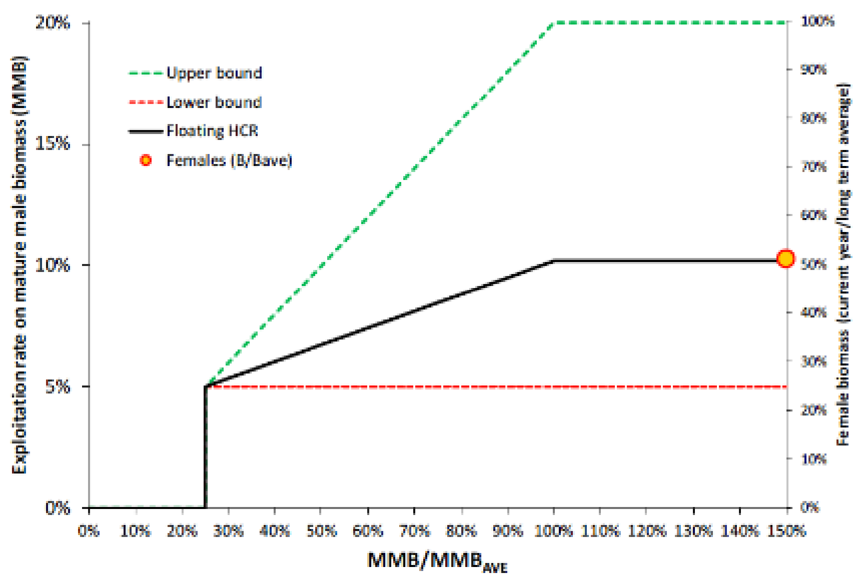


Figure 3. New ADFG “floating” sloping control rule to determine the maximum exploitation rate on mature male biomass (MMB) as a function of the ratio of current MMB to the average MMB over 1982-2018. The ratio of current mature female biomass (MFB) to MFB averaged over 1982-2018 is used to determine the value of the maximum exploitation rate for the control rule, up to a maximum of 20%. ADFG will use this control rule to determine TAC in the future.

Figure 4. Upper: retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The directed fishery was closed in 1984/85 and 1985/86, from 1996/97 to 2004/05, from 2010/11 to 2012/13, and 2016/17 and 2019/20.

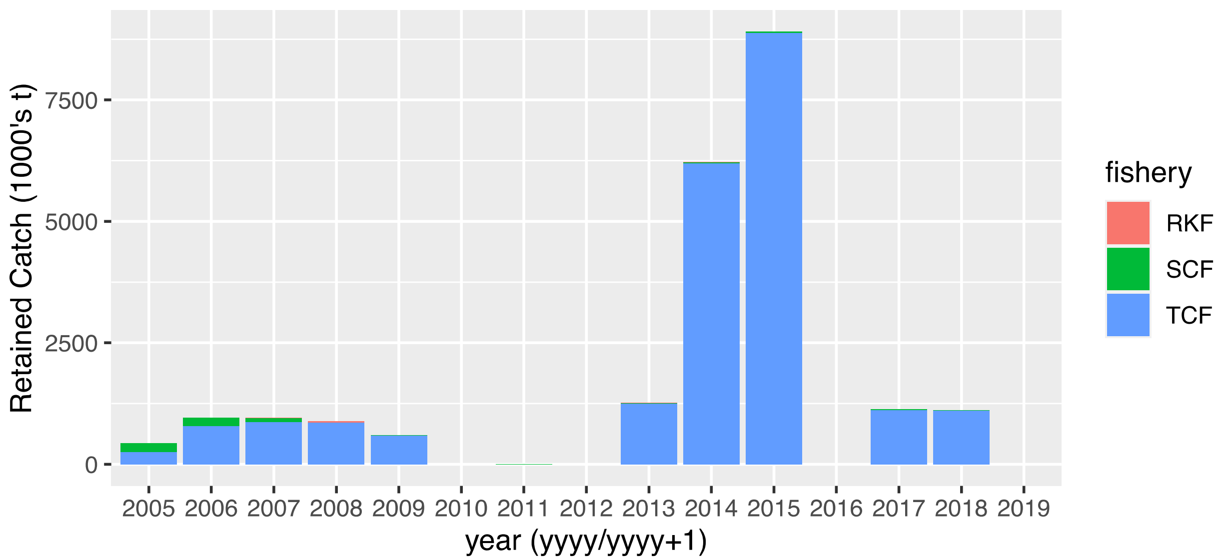


Figure 5. Time series of retained catch biomass (1000's t) in the directed Tanner crab (TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries since 2005. The directed fisheries were both closed from 2010/11 to 2012/13, as well as in 2016/17 and 2019/20. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch.

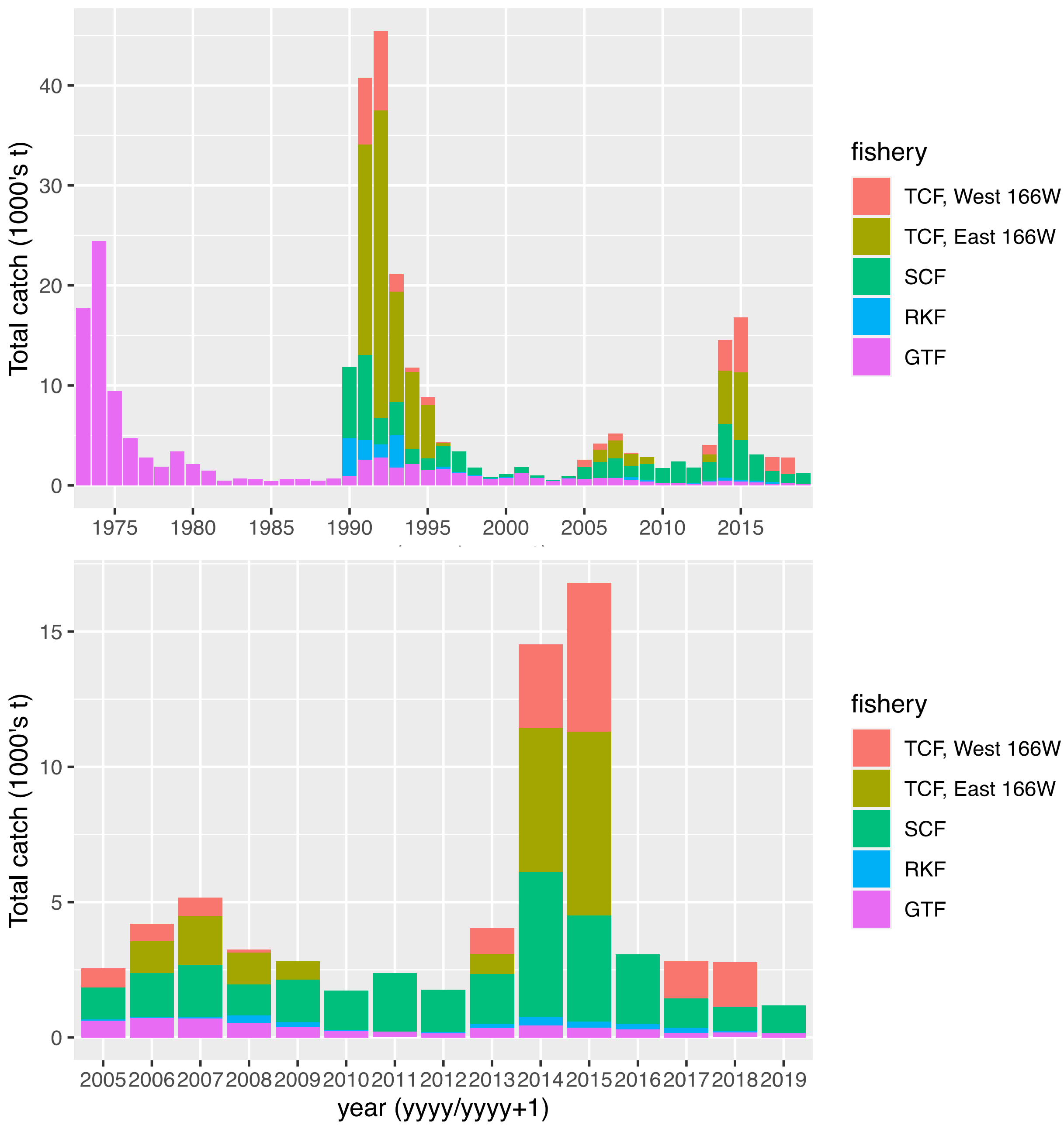


Figure 6. Upper: total catch (retained + discards) of Tanner crab (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Bycatch reporting began in 1973 for the groundfish fisheries and in the early 1990s for the crab fisheries. Lower: detail since 2005.

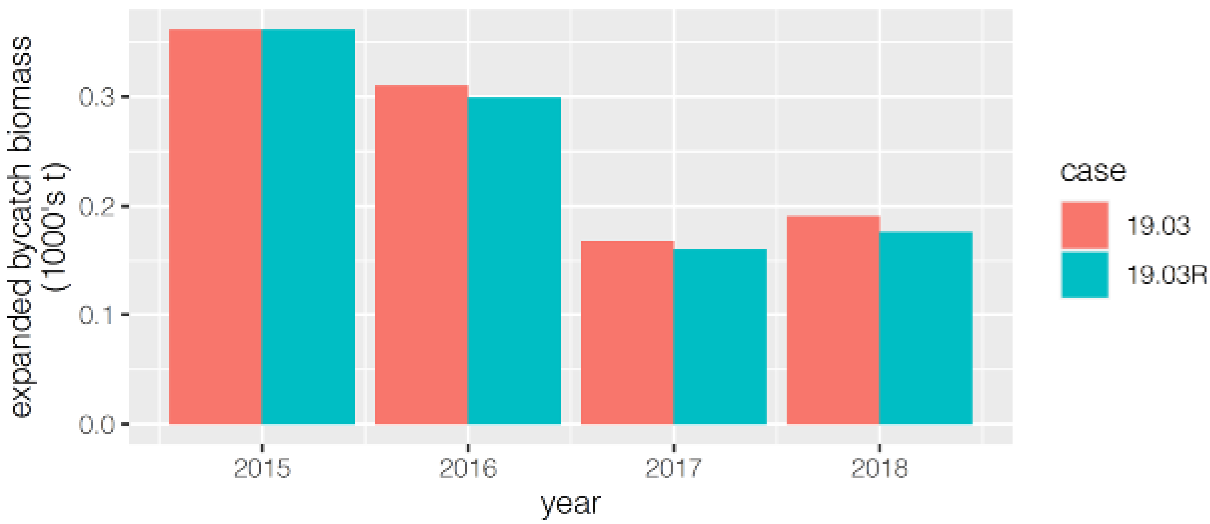


Figure 7. Changes in the expanded estimates of Tanner crab bycatch in the groundfish fisheries from the 2019 assessment to this one due to changes in the estimation algorithm used by AKFIN to align it with that used by the Regional Office. 19.03: 2019 assessment data; 19.03R:

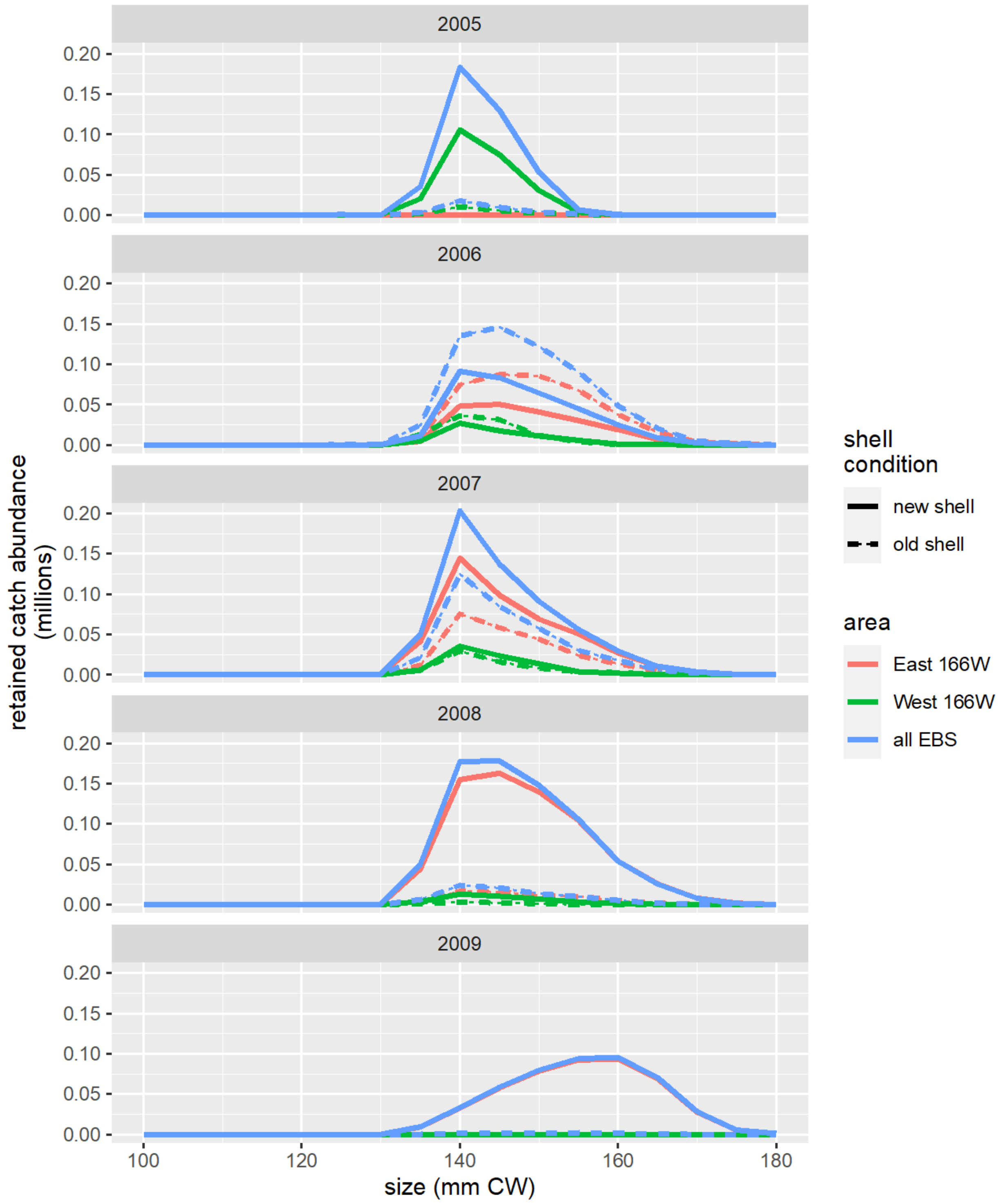


Figure 8. Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14. The directed fishery was closed in 2016/17 and 2019/20. Fishery area denoted by color: red—area west of 166ºW, green—area east of 166ºW; blue: all EBS (i.e., total). Shell condition is denoted by solid (new shell) or dotted (old shell) line type.

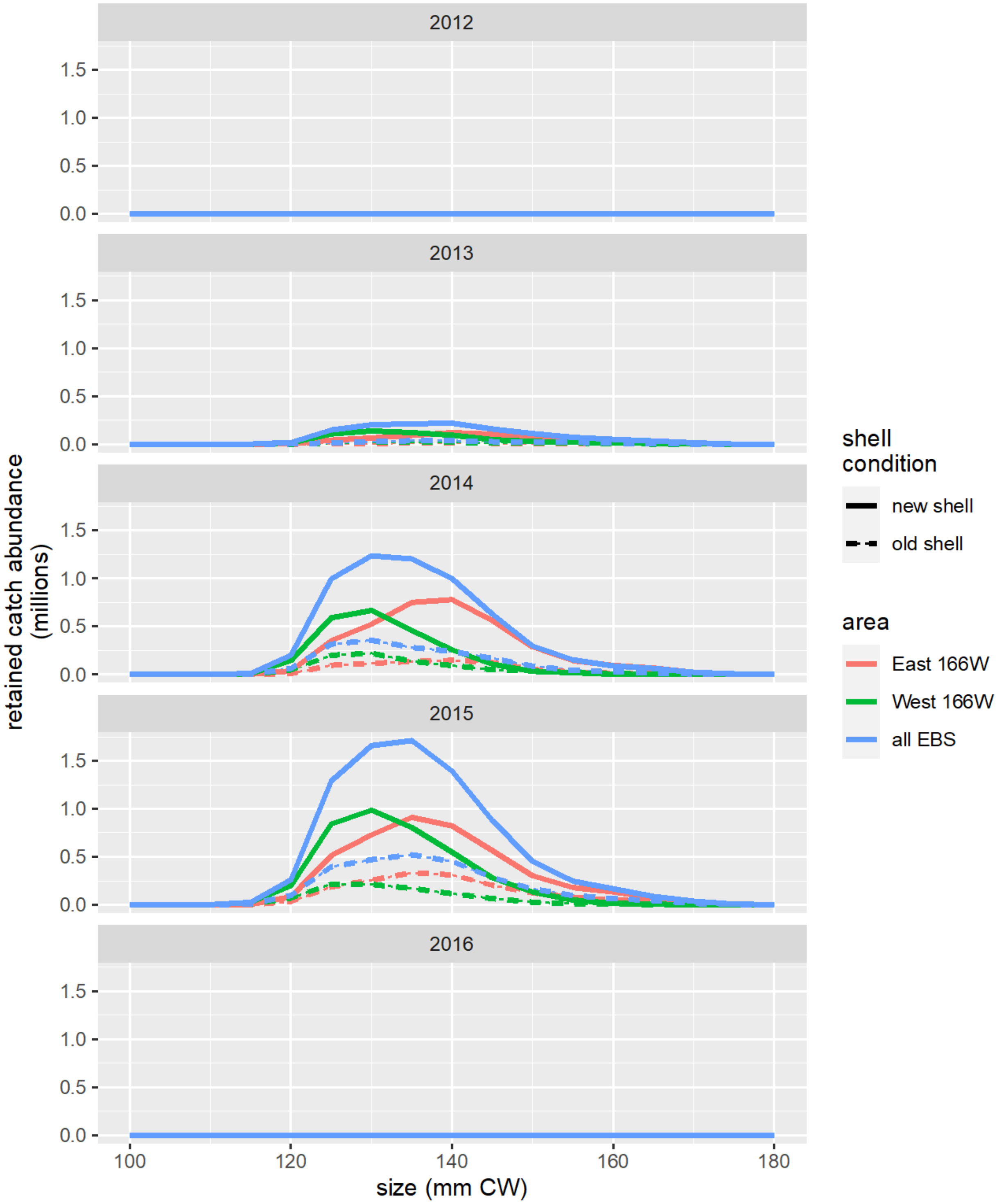


Figure 8 (cont.). Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14. The directed fishery was closed in 2016/17 and 2019/20. Fishery area denoted by color: red—area west of 166ºW, green—area east of 166ºW; blue: all EBS (i.e., total). Shell condition is denoted by solid (new shell) or dotted (old shell) line type.

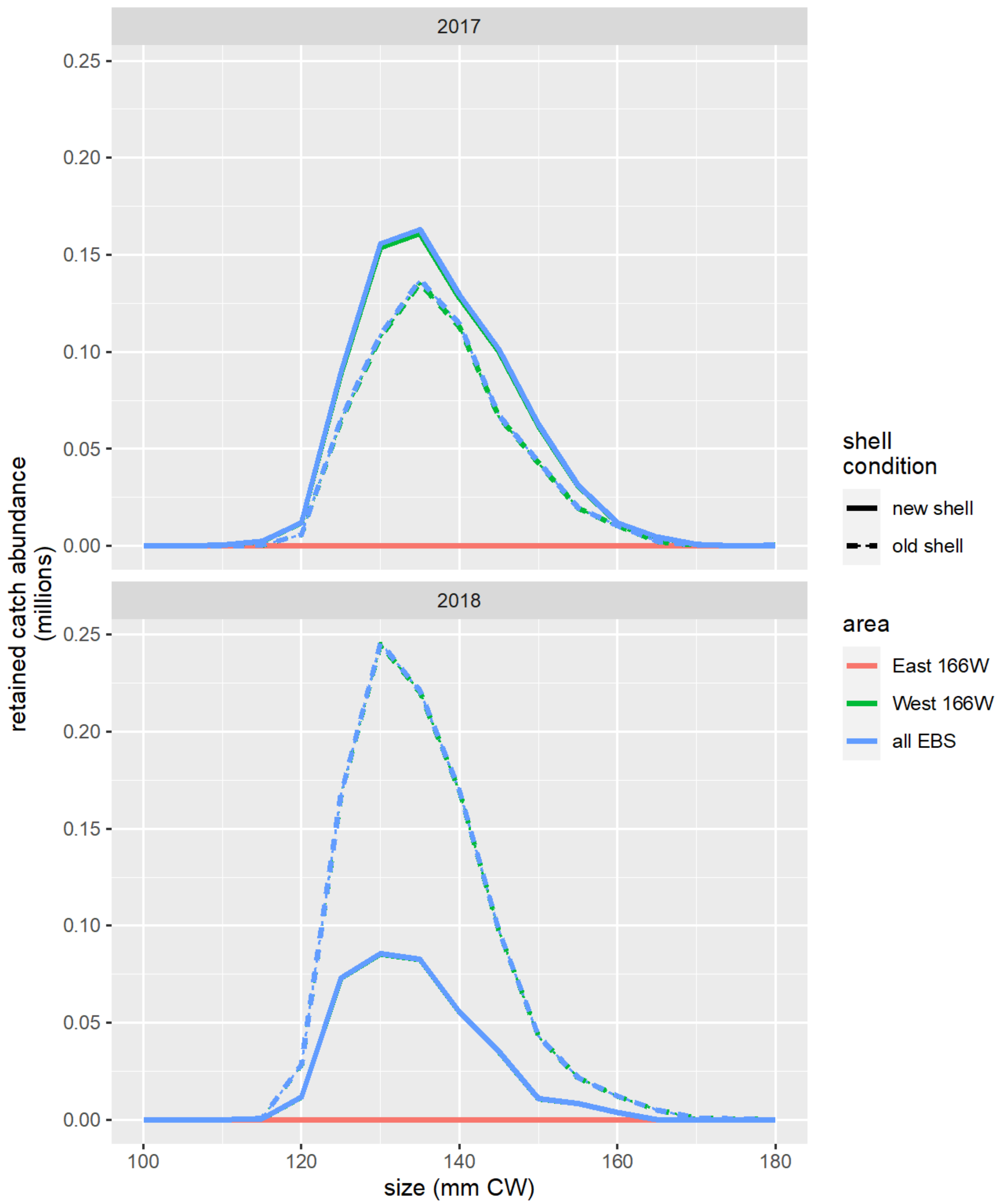


Figure 8 (cont.). Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14. The directed fishery was closed in 2016/17 and 2019/20. Fishery area denoted by color: red—area west of 166ºW, green—area east of 166ºW; blue: all EBS (i.e., total). Shell condition is denoted by solid (new shell) or dotted (old shell) line type.

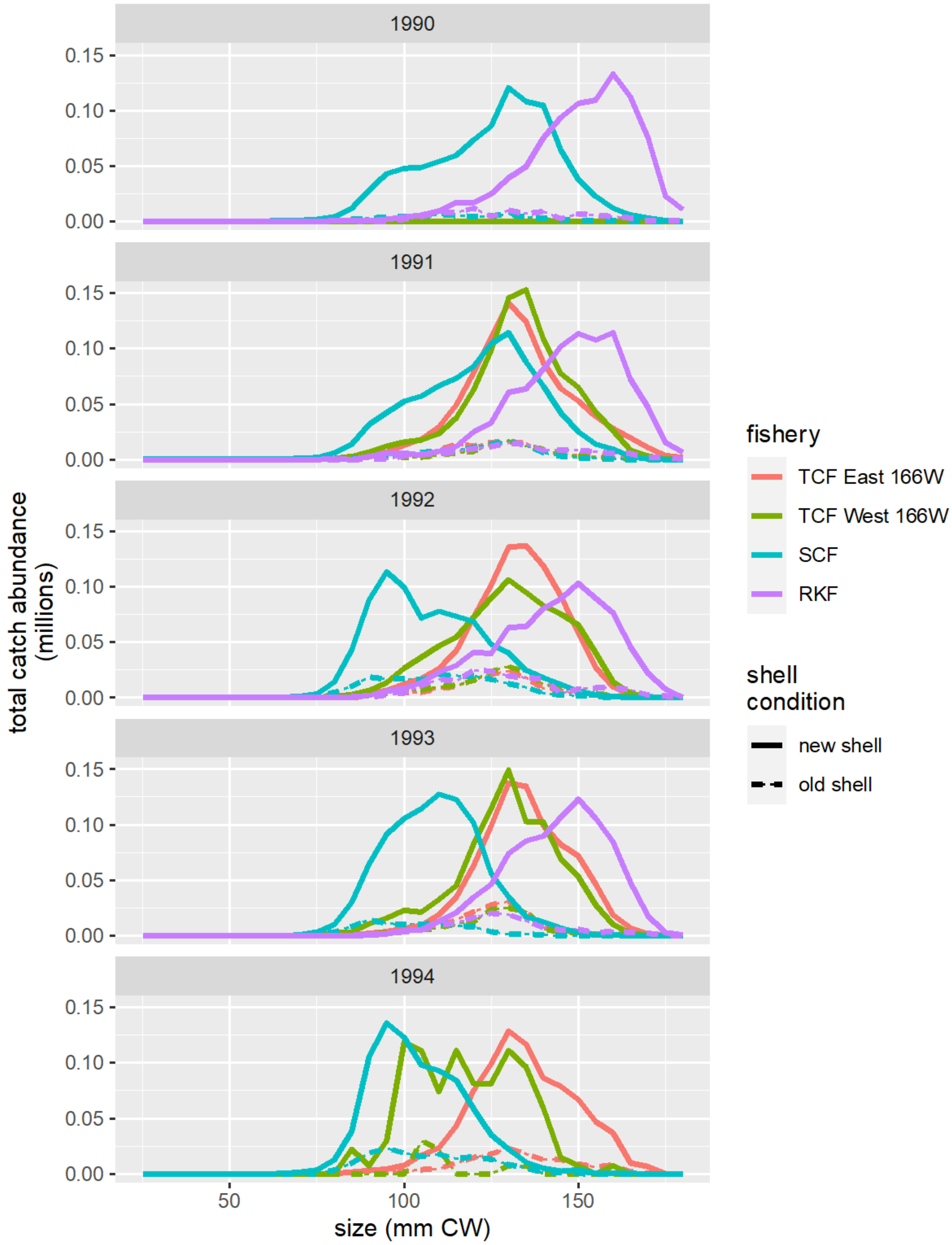


Figure 9. Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

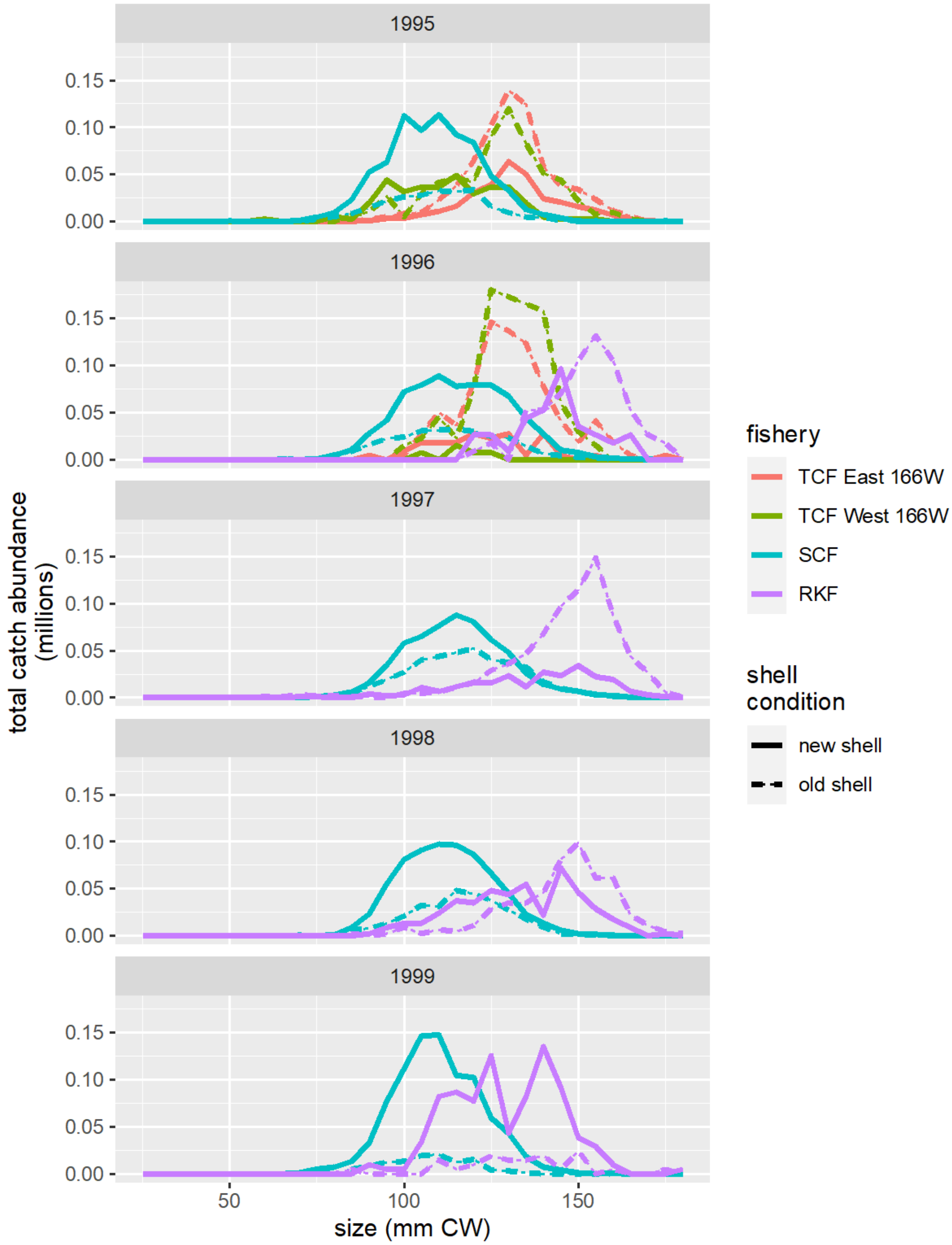


Figure 9 (cont.). Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

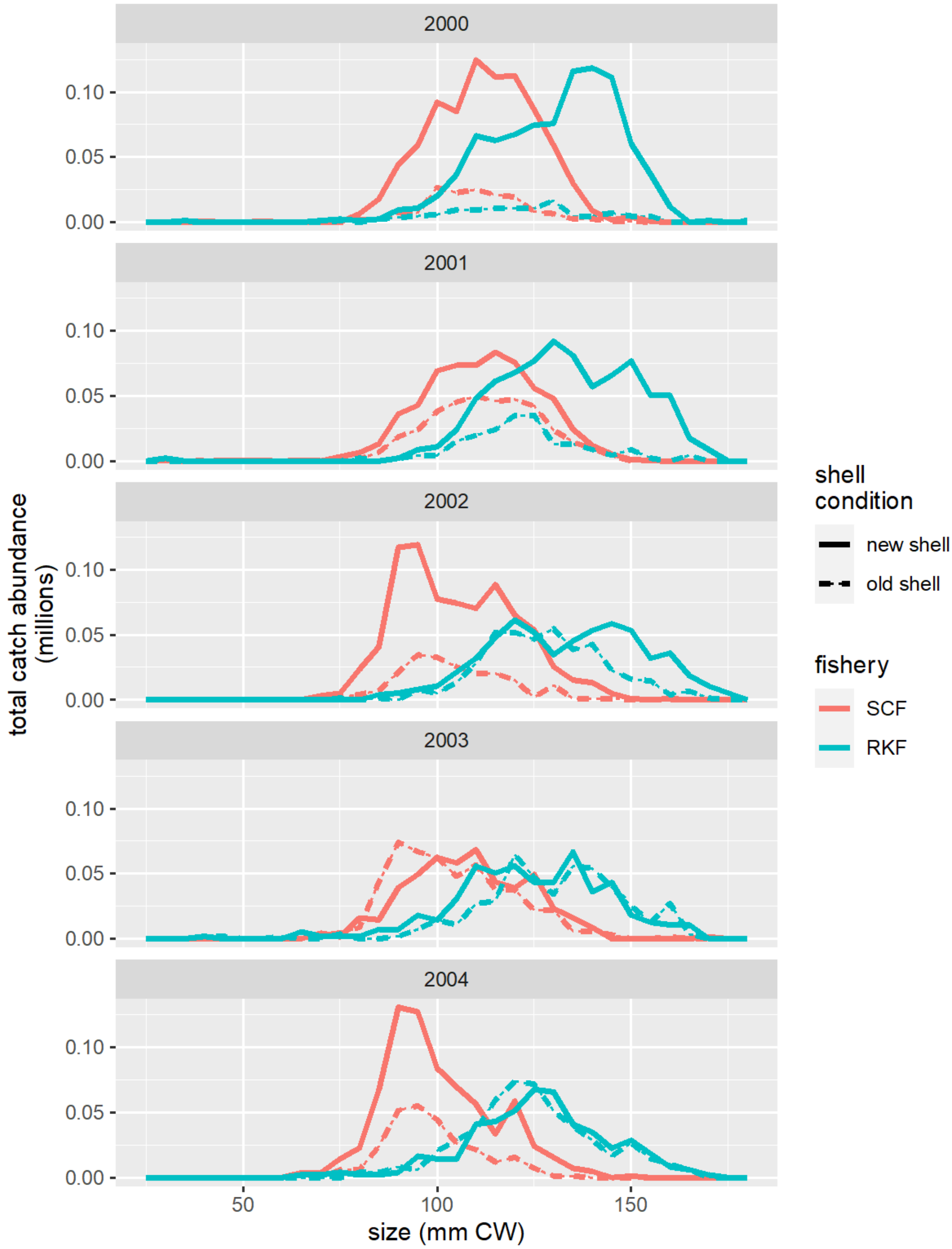
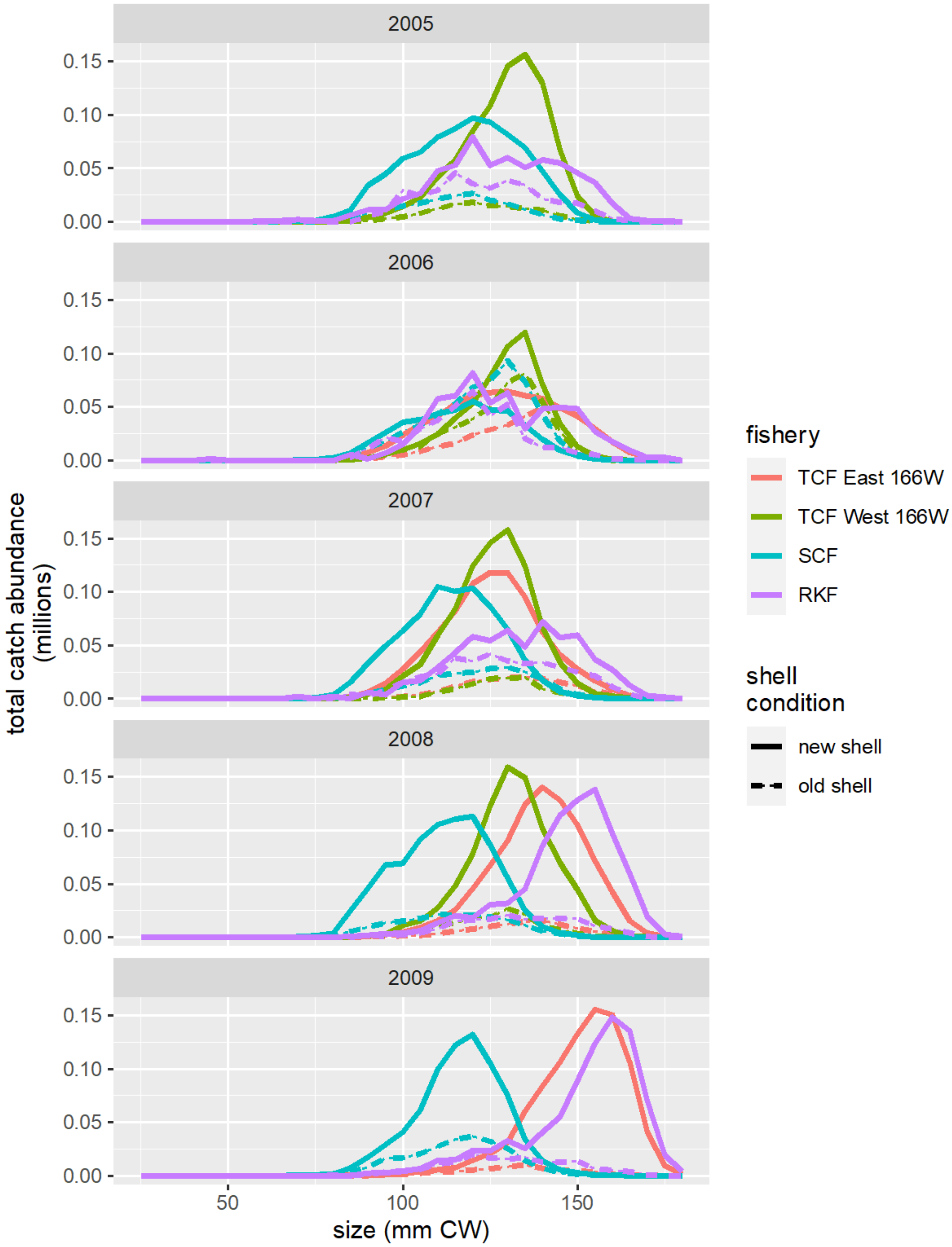


Figure 9 (cont.). Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.



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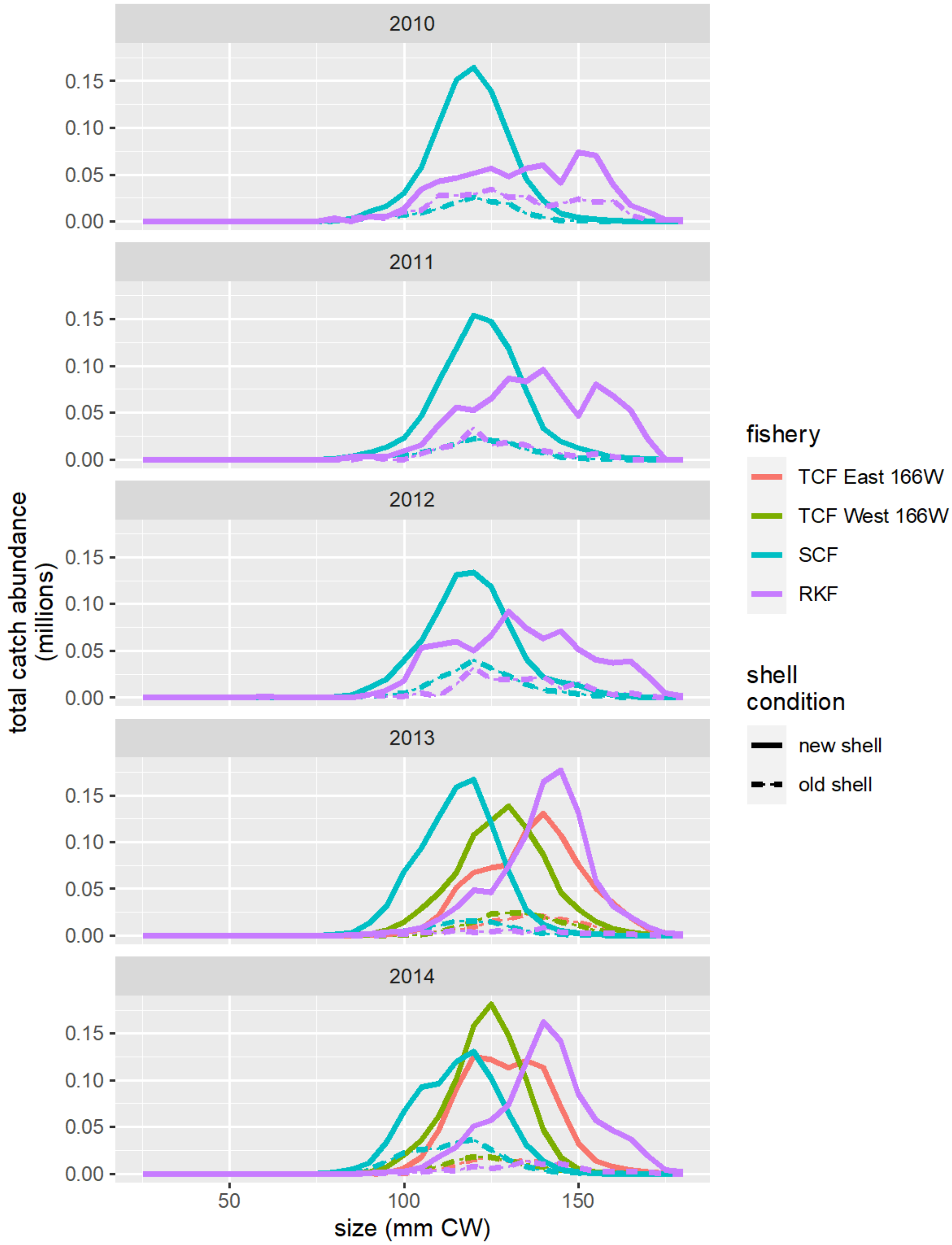

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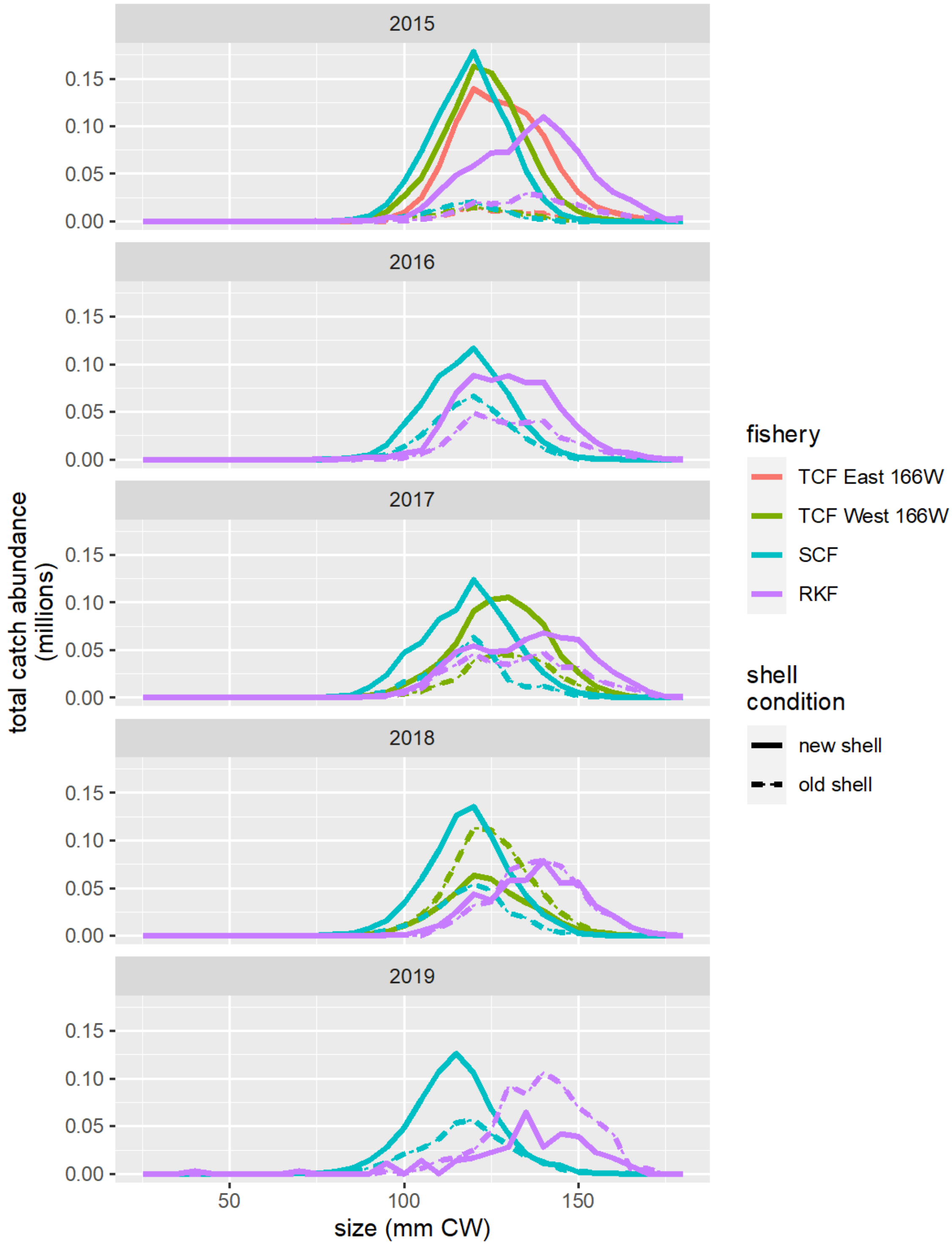

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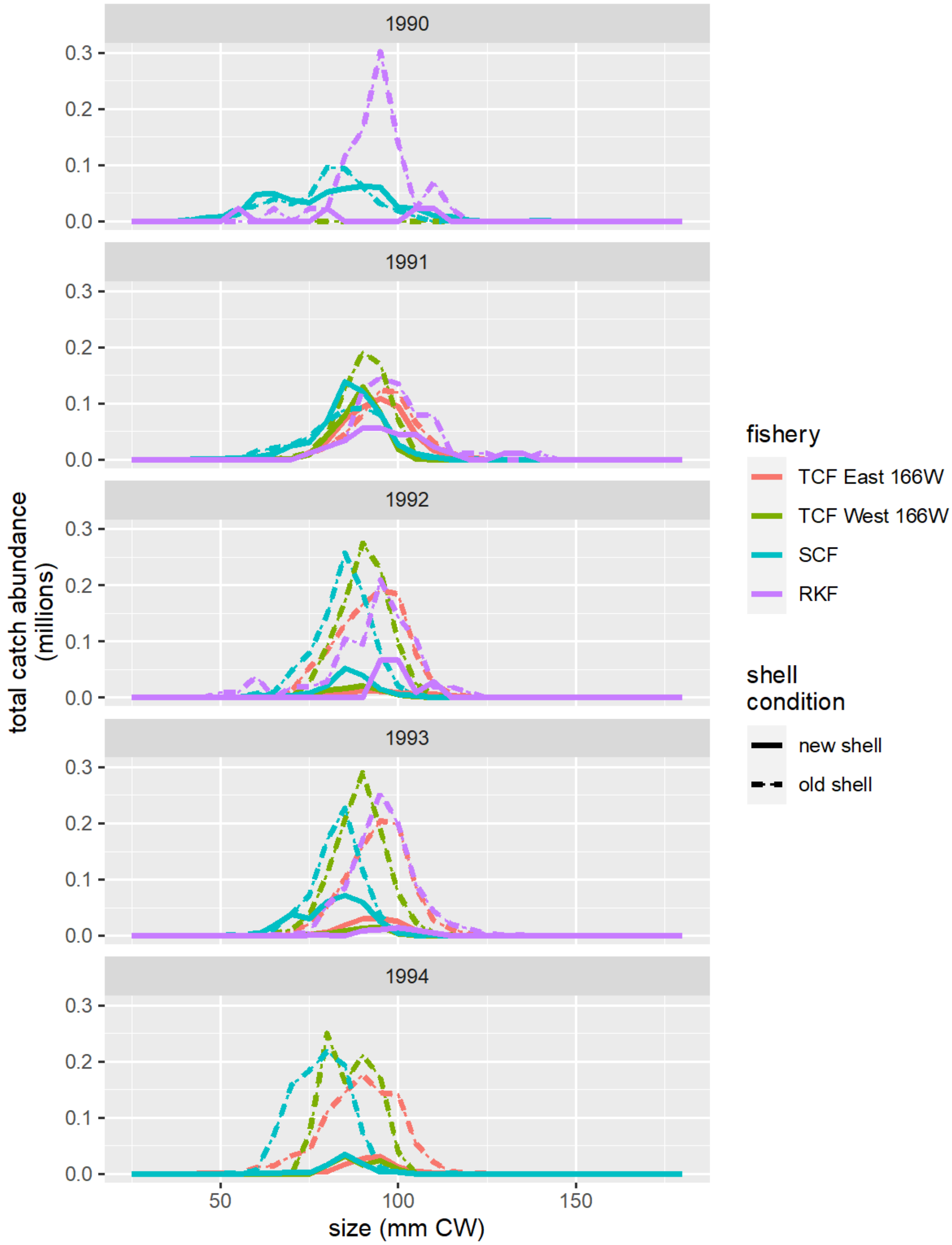


Figure 10. Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

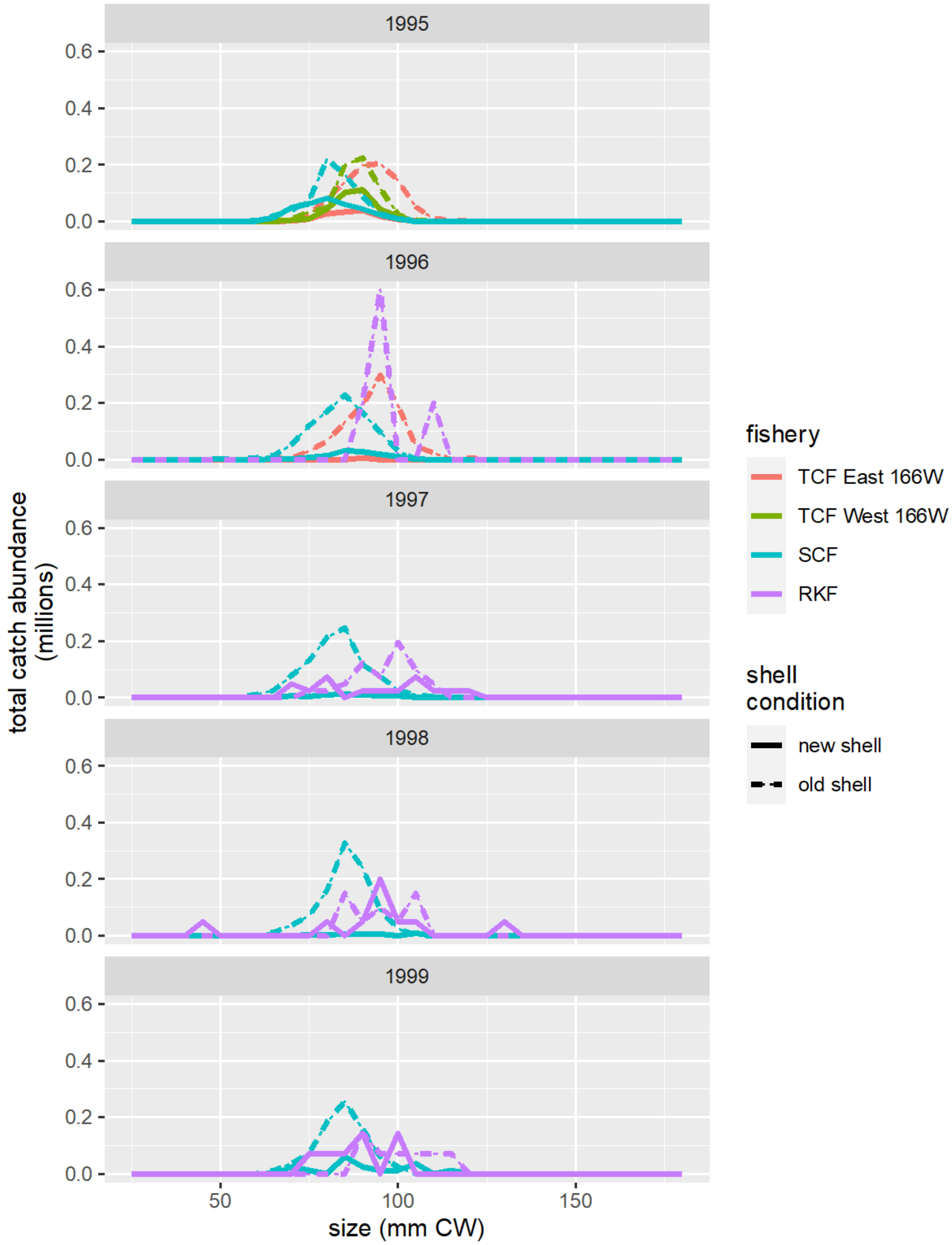


Figure 10 (cont.). Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

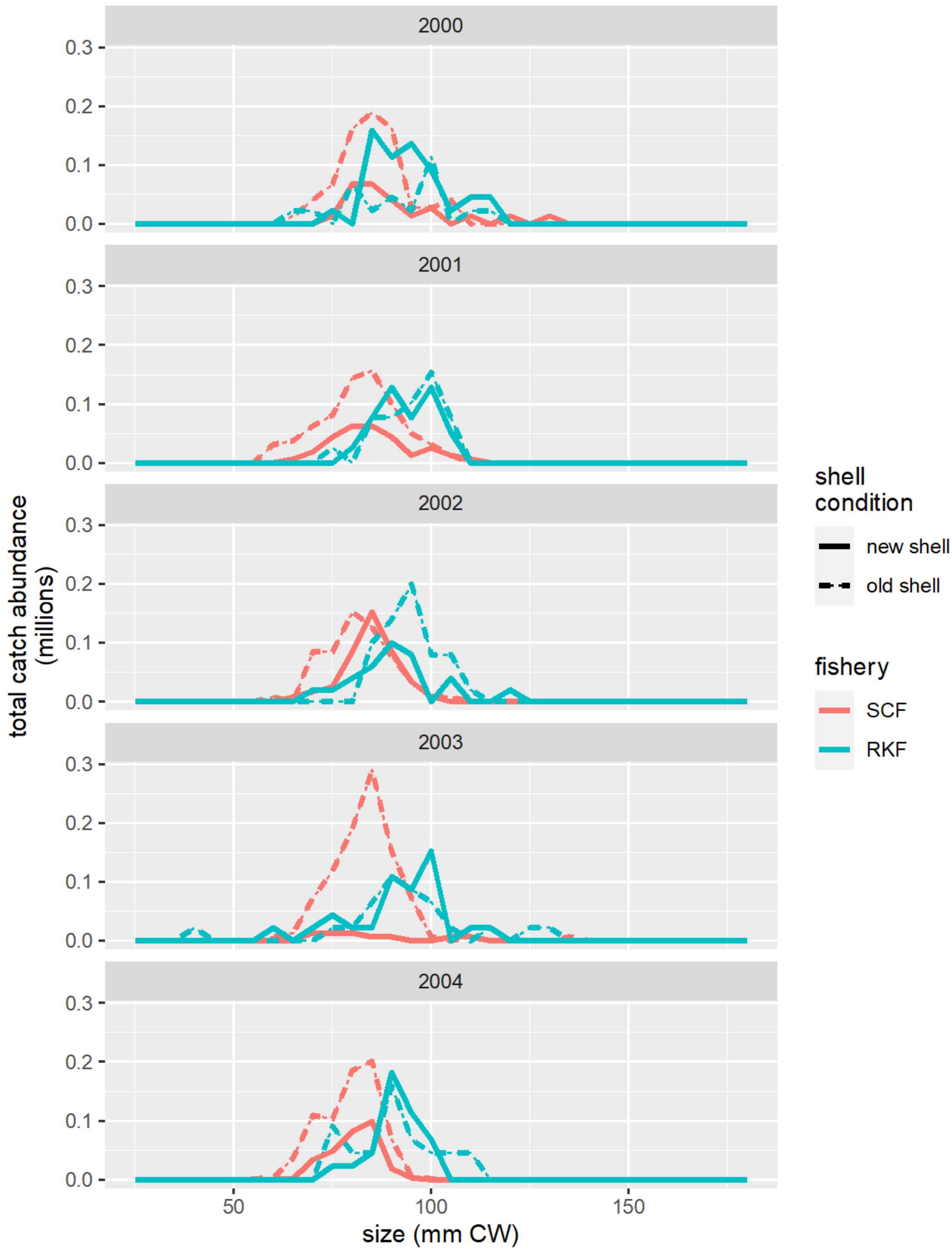
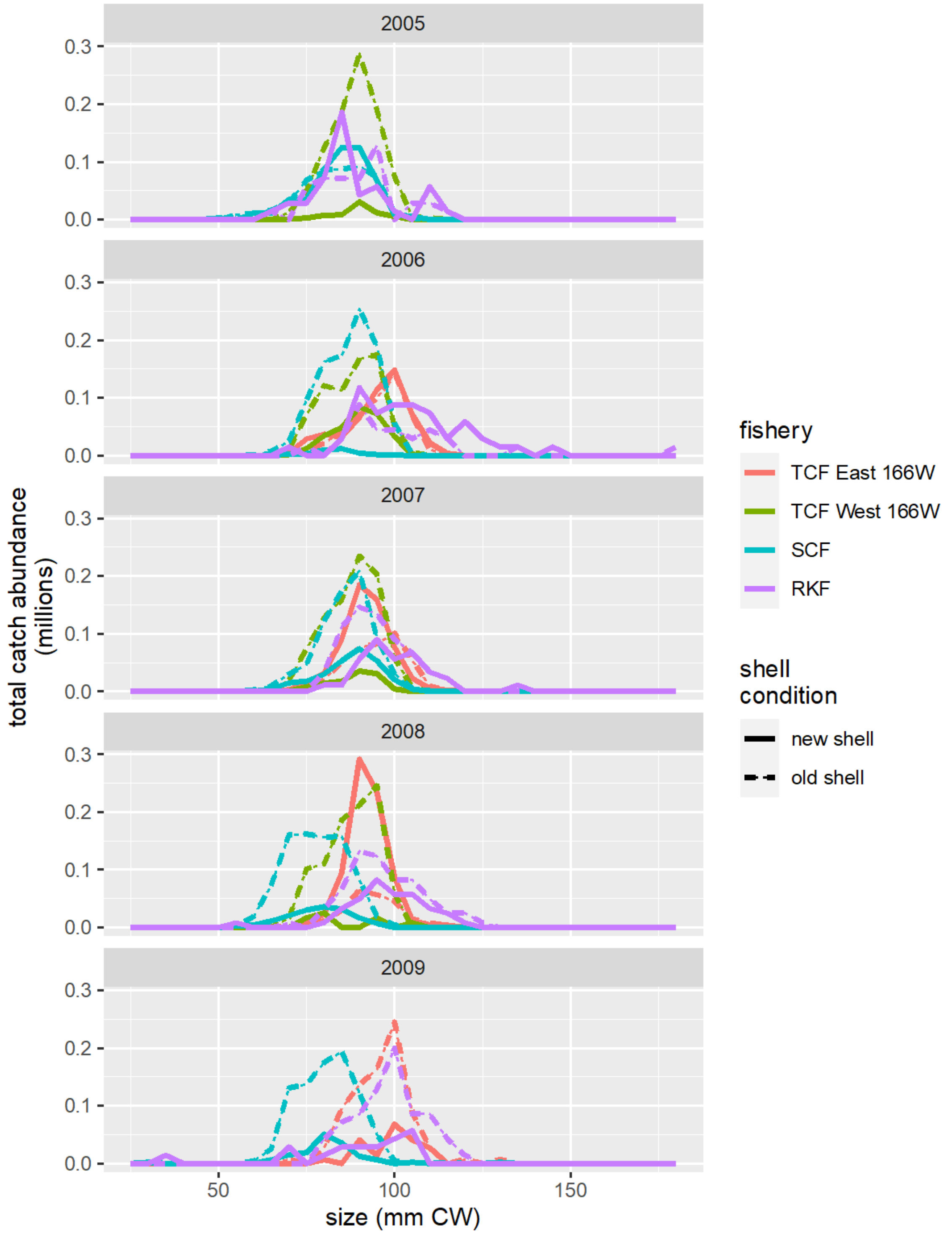


Figure 10 (cont.). Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.



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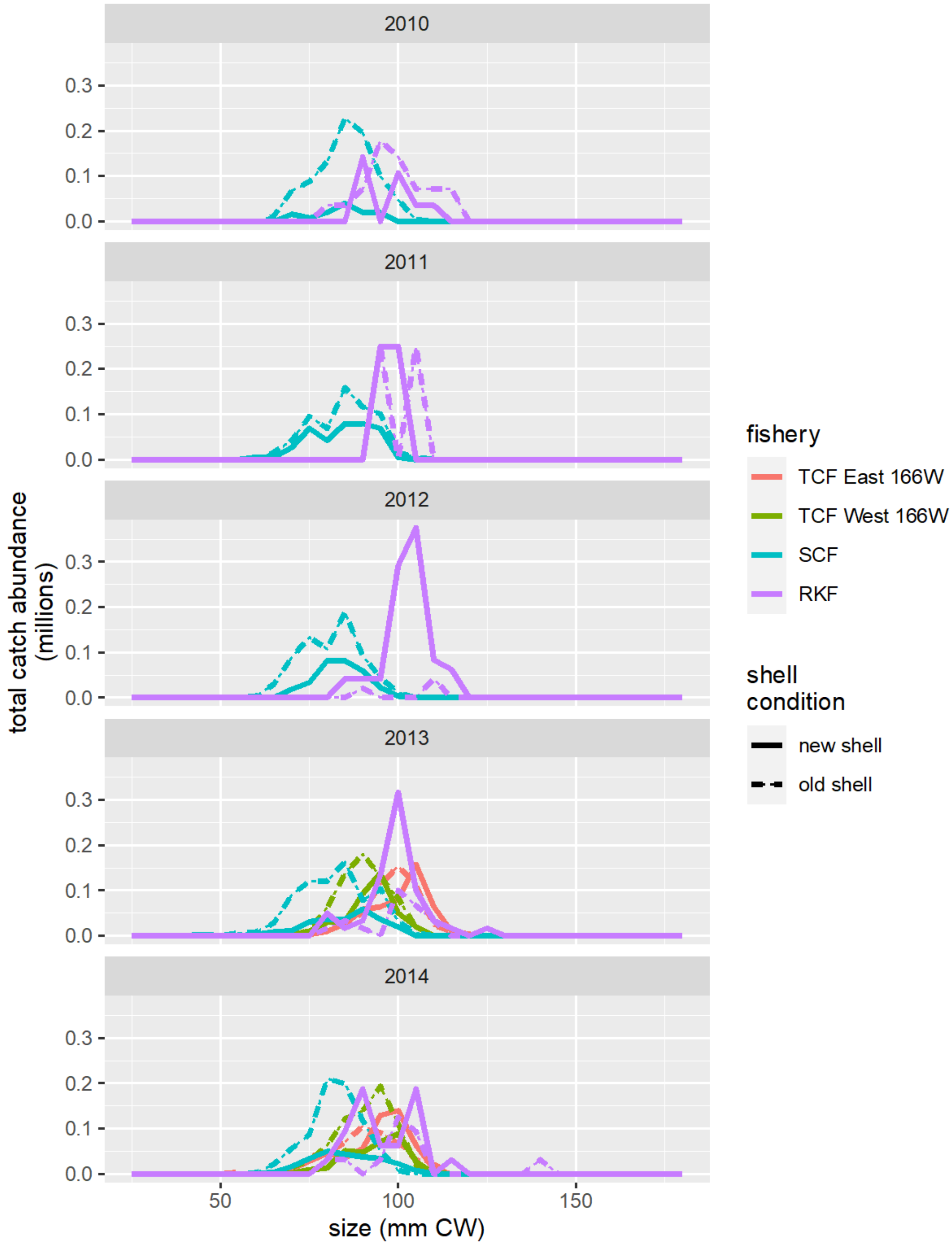

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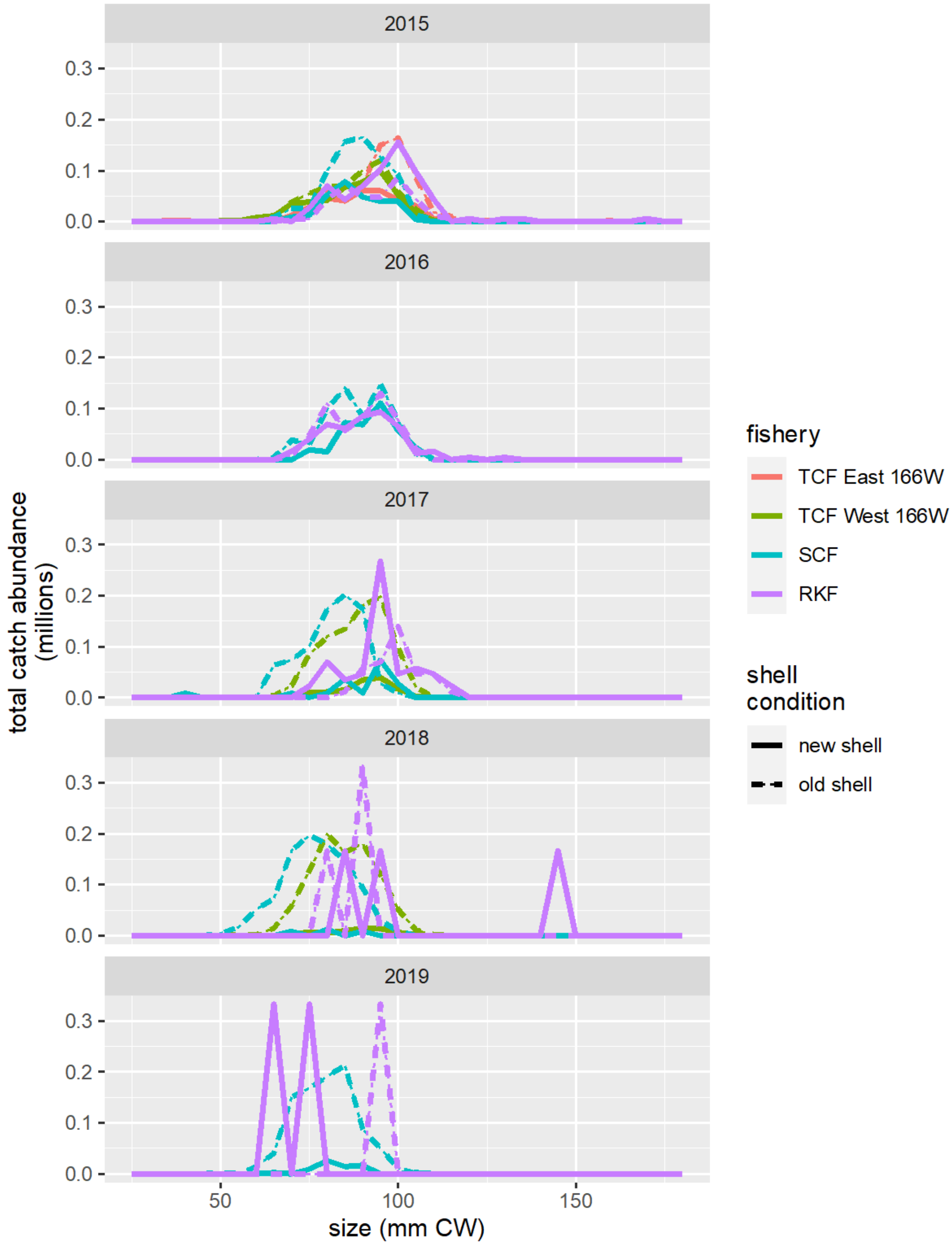

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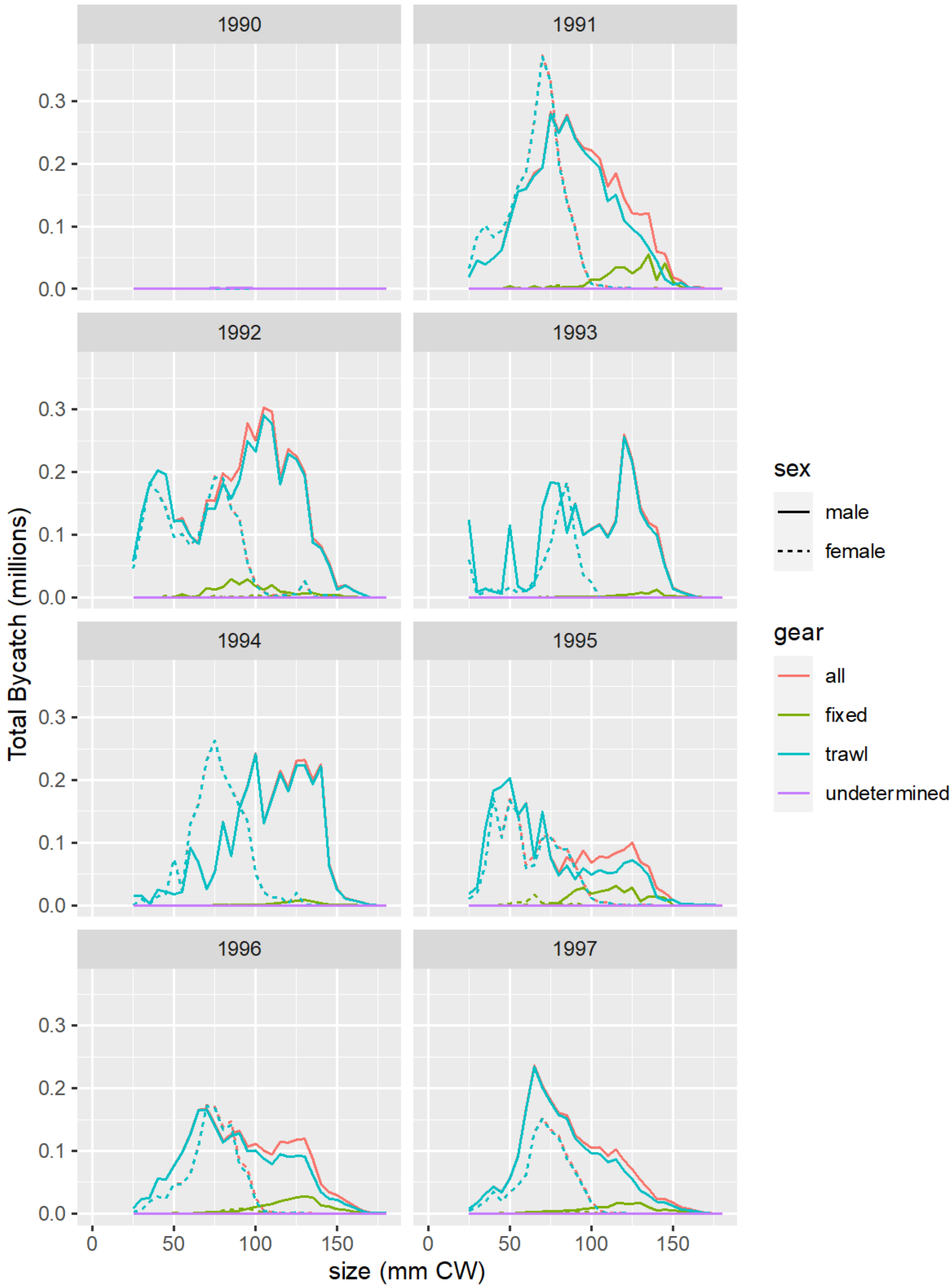


Figure 11. Annual bycatch size compositions in the groundfish fisheries by sex and gear type, expanded to total bycatch starting in 1990. Colors indicate gear type (red: all types, olive: fixed gear, cyan: trawl gear, purple: undetermined). Line type indicates sex (solid: males, dotted: females).

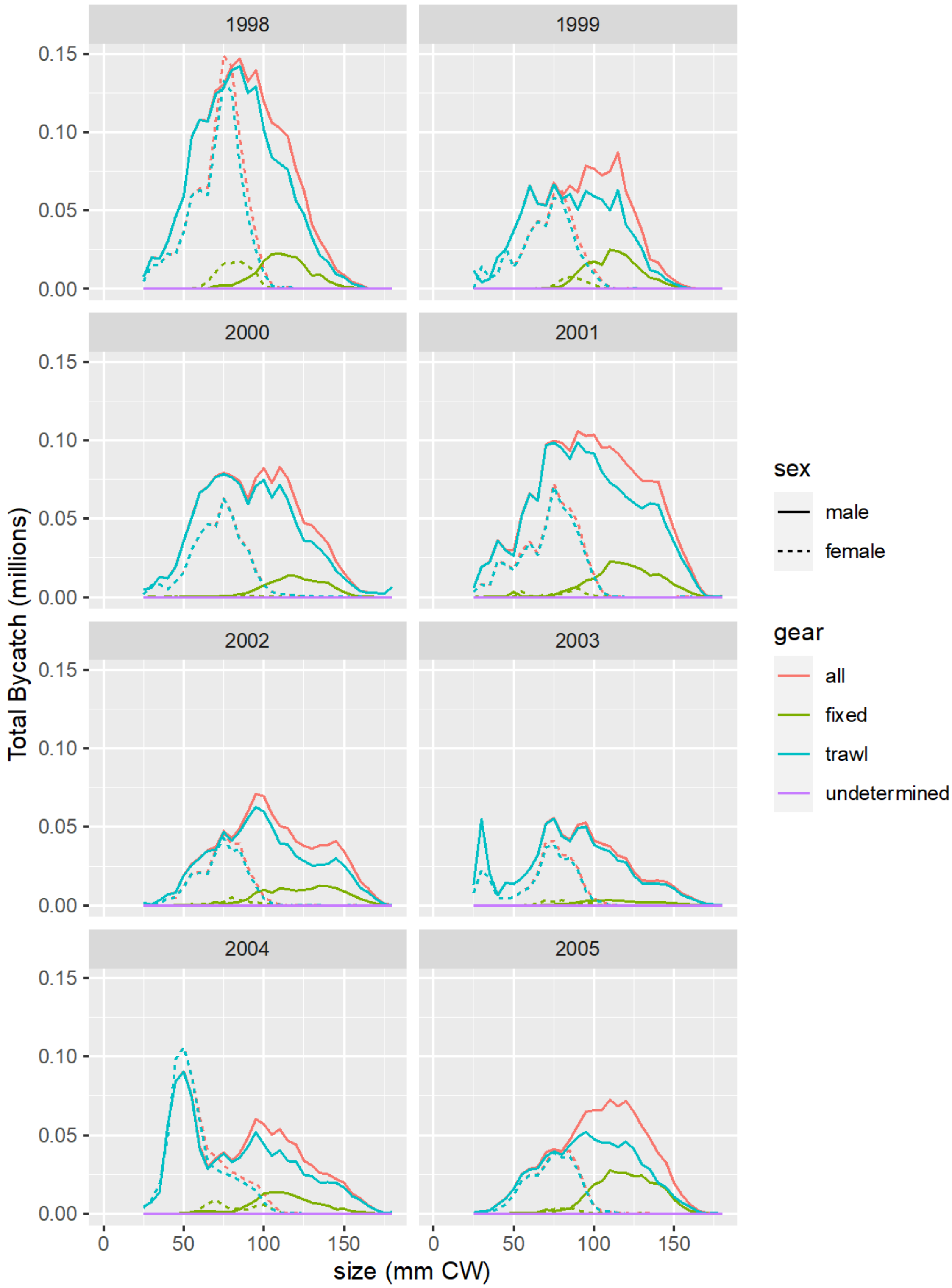
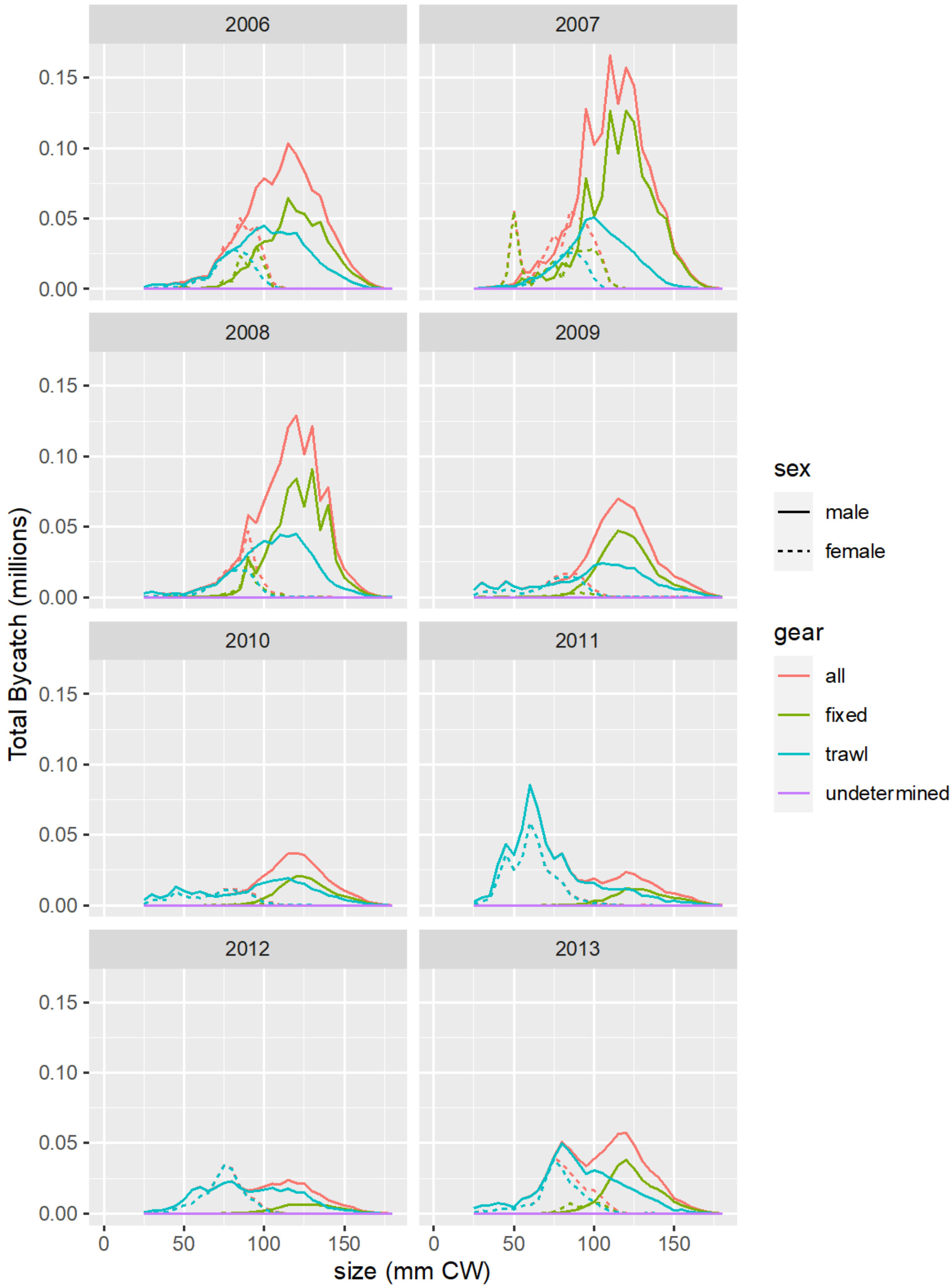


Figure 11 (cont.). Annual bycatch size compositions in the groundfish fisheries by sex and gear type, expanded to total bycatch starting in 1990. Colors indicate gear type (red: all types, olive: fixed gear, cyan: trawl gear, purple: undetermined). Line type indicates sex (solid: males, dotted: females).



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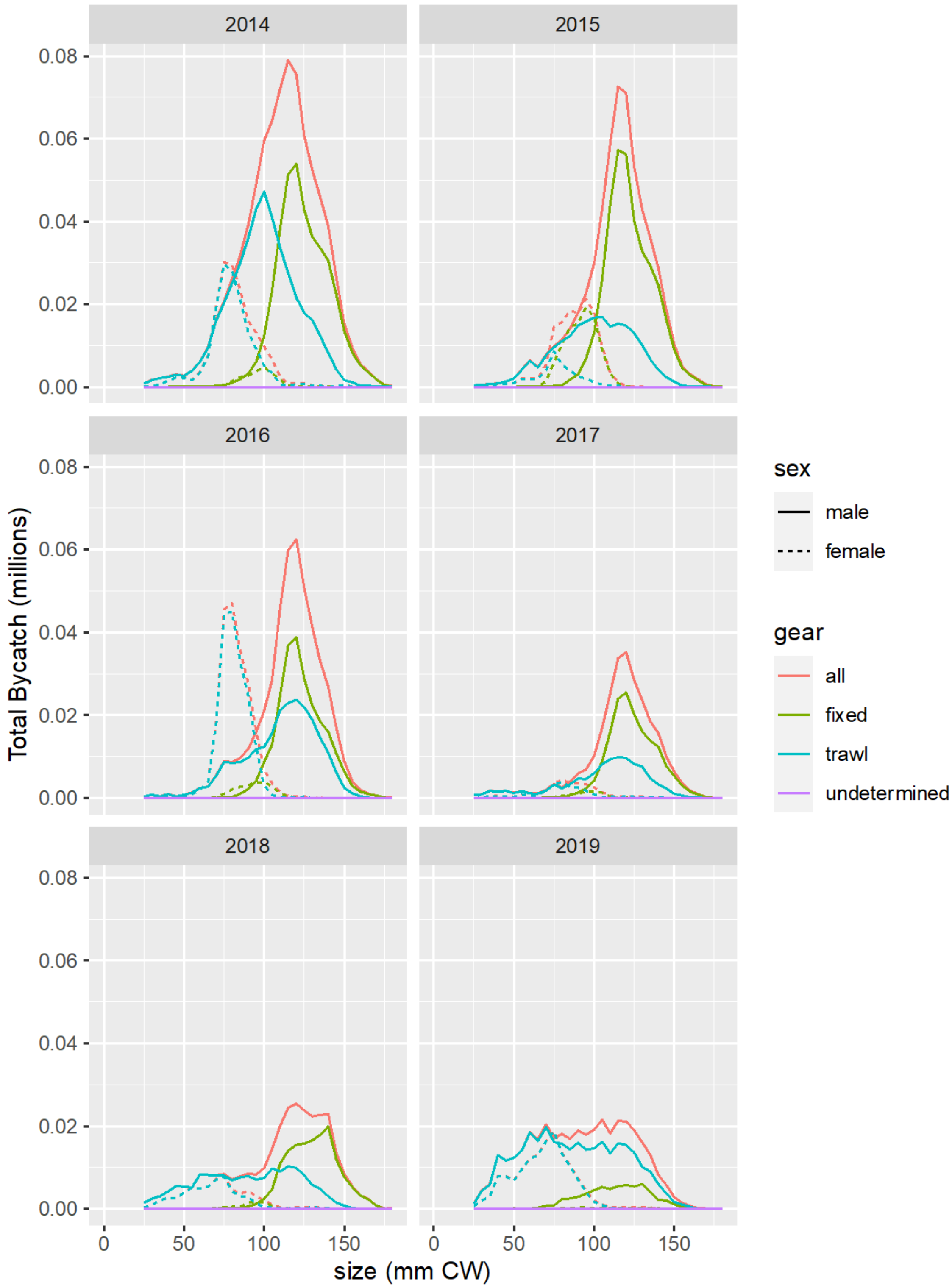

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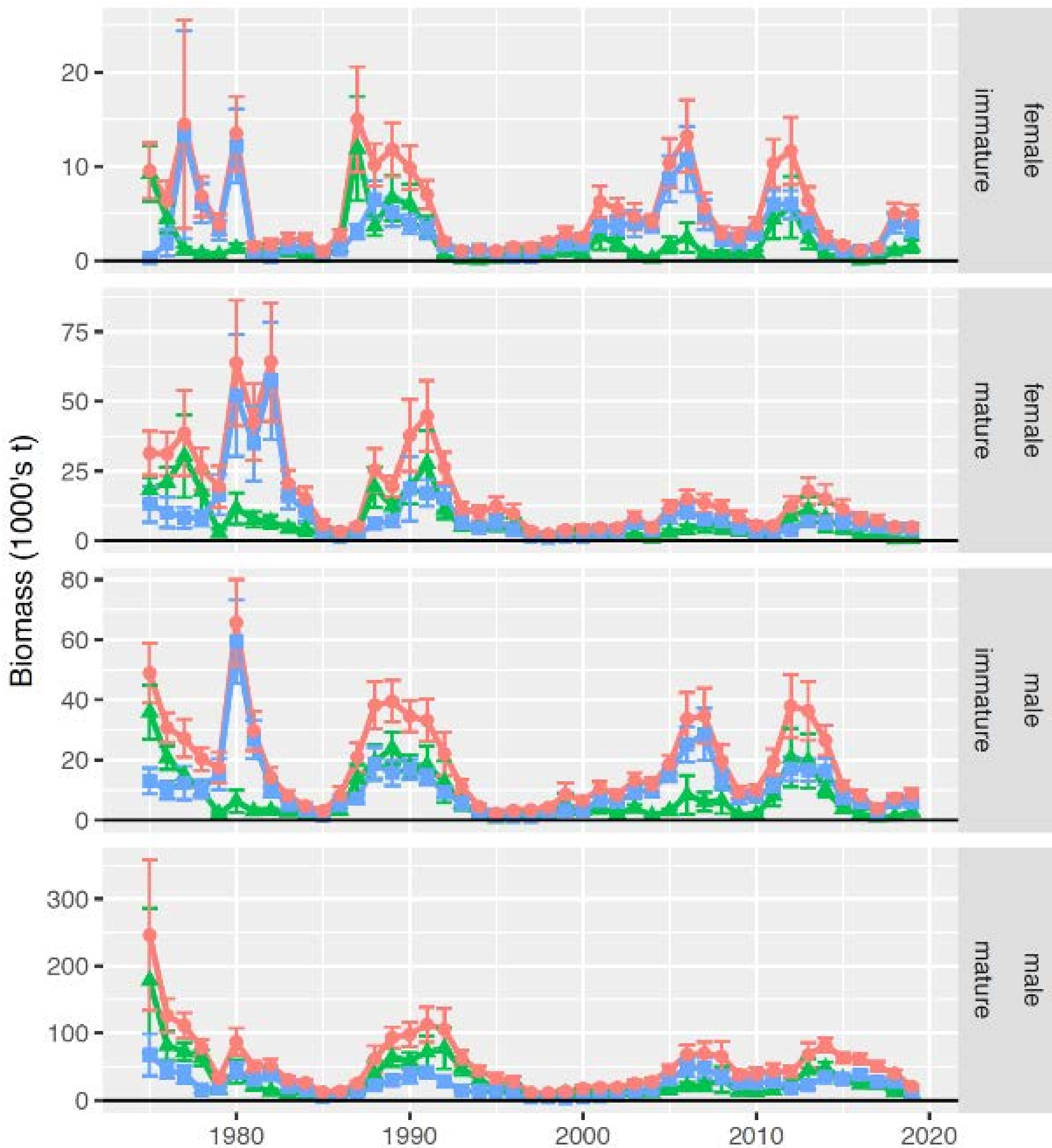

Figure 12. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey, by sex, maturity state, and management area. Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

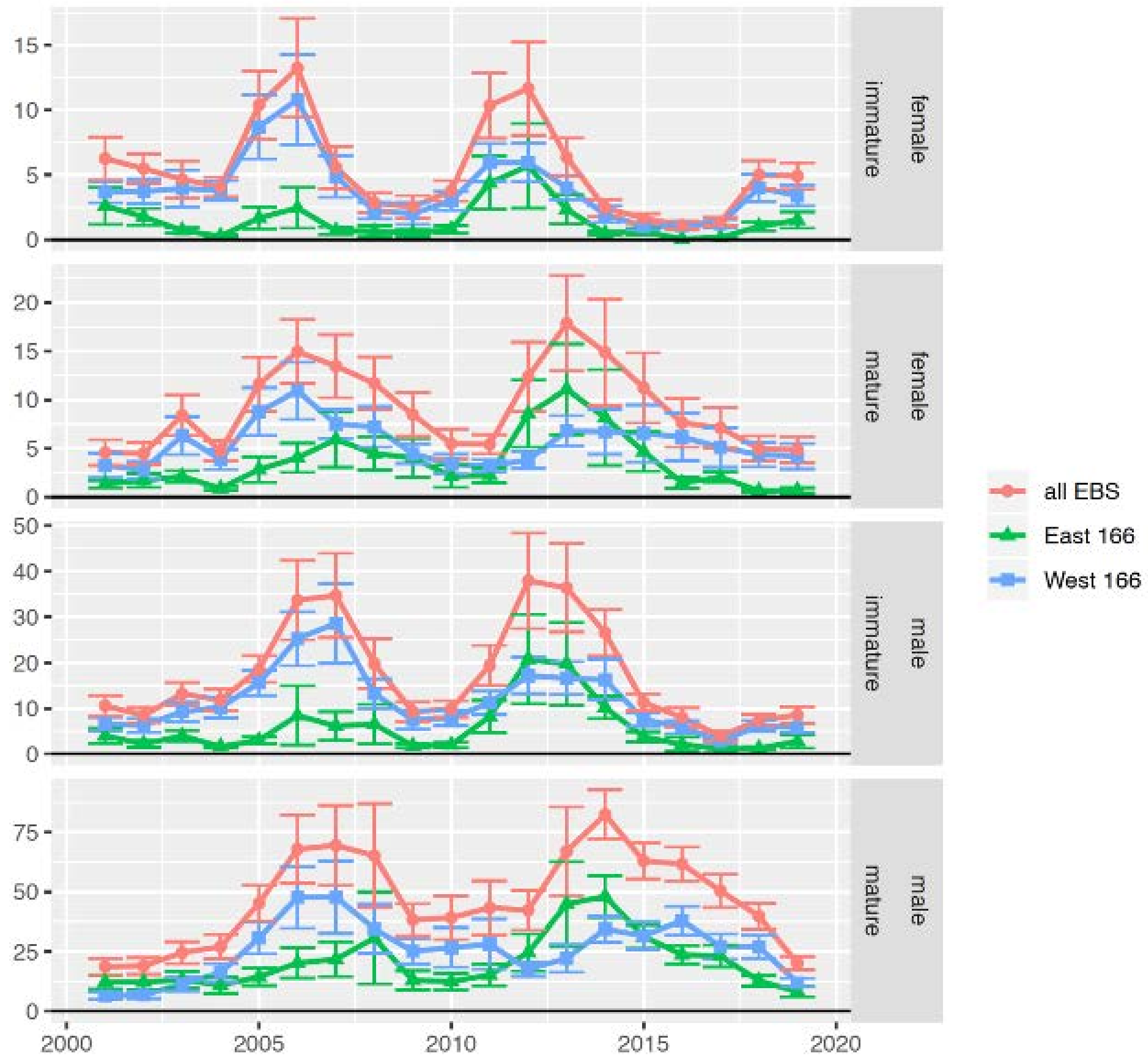

Figure 12 (cont.). Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey, by sex, maturity state, and management area. Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

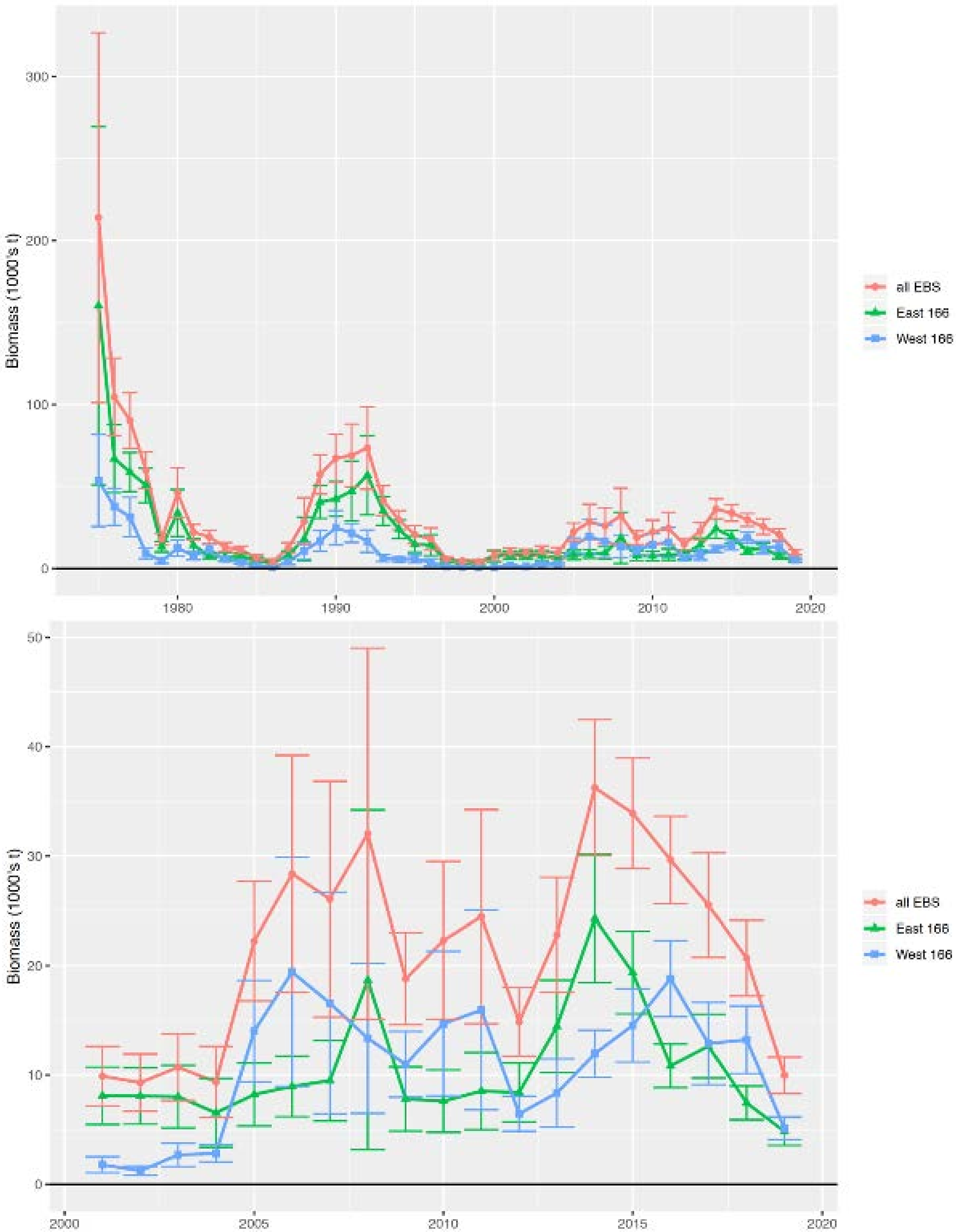

Figure 13. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey for preferred-size (>125 mm CW) legal males . Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

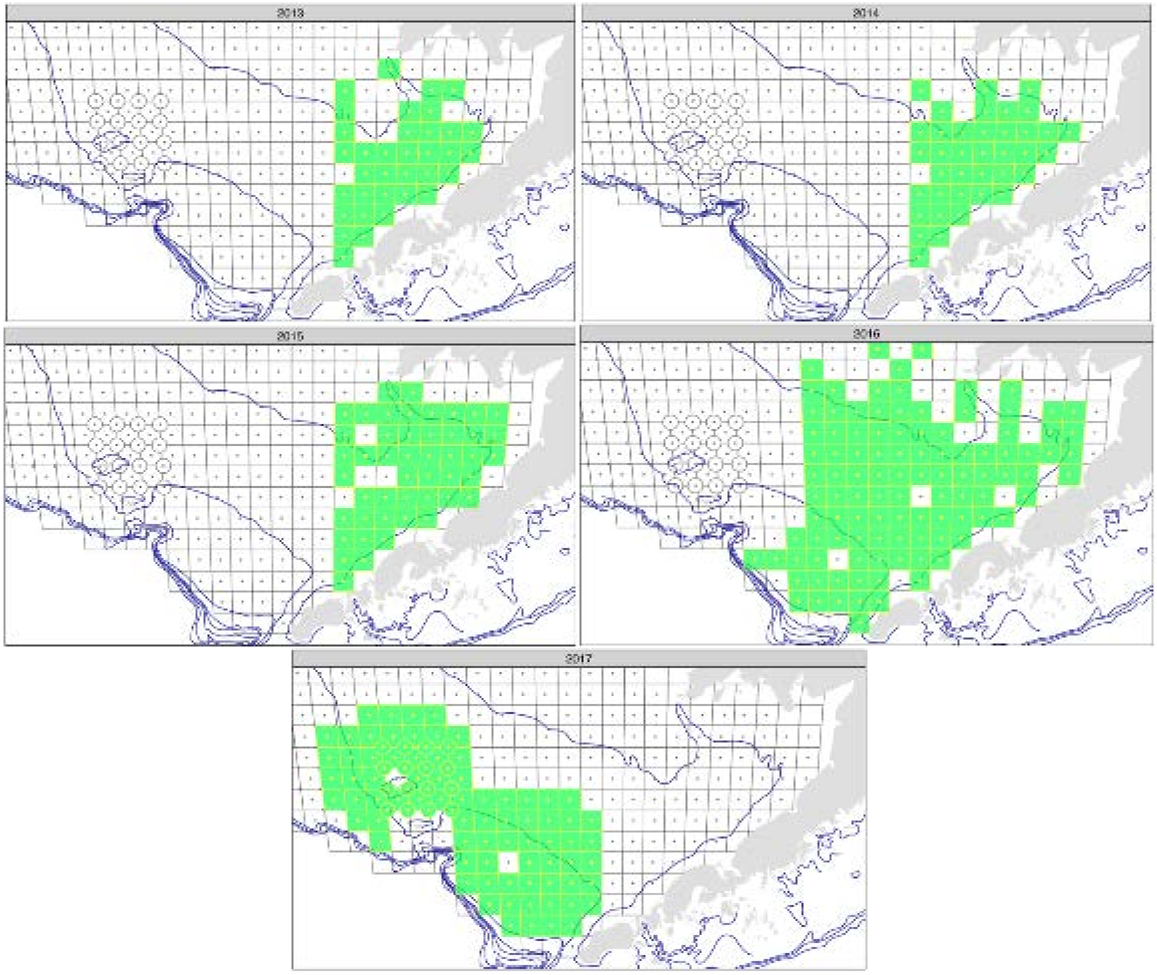

Figure 14. Spatial footprints (stations occupied in green) during the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. Squares and circles represent stations in the standard NMFS EBS bottom trawl survey (which extends beyond the area shown in the maps).

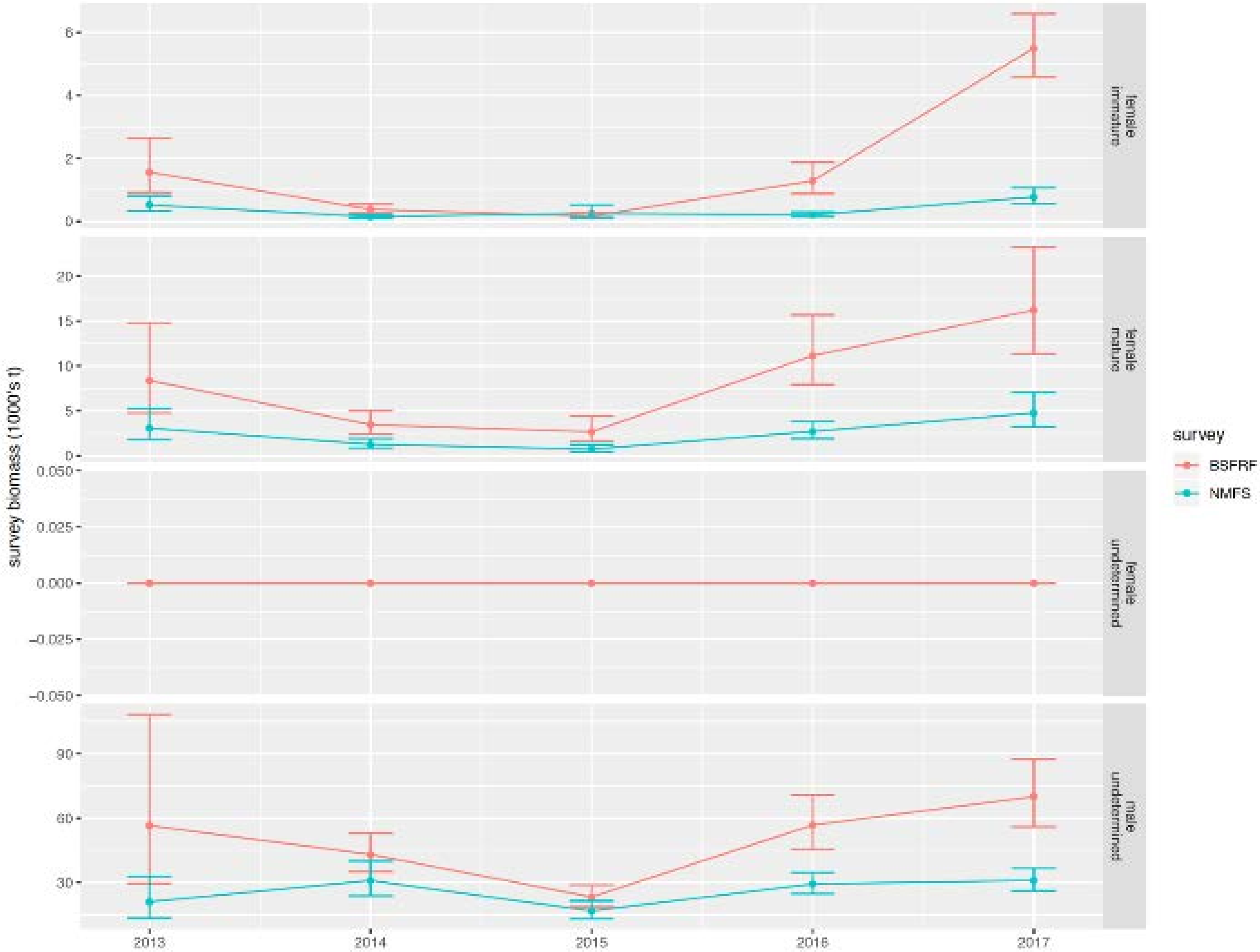

Figure 15. Annual estimates of area-swept biomass from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. The SBS studies had different spatial footprints each year, so annual changes in biomass do not necessarily reflect underlying population trends. Red lines: BSFRF; green lines: NMFS.

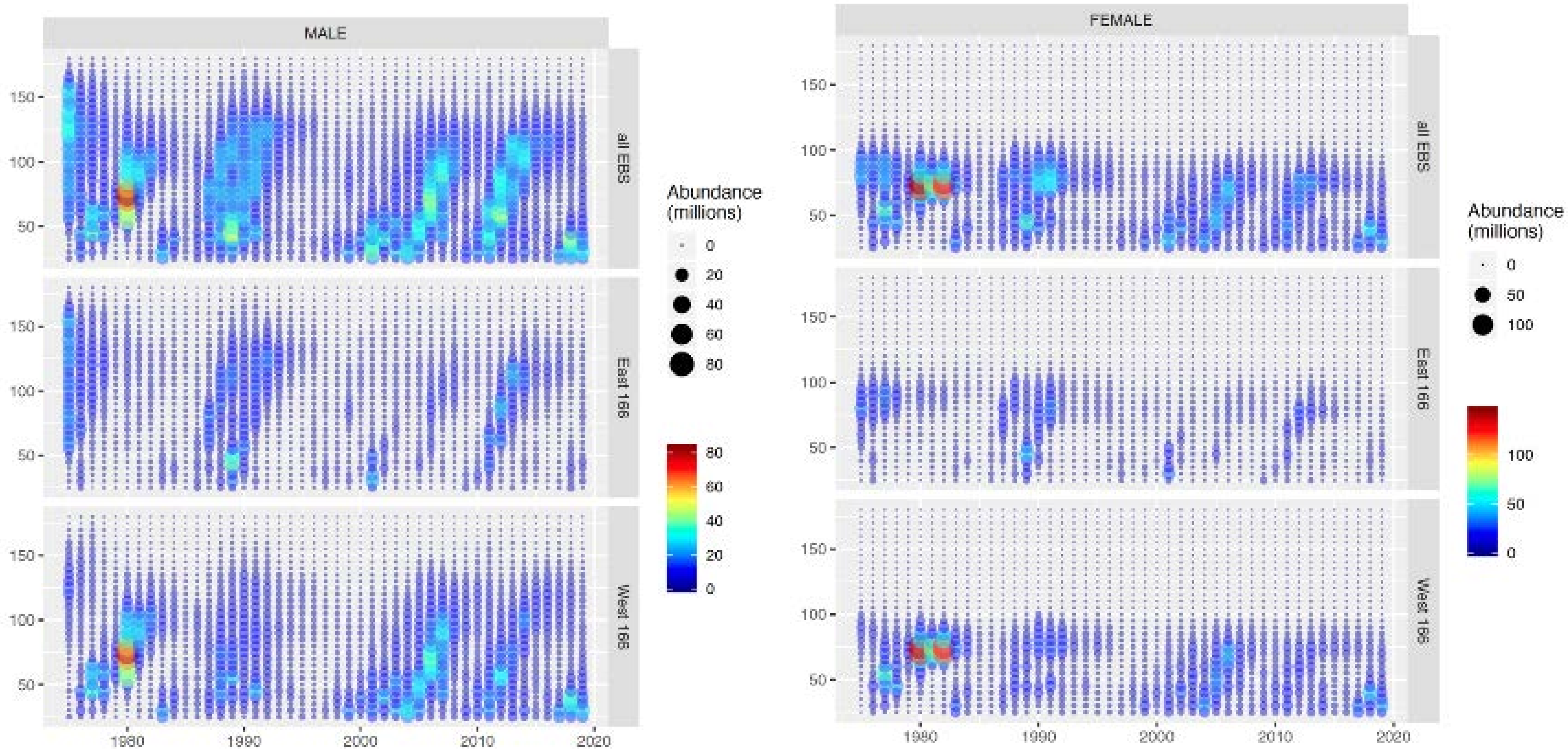

Figure 16. Size compositions from the NMFS EBS bottom trawl survey for 1975-2019.

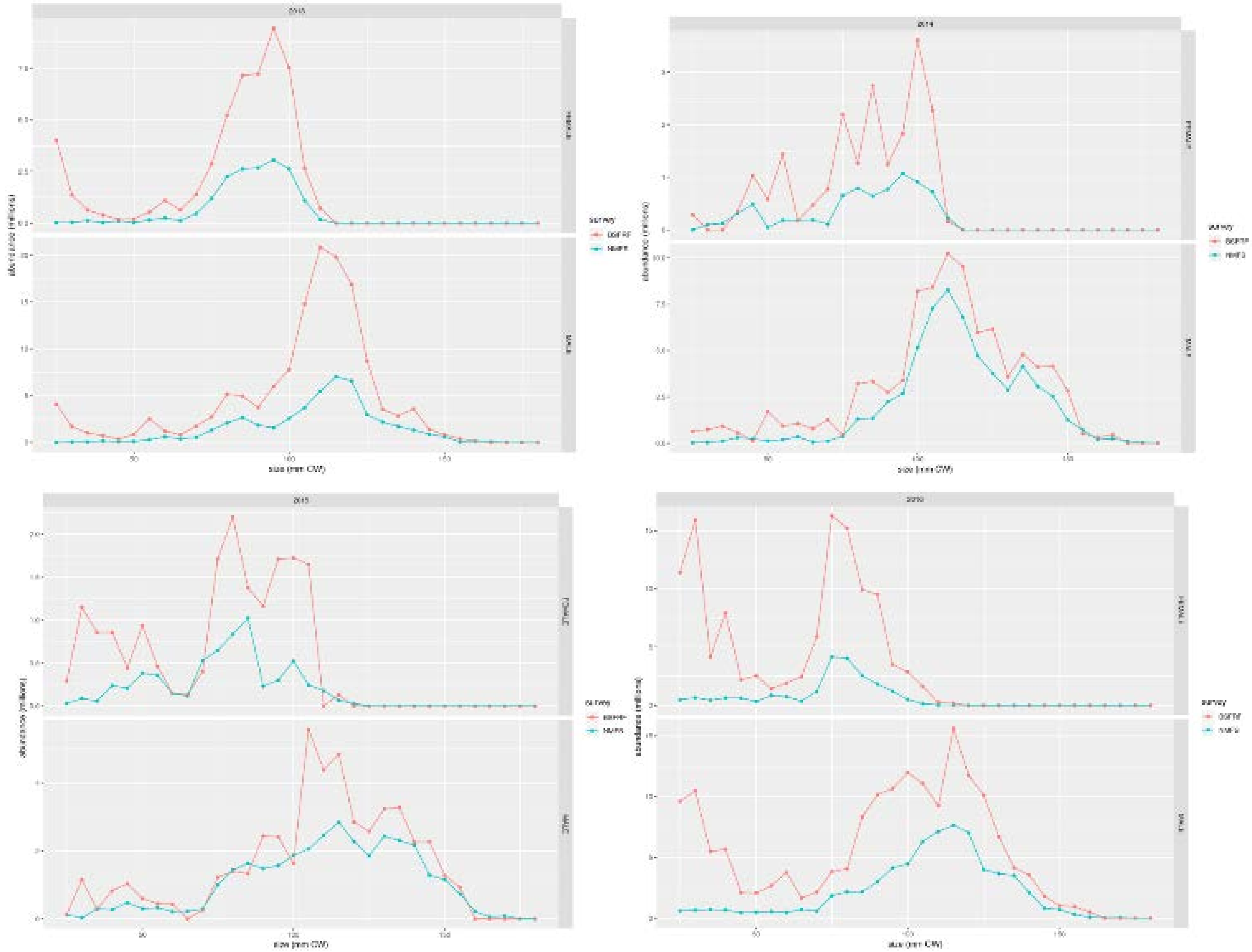

Figure 17. Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2016. Red lines: BSFRF; green lines: NMFS.

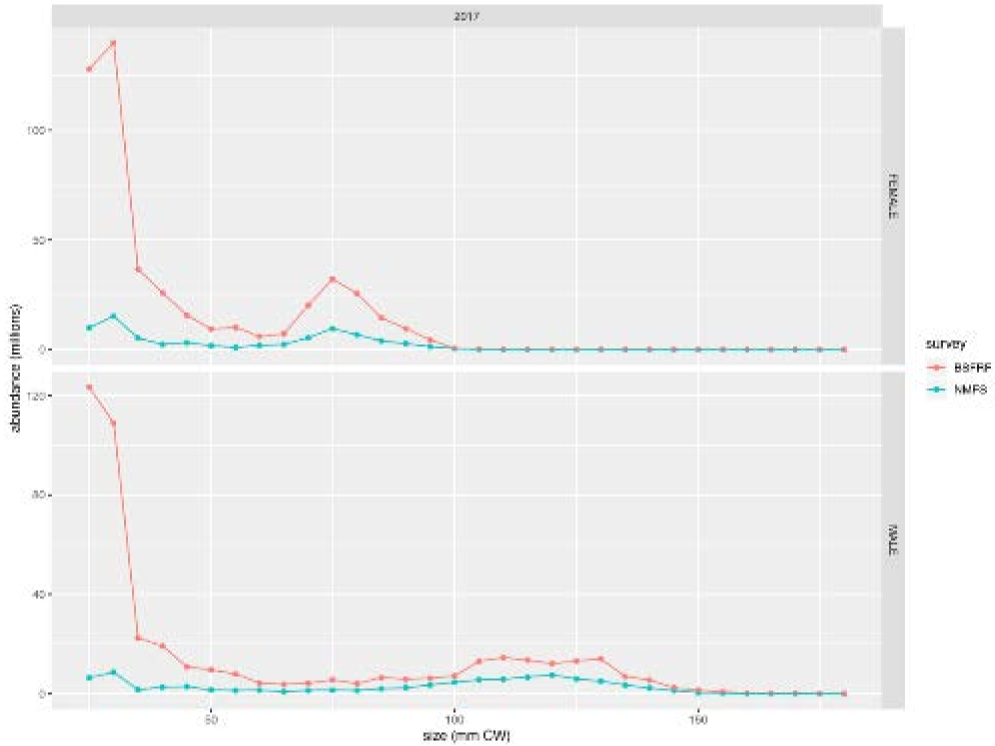

Figure 17 (cont.). Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2017. Red lines: BSFRF; green lines: NMFS

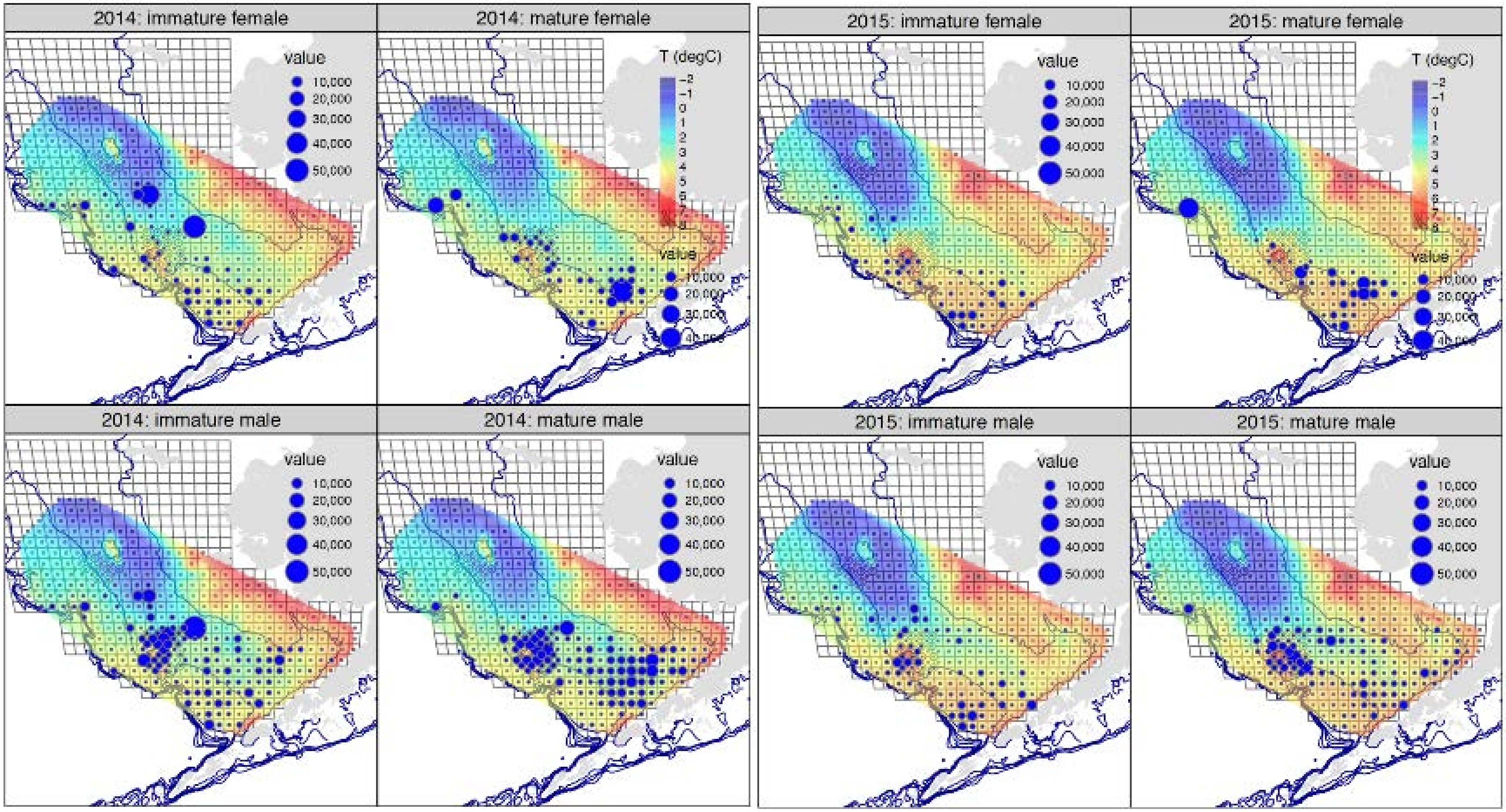

Figure 18. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2014 and 2015. Local abundance scales with symbol area. The background “heatmap” represents bottom water temperatures at the time of the survey.

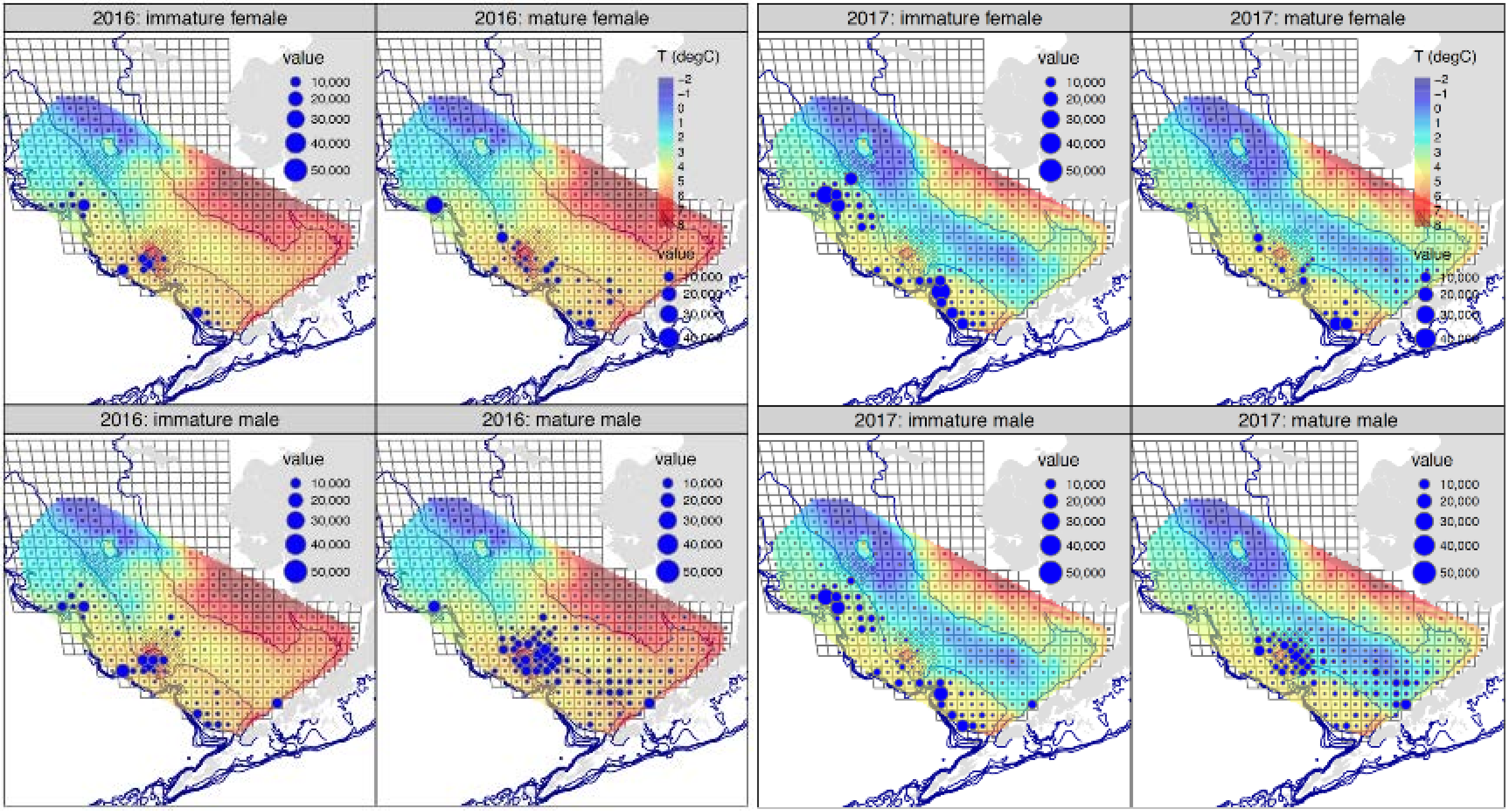

Figure 18 (cont.). Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2016 and 2017. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

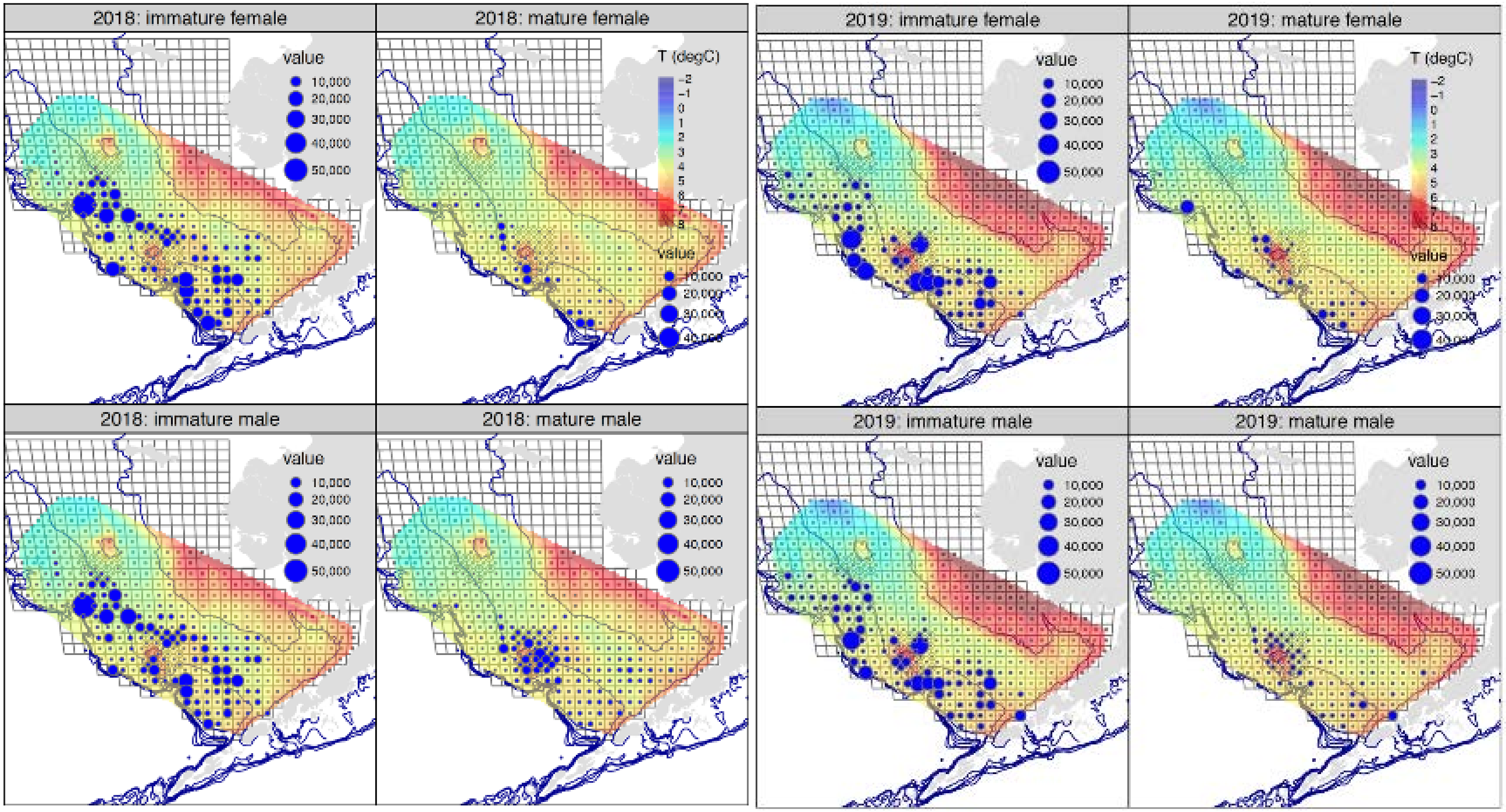

Figure 18 (cont.). Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2018 and 2019. Local abundance scales with symbol area. The background “heatmap” represents bottom water temperatures at the time of the survey.

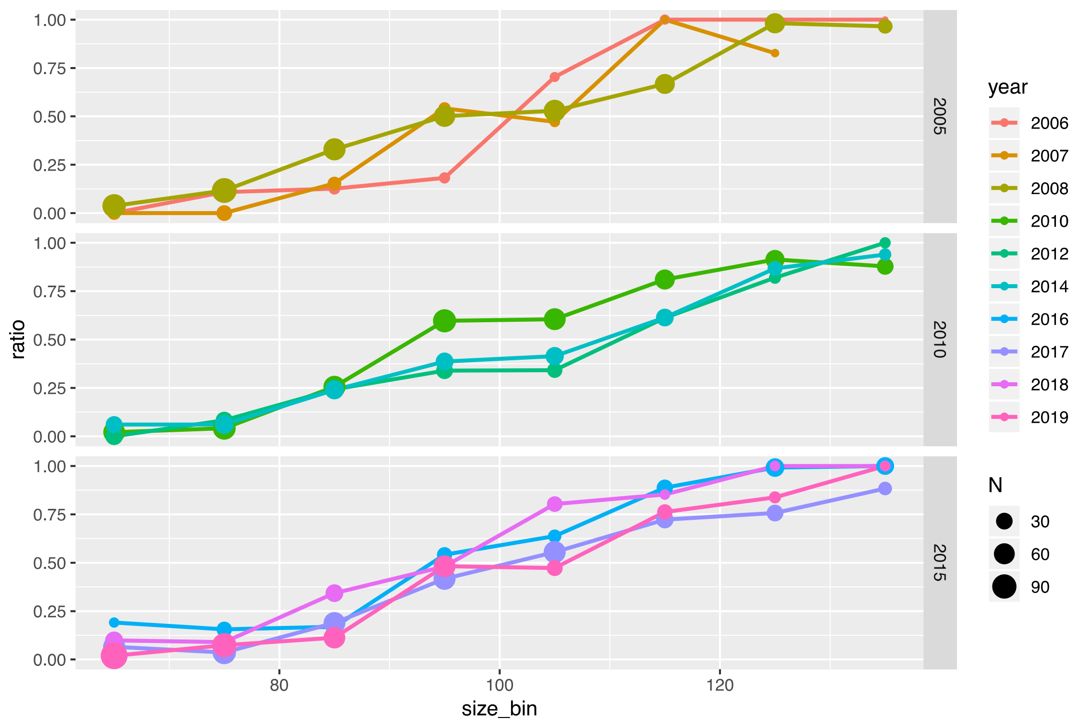

Figure 19. Male maturity ogives (the fraction of new shell mature males, relative to all new shell males) as determined from chela height:carapace width ratios from the NMFS EBS bottom trawl survey for years when chela heights were collected with 0.1 mm precision..

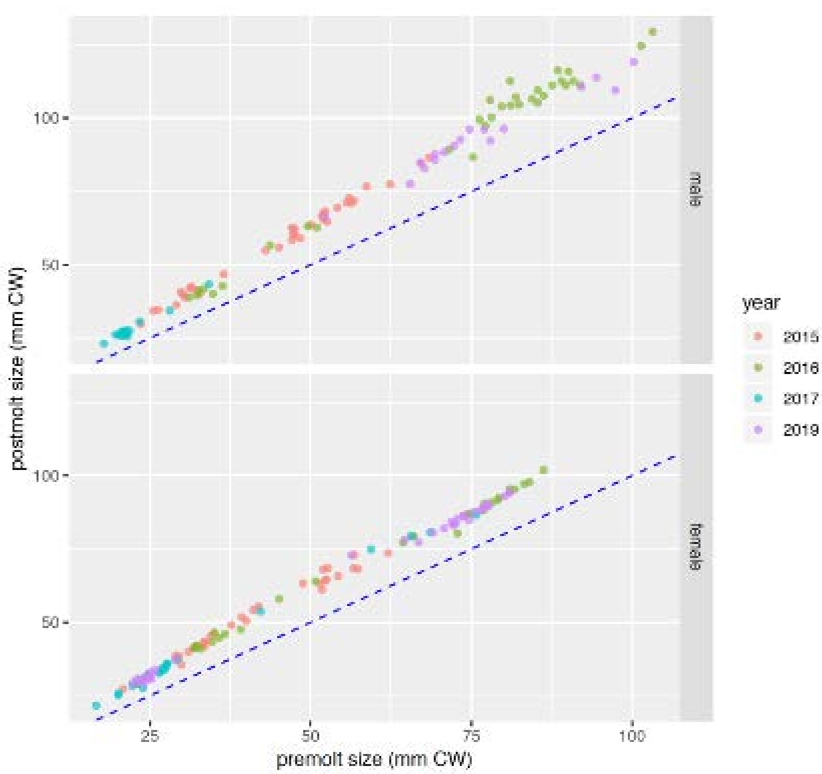

Figure 20. Molt increment data collected collaboratively by NMFS, BSFRF, and ADFG.

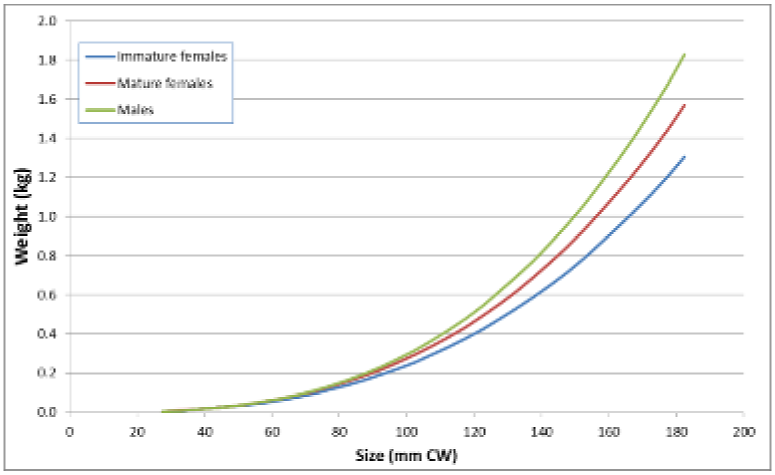

Figure 21. Size-weight relationships developed from NMFS EBS summer trawl survey data.

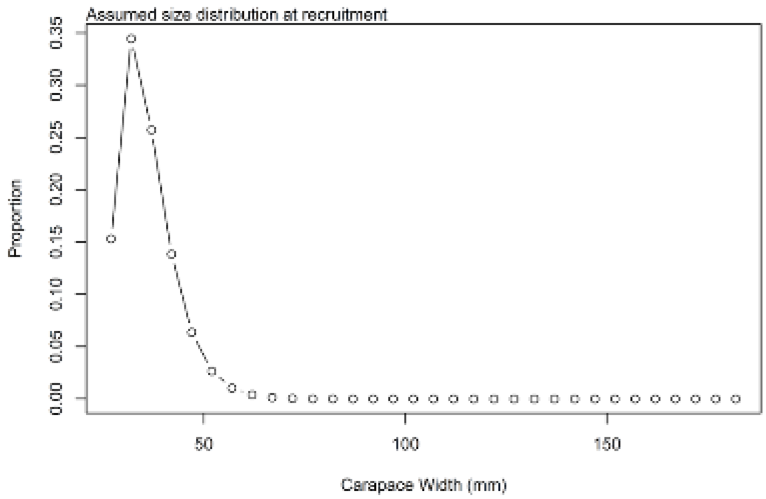

Figure 22. Assumed size distribution for recruits entering the population.

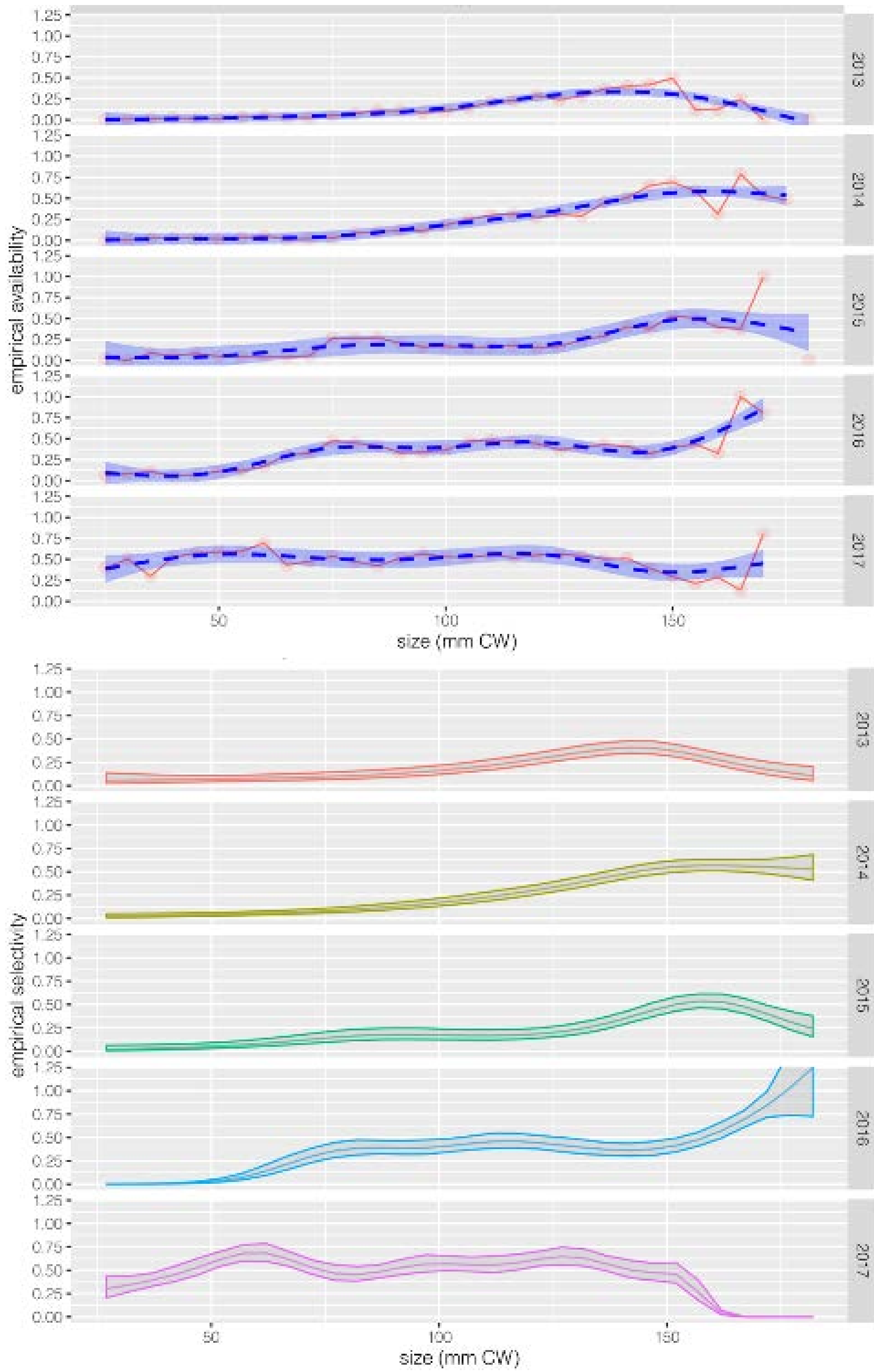

Figure 23. Upper: Empirical availability for males in SBS study areas, by year. Red line and points: annual ratios of NMFS abundance-at-size in SBS study areas to full survey area; dashed blue line and fill: LOESS smooth. Lower: “best”-fitting GAMs using cubic spline smooths to the values in the upper plot.

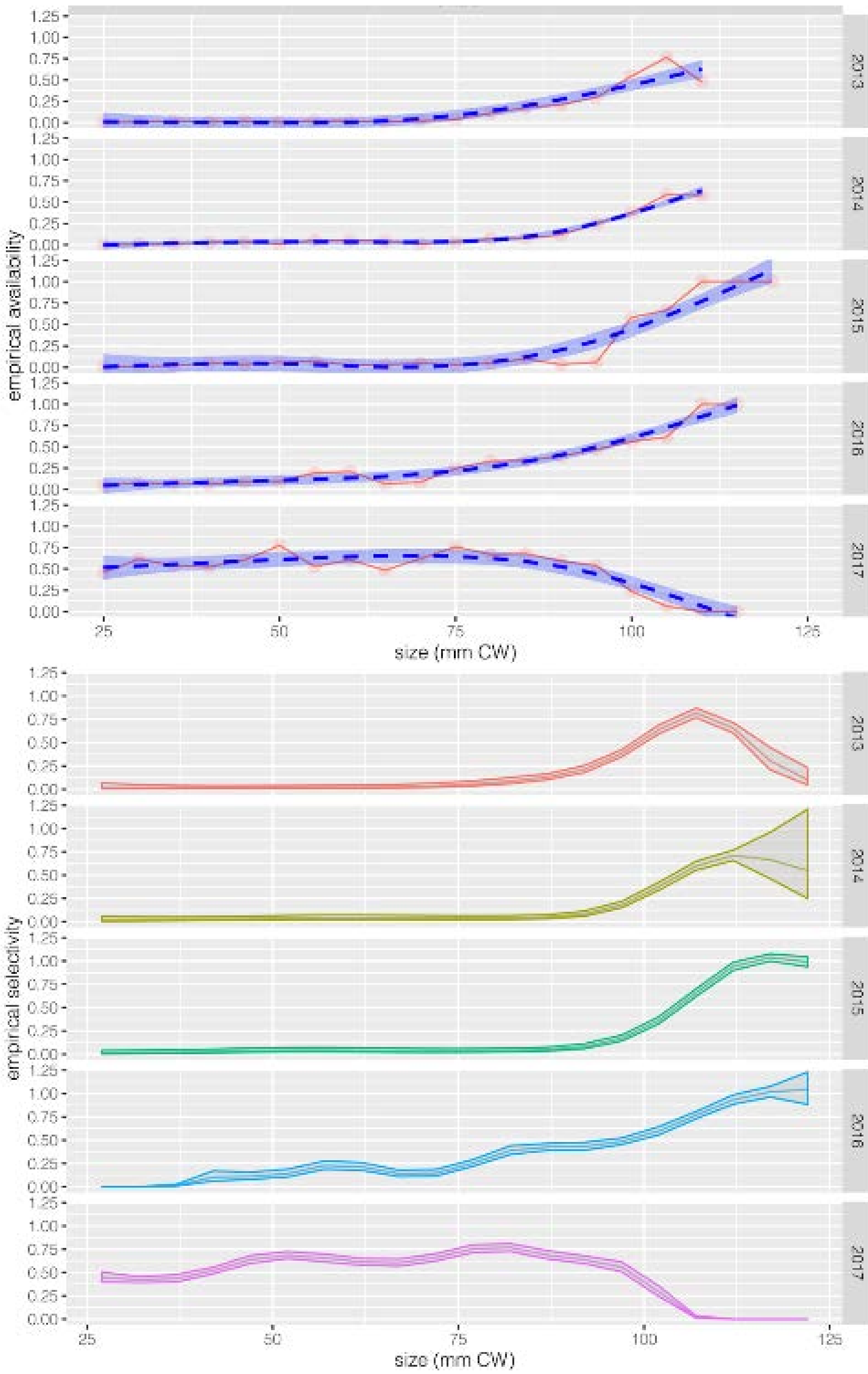

Figure 24. Upper: Empirical availability for females in SBS study areas, by year. Red line and points: annual ratios of NMFS abundance-at-size in SBS study areas to full survey area; dashed blue line and fill: LOESS smooth. Lower: “best”-fitting GAMs using cubic spline smooths to the values in the upper plot.

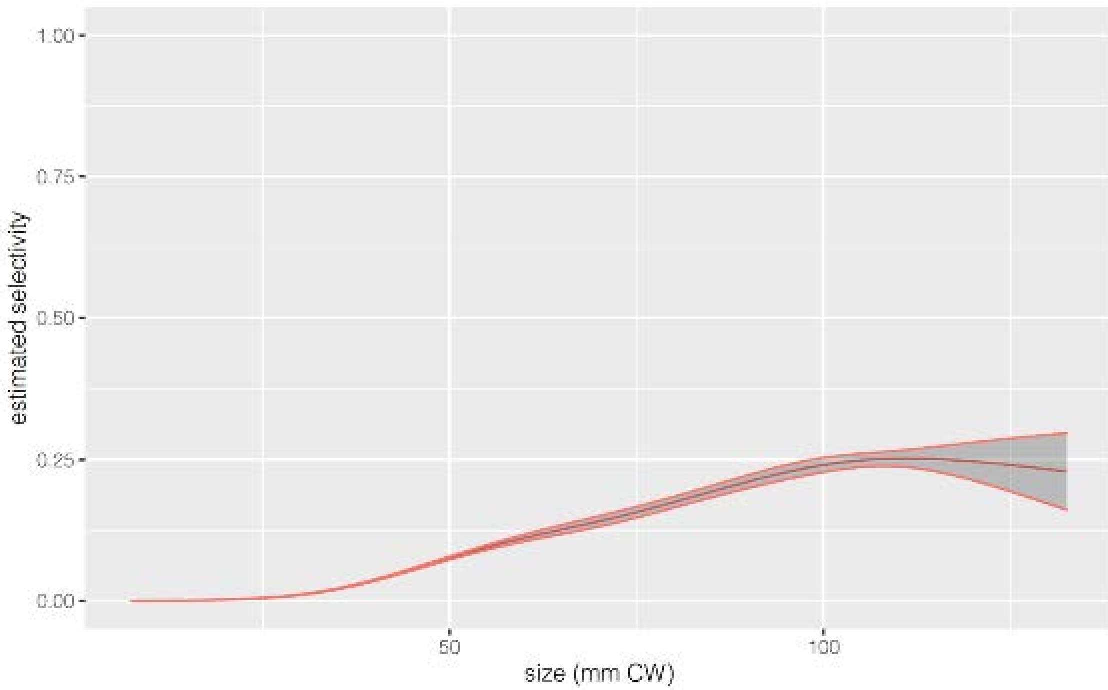

Figure 25. “Best”-fitting selectivity function for females from a catch-ratio analysis of the BSFRF-NMFS SBS data.

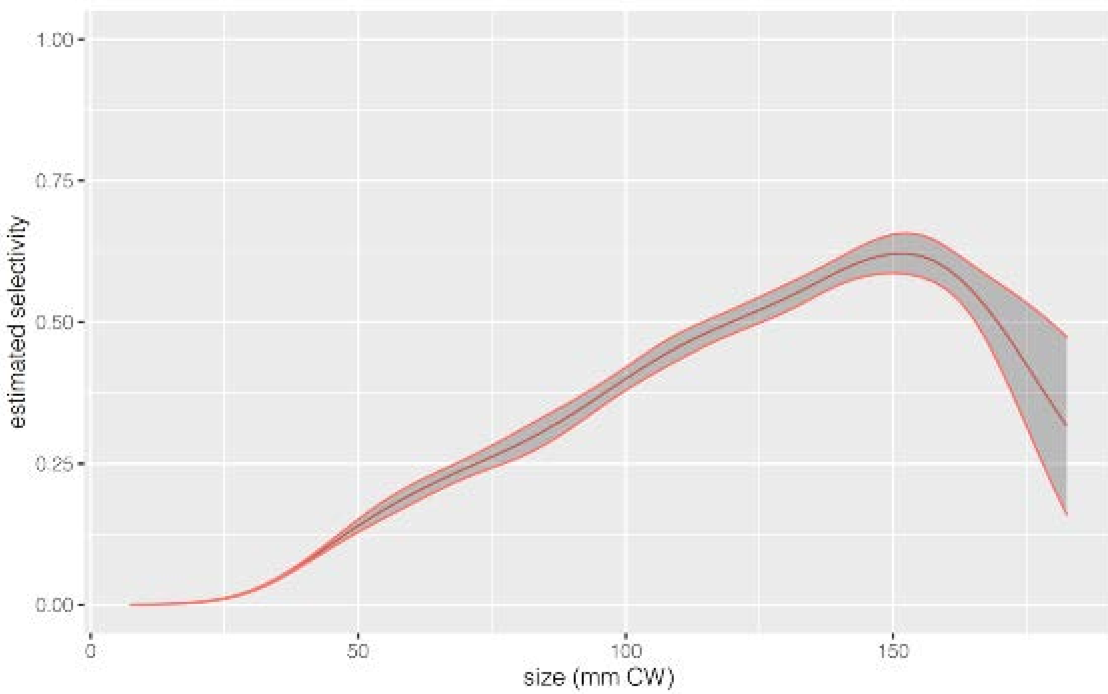

Figure 26. “Best”-fitting selectivity function for males from a catch-ratio analysis of the BSFRF-NMFS SBS data.

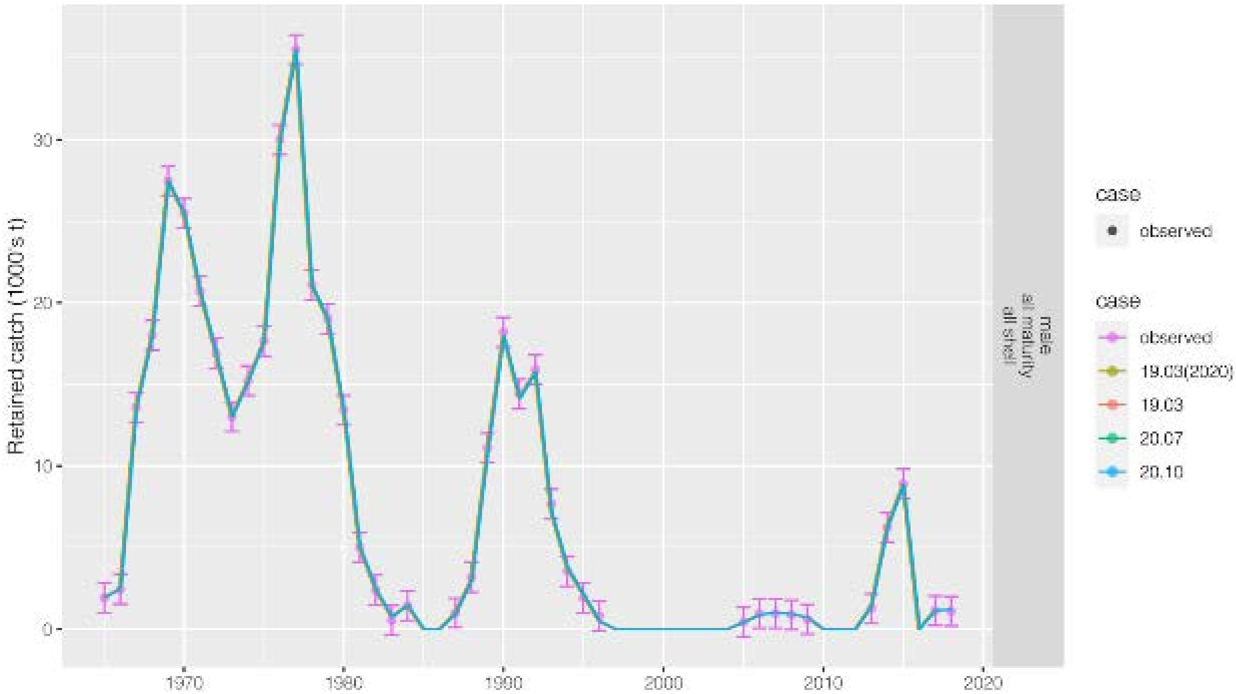

Figure 27. Fits to retained catch biomass in the directed fishery from all model scenarios.

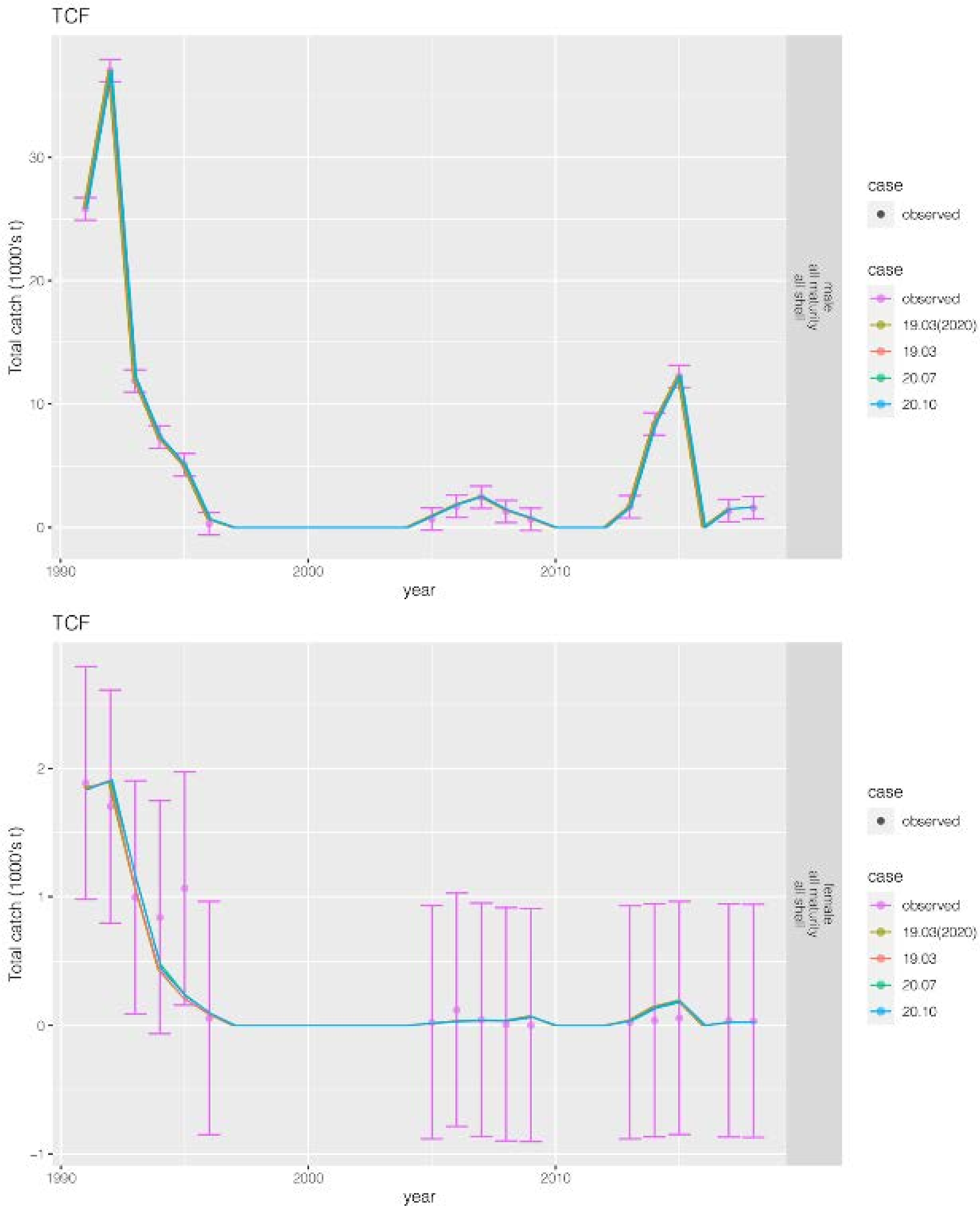

Figure 28. Fits to total catch biomass in the directed fishery from all model scenarios.

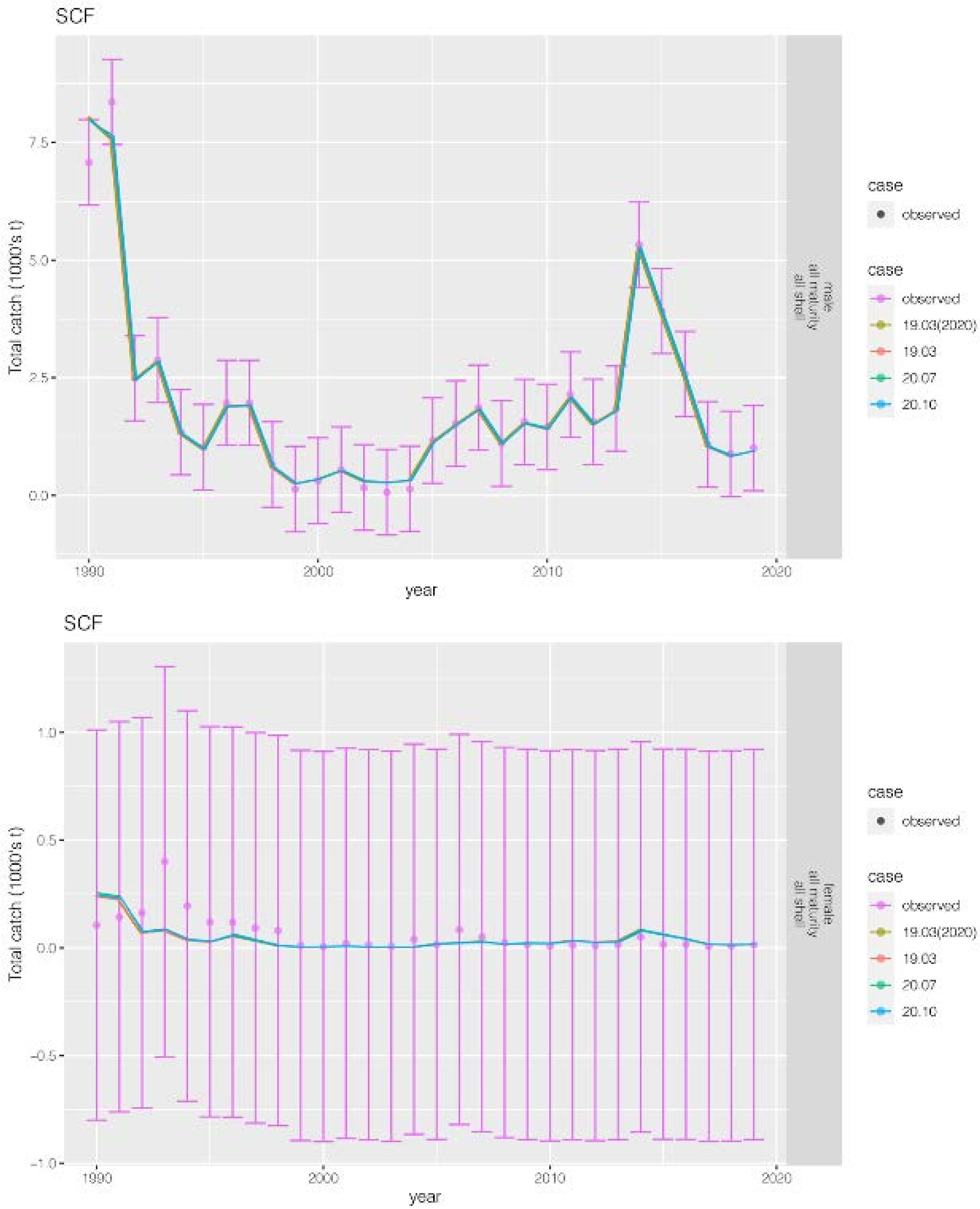

Figure 29. Fits to total catch biomass in the snow crab fishery from all scenarios.

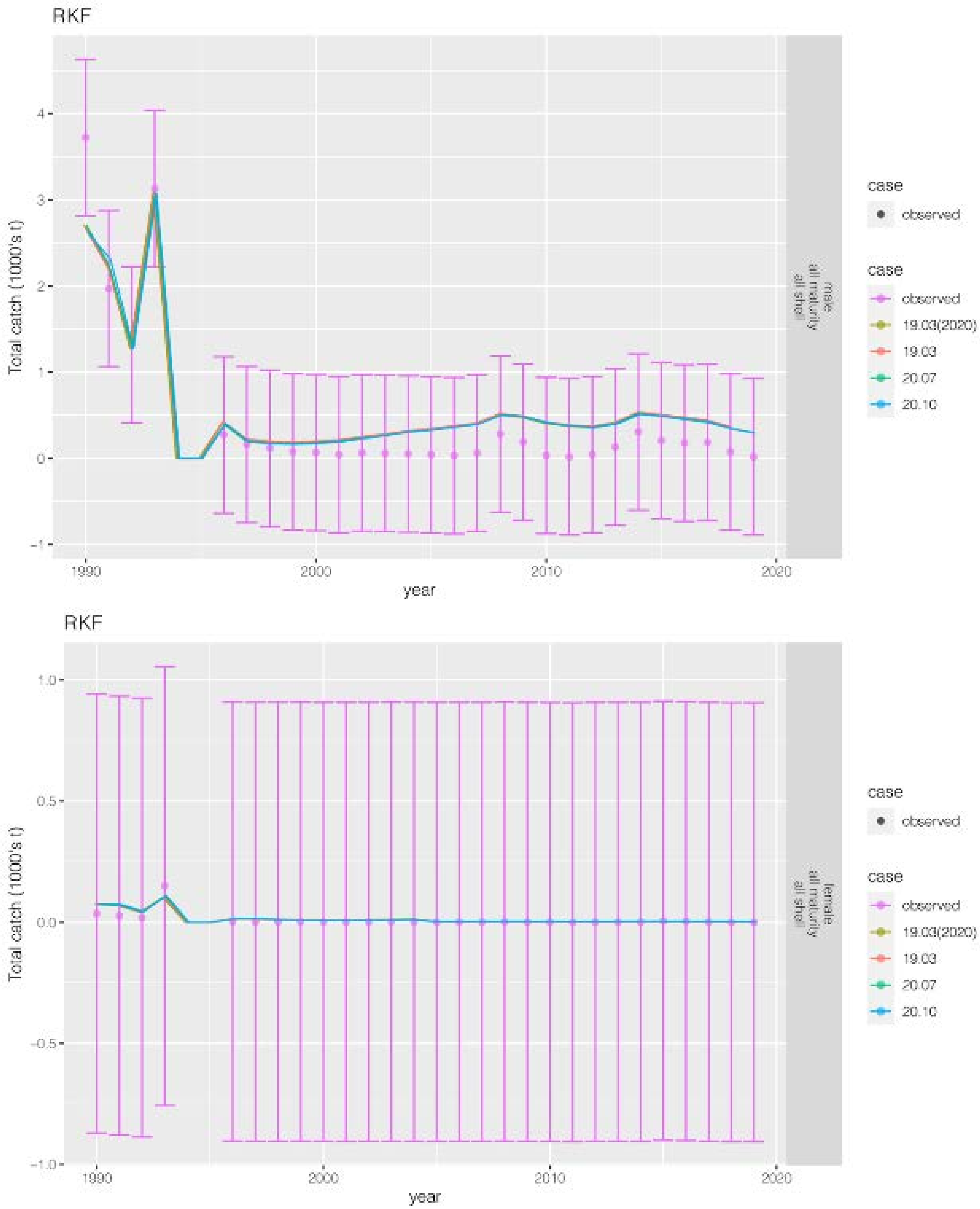

Figure 30. Fits to total catch biomass in the BBRKC fishery from all scenarios.

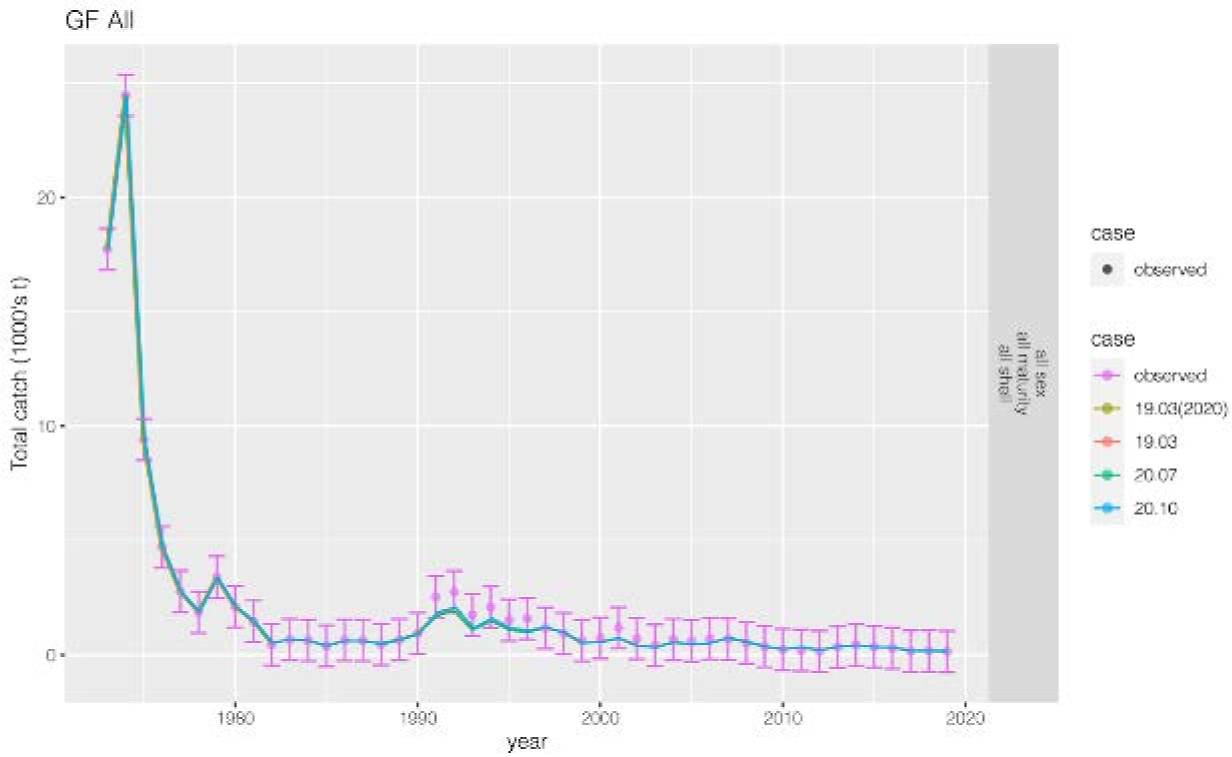

Figure 31. Fits to total catch biomass in the groundfish fisheries for all scenarios.

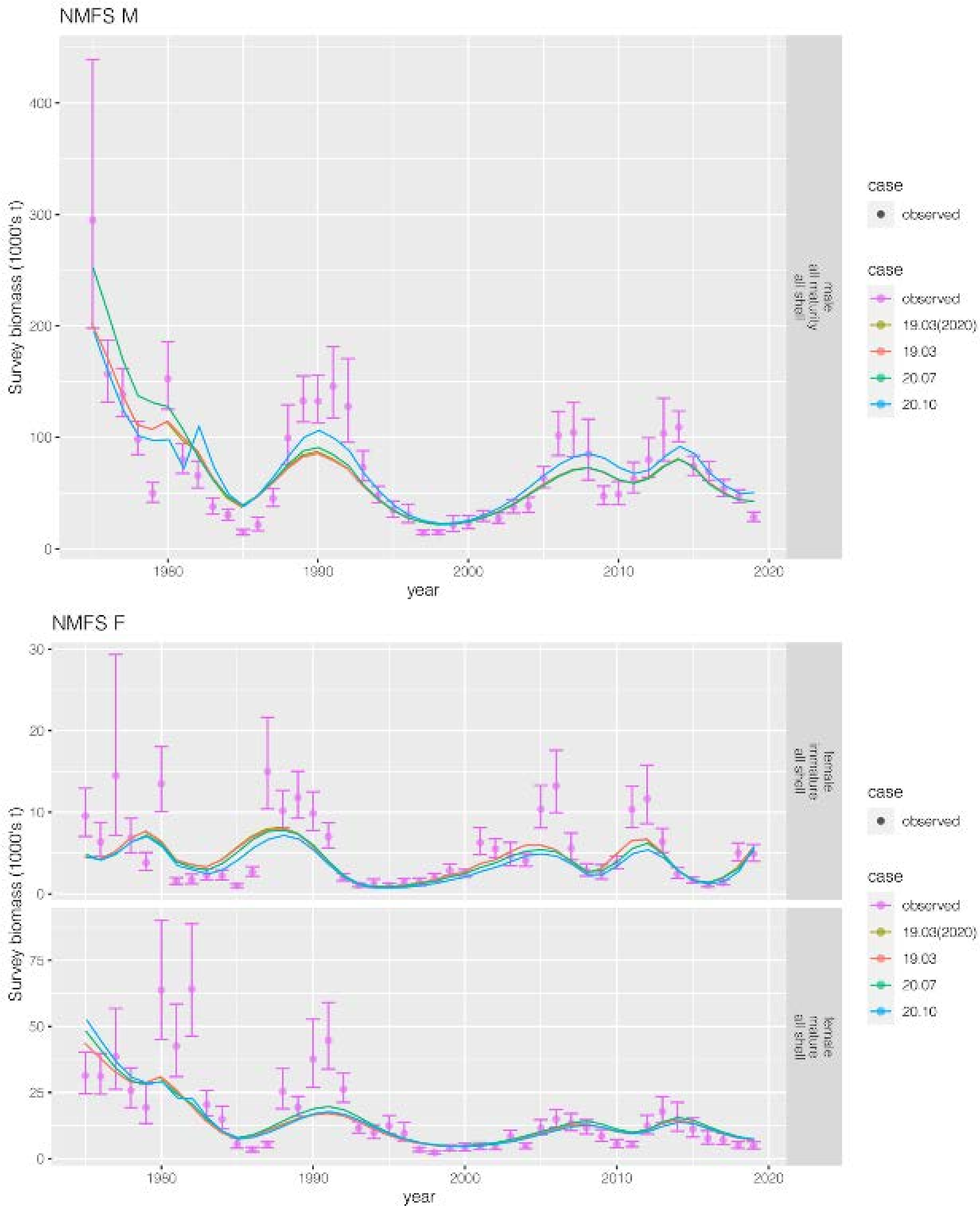

Figure 32. Fits to time series of all male (upper graph), immature female (center graph), and mature female (lower plot) biomass from the NMFS EBS shelf bottom trawl survey.

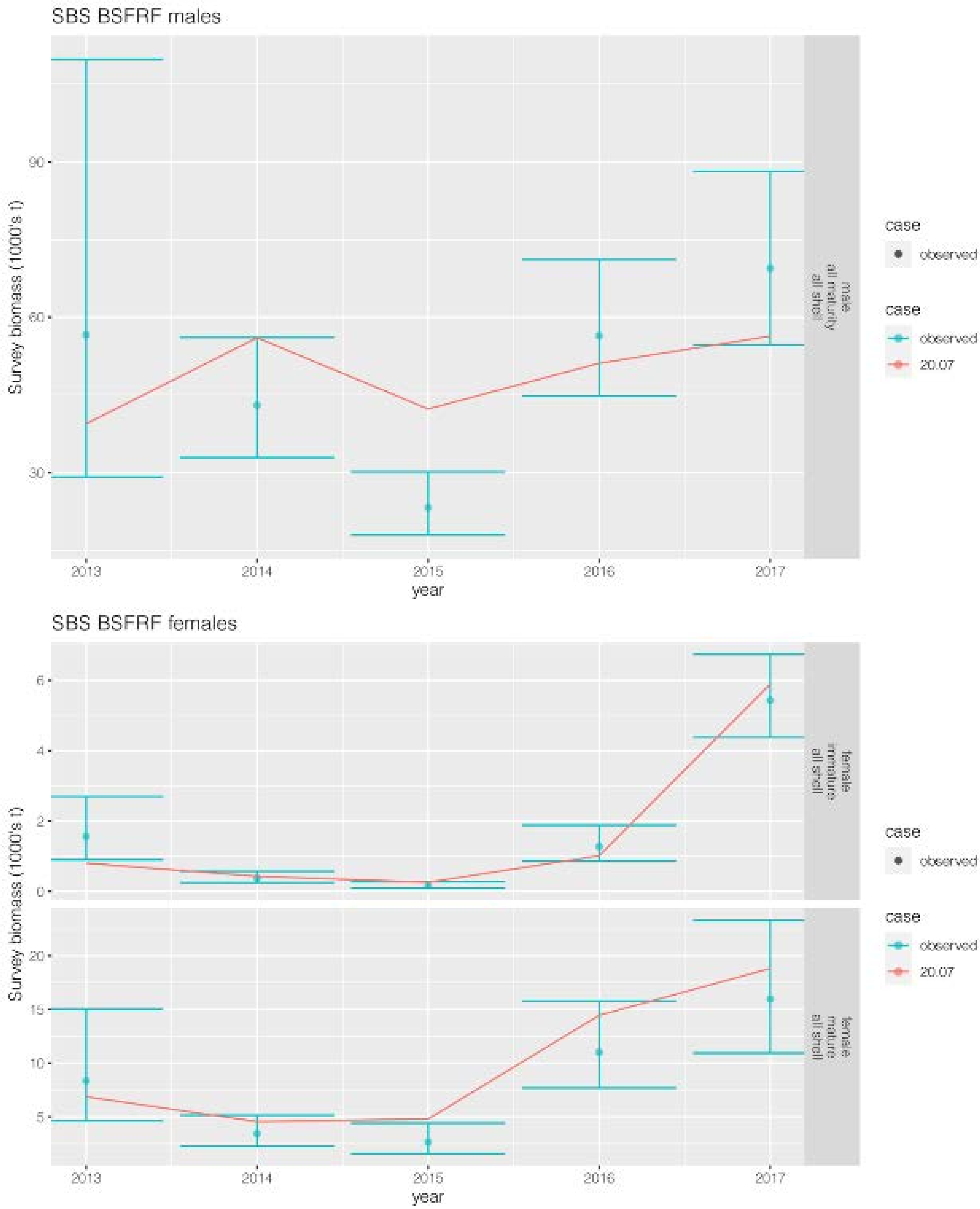

Figure 33. Fits to survey biomass from the BSFRF SBS bottom trawl survey data for scenario 20.07.

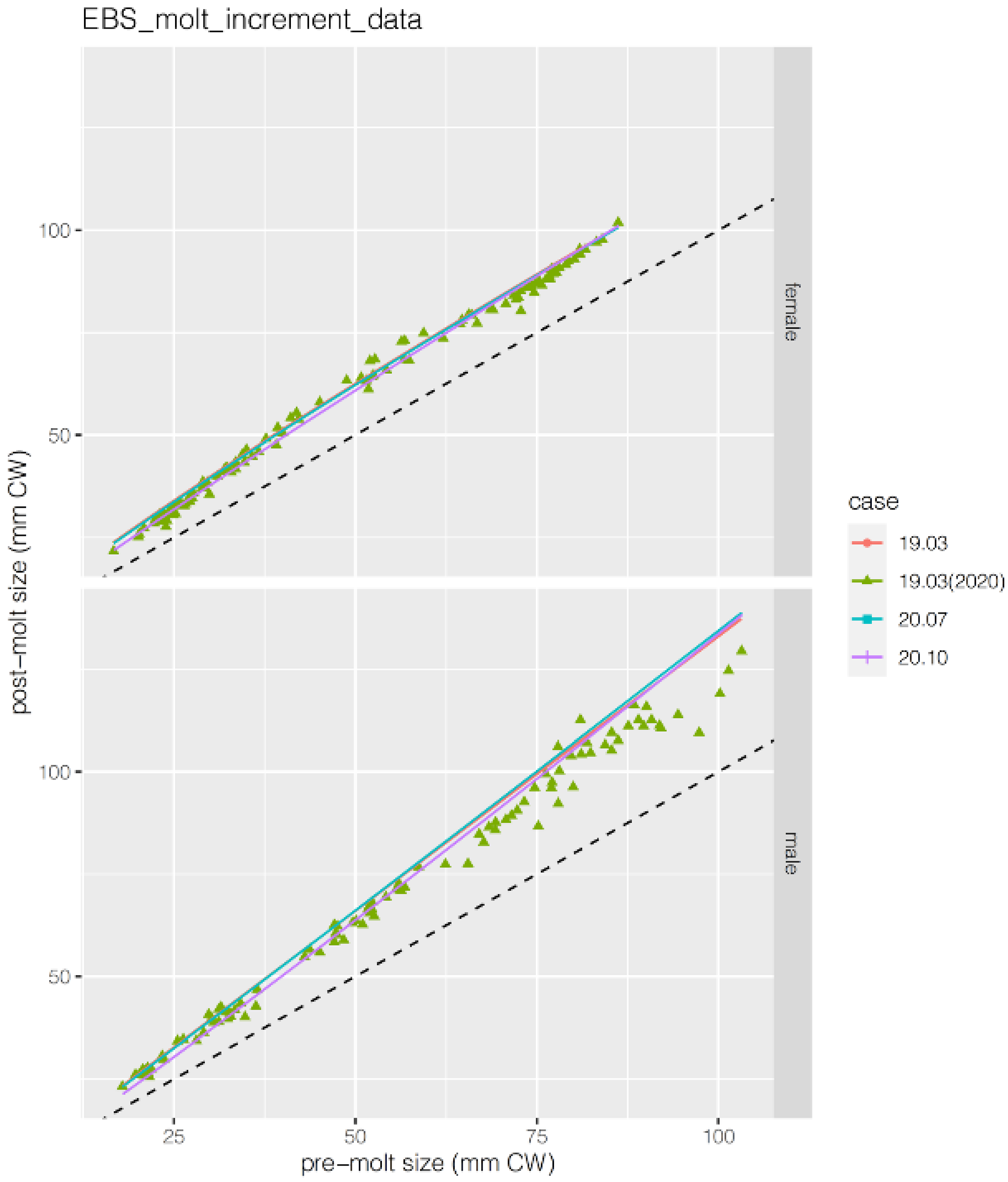

Figure 34. Fits to molt increment data for all scenarios.

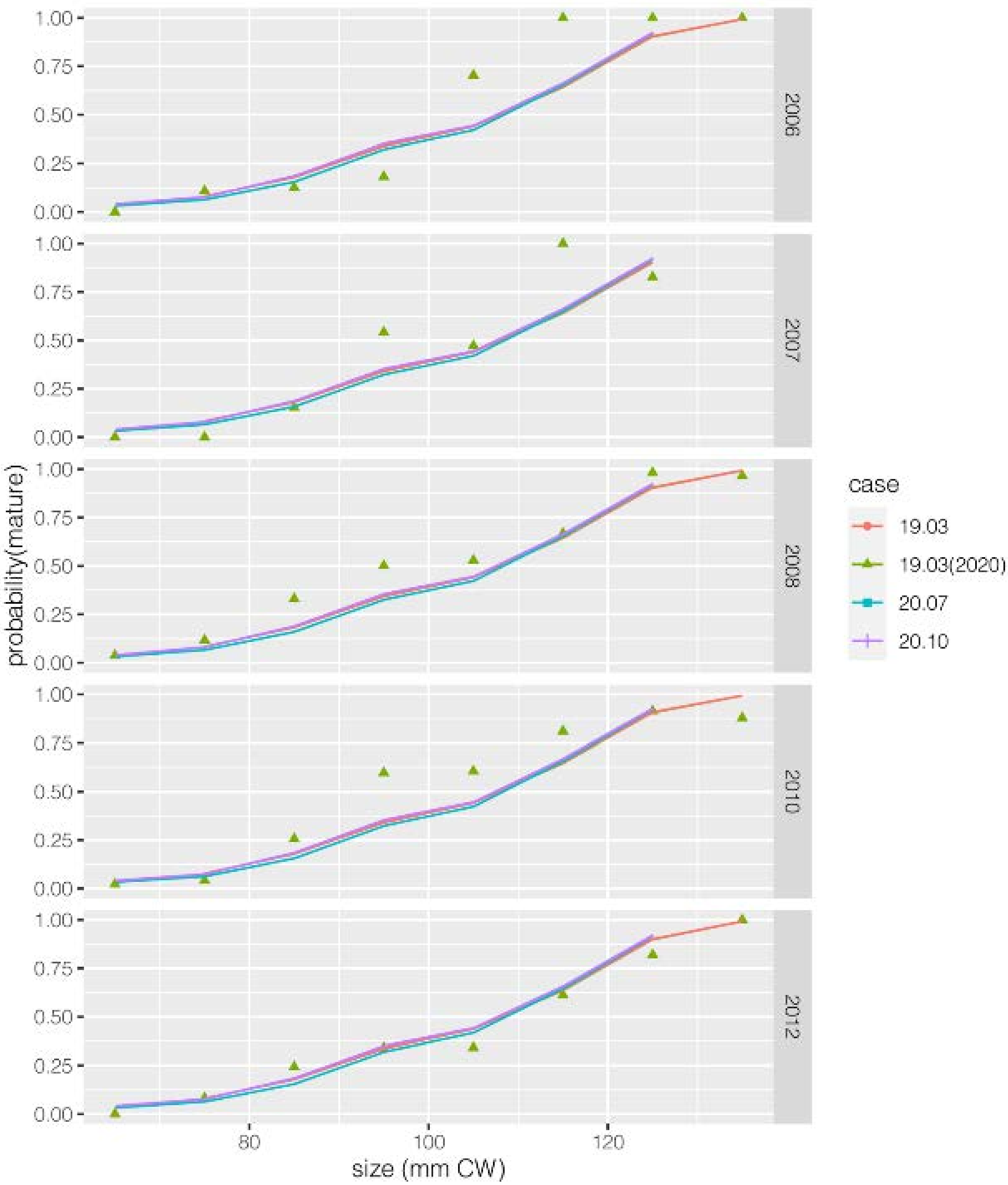

Figure 35. Fits to male maturity ogive data for all scenarios.

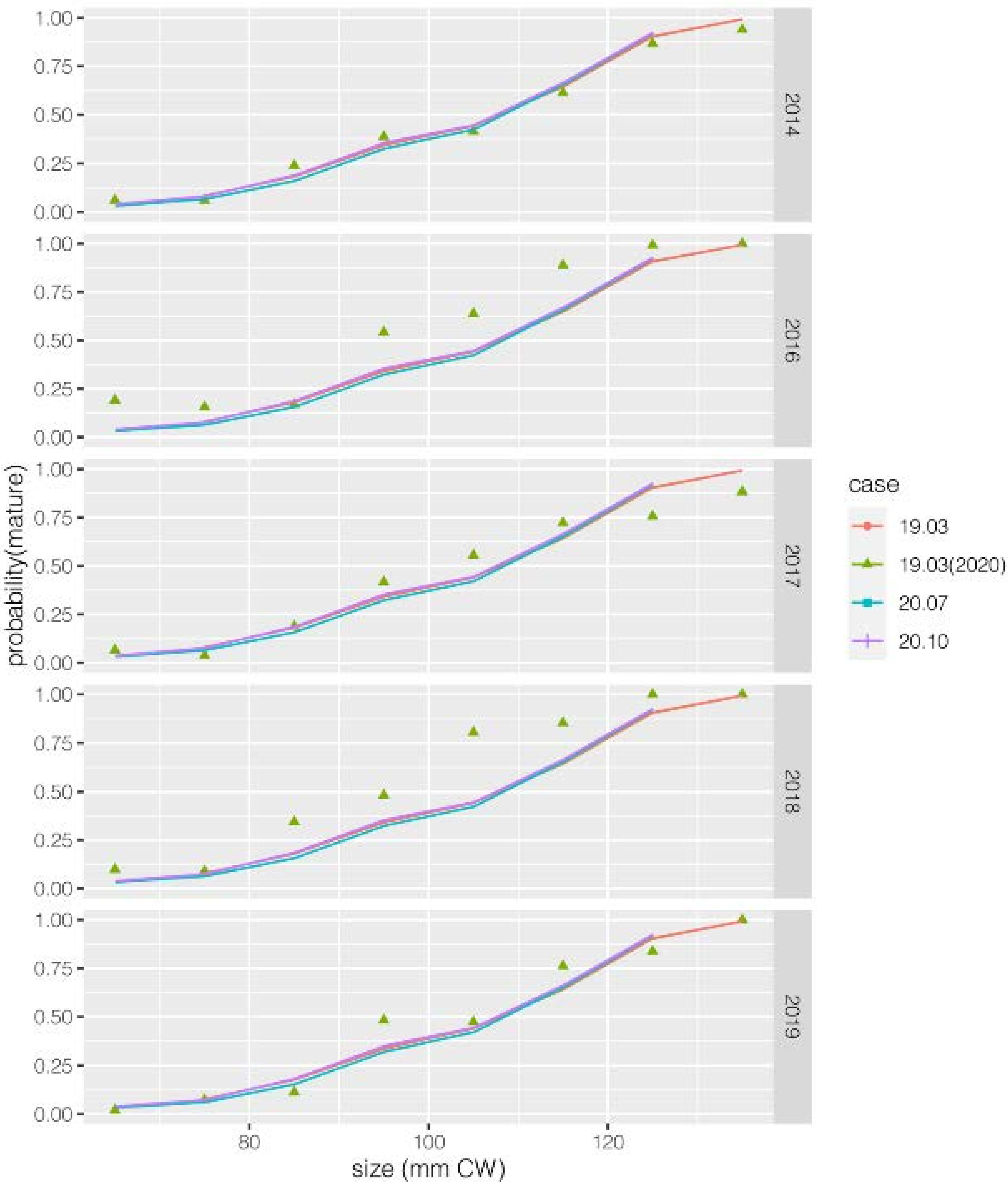

Figure35 (cont.). Fits to male maturity ogive data for all scenarios.

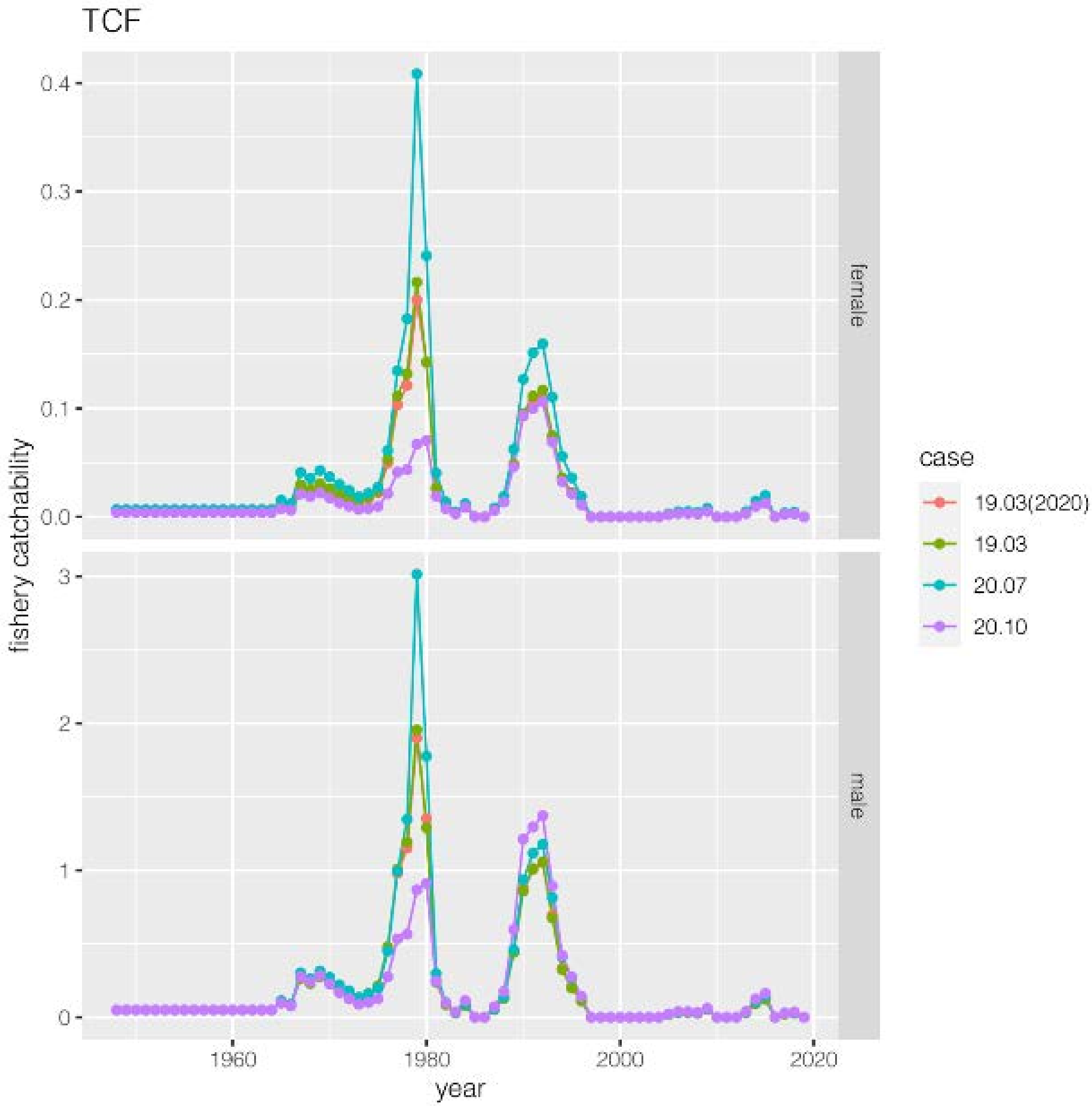

Figure 36. Directed fishery catchability (capture rates) from all model scenarios.

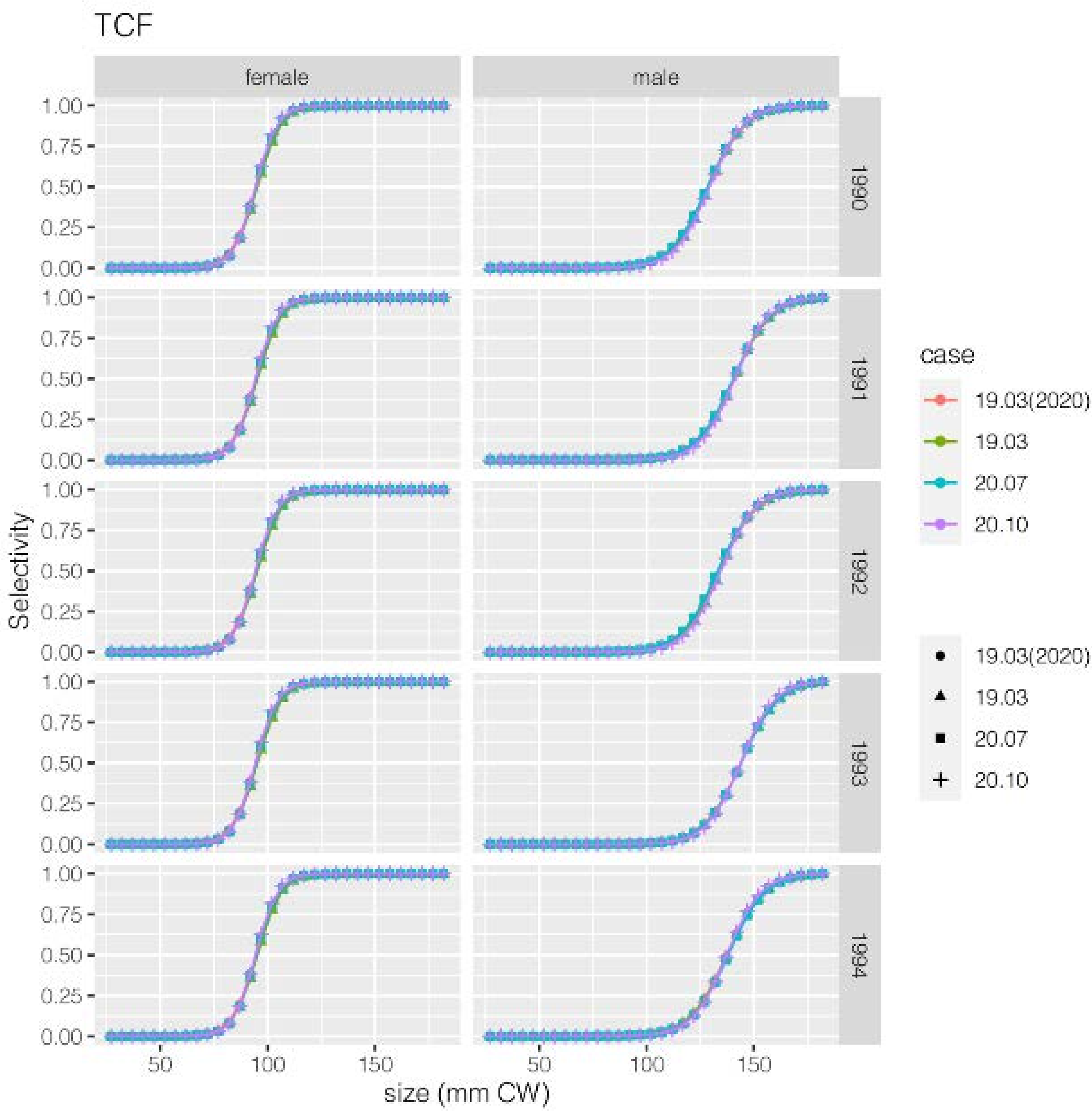

Figure 37. Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

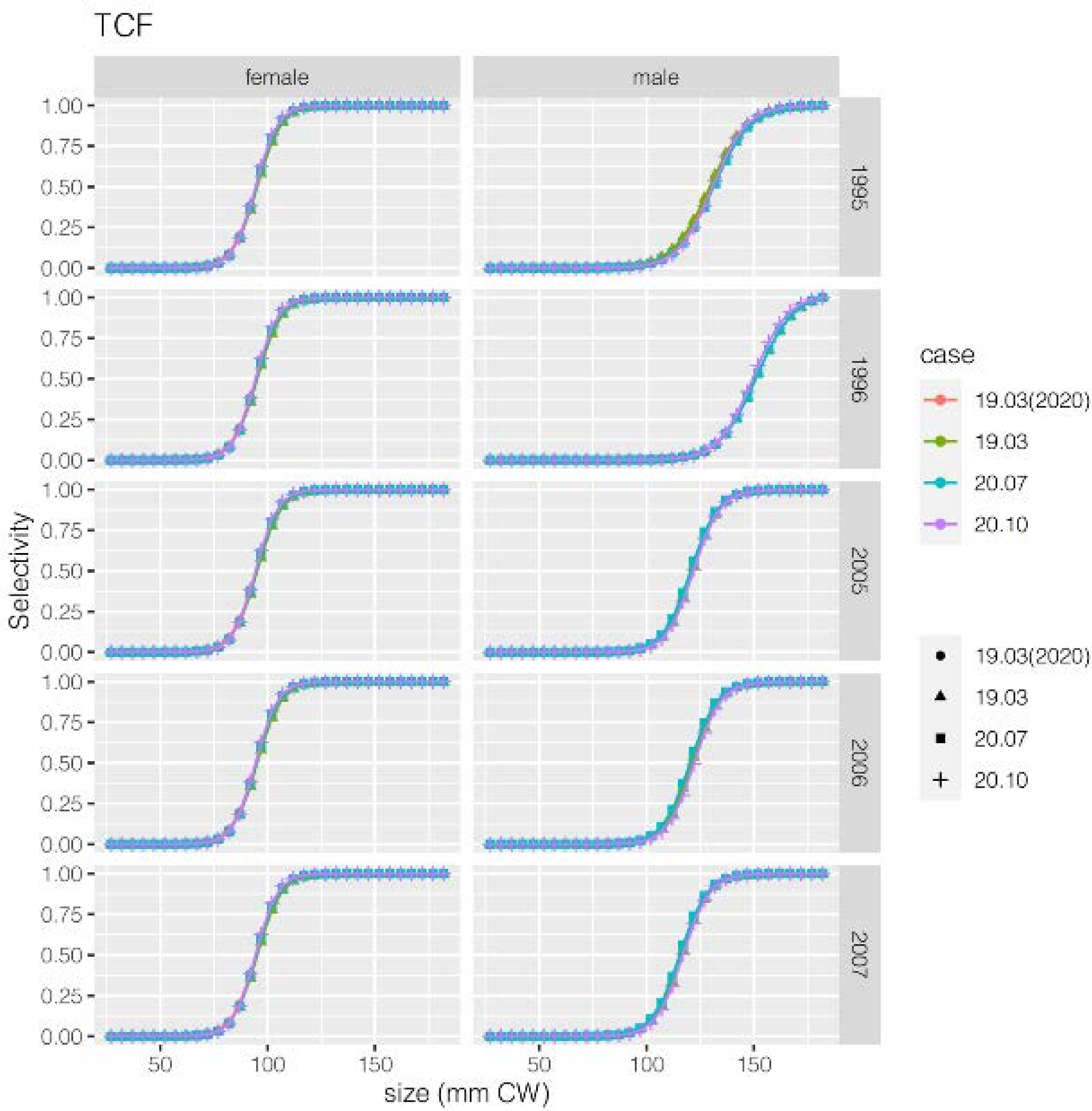

Figure 37 (cont.). Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

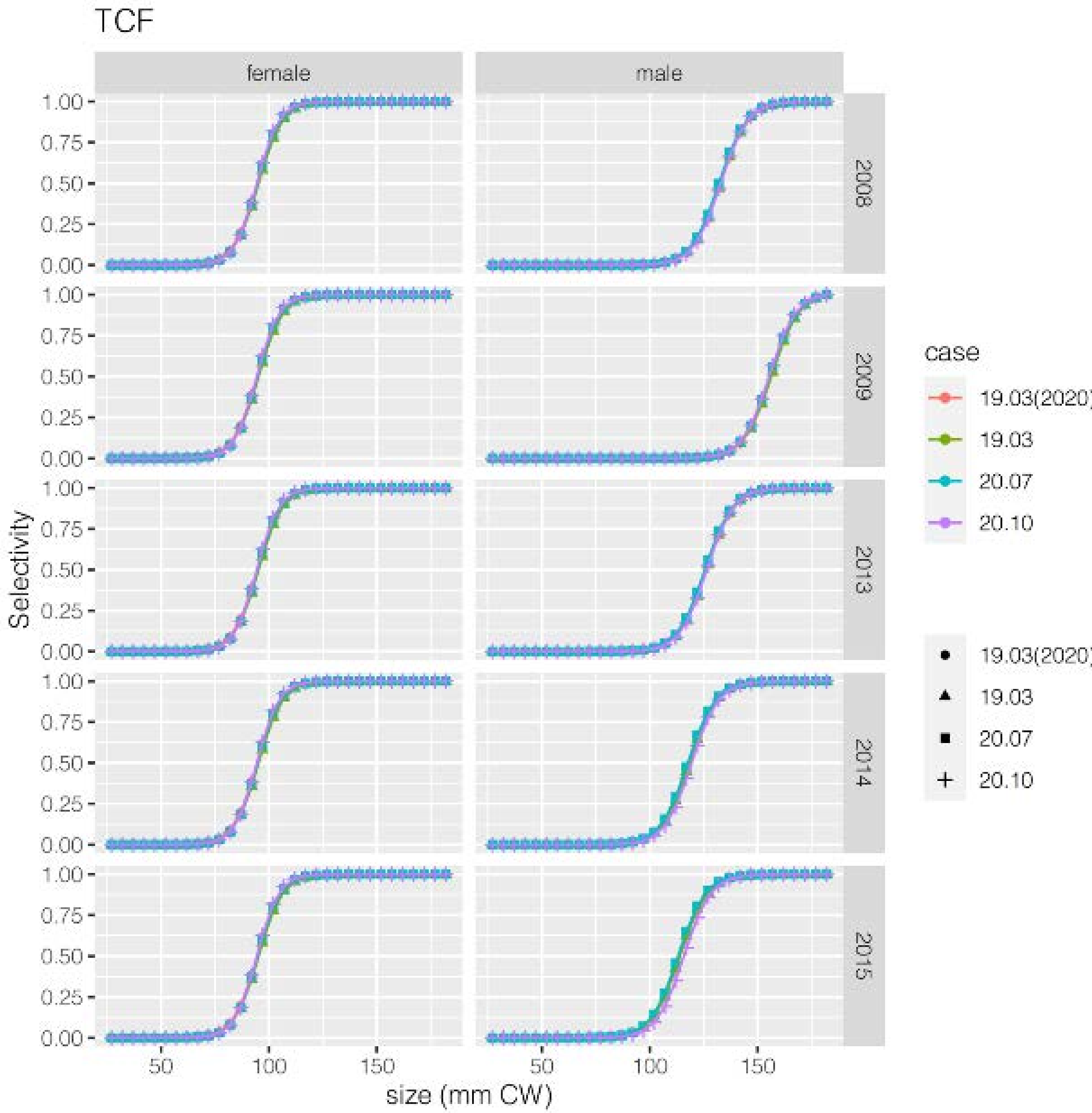

Figure 37 (cont.). Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

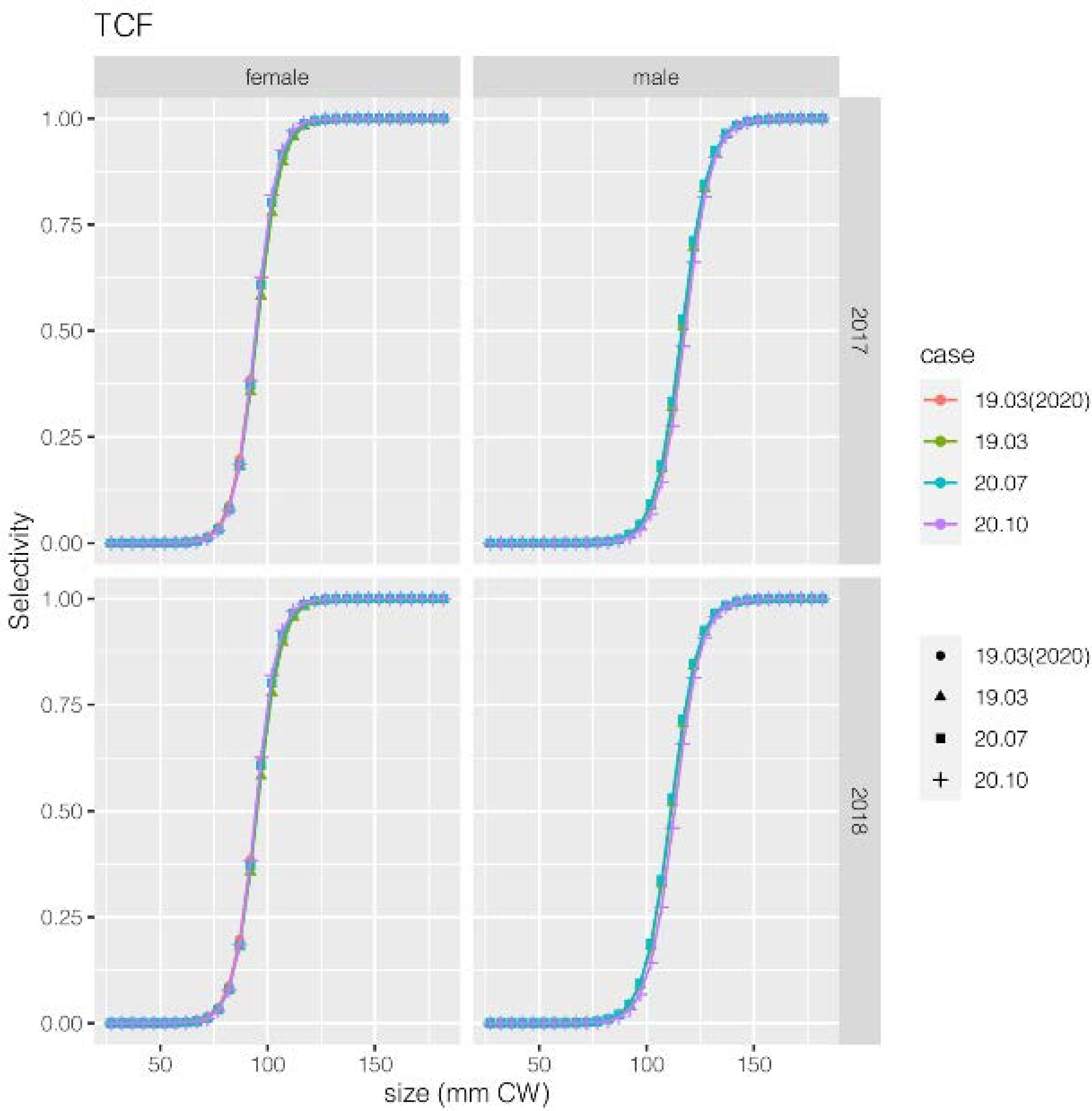

Figure 37 (cont.). Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

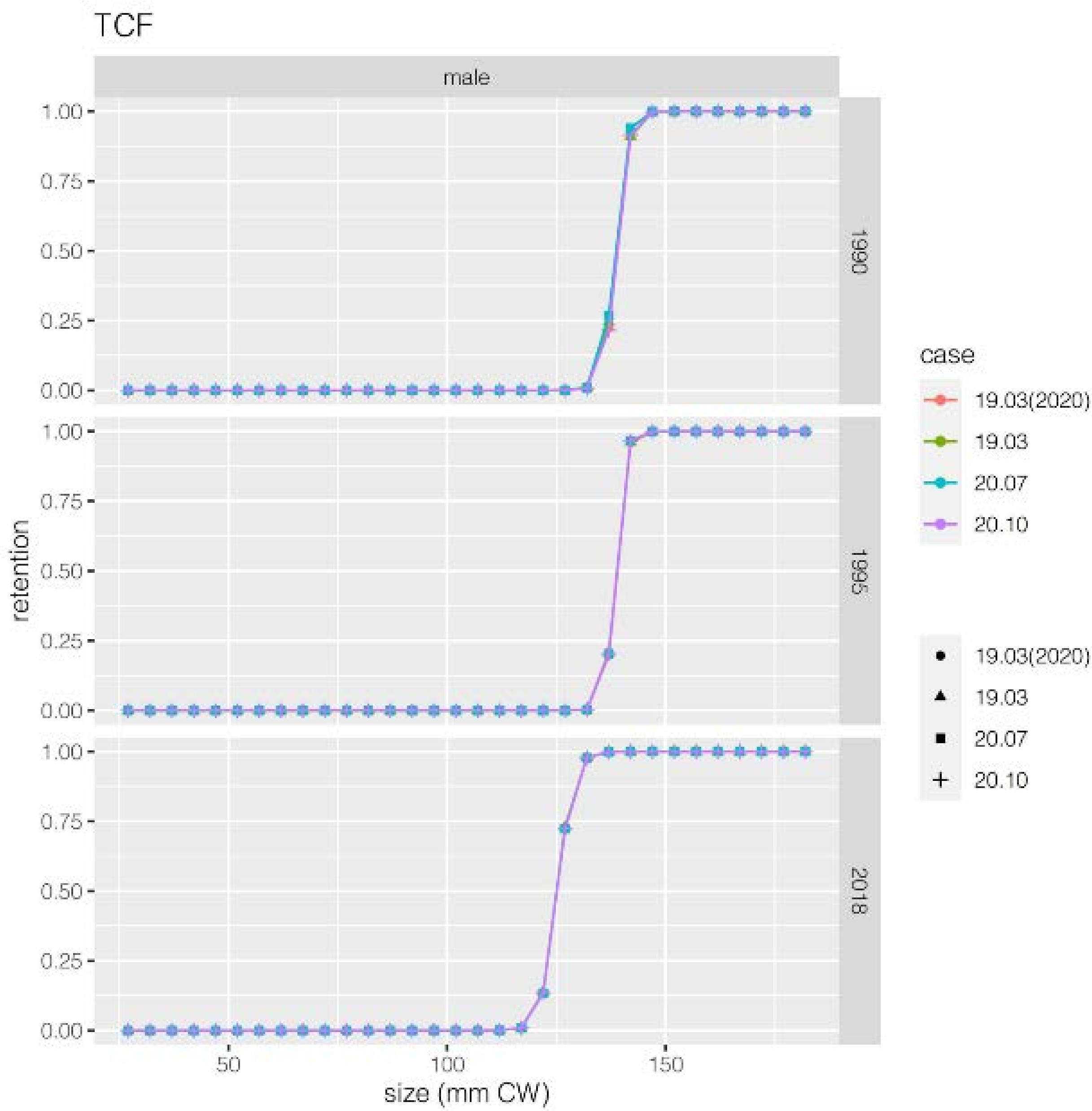

Figure 38. Directed fishery retention curves from all scenarios for the pre-1991, 1991-1996, and post-2004 time periods.

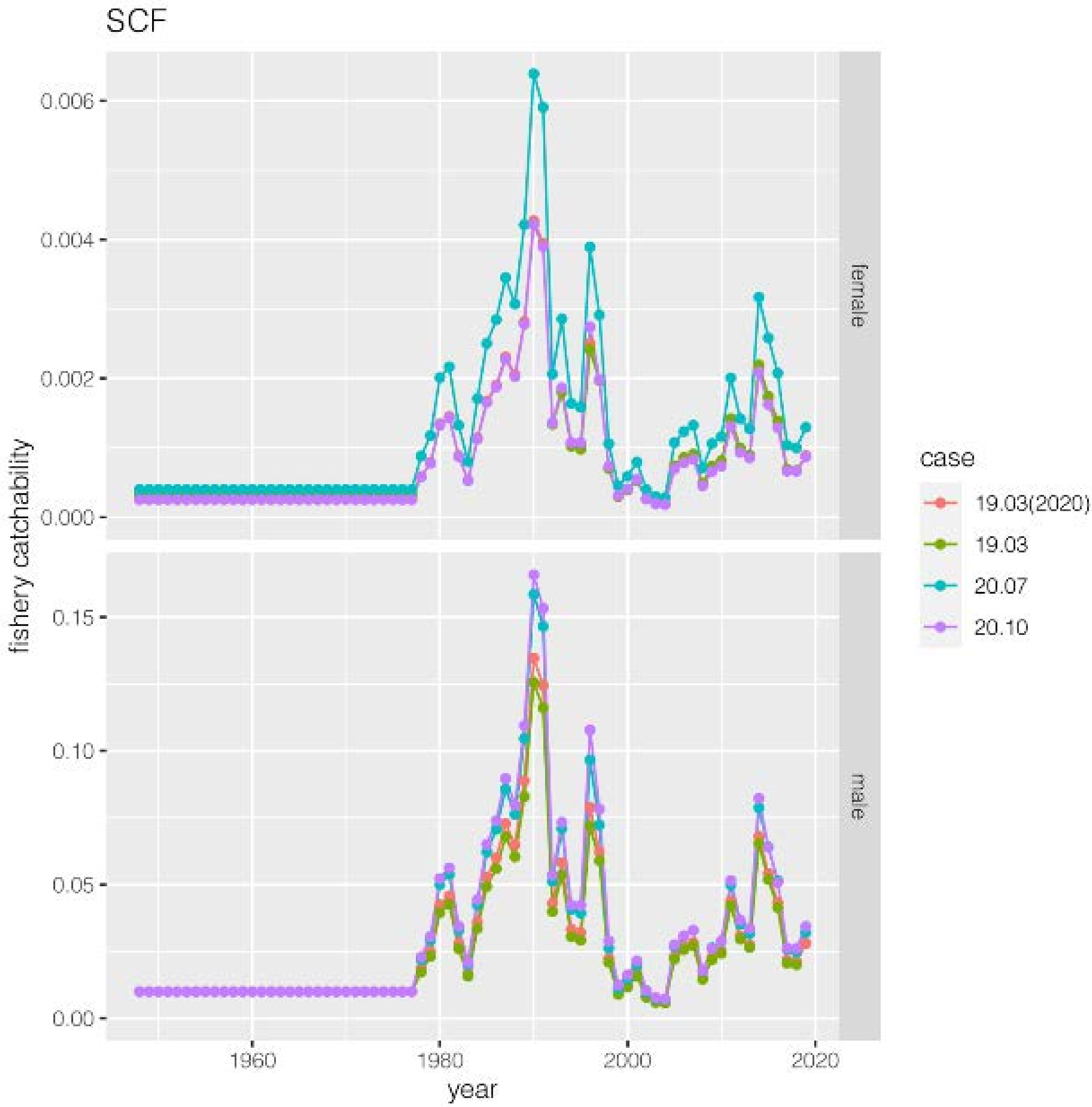

Figure 39. Snow crab fishery catchability (capture rates) from all scenarios.

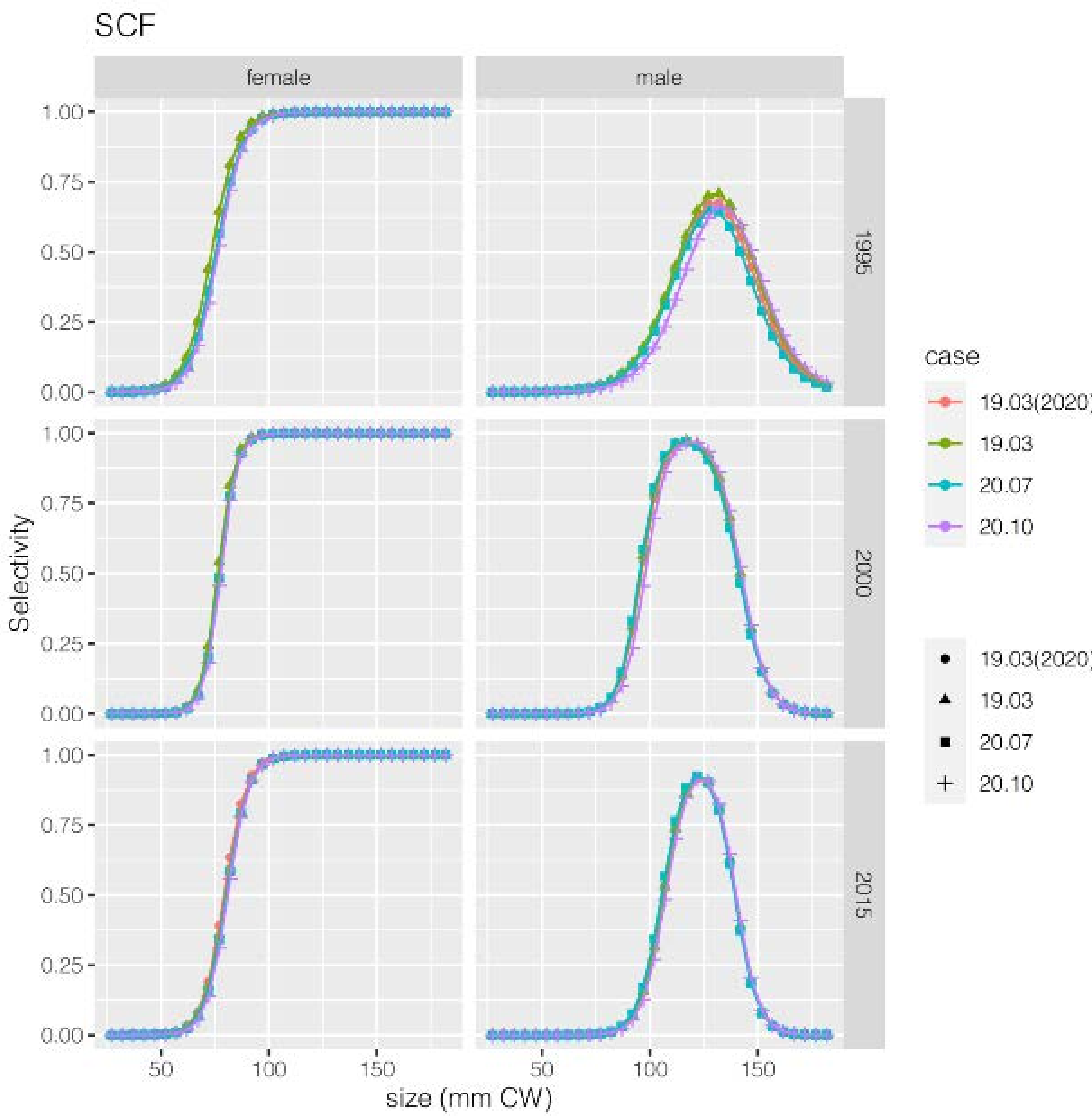

Figure 40. Snow crab fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

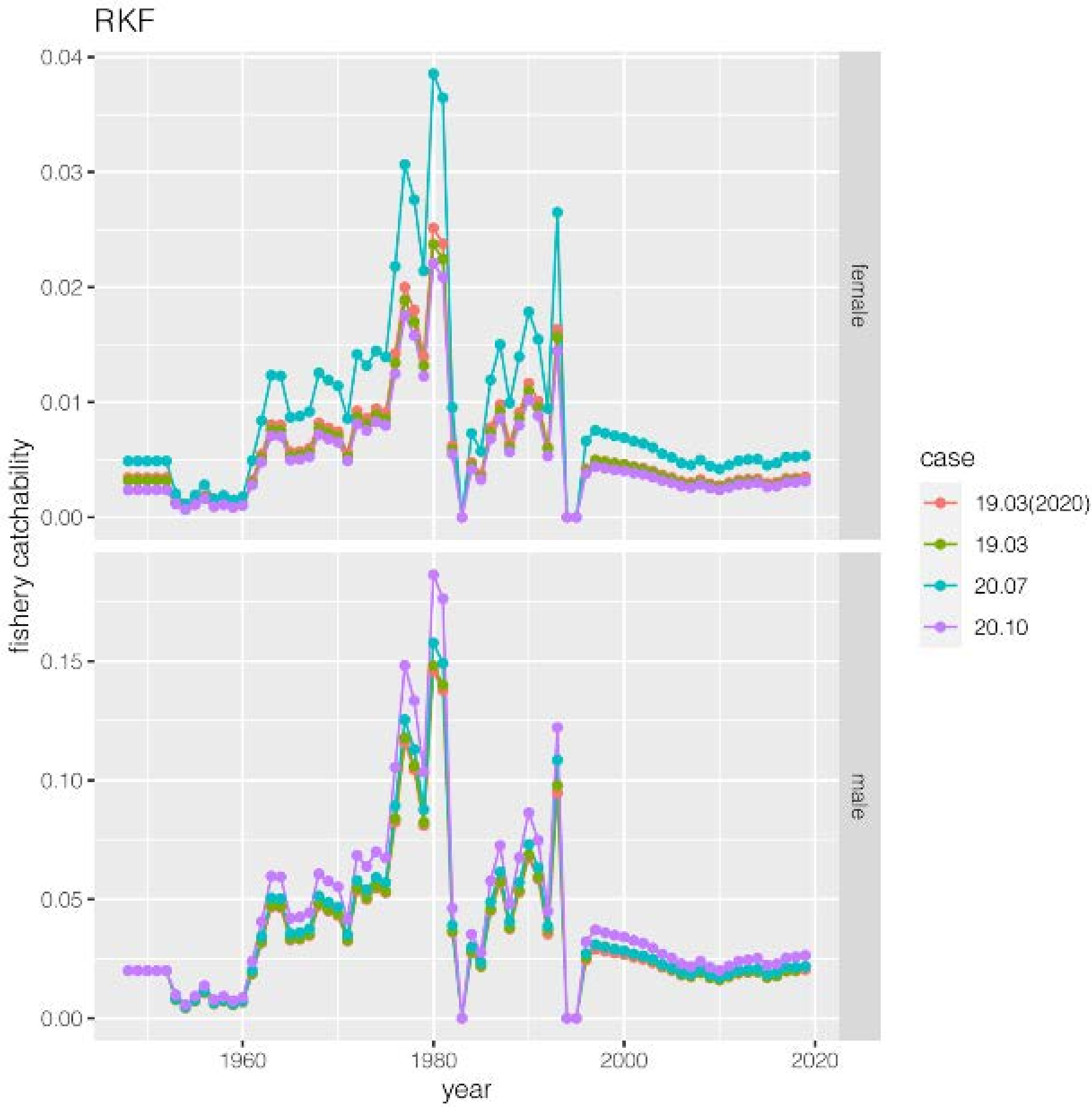

Figure 41. BBRKC fishery catchability (capture rates) from all scenarios.

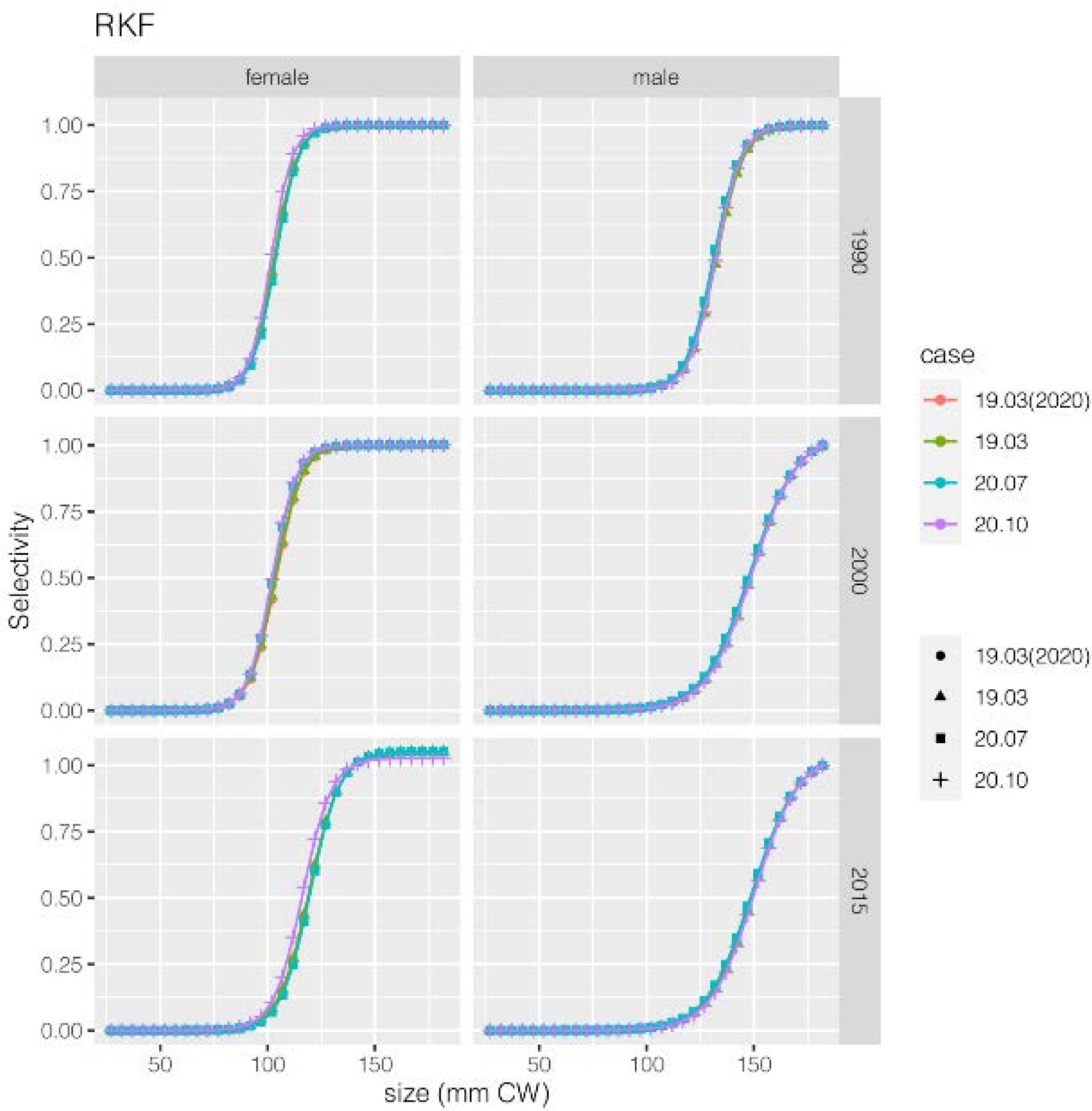

Figure 42. BBRKC fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

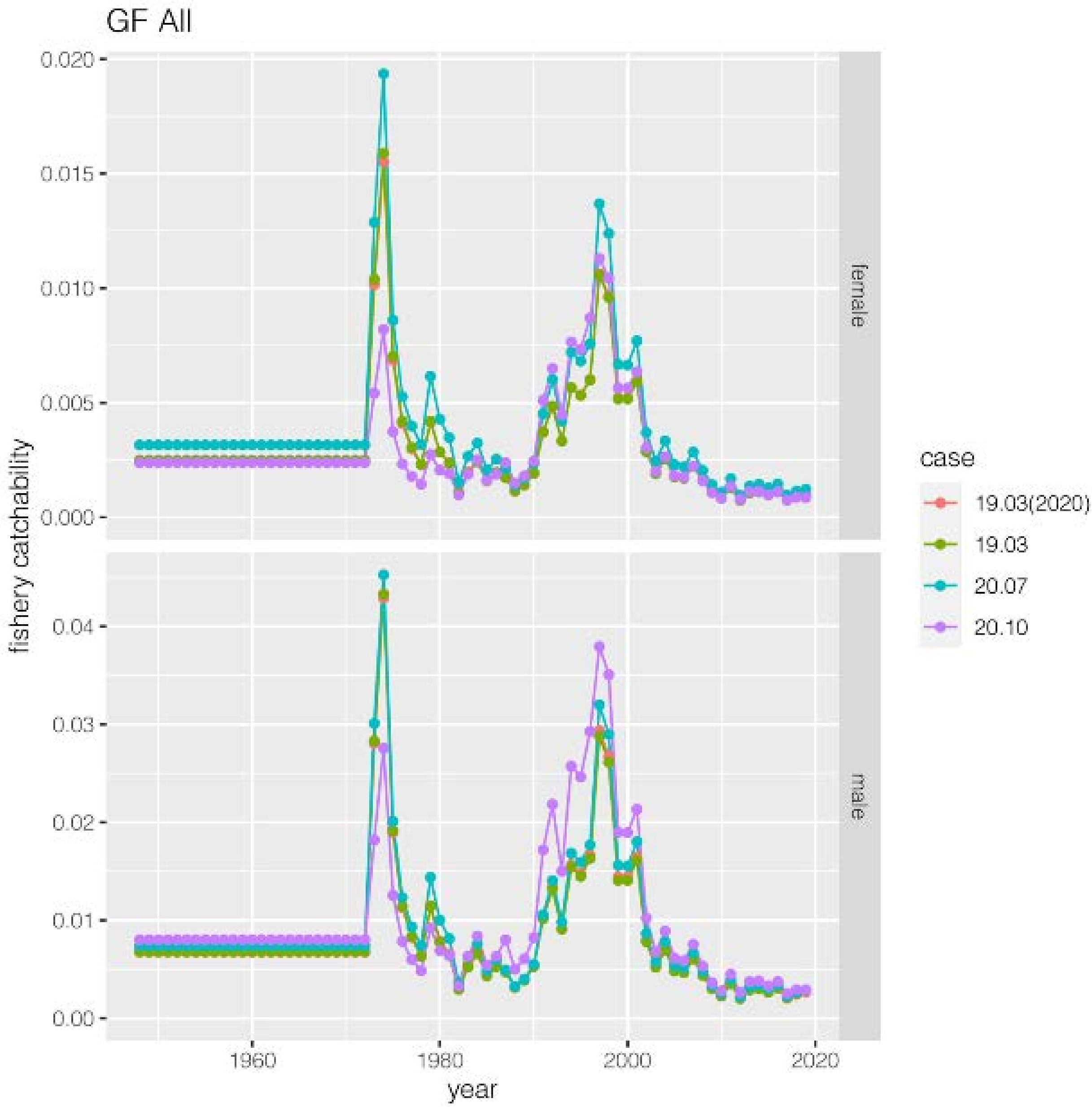

Figure 43. Catchability (capture rates) in the groundfish fisheries from all scenarios.

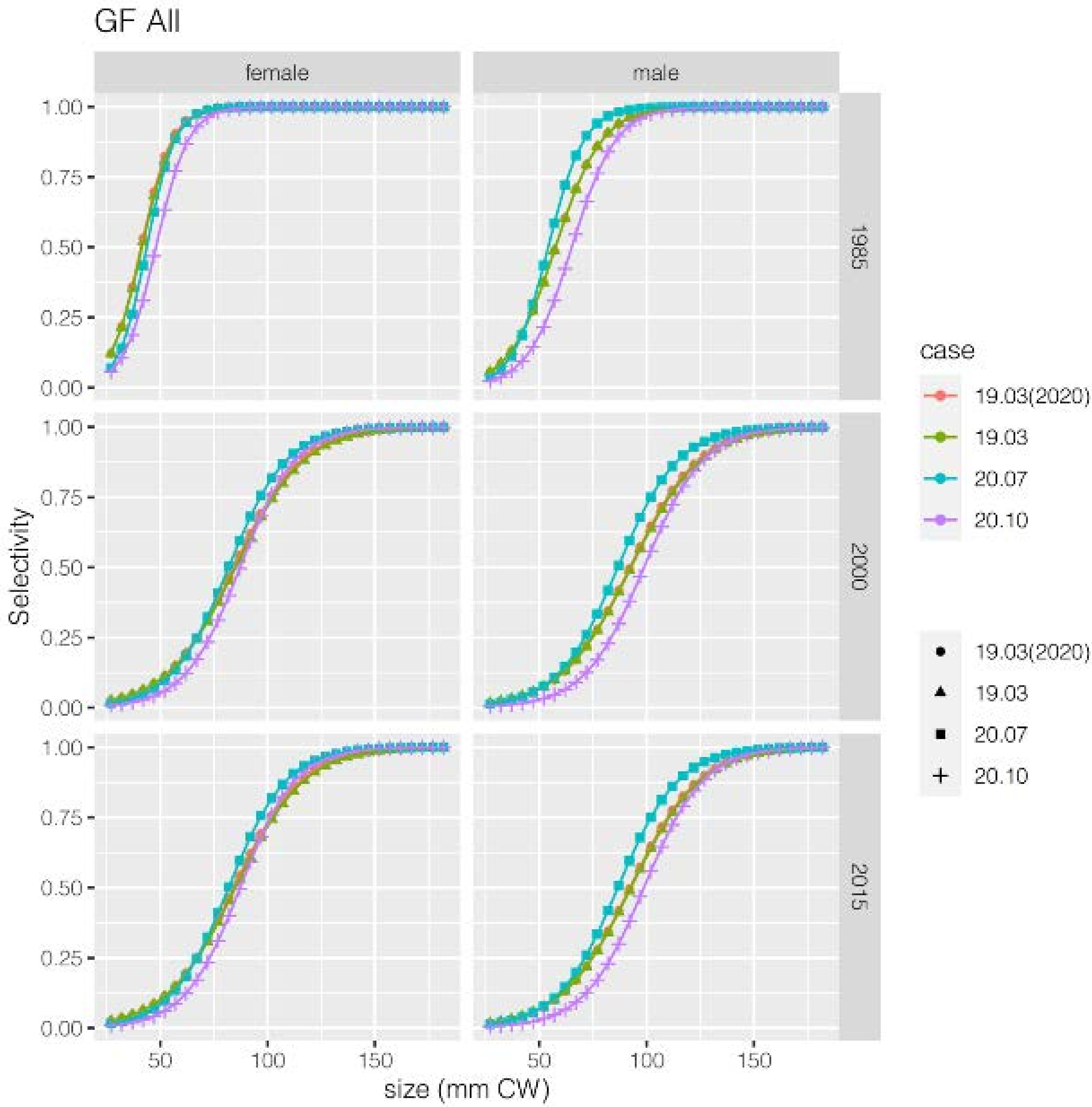

Figure 44. Groundfish fisheries selectivity curves from all scenarios estimated for 3 time periods: pre-1997, 1997-2004, 2005+.

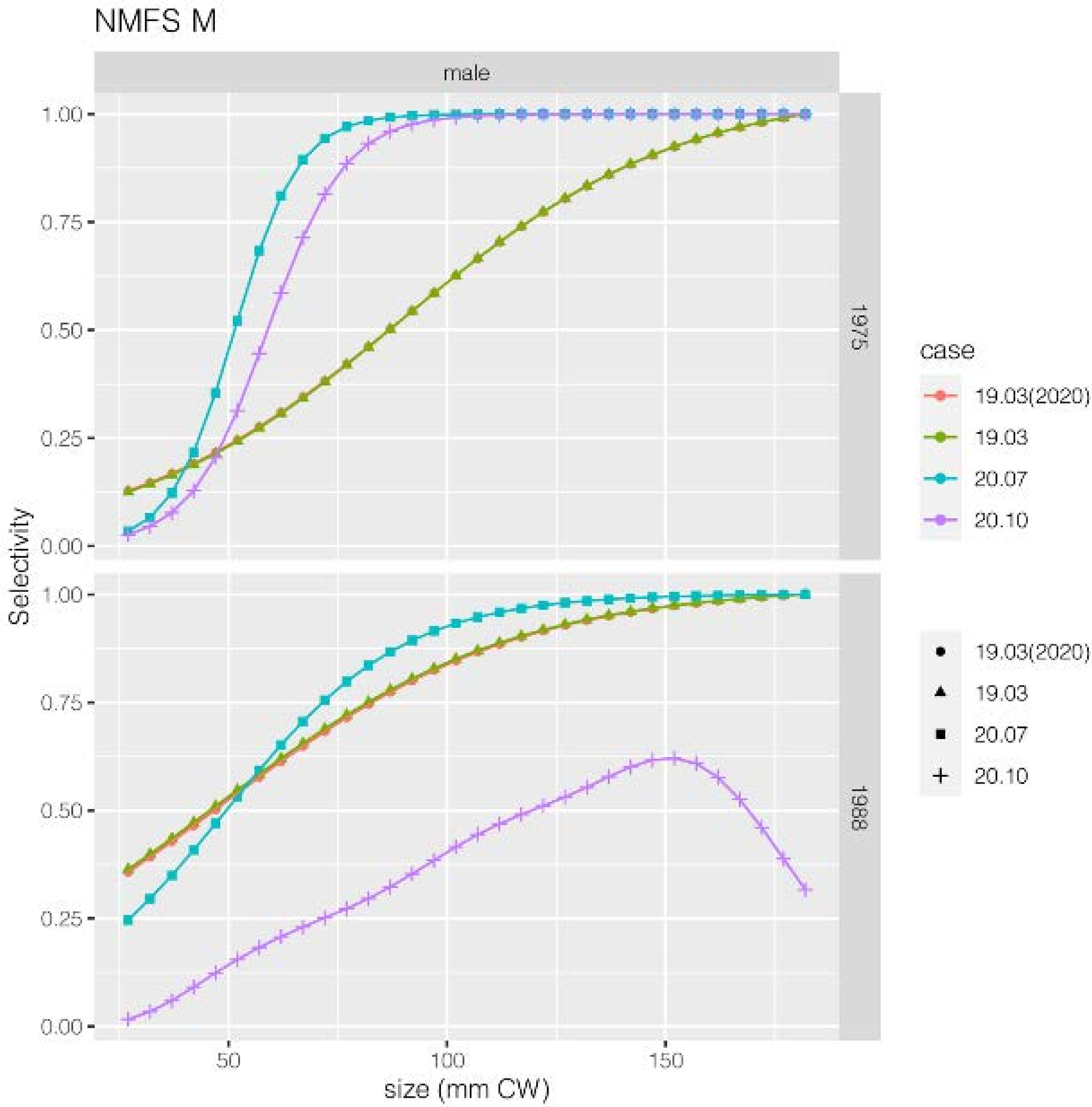

Figure 45. NMFS survey selectivity functions for males from all scenarios for the 1975-1981 and 1982+ time periods.

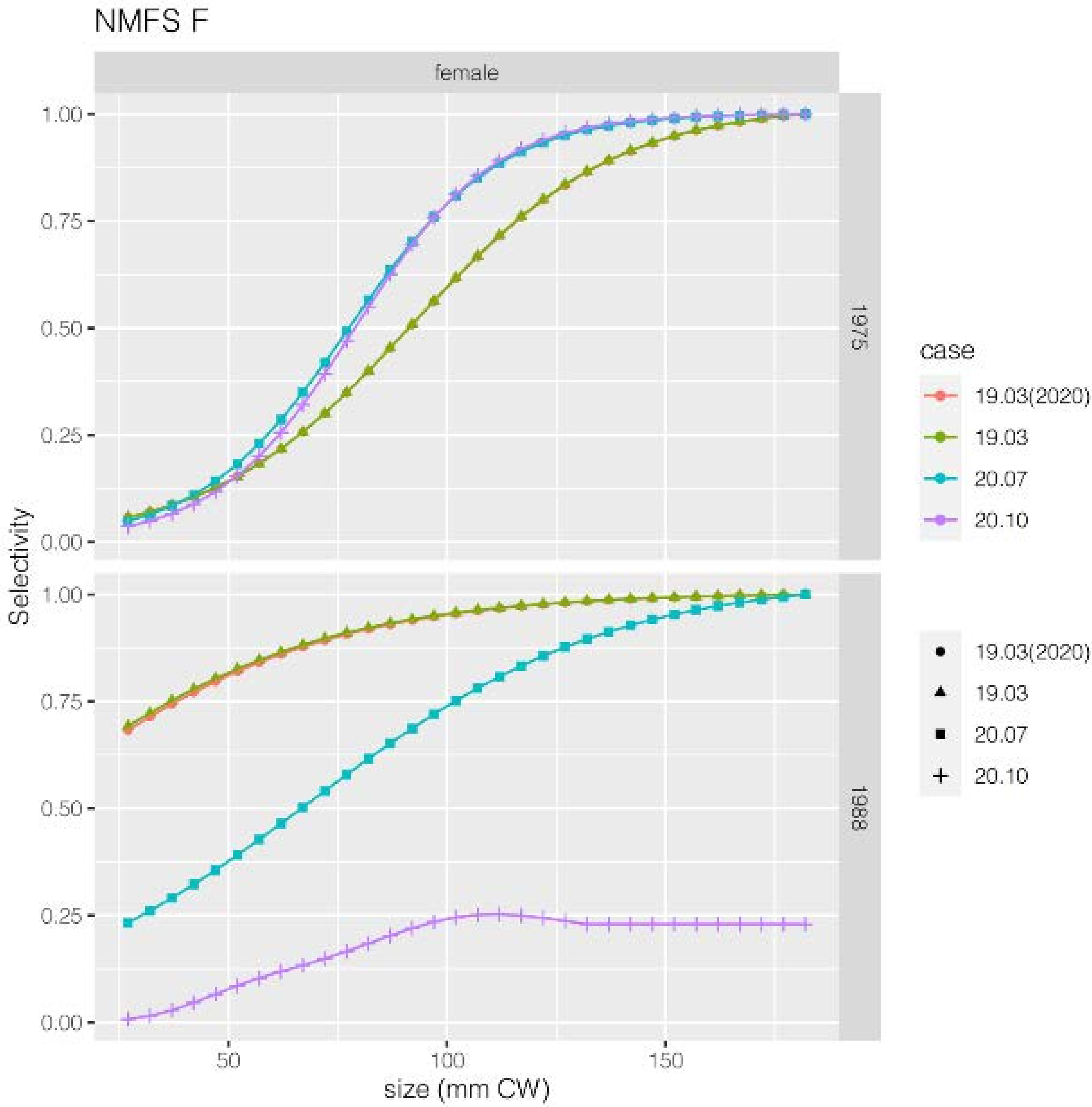

Figure 46. NMFS survey selectivity functions for females from all scenarios for the 1975-1981 and 1982+ time periods.

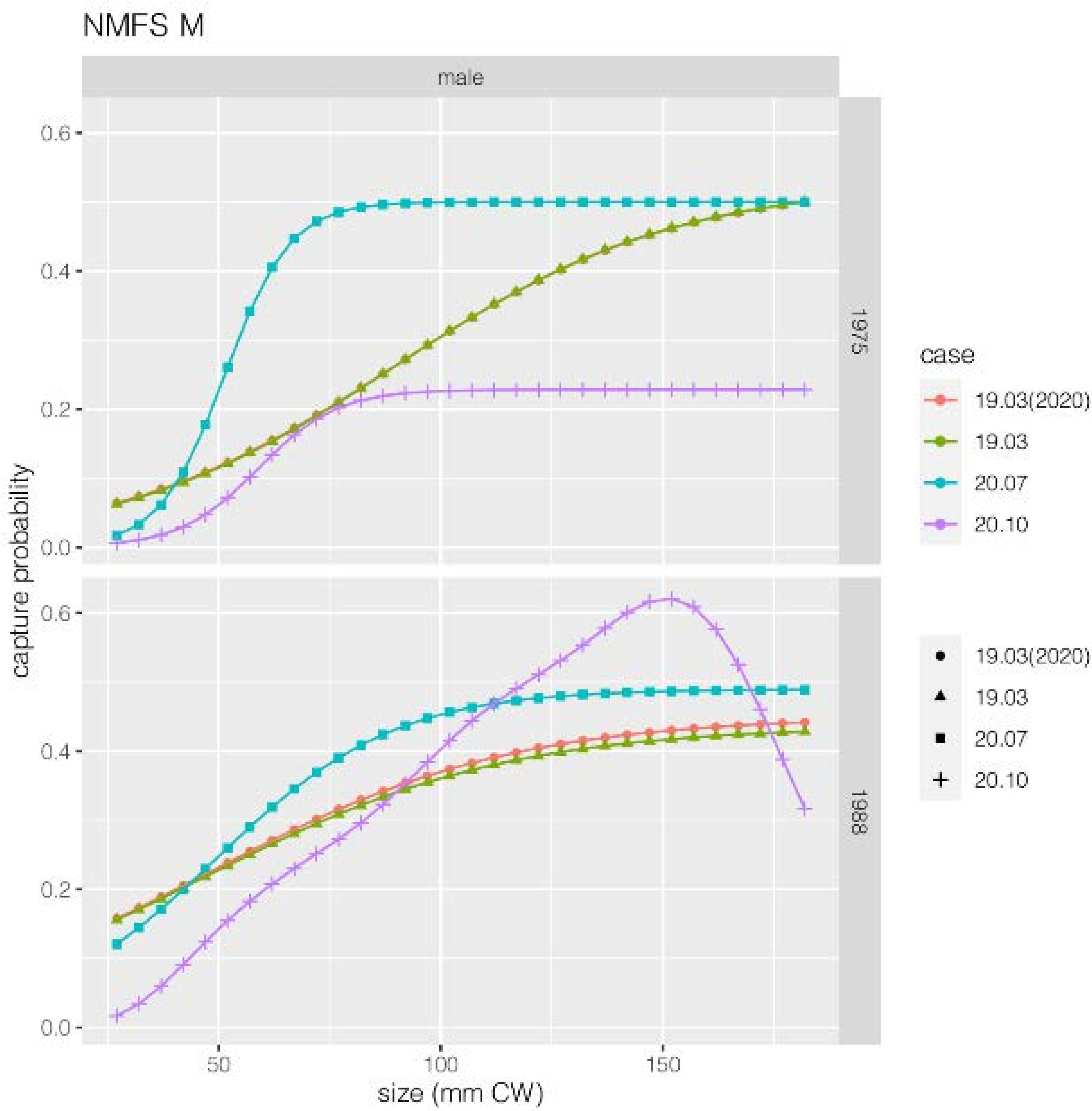

Figure 47. NMFS survey capture probabilities (fully-selected catchability x selectivity) for males from all scenarios for the 1975-1981 and 1982+ time periods.

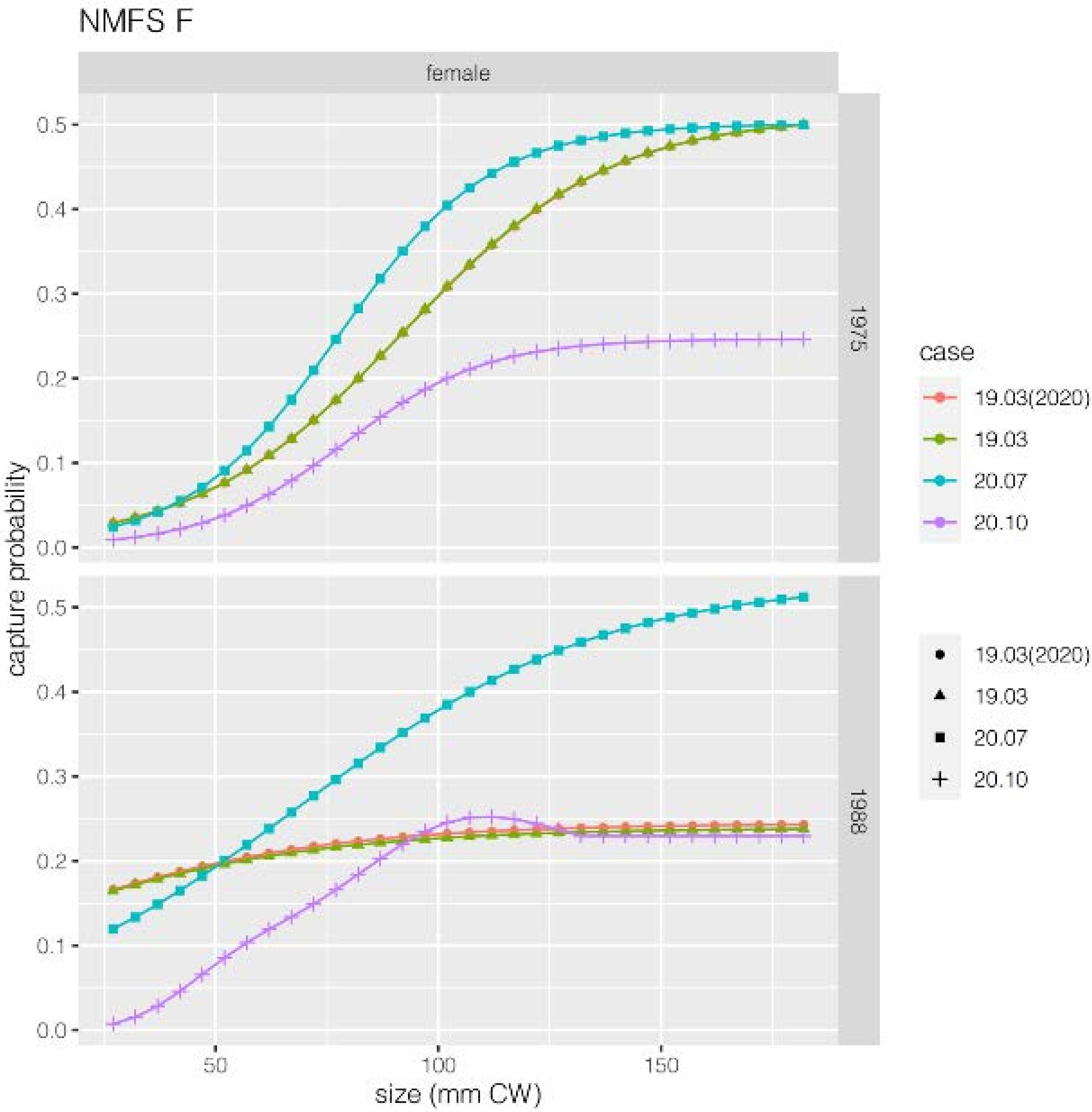

Figure 48. NMFS survey capture probabilities (fully-selected catchability x selectivity) for females from all scenarios for the 1975-1981 and 1982+ time periods.

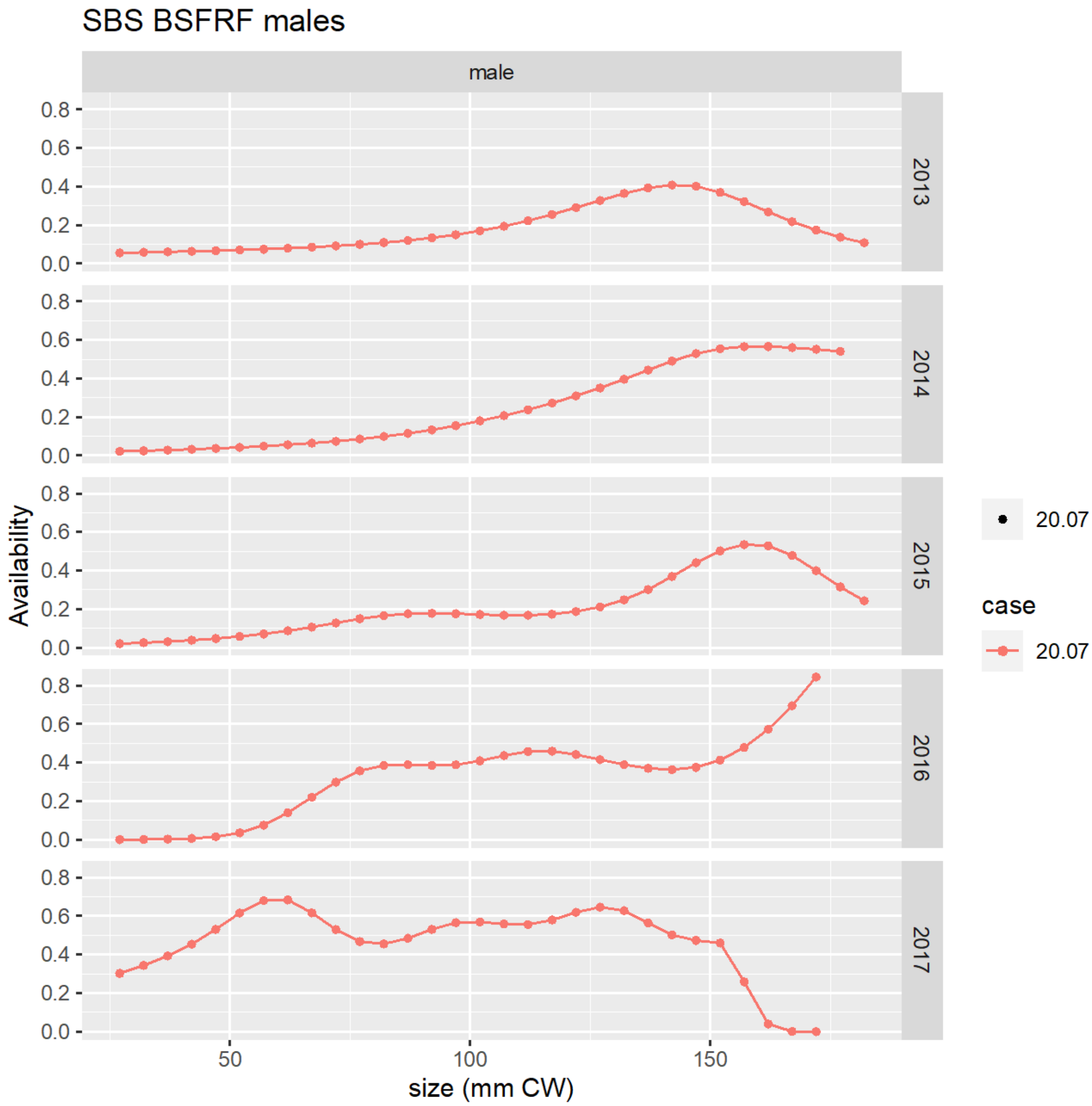

Figure 49. Annual availability functions for males in the BSFRF SBS surveys, for scenarios that include BSFRF SBS data. Availability functions were determined outside the model for Scenario 20.07.

Figure 50. Annual availability functions for females in the BSFRF SBS surveys, for scenarios that include BSFRF SBS data. Availability functions were determined outside the model for Scenario 20.07.

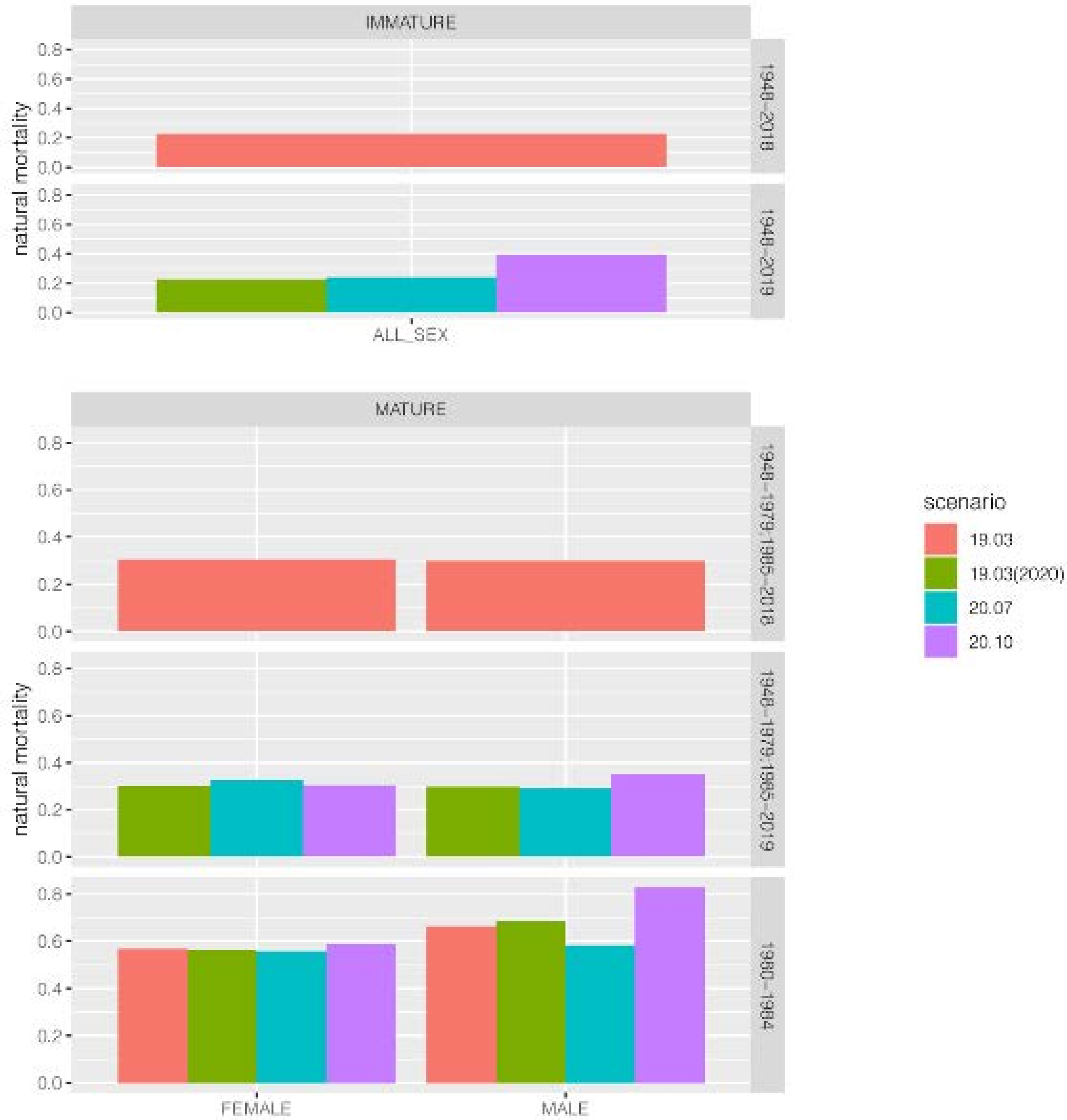

Figure 51. Estimates of natural mortality from all scenarios.

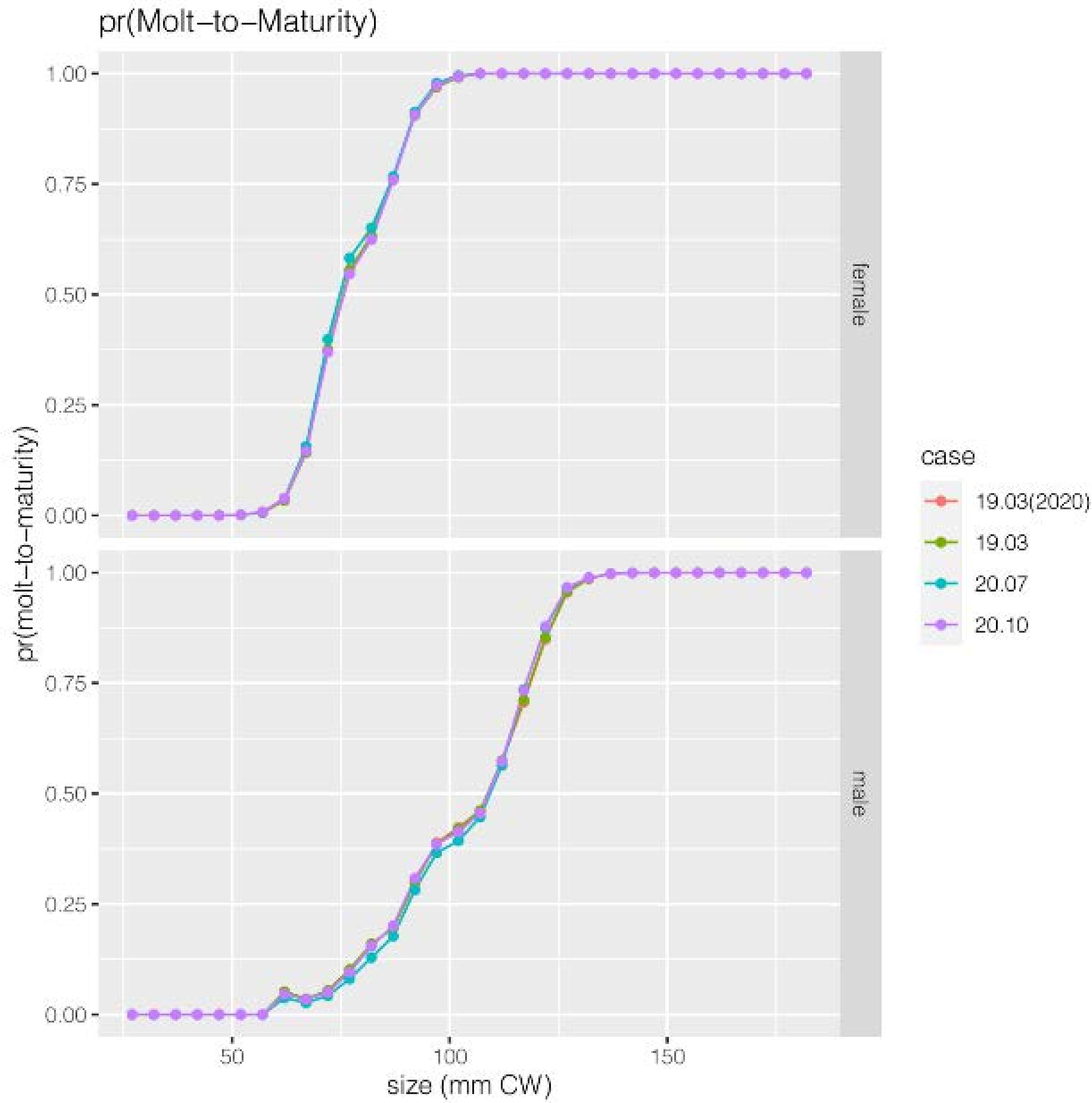

Figure 52. Estimates of the probability of terminal molt from all scenarios.

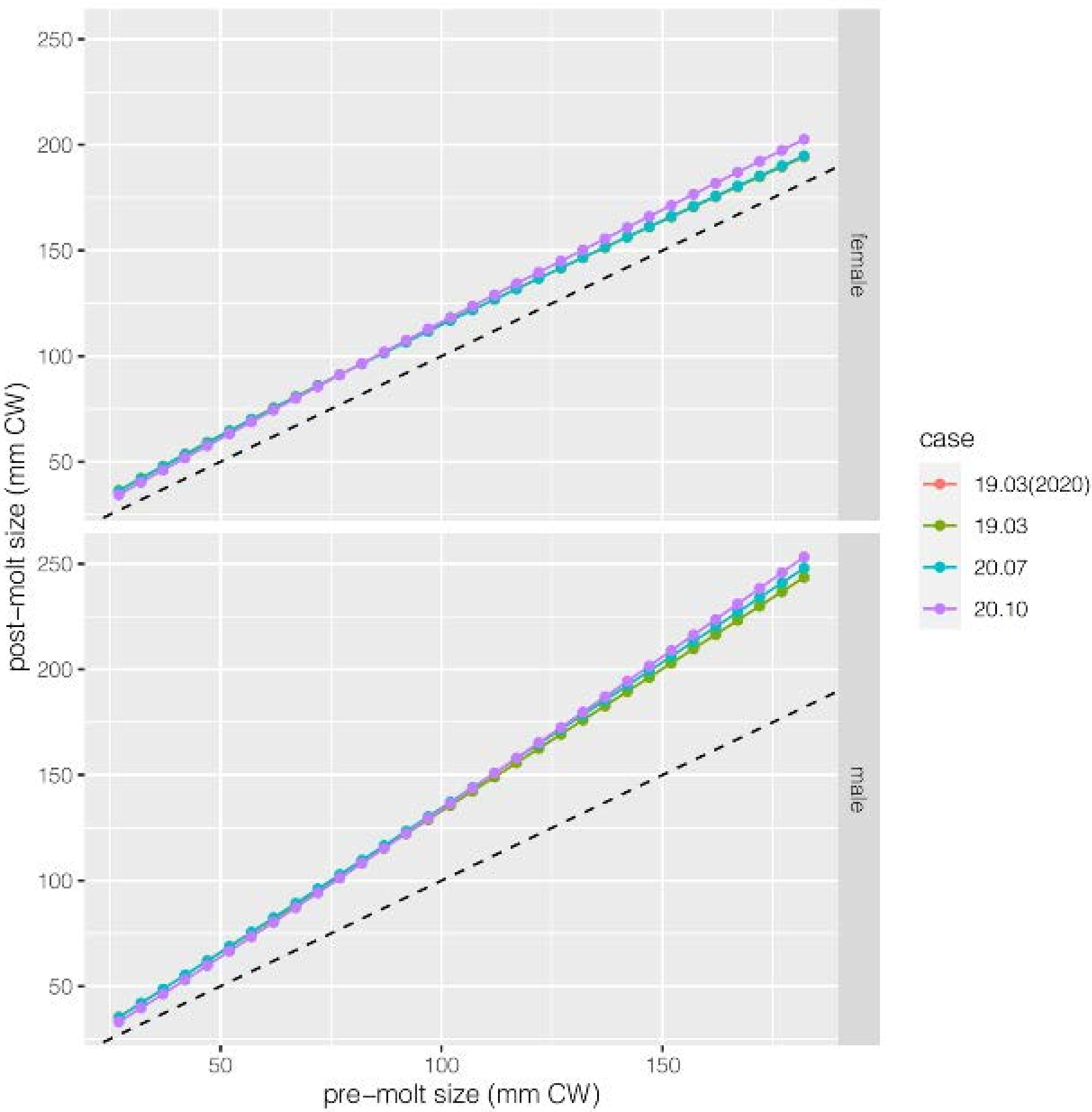

Figure 53. Estimates of mean growth from all scenarios. Dashed line is 1:1.

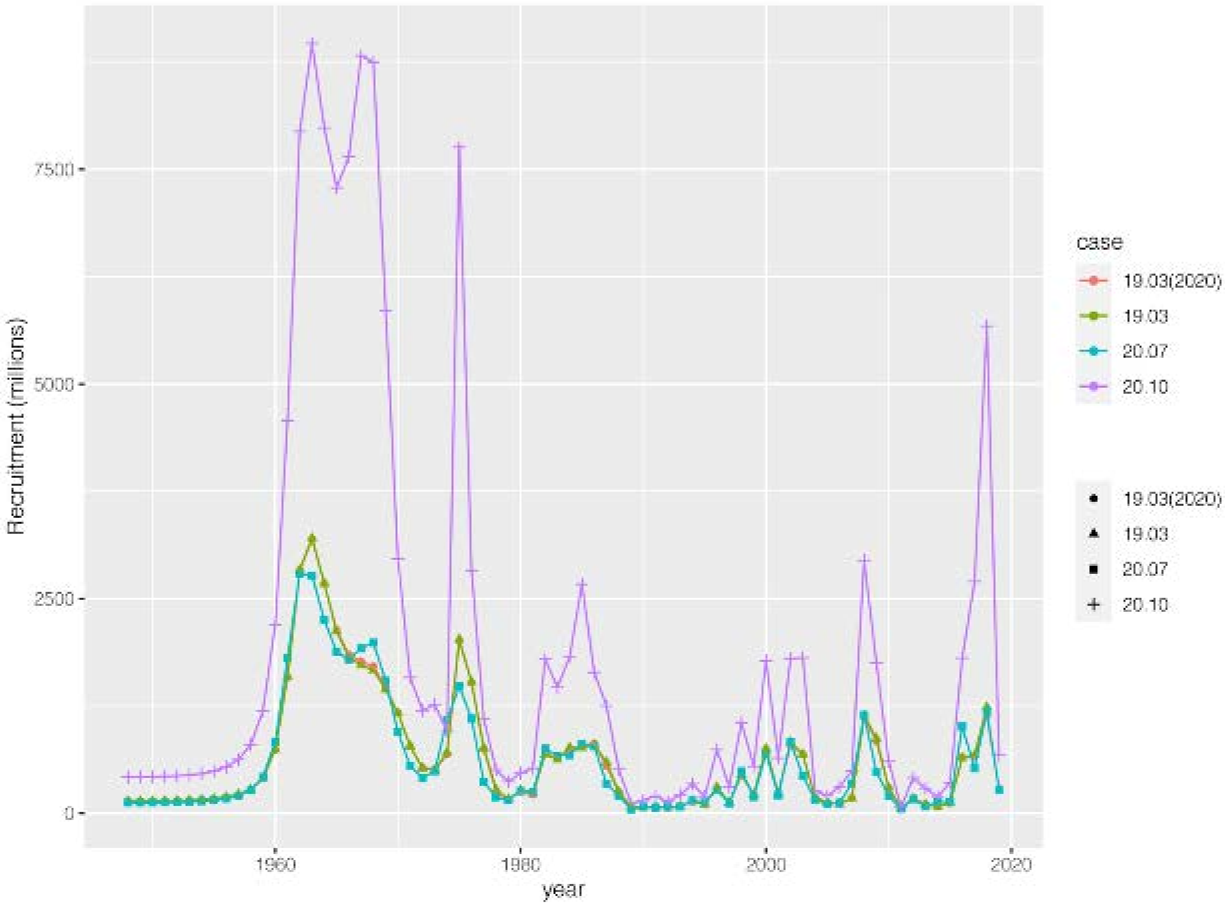

Figure 54. Estimated recruitment time series from all scenarios.

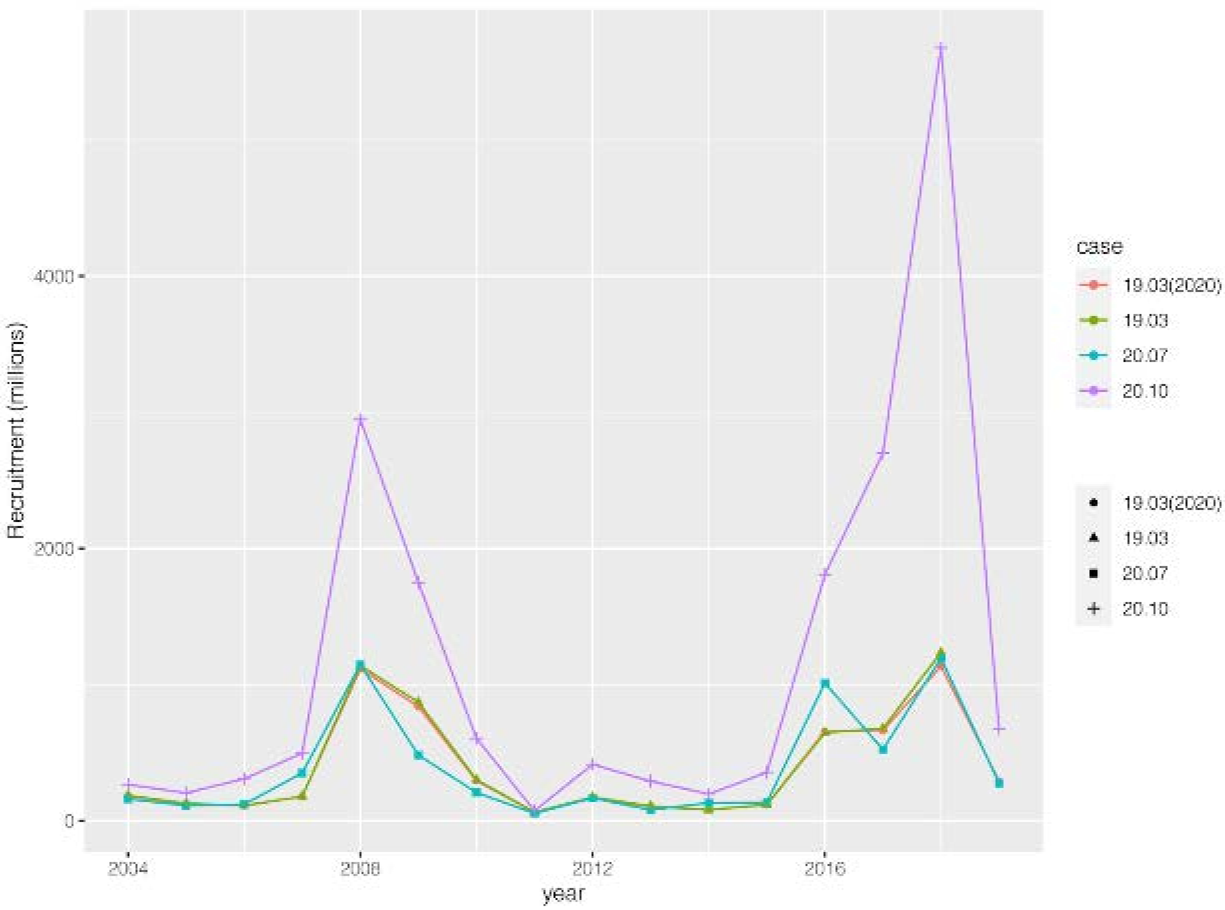

Figure 55. Estimated recent recruitment time series from all scenarios.

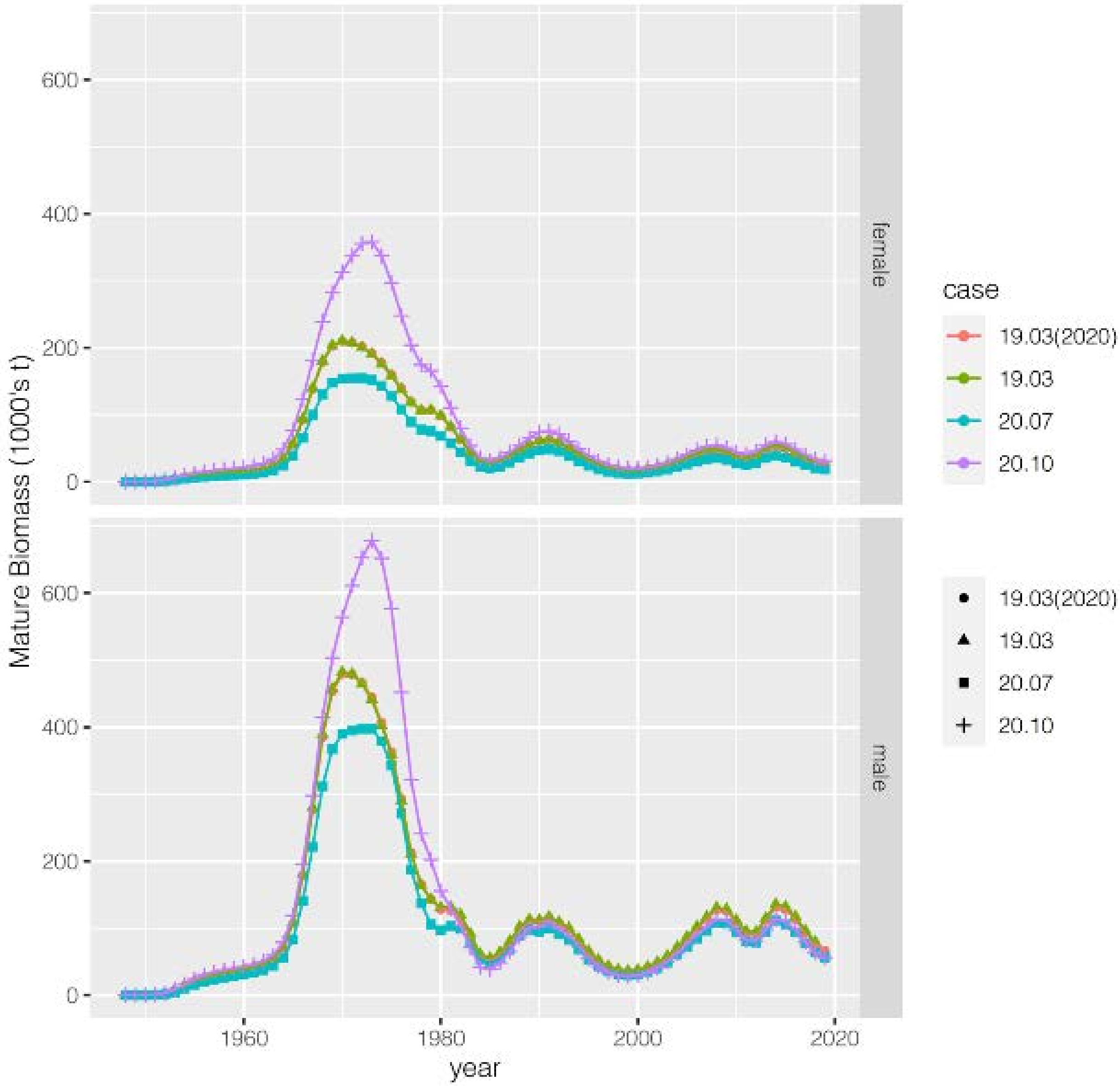

Figure 56. Estimated (Feb. 15) mature biomass time series from all scenarios.

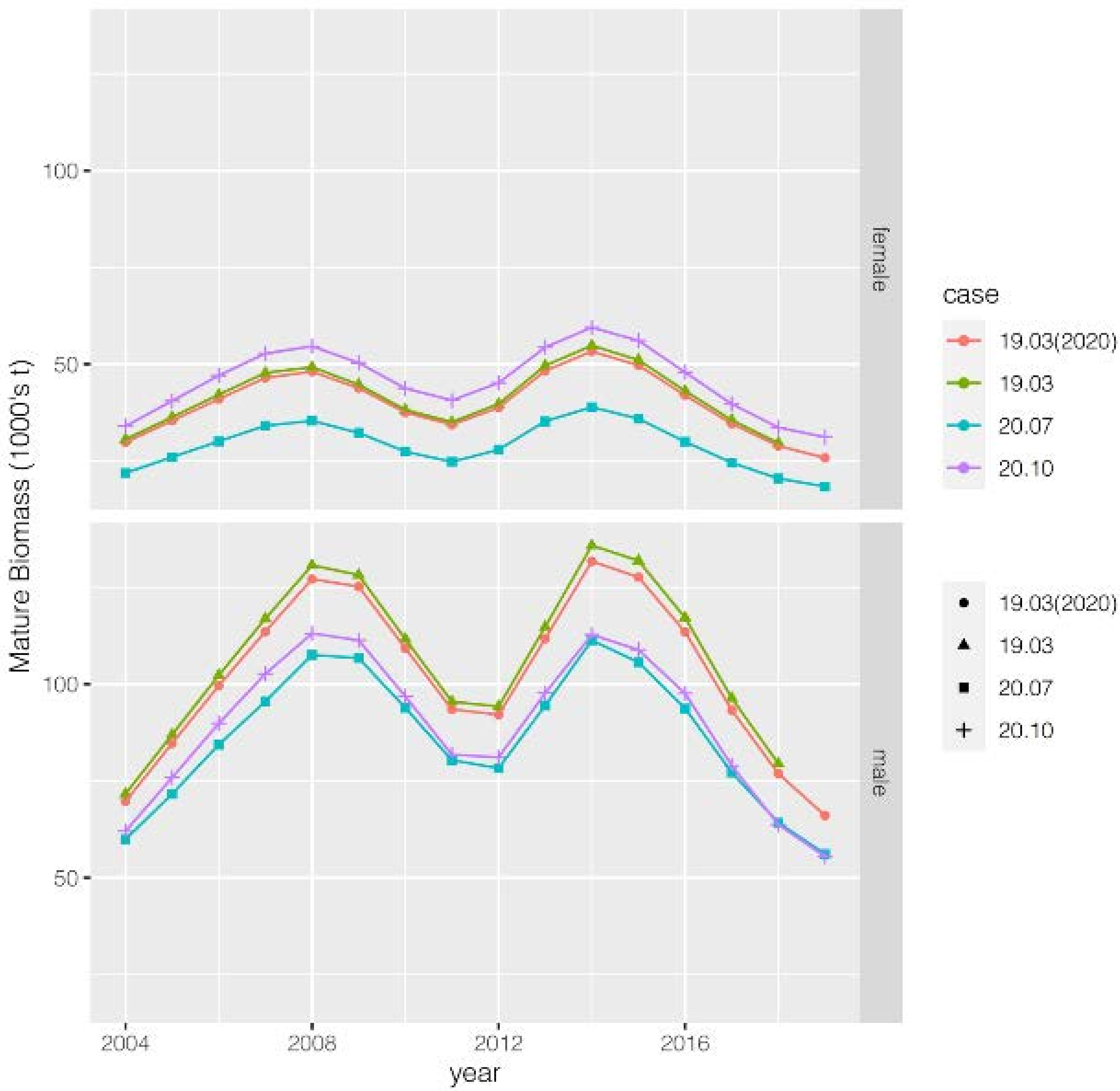

Figure 57. Estimated recent (Feb. 15) mature biomass time series from all scenarios.

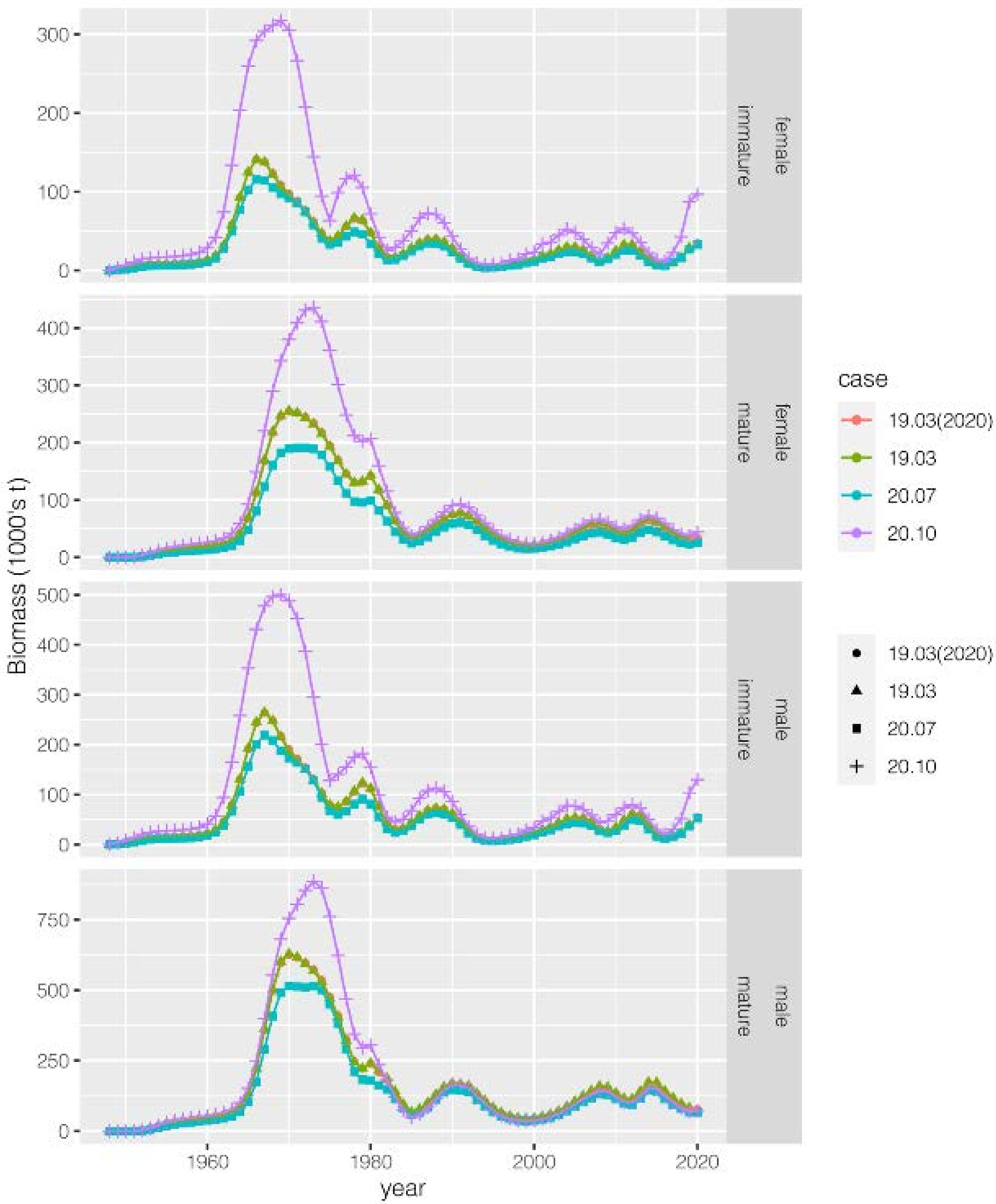

Figure 58. Estimated biomass (on July 1) time series by population category for all scenarios.

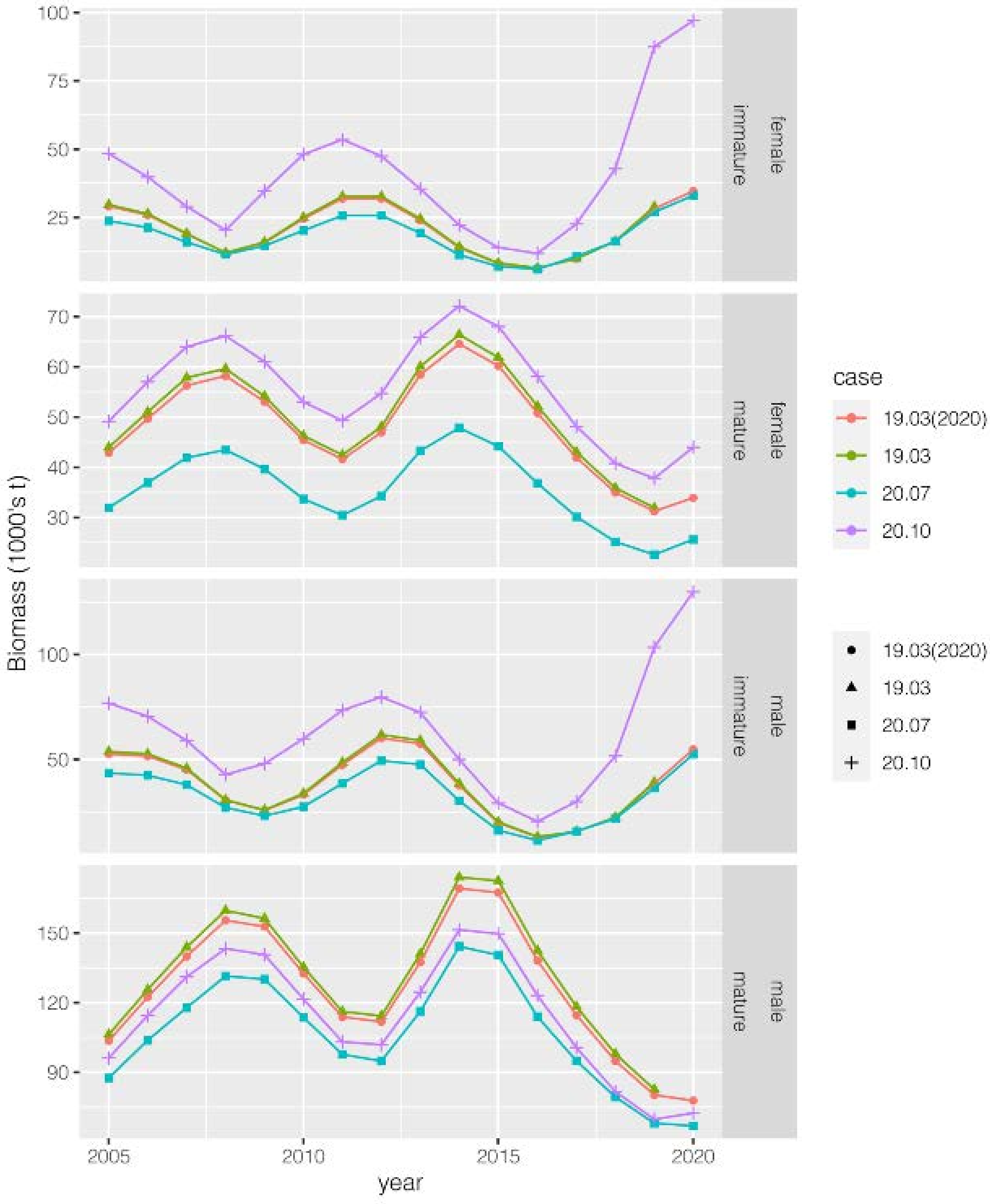

Figure 59. Estimated recent biomass (on July 1) time series by population category for all scenarios.

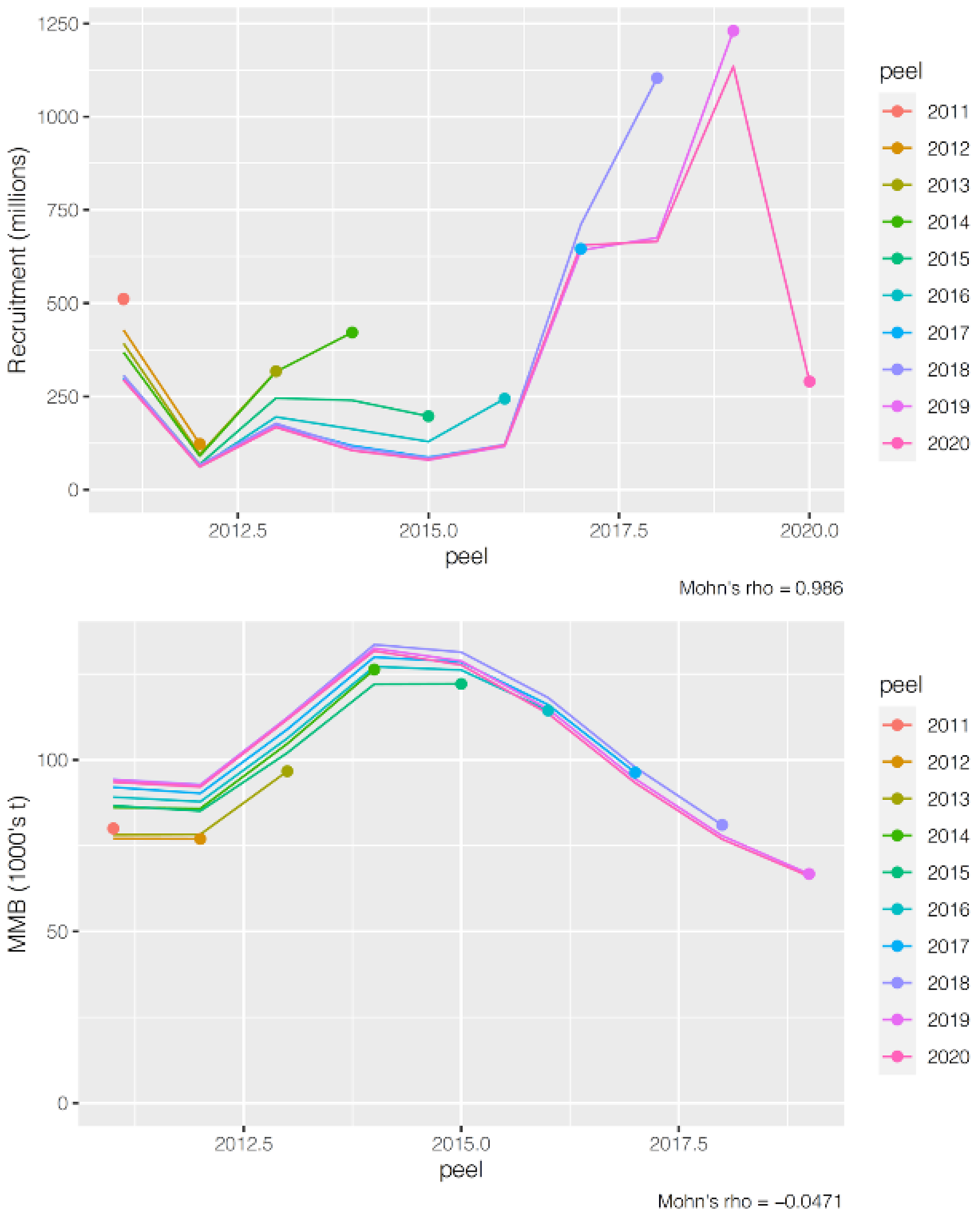

Figure 60. Retrospective patterns for Scenario 19.03(2020). Upper: recruitment. Lower: MMB.

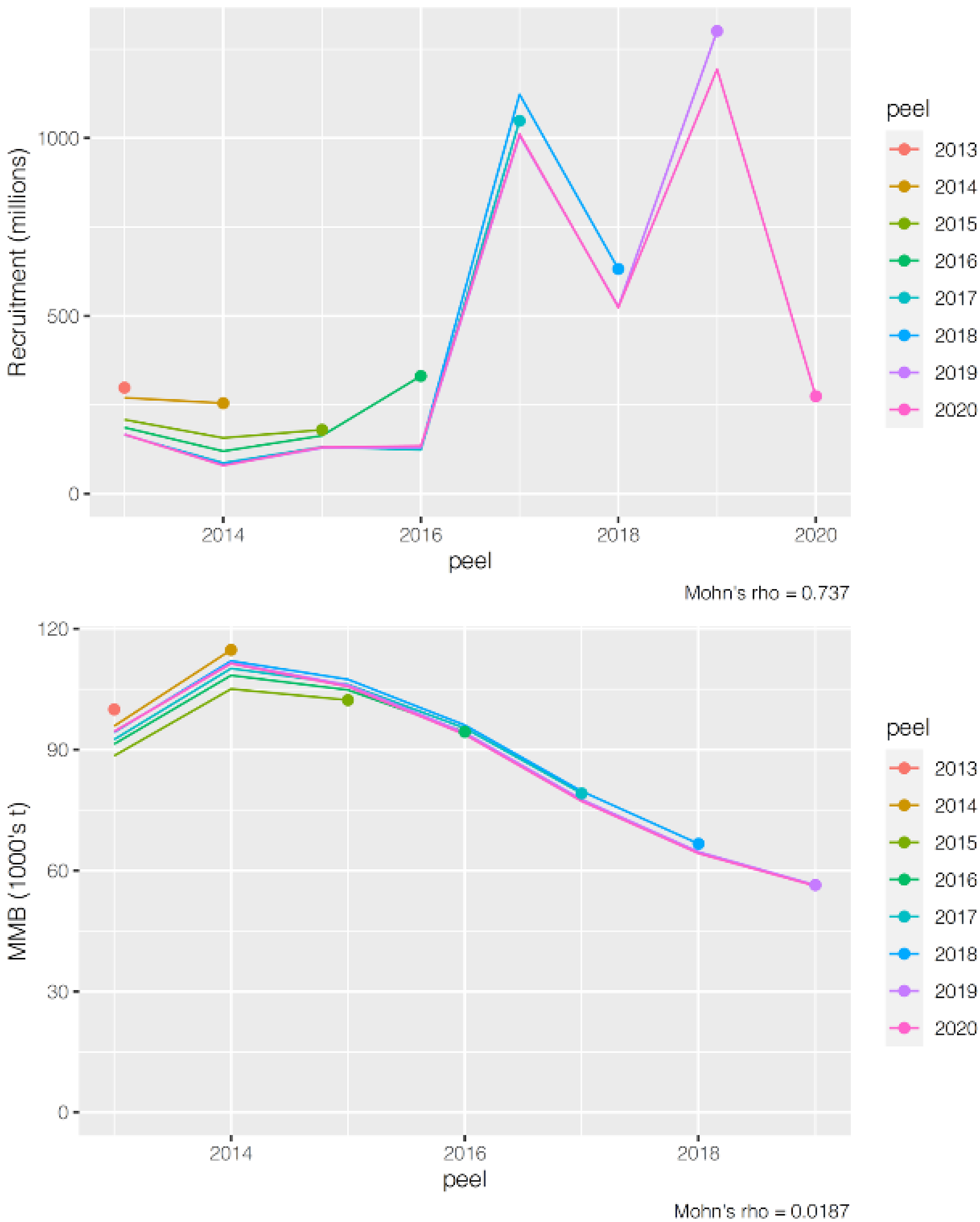

Figure 61. Retrospective patterns for Scenario 20.10. Upper: recruitment. Lower: MMB.

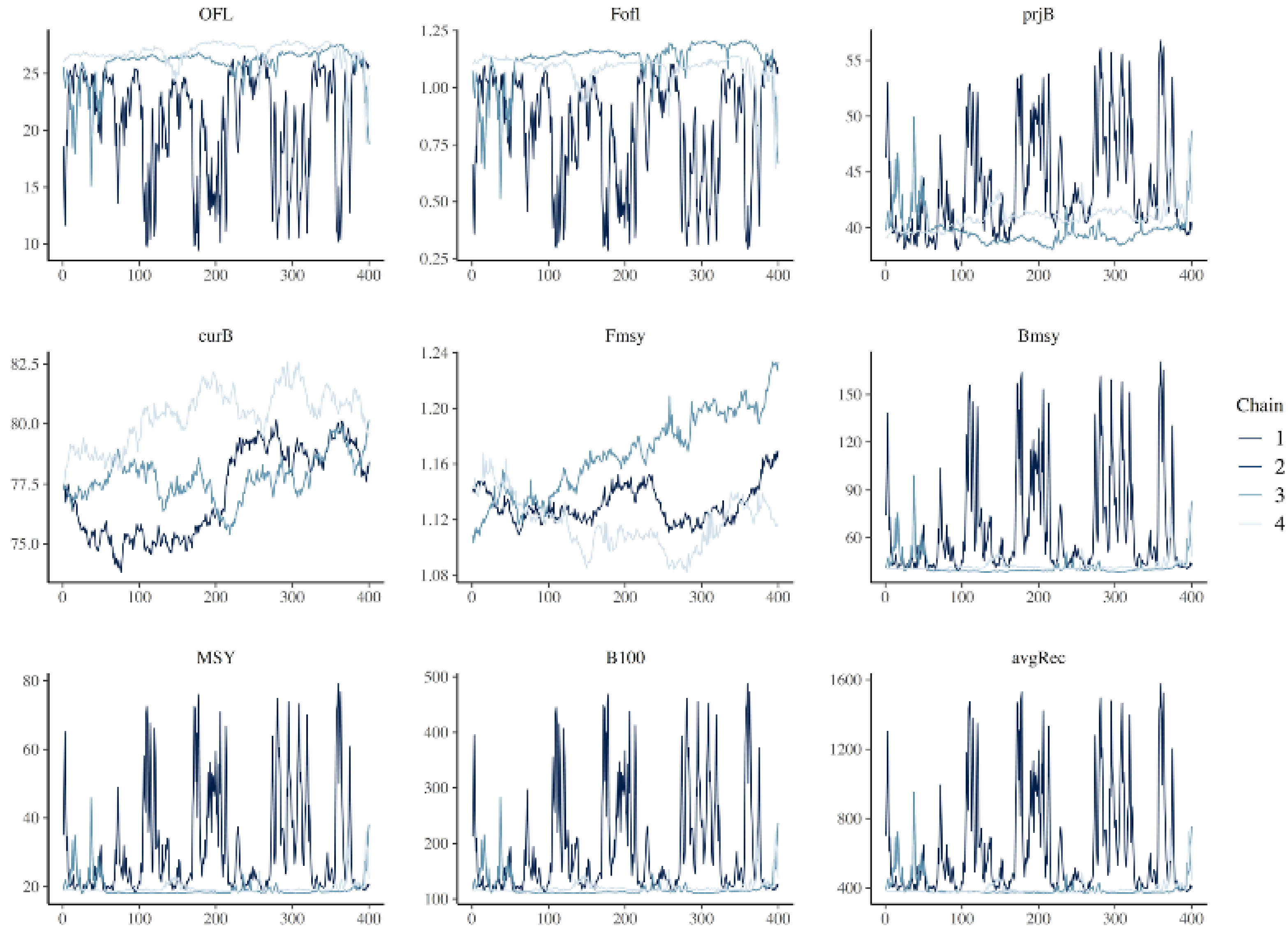

Figure 62. Traces for OFL-related quantities from 4 MCMC chains for Scenario 19.03(2020). Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

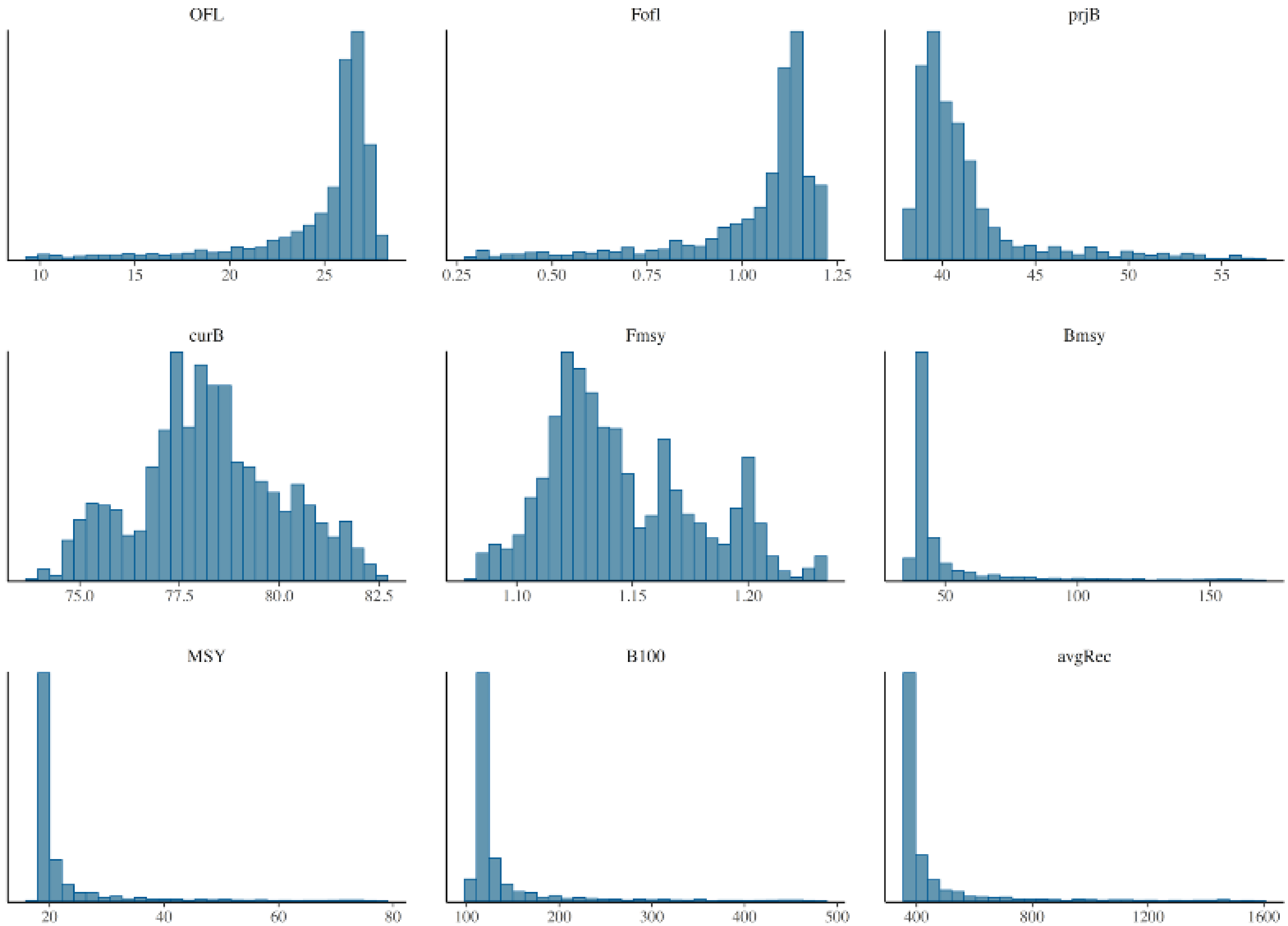

Figure 63. Histograms for OFL-related quantities from 4 MCMC chains for Scenario 19.03(2020). Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

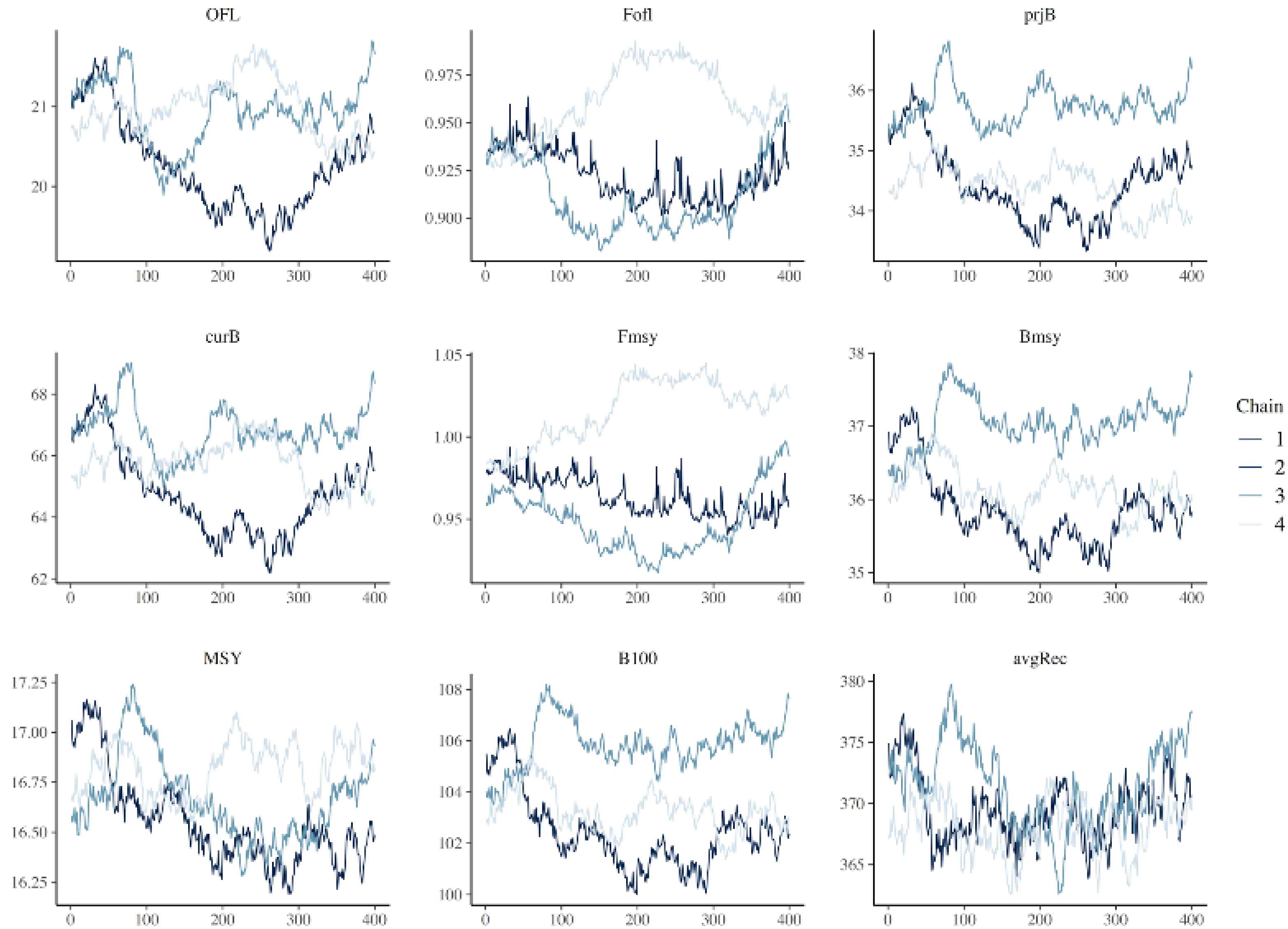

Figure 64. Traces for OFL-related quantities from 4 MCMC chains for Scenario 20.07. Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

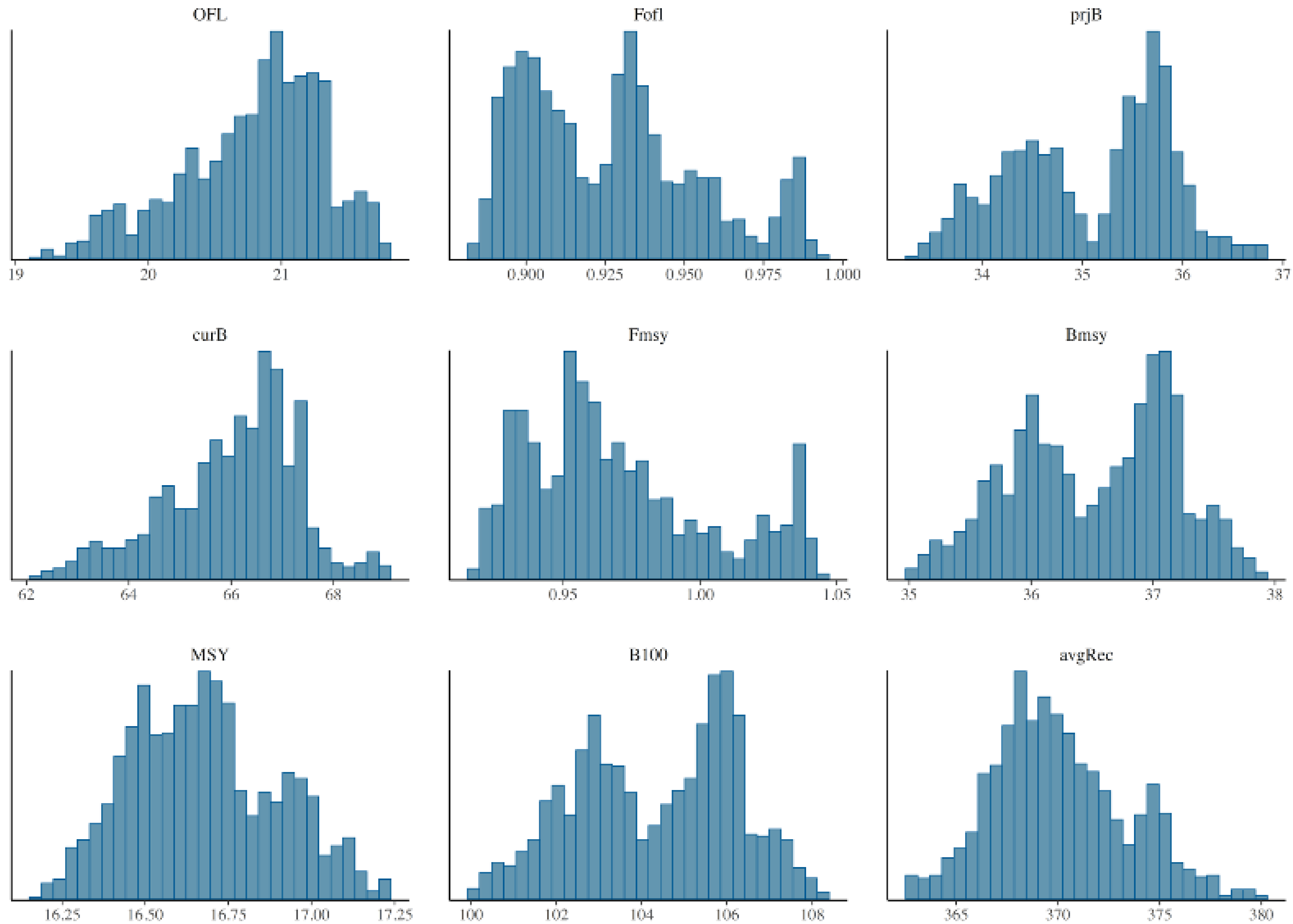

Figure 65. Histograms for OFL-related quantities from 4 MCMC chains for Scenario 20.07. Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

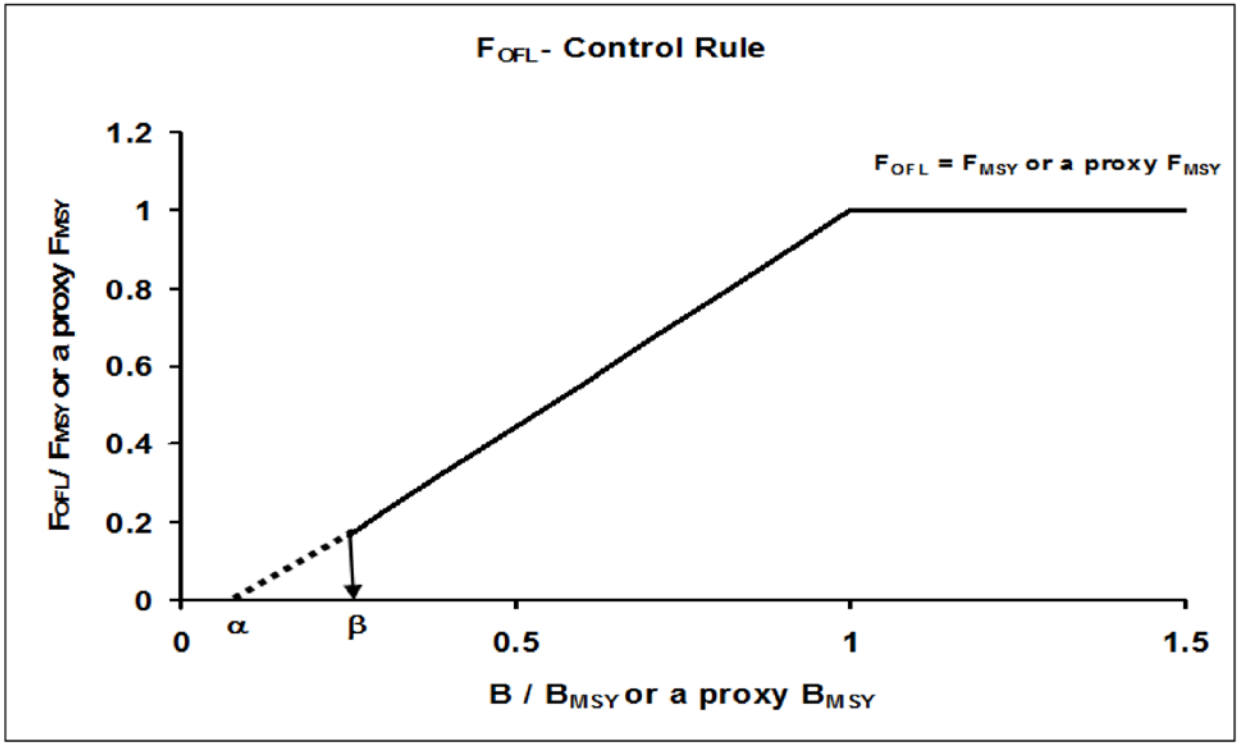

Figure 66. The F_{OFL} harvest control rule.

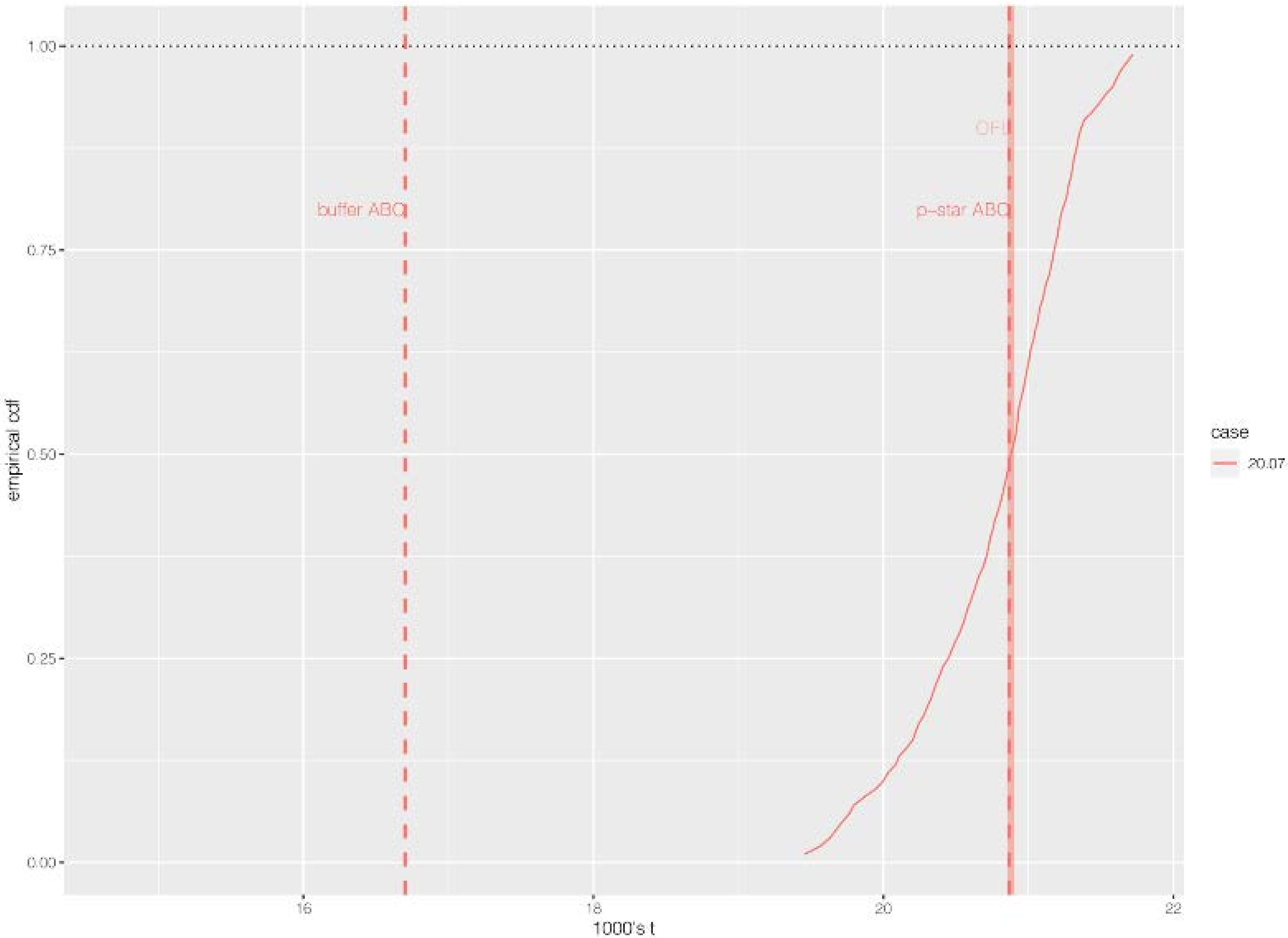

Figure 67. The OFL and ABC from the author's preferred model, scenario 20.07. 4 MCMC chains were merged to obtain the empirical distribution determining the p-star ABC.

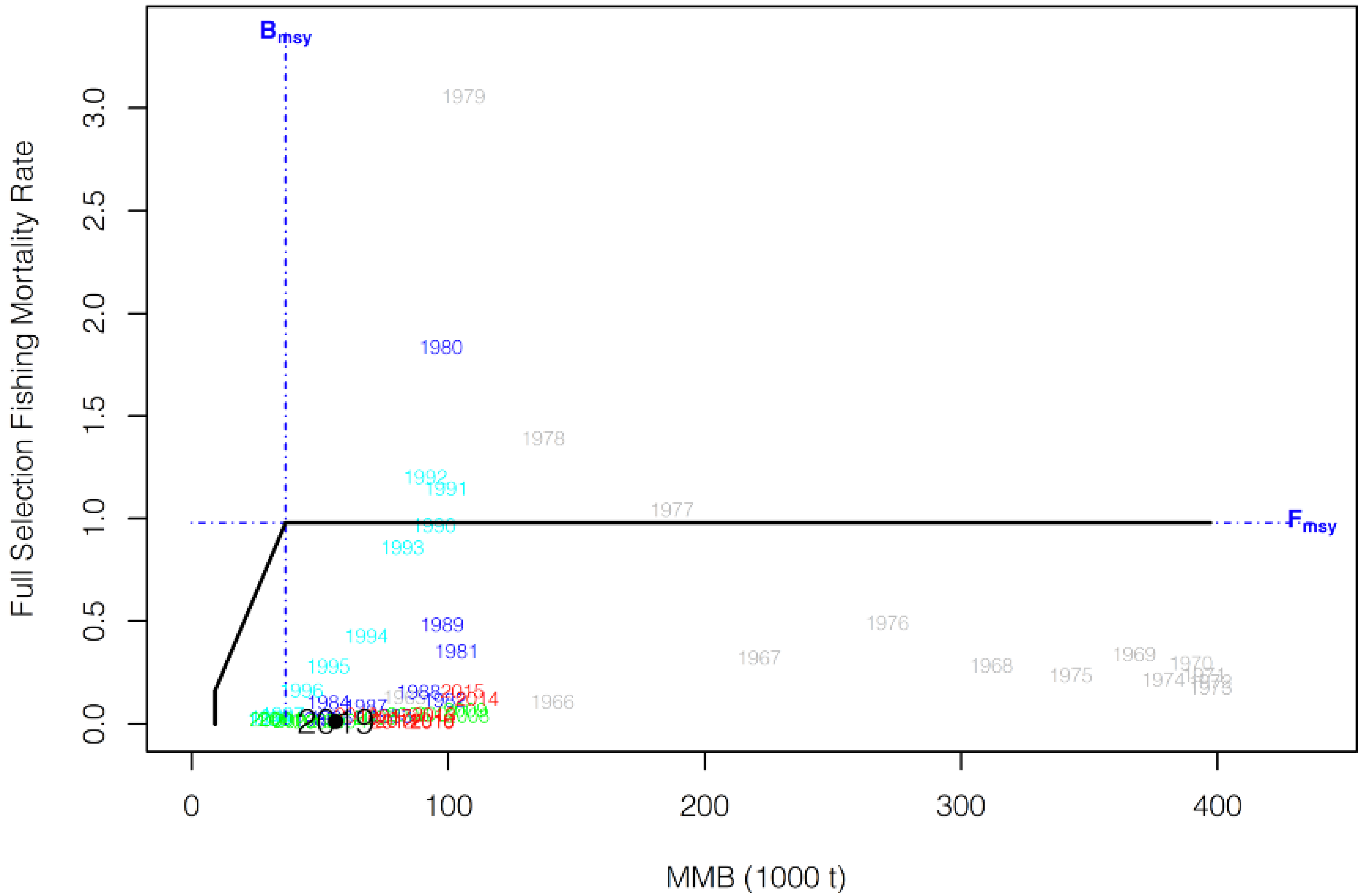

Figure 68. Quad plot for the author's preferred model, Scenario 20.07.

Appendix 1:
Description of the Tanner Crab Stock Assessment Model, Version 2

William T. Stockhausen
Alaska Fisheries Science Center
September 2020

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Introduction

The "TCSAM02" (Tanner Crab Stock Assessment Model, version 2) modeling framework was developed "from scratch" to eliminate many of the constraints imposed on potential future assessment models by TCSAM2013, the previous assessment model framework (Stockhausen, 2016). Like TCSAM2013, TCSAM02 uses AD Model Builder libraries as the basis for model optimization using a maximum likelihood (or Bayesian) approach. The model code for TCSAM02 is available on GitHub (the 2020 assessment model code is available at "202009CPTVersion"). TCSAM02 was first used for the Tanner crab assessment in 2017 (Stockhausen, 2017) and will be used until a transition is made to Gmacs (the Generalized Model for Alaska Crab Stocks). Gmacs is intended to be used for all crab stock assessments conducted for the North Pacific Fisheries Management Council (NPFMC), including both lithodid (king crab) and *Chionoecetes* (Tanner and snow crab) stocks, while TCSAM02 is specific to *Chionoecetes* biology (i.e., terminal molt).

TCSAM02 is referred to here as a "modeling framework" because, somewhat similar to Stock Synthesis (Methot and Wetzel, 2013), model structure and parameters are defined "on-the-fly" using control files—rather than editing and re-compiling the underlying code. In particular, the number of fisheries and surveys, as well as their associated data types (abundance, biomass, and /or size compositions) and the number and types of time blocks defined for every model parameter, are defined using control files in TCSAM02 and have not been pre-determined. Priors can be placed on any model parameter. New data types (e.g., growth data) can also be included in the model optimization that could not be fit with TCSAM2013. Additionally, status determination and OFL calculations can be done directly within a TCSAM02 model run, rather having to run a separate "projection model".

Several new features have been added to TCSAM02 since the 2019 assessment. These include:

1. the ability to programmatically specify a retrospective model run (i.e., running the model with a specified number of the most recent years of data and associated parameters excluded from the model fit and estimation)
2. an option to estimate selectivity/availability curves based on cubic splines
3. an option to apply selectivity (catchability) and/or availability curves estimated outside the model to survey or fishery data
4. an option to apply prior probabilities determined outside the model to selectivity (catchability) and/or availability curves estimated inside the model
5. an option to estimate "additional uncertainty" parameters associated with a survey

Model Description

A. General population dynamics

TCSAM02 is a stage/size-based population dynamics model. Population abundance at the start (July 1) of year *y* in the model, $n_{y,x,m,s,z}$, is characterized by sex *x* (male, female), maturity state *m* (immature, mature), shell condition *s* (new shell, old shell), and size *z* (carapace width, CW). Changes in abundance due to natural mortality, molting and growth, maturation, shell aging, fishing mortality and recruitment are tracked on an annual basis. Because the principal crab fisheries occur during the winter, the model year runs from July 1 to June 30 of the following calendar year.

The order of calculation steps to project population abundance from year *y* to *y*+1 depends on the assumed timing of the fisheries (δt_y^F) relative to molting/growth/mating (δt_y^m) in year *y*. The steps when the fisheries occur before molting/growth/mating ($\delta t_y^F \leq \delta t_y^m$) are outlined below first (Steps A1.1-A1.4), followed by the steps when molting/growth/mating occurs after the fisheries ($\delta t_y^m < \delta t_y^F$; Steps A2.1-A2.4).

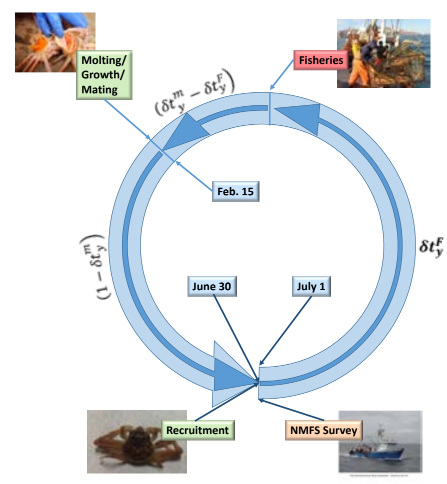

Fig. 1. Timing of annual events in TCSAM02 when fisheries occur before molting/growth/mating.

A1. Calculation sequence when $\delta t_y^F \leq \delta t_y^m$

Step A1.1: Survival prior to fisheries

Natural mortality is applied to the population from the start of the model year (July 1) until just prior to prosecution of pulse fisheries for year *y* at δt_y^F. The numbers surviving to δt_y^F in year *y* are given by:

$n_{y,x,m,s,z}^1 = e^{-M_{y,x,m,s,z} \cdot \delta t_y^F} \cdot n_{y,x,m,s,z}$	A1.1

where *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A1.2: Prosecution of the fisheries

The directed and bycatch fisheries are modeled as simultaneous pulse fisheries occurring at δt_y^F in year *y*. The numbers that remain after the fisheries are prosecuted are given by:

$n_{y,x,m,s,z}^2 = e^{-F_{y,x,m,s,z}^T} \cdot n_{y,x,m,s,z}^1$	A1.2

where $F_{y,x,m,s,z}^T$ represents the total fishing mortality (over all fisheries) on crab classified as *x*, *m*, *s*, *z* in year *y*.

Step A1.3: Survival after fisheries to time of molting/growth/mating

Natural mortality is again applied to the population from just after the fisheries to the time just before molting/growth/mating occurs for year *y* at δt_y^m (generally Feb. 15). The numbers surviving to δt_y^m in year *y* are given by:

$n_{y,x,m,s,z}^3 = e^{-M_{y,x,m,s,z} \cdot (\delta t_y^m - \delta t_y^F)} \cdot n_{y,x,m,s,z}^2$	A1.3

where, as above, *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A1.4: Molting, growth, and maturation
The changes in population structure due to molting, growth and maturation of immature (new shell) crab, as well as the change in shell condition for mature new shell (MAT, NS) crab to mature old shell (MAT, OS) crab due to aging, are given by:

$n^4_{y,x,MAT,NS,z} = \phi_{y,x,z} \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^3_{y,x,IMM,NS,z'}$	A1.4a
$n^4_{y,x,IMM,NS,z} = (1-\phi_{y,x,z}) \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^3_{y,x,IMM,NS,z'}$	A1.4b
$n^4_{y,x,MAT,OS,z} = n^3_{y,x,MAT,OS,z} + n^3_{y,x,MAT,NS,z}$	A1.4c

where $\Theta_{y,x,z,z'}$ is the growth transition matrix in year *y* for an immature new shell (IMM, NS) crab of sex *x* and pre-molt size *z'* to post-molt size *z* and $\phi_{y,x,z}$ is the probability that a just-molted crab of sex *x* and post-molt size *z* has undergone its terminal molt to maturity (MAT). All crab that molted remain new shell (NS) crab. Additionally, all mature crab that underwent terminal molt to maturity the previous year are assumed to change shell condition from new shell to old shell (A1.4c). Note that the numbers of immature old shell (IMM, OS) crab are identically zero in the current model because immature crab are assumed to molt each year until they undergo the terminal molt to maturity; consequently, the "missing" equation for *m=IMM*, *s=OS* is unnecessary.

Step A1.5: Survival to end of year, recruitment, and update to start of next year
Finally, the population abundance at the start of year *y*+1, due to natural mortality on crab from just after the time of molting/growth/mating in year *y* until the end of the model year (June 30) and recruitment ($R_{y,x,z}$) at the end of year *y* of immature new shell (IMM, NS) crab by sex *x* and size *z*, is given by:

$n_{y+1,x,m,s,z} = \begin{cases} e^{-M_{y,x,IMM,NS,z} \cdot (1-\delta t^m_y)} \cdot n^4_{y,x,IMM,NS,z} + R_{y,x,z} & m = IMM, s = NS \\ e^{-M_{y,x,m,s,z} \cdot (1-\delta t^m_y)} \cdot n^4_{y,x,m,s,z} & otherwise \end{cases}$	A1.5

A2. Calculation sequence when $\boldsymbol{\delta t^m_y < \delta t^F_y}$

Step A2.1: Survival prior to molting/growth/mating
As in the previous sequence, natural mortality is first applied to the population from the start of the model year (July 1), but this time until just prior to molting/growth/mating in year *y* at δt^m_y (generally Feb. 15). The numbers surviving at δt^m_y in year *y* are given by:

$n^1_{y,x,m,s,z} = e^{-M_{y,x,m,s,z} \cdot \delta t^m_y} \cdot n_{y,x,m,s,z}$	A2.1

where *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A2.2: Molting, growth, and maturation
The changes in population structure due to molting, growth and maturation of immature new shell (IMM, NS) crab, as well as the change in shell condition for mature new shell (MAT, NS) crab to mature old shell (MAT, OS) crab due to aging, are given by:

$n^2_{y,x,MAT,NS,z} = \phi_{y,x,z} \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^1_{y,x,IMM,NS,z'}$	A2.2a
$n^2_{y,x,IMM,NS,z} = (1 - \phi_{y,x,z}) \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^1_{y,x,IMM,NS,z'}$	A2.2b
$n^2_{y,x,MAT,OS,z} = n^1_{y,x,MAT,OS,z} + n^1_{y,x,MAT,NS,z}$	A2.2c

where $\Theta_{y,x,z,z'}$ is the growth transition matrix in year *y* for an immature new shell (IMM, NS) crab of sex *x* and pre-molt size *z'* to post-molt size *z* and $\phi_{y,x,z}$ is the probability that a just-molted crab of sex *x* and post-molt size *z* has undergone its terminal molt to maturity. Additionally, mature new shell (MAT, NS) crab that underwent their terminal molt to maturity the previous year are assumed to change shell condition from new shell to old shell (A2.2c). Again, the numbers of immature old shell crab are identically zero because immature crab are assumed to molt each year until they undergo the terminal molt to maturity.

Step A2.3: Survival after molting/growth/mating to prosecution of fisheries
Natural mortality is again applied to the population from just after molting/growth/mating to the time at which the fisheries occur for year *y* (at δt^F_y). The numbers surviving at δt^F_y in year *y* are then given by:

$n^3_{y,x,m,s,z} = e^{-M_{y,x,m,s,z} \cdot (\delta t^F_y - \delta t^m_y)} \cdot n^2_{y,x,m,s,z}$	A2.3

where, as above, *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A2.4: Prosecution of the fisheries
The directed fishery and bycatch fisheries are modeled as pulse fisheries occurring at δt^F_y in year *y*. The numbers that remain after the fisheries are prosecuted are given by:

$n^4_{y,x,m,s,z} = e^{-F^T_{y,x,m,s,z}} \cdot n^3_{y,x,m,s,z}$	A2.4

where $F^T_{y,x,m,s,z}$ represents the total fishing mortality (over all fisheries) on crab classified as *x*, *m*, *s*, *z* in year *y*.

Step A2.5: Survival to end of year, recruitment, and update to start of next year
Finally, population abundance at the start of year *y*+1 due to natural mortality on crab from just after prosecution of the fisheries in year *y* until the end of the model year (June 30) and recruitment of immature new (IMM, NS) shell crab at the end of year *y* ($R_{y,x,z}$) and are given by:

$n_{y+1,x,m,s,z} = \begin{cases} e^{-M_{y,x,IMM,NS,z} \cdot (1-\delta t^F_y)} \cdot n^4_{y,x,IMM,NS,z} + R_{y,x,z} & m = IMM, s = NS \\ e^{-M_{y,x,m,s,z} \cdot (1-\delta t^F_y)} \cdot n^4_{y,x,m,s,z} & otherwise \end{cases}$	A2.5

B. Parameter specification

Because parameterization of many model processes (e.g., natural mortality, fishing mortality) in TCSAM02 is fairly flexible, it is worthwhile discussing how model processes and their associated parameters are configured in TCSAM02 before discussing details of the model processes themselves. Each type of model process has a set of (potentially estimable) model parameters and other information associated with it, but different “elements” of a model process can be defined that apply, for example, to different segments of the population and/or during different time blocks. In turn, several “elements” of a model parameter associated with a model process may also be defined (and applied to different elements of the process). At least one combination of model parameters and other information associated with a model process must be defined—i.e., one process element must be defined.

Model processes and parameters are configured in a “ModelParametersInfo” file, one of the three control files required for a model run (the others are the “ModelConfiguration” file and the “ModelOptions” file). As an example of the model processes and parameter specification syntax, Text Box 1 presents the part of a “ModelParametersInfo” file concerned with specifying fishing processes in the directed Tanner crab fishery.

In Text Box 1, the keyword “fisheries” identifies the model process in question. The first section, following the “PARAMETER_COMBINATIONS” keyword (up to the first set of triple blue dots), specifies the indices associated with fishing process parameters (pHM, pLnC, pDC1, pDC2, pDC3, pDC4, pDevsLnC, pLnEffX, pLgtRet), selectivity and retention functions (idxSelFcn, idxRetFcn), and effort averaging time period (effAvgID) that apply to a single fishing process element. In this example, the indices for the selectivity and retention functions, as well as those for the effort averaging time period, constitute the “other information” specified for each fishing process element. Each fishing process element in turn applies to a specific fishery (FISHERY=1 indicates the directed fishery, in this case), time block (specified by YEAR_BLOCK), and components of the model population (specified by SEX, MATURITY STATE, and SHELL CONDITION). Using indices to identify which parameters and selectivity and retention functions apply to a given combination of fishery/time block/sex/maturity state/shell condition allows one to “share” individual parameters and selectivity and retention functions across different fishery/time block/sex/maturity state/shell condition combinations.

The second section (following the “PARAMETERS” keyword) determines the characteristics for each of the fishing process parameters, organized by parameter name (note: the parameters associated with the different selectivity and retention functions are specified in a different section of the ModelParametersInfo file). Here, each parameter name corresponds to an ADMB “param_init_bounded_number_vector” in the model code—the exception being pDevsLnC, which corresponds to an ADMB “param_init_bounded_vector_vector”.

Each row under a “non-devs” parameter name in the fisheries section (e.g., pLnC) specifies the index used to associate an element of the parameter with the fishing processes defined in the PARAMETER_COMBINATIONS section, as well as characteristics of the element in the associated ADMB number_vector (upper and lower bounds, initial value, and initial estimation phase), various flags for initialization (“jitter”, “resample”), definition of an associated prior probability distribution, and a label. Each row under a “devs” parameter name (e.g., pDevsLnC) specifies much the same information for the associated ADMB devs vector, with the “read” flag replacing the “initial value” entry. If “read?” is TRUE, then a vector of initial values is read from the file after all “info” rows for the devs parameter have been read. The “jitter” flag (if set to TRUE) provides the ability to change the initial value for an element of a non-devs parameter using a randomly selected value based on the element’s upper and lower bounds. For a devs parameter, an element with jitter set to TRUE is initialized using a vector of randomly-generated numbers (subject to being a devs vector within the upper and lower bounds). The “resample” flag was intended to specify an alternative method to providing randomly-generated initial values (based on an element’s prior probability distribution, rather than its upper and lower bounds), but this has not yet been fully implemented.

Some model processes apply only to specific segments of the population (e.g., growth only applies to immature, new shell crab). In general, though, a model process element can be defined to apply to any segment of the population (by specifying SEX, MATURITY STATE, and SHELL CONDITION appropriately) and range of years (by specifying YEAR_BLOCK). In turn, an element of a parameter may be “shared” across multiple processes by specifying the element’s index in multiple rows of a PARAMETERS_COMBINATION block.

```
#-------------------------------
# Fishery parameters
#-------------------------------
fisheries #process name
PARAMETER_COMBINATIONS
42  #number of rows defining parameter combinations for all fisheries
#Directed Tanner Crab Fishery (TCF)
#                                           |MATURITY|SHELL|                                |pDevs| pLn | pLgt| idx  | idx  |  eff  |
#id  FISHERY  YEAR_BLOCK             SEX    | STATE  |COND |  pHM  pLnC pDC1 pDC2 pDC3 pDC4 | LnC | EffX| Ret |SelFcn|RetFcn| AvgID |  label
1       1     [-1:1964]              MALE      ALL    ALL     1    1    0     0    0    0      0     0    0     9       5       0    TCF:_M_T1
2       1     [1965:1984;1987:1990]  MALE      ALL    ALL     1    2    0     0    0    0      1     0    0     9       5       0    TCF:_M_T2
3       1     [1991:1996]            MALE      ALL    ALL     1    2    0     0    0    0      1     0    0    10       6       0    TCF:_M_T3
4       1     [2005:2009]            MALE      ALL    ALL     1    2    0     0    0    0      1     0    1    11       7       0    TCF:_M_T4
5       1     [2013:-1]              MALE      ALL    ALL     1    2    0     0    0    0      1     0    1    12       8       0    TCF:_M_T5
6       1     [-1:1964]              FEMALE    ALL    ALL     1    1    0     1    0    0      0     0    0    13       0       0    TCF:_F_T1
7       1     [1965:1984;1987:1996]  FEMALE    ALL    ALL     1    2    0     1    0    0      1     0    0    13       0       0    TCF:_F_T2
8       1     [2005:2009;2013:-1]    FEMALE    ALL    ALL     1    2    0     1    0    0      1     0    0    14       0       0    TCF:_F_T3
…
PARAMETERS
pHM #handling mortality (0-1)
3   #number of parameters
#   |   limits    |       | initial | start |         |-       priors          -|
#id |lower   upper|jitter?| value   | phase |resample?| wgt| type| params| consts|  label
1      0       1    OFF     0.321      -1       OFF      1   none    none     none    handling_mortality_for_crab_pot_fisheries
…
pLnC #base (ln-scale) capture rate (mature males)
9    #number of parameters
#   |   limits    |       |  initial    | start |         |-       priors          -|
#id |lower   upper|jitter?|   value     | phase |resample?| wgt| type| params| consts|  label
 1    -15      15     OFF    -2.995732274    -1       OFF       1   none  none    none      TCF:_base_capture_rate,_pre-1965_(=0.05)
 2    -15      15     ON     -1.164816291     1       OFF       1   none  none    none      TCF:_base_capture_rate,_1965+
…
pDC1 #main temporal ln-scale capture rate offset
0    #number of parameters
pDC2 #ln-scale capture rate offset for female crabs
6    #number of parameters
#   |   limits    |       |  initial    | start |         |-       priors           -|
#id |lower  upper |jitter?|   value     | phase |resample?|  wgt  type  params  consts|  label
1    -5.0    5.0      ON    -2.058610432    1       OFF       1.0  none   none    none   TCF:_female_offset
…
pDevsLnC #annual ln-scale capture rate deviations
6        #number of parameter vectors
#    | index  |            index                    |       |   limits     |          |initial |start |         |-      priors                 -|
#id  |  type  |            block                    | read? |lower   upper | jitter?| value  |phase |resample?|  wgt | type | params | consts |label
 1     YEAR   [1965:1984;1987:1996;2005:2009;2013:-1]  FALSE   -15     15       ON       0        1      OFF       2.0  normal    0 1     none    TCF:_T2345
…
```

Text Box 1. Abbreviated example of process and parameter specifications in a "ModelParametersInfo" file for fishing mortality in TCSAM02. Only parameter combinations and parameters relevant to the directed fishery are shown. Input values are in black text, comments are in green, triple blue dots indicate additional input lines not shown.

C. Model processes: natural mortality

The natural mortality rate applied to crab of sex *x*, maturity state *m*, shell condition *s*, and size *z* in year *y*, $M_{y,x,m,s,z}$, can be specified using one of two parameterizations. The first parameterization option uses a ln-scale parameterization with an option to include an inverse- size dependence using Lorenzen's approach:

$lnM_{y,x,m,s} = \mu^0_{y,x,m,s} + \sum_{i=1}^{4} \delta\mu^i_{y,x,m,s}$	C.1a
$M_{y,x,m,s,z} = \begin{cases} \exp(lnM_{y,x,m,s}) & if\ Lorenzen\ option\ is\ not\ selected \\ \exp(lnM_{y,x,m,s}) \cdot \frac{z_{base}}{z} & if\ Lorenzen\ option\ is\ selected \end{cases}$	C.1b C.1c

where the μ^0 and the $\delta\mu^i$'s are (potentially) estimable parameters defined for time block *T*, sex *S* (MALE, FEMALE, or ANY), maturity *M* (IMMATURE, MATURE, or ANY), and shell condition *S* (NEWSHELL, OLDSHELL, or ANY), and {*y*,*x*,*m*,*s*} falls into the set {*T*,*X*,*M*,*S*}. In Eq. C.1c, z_{base} denotes the specified reference size (mm CW) for the inverse-size dependence.

The second parameterization option uses an arithmetic parameterization in order to provide backward compatibility with the 2016 assessment model based on TCSAM2013. In TCSAM2013, the natural mortality rate $M_{y,x,m,s,z}$ was parameterized using:

$M_{y,x,m=IMM,s,z} = M^{base} \cdot \delta M_{IMM}$	C.2a
$M_{y,x,m=MAT,s,z} = \begin{cases} M^{base} \cdot \delta M_{x,MAT} & otherwise \\ M^{base} \cdot \delta M_{x,MAT} \cdot \delta M^T_{x,MAT} & 1980 \le y \le 1984 \end{cases}$	C.2b

where M^{base} was a fixed value (0.23 yr^{-1}), δM_{IMM} was a multiplicative factor applied for all immature crab, the $\delta M_{x,MAT}$ were sex-specific multiplicative factors for mature crab, and the $\delta M^T_{x,MAT}$ were additional sex-specific multiplicative factors for mature crab during the 1980-1984 time block (which has been identified as a period of enhanced natural mortality on mature crab, the mechanisms for which are not understood). While it would be possible to replicate Eq.s C.2a and C.2b using ln-scale parameters, TCSAM2013 also placed informative arithmetic-scale priors on some of these parameters—and this could not be duplicated on the ln-scale. Consequently, the second option uses the following parameterization, where the parameters (and associated priors) are defined on the arithmetic-scale:

$lnM_{y,x,m,s} = \ln[\mu^0_{y,x,m,s}] + \sum_{i=1}^{4} \ln[\delta\mu^i_{y,x,m,s}]$	C.3a

A system of equations identical to C.2a-b can be achieved under the following assignments:

$\mu^0_{\{y,x,m,s\}\in\{T=ALL,X=ALL,M=ALL,S=ALL\}} = M^{base}$	C.4a
$\delta\mu^1_{\{y,x,m,s\}\in\{T=ALL,X=ALL,M=IMM,S=ALL\}} = \delta M_{IMM}$	C.4e
$\delta\mu^1_{\{y,x,m,s\}\in\{T=ALL,X=x,M=MAT,S=ALL\}} = \delta M_{x,MAT}$	C.4f
$\delta\mu^2_{\{y,x,m,s\}\in\{T=1980-1984,X=x,M=MAT,S=ALL\}} = \delta M^T_{x,MAT}$	C.4g

where unassigned $\delta\mu^{i}_{y,x,m,s}$ are set equal to 1. Pending further model testing using alternative model configurations, the TCSAM2013 option is standard.

It is worth noting explicitly that, given the number of potential parameters above that could be used, extreme care must be taken when defining a model to achieve a set of parameters that are not confounded and are, at least potentially, estimable.

D. Model processes: growth

Because Tanner crab are assumed to undergo a terminal molt to maturity, in TCSAM02 only immature crab experience growth. Annual growth of immature crab is implemented as using two options, the first based on a formulation used in Gmacs and the second (mainly for purposes of backward compatibility) based on that used in TCSAM2013. In TCSAM02, growth can vary by time block and sex, so it is expressed by sex-specific transition matrices for time block *t*, $\Theta_{t,x,z,z'}$, that specify the probability that crab of sex *x* in pre-molt size bin z' grow to post-molt size bin z at molting.

In the Gmacs-like approach (the standard approach as of May, 2017), the sex-specific growth matrices are given by:

$\Theta_{t,x,z,z'} = c_{t,x,z'} \cdot \int_{z-bin/2}^{z+bin/2} \Gamma\left(\frac{z'' - \bar{z}_{t,x,z'}}{\beta_{t,x}}\right) dz''$	Sex-specific (*x*) transition matrix for growth from pre-molt z' to post-molt z, with $z \geq z'$	D.1a
$c_{t,x,z'} = \left[\int_{z'}^{\infty} \Gamma\left(\frac{z'' - \bar{z}_{t,x,z'}}{\beta_{t,x}}\right) dz''\right]^{-1}$	Normalization constant so $1 = \sum_{z} \Theta_{t,x,z,z'}$	D.1b
$\bar{z}_{t,x,z'} = e^{a_{t,x}} \cdot z'^{b_{t,x}}$	Mean size after molt, given pre-molt size z'	D.1c

where the integral represents a cumulative gamma distribution across the post-molt (z) size bin. This approach may have better numerical stability properties than the TCSAM2013 approach below.

The TCSAM2013 approach is an approximation to the Gmacs approach, where the sex-specific growth matrices $\Theta_{t,x,z,z'}$ are given by

$\Theta_{t,x,z,z'} = c_{t,x,z'} \cdot \Delta_{z,z'}{}^{\alpha_{t,x,z'}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_{t,x}}}$	Sex-specific (*x*) transition matrix for growth from pre-molt z' to post-molt z, with $z \geq z'$	D.2a
$c_{t,x,z'} = \left[\sum_{z'} \Delta_{z,z'}{}^{\alpha_{t,x,z'}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_{t,x}}}\right]^{-1}$	Normalization constant so $1 = \sum_{z} \Theta_{t,x,z,z'}$	D.2b
$\Delta_{z,z'} = z - z'$	Actual growth increment	D.2c
$\alpha_{t,x,z'} = \left[\bar{z}_{t,x,z'} - z'\right]/\beta_{t,x}$	Mean molt increment, scaled by $\beta_{t,x}$	D.2d
$\bar{z}_{t,x,z'} = e^{a_{t,x}} \cdot z'^{b_{t,x}}$	Mean size after molt, given pre-molt size z'	D.2e

In both approaches, the $a_{t,x}$, $b_{t,x}$, and $\beta_{t,x}$ are arithmetic-scale parameters with imposed bounds. $\Theta_{t,x,z,z'}$ is used to update the numbers-at-size for immature crab, $n_{y,x,z}$, from pre-molt size z' to post-molt size z using:

$n^{+}_{y,x,z} = \sum_{z'} \Theta_{t,x,z,z'} \cdot n_{y,x,z'}$	numbers at size of immature crab after growth	D.3

where y falls within time block t (see also Eq.s A1.4a-b and A2.2a-b).

Priors using normal distributions are imposed on $a_{t,x}$ and $b_{t,x}$ in TCSAM2013, with the values of the hyper-parameters hard-wired in the model code. While priors may be defined for the associated parameters here, these are identified by the user in the model input files and are not hard-wired in the model code.

E. Model processes: maturity (terminal molt)

Maturation of immature crab in TCSAM02 is based on a similar approach to that taken in TCSAM2013, except that the sex- and size-specific probabilities of terminal molt for immature crab, $\phi_{t,x,z}$ (where size z is post-molt size), can vary by time block. After molting and growth, the numbers of (new shell) crab at post-molt size z remaining immature, $n^{+}_{y,x,IMM,NS,z}$, and those maturing, $n^{+}_{x,MAT,NS,z}$, are given by:

$n^{+}_{y,x,IMM,NS,z} = \left(1-\phi_{t,x,z}\right) \cdot n_{y,x,IMM,NS,z}$ $n^{+}_{y,x,MAT,NS,z} = \phi_{t,x,z} \cdot n_{y,x,IMM,NS,z}$	crab remaining immature crab maturing (terminal molt)	E.1a E.1b

where y falls in time block t and $n_{y,x,IMM,NS,z}$ is the number of immature, new shell crab of sex x at post-molt size z.

The sex- and size-specific probabilities of terminal molt, $\phi_{t,x,z}$, are related to logit-scale model parameters $p^{mat}_{t,x,z}$ by:

$\phi_{t,FEM,z} = \begin{cases} \dfrac{1}{1+e^{p^{mat}_{t,FEM,z}}} & z \le z^{mat}_{t,FEM} \\ 1 & z > z^{mat}_{t,FEM} \end{cases}$	female probabilities of maturing at post-molt size z	E.2a
$\phi_{t,MALE,z} = \begin{cases} \dfrac{1}{1+e^{p^{mat}_{t,MALE,z}}} & z \le z^{mat}_{t,MALE} \\ 1 & z > z^{mat}_{t,MALE} \end{cases}$	male probabilities of maturing at post-molt size z	E.2b

where the $z^{mat}_{t,x}$ are constants specifying the minimum pre-molt size at which to assume all immature crab will mature upon molting. The $z^{mat}_{t,x}$ are used here pedagogically; in actuality, the user specifies the *number* of logit-scale parameters to estimate (one per size bin starting with the first bin) for each sex, and this determines the $z^{mat}_{t,x}$ used above. This parameterization is similar to that implemented in TCSAM2013 for the 2016 assessment model.

Second difference penalties are applied to the parameter estimates in TCSAM2013's objective function to promote relatively smooth changes in these parameters with size. Similar penalties (smoothness, non-decreasing) can be applied in TCSAM02.

F. Model processes: recruitment

Recruitment in TCSAM02 consists of immature new shell crab entering the population at the end of the model year (June 30). Recruitment in TCSAM02 has a similar functional form to that used in TCSAM2013, except that the sex ratio at recruitment is not fixed at 1:1 and multiple time blocks can be specified. In TCSAM2013, two time blocks were defined: "historical" (model start to 1974) and "current" (1975-present), with "current" recruitment starting in the first year of NMFS survey data. In TCSAM02, recruitment in year y of immature new shell crab of sex x at size z is specified as

$R_{y,x,z} = \dot{R}_y \cdot \ddot{R}_{y,x} \cdot \dddot{R}_{y,z}$	recruitment of immature, new shell crab by sex and size bin	F.1

where $\dot{R}_y$ represents total recruitment in year *y* and $\ddot{R}_{y,x}$ represents the fraction of sex *x* crab recruiting, and $\dddot{R}_{y,z}$is the size distribution of recruits, which is assumed identical for males and females.

Total recruitment in year *y*, $\dot{R}_y$, is parameterized as

$\dot{R}_y = e^{pLnR_t + \delta R_{t,y}} \quad y \in t$	total recruitment in year *y*	F.2

where *y* falls within time block *t*, $pLnR_t$ is the ln-scale mean recruitment parameter for *t*, and $\delta R_{t,y}$is an element of a "devs" parameter vector for *t* (constrained such that the elements of the vector sum to zero over the time block).

The fraction of crab recruiting as sex *x* in year *y* in time block *t* is parameterized using the logistic model

$\ddot{R}_{y,x} = \begin{cases} \frac{1}{1+e^{pLgtRx_t}} & x = MALE \\ 1 - \ddot{R}_{y,MALE} & x = FEMALE \end{cases} \quad y \in t$	sex-specific fraction recruiting in year *y*	F.3

where $pLgtRx_t$ is a logit-scale parameter determining the sex ratio in time block *t*.

The size distribution for recruits in time block *t*, $\dddot{R}_{t,z}$, is assumed to be a gamma distribution and is parameterized as

$\dddot{R}_{t,z} = c^{-1} \cdot \Delta_z^{\frac{\alpha_t}{\beta_t}-1} \cdot e^{-\frac{\Delta_z}{\beta_t}}$	size distribution of recruiting crab	F.4
$c_t = \sum_z \Delta_z^{\frac{\alpha_t}{\beta_t}-1} \cdot e^{-\frac{\Delta_z}{\beta_t}}$	normalization constant so that $1 = \sum_z \dddot{R}_{t,z}$	F.5
$\Delta_z = z + \delta z/2 - z_{min}$	offset from minimum size bin	F.6
$\alpha_t = e^{pLnRa_t}$	gamma distribution location parameter	F.7
$\beta_t = e^{pLnRb_t}$	gamma distribution shape parameter	F.8

where $pLnRa_t$ and $pLnRb_t$ are the ln-scale location and shape parameters and the constant δz is the size bin spacing.

A final time-blocked parameter, $pLnRCV_t$, is associated with the recruitment process representing the ln-scale coefficient of variation (cv) in recruitment variability in time block *t*. These parameters are used to apply priors on the recruitment "devs" in the model likelihood function.

G. Selectivity and retention functions

Selectivity and retention functions in TCSAM02 are specified independently from the fisheries and surveys to which they are subsequently applied. This allows a single selectivity function to be "shared" among multiple fisheries and/or surveys, as well as among multiple time block/sex/maturity state/shell condition categories, if so desired.

Currently, the following functions are available for use as selectivity or retention curves in a model:

$S_z = \left\{1 + e^{-\beta\cdot(z - z_{50})}\right\}^{-1}$	standard logistic	G.1
$S_z = \left\{1 + e^{-\beta\cdot(z - \exp(lnZ_{50}))}\right\}^{-1}$	logistic w/ alternative parameterization	G.2
$S_z = \left\{1 + e^{-\ln(19)\cdot\frac{(z - z_{50})}{\Delta z_{95-50}}}\right\}^{-1}$	logistic w/ alternative parameterization	G.3
$S_z = \left\{1 + e^{-\ln(19)\cdot\frac{(z - z_{50})}{\exp(ln\Delta z_{95-50})}}\right\}^{-1}$	logistic w/ alternative parameterization	G.4
$S_z = \left\{1 + e^{-\ln(19)\cdot\frac{(z - \exp(lnZ_{50}))}{\exp(ln\Delta z_{95-50})}}\right\}^{-1}$	logistic w/ alternative parameterization	G.5
$S_z = \frac{1}{1 + e^{-\beta_a\cdot(z - z_{a50})}} \cdot \frac{1}{1 + e^{\beta_d\cdot(z - z_{d50})}}$	double logistic	G.6
$S_z = \frac{1}{1 + e^{-\ln(19)\cdot\frac{(z - z_{a50})}{\Delta z_{a(95-50)}}}} \cdot \frac{1}{1 + e^{\ln(19)\cdot\frac{(z - z_{d50})}{\Delta z_{d(95-50)}}}}$	double logistic with alt. parameterization	G.7
$S_z = \frac{1}{1 + e^{-\ln(19)\cdot\frac{(z - z_{a50})}{\exp(ln\Delta z_{a(95-50)})}}} \cdot \frac{1}{1 + e^{\ln(19)\cdot\frac{(z - z_{d50})}{\exp(ln\Delta z_{d(95-50)})}}}$ $where\ z_{d50} = [z_{a50} + \exp(ln\Delta z_{a(95-50)}) + \exp(ln\Delta z_{d(95-50)})]$	double logistic with alt. parameterization	G.8
$S_z = \frac{1}{1 + e^{-\ln(19)\cdot\frac{(z - \exp(lnz_{a50}))}{\exp(ln\Delta z_{a(95-50)})}}} \cdot \frac{1}{1 + e^{\ln(19)\cdot\frac{(z - z_{d50})}{\exp(ln\Delta z_{d(95-50)})}}}$ $where\ z_{d50} = [\exp(lnz_{a50}) + \exp(ln\Delta z_{a(95-50)}) + \exp(ln\Delta z_{d(95-50)})]$	double logistic with alt. parameterization	G.9
$S_z = \frac{1}{1 + e^{-\beta_a\cdot(z - z_{a50})}} \cdot \frac{1}{1 + e^{\beta_d\cdot(z - [z_{a50} + \exp(lnZ_{d50-a50})])}}$	double logistic with alt. parameterization	G.10

A double normal selectivity function (requiring 6 parameters to specify) has also been implemented as an alternative to the double logistic functions. In the above functions, all symbols (e.g., β, z_{50}, Δz_{95-50}) represent parameter values, except "z" which represents crab size.

Selectivity parameters are defined independently of the functions themselves, and subsequently assigned. It is thus possible to "share" parameters across multiple functions. The "parameters" used in selectivity functions are further divided into mean parameters across a time block and annual deviations within a time block. To accommodate the 6-parameter double normal equation, six "mean" parameter sets (*pS1*, *pS2*,…, *pS6*) and six associated sets of "devs" parameter vectors (*pDevsS1*, *pDevsS2*,…, *pDevsS6*) are defined to specify the parameterization of individual selectivity/retention functions. Thus, for example, z_{50} in eq. F1 is actually expressed as $z_{50,y} = \bar{z}_{50} + \delta z_{50,y}$ in terms of model parameters *pS1* and $pDevsS1_y$, where $\bar{z}_{50} = pS1$ is the mean size-at-50%-selected over the time period and $\delta z_{50,y} = pDevsS1_y$ is the annual deviation.

Finally, three different options to normalize individual selectivity curves are provided: 1) no normalization, 2) specifying a fully-selected size, and 3) re-scaling such that the maximum value of the re-scaled function is 1. A normalization option must be specified in the model input files for each defined selectivity/retention curve.

H. Fisheries

Unlike TCSAM2013, which explicitly models 4 fisheries that catch Tanner crab (one as a directed fishery, three as bycatch), there is no constraint in TCSAM02 on the number of fisheries that can be incorporated in the model. All fisheries are modeled as "pulse" fisheries occurring at the same time.

TCSAM02 uses the Gmacs approach to modeling fishing mortality (also implemented in TCSAM2013). The total (retained + discards) fishing mortality rate, $F_{f,y,x,m,s,z}$, in fishery *f* during year *y* on crab in state *x*, *m*, *s*, and *z* (i.e., sex, maturity state, shell condition, and size) is related to the associated fishery capture rate $\phi_{f,y,x,m,s,z}$ by

$F_{f,y,x,m,s,z} = \left[h_{f,t} \cdot \left(1 - \rho_{f,y,x,m,s,z}\right) + \rho_{f,y,x,m,s,z}\right] \cdot \phi_{f,y,x,m,s,z}$	fishing mortality rate	H.1

where $h_{f,t}$ is the handling (discard) mortality for fishery *f* in time block t (which includes year *y*) and $\rho_{f,y,x,m,s,z}$ is the fraction of crabs in state *x*, *m*, *s*, *z* that were caught and retained (i.e., the retention function). The retention function is assumed to be identically 0 for females in a directed fishery and for both sexes in a bycatch fishery.

In TCSAM2013, the same retention function (in each of two time blocks) was applied to male crab regardless of maturity state or shell condition. Additionally, full retention of large males was assumed, such that the retention function essentially reached 1 at large sizes. In TCSAM02, different retention functions can be applied based on maturity state and/or shell condition, and "max retention" is now an (potentially) estimable logit-scale parameter. Thus, in TCSAM02, the retention function $\rho_{f,y,x,m,s,z}$ is given by

$\rho_{f,y,x,m,s,z} = \dfrac{1}{1 + e^{\rho_{f,t,x,m,s}}} \cdot R_{f,y,x,m,s,z}$	retention function	H.2

where *f* corresponds to the directed fishery, *y* is in time block *t*, *x*=MALE, $\rho_{f,t,x,m,s}$ is the corresponding logit-scale "max retention" parameter, and $R_{f,y,x,m,s,z}$ is the associated selectivity/retention curve.

If $n_{y,x,m,s,z}$ is the number of crab classified as *x*, *m*, *s*, *z* in year *y* just prior to the prosecution of the fisheries, then

$c_{f,y,x,m,s,z} = \dfrac{\phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of crab captured	H.3

is the number of crab classified in that state that were *captured* by fishery *f*, where $F^T_{y,x,m,s,z} = \sum_f F_{f,y,x,m,s,z}$ represents the total (across all fisheries) fishing mortality on those crab. The number of crab retained in fishery *f* classified as *x*, *m*, *s*, *z* in year *y* is given by

$r_{f,y,x,m,s,z} = \dfrac{\rho_{f,y,x,m,s,z} \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of retained crab	H.4

while the number of discarded crab, $d_{f,y,x,m,s,z}$, is given by

$d_{f,y,x,m,s,z} = \frac{(1-\rho_{f,y,x,m,s,z}) \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of discarded crab	H.5

and the discard mortality, $dm_{f,y,x,m,s,z}$, is

$dm_{f,y,x,m,s,z} = \frac{h_{f,y} \cdot (1-\rho_{f,y,x,m,s,z}) \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	discard mortality (numbers)	H.6

The capture rate $\phi_{f,y,x,m,s,z}$ (*not* the fishing mortality rate $F_{f,y,x,m,s,z}$) is modeled as a function separable into separate year and size components such that

$\phi_{f,y,x,m,s,z} = \phi_{f,y,x,m,s} \cdot S_{f,y,x,m,s,z}$	fishing capture rate	H.7

where $\phi_{f,y,x,m,s}$ is the fully-selected capture rate in year *y* and $S_{f,y,x,m,s,z}$ is the size-specific selectivity.

The fully-selected capture rate $\phi_{f,y,x,m,s}$ for *y* in time block *t* is parameterized in the following manner:

$\phi_{f,y,x,m,s} = \exp\left(\overline{lnC}_{f,t,x,m,s} + pDevsC_{f,y,x,m,s}\right)$	H.8

where the $pDevsC_{f,y,x,m,s}$ are elements for year *y* in time block *t* of a "devs" vectors representing annual variations from the ln-scale mean fully-selected capture rate $\overline{lnC}_{f,t,x,m,s}$. The latter is expressed in terms of model parameters as

$\overline{lnC}_{f,t,x,m,s} = pLnC_{f,t,x,m,s} + \sum_{i=1}^{4} \delta C^i_{f,t,x,m,s}$	H.9

where the $pLnC_{f,t,x,m,s}$ is the mean ln-scale capture rate (e.g., for mature males) and the $\delta C^i_{f,t,x,m,s}$ are ln-scale offsets.

I. Surveys

If $n_{y,x,m,s,z}$ is the number of crab classified as *x*, *m*, *s*, *z* in year *y* just prior to the prosecution of a survey, then the survey abundance, $a_{v,y,x,m,s,z}$, of crab classified in that state by survey *v* is given by

$a_{v,y,x,m,s,z} = q_{v,y,x,m,s,z} \cdot n_{y,x,m,s,z}$	survey abundance	I.1

where $q_{v,y,x,m,s,z}$ is the size-specific survey catchability on this component of the population.

The survey catchability $q_{v,y,x,m,s,z}$ is decomposed in the usual fashion into separate time block and size components such that, for *y* in time block *t*:

$q_{v,y,x,m,s,z} = q_{v,t,x,m,s} \cdot S_{v,t,x,m,s,z} \cdot A_{v,t,x,m,s,z}$	survey catchability	I.2

where $q_{v,t,x,m,s}$ is the fully-selected catchability in time block *t*, $S_{v,t,x,m,s,z}$ is the size-specific survey selectivity, and $A_{v,t,x,m,s,z}$ is the size-specific availability of the population to the survey. If the survey covers the complete stock area (as the standard NMFS EBS bottom trawl is assumed to do for Tanner crab), then $A_{v,t,x,m,s,z} \equiv 1$. However, if the survey does not cover the complete stock, as is the case with the BSFRF/NMFS side-by-side catchability studies, then $A_{v,t,x,m,s,z}$ needs to be estimated or assumed.

The fully-selected catchability $q_{v,t,x,m,s}$ is parameterized in a fashion similar to that for fully-selected fishery capture rates (except that annual "devs" are not included) in the following manner:

$q_{v,t,x,m,s} = \exp\left(pLnQ_{v,t,x,m,s} + \sum_{i=1}^{4} \delta Q^{i}_{v,t,x,m,s}\right)$	I.3

where the $pLnQ_{v,t,x,m,s}$ is the mean ln-scale catchability (e.g., for mature males) and the $\delta Q^{i}_{v,t,x,m,s}$ are ln-scale offsets.

J. Model fitting: objective function equations

The TCSAM02 model is fit by minimizing an objective function, $\wp$, with additive components consisting of: 1) negative log-likelihood functions based on specified prior probability distributions associated with user-specified model parameters, and 2) several negative log-likelihood functions based on input data components, of the form:

$\wp = -2\sum_{p} \lambda_p \cdot \ln(\wp_p) - 2\sum_{l} \lambda_l \cdot \ln(\mathcal{L}_l)$	model objective function	J.1

where $\wp_p$ represents the pth prior probability function, $\mathcal{L}_l$ represents the lth likelihood function, and the λ's represent user-adjustable weights for each component.

Prior Probability Functions

Prior probability functions can be associated with each model parameter or parameter vector by the user in the model input files (see Section L below for examples on specifying priors).

Likelihood Functions

The likelihood components included in the model's objective function are based on normalized size frequencies and time series of abundance or biomass from fishery or survey data. Survey data optionally consists of abundance and/or biomass time series for males, females, and/or all crab (with associated survey cv's), as well as size frequencies by sex, maturity state, and shell condition. Fishery data consists of similar data types for optional retained, discard, and total catch components.

Size frequency components

Likelihood components involving size frequencies are based on multinomial sampling:

$\ln(\mathcal{L}) = \sum_{y} n_{y,c} \cdot \sum_{z} \left\{p^{obs}_{y,c,z} \cdot \ln\left(p^{mod}_{y,c,z} + \delta\right) - p^{obs}_{y,c,z} \cdot \ln\left(p^{obs}_{y,c,z} + \delta\right)\right\}$	multinomial log-likelihood	J.2

where the y's are years for which data exists, "c" indicates the population component classifiers (i.e., sex, maturity state, shell condition) the size frequency refers to, $n_{y,c}$ is the classifier-specific effective sample size for year y, $p^{obs}_{y,c,z}$ is the observed size composition in size bin *z* (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p^{mod}_{y,c,z}$ is the corresponding model-estimated size composition, and δ is a small constant. The manner in which the observed and estimated size frequencies for each data component are aggregated (e.g., over shell condition) prior to normalization is specified by the user in the model input files. Data can be entered in input files at less-aggregated levels of than will be used in the model; it will be aggregated in the model to the requested level before fitting occurs.

Aggregated abundance/biomass components

Likelihood components involving aggregated (over size, at least) abundance and or biomass time series can be computed using one of three potential likelihood functions: the normal, the lognormal, and the "norm2". The likelihood function used for each data component is user-specified in the model input files.

The ln-scale normal likelihood function is

$\ln(\mathcal{L}^N)_c \;=-\dfrac{1}{2}\sum_y\left\{\dfrac{\left[a_{y,c}^{obs}-a_{y,c}^{mod}\right]^2}{\sigma_{y,c}^2}\right\}$	normal log-likelihood	J.3

where $a_{y,c}^{obs}$ is the observed abundance/biomass value in year *y* for aggregation level *c*, $a_{y,c}^{mod}$ is the associated model estimate, and $\sigma_{y,c}^2$ is the variance associated with the observation.

The ln-scale lognormal likelihood function is

$\ln(\mathcal{L}^{LN})_c \;=-\dfrac{1}{2}\sum_y\left\{\dfrac{\left[ln\left(a_{y,c}^{obs}+\delta\right)-ln\left(a_{y,c}^{mod}+\delta\right)\right]^2}{\sigma_{y,c}^2}\right\}$	lognormal log-likelihood	J.4

where $a_{y,c}^{obs}$ is the observed abundance/biomass value in year *y* for aggregation level *c*, $a_{y,c}^{mod}$ is the associated model estimate, and $\sigma_{y,c}^2$ is the ln-scale variance associated with the observation.

For consistency with TCSAM2013, a third type, the "norm2", may also be specified

$\ln(\mathcal{L}^{N2})_x \;=-\dfrac{1}{2}\sum_y\left[a_{y,x}^{obs}-a_{y,x}^{mod}\right]^2$	"norm2" log-likelihood	J.5

This is equivalent to specifying a normal log-likelihood with $\sigma_{y,x}^2 \equiv 1.0$. This is the standard likelihood function applied in TCSAM2013 to fishery catch time series.

Growth data

Growth (molt increment) data can be fit as part of a TCSAM02 model. Multiple datasets can be fit at the same time. The likelihood for each dataset (L_d) is based on the same gamma distribution used in the growth model:

$\mathrm{L}_d = -\sum_{i\in d} ln\left\{\Gamma\left(\dfrac{\tilde{z}_i-\bar{z}_{y_i,x_i,z_i}}{\beta_{y_i,x_i}}\right)\right\}$	gamma log-likelihood	J.6

where z_i and $\tilde{z}_i$ are the pre-molt and post-molt sizes for individual *i* (of sex x_i collected in year y_i) in dataset *d*, respectively, $\bar{z}_{y_i,x_i,z_i}$ is the predicted mean post-molt size for individual *i*, and β_{y_i,x_i} is the scale factor for the gamma distribution corresponding to individual *i*.

Maturity ogive data

Annual maturity ogive data, the observed proportions-at-size of mature crab in a given year, can also be fit as part of a TCSAM02 model. This data consists of proportions of mature crab observed within a size bin, as well as the total number of observations for that size bin. The proportions are assumed to represent the fraction of new shell mature crab (i.e., having gone through terminal molt within the previous growth season) to all new shell crab within the size bin in that year. Multiple datasets can be fit at the same time. The likelihood for each observation is based on a binomial distribution with sample size equal to the number of observations within the corresponding size bin, so the likelihood for each dataset (L_m) is given by:

$\mathrm{L}_m = \sum_{y,z} n_{y,z} \cdot \{p_{y,z}^{obs} \cdot \ln(p_{y,z}^{mod} + \delta) + (1 - p_{y,z}^{obs}) \cdot \ln(1 - p_{y,z}^{mod} + \delta)\}$	binomial log-likelihood	J.7

where *y* is a year, *z* is a size bin, $n_{y,z}$ is the total number of classified crab in size bin *z* in year *y*, $p_{y,z}^{obs}$ is the observed ratio of mature, new shell males to total new shell males in size bin z in year y, $p_{y,z}^{obs}$ is the corresponding model-predicted ratio, and δ is a small constant to prevent trying to calculate ln(0).

Effort data

In both TCSAM2013 and TCSAM02, fishery-specific effort data is used to predict annual fully-selected fishery capture rates for Tanner crab bycatch in the snow crab and Bristol Bay red king crab fisheries in the period before at-sea observer data is available (i.e., prior to 1991), based on the assumed relationship

$$F_{f,y} = q_f \cdot E_{f,y}$$

where $F_{f,y}$ is the fully-selected capture rate in fishery *f* in year *y*, q_f is the estimated catchability in fishery f, and $E_{f,y}$ is the reported annual, fishery-specific effort (in pots). In TCAM2013, the fishery *q*'s are estimated directly from the ratio of fishery mean *F* to mean *E* over the time period (t_f) when at-sea observer data is available from which to estimate the $F_{f,y}$'s as parameters:

$$q_f = \frac{\sum_{y \in t_f} F_{f,y}}{\sum_{y \in t_f} E_{f,y}}.$$

Note that, in this formulation, the fishery *q*'s are not parameters (i.e., estimated via maximizing the likelihood) in the model. In TCSAM2013, the time period over which *q* is estimated for each fishery is hard-wired. This approach is also available as an option in TCSAM02, although different time periods for the averaging can be specified in the model options file.

A second approach to effort extrapolation in which the fishery *q*'s are fully-fledged parameters estimated as part of maximizing the likelihood is provided in TCSAM02 as an option, as well. In this case, the effort data is assumed to have a lognormal error distribution and the following negative log-likelihood components are included in the overall model objective function:

$$L_f = \sum_y \frac{\left(\ln(E_{f,y} + \delta) - \ln\left(\frac{F_{f,y}}{q_f} + \delta\right)\right)^2}{2 \cdot \sigma_f^2}$$

where σ_f^2 is the assumed ln-scale variance associated with the effort data and δ is a small value so that the arguments of the ln functions do not go to zero.

Aggregation fitting levels

A number of different ways to aggregate input data and model estimates prior to fitting likelihood functions have been implemented in TCSAM02. These include:

Abundance/Biomass	Size Conpositions	
by	by	extended by
total	total	x
x		x, m
x, mature only	x	--
x, m		m
x, s		s
x, m, s	x, m	--
		s
	x, s	
	x, m, s	

where *x*, *m*, *s* refer to sex, maturity state and shell condition and missing levels are aggregated over. For size compositions that are "extended by" x, m, s, or $\{x, m\}$, this involves appending the size compositions corresponding to each combination of "extended by" factor levels, renormalizing the extended composition to sum to 1, and then fitting the extended composition using a multinomial likelihood.

K. Devs vectors

For TCSAM02 to accommodate arbitrary numbers of fisheries and time blocks, it is necessary to be able to define arbitrary numbers of "devs" vectors. This is currently not possible using the ADMB C++ libraries, so TCSAM02 uses an alternative implementation of devs vectors from that implemented in ADMB. For the 2017 assessment, an *n*-element "devs" vector was implemented using an *n*-element bounded parameter vector. with the final element of the "devs" vector defined as $-\sum_{n-1} v_i$, where v_i was the ith value of the parameter (or devs) vector, so that the sum over all elements of the devs vector was identically 0. Penalties were placed on the final element of the devs vector to ensure it was bounded in the same manner as the parameter vector. However, this approach was problematic when initializing the model with the values for the *n*-1 elements that defined the n-element devs vector, the value of the n-th element ($-\sum_{n-1} v_i$) was not guaranteed to satisfy the bounds placed on the vector. Thus, this approach was revised to allow specification of all n element values (the $v_n = -\sum_{n-1} v_i$ constraint was removed) while the likelihood penalty was changed to ensure the sum of the elements was 0. The new approach also has the advantage that it more closely follows the one used in ADMB to define "devs" vectors. Test runs with both approaches showed no effect on convergence to the MLE solution.

L. Priors for model parameters

A prior probability distribution can be specified for any element of model parameter. The following distributions are available for use as priors:

indicator	**parameters**	**constants**	**description**
none	none	none	no prior applied
ar1_normal	μ, σ	none	random walk with normal deviates
cauchy	x_0, γ	none	Cauchy pdf
chisquare	υ	none	χ^2 pdf
constant	min, max	none	uniform pdf
exponential	λ	none	exponential pdf
gamma	r, μ	none	gamma pdf
invchisquare	υ	none	inverse χ^2 pdf

invgamma	r, μ	none	inverse gamma pdf
invgaussian	μ, λ	none	inverse Gaussian pdf
lognormal	median, CV	none	lognormal pdf
logscale_normal	median, CV	none	normal pdf on ln-scale
normal	μ, σ	none	normal pdf
scaled_invchisquare	υ, s	none	inverse χ^2 scaled pdf
scaledCV_invchisquare	υ, CV	none	inverse χ^2 pdf, scaled by CV
t	υ	none	t distribution
truncated_normal	μ, σ	min, max	truncated normal pdf

M. Parameters and other information determined outside the model

Several nominal model parameters are not estimated in the model, rather they are fixed to values determined outside the model. These include Tanner crab handling mortality rates for discards in the crab fisheries (32.1%), the groundfish trawl fisheries (80%), and the groundfish pot fisheries (50%), as well the base rate for natural mortality (0.23 yr^{-1}). Sex- and maturity-state-specific parameters for individual weight-at-size have also been determined outside the model, based on fits to data collected on the NMFS EBS bottom trawl survey (Daly et al., 2016). Weight-at-size, $w_{x,m,z}$, is given by

$$w_{x,m,z} = a_{x,m} \cdot z^{b_{x,m}}$$

where

sex	**maturity state**	$\boldsymbol{a_{x,m}}$	$\boldsymbol{b_{x,m}}$
male	all states	0.000270	3.022134
female	immature	0.000562	2.816928
	mature	0.000441	2.898686

and size is in mm CW and weight is in kg.

N. OFL calculations and stock status determination

Overfishing level (OFL) calculations and stock status determination for Tanner crab are based on Tier 3 considerations for crab stocks as defined by the North Pacific Fishery Management Council (NPFMC; NPFMC 2016). Tier 3 considerations require life history information such as natural mortality rates, growth, and maturity but use proxies based on a spawner-per-recruit approach for F_{MSY}, B_{MSY}, and MSY because there is no reliable stock-recruit relationship. Equilibrium recruitment is assumed to be equal to the average recruitment over a selected time period (1982-present for Tanner crab). For Tier 3 stocks, the proxy for B_{MSY} is defined as 35% of longterm (equilibrium) mature male biomass (MMB) for the unfished stock (B_0). The proxy F_{MSY} for Tier 3 stocks is then the directed fishing mortality rate that results in $B_{35\%}$ (i.e., $F_{35\%}$), while the MSY proxy is the longterm total (retained plus discard) catch mortality resulting from fishing at F_{MSY}. The OFL calculation for the upcoming year is based on a sloping

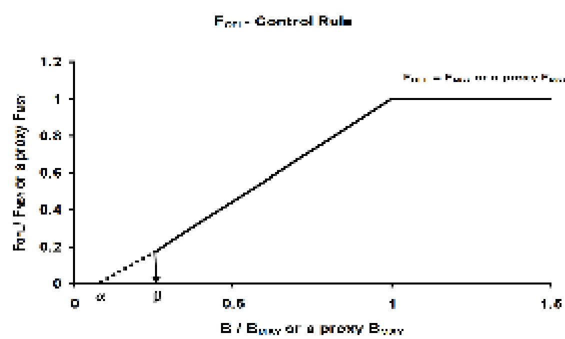

Fig. 2. The F_{OFL} harvest control rule.

harvest control rule for F_{OFL} (Fig. 2), the directed fishing mortality rate that results in the OFL. If the "current" MMB (projected to Feb. 15 of the upcoming year under the F_{OFL}) is above B_{MSY} ($B_{35\%}$), then $F_{OFL}=F_{MSY}=F_{35\%}$. If the current MMB is between $\beta \cdot B_{MSY}$ and B_{MSY}, then F_{OFL} is determined from the slope of the control rule. In either of these cases, the OFL is simply the projected total catch mortality under directed fishing at F_{OFL}. If current MMB is less than $\beta \cdot B_{MSY}$, then no directed fishing is allowed (F_{OFL}=0) and the OFL is set to provide for stock rebuilding with bycatch in non-directed fisheries. Note that if current MMB is less than B_{MSY}, then the process of determining F_{OFL} is generally an iterative one.

Stock status is determined by comparing "current" MMB with the Minimum Stock Size Threshold (MSST), which is defined as $0.5xB_{MSY}$: if "current" MMB is below the MSST, then the stock is overfished—otherwise, it is not overfished.

N.1 Equilibrium conditions

Both OFL calculations and stock status determination utilize equilibrium considerations, both equilibrium under unfished conditions (to determine B_0 and $B_{35\%}$) and under fished conditions (to determine $F_{35\%}$). For Tier 3 stocks, because there is no reliable stock-recruit relationship, analytical solutions can be found for equilibrium conditions for any fishing mortality conditions. These solutions are described below (the notation differs somewhat from that used in previous sections).

N.1.1 Population states

The Tanner crab population on July 1 can be characterized by abundance-at-size in four population states:

in– immature new shell crab
io– immature old shell crab
mn – mature new shell crab
mo – mature old shell crab

where each of these states represents a vector of abundance-at-size (i.e., a vector subscripted by size).

N.1.2 Population processes

The following processes then describe the dynamics of the population over a year:

S_1 – survival from start of year to time of molting/growth of immature crab, possibly including fishing mortality (a diagonal matrix)
S_2 – survival after time of molting/growth of immature crab to end of year, possibly including fishing mortality (a diagonal matrix)
Φ – probability of an immature crab molting (pr(molt|*z*), where *z* is pre-molt size; a diagonal matrix) (pr(molt|*z*) is assumed to be 1 in TCSAM02).
Θ – probability that a molt was terminal (pr(molt to maturity|*z*, molt), where *z* is post-molt size; a diagonal matrix)
T – size transition matrix (a non-diagonal matrix)
1 – identity matrix
R –number of recruits by size (a vector)

The matrices above are doubly–subscripted, and *R* is singly-subscripted, by size. Additionally, the matrices above (except for the identity matrix) can also be subscripted by population state (*in*, *io*, *mn*, *mo*) for generality. For example, survival of immature crab may differ between those that molted and those that skipped.

N.1.3 Population dynamics

The following equations then describe the development of the population from the beginning of one year to the beginning of the next:

$$in^{+} = R + S_{2in} \cdot \{(1-\Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + T_{io} \cdot (1-\Theta_{io}) \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \quad \text{(N.1)}$$
$$io^{+} = S_{2io} \cdot \{(1-\Phi_{in}) \cdot S_{1in} \cdot in + (1-\Phi_{io}) \cdot S_{1io} \cdot io\} \quad \text{(N.2)}$$
$$mn^{+} = S_{2mn} \cdot \{\Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \quad \text{(N.3)}$$
$$mo^{+} = S_{2mo} \cdot \{S_{1mn} \cdot mn + S_{1mo} \cdot mo\} \quad \text{(N.4)}$$

where "+" indicates year+1 and all recruits (*R*) are assumed to be new shell.

N.1.4 Equilibrium equations

The equations reflecting equilibrium conditions (i.e., $in^{+} = in$, etc.) are simply:

$$in = R + S_{2in} \cdot \{(1-\Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + (1-\Theta_{io}) \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \quad \text{(N.5)}$$
$$io = S_{2io} \cdot \{(1-\Phi_{in}) \cdot S_{1in} \cdot in + (1-\Phi_{io}) \cdot S_{1io} \cdot io\} \quad \text{(N.6)}$$
$$mn = S_{2mn} \cdot \{\Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \quad \text{(N.7)}$$
$$mo = S_{2mo} \cdot \{S_{1mn} \cdot mn + S_{1mo} \cdot mo\} \quad \text{(N.8)}$$

where *R* above is now the equilibrium (longterm average) number of recruits-at-size vector.

N.1.5 Equilibrium solution

The equilibrium solution can be obtained by rewriting the above equilibrium equations as:

$$in = R + A \cdot in + B \cdot io \quad \text{(N.9)}$$
$$io = C \cdot in + D \cdot io \quad \text{(N.10)}$$
$$mn = E \cdot in + F \cdot io \quad \text{(N.11)}$$
$$mo = G \cdot mn + H \cdot mo \quad \text{(N.12)}$$

where *A*, *B*, *C*, *D*, *E*, *F*, *G*, and *H* are square matrices. Solving for *io* in terms of *in* in eq. 10, one obtains

$$io = \{1-D\}^{-1} \cdot C \cdot in \quad \text{(N.13)}$$

Plugging eq. 13 into 9 and solving for *in* yields

$$in = \{1 - A - B \cdot [1-D]^{-1} \cdot C\}^{-1} \cdot R \quad \text{(N.14)}$$

Equations 13 for *io* and 14 for *in* can simply be plugged into eq. 11 to yield *mn:*

$$mn = E \cdot in + F \cdot io \quad \text{(N.15)}$$

while eq. 12 can then be solved for *mo,* yielding:

$$mo = \{1-H\}^{-1} \cdot G \cdot mn \quad \text{(N.16)}$$

where (for completeness):

$$A = S_{2in} \cdot (1-\Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \quad \text{(N.17)}$$
$$B = S_{2in} \cdot (1-\Theta_{io}) \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \quad \text{(N.18)}$$
$$C = S_{2io} \cdot (1-\Phi_{in}) \cdot S_{1in} \quad \text{(N.19)}$$
$$D = S_{2io} \cdot (1-\Phi_{io}) \cdot S_{1io} \quad \text{(N.20)}$$
$$E = S_{2mn} \cdot \Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \quad \text{(N.21)}$$

$$F = S_{2mn} \cdot \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \quad \text{(N.22)}$$
$$G = S_{2mo} \cdot S_{1mn} \quad \text{(N.23)}$$
$$H = S_{2mo} \cdot S_{1mo} \quad \text{(N.24)}$$

Note that Θ, the size-specific conditional probability of a molt being the terminal molt-to-maturity, is defined above on the basis of post-molt, not pre-molt, size. This implies that whether or not a molt is terminal depends on the size a crab grows into, not the size it at which it molted. An alternative approach would be to assume that the conditional probability of terminal molt is determined by pre-molt size. This would result in an alternative set of equations, but these can be easily obtained from the ones above by simply reversing the order of the terms involving T and Θ (e.g., the term $(1 - \Theta_{in}) \cdot T_{in}$ becomes $T_{in} \cdot (1 - \Theta_{in})$).

N.2 OFL calculations

Because a number of the calculations involved in determining the OFL are iterative in nature, the OFL calculations do not involve automatically-differentiated (AD) variables. Additionally, they are only done after model convergence or when evaluating an MCMC chain. The steps involved in calculating the OFL are outlined as follows:

1. The initial population numbers-at-sex/maturity state/shell condition/size for the upcoming year are copied to a non-AD array.
2. Mean recruitment is estimated over a pre-determined time frame (currently 1982-present).
3. The arrays associated with all population rates in the final year are copied to non-AD arrays for use in the upcoming year.
4. Calculate the average selectivity and retention functions for all fisheries over the most recent 5-year period.
5. Determine the average maximum capture rates for all fisheries over the most recent 5-year period.
6. Using the equilibrium equations, calculate B_0 for unfished stock (B35% = 0.35*B_0).
7. Using the equilibrium equations, iterate on the maximum capture rate for males in the directed fishery to find the one ($F_{35\%}$) that results in the equilibrium MMB = $B_{35\%}$.
8. Calculate "current" MMB under directed fishing at F=$F_{35\%}$ by projecting initial population (1) to Feb. 15.
    a. If current MMB > $B_{35\%}$, F_{OFL} = $F_{35\%}$. The associated total catch mortality is OFL.
    b. Otherwise
        i. set directed F based on the harvest control rule and the ratio of the calculated current MMB to $B_{35\%}$
        ii. recalculate current MMB
        iii. iterate i-iii until current MMB doesn't change between iterations. Then $F_{OFL} = F\ (< F_{35\%})$ and the OFL is the associated total (retained plus discard) catch mortality.

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Appendix 2:
Assessment Model Sensitivity to a Missing Terminal Year Survey

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1.0 Introduction

The 2020 NMFS Eastern Bering Sea shelf bottom trawl survey was cancelled due to concerns related to the Covid-19 pandemic. The survey had been conducted annually since 1975 and represents the primary source of fishery-independent data for the Tanner crab assessment. As such, the loss of the 2020 survey might be expected to have a substantial impact on the uncertainty associated with estimates of stock size and management-related quantities estimated by the Tanner crab assessment model. Consequently, the CPT and SSC requested that assessment authors conduct analyses to assess the additional uncertainty the loss of a survey in the terminal year of the assessment would have on estimates from the assessment model. This appendix presents the results of those analyses for Tanner crab.

2.0 Methods

The CPT requested that the likely uncertainty associated with the absence of a survey in the terminal year of the assessment be evaluated using two methods: 1) a retrospective analysis and 2) a sensitivity study using simulated survey data for 2020.

2.1 Retrospective analysis

A standard retrospective analysis consists of sequentially dropping the most recent year from the assessment and re-evaluating the estimates from the assessment model, repeating the process for a period of several years. Each year that is dropped from the assessment is referred to as a "peel", as are the results from the model run with data up to the "peeled" year. Large differences or trends in differences between estimates of a model quantity from the assessment and the peels can indicate underlying structural problems in the assessment model or conflicting information in the data.

The analysis the CPT requested consisted of comparing the results from each model run in a standard retrospective analysis using the accepted 2019 assessment model with a corresponding model run with the terminal year survey dropped from the model. The emphasis is not on the retrospective patterns (i.e., what happens when you sequentially remove each year of data) but on the differences between quantities from the model run that includes the terminal year survey and that which drops it. Here, I quantified the relative error (ε_y) in several management-related quantities (B_{MSY}, terminal year MMB, OFL, and the stock status) in terminal year y between the run with the terminal year survey (v_y) and the run with it dropped ($\tilde{v}_y$), where for each year for a given quantity

$$\varepsilon_y = 100 * \frac{\tilde{v}_y - v_y}{v_y}$$

The mean size of the errors across years (terminal years 2010-2019) for a given quantity was characterized using the relative root-mean-square error, ρ:

$$\rho = \sqrt{\frac{1}{10}\sum_{y=2010}^{2019} \varepsilon_y^2}$$

2.2 Simulation sensitivity analysis

The simulation sensitivity analysis the CPT requested was based on simulating NMFS survey data for 2020 under "reasonable" excursions from the assessment model estimates for 2020 and re-running the model while including the simulated 2020 survey data as "real". This method evaluates the impact of different hypothetical 2020 survey outcomes, and is based on a SSC recommendation in its June 2020 minutes. The method is as follows:

1. For the survey time series fit in proposed base model for this year, calculate the multiplicative residuals, $\tilde{v}_y / v_y$, where v_y is the observed survey biomass, and $\tilde{v}_y$ is the predicted survey biomass after fitting the model.
2. Obtain the 25th and the 75th percentiles of the multiplicative residuals.
3. Obtain the predicted survey values for 2020 from the base model run.
4. Multiply the predicted survey values for 2020 by the 25th and 75th percentile of the multiplicative residual to create low and high survey observations for 2020.
5. Assume a CV equal to the median survey CV and fit these values in two model runs.
6. Compare the differences in management-related quantities such as OFL and MMB among the three model runs.

The rationale for the 25th and 75th percentiles is that they are a typical high and low value for the survey. Large changes in management quantities such as OFL and MMB indicate high sensitivity.

The base model (19.03) fits survey biomass time series for all males, immature females, and mature females. The procedure described above was thus followed to generate bracketing simulated 2020 survey biomass data for these population components. The base model was then run for the two bracketing 2020 surveys and the remaining data, and the sensitivity of average recruitment, BMSY, terminal year MMB, OFL, and projected MMB to the bracketing 2020 survey data was examined.

3.0 Results

3.1 Retrospective analysis

The retrospective patterns for estimated recruitment and MMB are shown for the 2019 assessment in Figure 3.1.1. The corresponding patterns for estimated recruitment and MMB when the terminal year survey is missing are shown in Figure 3.1.2. The missing terminal year survey appears to affect the overall scale of the retrospective patterns in MMB somewhat, but not the pattern of interannual changes. In contrast, whether or not the terminal year survey is missing has a dramatic effect on the estimate of terminal year recruitment in several years. This, in turn, has a dramatic effect on the value of average recruitment (Figure 3.1.3) and associated management-related quantities such as B_{MSY}, because the averaging time period used in the Tanner crab assessment is 1982 to the terminal year and quantities like B_{MSY} scale with average recruitment.

However, using the averaging time period 1982 to (terminal year – 1) ameliorates the change in average recruitment due to a missing terminal year survey, as well as other management-related quantities (Figure 3.1.4[.1.2.6…]). In general, relative differences between management quantities calculated from models with and without a terminal year survey are small (Table 3.1.1), with root mean square relative errors on the order of 3%, with a maximum relative error of 7.26% in the 2016 estimate of average recruitment.

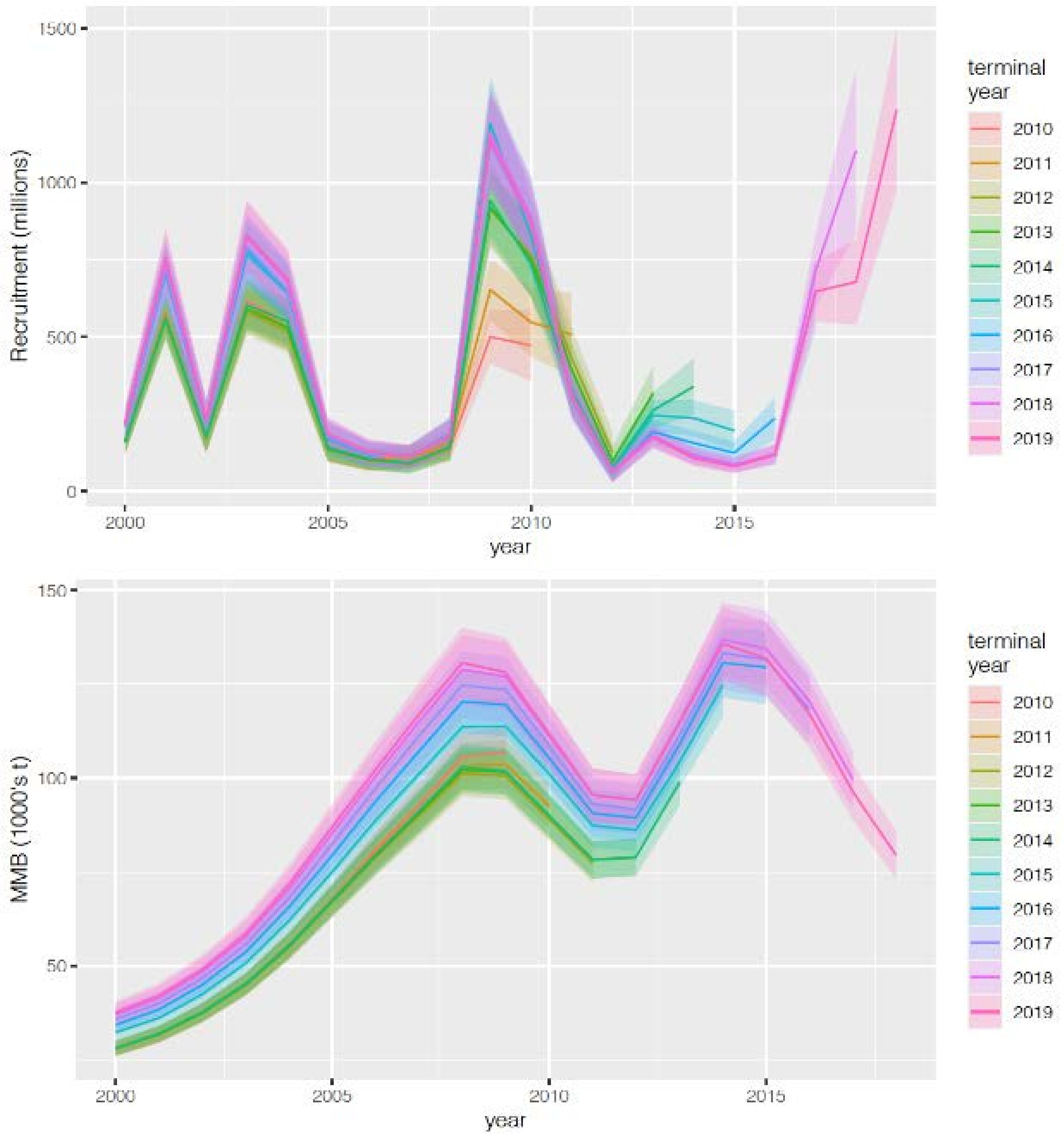

Fig. 3.1.1. 10-year retrospective patterns for the 2019 assessment model (19.03) in estimated recruitment (upper graph) and mature male biomass (MMB; lower graph). Shaded areas represent +/- 1 standard deviation of the estimate. All peels include the terminal year survey.

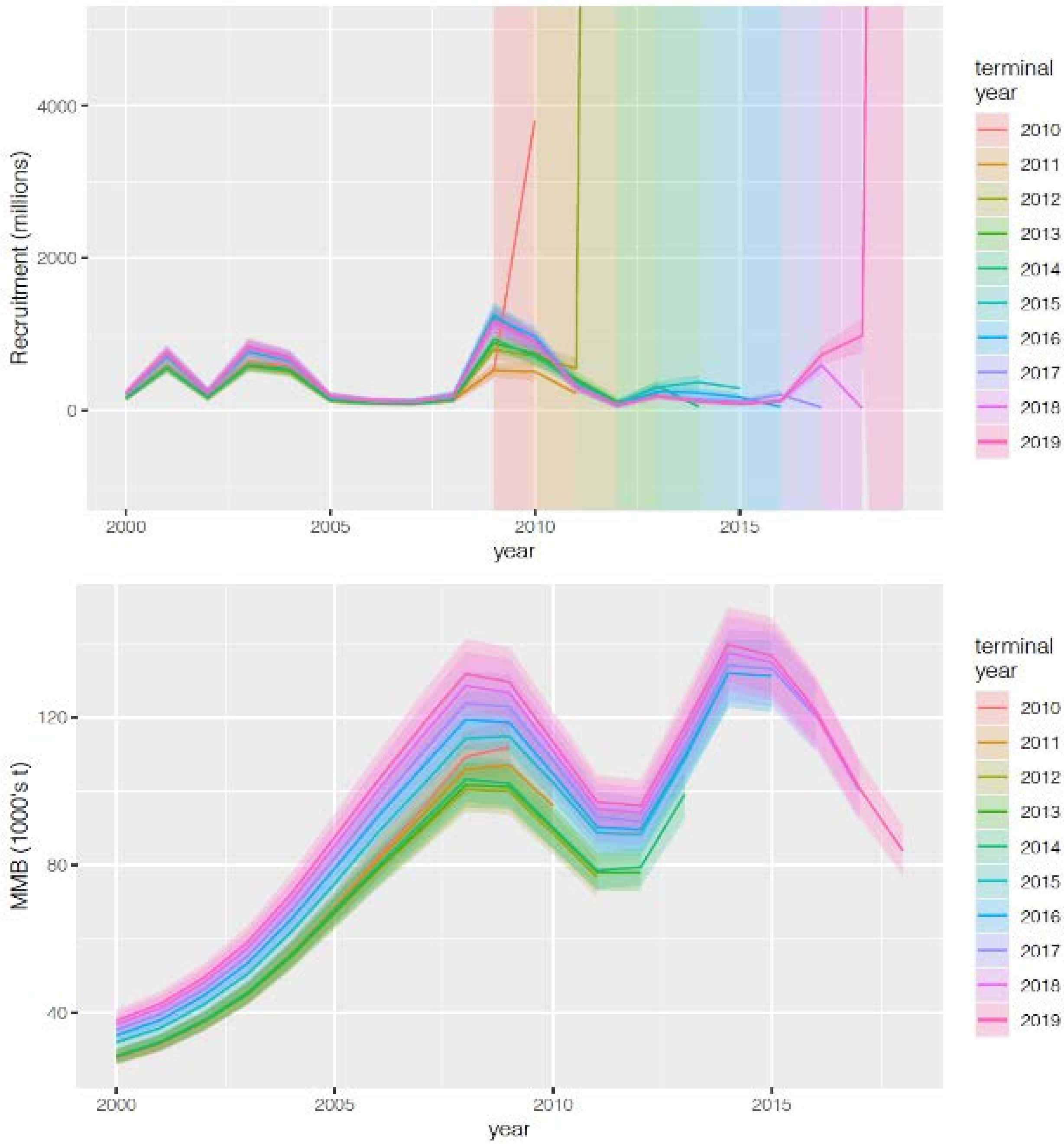

Fig. 3.1.2. 10-year retrospective patterns in estimated recruitment (upper graph) and mature male biomass (MMB; lower graph) for the 2019 assessment model (19.03) with missing terminal year survey. Shaded areas represent +/- 1 standard deviation of the estimate (note that the standard deviations for recruitment in the terminal year for the 2010, 2012, and 2019 peels are larger than the axis scaling). All peels exclude the corresponding terminal year survey.

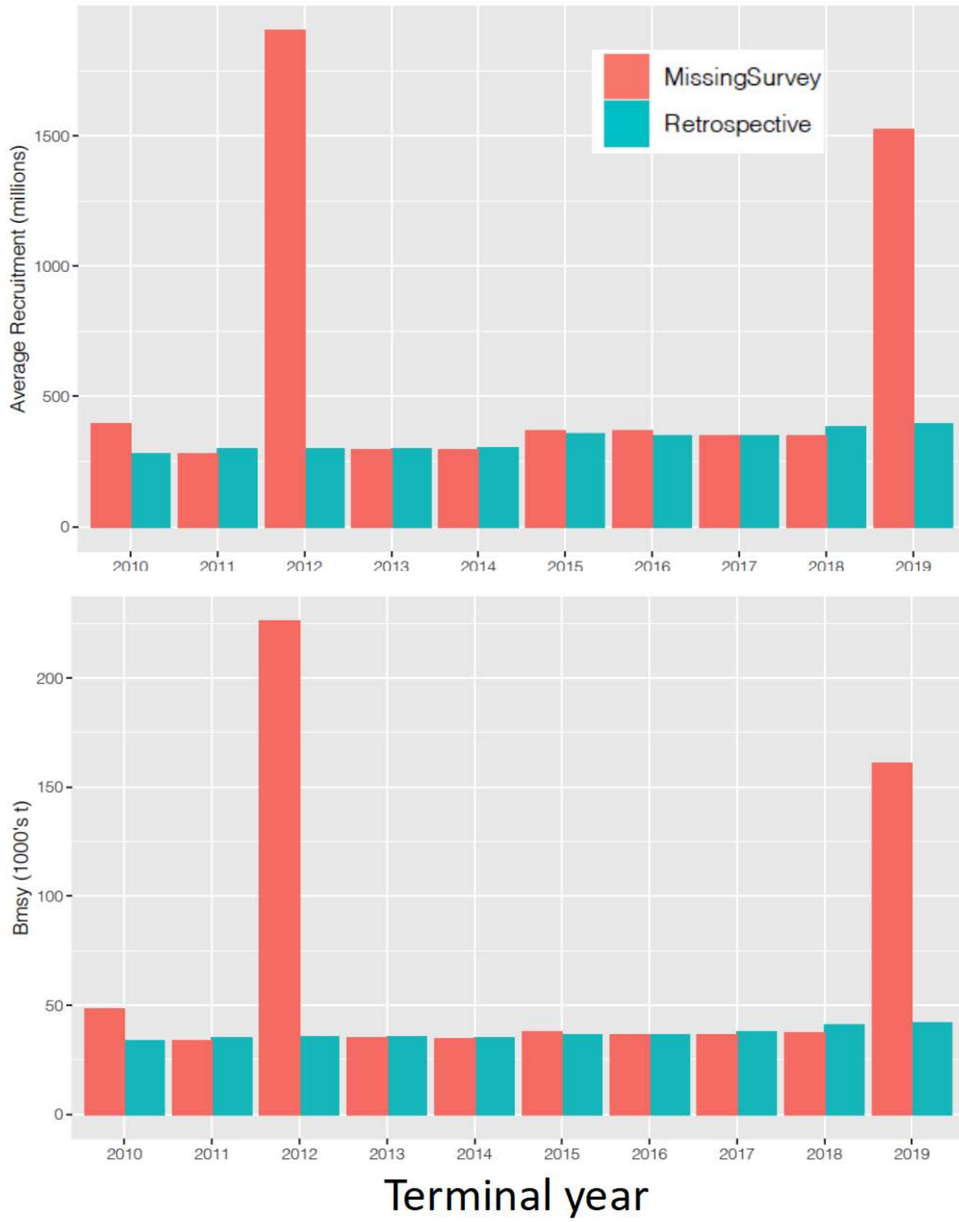

Fig. 3.1.3. Comparison, by terminal year, of estimated average recruitment and the associated B_{MSY} for the models with ("Retrospective") and without ("MissingSurvey") a terminal year survey. Average recruitment here is based on the standard time period used in the Tanner crab assessment, which is 1982 to the terminal year.

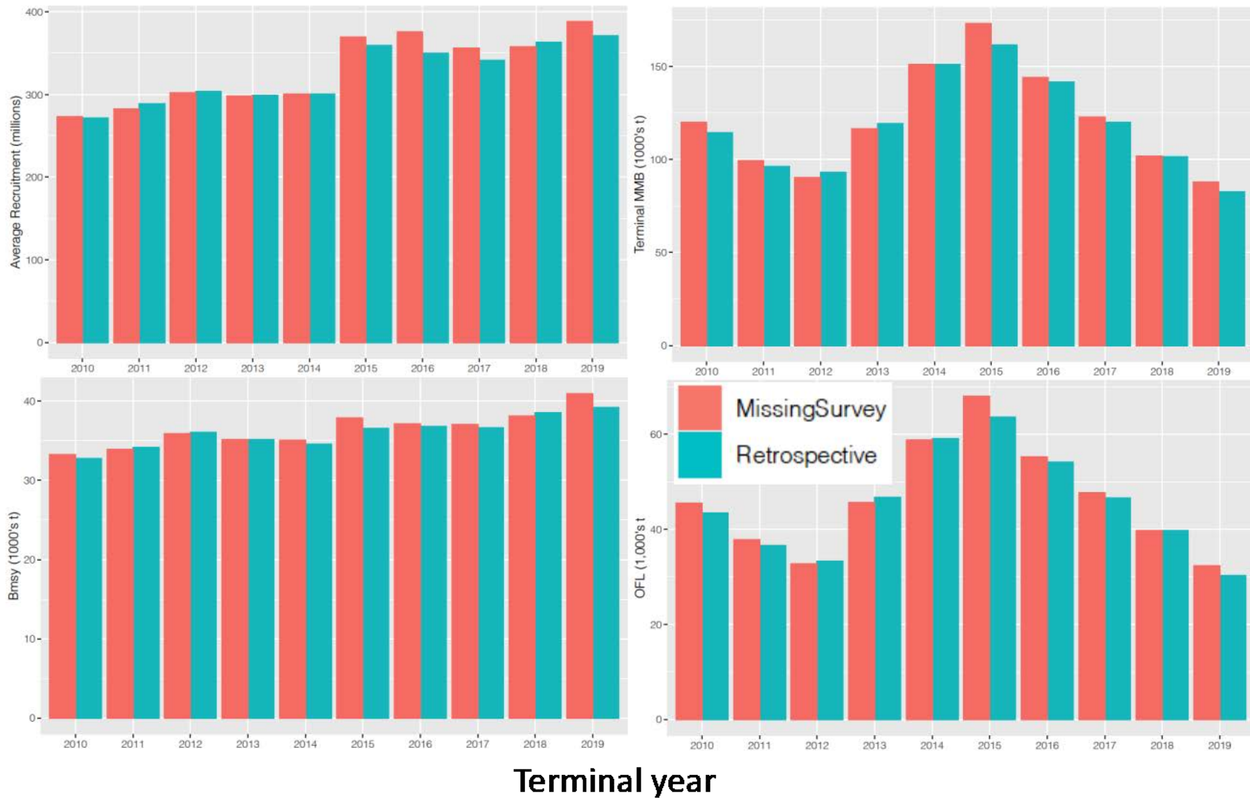

Fig. 3.1.4. Comparison, by terminal year, of estimated average recruitment (upper left), BMSY (lower left), terminal year MMB (upper right) and OFL (lower right) for the models with (“Retrospective”) and without (“MissingSurvey”) a terminal year survey. The terminal year recruitment estimate was excluded from the averaging period.

Table 3.1.1. Relative difference between retrospective peel with and without a terminal year survey. RMS: root mean square of relative differences. The period 1982 to (terminal year-1) is used to calculate average recruitment.

year	% Difference			
	average recruitment	Bmsy	Terminal MMB	OFL
2010	-0.43	-1.50	-4.78	-4.71
2011	2.24	0.66	-3.23	-3.41
2012	0.52	0.47	2.96	1.69
2013	0.30	-0.03	2.16	2.10
2014	-0.10	-1.61	-0.11	0.34
2015	-2.77	-3.56	-7.00	-6.83
2016	-7.26	-1.01	-1.82	-1.87
2017	-4.34	-1.04	-2.21	-2.35
2018	1.35	0.98	-0.43	-0.30
2019	-4.62	-4.34	-6.26	-6.84
RMS	3.29	2.00	3.79	3.79

3.2 Simulation sensitivity analysis

The base model (19.03) fits to male, immature female, and mature female survey biomass time series are shown in Figure 3.2.1. The resulting multiplicative differences are shown in Figure 3.2.2. Values for the 25% and 75% multiplicative quantiles for simulated survey biomass and the cv's used for the simulated survey data in the two bracketing model runs are given in the following table:

Table 3.2.1. 25% and 75% multiplicative quantiles used to determine the simulated survey biomass data, as well as the assumed cv's.

population category		multiplier		CV's
sex	maturity	25%	75%	
males	all	0.8103	1.2972	0.138
females	immature	0.6239	1.2772	0.206
	mature	0.7467	1.4653	0.216

Model fits from runs with the simulated 2020 surveys are compared with the base model run (without 2020 survey data) in Figure 3.2.3. Note that the base model run does not fit the observed survey biomass values for 2019 very well, and that it predicts overall increases in survey biomass for 2020 for all three stock components (ie., males, immature and mature females). The models with the simulated 2020 survey data fit the data reasonably well (i.e., they fall within the 80% confidence intervals) for males and immature females, but not for mature females. The model estimates for the latter quantity are almost the same for all three models, despite large differences in "observed" mature female survey biomass in 2020. At the scales used in the graphs, differences in the model predictions of the survey biomass time series among the three model runs can be traced back as far as 2014 for males and mature females. These are related to differences in estimated recruitment among the three models (Figure 3.2.4). While estimated recruitments for the terminal year vary widely, as one would expect given the differences in data for 2020, smaller differences among the estimates can be traced back to 2013 (entering the population in 2014), with estimates from SimSurvey75Q and SimSurvey25Q consistently higher and lower, respectively, than the base model without a 2020 survey.

Management-related quantities from the bracketing simulations and the base model are documented in Table 3.2.2 and illustrated in Figure 3.2.5. Differences among the models are primarily driven by the different estimates of average recruitment (the terminal year estimate of recruitment was dropped from the averaging period), with differences ranging up to 20% for equilibrium-related abundance/biomass quantities (average recruitment, B_{100} and B_{MSY}, and MSY). The differences in terminal year MMB are fairly small (<5%). One "twist" to the results here is that the OFL for both models with simulated 2020 surveys is less than the base case, with differences < 3%. This is due to the sloping control rule coming into effect for SimSurvey75Q (status<1), reducing F_{OFL} relative to F_{MSY}.

Table 3.2.2. Summary of management-related quantities from the simulation sensitivity model runs. "Status" is the ratio of projected MMB to B_{MSY}; the "kink" in the OFL control rule occurs where status=1.

management quantities	units	case			% difference from base	
		SimSurvey25Q	19.03_2020	SimSurvey75Q	SimSurvey25Q	SimSurvey75Q
average recruitment	millions	383.96	369.79	440.37	3.8	19.1
B100	1000's t	115.39	110.95	132.64	4.0	19.6
Bmsy	1000's t	40.39	38.83	46.42	4.0	19.6
terminal MMB	1000's t	77.76	75.43	79.15	3.1	4.9
Fmsy	per year	1.14	1.14	1.14	-0.1	-0.2
MSY	1000's t	18.90	18.20	21.70	3.9	19.2
Fofl	per year	1.11	1.11	1.01	-0.4	-9.5
OFL	1000's t	26.15	25.54	25.04	2.4	-2.0
projected MMB	1000's t	39.38	37.98	41.62	3.7	9.6
status	--	0.98	0.98	0.90	-0.3	-8.3

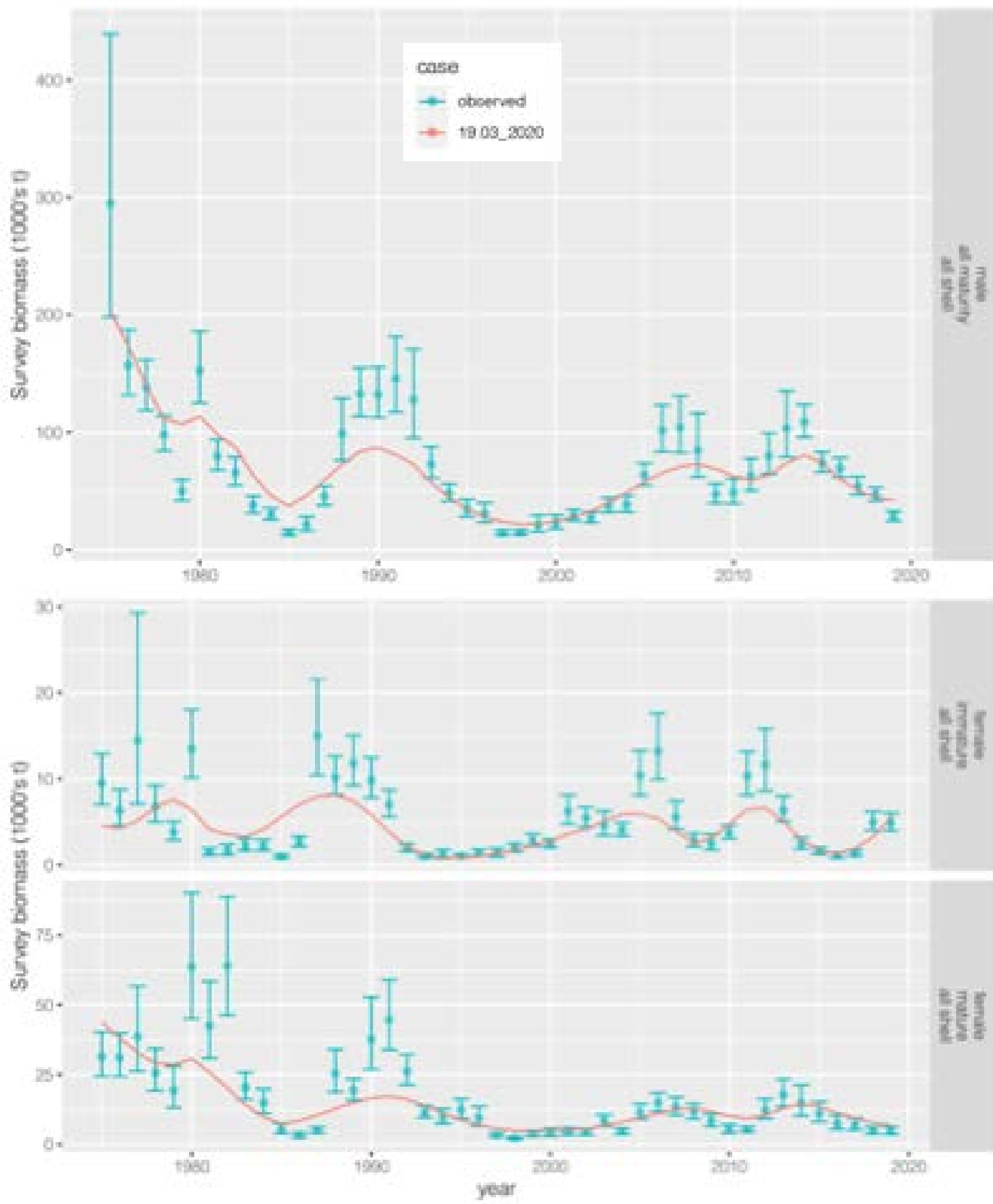

Fig. 3.2.1. Observed and predicted survey biomass time series for Model 19.03_2020 by population category. The graphs do not show the predicted 2020 survey biomass.

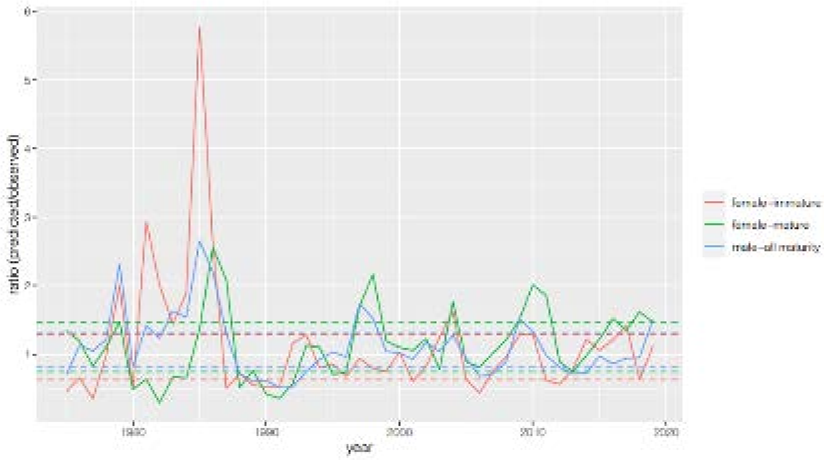

Fig. 3.2.2. Ratios (solid lines) of predicted to observed survey biomass values. Upper and lower dashed lines are 75% and 25% quantile values for the ratios. Colors indicate population category.

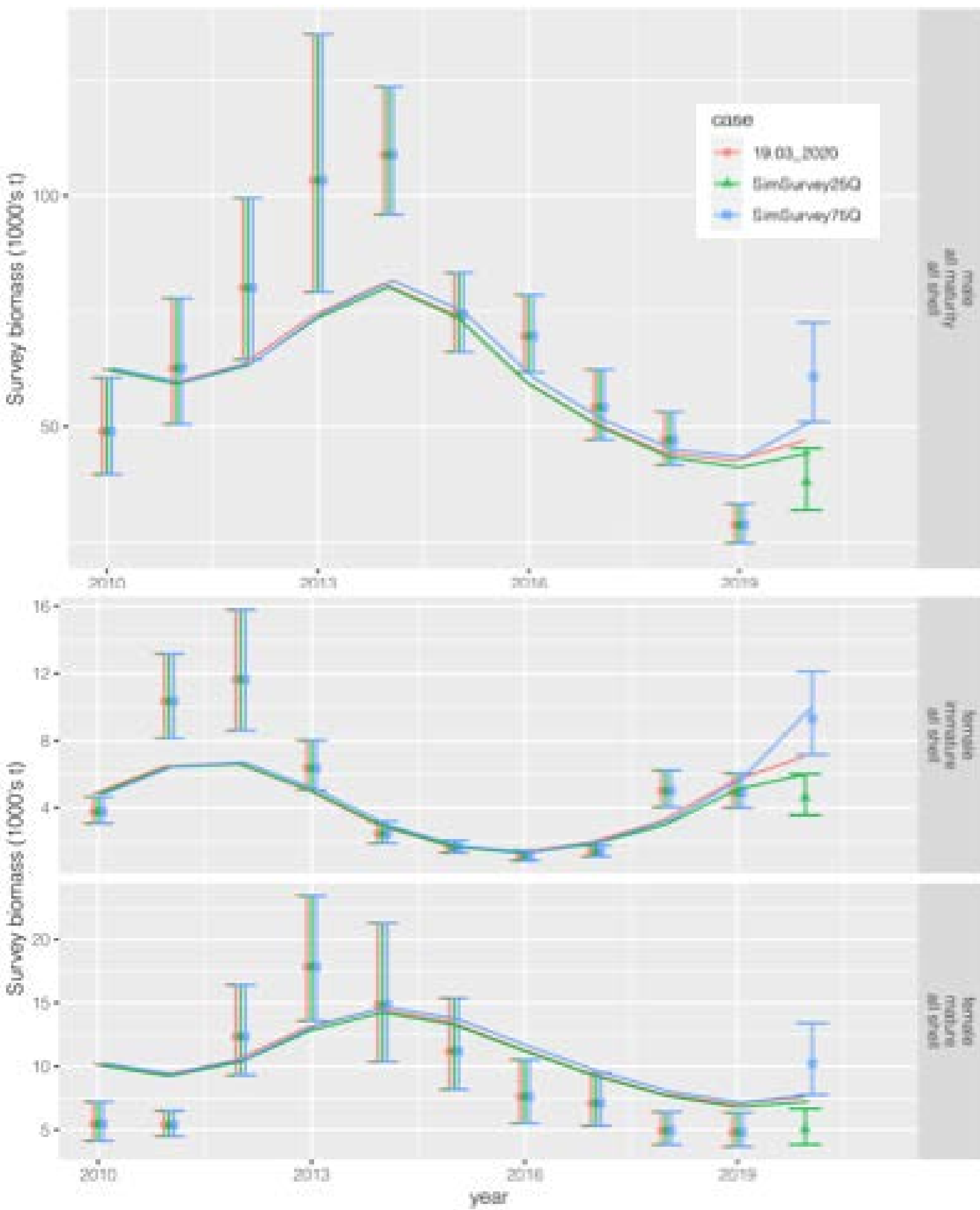

Fig. 3.2.3. Model fits (2000-2020; lines) to actual survey biomass data (1975-2019, all models; symbols) and simulated 2020 survey data (SimSurvey25Q and SimSurvey75Q models; symbols). SimSurveyQ25: simulated 2020 survey biomass data using the 25% multiplicative error quantile. SimSurveyQ75: simulated 2020 survey biomass data using the 75% multiplicative error quantile. Error bars indicate 80% confidence intervals.

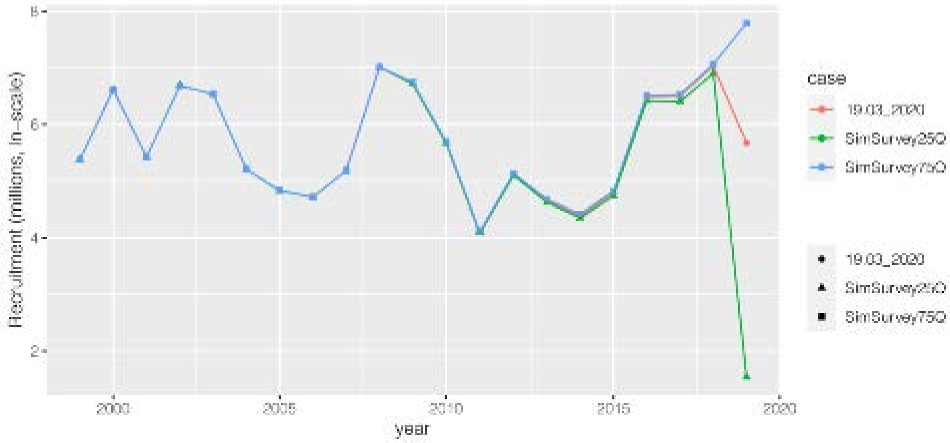

Figure 3.2.4. Comparison of estimated recruitment time series (only final 20 years shown) from the simulation sensitivity runs. The values are plotted on the natural log scale. Note that year indexing here is such that recruitment in year *y* enters the population in year *y*+1.

Fig. 3.2.5. Comparison of management-related quantities from the simulation sensitivity model runs. 19.03_2020: base model with 2020 data (no survey). SimSurveyQ25: simulated 2020 survey biomass data using the 25% multiplicative error quantile. SimSurveyQ75: simulated 2020 survey biomass data using the 75% multiplicative error quantile.

4.0 Discussion

Results from both the retrospective and simulation sensitivity analyses suggest that the principal effect on the Tanner crab assessment due to the missing 2020 NMFS EBS bottom trawl survey is the effect on estimated recruitment in the terminal year (i.e., recruits entering the population in 2020). The potential for vastly different estimates of terminal year recruitment is evident from both sets of analyses (see Figures 3.1.2, 3.1.3, and 3.2.4), and the estimated errors associated with these estimates reflect this uncertainty (Figure 3.1.2). However, errors in OFL related to the missing 2020 NMFS EBS bottom trawl survey will be relatively small, on the order of a few percent, if the period for determining average recruitment (used to scale B_{MSY}) is changed by dropping the (highly uncertain) estimate of recruitment in the terminal year. This is primarily because few recruitment-sized crab are taken as bycatch in the fisheries that capture Tanner crab and thus recruits contribute very little to the OFL. A secondary factor is that, in the current Tanner crab assessment model, terminal year recruitment has no effect on terminal year MMB (all recruits are immature) or projected MMB (very few males undergo the molt to maturity in the year following recruitment, and those that do are small and weigh much less than larger males). However, the missing survey and associated effects on the estimate of terminal year recruitment will play an increasingly important role in projecting the population forward in time beyond a single year, as the SSC has requested, as the estimated terminal year recruitment propagates into larger size classes in the population.

For this assessment, it is clear that management-related quantities need to be based on a recruitment-averaging period from which the terminal year is dropped. The BBRKC and snow crab assessments do not include the terminal year estimate of recruitment in the averaging periods used in those assessments, so this change has the added effect of bringing the Tanner crab assessment more in line with other Tier 3 assessments.

Appendix 3:
Estimating the Availability of Tanner Crab in the BSFRF Side-by-Side Studies

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Introduction

The NMFS eastern Bering Sea shelf (EBS) summer bottom trawl survey provides annual indices of the sex/size-specific abundance of Tanner crab (and other crab and groundfish stocks) on the shelf that are critical to estimating population size and productivity in the Tanner crab assessment model to provide annual advice to fishery managers on the maximum level of fishery catches that can be sustainably taken from the stock. However, these indices are relative, rather than absolute, estimates of abundance because the bottom trawl sampling gear the survey uses does not catch all Tanner crab in its path during a tow, and it catches relatively fewer small crab than large crab. Smaller crab, for example, may pass under the sampling gear or through the net mesh before entering the cod end. These indices can generally give useful information on the relative size of interannual fluctuations in different stock components, but it is necessary for them to be "scaled up" to absolute estimates of stock size in order to determine stock productivity and what a suitable catch limit should be.

In an integrated stock assessment, the assessment model typically estimates the so-called "catchability" of the survey simultaneous with estimating changes in stock abundance over time by incorporating additional information on natural mortality rates, growth, and fishery catches. As used here, "survey catchability" refers to the ratio of the numbers in a sex/size class seen in the survey, $N_{y,x,z}^{survey}$, to those in the stock, $N_{y,x,z}^{stock}$, in year *y*, where *x*, *z* denotes the se<u>x</u>/si<u>z</u>e class. Thus,

$$N_{y,x,z}^{survey} = C_{y,x,z}^{survey} \cdot N_{y,x,z}^{stock} \quad (1)$$

where $C_{y,x,z}^{survey}$ denotes survey catchability. In practice, survey catchability is assumed to be the same from year-to-year unless survey practices (e.g., gear, area surveyed, sampling protocols) have changed, so catchability will be denoted C_{z}^{survey}, where the *x* is now implied. Conceptually, then, the assessment model adjusts estimates of survey catchability, natural and fishing mortality rates, growth, and annual recruitment (the addition of new individuals to the stock) to determine the stock's population trajectory over time ($N_{y,x,z}^{stock}$) and find the best fit to the observed survey indices and fishery catches. In this framework, the mortality due to fishing is generally the only data that provides information on an absolute, rather than relative, scale. When fishing mortality is small, as it has been for Tanner crab since the mid-1990's, it can be difficult for the assessment model to unambiguously determine survey catchability and thus the absolute scale of the stock.

In order to better characterize the catchability of the NMFS survey, the Bering Sea Research Foundation (BSFRF) conducted annual paired tow experiments in coordination with the NMFS survey from 2013-2018 in which BSFRF tows were conducted "side-by-side" (SBS) with NMFS tows at standard survey stations. The BSFRF tows were conducted using a modified nephrops bottom trawl that (assumedly) captured all crab in its path. As such, the catchability for the BSFRF survey, C_{z}^{BSFRF}, was assumed to be 1 for all crab sex/size classes and it thus provided estimates of absolute stock size within the areas in which the SBS tows were conducted.

If the annual SBS studies had encompassed the entire stock, the resulting indices of abundance would have been absolute estimates of stock size. However, the studies were conducted within smaller areas that differed each year (Figure 1). As a consequence, the "availability" of crab to the SBS studies needs to be taken into account in order for these to provide information on absolute stock size. Here, "availability" as it pertains to a survey refers to the fraction of individuals in the surveyed population that are available to be captured in a survey (i.e., the fraction that could conceivably be caught). Availability is considered to be 1 when the survey area encompasses the entire population/stock area and no individuals occupy refuge habitats that cannot be surveyed (e.g., untrawlable rocky bottom). When a survey area does not encompass the entire population/stock area, then availability is less than 1. In addition, availability will be different for different components (e.g., males/females or small/large individuals) of a surveyed stock if the spatial distributions of the stock components are different. Availability may also change with time if the survey is conducted multiple times using different areas or if the spatial distribution of the stock changes. If availability is not considered to be 1 for a survey, it can incorporated into Eq. 1 in the form

$$N_z^{survey} = A_z^{survey} \cdot C_z^{survey} \cdot N_z^{stock} \tag{2}$$

where *A* represents sex/size-specific availability.

Using Eq. 2, relationships can be derived between the estimated annual survey abundances in the complete NMFS survey, in that part of the NMFS survey at which the SBS tows occurred, and in the BSFRF SBS survey. Availability in the NMFS EBS bottom trawl survey is considered to be 1 for all Tanner crab in the EBS stock. Because the SBS selectivity studies were conducted on smaller areas than the full survey, availability to the NMFS and BSFRF gear in these studies must be less than or equal to 1. The BSFRF gear is assumed to catch all crab within the footprint of a tow (i.e., it is non-selective and provides an estimate of absolute abundance), so the following relationships are assumed to hold:

$$N_z^{NMFS\,EBS} = 1 \cdot C_z^{NMFS} \cdot N_z^{EBS} \tag{3}$$

$$N_z^{NMFS\,SBS} = A_z^{SBS} \cdot C_z^{NMFS} \cdot N_z^{EBS} \tag{4}$$

$$N_z^{BSFRF\,SBS} = A_z^{SBS} \cdot 1 \cdot N_z^{EBS} \tag{5}$$

where A_z^{SBS} is the availability of crab in the SBS study area the assumptions $A_z^{EBS} \equiv 1$ and $C_z^{BSFRF} \equiv 1$ have been substituted into Eq.s 4 and 5.

Scenario M19F04 from last year's assessment (Stockhausen, 2019) included the 2013-2017 NMFS SBS and BSFRF SBS abundance indices in the model optimization in addition to the NMFS EBS survey indices and estimated both the NMFS survey catchability (C_z^{NMFS}) and the annual size-specific availability for the corresponding SBS study area (A_z^{SBS})—the former assuming a logistic form for survey catchability and the latter using a non-parametric, "smoothed" approach that placed fewer constraints on the shapes of the size-specific availability curves. The results were was not particularly satisfying (Stockhausen, 2019); it was felt that the redundancy expressed in Eq.s 3-5 potentially led to confounded parameter estimates that negated the information on absolute scale the SBFRF data. It was suggested that the annual availability curves did not need to be estimated inside the model, but could be determined empirically outside the model by noting that dividing Eq. 4 by Eq. 3 yields:

$$A_z^{SBS} = \frac{N_z^{NMFS\,SBS}}{N_z^{NMFS\,EBS}} \tag{6}$$

which allows one to estimate annual SBS availabilities outside the assessment model using the ratios of size compositions from the NMFS survey within the SBS to those from the full EBS.

Methods

Size compositions were calculated using the standard NMFS EBS shelf survey stratified, area-swept expansions to estimate annual survey abundance by sex and 5-mm CW size class for the entire EBS from the NMFS surveys in 2013-2017. Size compositions were then calculated using non-stratified, area-swept expansions of the data from NMSF survey stations at which SBS tows were conducted for each year. The expansions for the SBS areas were not stratified using the NMFS EBS shelf survey strata because this tended to overweight data from strata which included only one or two SBS stations.

Annual estimates of sex/size-specific availability were then calculated using Eq. 6. These estimates were then fit by generalized additive models using R (R Core Team, 2020) and the mgcv package (Wood, 2011; Wood, 2017). The sex-specific estimated availability for each year was fit using mgcv’s gam function, assuming a normal error distribution with a log link function and using a cubic spline smoothing term across size. The cubic splines were penalized using the conventional cubic spline penalty and the degree of smoothing was determined automatically.

Results

The NMFS SBS and EBS size compositions, and resulting “raw” empirical availability curves, from the 2013-2017 SBS selectivity studies are shown in Figures 2 and 3 below. Availability was generally small (< 0.25) for female Tanner crab smaller than 80 mm CW and increased with size in 2013-2015 when the study areas were in the inner and middle shelf domains near Bristol Bay. When the study area shifted west to the Pribilof Islands in 2017, availability increased for small females but decreased for large females. Availabilities for male Tanner crab showed similar patterns for small crab (< 100 mm), but availability tended to decrease with size for the largest males (> 150 mm CW), except in 2016. Clearly, though, the patterns are different between the sexes and on an annual basis.

The smooth fits determined by the GAM analysis are shown in the upper plots in Figures 4 and 5 for females and males, respectively. Residuals from the fits are plotted against fitted values and in histograms in the lower plots of Figures 4 and 5.

The values for the smooth fits at the mid-points of each model size bin were used in Scenario 20.07 to define the availability curves necessary to include the BSFRF SBS data in the model fitting procedure without having to include the NMFS SBS data, as well.

Acknowledgments

The author would like to thank Scott Goodman and Madi Shipley at Natural Resources Consulting, Inc. for providing the BSFRF SBS data used in the assessment.

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Figures

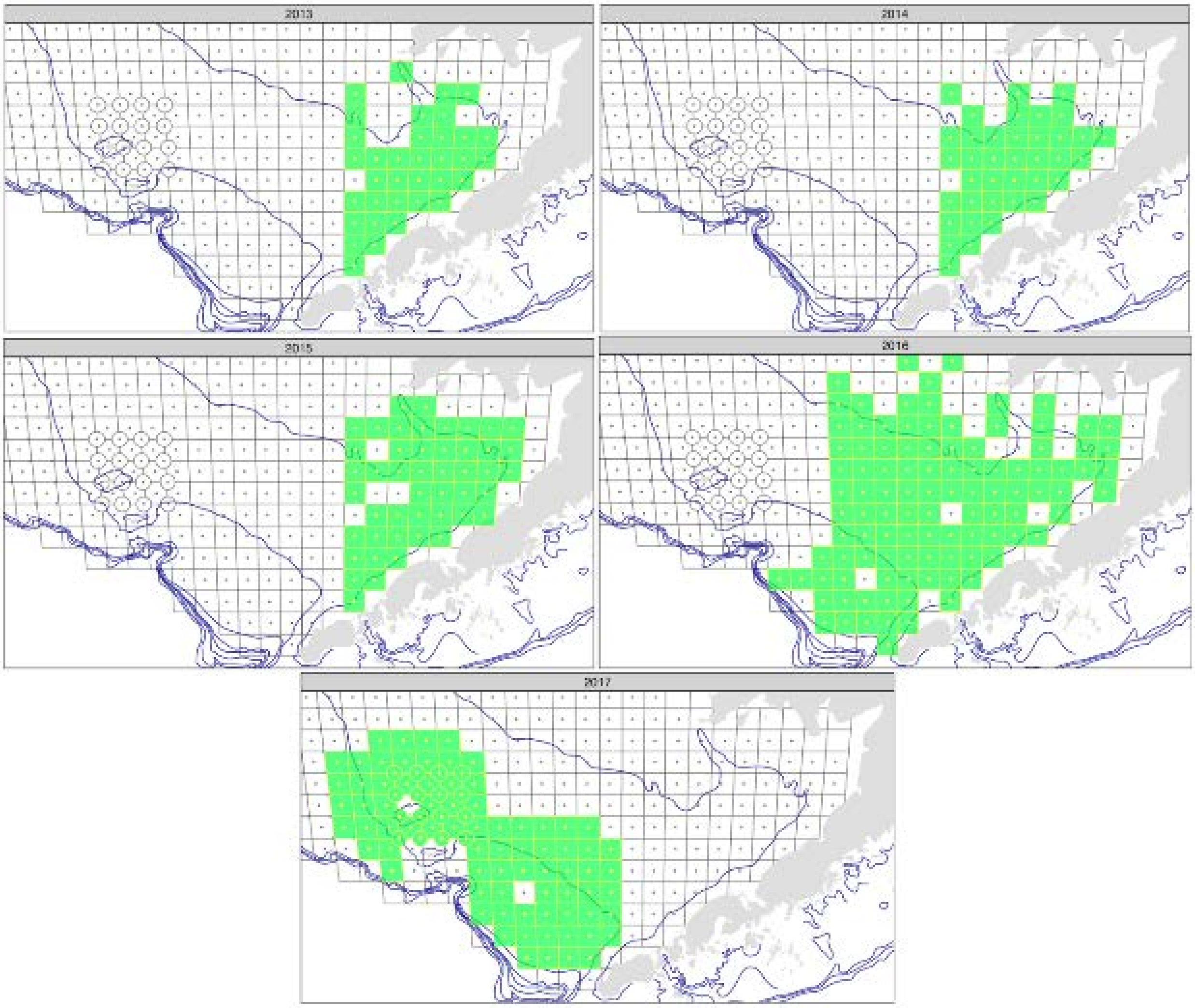

Figure 1. Spatial footprints (stations occupied in green) during the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. Squares and circles represent stations in the standard NMFS EBS bottom trawl survey (which extends beyond the area shown in the maps).

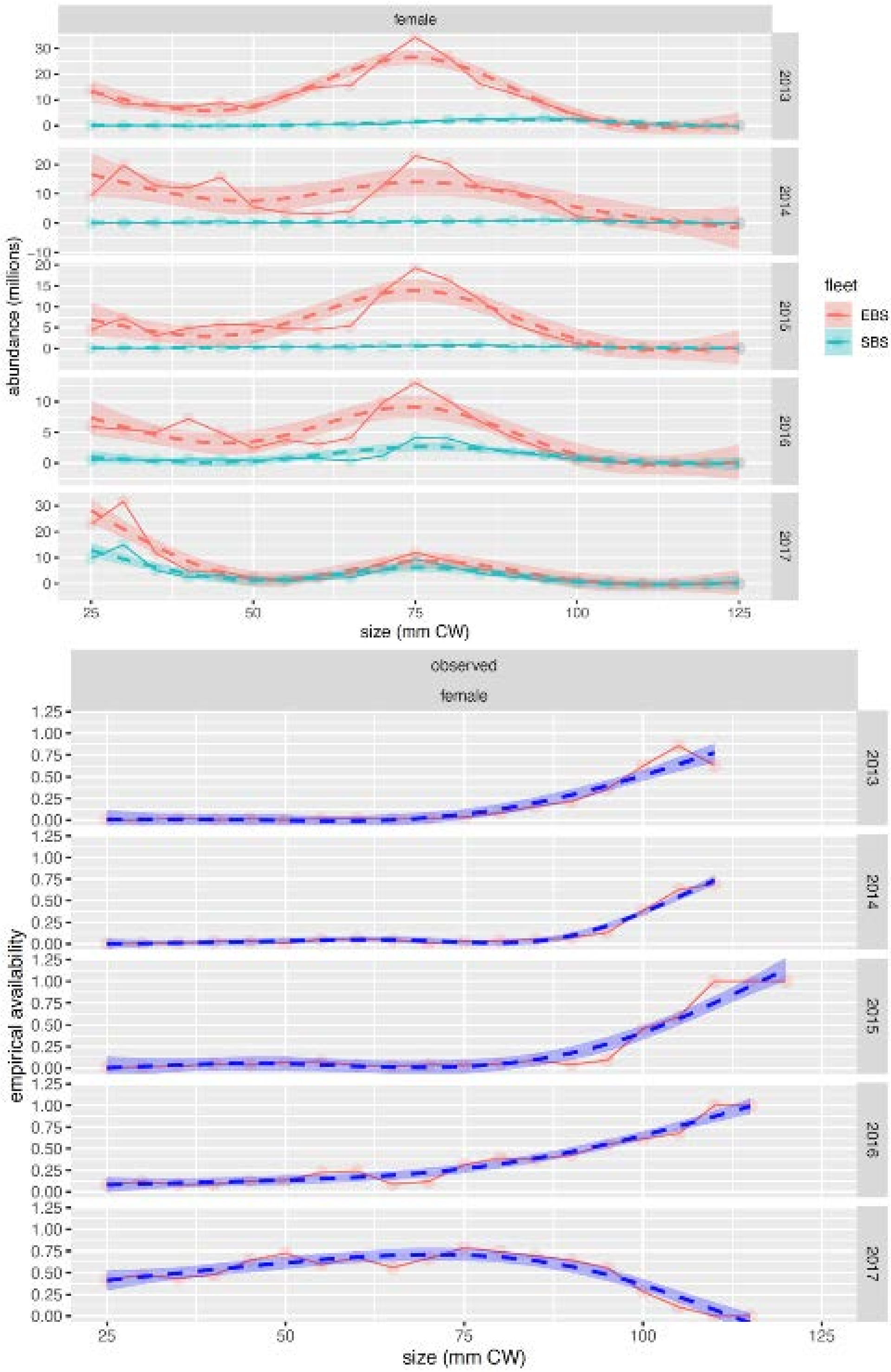

Figure 2. Upper plot: NMFS bottom trawl survey size compositions for female Tanner crab from the EBS (orange) and SBS (green) survey areas for 2013-2017. Solid lines and dots are “raw” estimates, dashed lines are smoothed fits using cubic splines. Lower plot: empirical availability curves calculated using Equation 6. Red lines and dots: “raw” curves, dashed lines and fills: smoothed fits.

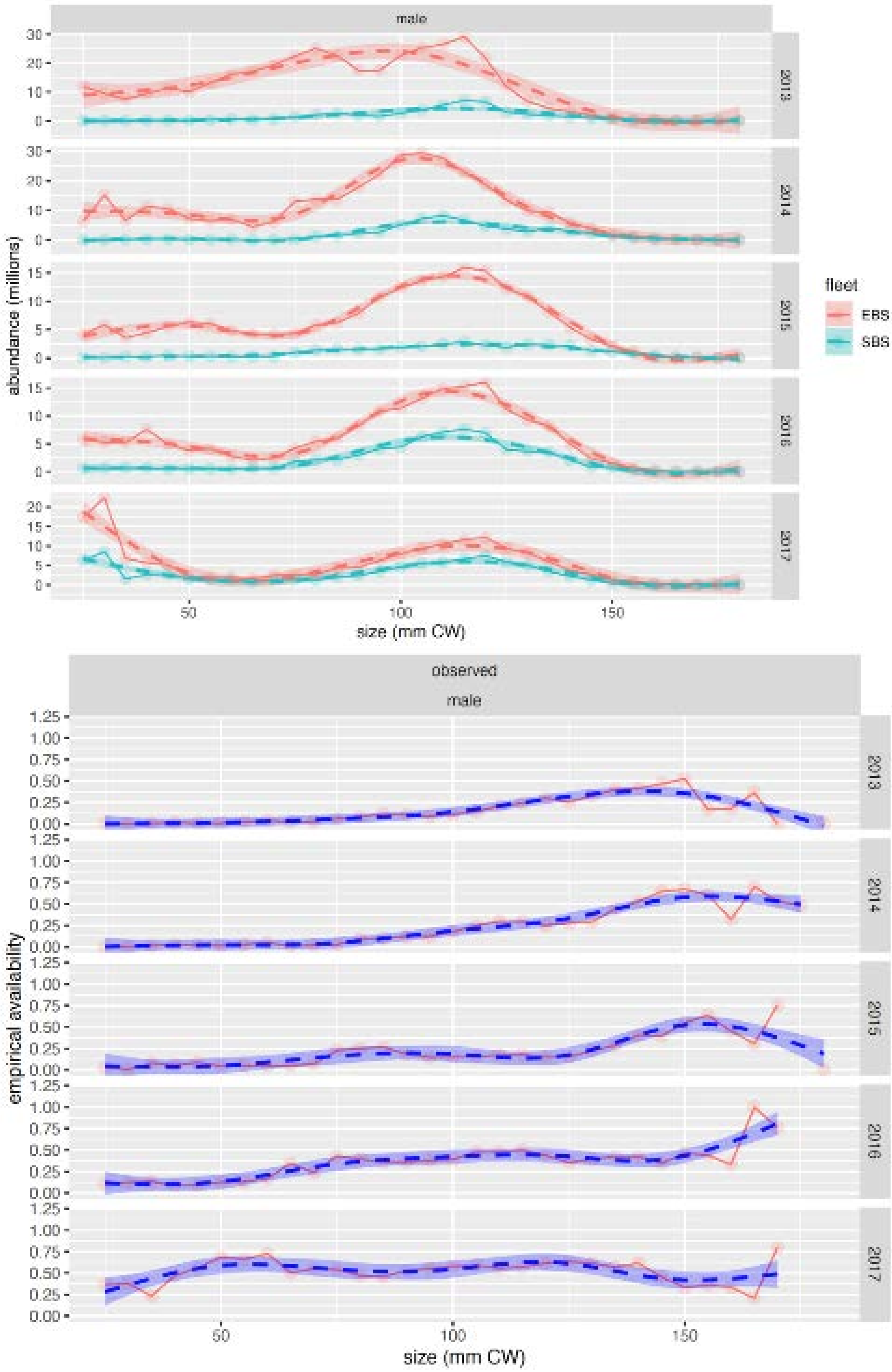

Figure 3. Upper plot: NMFS bottom trawl survey size compositions for male Tanner crab from the EBS (orange) and SBS (green) survey areas for 2013-2017. Solid lines and dots are "raw" estimates, dashed lines are smoothed fits using cubic splines. Lower plot: empirical availability curves calculated using Equation 6. Red lines and dots: "raw" curves, dashed lines and fills: smoothed fits.

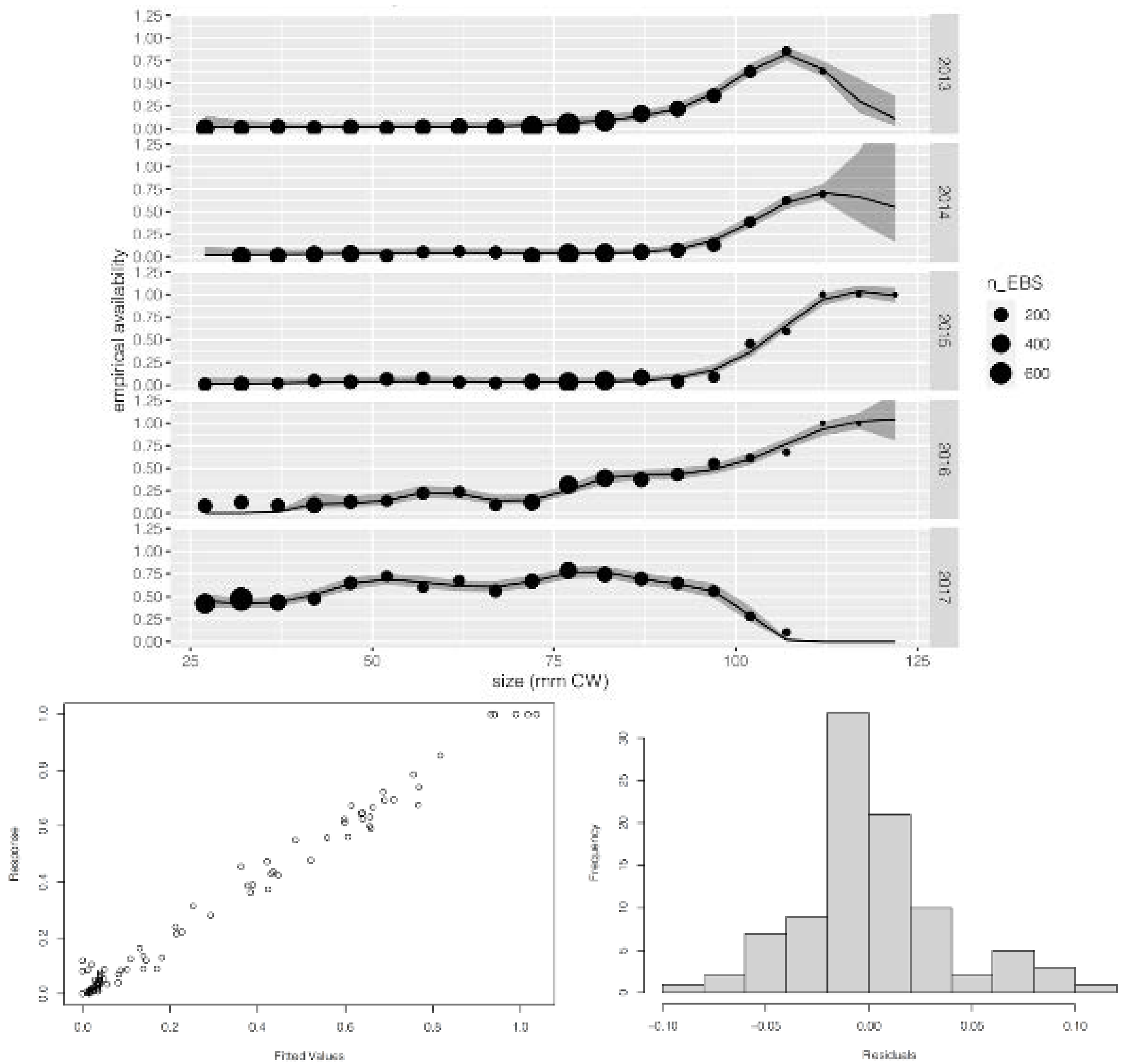

Figure 4. Upper: Empirical availability for females in the SBS study areas, by year. Upper: empirical values (points; size relative number of individuals sampled in the full survey) and the “best”-fitting GAM, by year, using cubic splines (lines; shading indicates 95% confidence intervals). Lower: diagnostic checks with response variables plotted against fitted values (left) and a histogram of residuals (right).

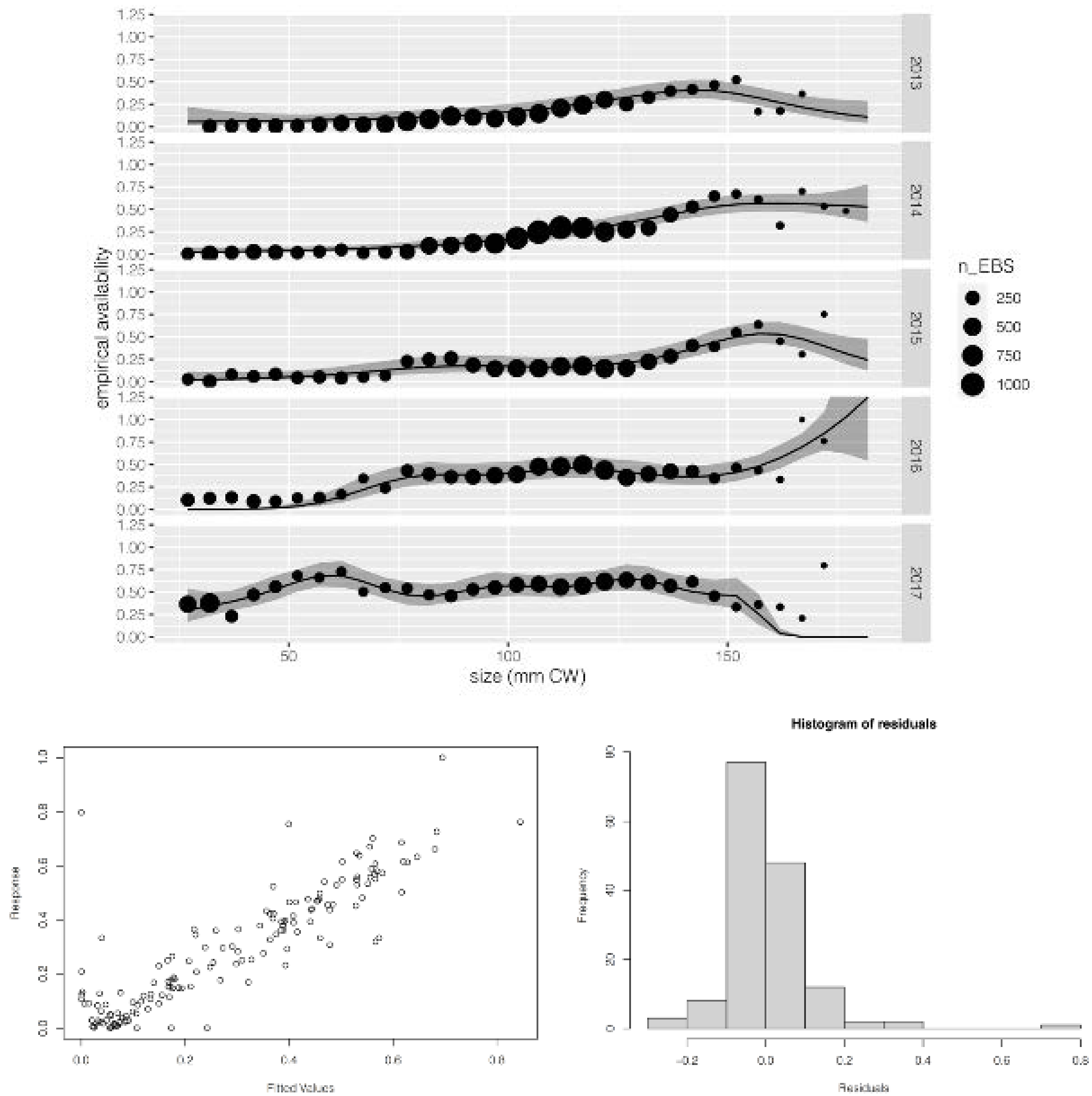

Figure 5. Upper: Empirical availability for males in the SBS study areas, by year. Upper: empirical values (points; size relative number of individuals sampled in the full survey) and the “best”-fitting GAM, by year, using cubic splines (lines; shading indicates 95% confidence intervals). Lower: diagnostic checks with response variables plotted against fitted values (left) and a histogram of residuals (right).

Appendix 4:
Estimated Survey Catchability for Tanner Crab in the Eastern Bering Sea Survey using Side-by-Side Gear Comparisons

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September 2020

Introduction

The NMFS eastern Bering Sea shelf (EBS) summer bottom trawl survey provides annual indices of the sex/size-specific abundance of Tanner crab (and other crab and groundfish stocks) on the shelf that are critical to estimating population size and productivity in the Tanner crab assessment model to provide annual advice to fishery managers on the maximum level of fishery catches that can be sustainably taken from the stock. However, these indices are relative, rather than absolute, estimates of abundance because the bottom trawl sampling gear the survey uses does not catch all Tanner crab in its path during a tow, and it catches relatively fewer small crab than large crab. Smaller crab, for example, may pass under the sampling gear or through the net mesh before entering the cod end. These indices can generally give useful information on the relative size of interannual fluctuations in different stock components, but it is necessary for them to be "scaled up" to absolute estimates of stock size in order to determine stock productivity and what a suitable catch limit should be.

In an integrated stock assessment, the assessment model typically estimates the so-called "catchability" of the survey simultaneous with estimating changes in stock abundance over time by incorporating additional information on natural mortality rates, growth, and fishery catches. As used here, "survey catchability" refers to the ratio of the numbers in a sex/size class seen in the survey, $N_{y,x,z}^{survey}$, to those in the stock, $N_{y,x,z}^{stock}$, in year *y*, where *x*, *z* denotes the se<u>x</u>/si<u>z</u>e class. Thus,

$$N_{y,x,z}^{survey} = C_{y,x,z}^{survey} \cdot N_{y,x,z}^{stock} \qquad (1)$$

where $C_{y,x,z}^{survey}$ denotes survey catchability. In practice, survey catchability is assumed to be the same from year-to-year unless survey practices (e.g., gear, area surveyed, sampling protocols) have changed, so catchability will be denoted C_z^{survey}, where the *x* is now implied. Conceptually, then, the assessment model adjusts estimates of survey catchability, natural and fishing mortality rates, growth, and annual recruitment (the addition of new individuals to the stock) to determine the stock's population trajectory over time ($N_{y,x,z}^{stock}$) and find the best fit to the observed survey indices and fishery catches. In this framework, the mortality due to fishing is generally the only data that provides information on an absolute, rather than relative, scale. When fishing mortality is small, as it has been for Tanner crab since the mid-1990's, it can be difficult for the assessment model to unambiguously determine survey catchability and thus the absolute scale of the stock.

In order to better characterize the catchability of the NMFS survey, the Bering Sea Research Foundation (BSFRF) conducted annual paired tow experiments in coordination with the NMFS survey from 2013-2018 in which BSFRF tows were conducted "side-by-side" (SBS) with NMFS tows at standard survey stations. The data from these SBS paired tows are used here to estimate sex- and size- specific catchability curves for the NMFS survey outside the assessment model. These curves are then used in Scenario 20.10 in this assessment in lieu of estimating the curves within the assessment.

Methods

Data

The BSFRF SBS study data for 2013-2017 was provided by Scott Goodman and Madi Shipley at NRC, Inc. Corresponding NMFS hauls were identified using common dates and station id's. Individual crab observations were binned by sex using 5-mm CW bins on a haul-by-haul basis, then expanded to the appropriate SBS area using standard area-swept expansions that also took sampling fractions into account.

Direct estimation of survey catchability

As used herein, "survey catchability" refers to the fraction of individuals in a population that are available to be captured in a survey or by a fishing fleet (i.e., the fraction that could conceivably be caught). In the case of surveys, availability is considered to be 1 when the survey area encompasses the entire population/stock area and no individuals occupy refuge habitats that cannot be surveyed (e.g., untrawlable rocky bottom). When a survey area does not encompass the entire population/stock area, then availability will be less than 1, and may be different depending on what component (e.g., sex, size class) of the stock is considered. In the assessment model, size-specific survey abundance is related to size-specific stock abundance by

$$N_z^{survey} = C_z^{survey} \cdot A_z^{survey} \cdot N_z^{stock} \tag{2}$$

where *z* represents size (i.e., carapace width), *N* represents size-specific abundance, *A* represents size-specific availability, and *C* represents size-specific survey catchability. It is worth pointing out that N_z^{survey} represents the survey catch abundance expanded, using area-swept methods, to the area corresponding to the availability.

Availability in the NMFS EBS bottom trawl survey is considered to be 1 for all Tanner crab in the EBS stock, because the survey area is considered to encompass the stock's distribution. Because the SBS selectivity studies were conducted on smaller areas than the full survey, availability to the NMFS and BSFRF gear in these studies may be less than 1, and may depend on size and sex. The BSFRF gear is assumed to catch all crab within the footprint of a tow (i.e., it is non-selective and provides an estimate of absolute abundance), so the following relationships are assumed in the assessment model to hold:

$$N_z^{NMFS\,EBS} = 1 \cdot C_z^{NMFS} \cdot N_z^{EBS} \tag{3}$$

$$N_z^{NMFS\,SBS} = A_z^{SBS} \cdot C_z^{NMFS} \cdot N_z^{EBS} \tag{4}$$

$$N_z^{BSFRF\,SBS} = A_z^{SBS} \cdot 1 \cdot N_z^{EBS} \tag{5}$$

where the assumptions $A_z^{EBS} \equiv 1$ and $C_z^{BSFRF} \equiv 1$ in the equations above.

Using Equations 2-4, it is also possible to estimate NMFS survey catchability (C_z^{NMFS}) directly from the SBS study data. Dividing Equation 3 by Equation 4 yields:

$$C_z^{NMFS} = \frac{N_z^{NMFS\,SBS}}{N_z^{BSFRF\,SBS}} \tag{6}$$

which provides an empirical estimate of NMFS survey catchability outside the assessment model.

Catch-comparison analysis

Equation 5 can also be applied to the individual SBS paired hauls singly or *en masse*, as in Kotwicki et al. (2017). When considered to represent a single set of paired-tow hauls, Equation 5 can be rewritten in terms of the numbers of crab sampled in a paired haul:

$$C_z^{NMFS} = \frac{N_z^{NMFS\,SBS}}{N_z^{BSFRF\,SBS}} = \frac{n_z^{NMFS\,SBS}.\left(\frac{A^{SBS}}{\alpha^{NMFS}.\Sigma^{NMFS}}\right)}{n_z^{BSFRF\,SBS}.\left(\frac{A^{SBS}}{\alpha^{BSFRF}.\Sigma^{BSFRF}}\right)} \tag{7}$$

where the n's are the actual numbers sampled by each gear, the α's are the areas swept by each gear, the Σ's are the sampling fractions for each haul type, and A^{SBS} represents the study area the catch is expanded to. Equation 6 can be rearranged (after some tedious algebra) so that the fraction of all crab caught in size class z that were caught by the NMFS gear, $\phi = \frac{n_z^{NMFS\,SBS}}{n_z^{NMFS\,SBS}+n_z^{BSFRF\,SBS}}$, can be expressed as:

$$\phi_z = \frac{n_z^{NMFS\,SBS}}{n_z^{NMFS\,SBS}+n_z^{BSFRF\,SBS}} = \frac{C_z^{NMFS}}{C_z^{NMFS}+R_\alpha \cdot R_\Sigma} \tag{8}$$

where $R_\alpha = \frac{\alpha^{BSFRF}}{\alpha^{NMFS}}$ is the ratio of areas swept by the two gears and $R_\Sigma = \frac{\Sigma^{BSFRF}}{\Sigma^{NMFS}}$ is the ratio of sampling fractions. The number of crab caught in size bin *z* by the NMFS gear, conditional on the total number of crab caught by both gears in *z* can be modeled as a binomially-distributed random variable with probability of success ϕ_z (Somerton et al., 2013). On the logit scale, Equation 7 becomes

$$logit(\phi_z) = \ln\left(\frac{\phi_z}{1-\phi_z}\right) = \ln(C_z^{NMFS}) - ln(R_\alpha \cdot R_\Sigma) \tag{9}$$

Fryer et al (2003) and Somerton et al. (2013) modeled $logit(\phi_z)$ as smooth functions of size and other haul-specific environmental characteristics (e.g., depth and sediment size). Here, I followed Brooks (2020) instead and modeled $\ln(C_z^{NMFS})$ directly as a smooth function of size. Thus, I fit different models of the form

$$logit(\phi_z) = \ln(C_z^{NMFS}) - ln(R_\alpha \cdot R_\Sigma) = s(z) - ln(R_\alpha \cdot R_\Sigma) \tag{10}$$

to the SBS data using the R package "selfisher" (R Core Team, 2020; Brooks, 2020), where $ln(R_\alpha \cdot R_\Sigma)$ was treated as a haul-specific offset and several candidate models for the smooth function *s*(*z*), including a logistic function and cubic splines with different degrees of freedom, were evaluated. Given time constraints, I was not able to test whether or not incorporating environmental characteristics such as haul depth or sediment size would be appropriate. This is an area for future research.

Data from SBS hauls taken during 2016 and 2017, in which the SBS studies were specifically focused on Tanner crab, were included in the model fits. Analyses were performed separately for males and females to develop sex-specific catchability curves. Because the assessment model assumes a single catchability curve applies (by sex) to the entire 1982-2019 time period, no year effects were included in the model fits. The model that "best" fit the data was identified from among the set of candidate models using BIC (Bayes Information Criterion).

Results

Direct estimates of survey catchability

The NMFS and BSFRF size compositions and resulting "raw" empirical catchability curves from the 2013-2017 SBS selectivity studies are shown in Figures 1 and 2. These empirical catchability curves exhibit a fair bit of interannual variability in size-specific catchability for both males and females. They also suggest that the shapes of the selectivity curves are not really logistic (in contrast to assumptions made in the current assessment model).

Catch-comparison analysis

The models for $\ln(C_z^{NMFS})$ that best fit the SBS haul data for 2016 and 2017 were cubic splines with 5 and 8 degrees of freedom for females and males, respectively (Tables 1 and 2; Figure3). The model comparisons found that logistic curves fit the data much worse for both sexes than did the best spline curve.

Acknowledgments

The author would like to thank Scott Goodman and Madi Shipley at Natural Resources Consulting, Inc. for providing the BSFRF SBS data used in the assessment.

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Tables

Table 1. Model fitting results for females. Best fitting model is in first row.

smooth type	degrees of freedom	delta BIC
cubic spline	5	0
	6	1.7
	7	4.6
	8	12
	10	18.9
	9	21.6
	4	36.8
	3	207.8
logistic	**2**	**779.2**

Table 2. Model fitting results for males. Best fitting model is in first row.

smooth type	degrees of freedom	delta BIC
cubic spline	8	0
	7	1.2
	9	7.2
	6	7.7
	10	15
	5	47.7
	4	166.6
	3	300.5
logistic	**2**	**654**

Figures

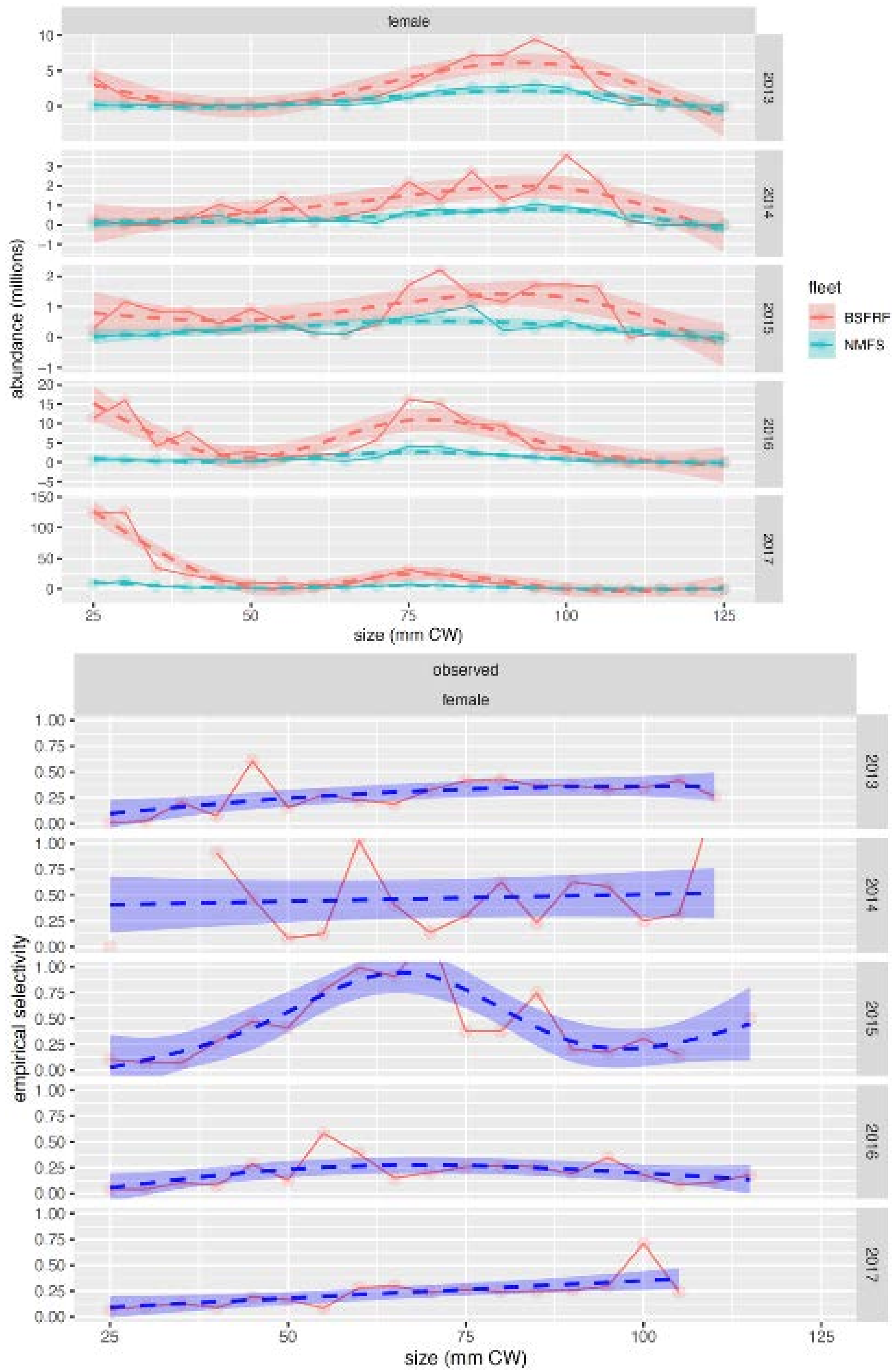

Figure 1. Upper: BSFRF (orange) and NMFS (green) size compositions for female Tanner crab from the SBS study areas for 2013-2017. Solid lines and dots are "raw" estimates, dashed lines are smoothed fits using cubic splines. Lower: empirical catchability curves calculated using Equation 5. Red lines and dots: "raw" curves, dashed lines and fills: smoothed fits.

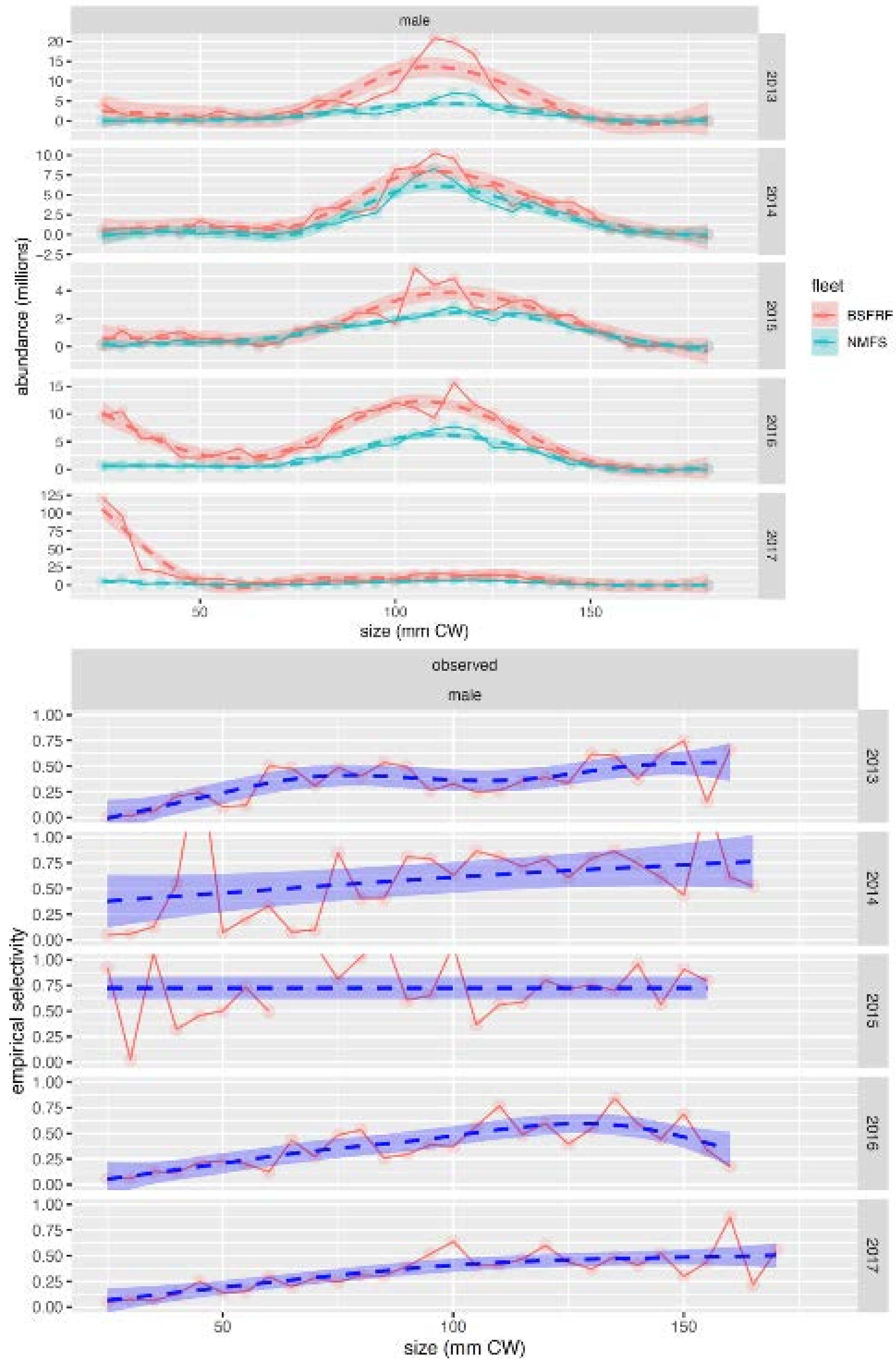

Figure 2. Upper: BSFRF (orange) and NMFS (green) size compositions for male Tanner crab from the SBS study areas for 2013-2017. Solid lines and dots are “raw” estimates, dashed lines are smoothed fits using cubic splines. Lower: empirical catchability curves calculated using Equation 5. Red lines and dots: “raw” curves, dashed lines and fills: smoothed fits.

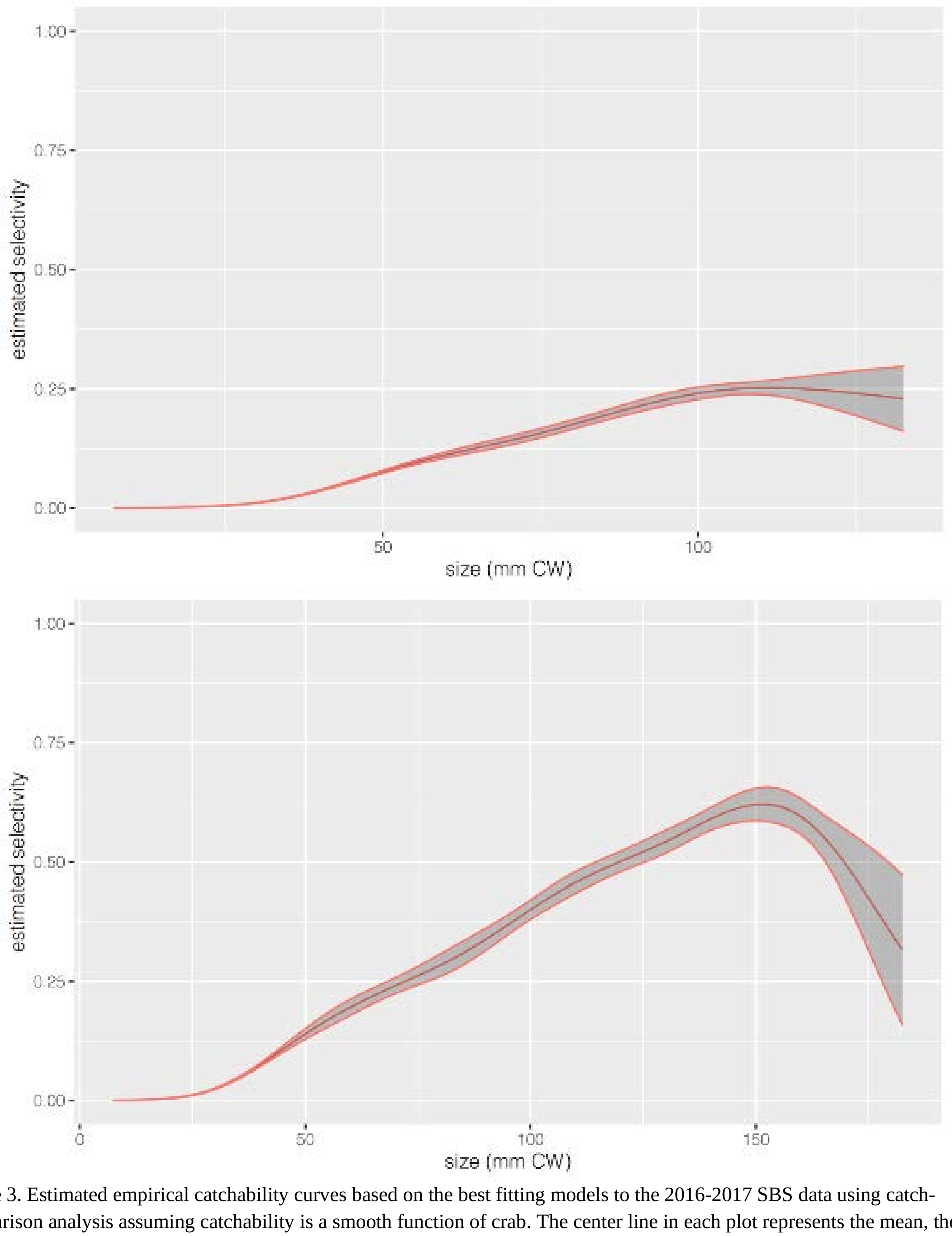

Figure 3. Estimated empirical catchability curves based on the best fitting models to the 2016-2017 SBS data using catch-comparison analysis assuming catchability is a smooth function of crab. The center line in each plot represents the mean, the fills represent 80% confidence intervals. Note the difference in x-axis scales.

Appendix 5: Fits to Aggregated Fishery Catch Data – 19.03(2020) vs 19.03 vs 20.07 vs 20.10

William Stockhausen

01 September, 2020

Contents

Model fits to aggregated fisheries catch data

Fits to the aggregated fisheries catch data available to the model(s) are presented in this section. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Fishery retained catch biomass

Fits

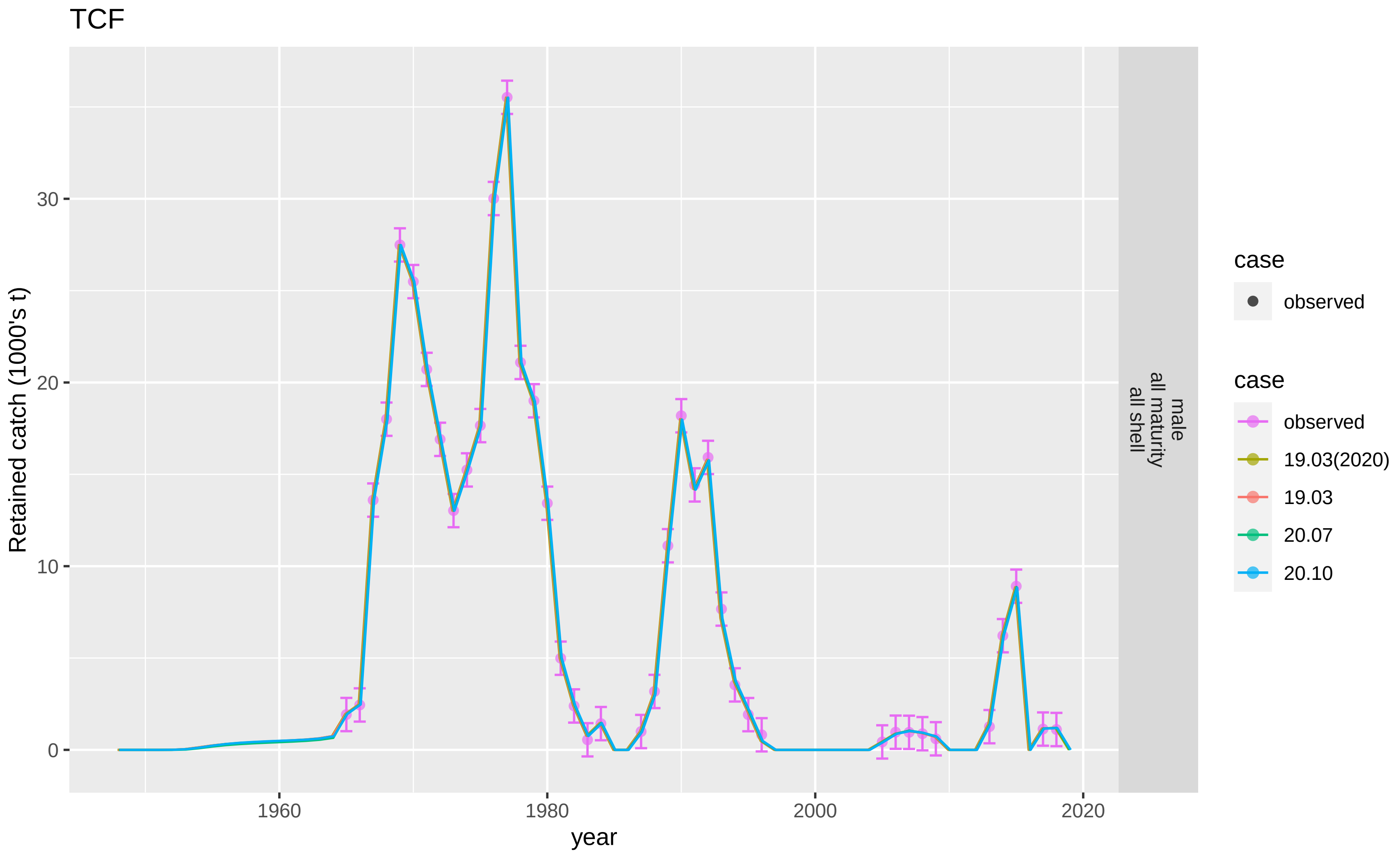

Figure 1: Comparison of observed and predicted male retained catch biomass for TCF.

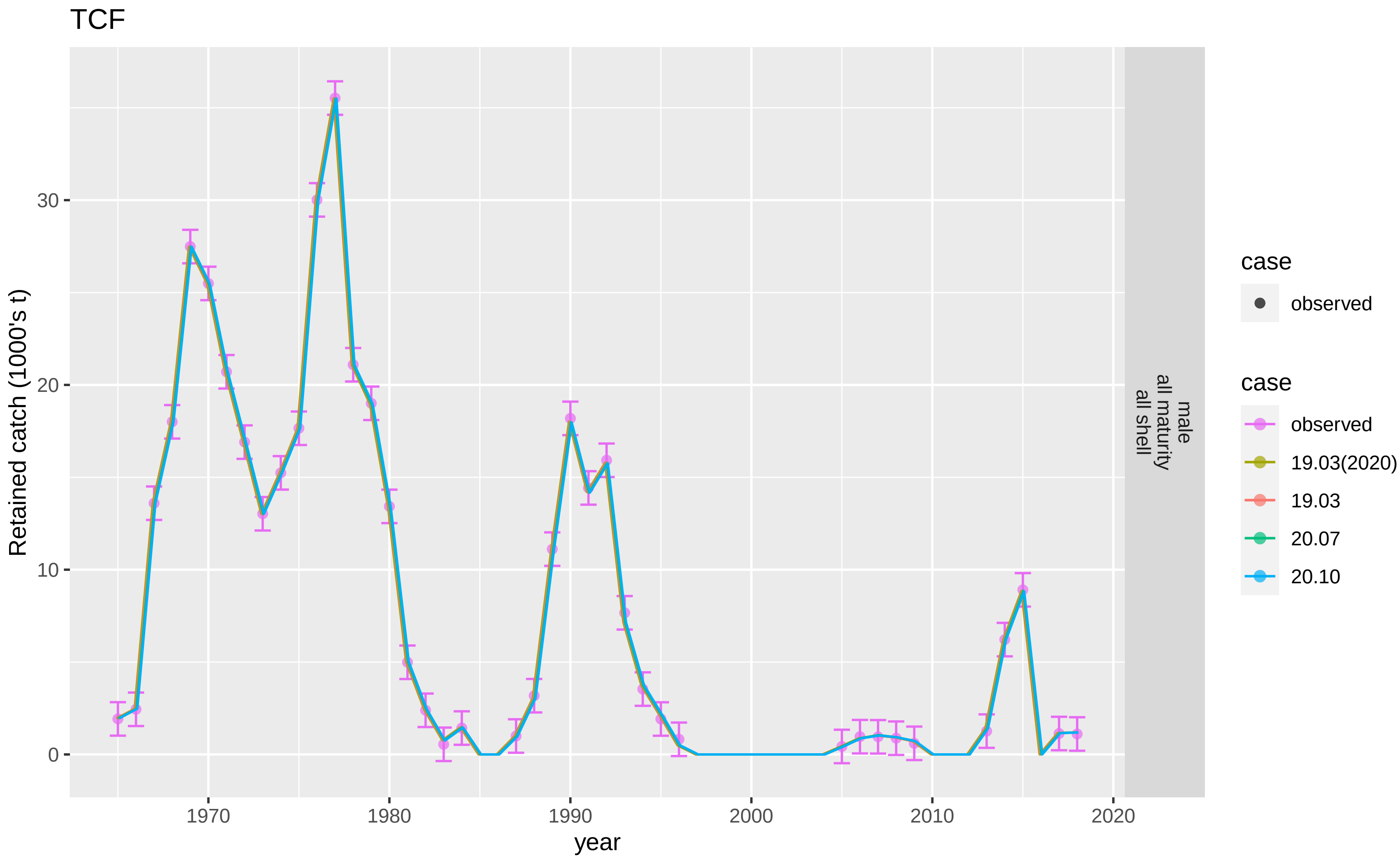

Figure 2: Comparison of observed and predicted male retained catch biomass for TCF. Observed time period.

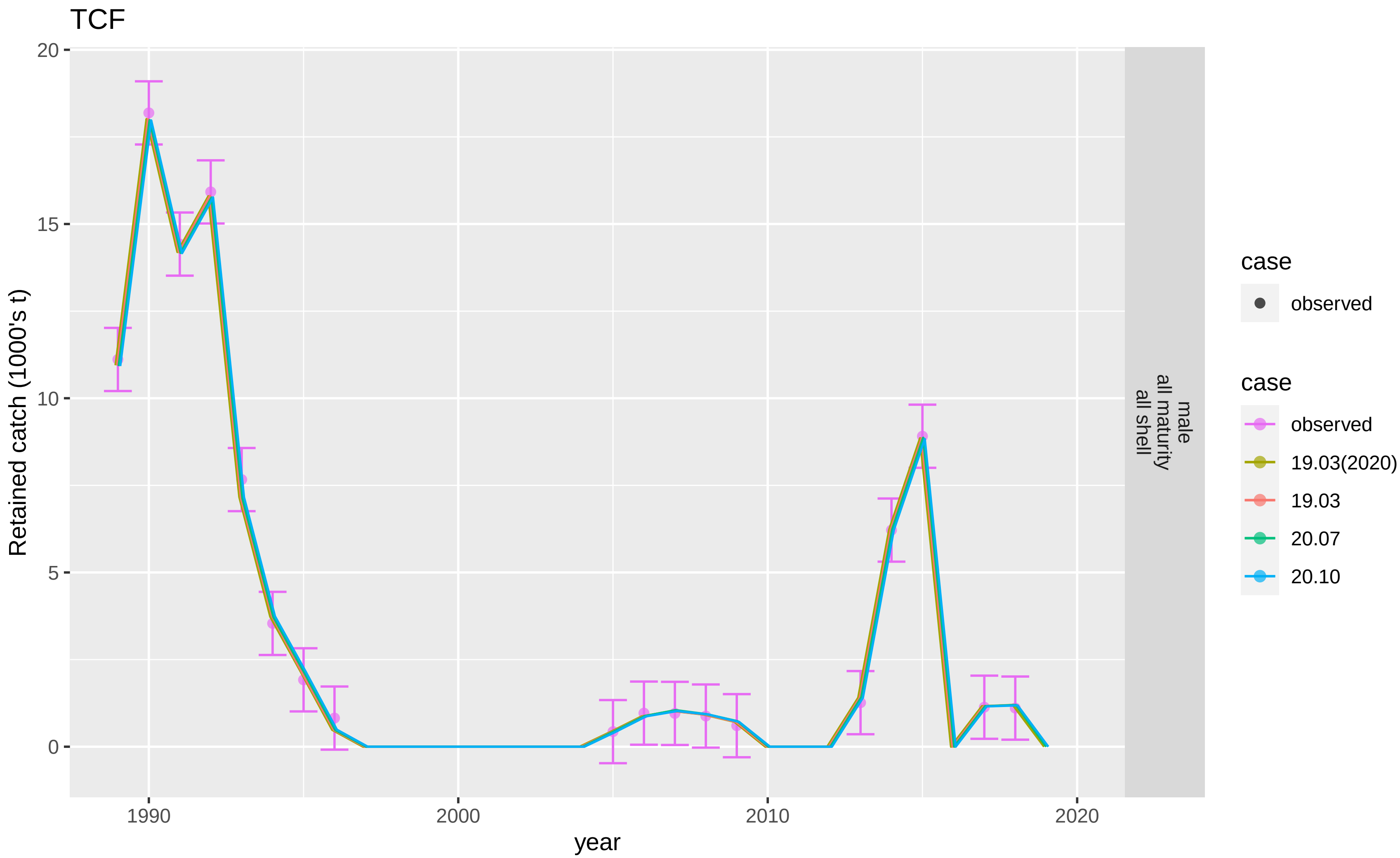

Figure 3: Comparison of observed and predicted male retained catch biomass for TCF. Recent time period.

Z-scores

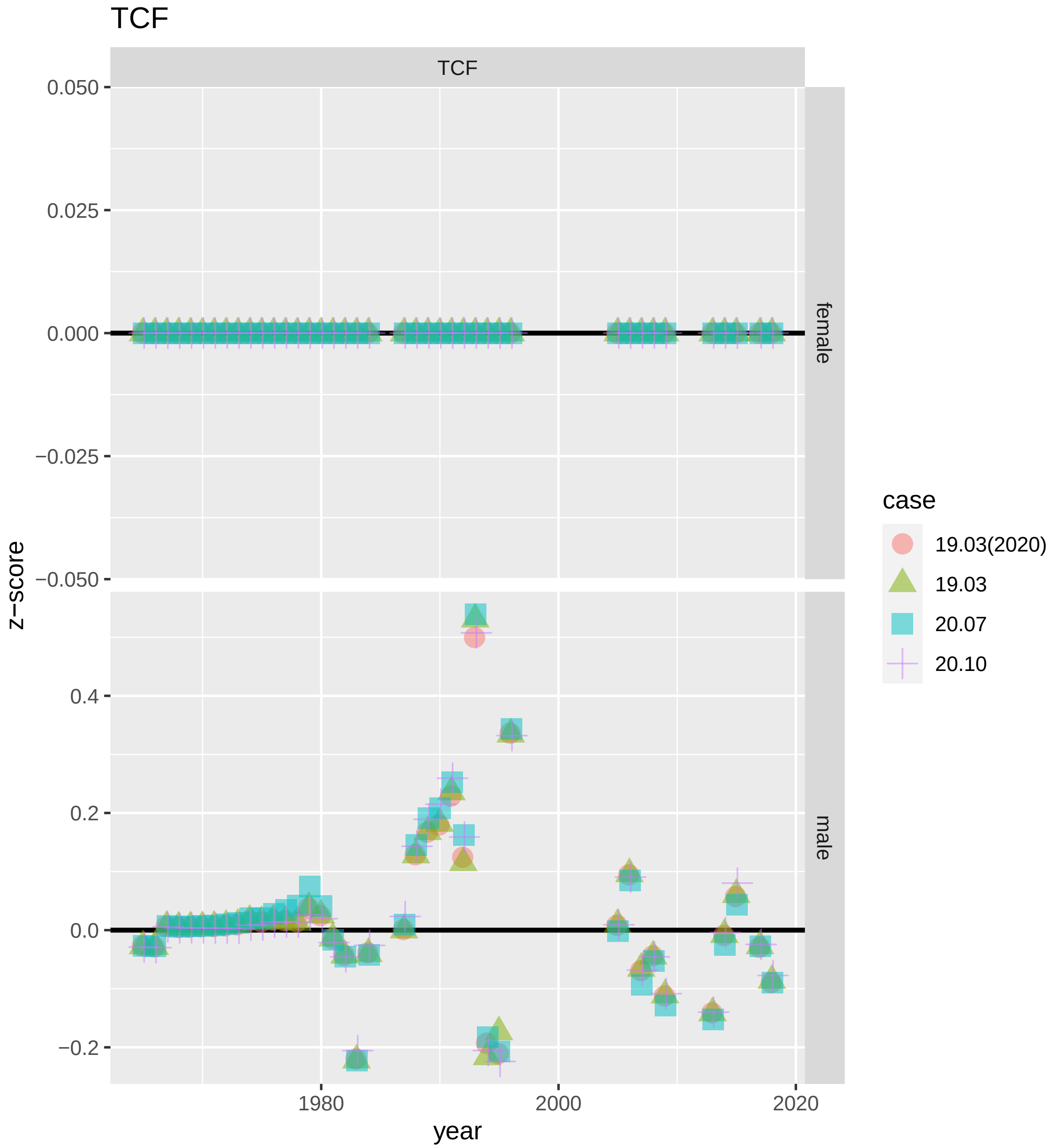

Figure 4: Z-scores for retained catch biomass in TCF.

Fishery retained catch abundance

Fits

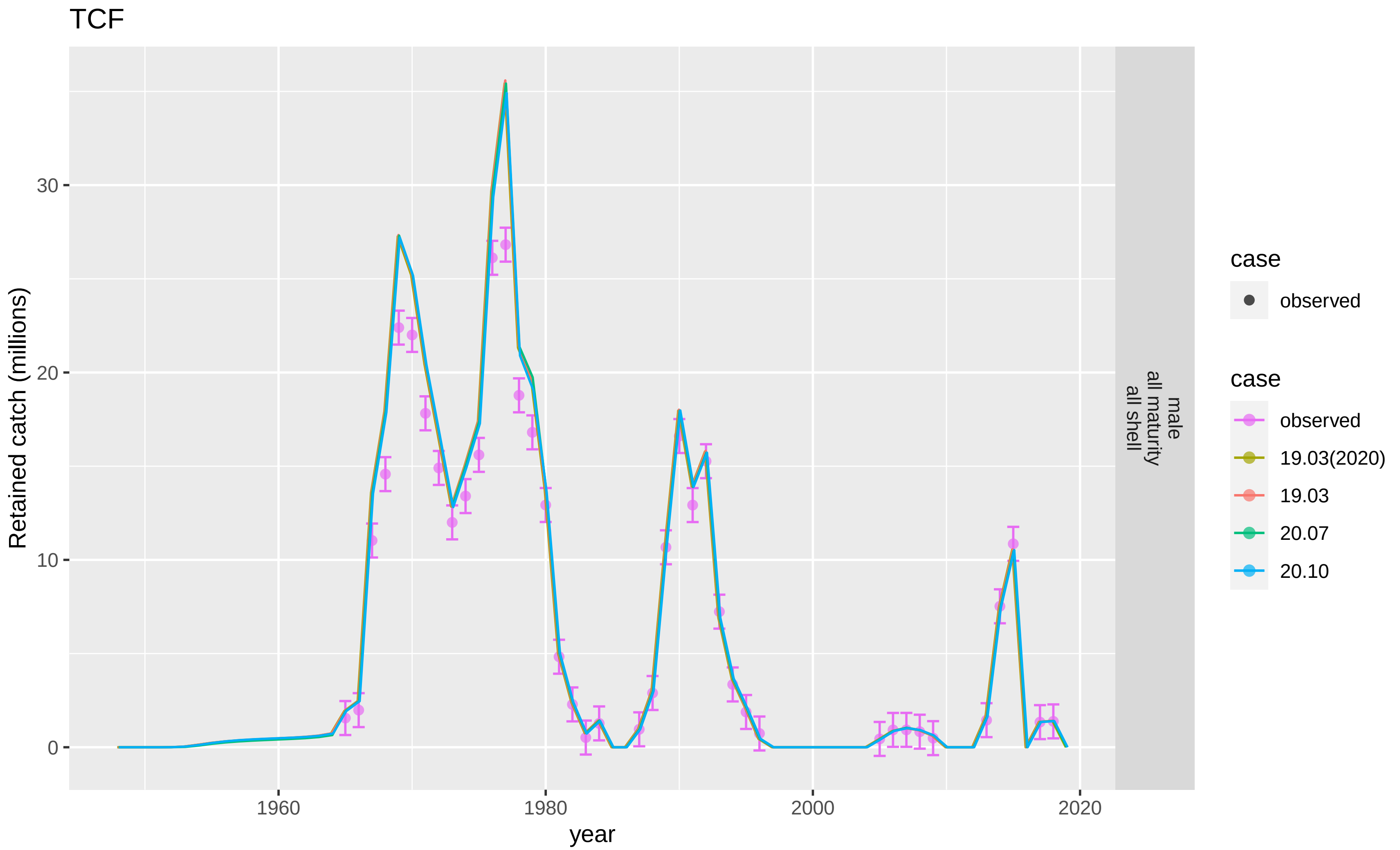

Figure 5: Comparison of observed and predicted male retained catch abundance for TCF.

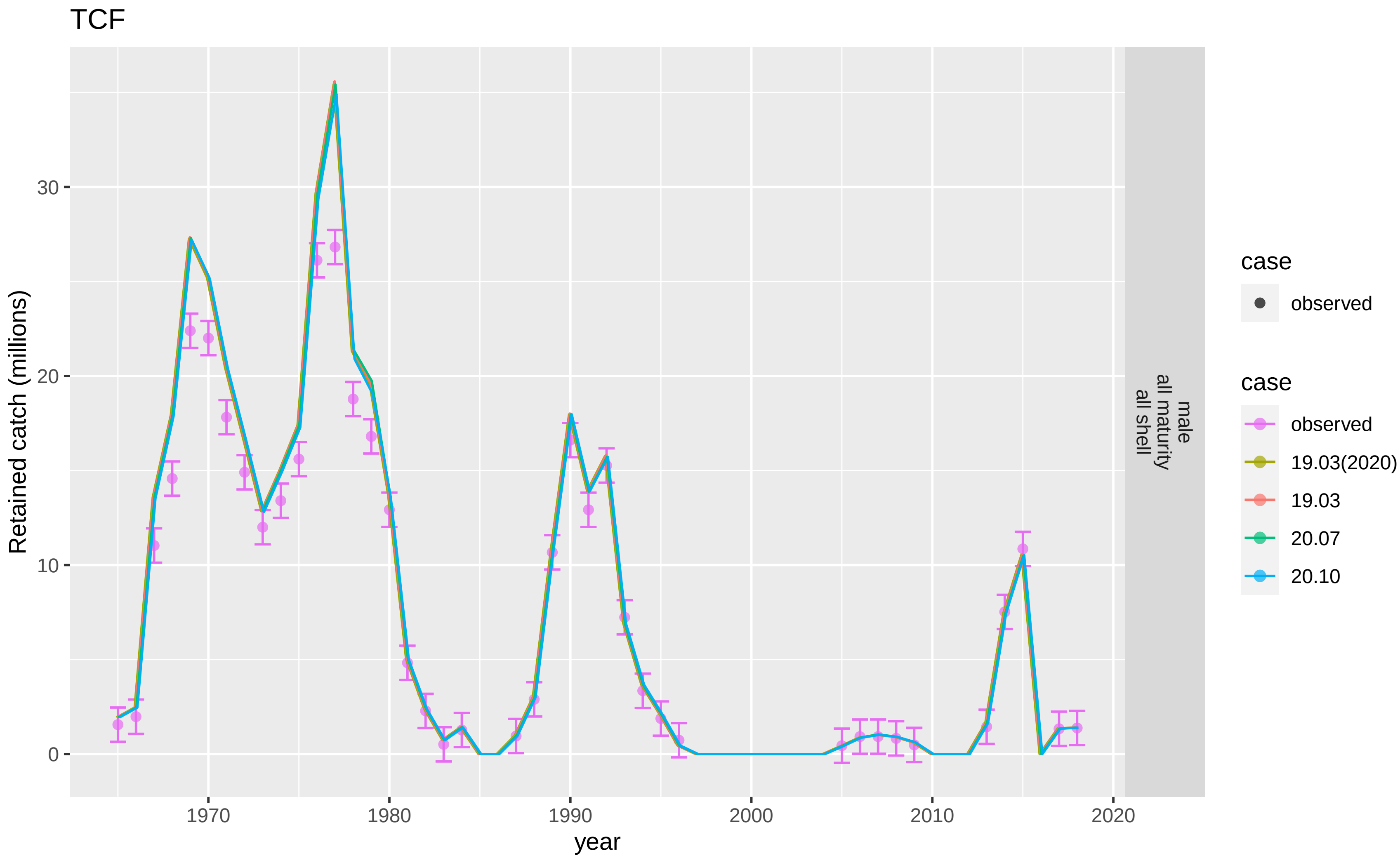

Figure 6: Comparison of observed and predicted male retained catch abundance for TCF. Recent time period.

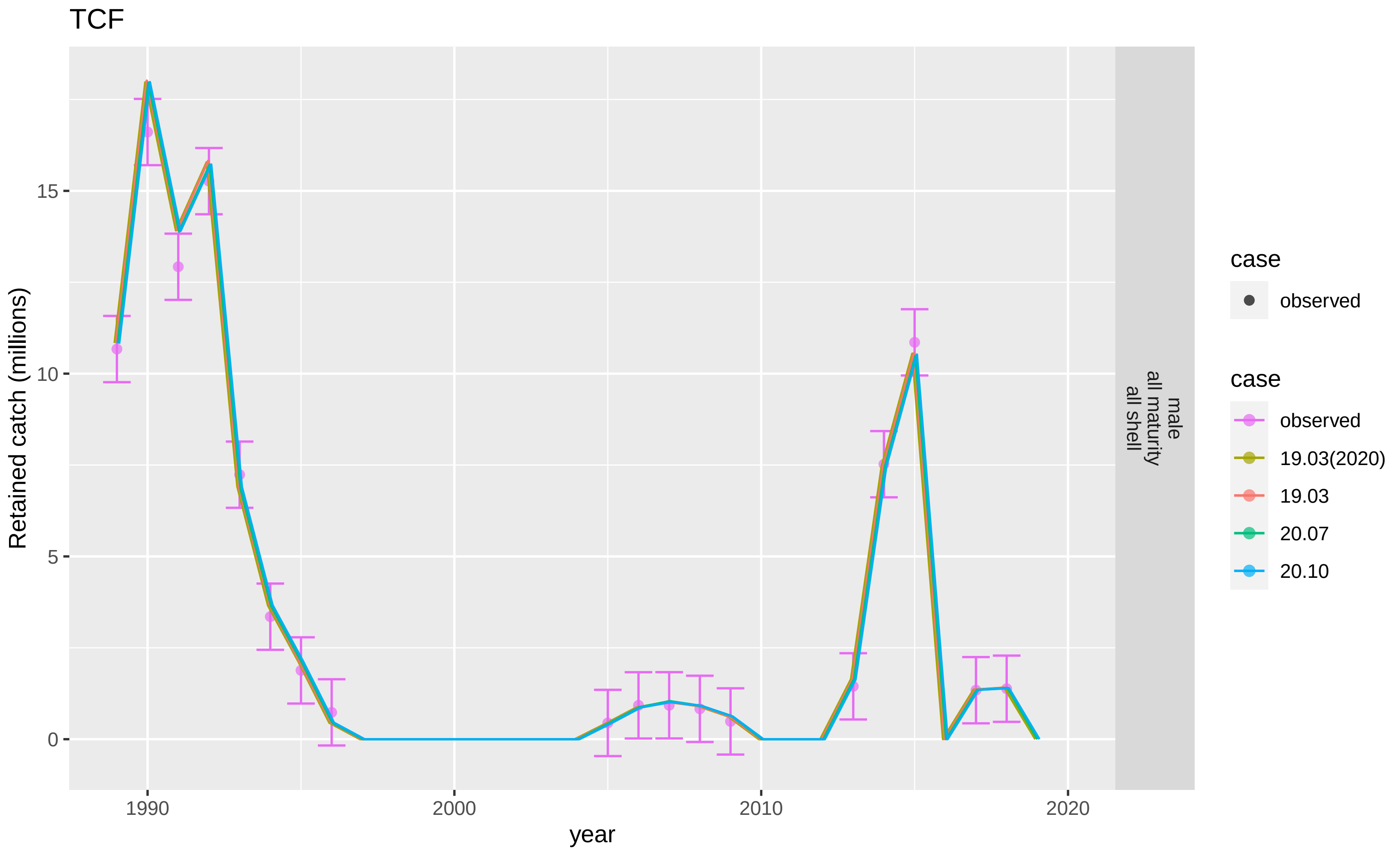

Figure 7: Comparison of observed and predicted male retained catch abundance for TCF. Observed time period.

Z-scores

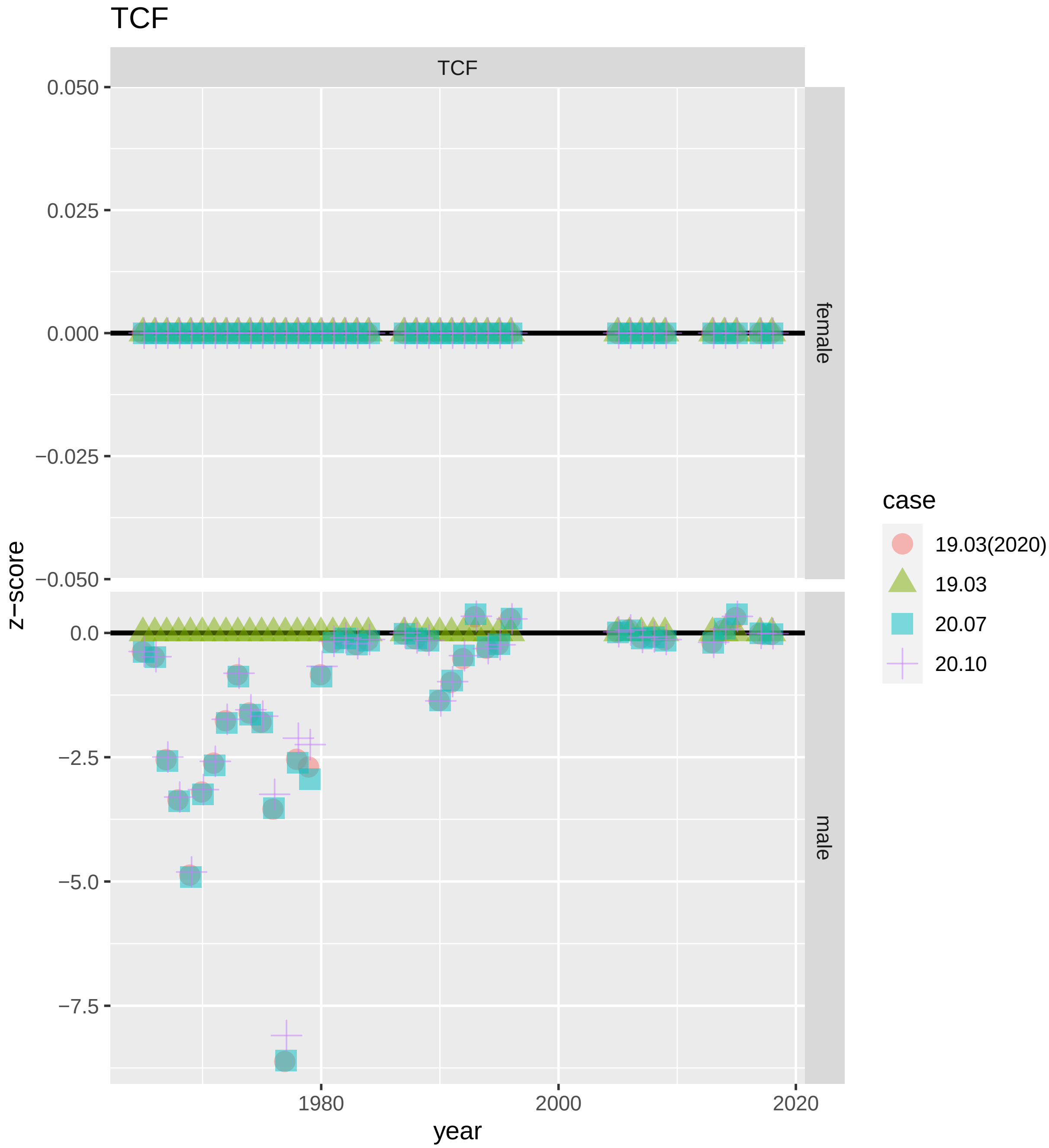

Figure 8: Z-scores for retained catch abundance in TCF.

Fishery total catch biomass

Fits

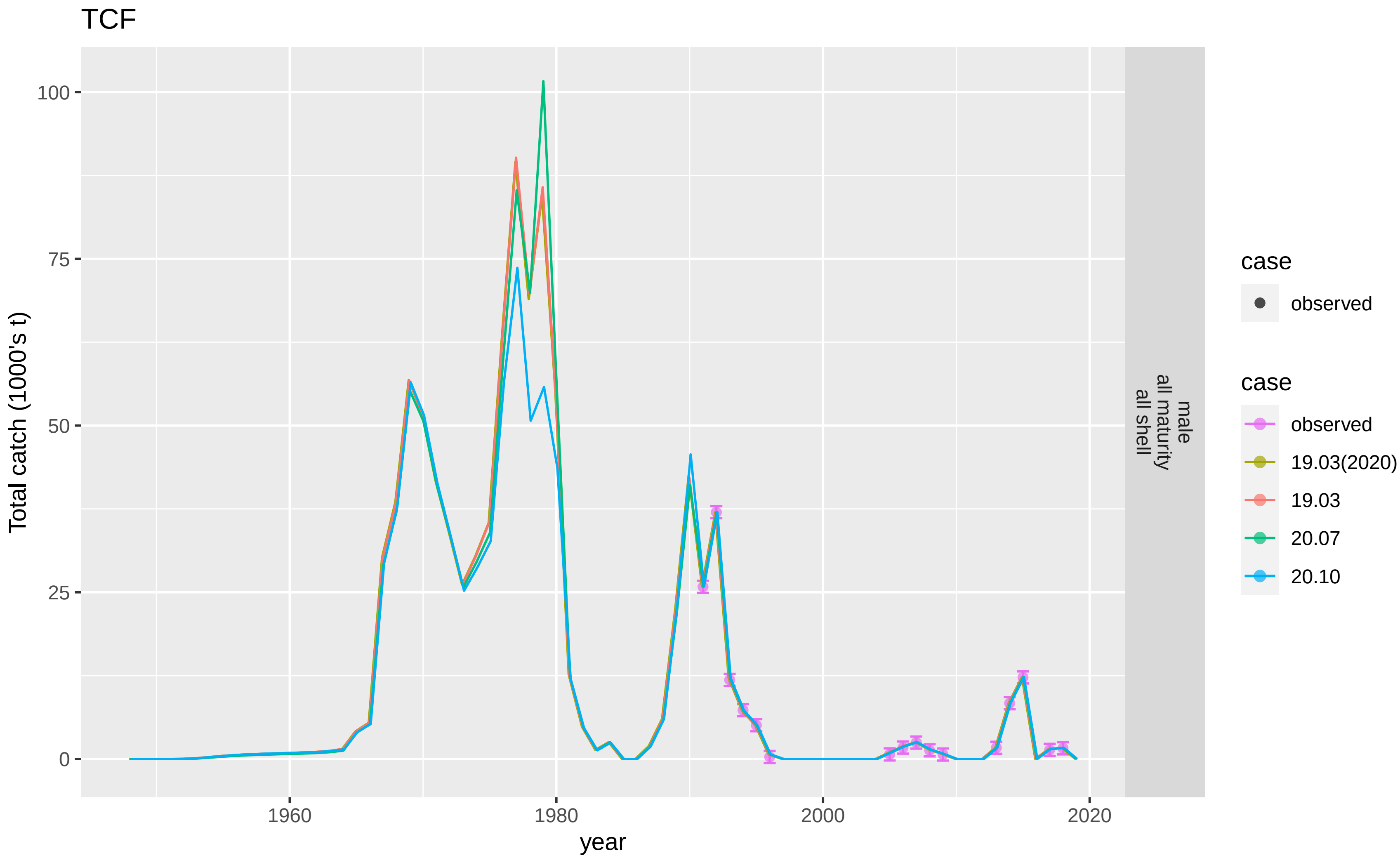

Figure 9: Comparison of observed and predicted total male catch biomass for TCF.

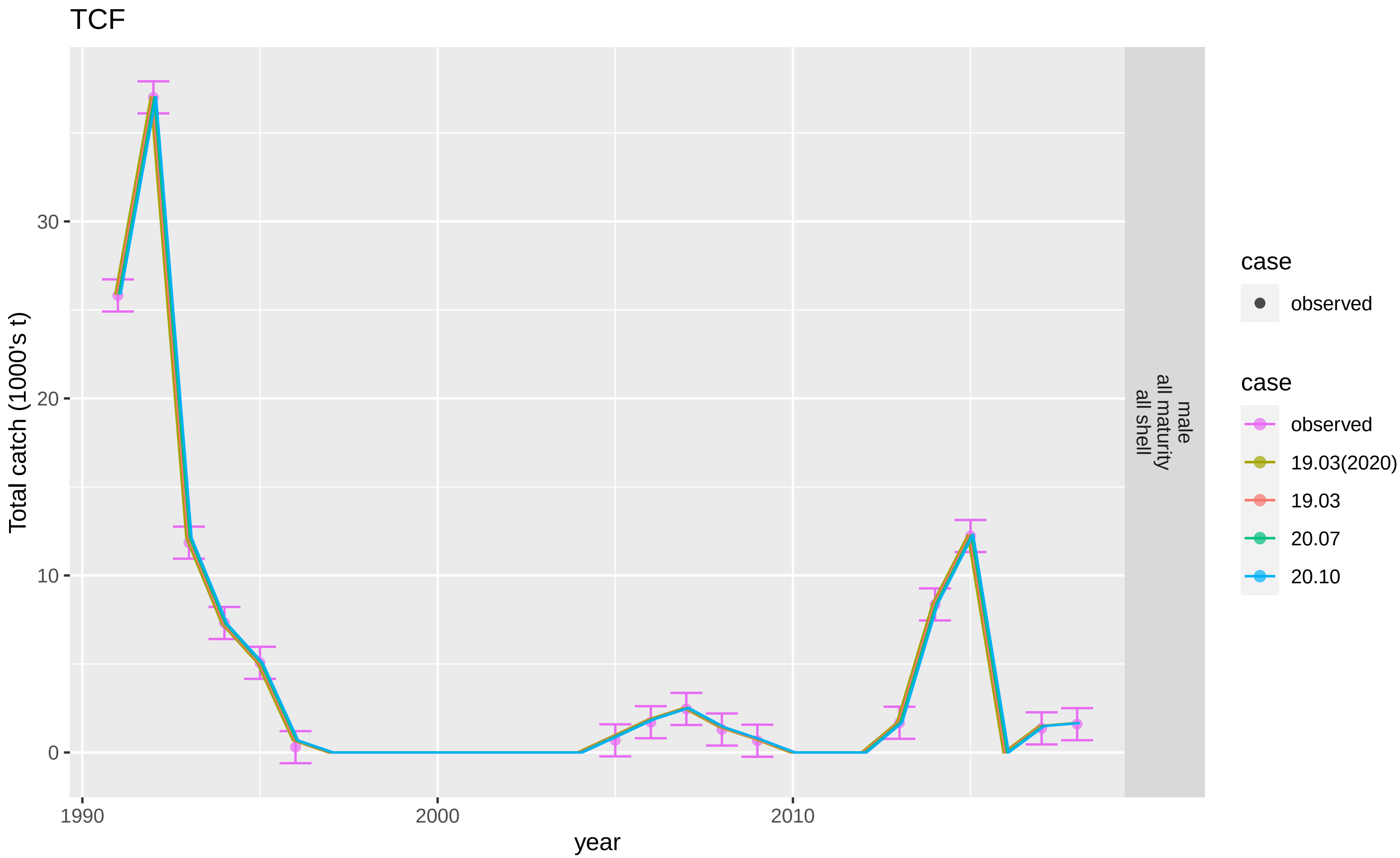

Figure 10: Comparison of observed and predicted total male catch biomass for TCF. Observed time period.

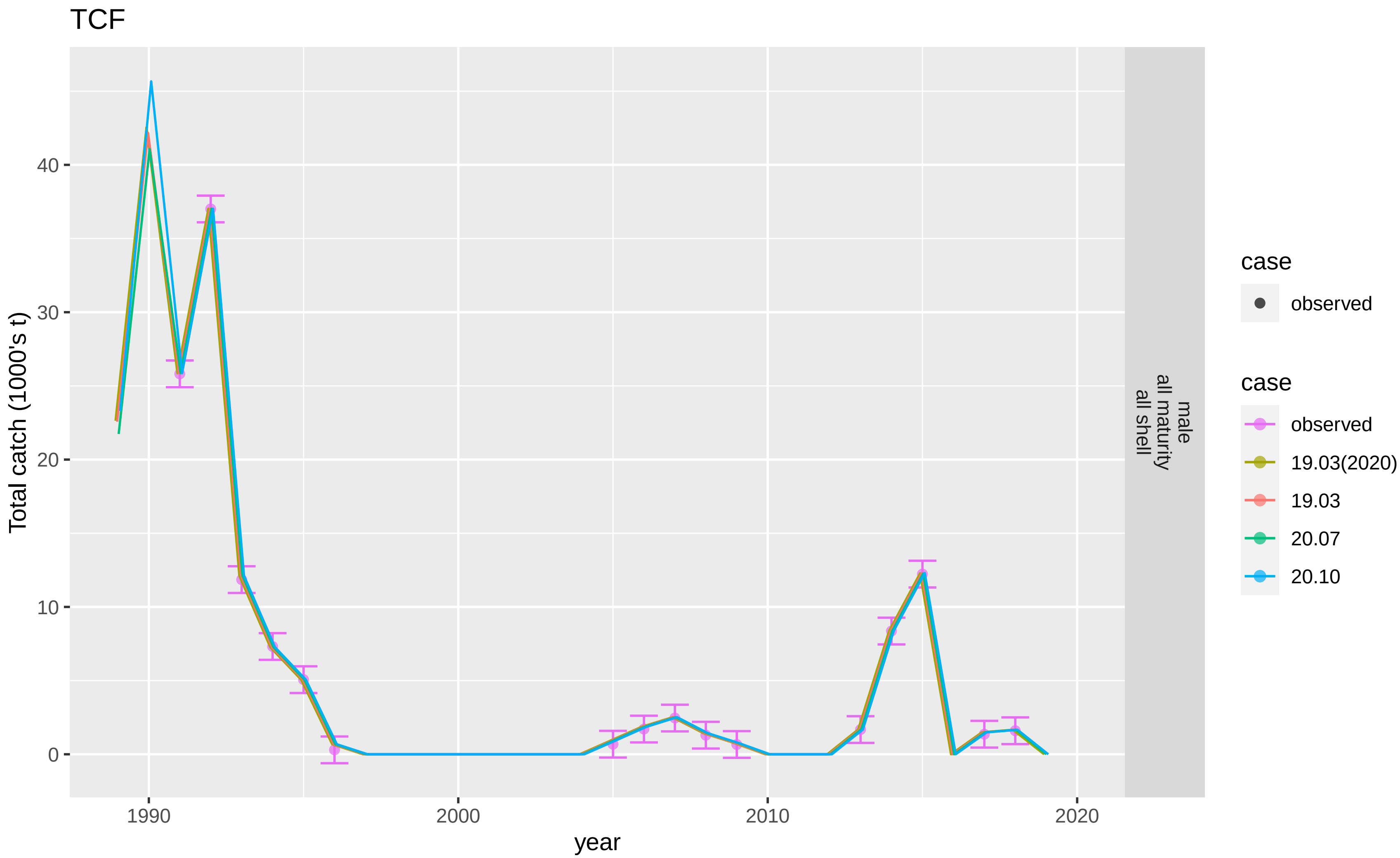

Figure 11: Comparison of observed and predicted total male catch biomass for TCF. Recent time period.

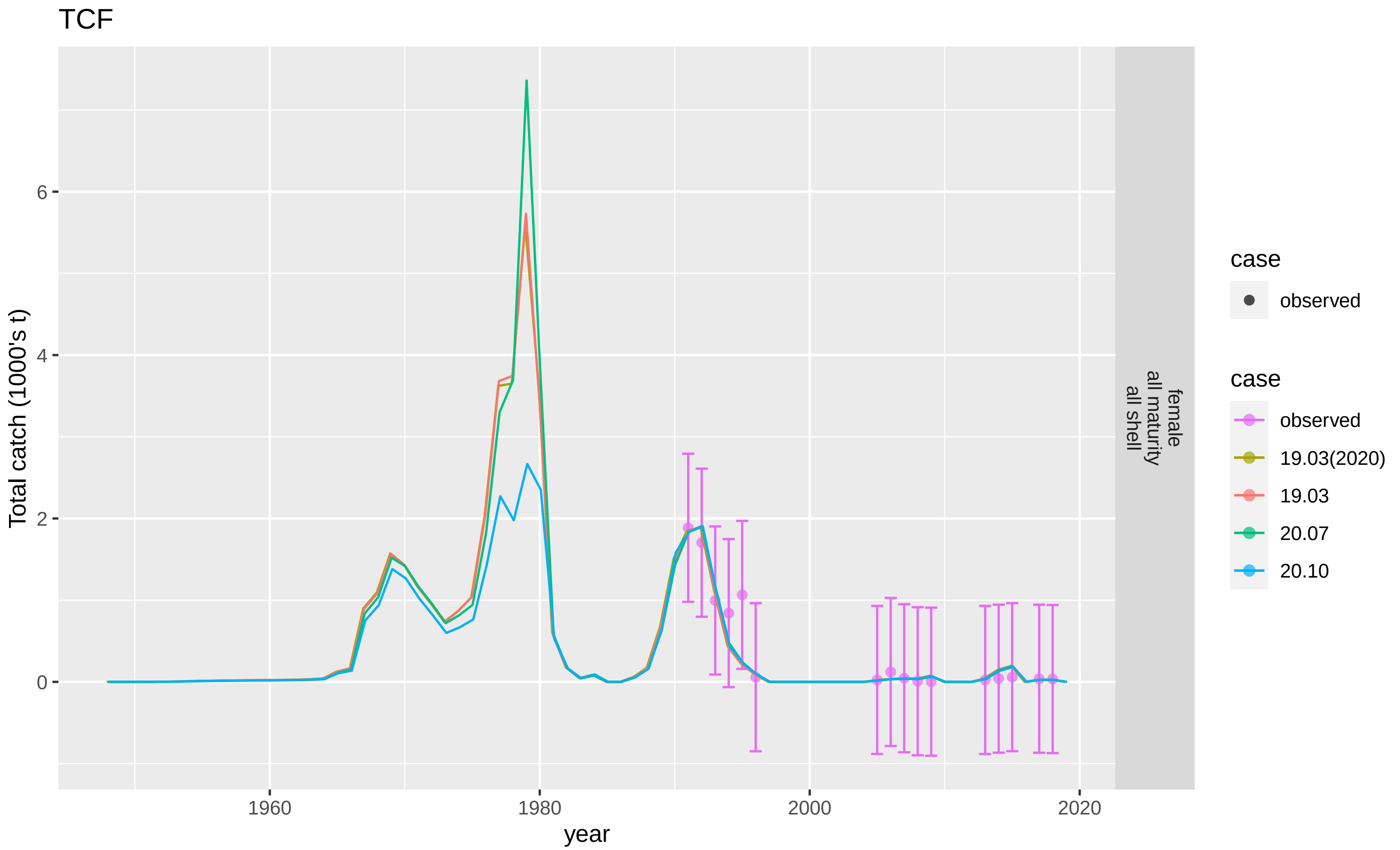

Figure 12: Comparison of observed and predicted total female catch biomass for TCF.

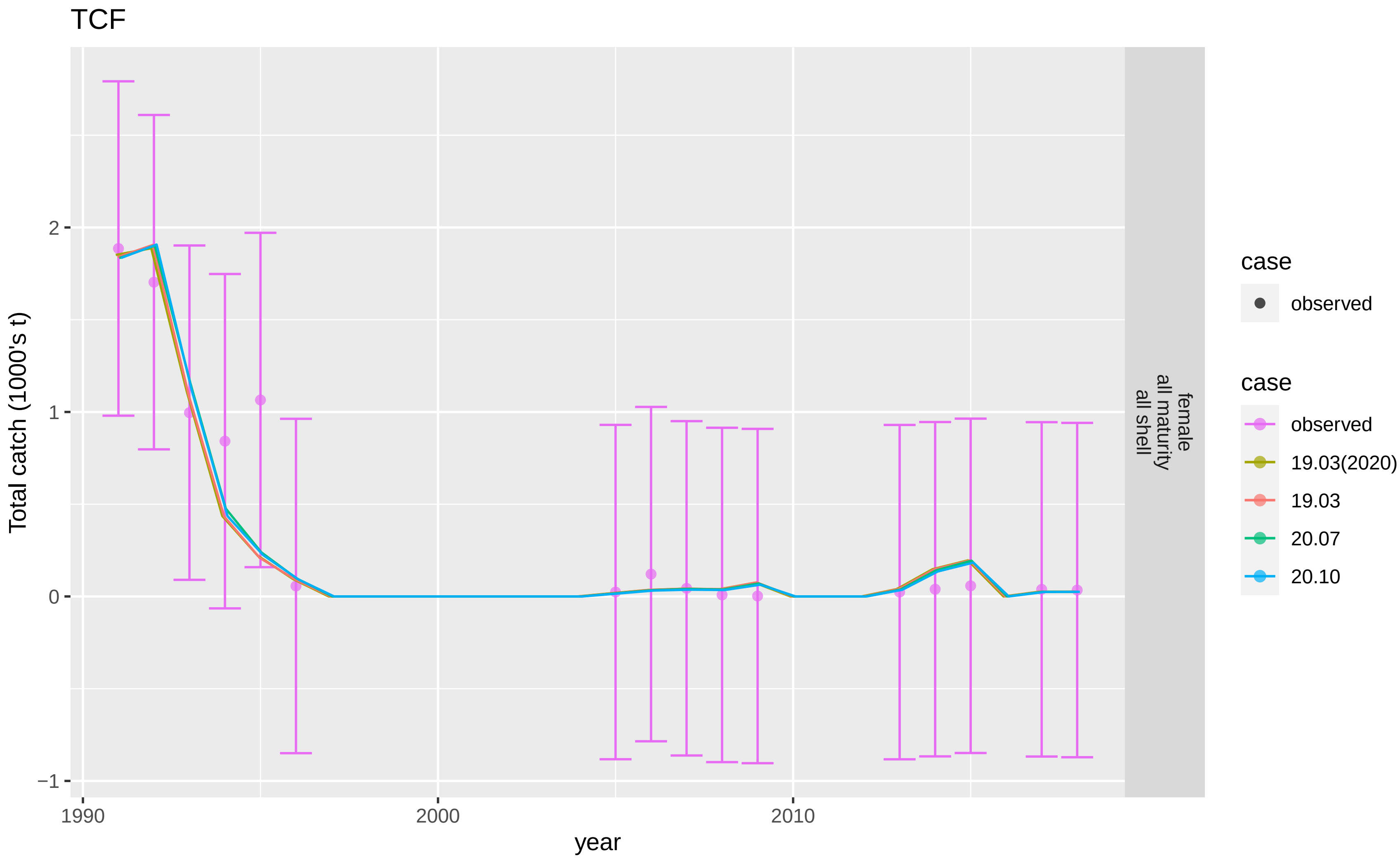

Figure 13: Comparison of observed and predicted total female catch biomass for TCF. Observed time period.

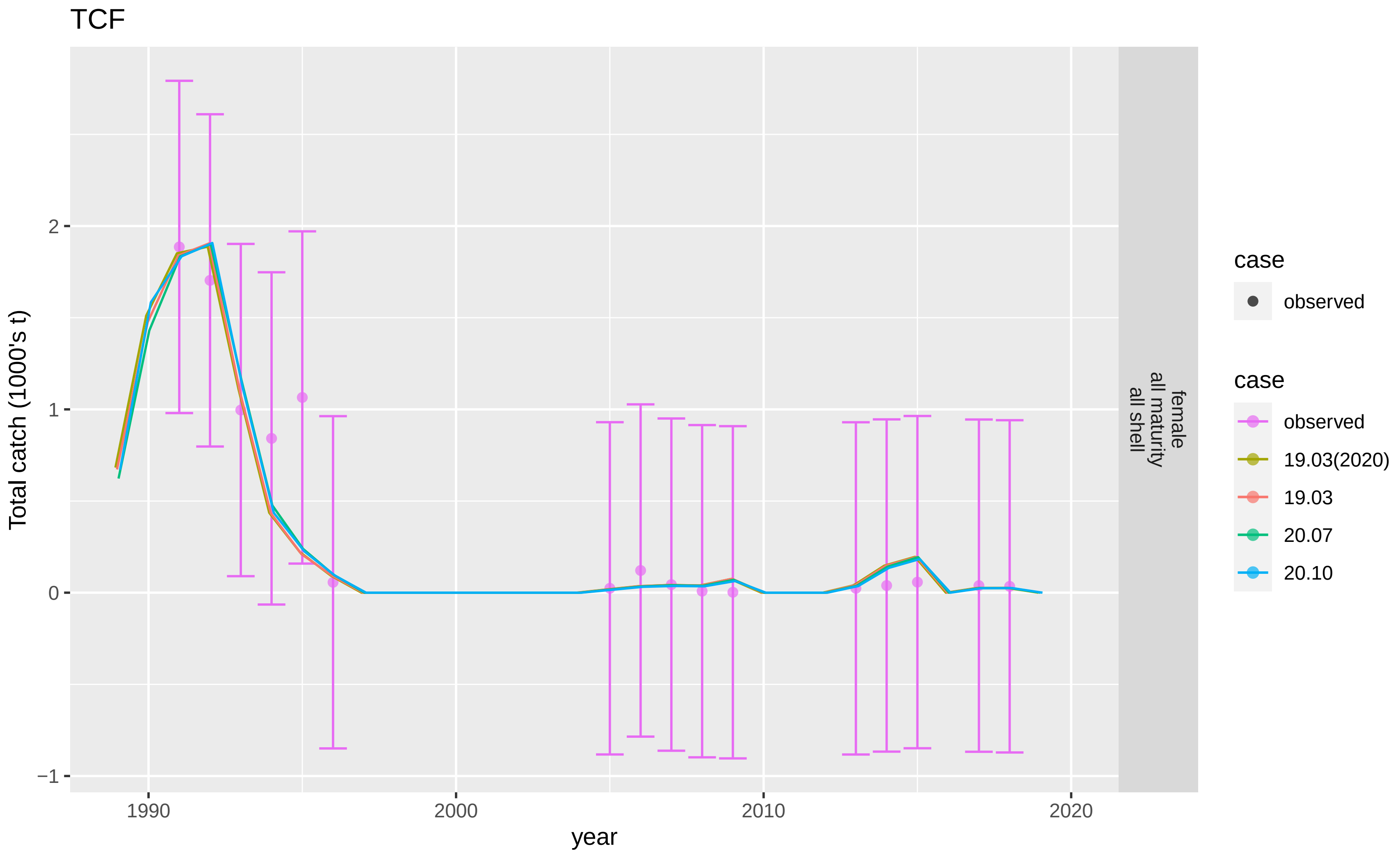

Figure 14: Comparison of observed and predicted total female catch biomass for TCF. Recent time period.

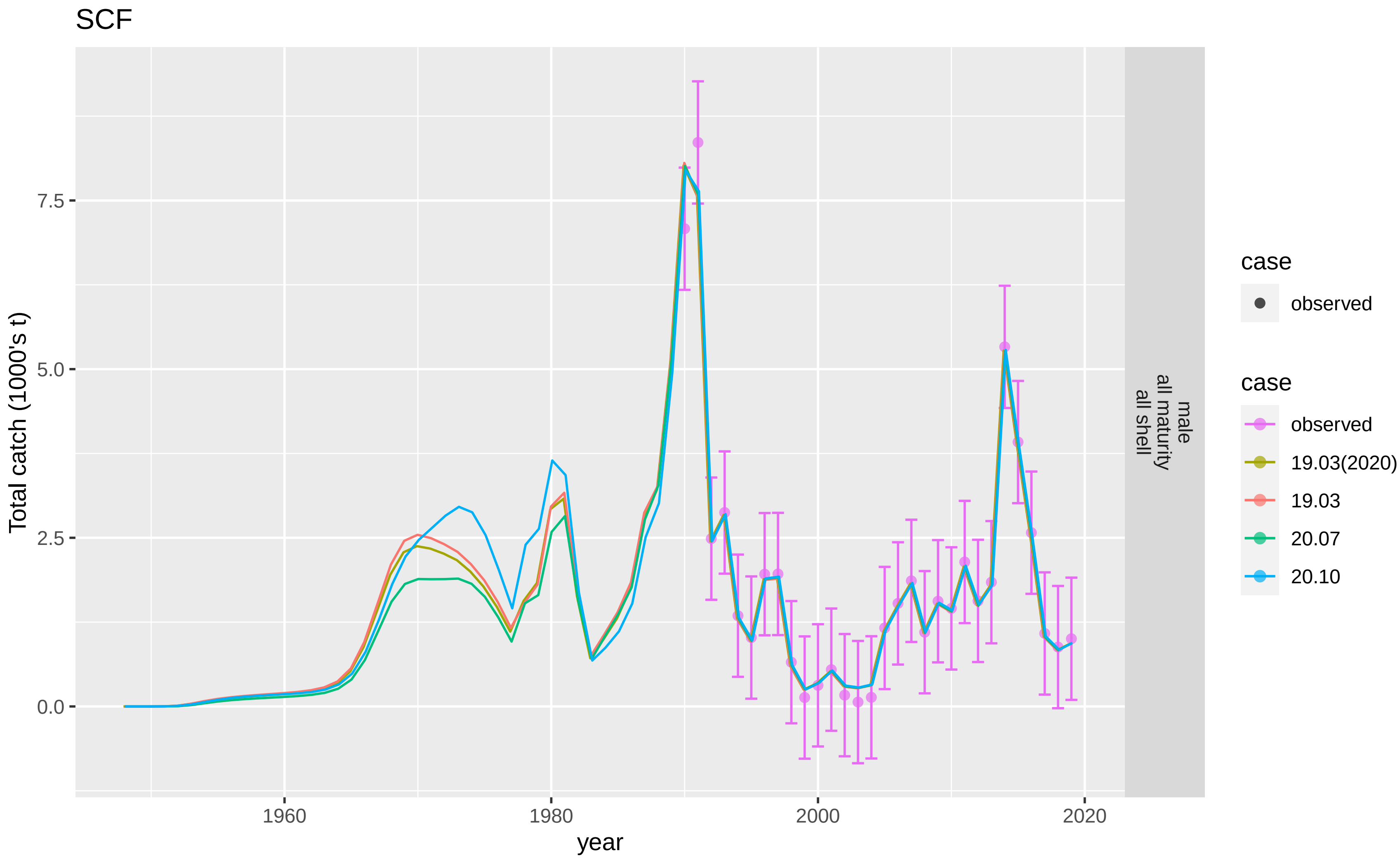

Figure 15: Comparison of observed and predicted total male catch biomass for SCF.

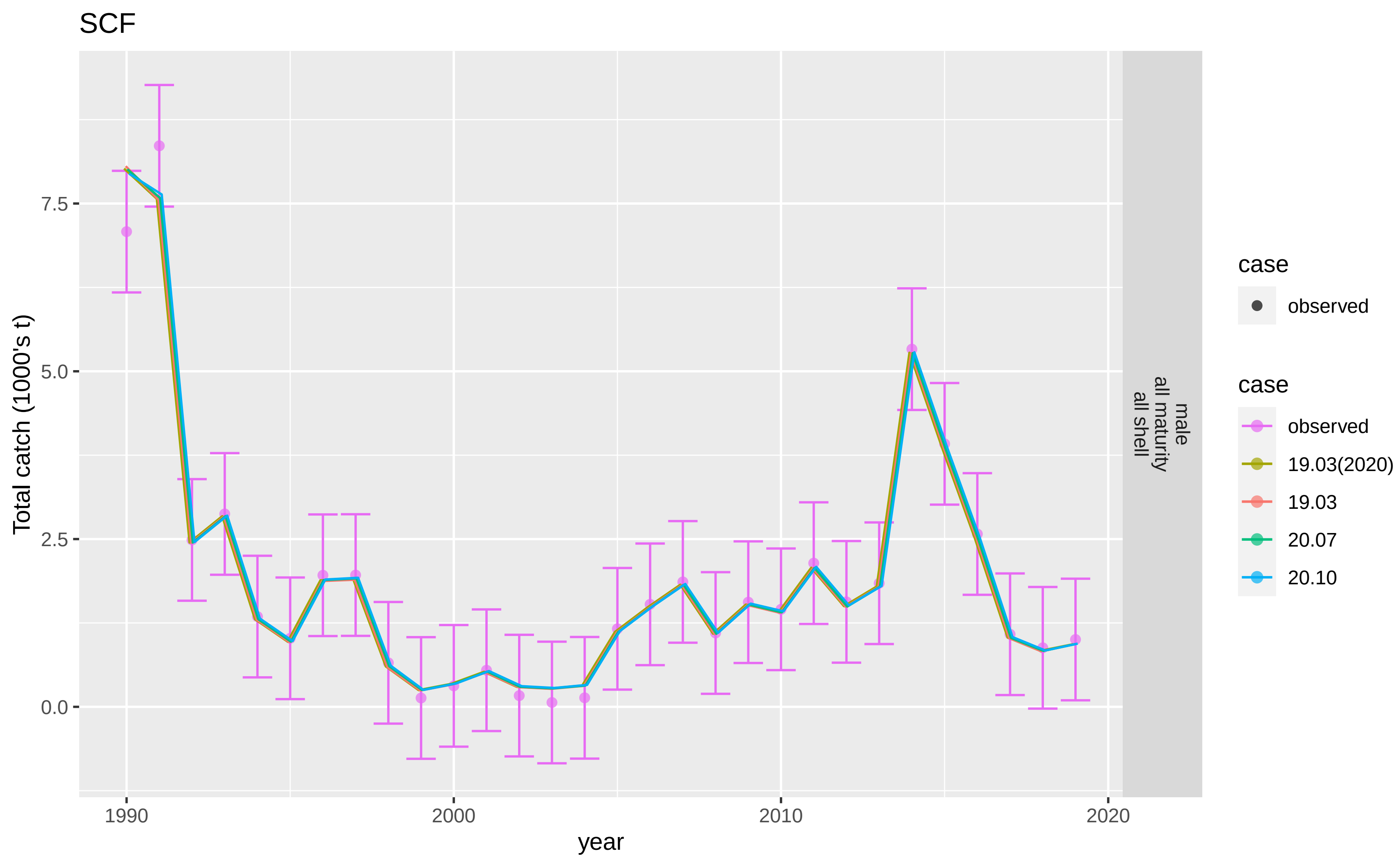

Figure 16: Comparison of observed and predicted total male catch biomass for SCF. Observed time period.

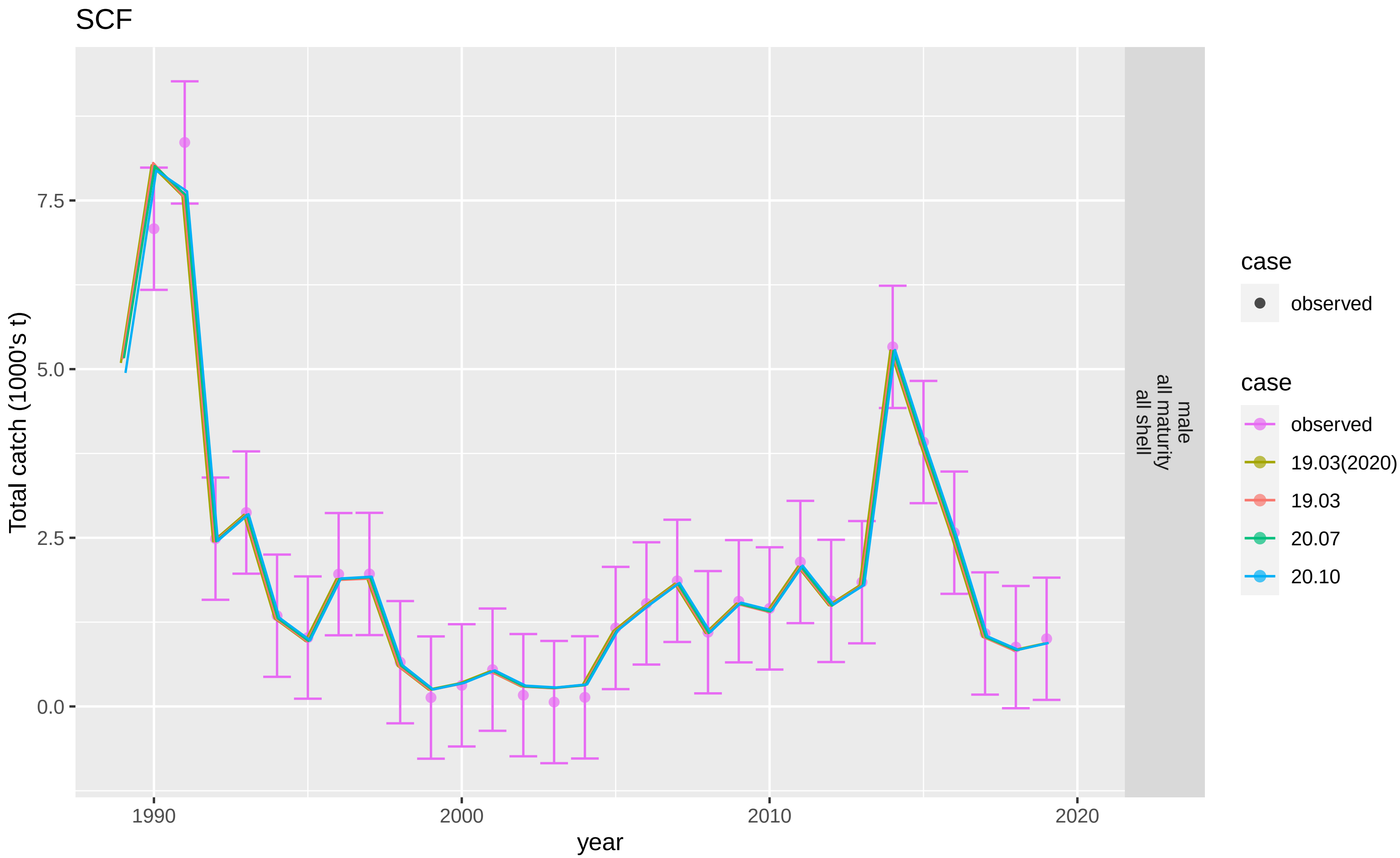

Figure 17: Comparison of observed and predicted total male catch biomass for SCF. Recent time period.

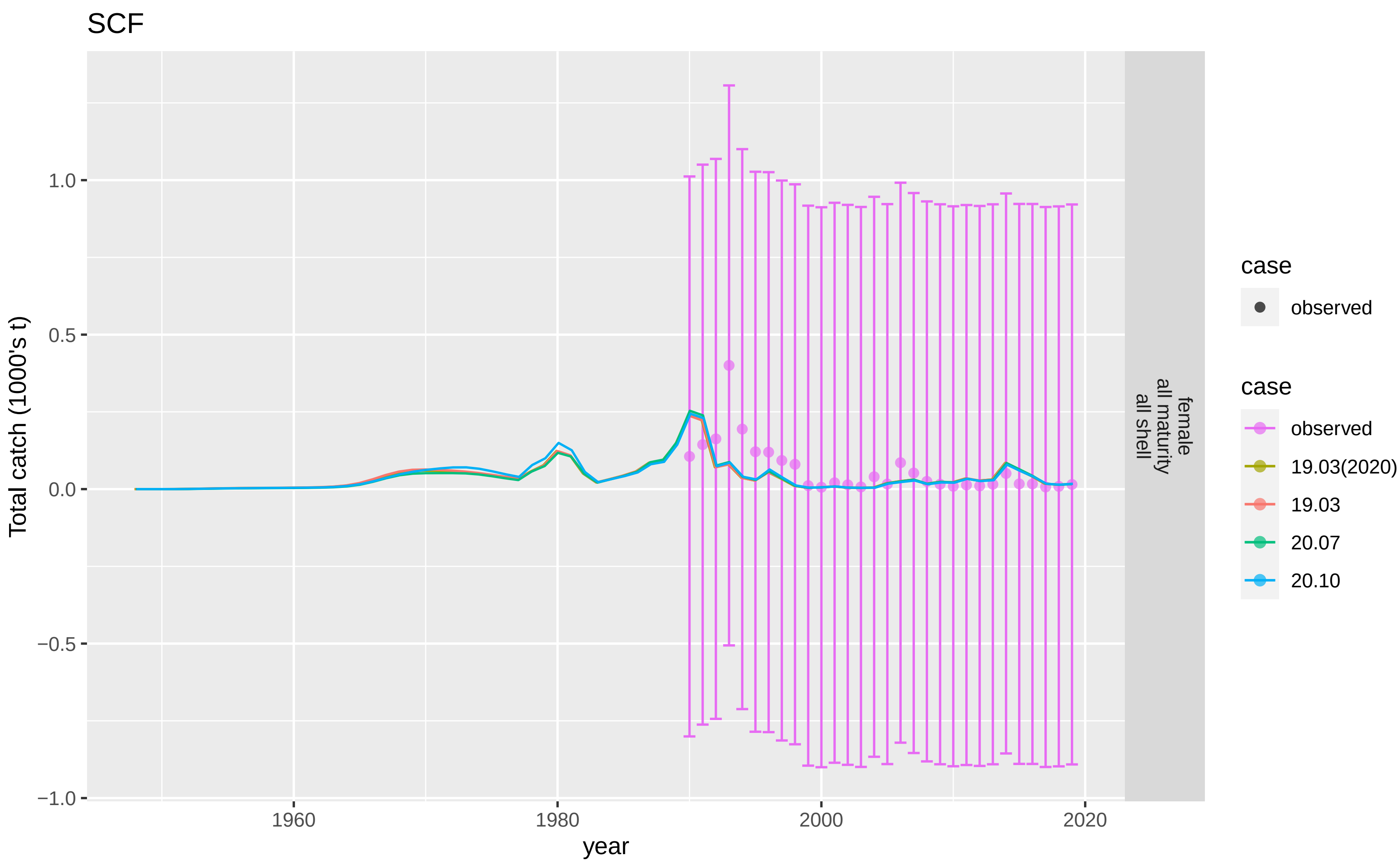

Figure 18: Comparison of observed and predicted total female catch biomass for SCF.

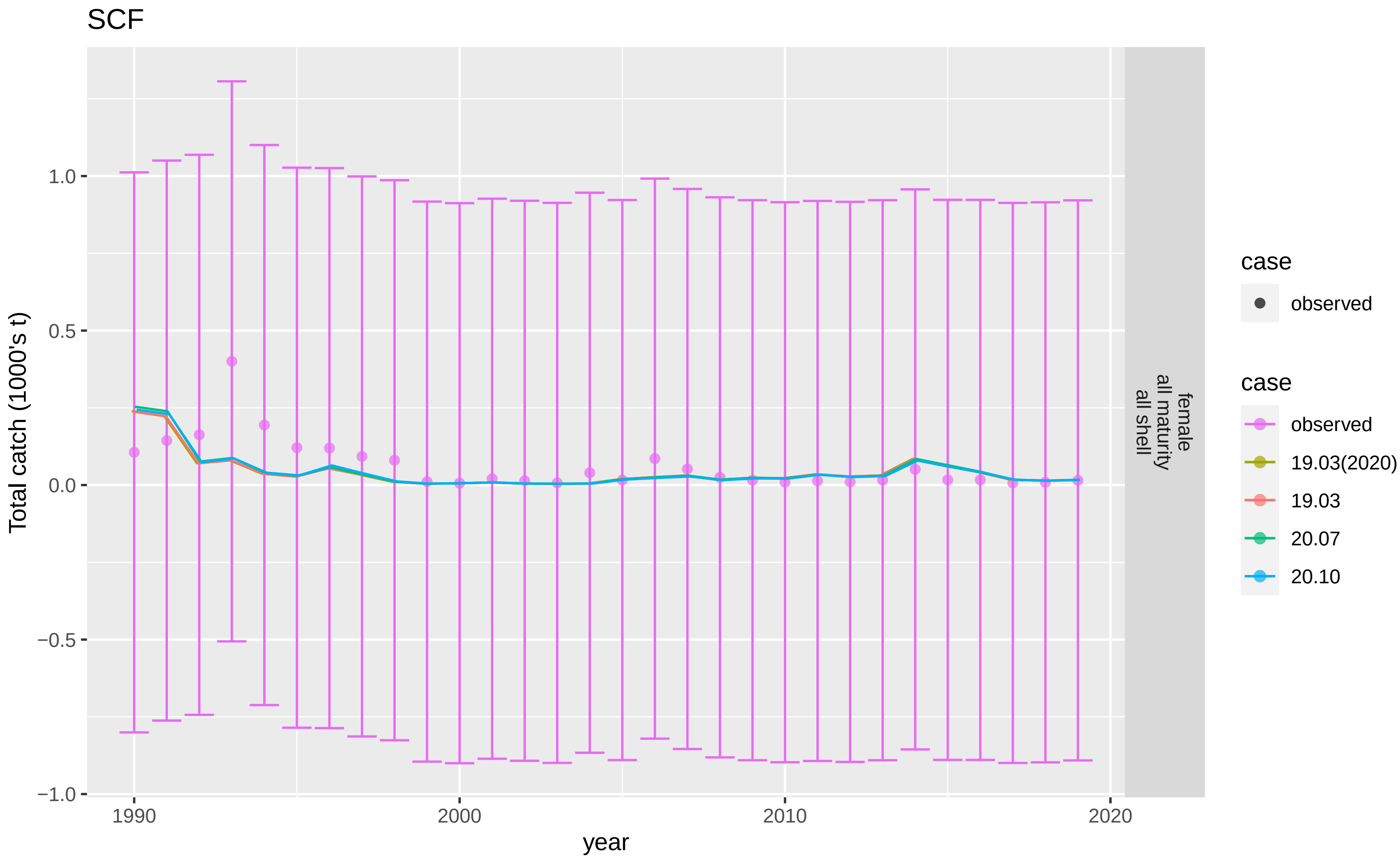

Figure 19: Comparison of observed and predicted total female catch biomass for SCF. Observed time period.

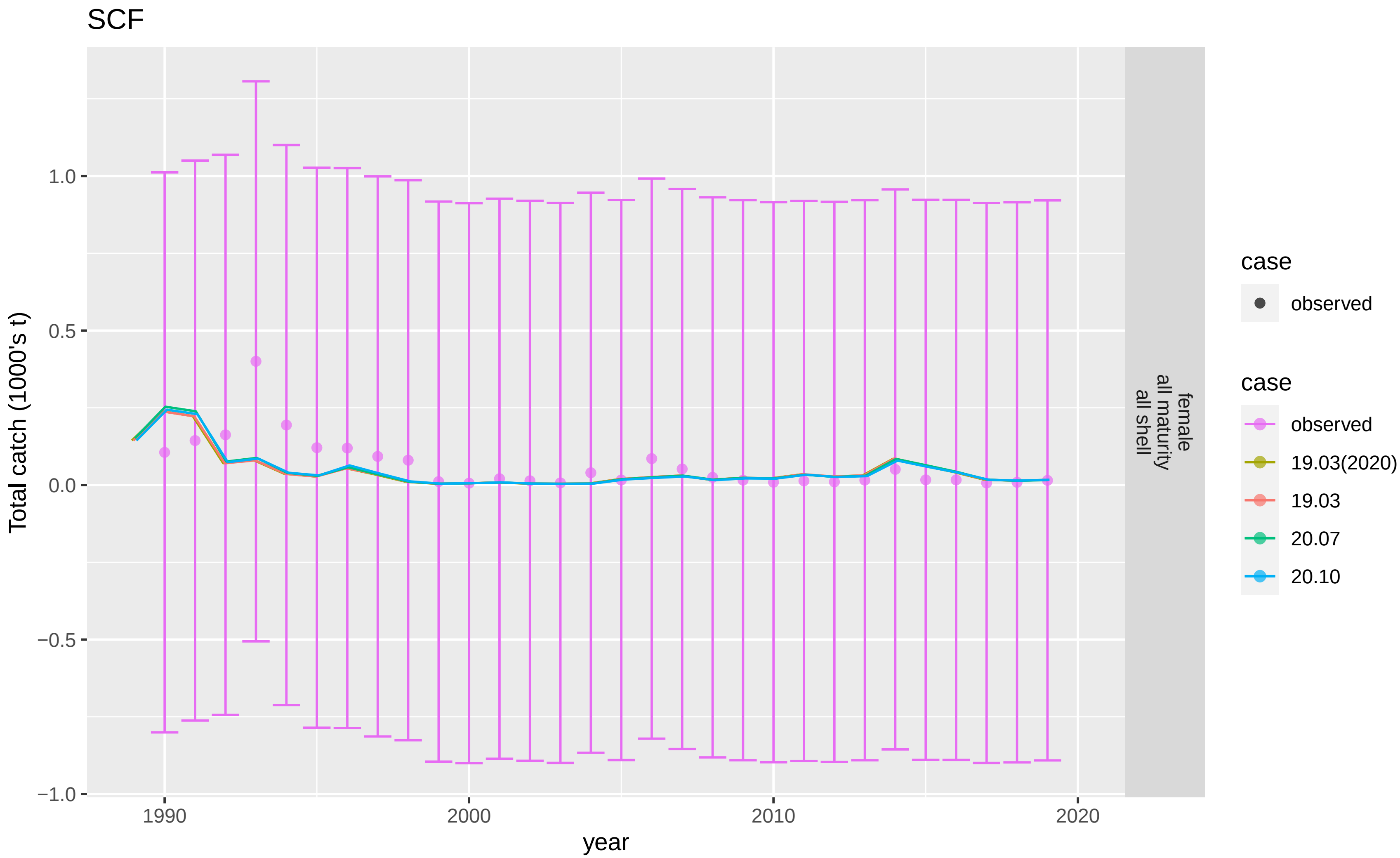

Figure 20: Comparison of observed and predicted total female catch biomass for SCF. Recent time period.

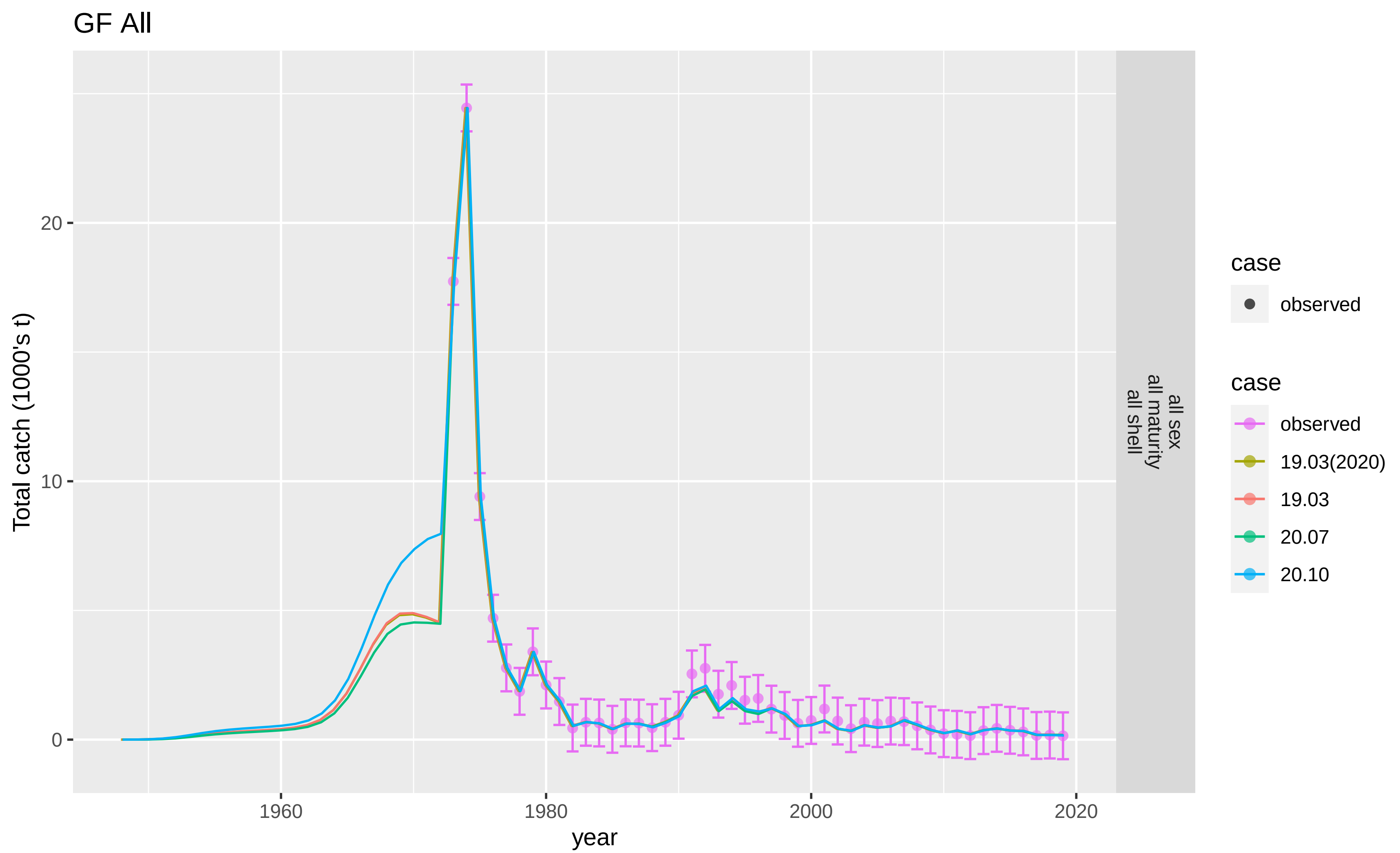

Figure 21: Comparison of observed and predicted total all sex catch biomass for GF All.

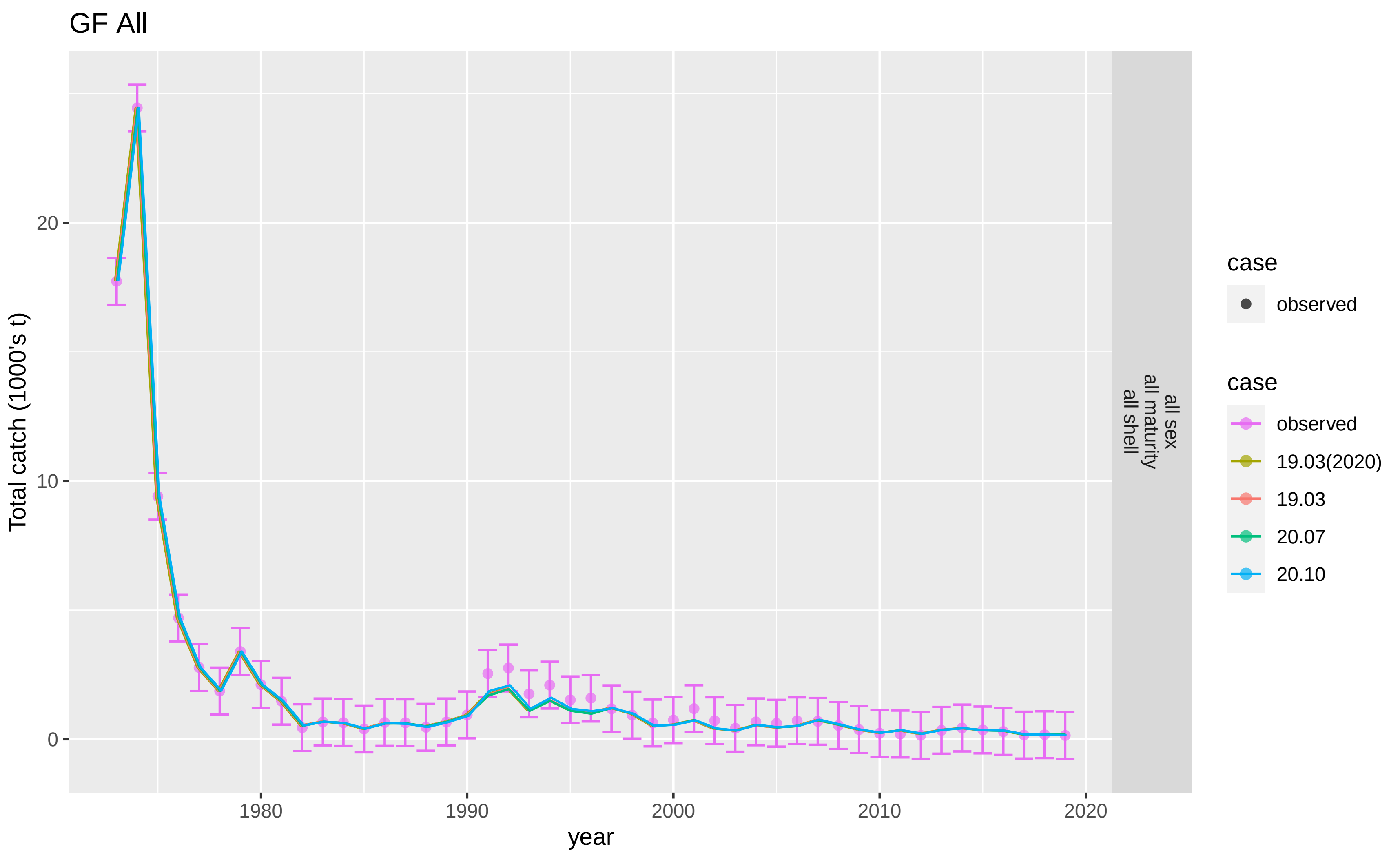

Figure 22: Comparison of observed and predicted total all sex catch biomass for GF All. Observed time period.

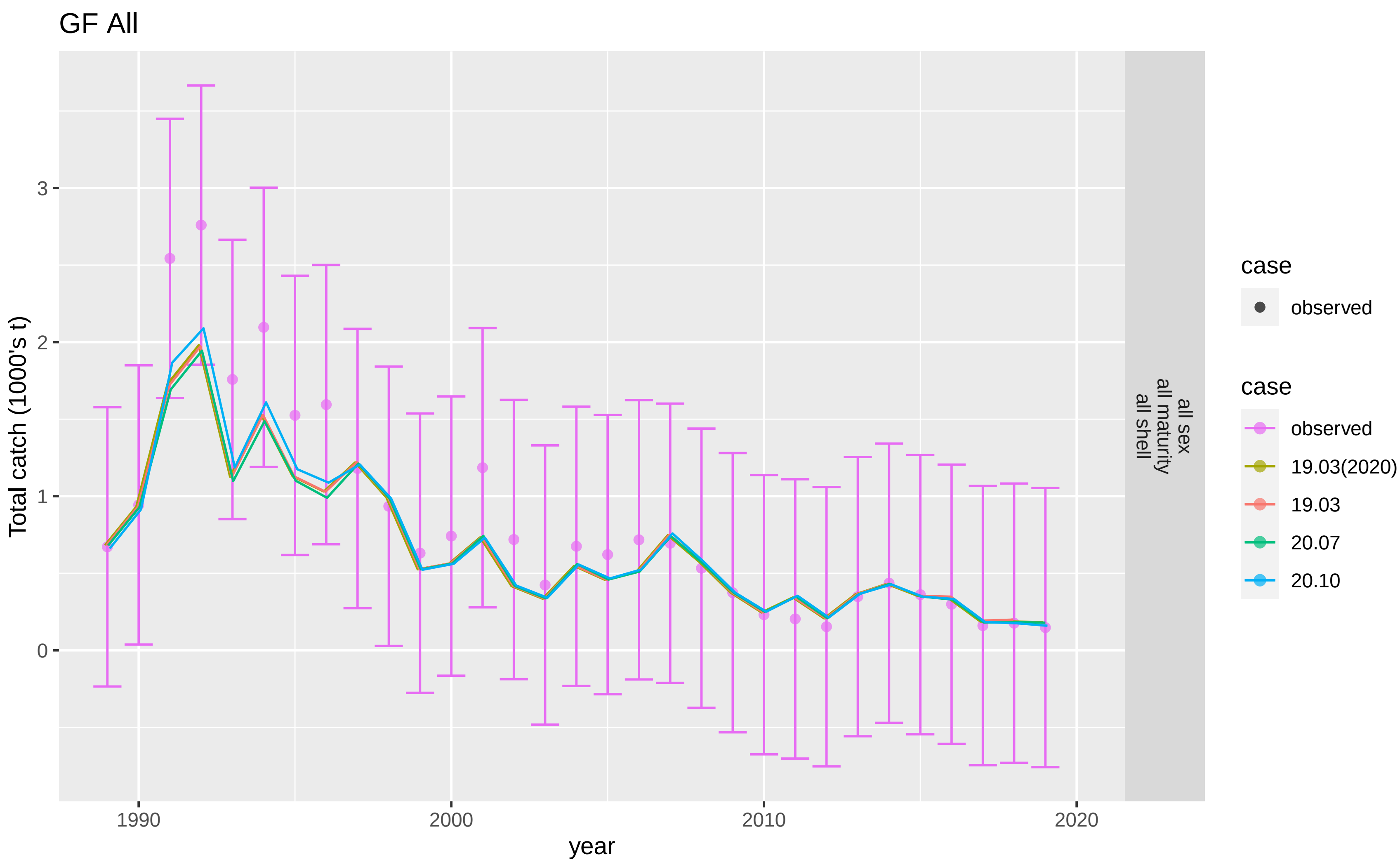

Figure 23: Comparison of observed and predicted total all sex catch biomass for GF All. Recent time period.

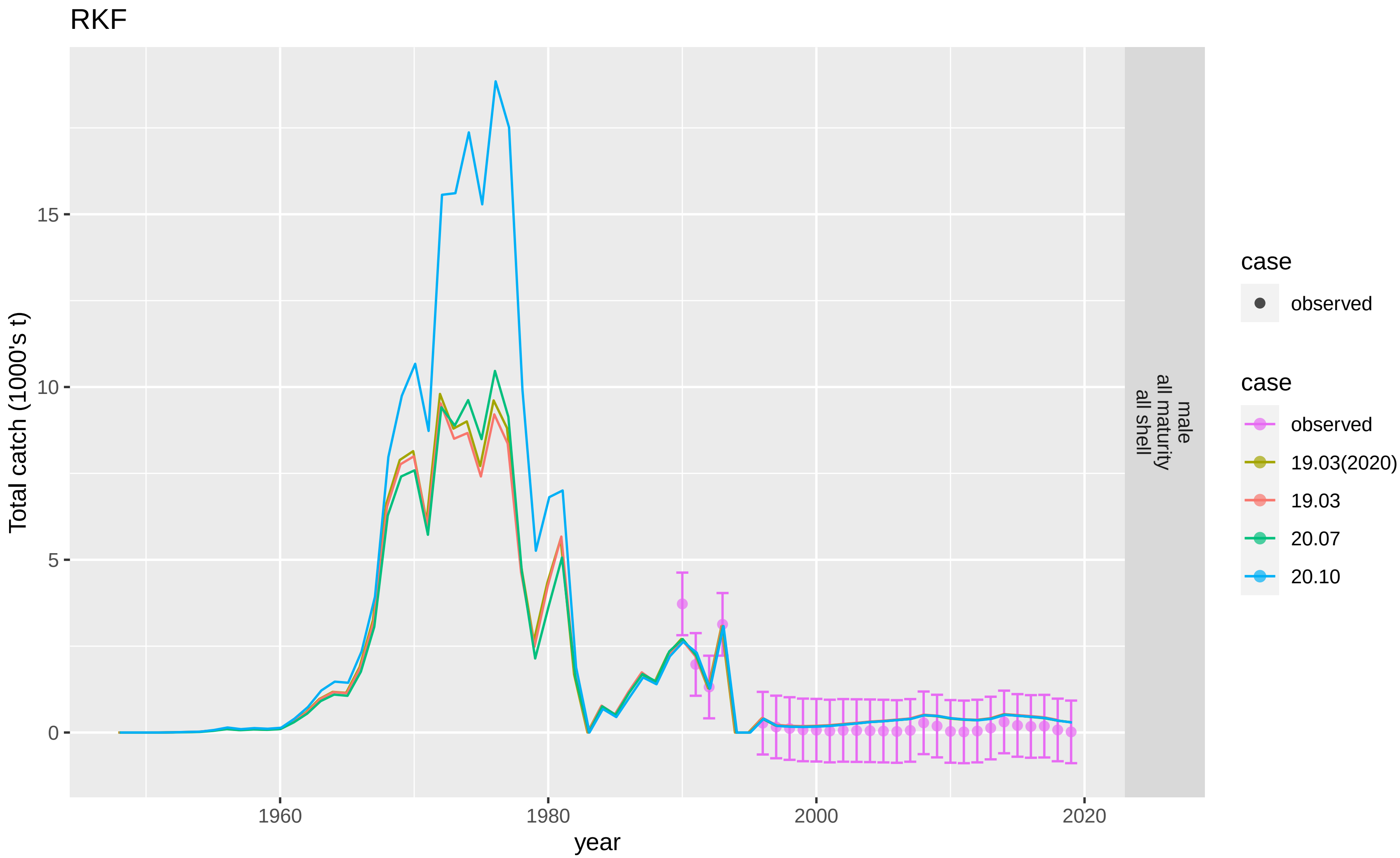

Figure 24: Comparison of observed and predicted total male catch biomass for RKF.

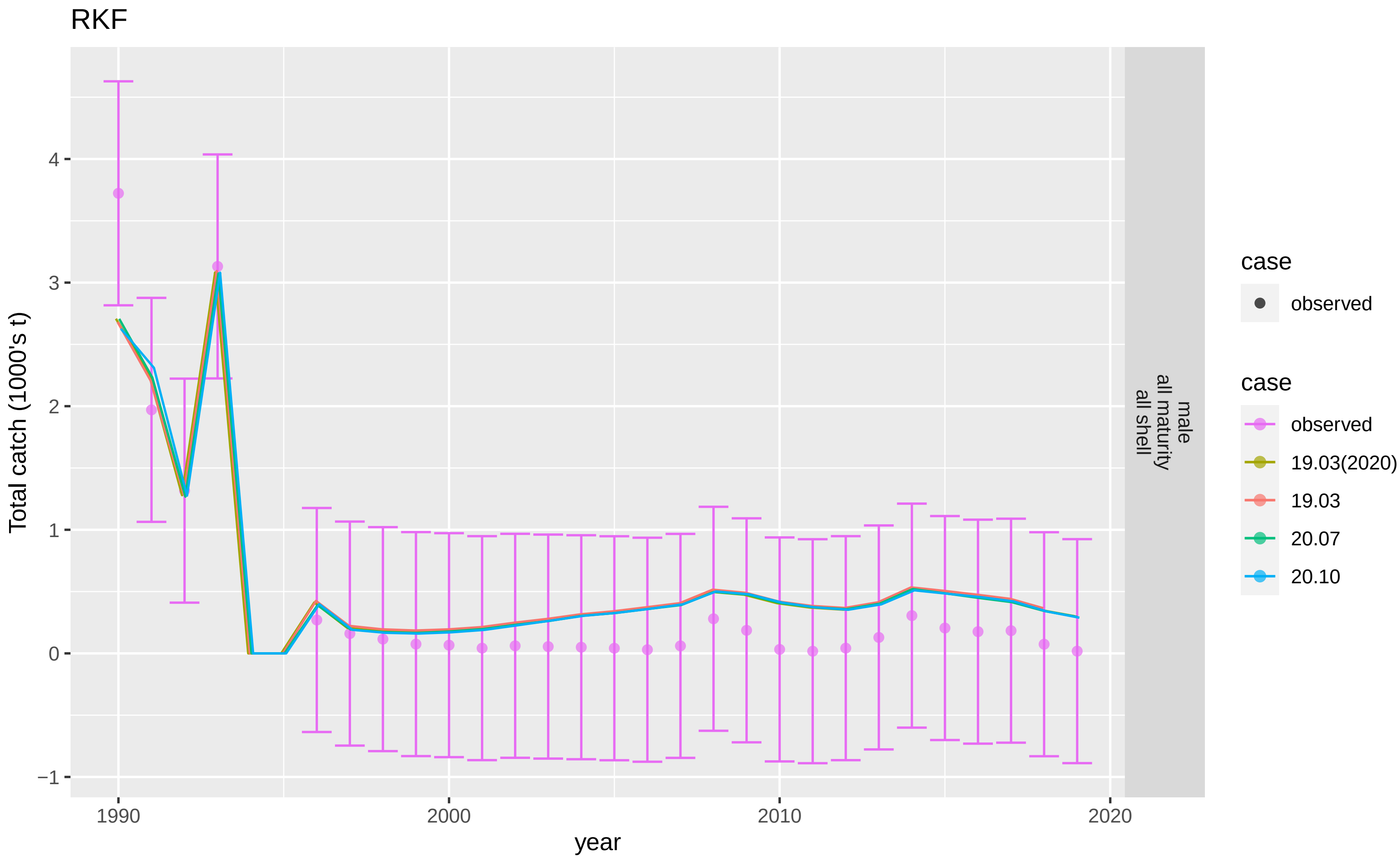

Figure 25: Comparison of observed and predicted total male catch biomass for RKF. Observed time period.

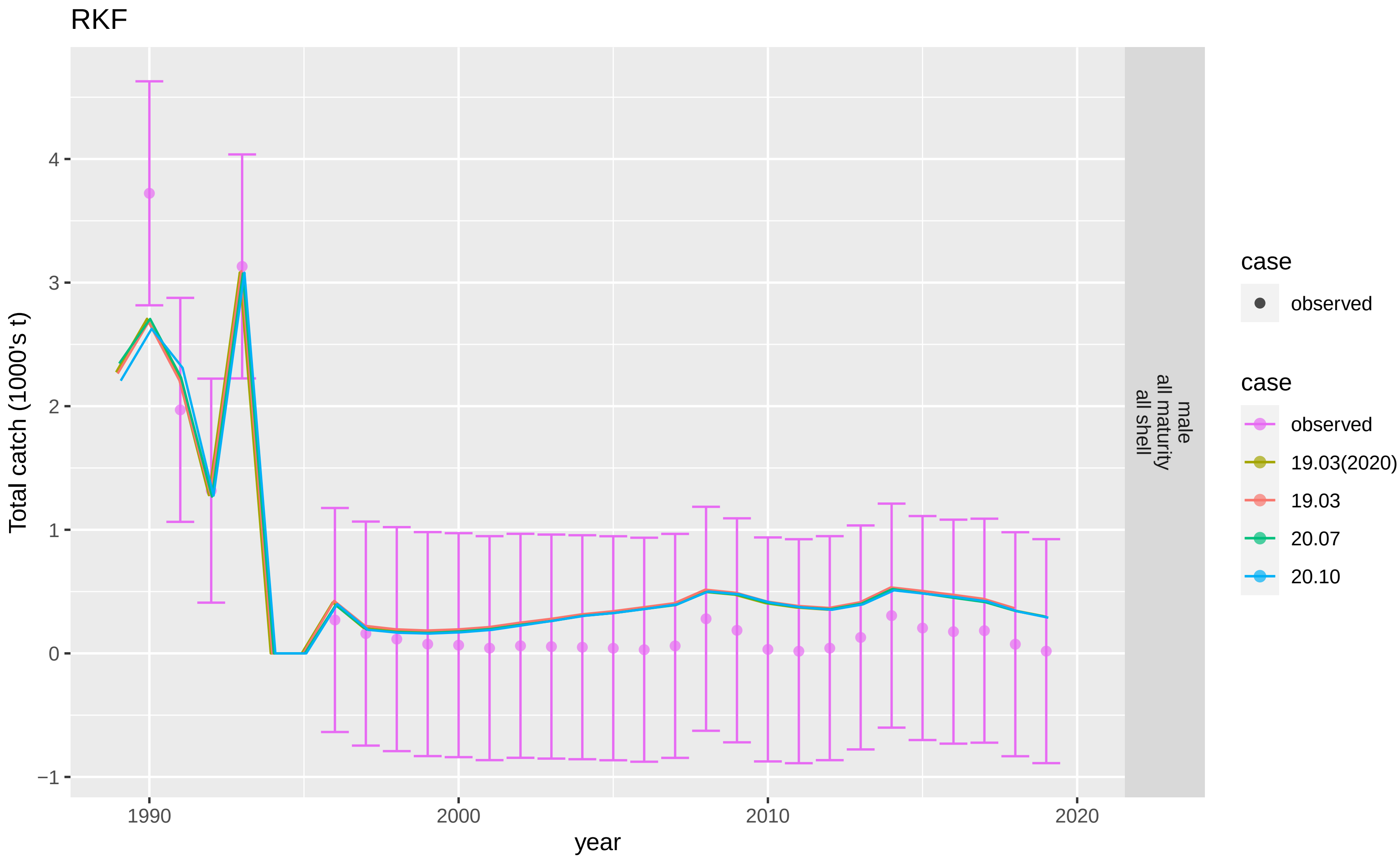

Figure 26: Comparison of observed and predicted total male catch biomass for RKF. Recent time period.

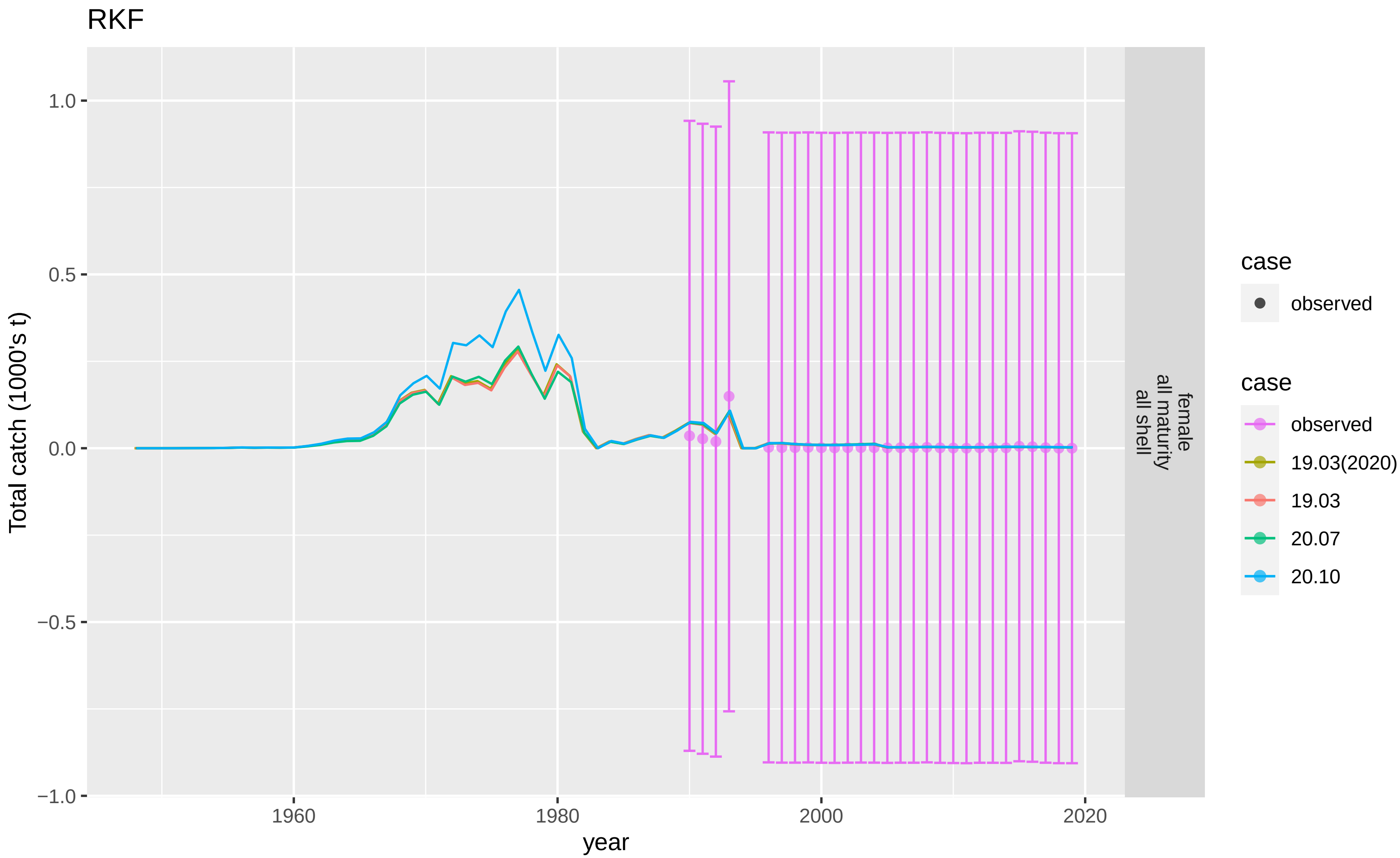

Figure 27: Comparison of observed and predicted total female catch biomass for RKF.

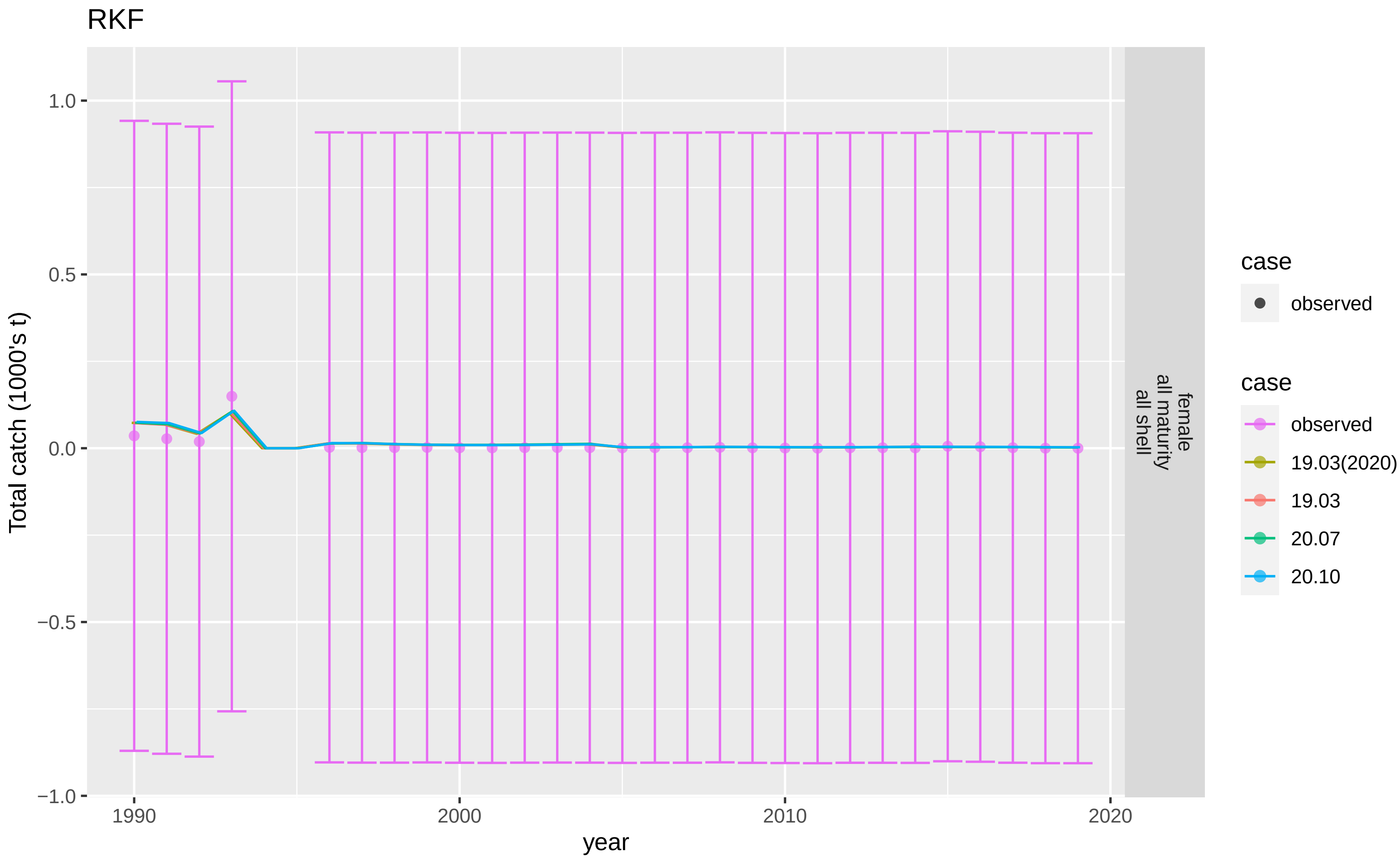

Figure 28: Comparison of observed and predicted total female catch biomass for RKF. Observed time period.

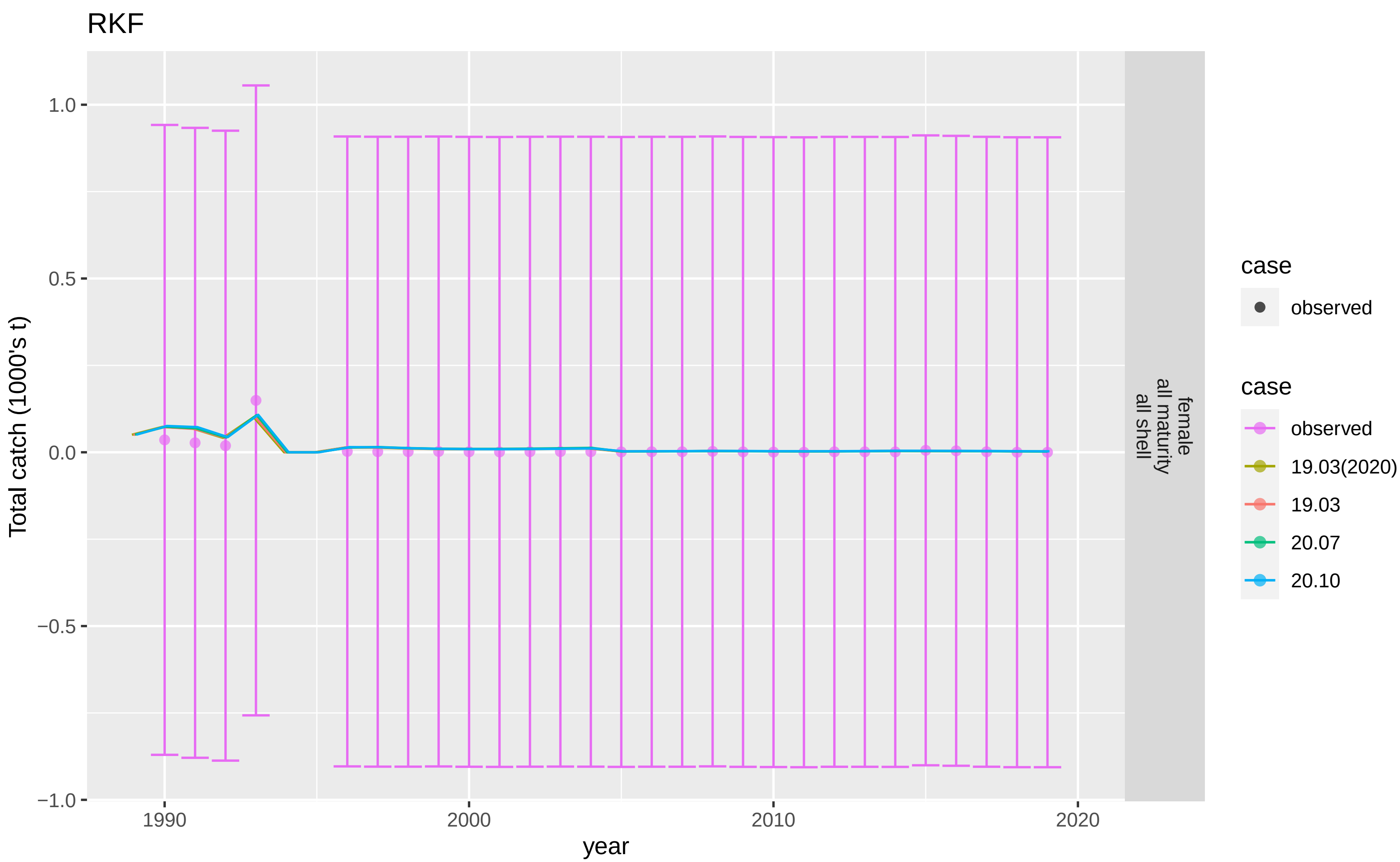

Figure 29: Comparison of observed and predicted total female catch biomass for RKF. Recent time period.

Z-scores

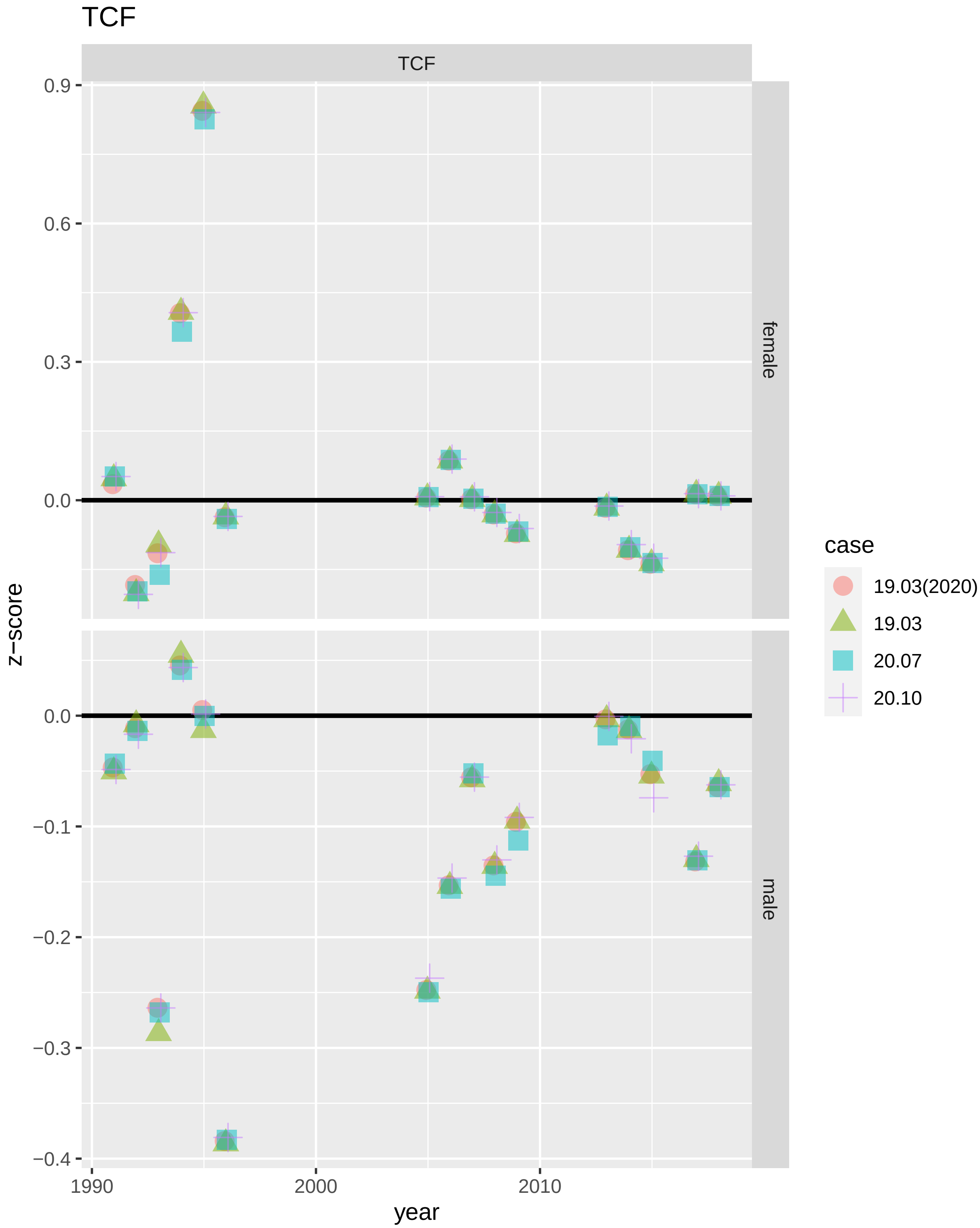

Figure 30: Z-scores for total catch biomass in TCF.

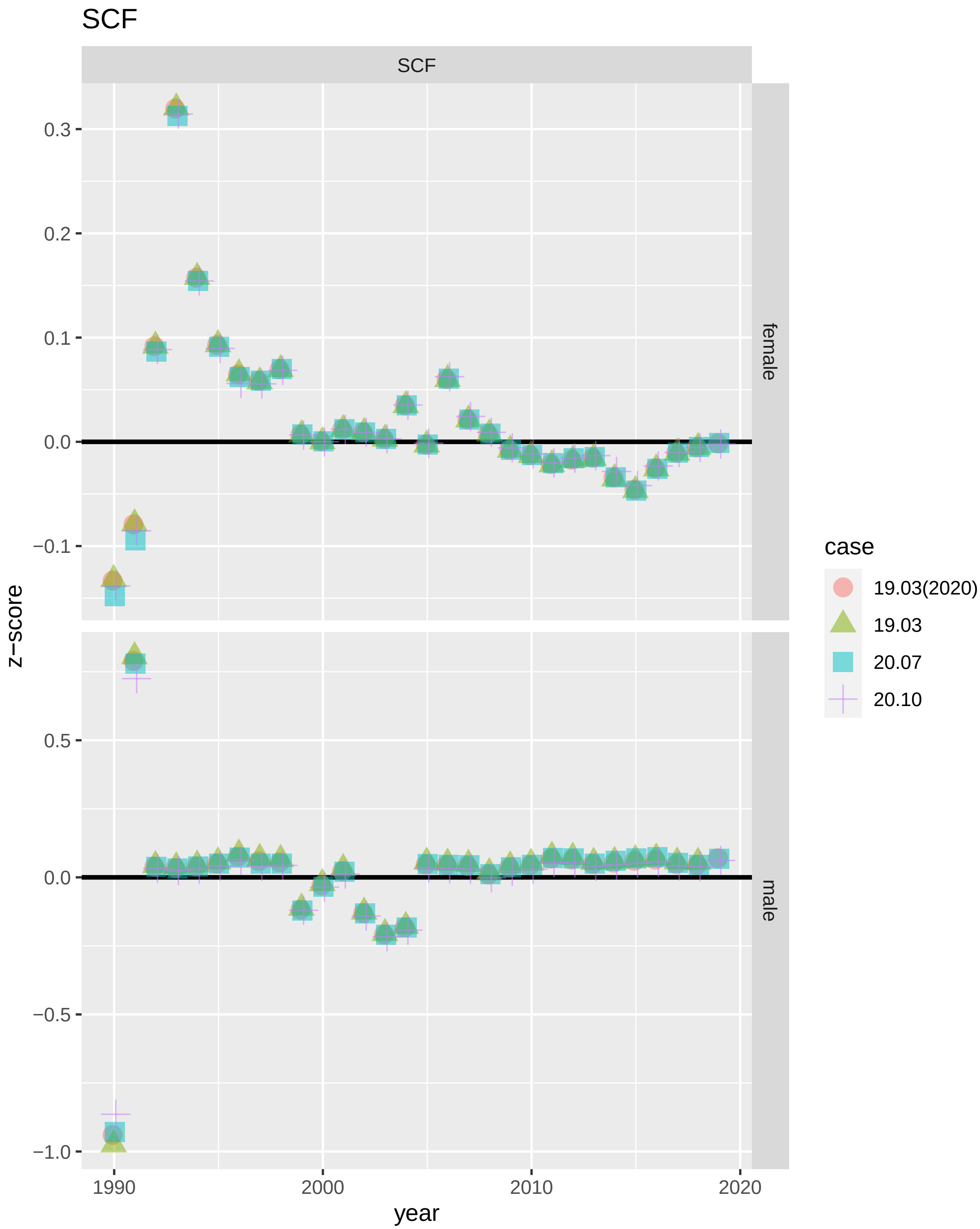

Figure 31: Z-scores for total catch biomass in SCF.

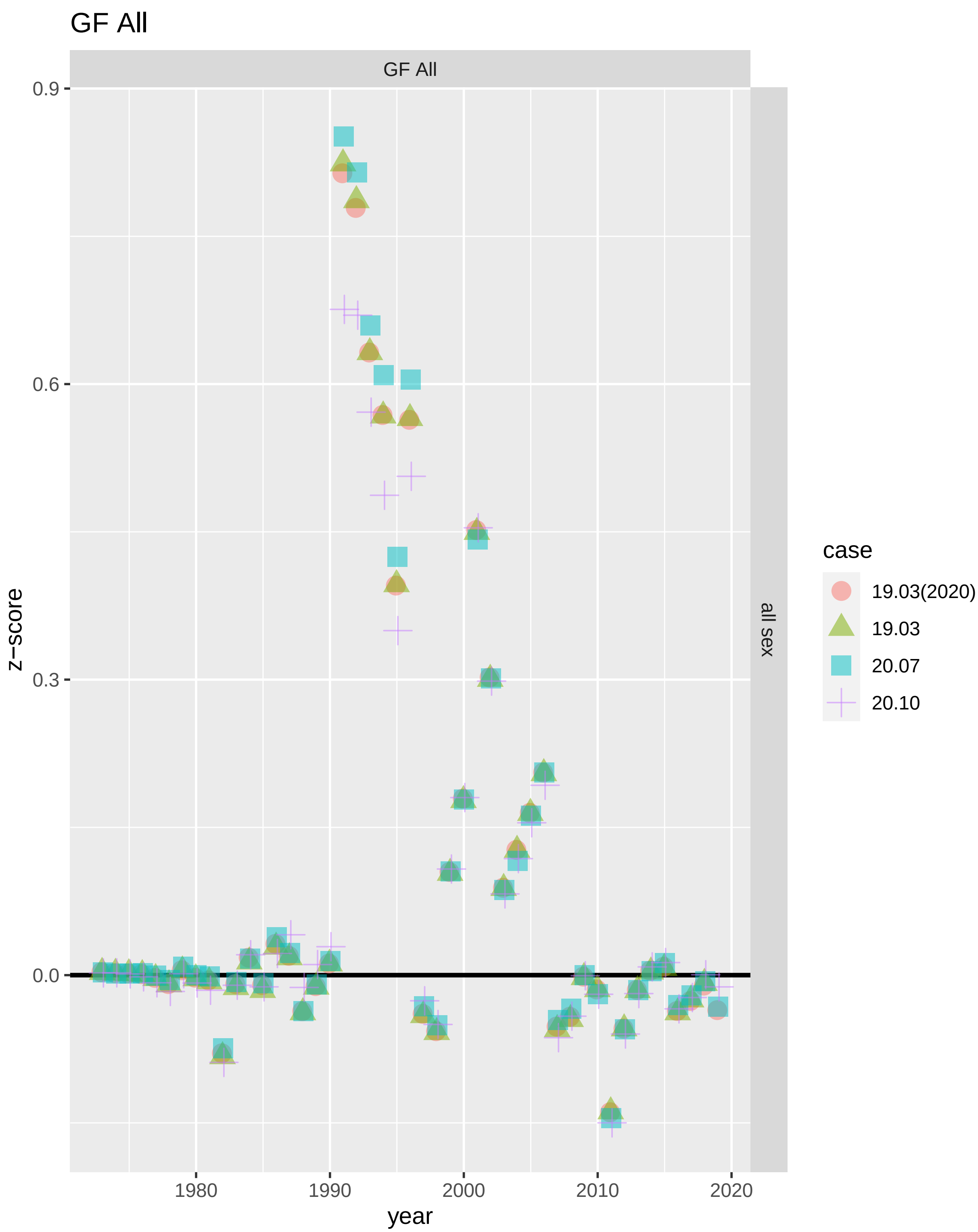

Figure 32: Z-scores for total catch biomass in GF All.

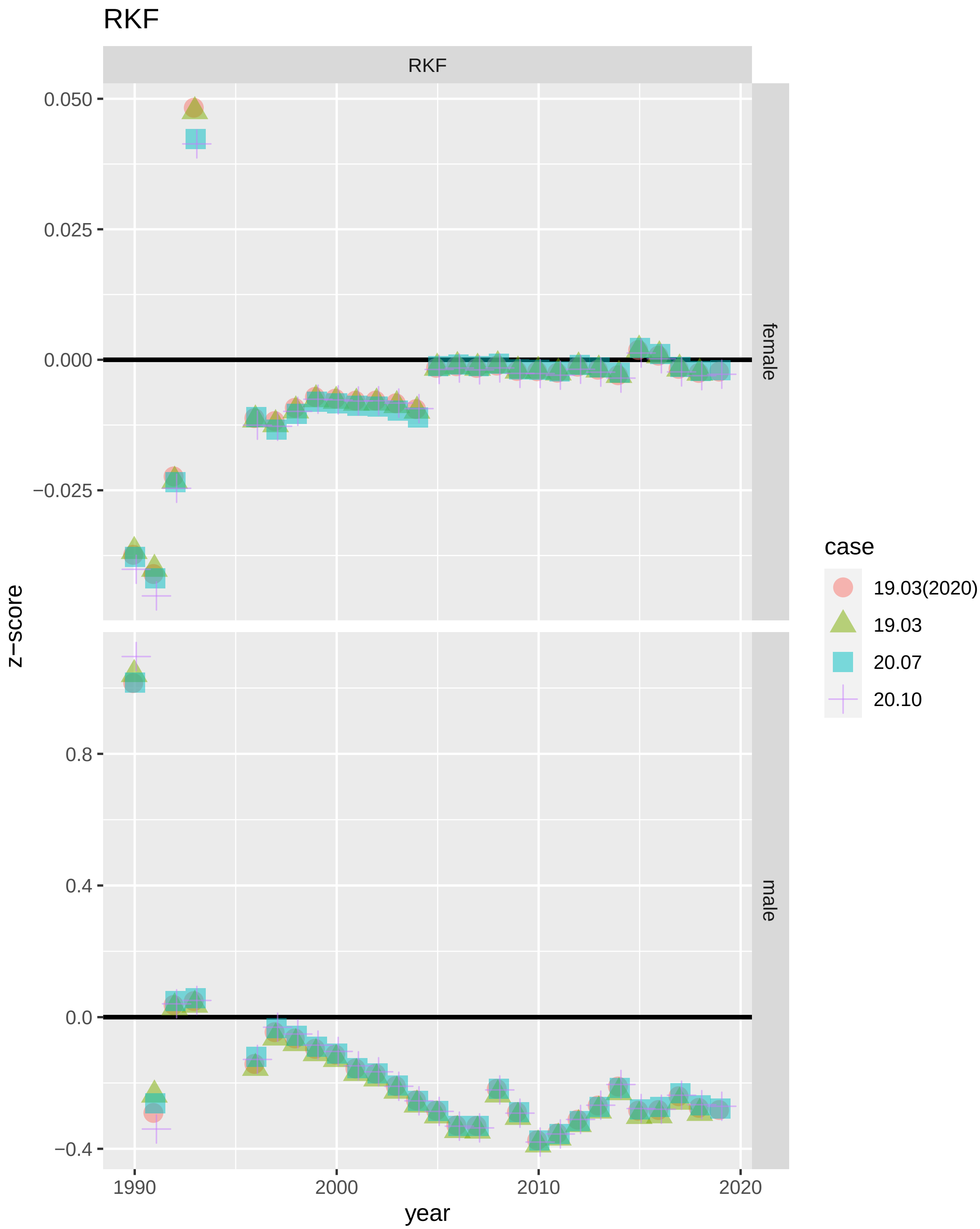

Figure 33: Z-scores for total catch biomass in RKF.

Fishery total catch abundance

Fits

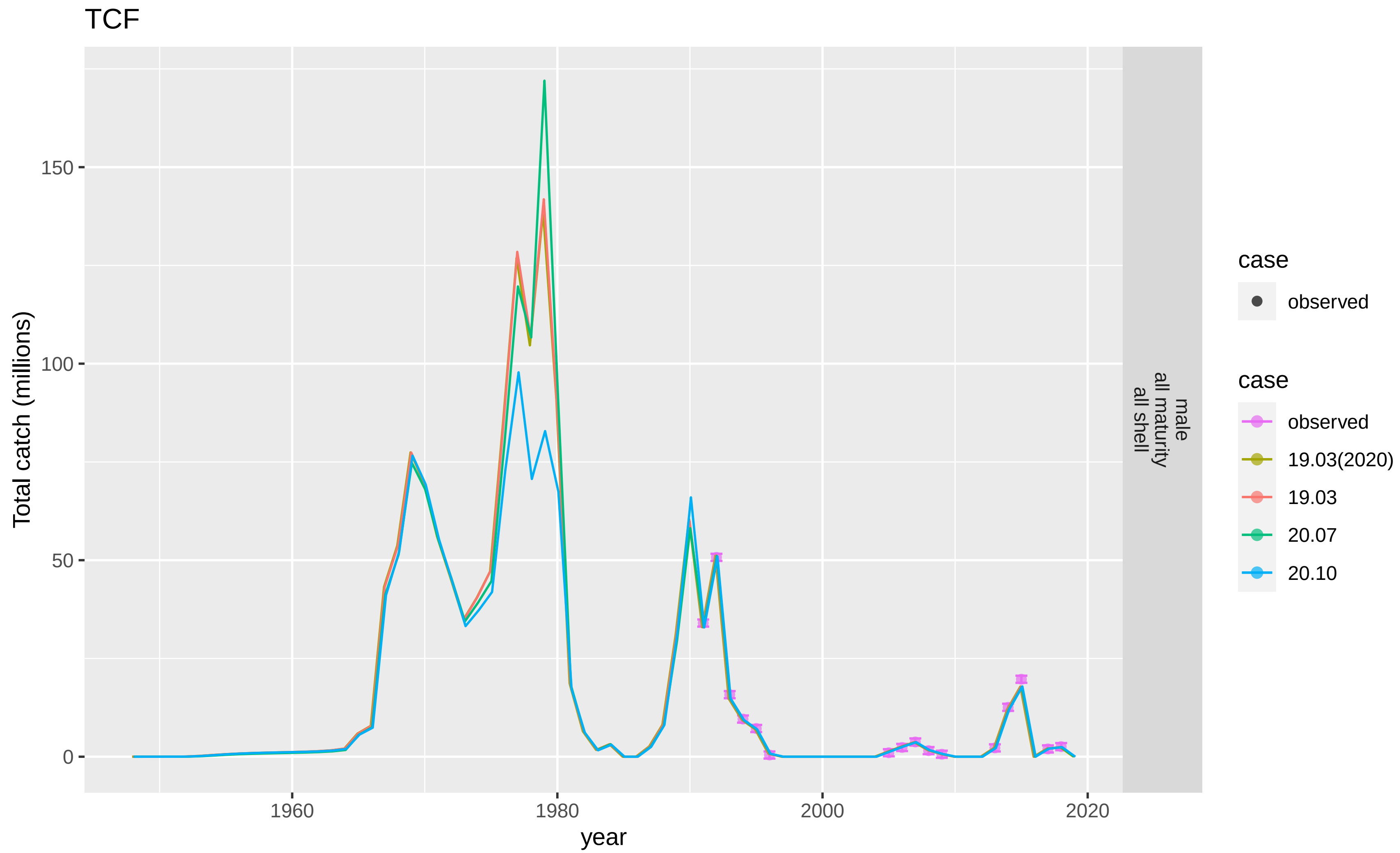

Figure 34: Comparison of observed and predicted male total catch abundance for TCF.

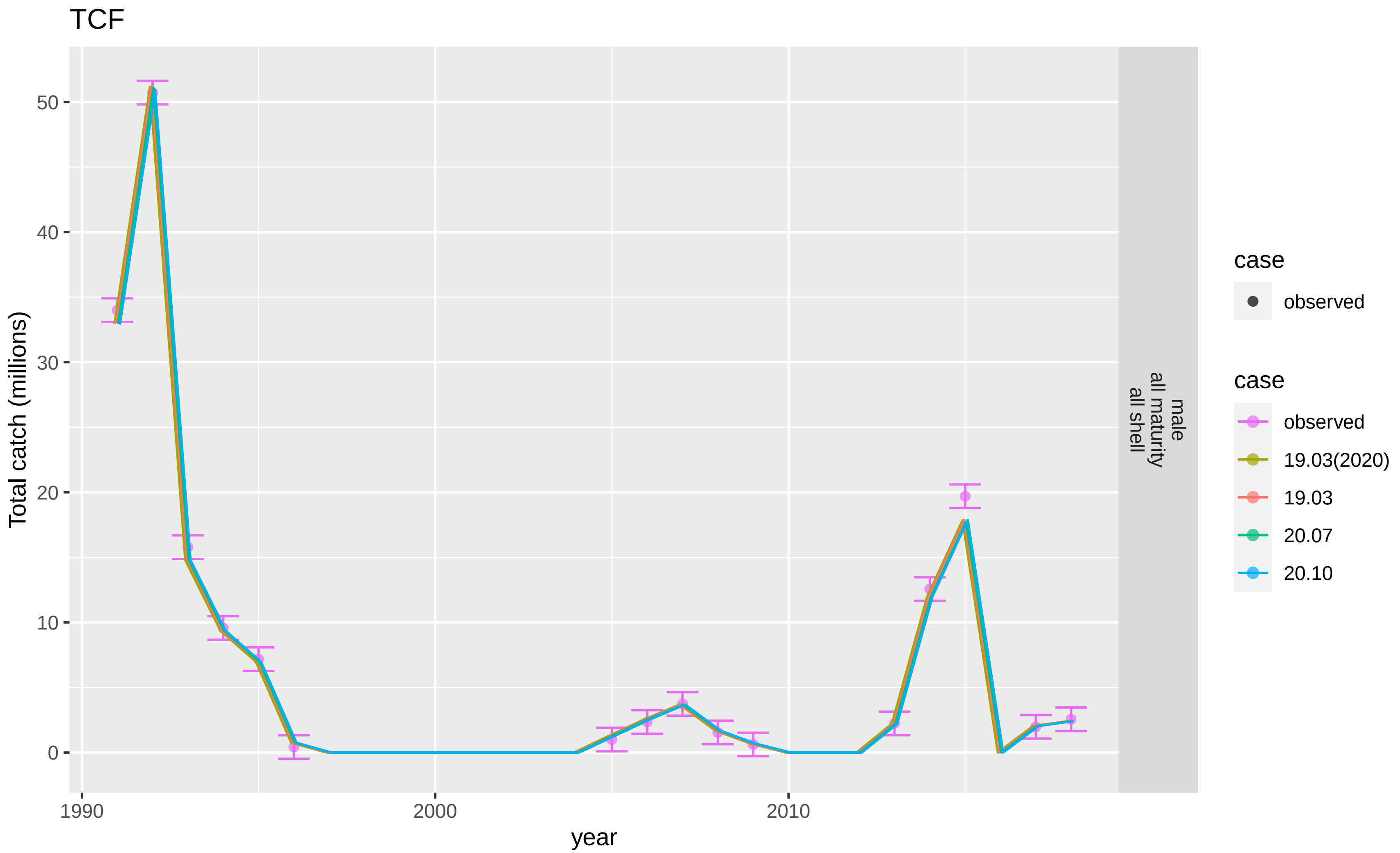

Figure 35: Comparison of observed and predicted male total catch abundance for TCF. Observed time period.

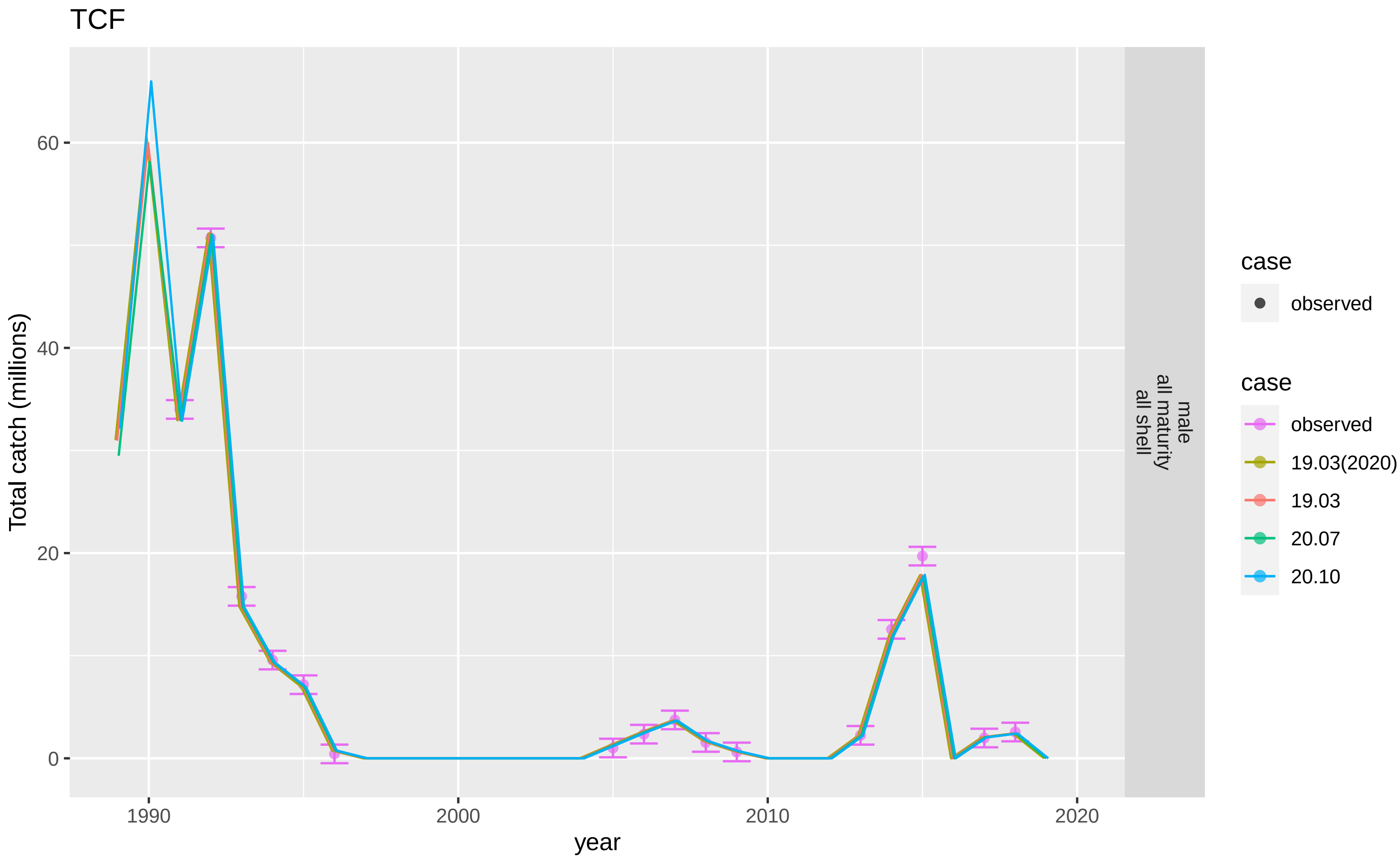

Figure 36: Comparison of observed and predicted male total catch abundance for TCF. Recent time period.

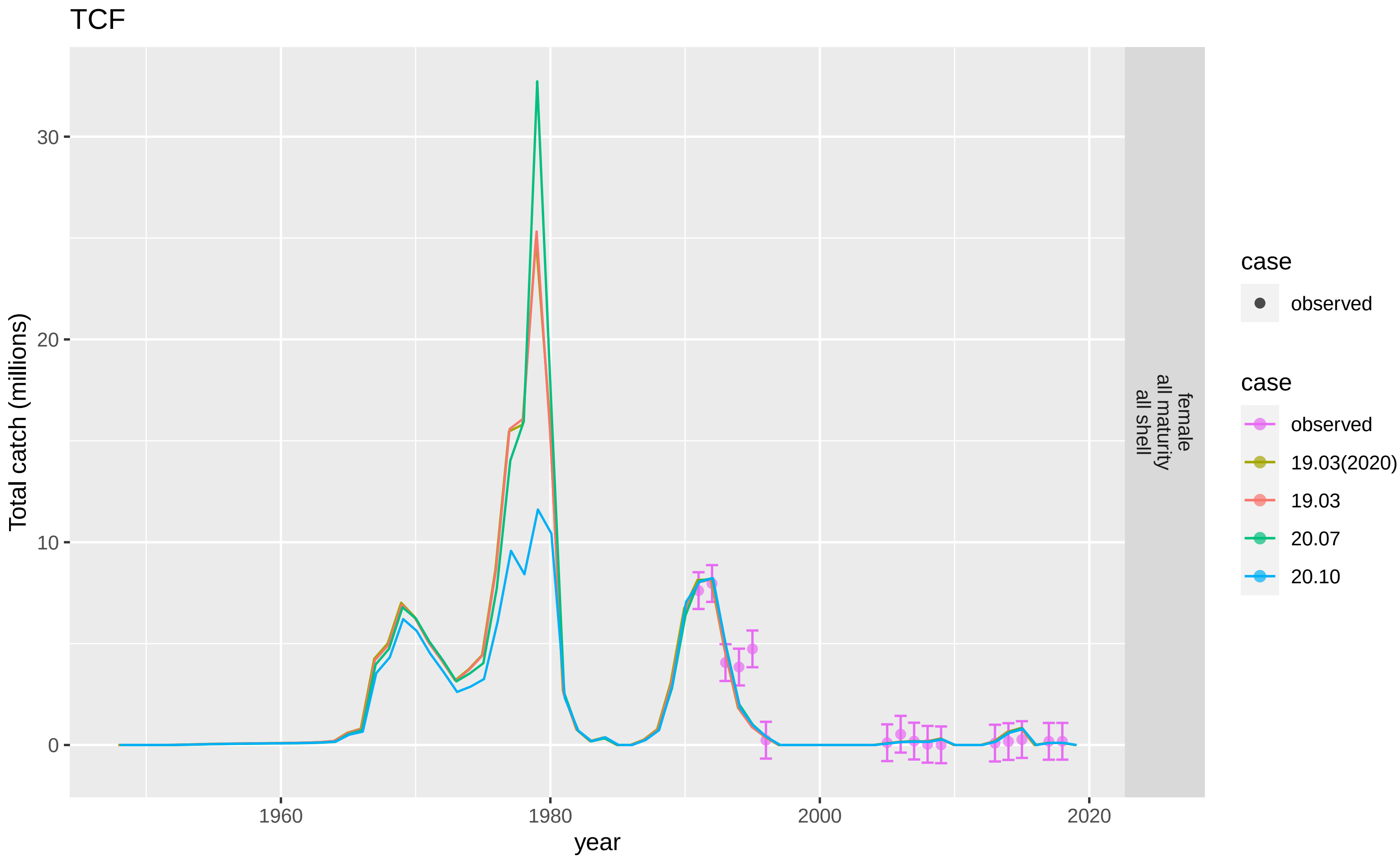

Figure 37: Comparison of observed and predicted female total catch abundance for TCF.

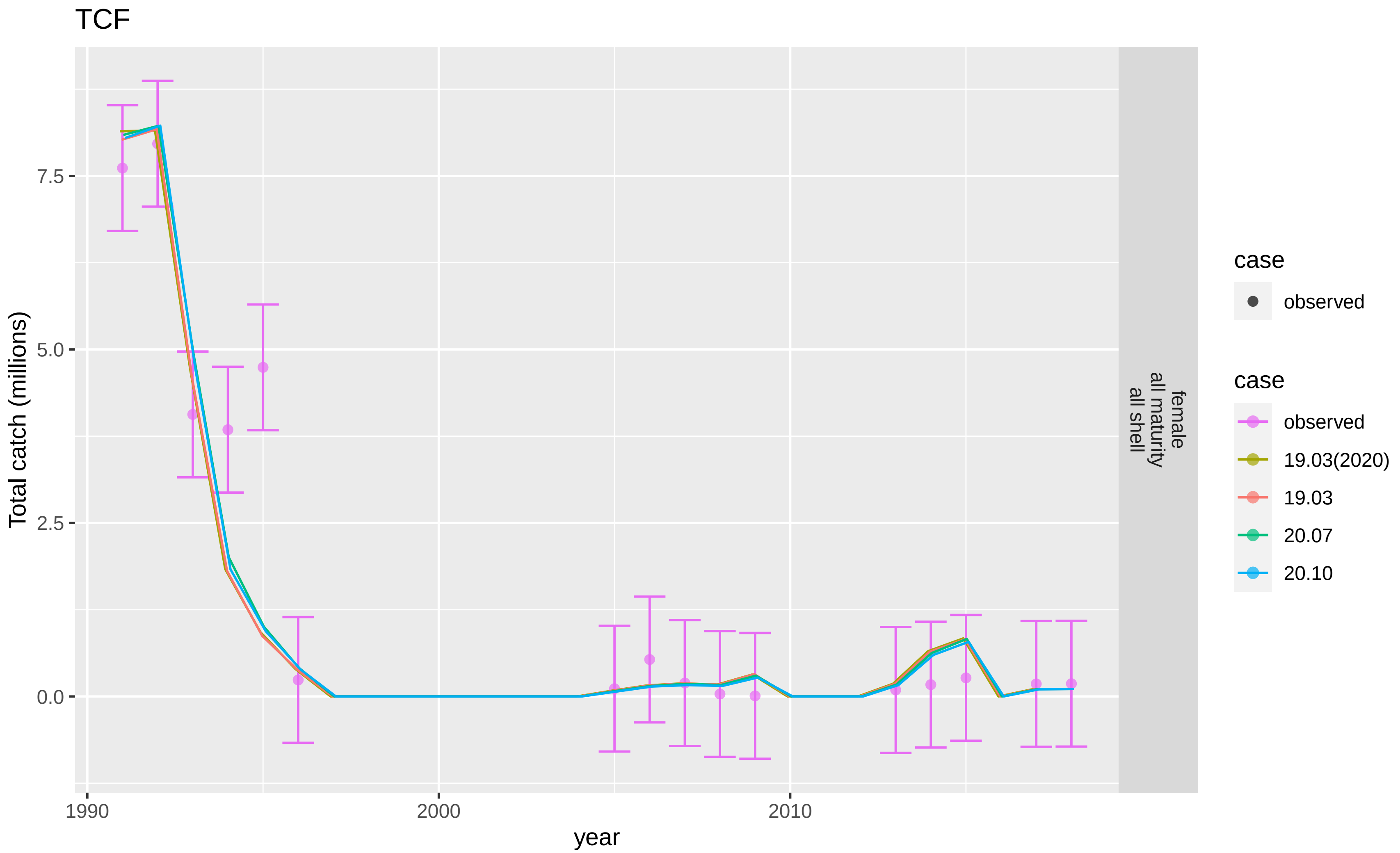

Figure 38: Comparison of observed and predicted female total catch abundance for TCF. Observed time period.

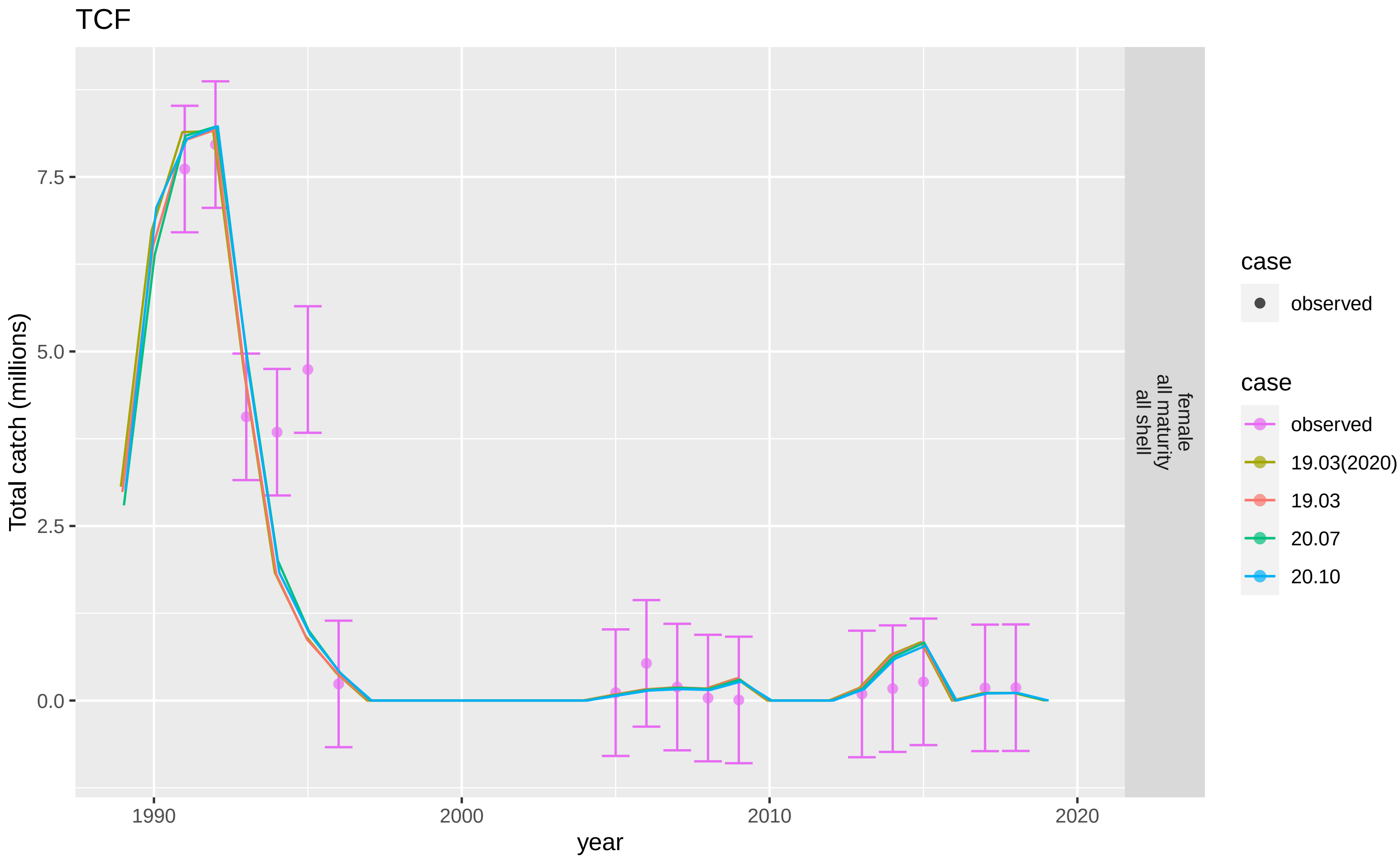

Figure 39: Comparison of observed and predicted female total catch abundance for TCF. Recent time period.

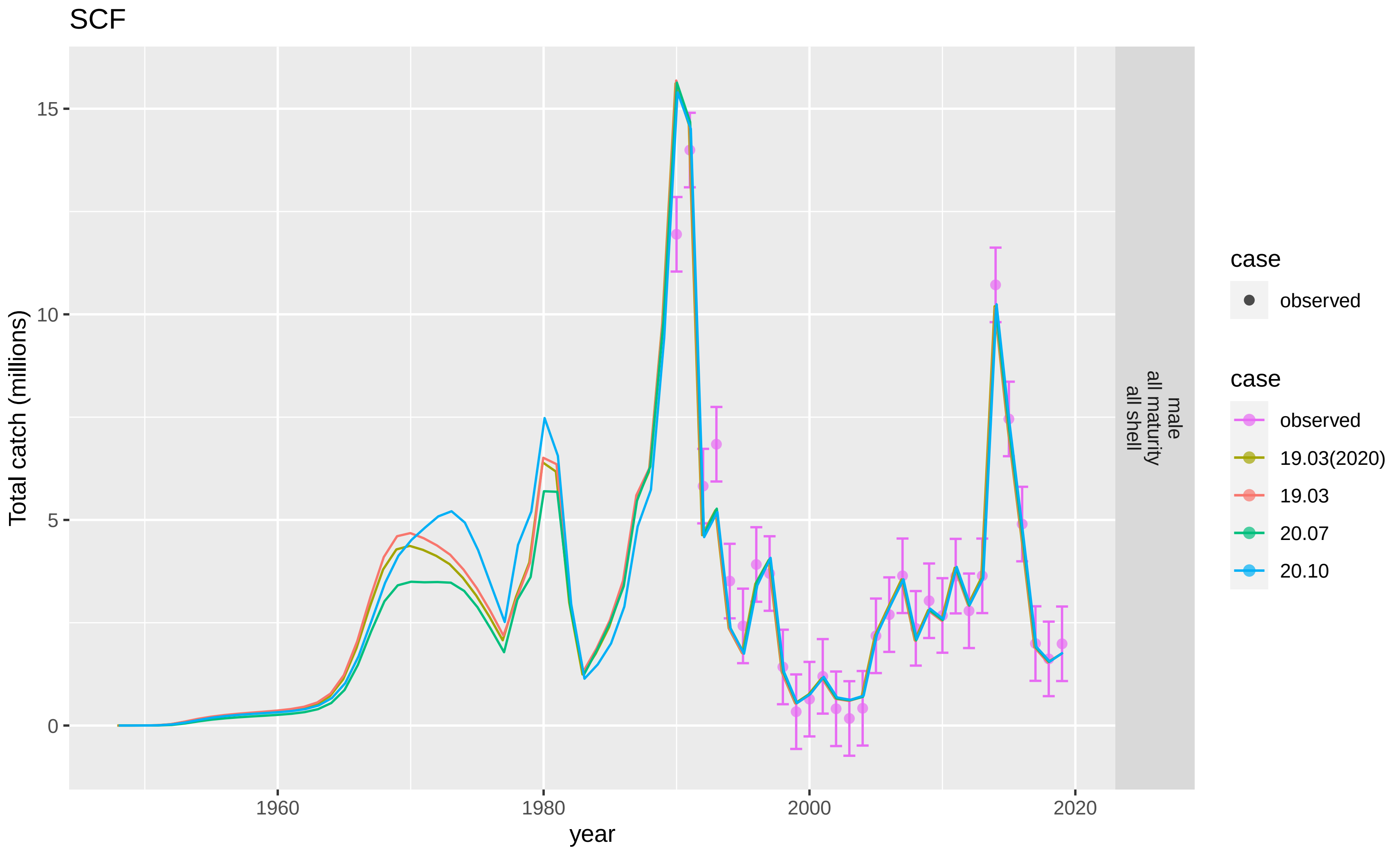

Figure 40: Comparison of observed and predicted male total catch abundance for SCF.

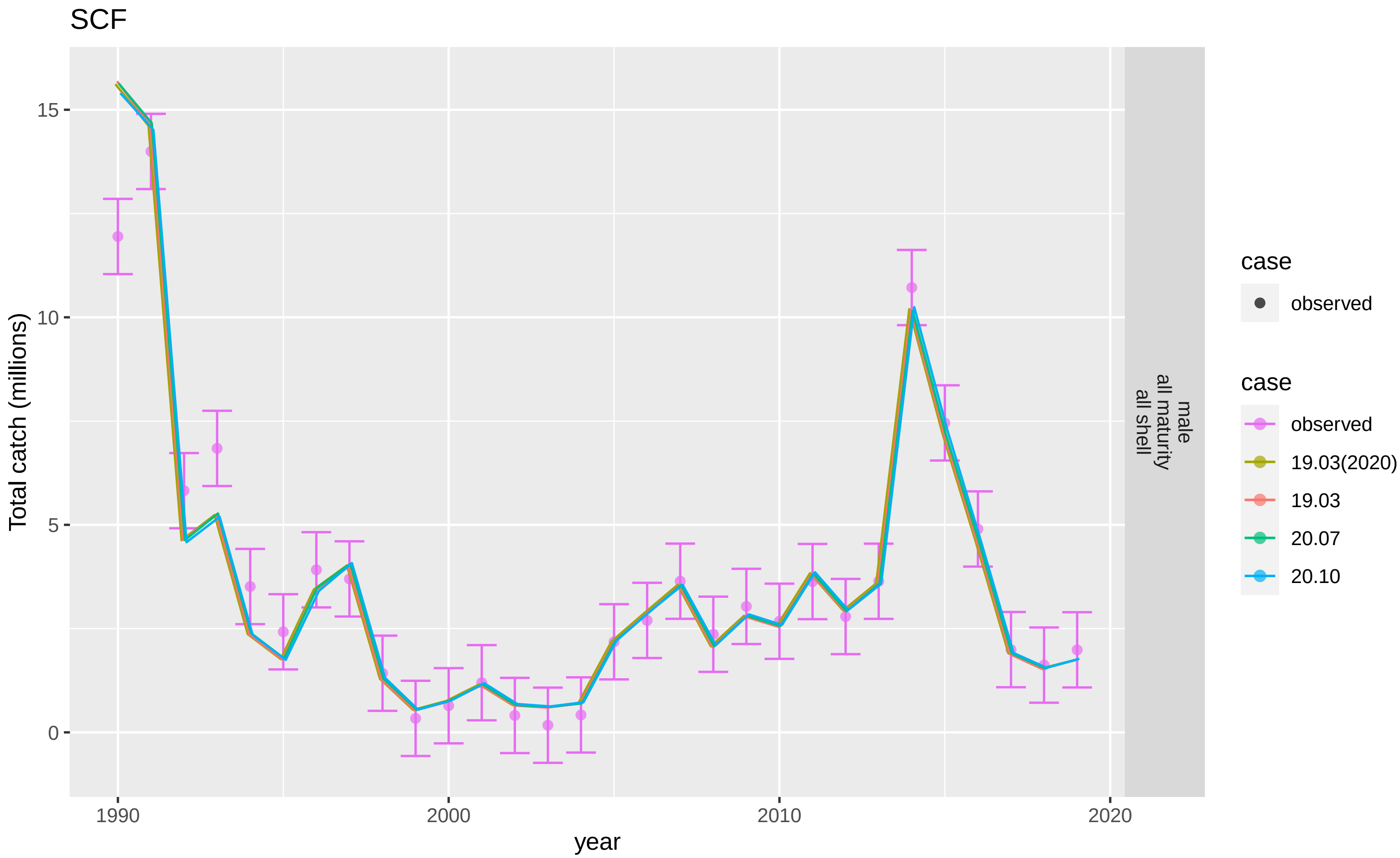

Figure 41: Comparison of observed and predicted male total catch abundance for SCF. Observed time period.

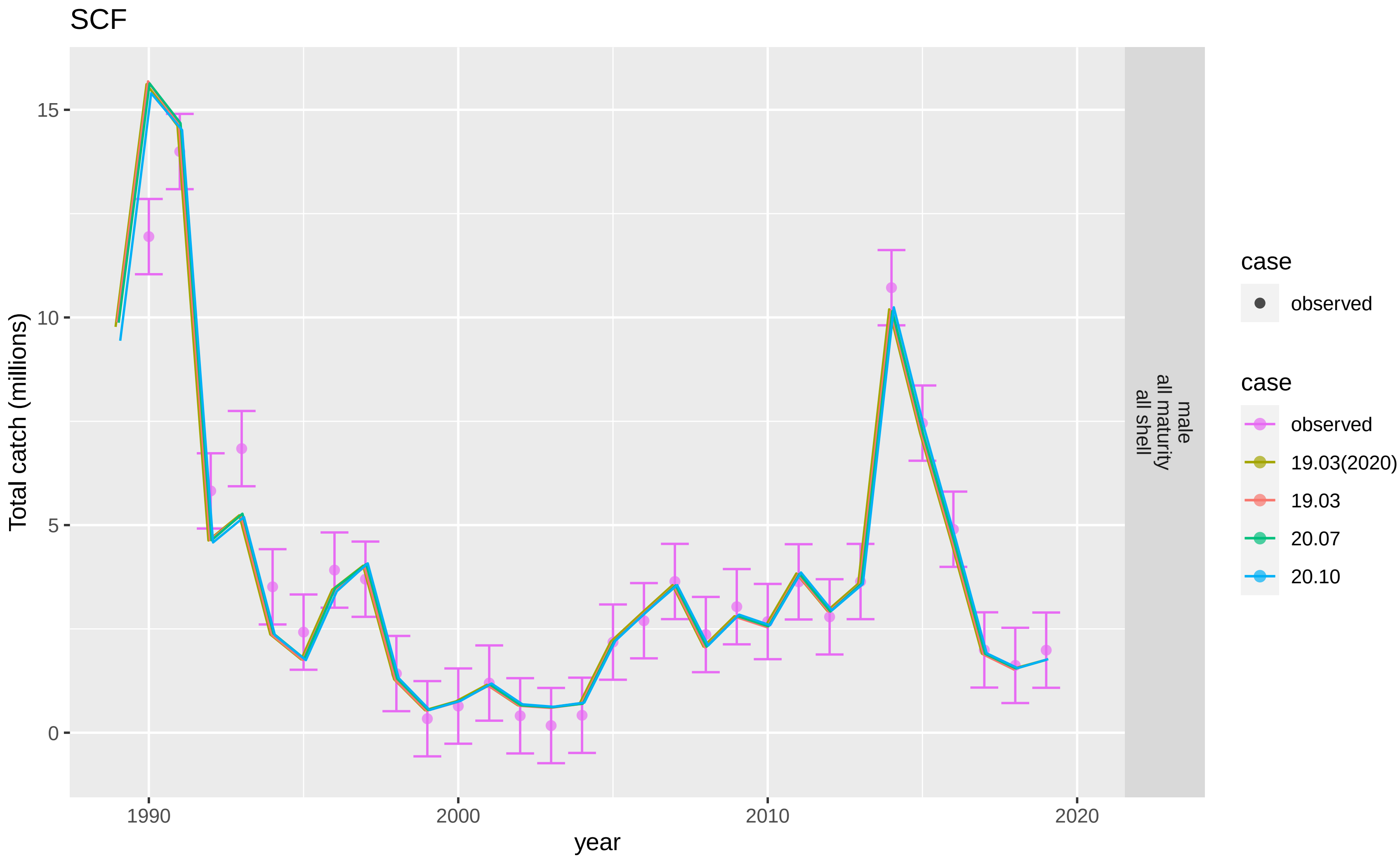

Figure 42: Comparison of observed and predicted male total catch abundance for SCF. Recent time period.

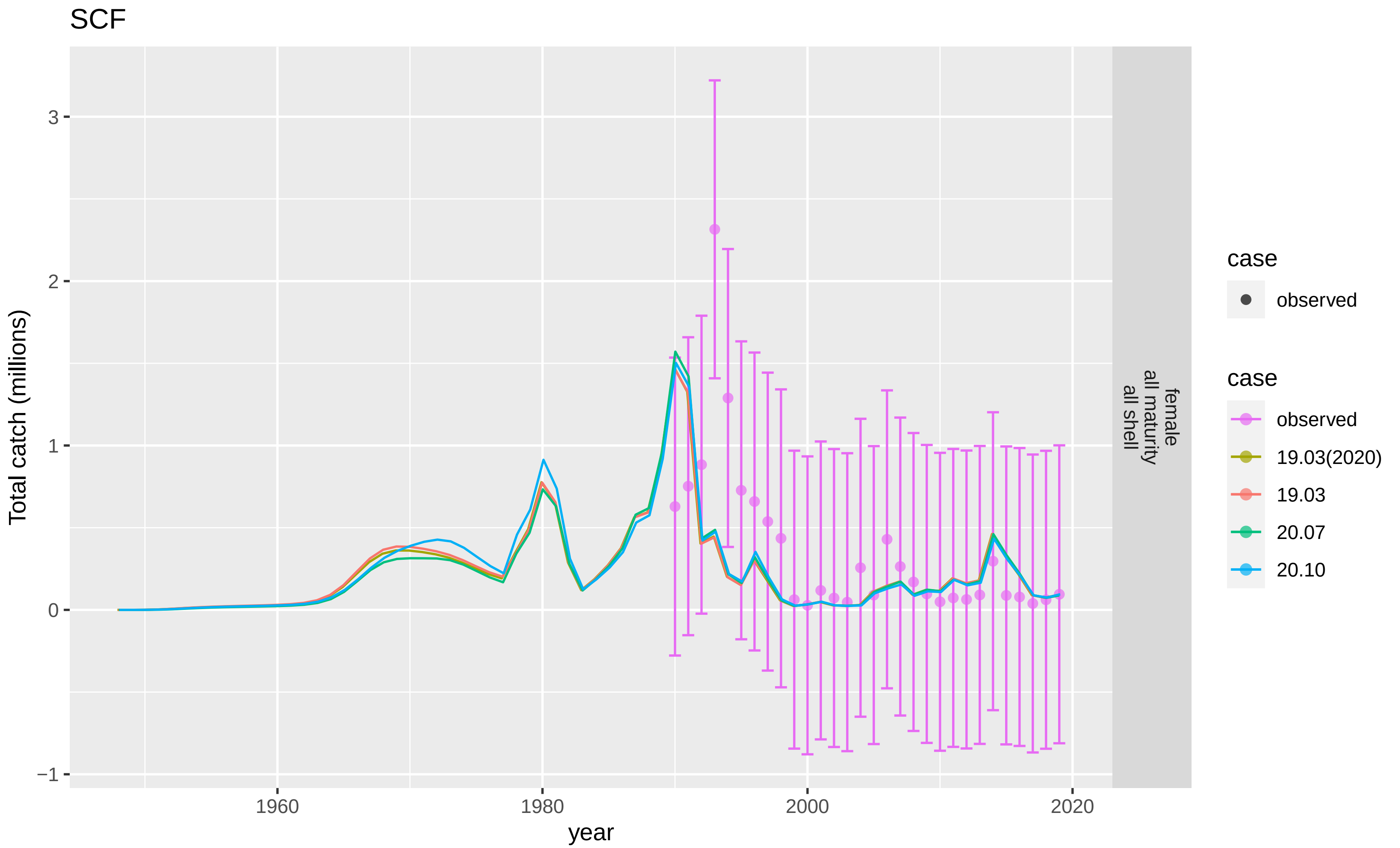

Figure 43: Comparison of observed and predicted female total catch abundance for SCF.

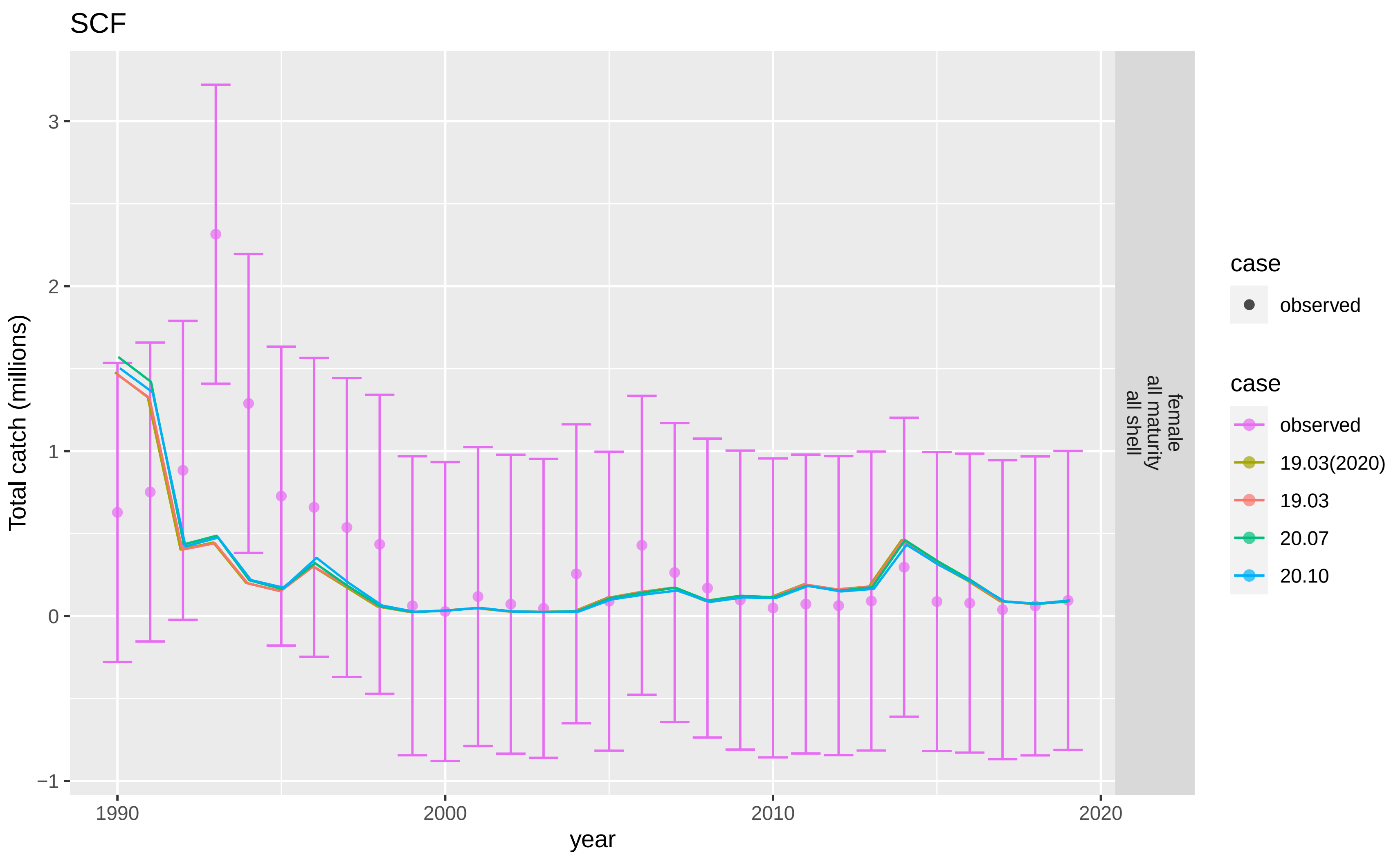

Figure 44: Comparison of observed and predicted female total catch abundance for SCF. Observed time period.

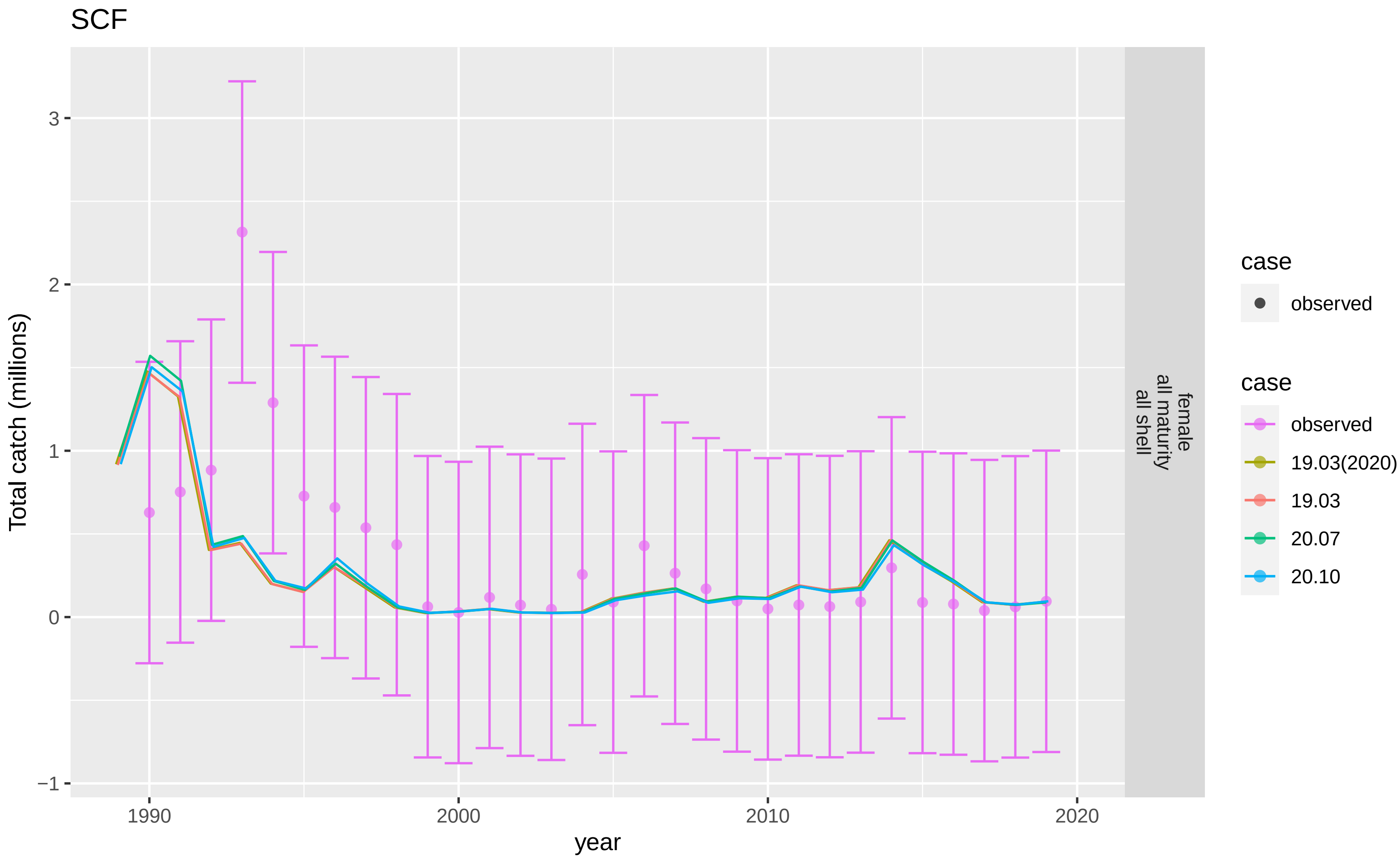

Figure 45: Comparison of observed and predicted female total catch abundance for SCF. Recent time period.

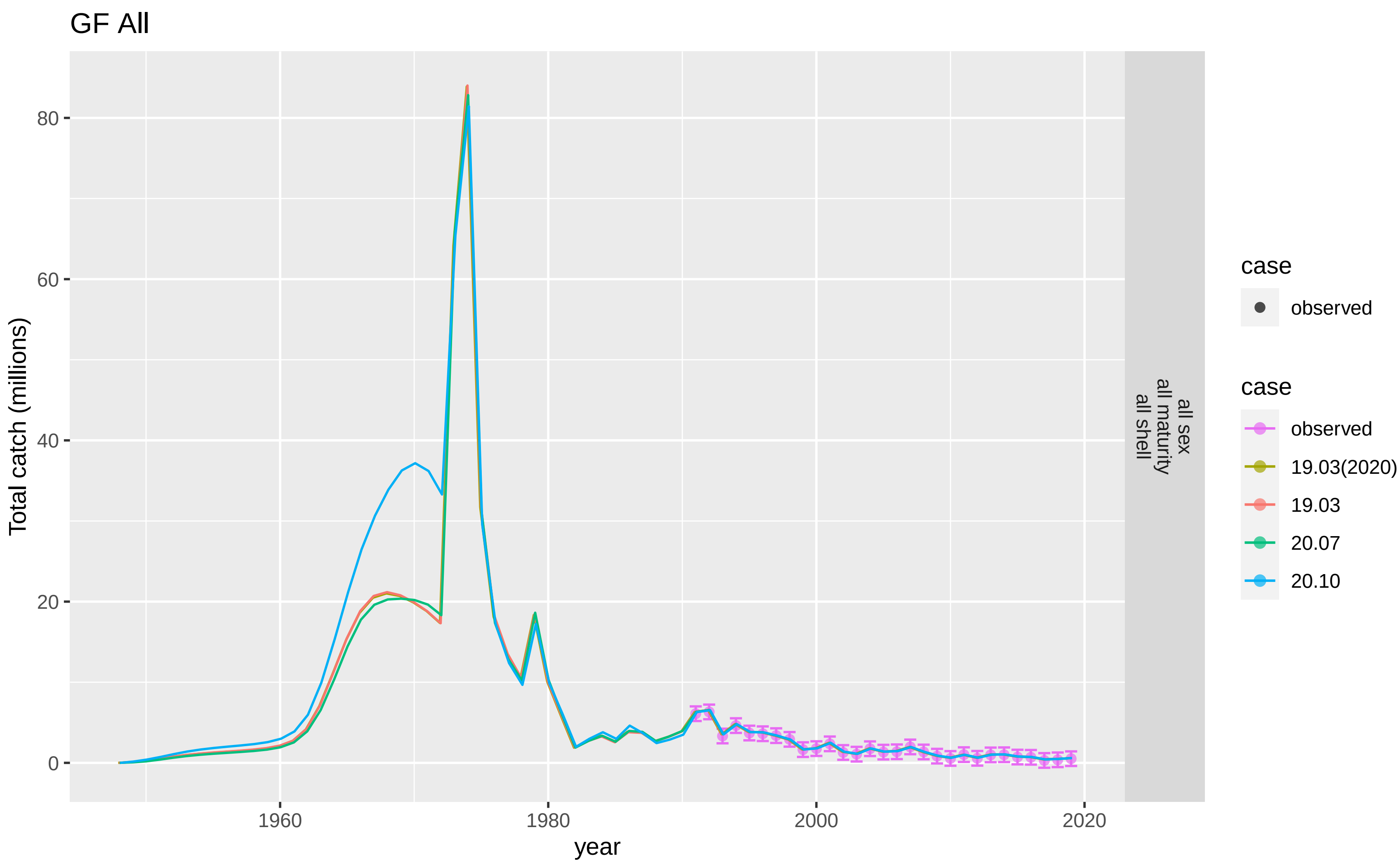

Figure 46: Comparison of observed and predicted all sex total catch abundance for GF All.

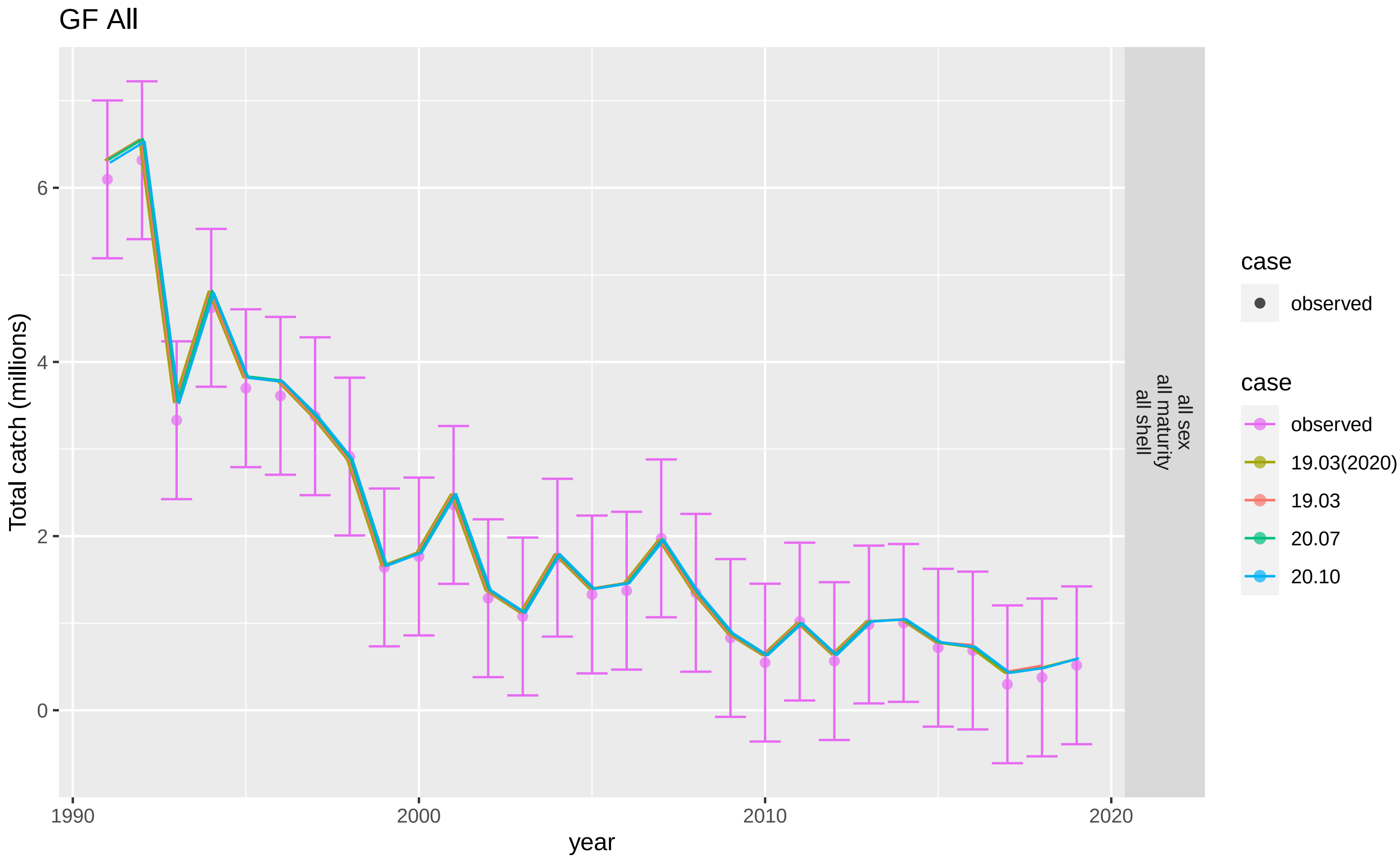

Figure 47: Comparison of observed and predicted all sex total catch abundance for GF All. Observed time period.

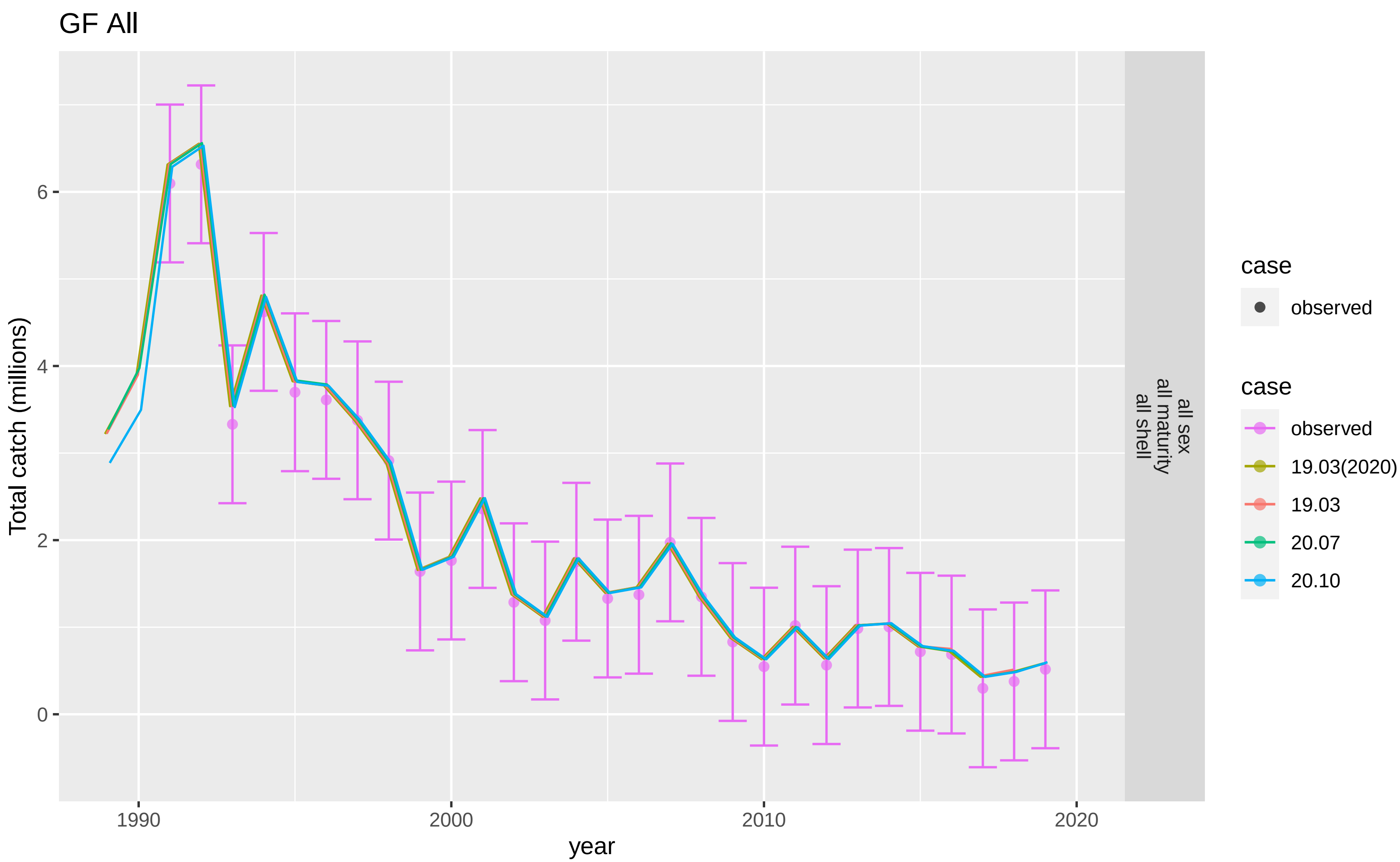

Figure 48: Comparison of observed and predicted all sex total catch abundance for GF All. Recent time period.

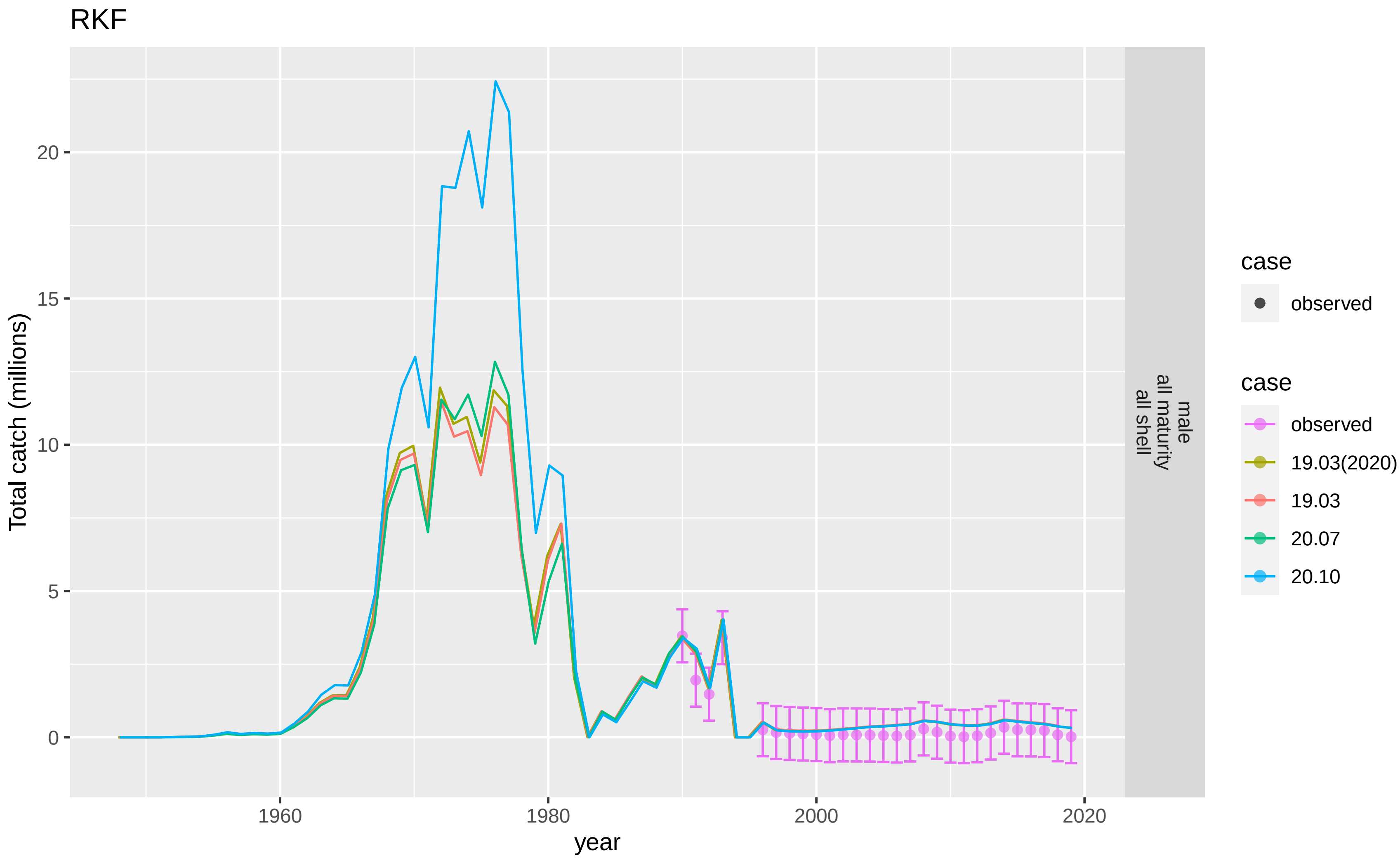

Figure 49: Comparison of observed and predicted male total catch abundance for RKF.

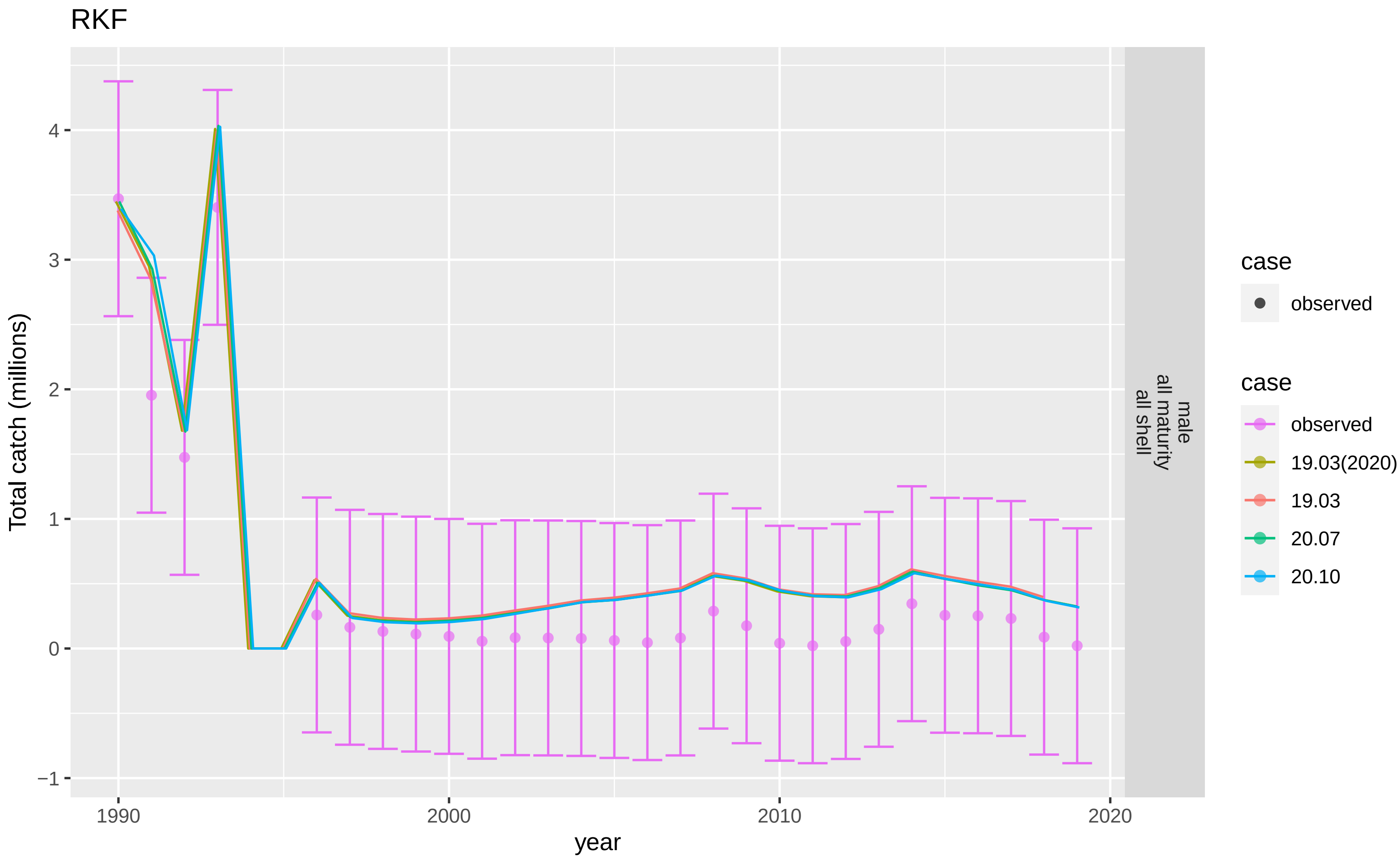

Figure 50: Comparison of observed and predicted male total catch abundance for RKF. Observed time period.

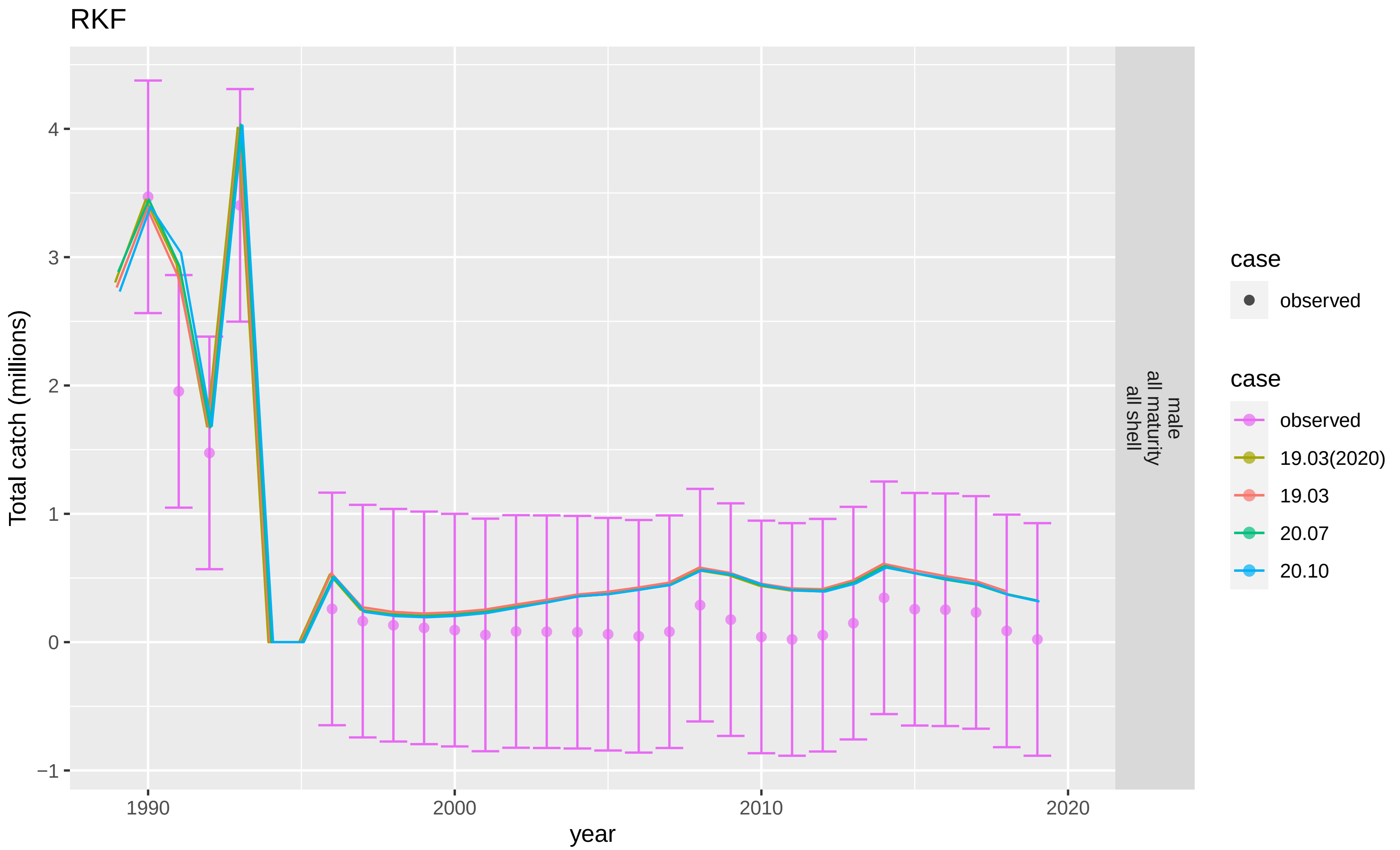

Figure 51: Comparison of observed and predicted male total catch abundance for RKF. Recent time period.

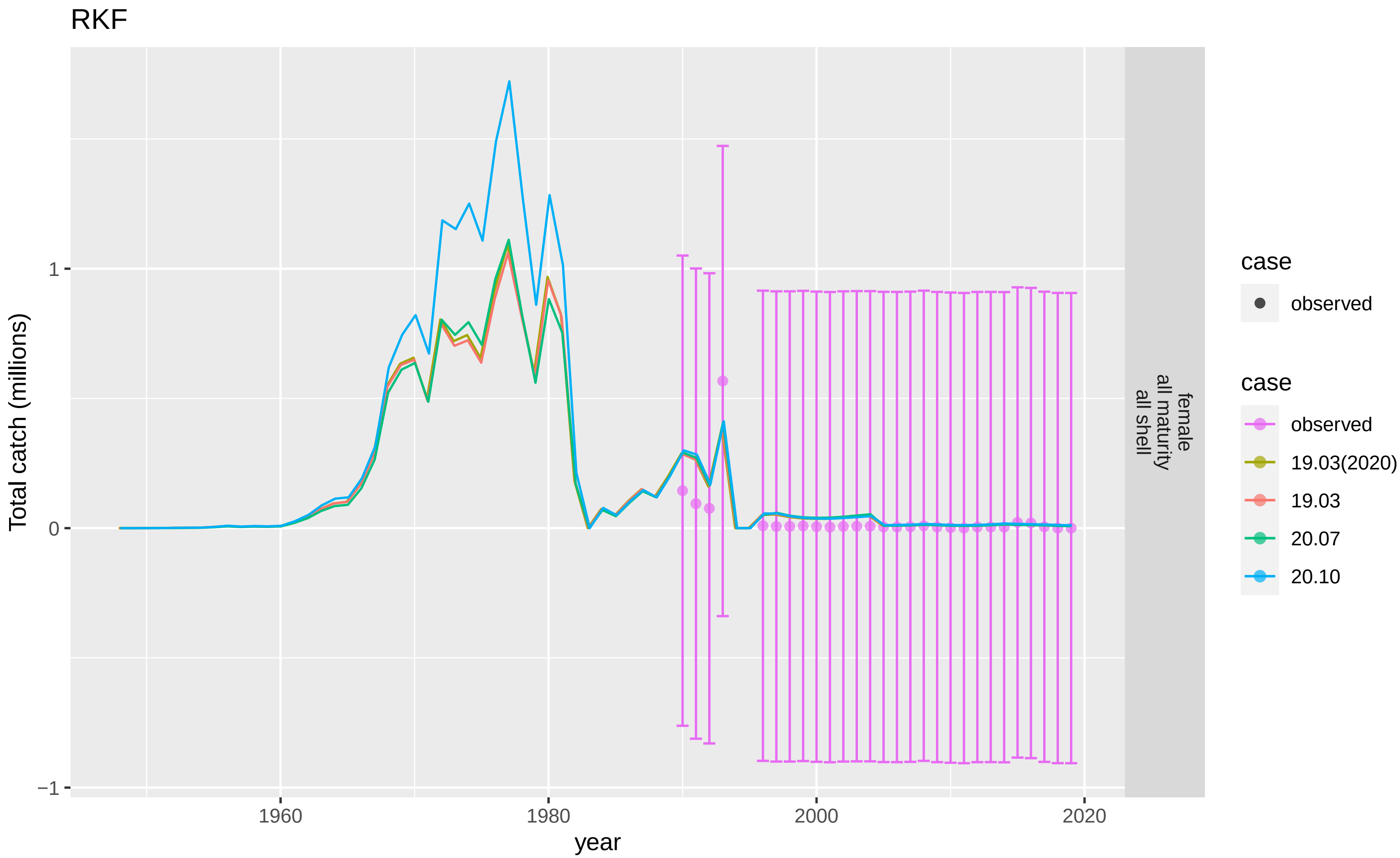

Figure 52: Comparison of observed and predicted female total catch abundance for RKF.

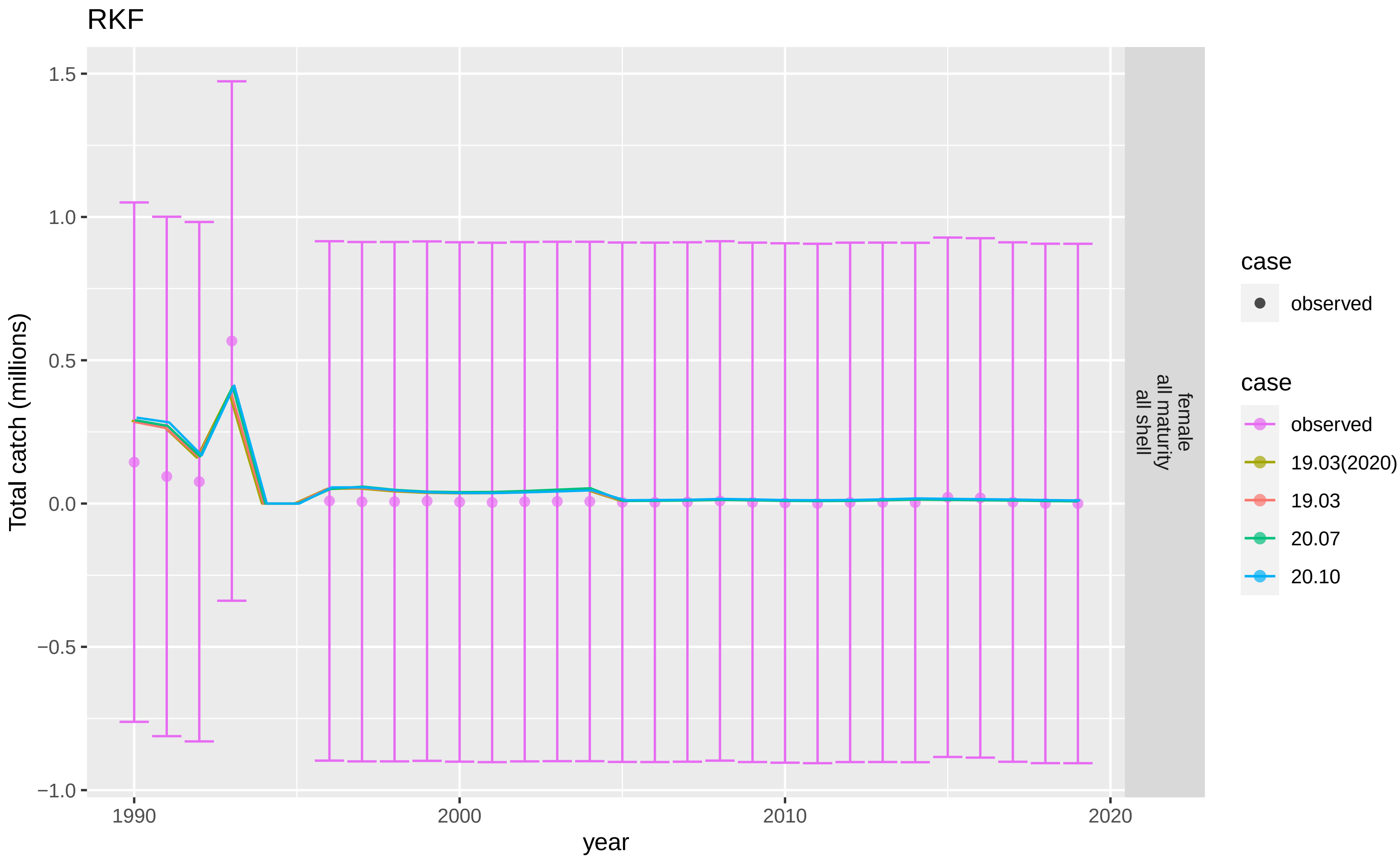

Figure 53: Comparison of observed and predicted female total catch abundance for RKF. Observed time period.

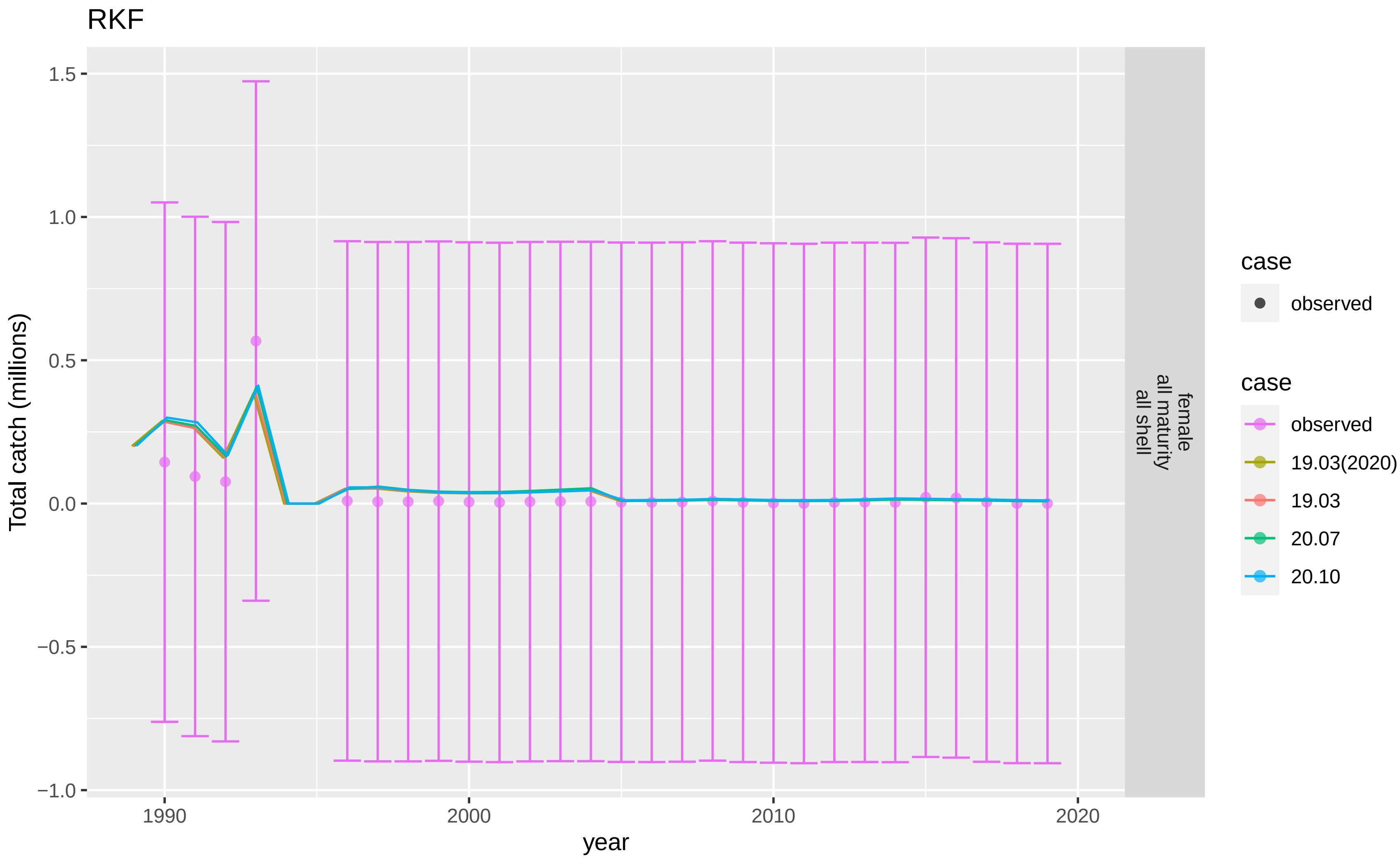

Figure 54: Comparison of observed and predicted female total catch abundance for RKF. Recent time period.

Z-scores

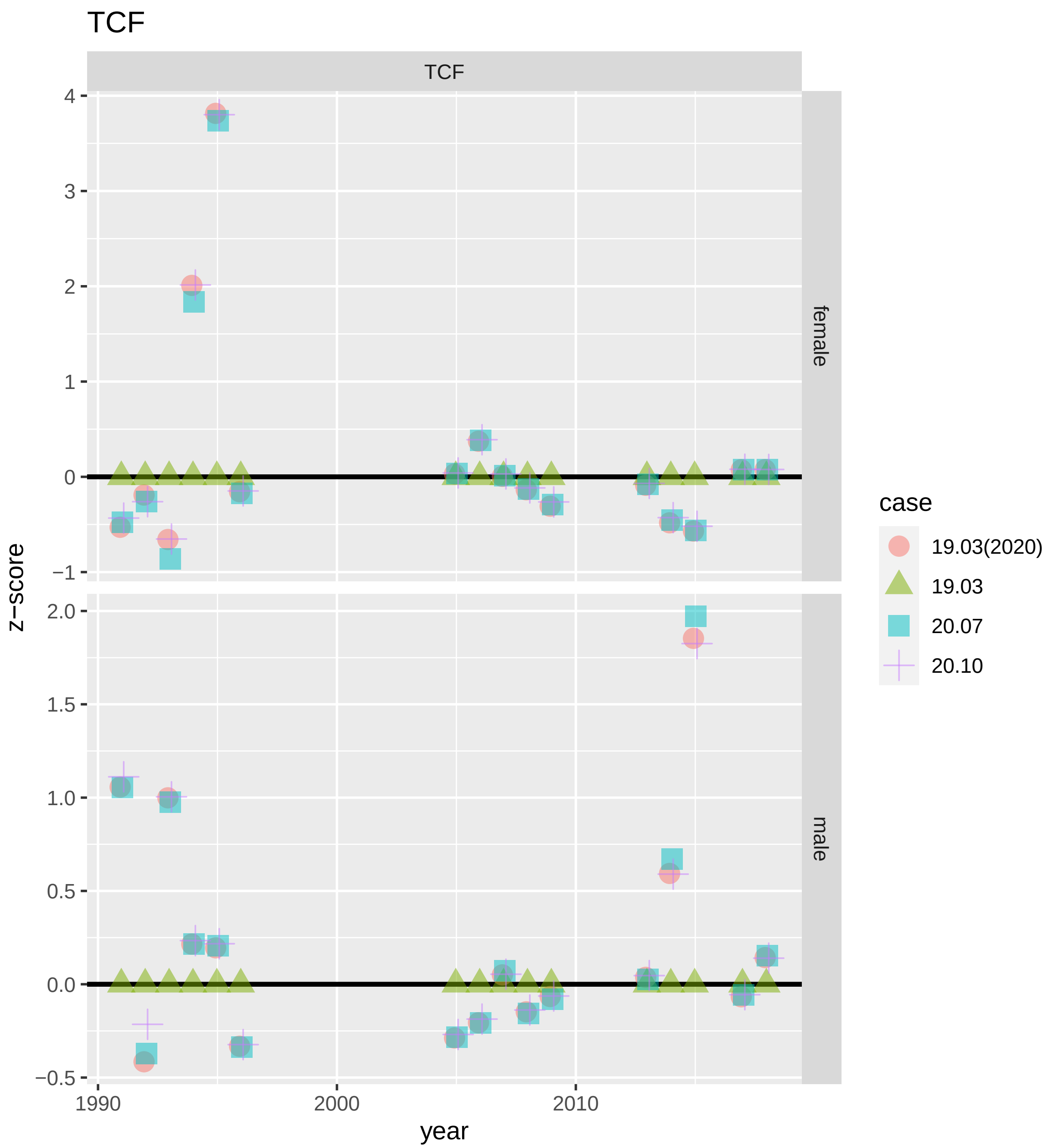

Figure 55: Z-scores for total catch abundance in TCF.

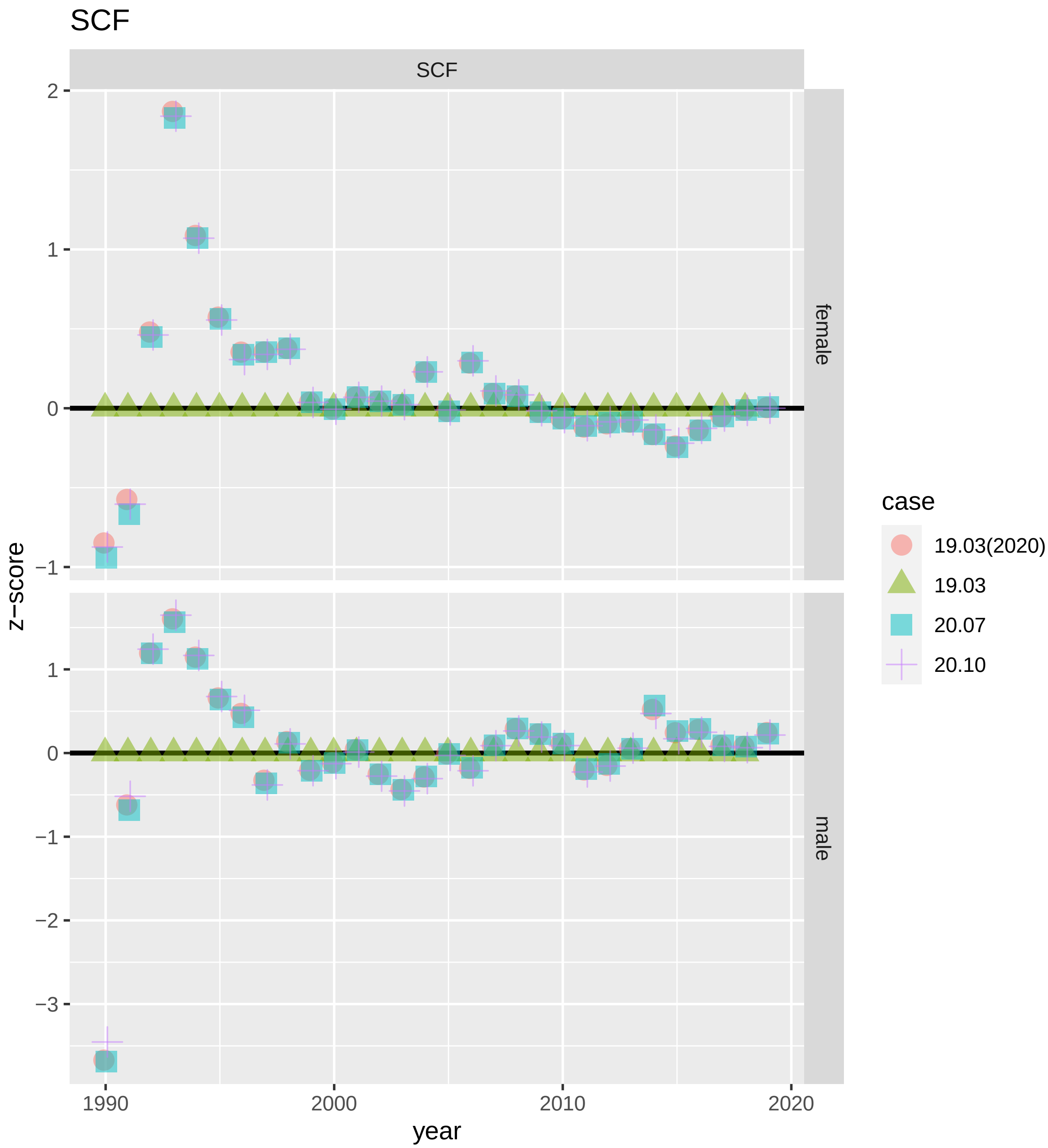

Figure 56: Z-scores for total catch abundance in SCF.

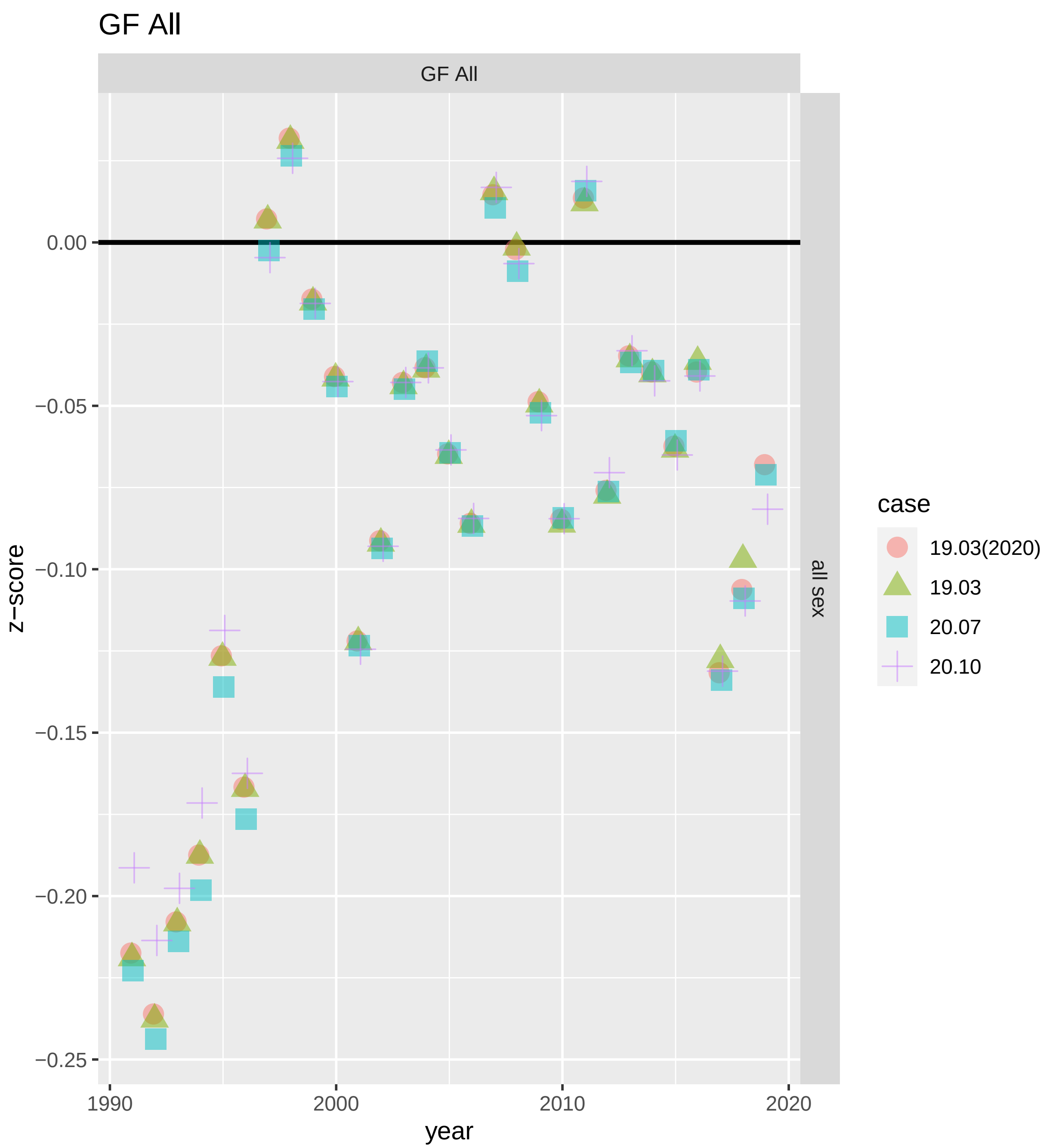

Figure 57: Z-scores for total catch abundance in GF All.

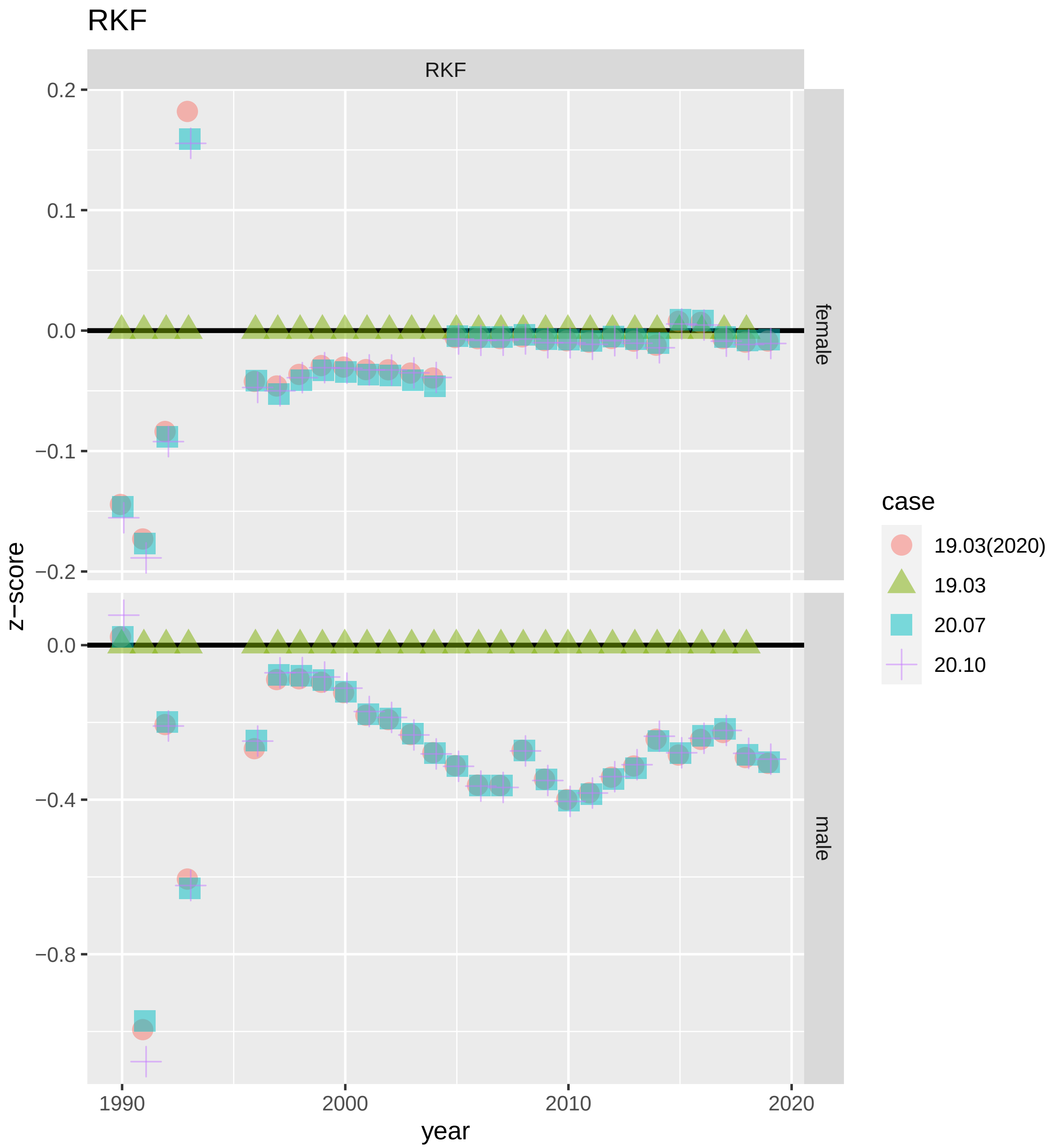

Figure 58: Z-scores for total catch abundance in RKF.

Appendix 6: Fits to Aggregated Survey Catch Data – 19.03(2020) vs 19.03 vs 20.07 vs 20.10

William Stockhausen

01 September, 2020

Contents

Model fits to aggregated survey catch data

Fits to the aggregated survey catch data available to the model(s) are presented in this section. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Survey biomass

Fits

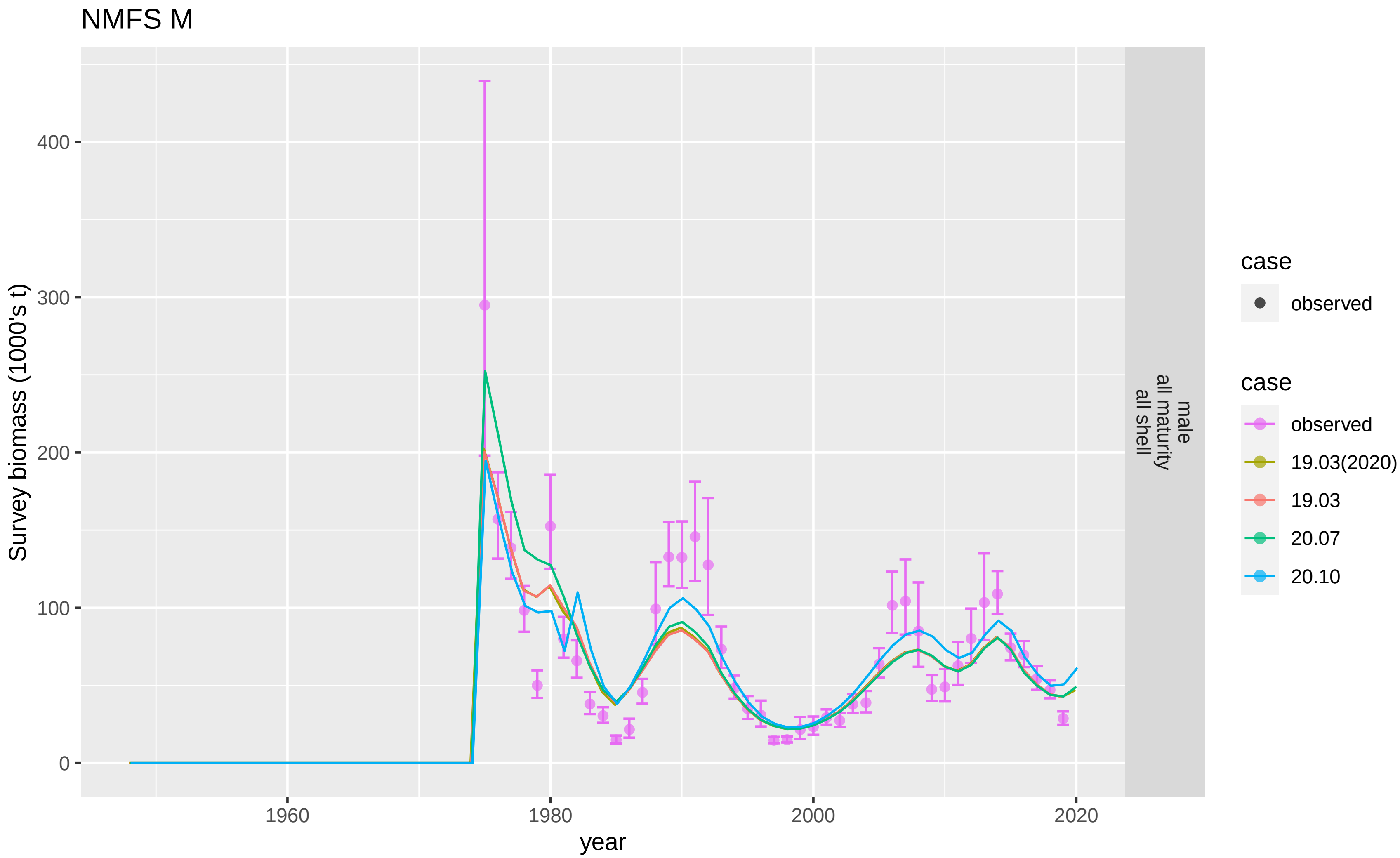

Figure 1: Comparison of observed and predicted male survey biomass for NMFS M.

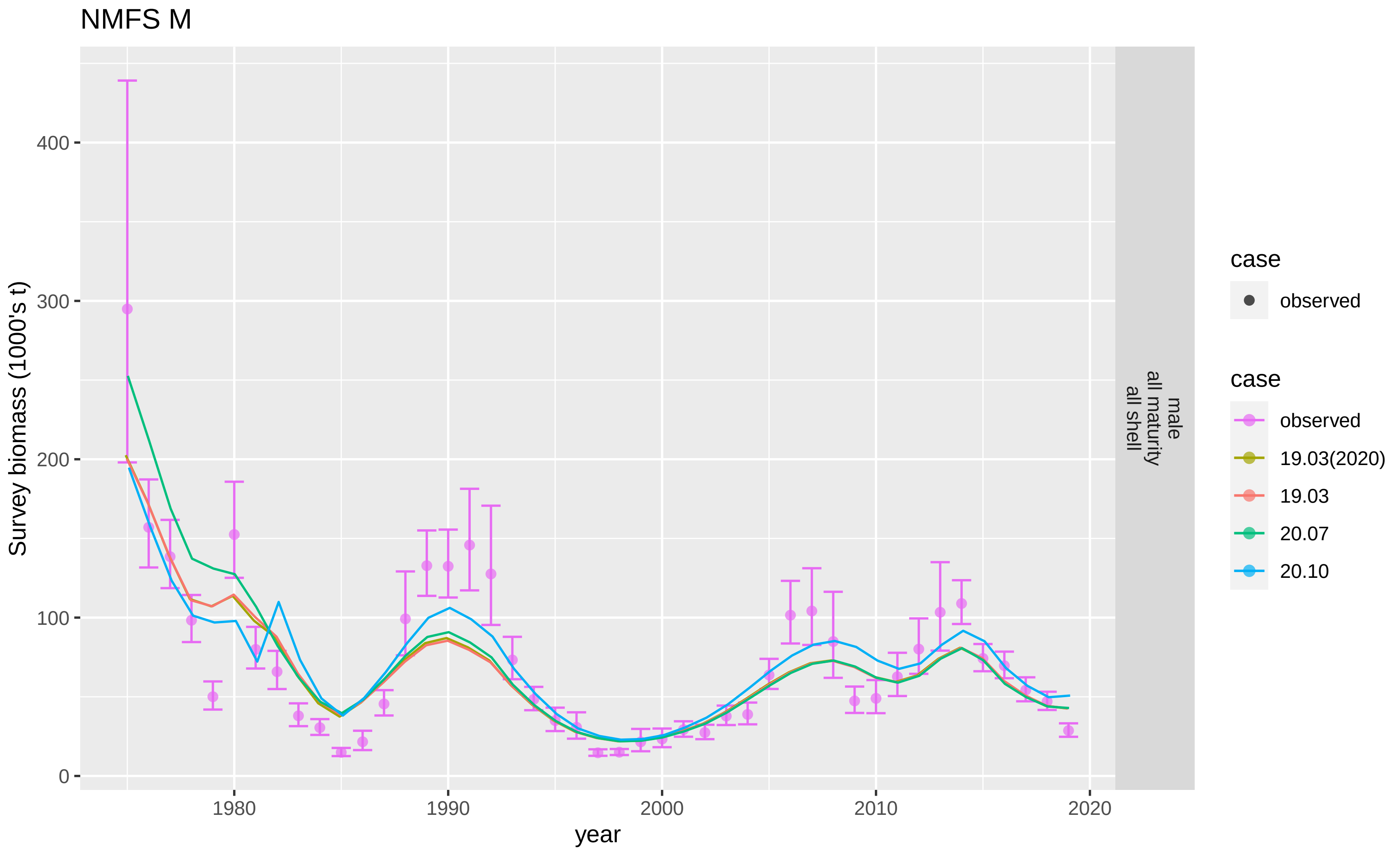

Figure 2: Comparison of observed and predicted male survey biomass for NMFS M. Observed time period.

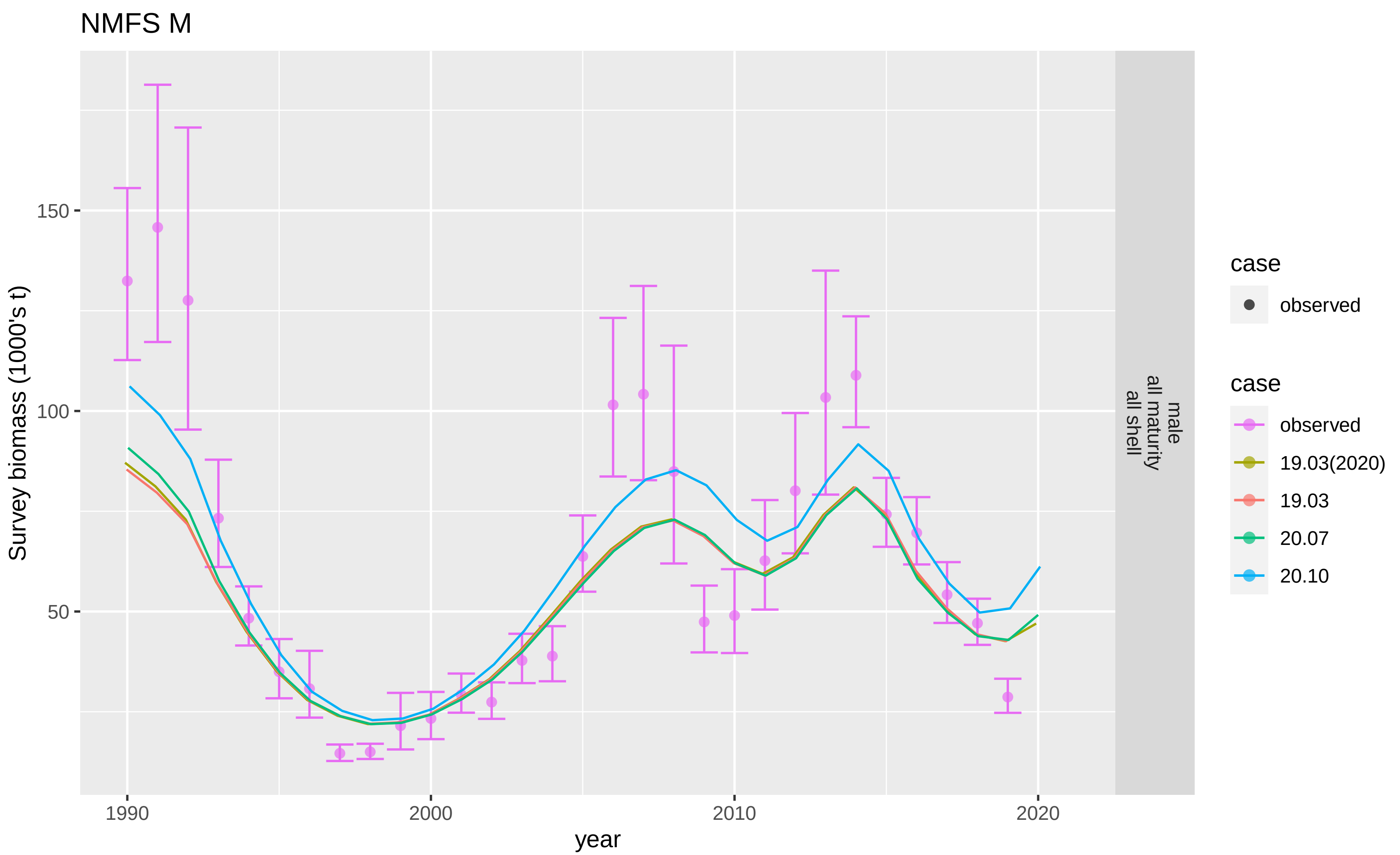

Figure 3: Comparison of observed and predicted male survey biomass for NMFS M. Recent time period.

Figure 4: Comparison of observed and predicted female survey biomass for NMFS F.

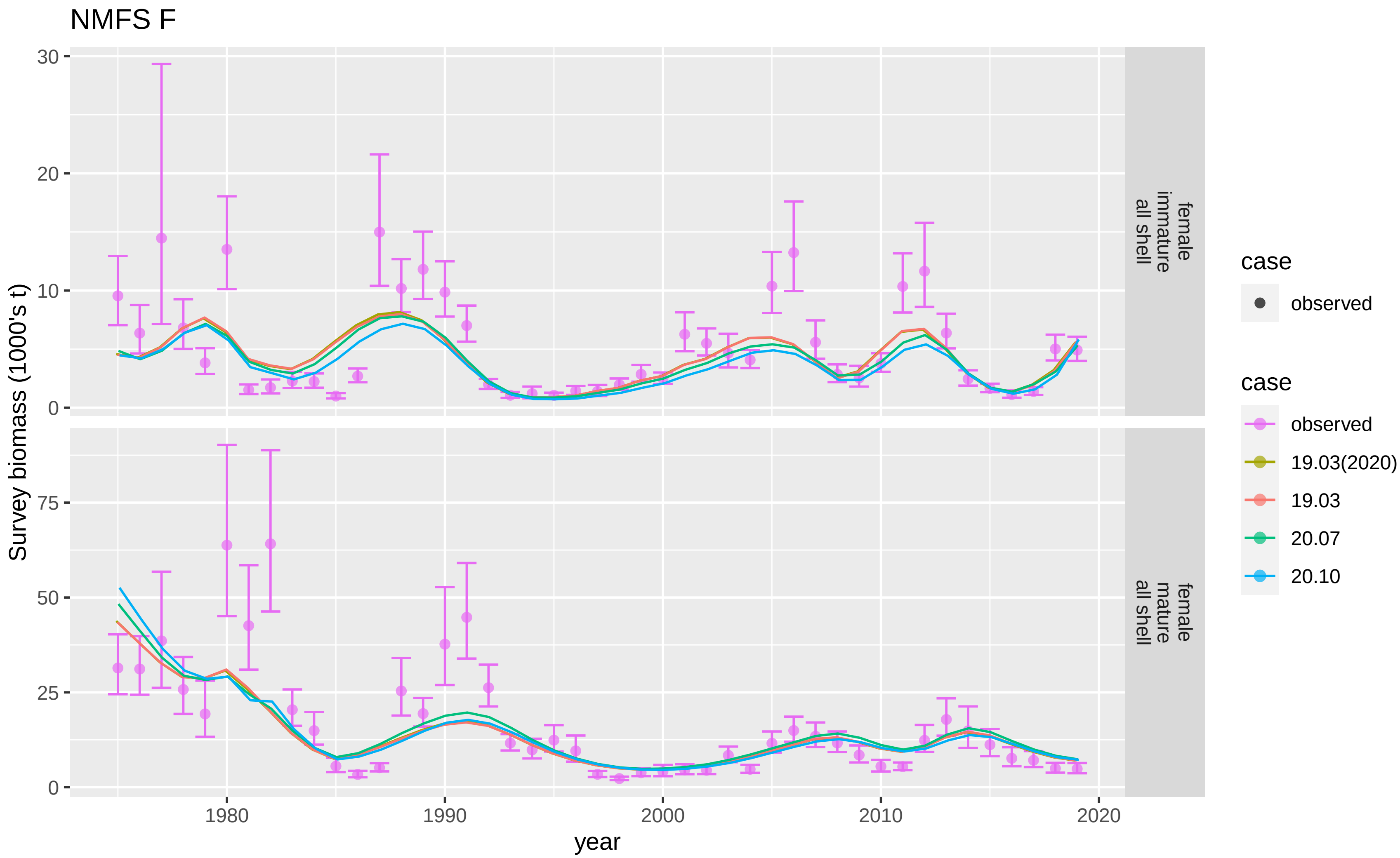

Figure 5: Comparison of observed and predicted female survey biomass for NMFS F. Observed time period.

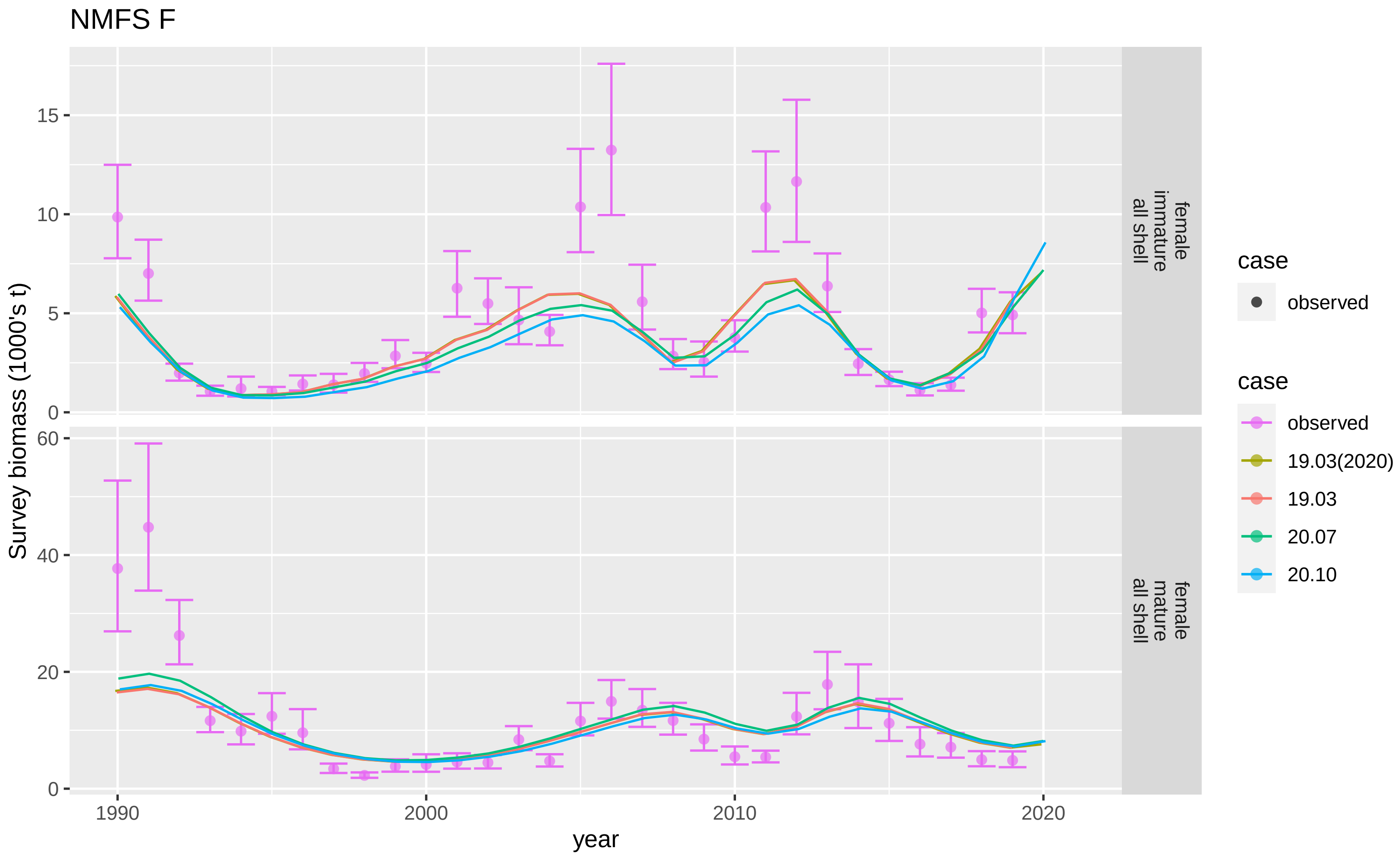

Figure 6: Comparison of observed and predicted female survey biomass for NMFS F. Recent time period.

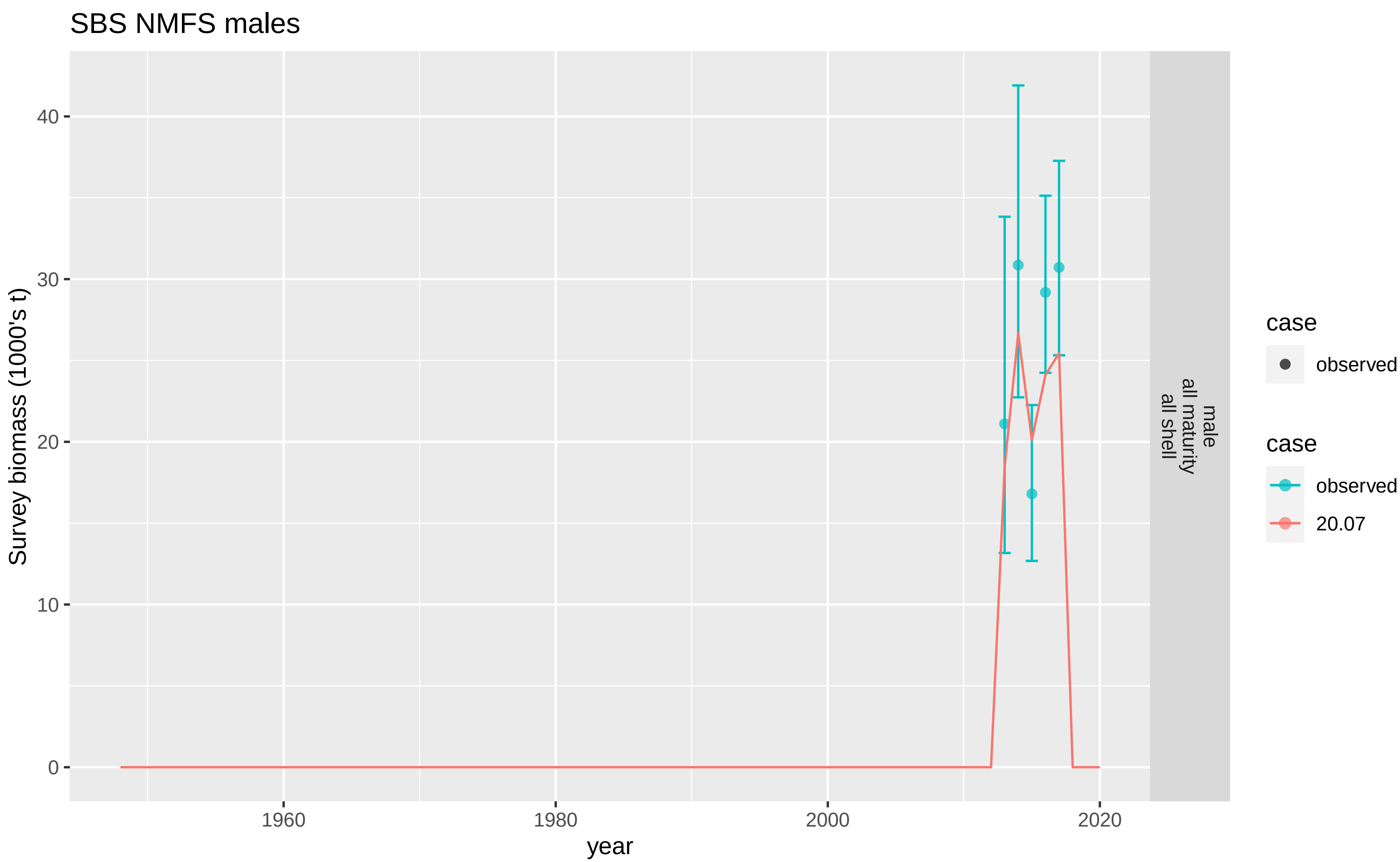

Figure 7: Comparison of observed and predicted male survey biomass for SBS NMFS males.

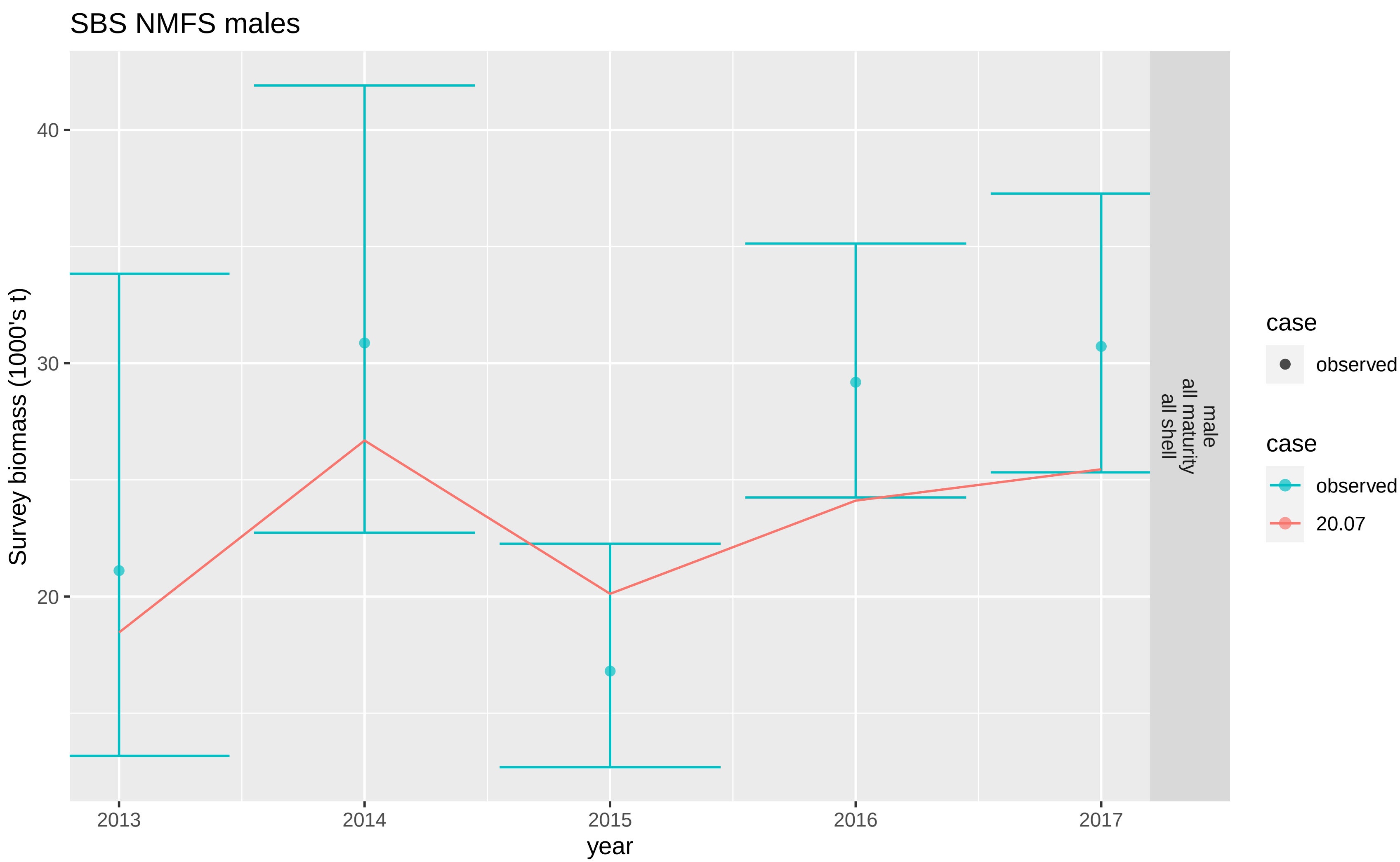

Figure 8: Comparison of observed and predicted male survey biomass for SBS NMFS males. Observed time period.

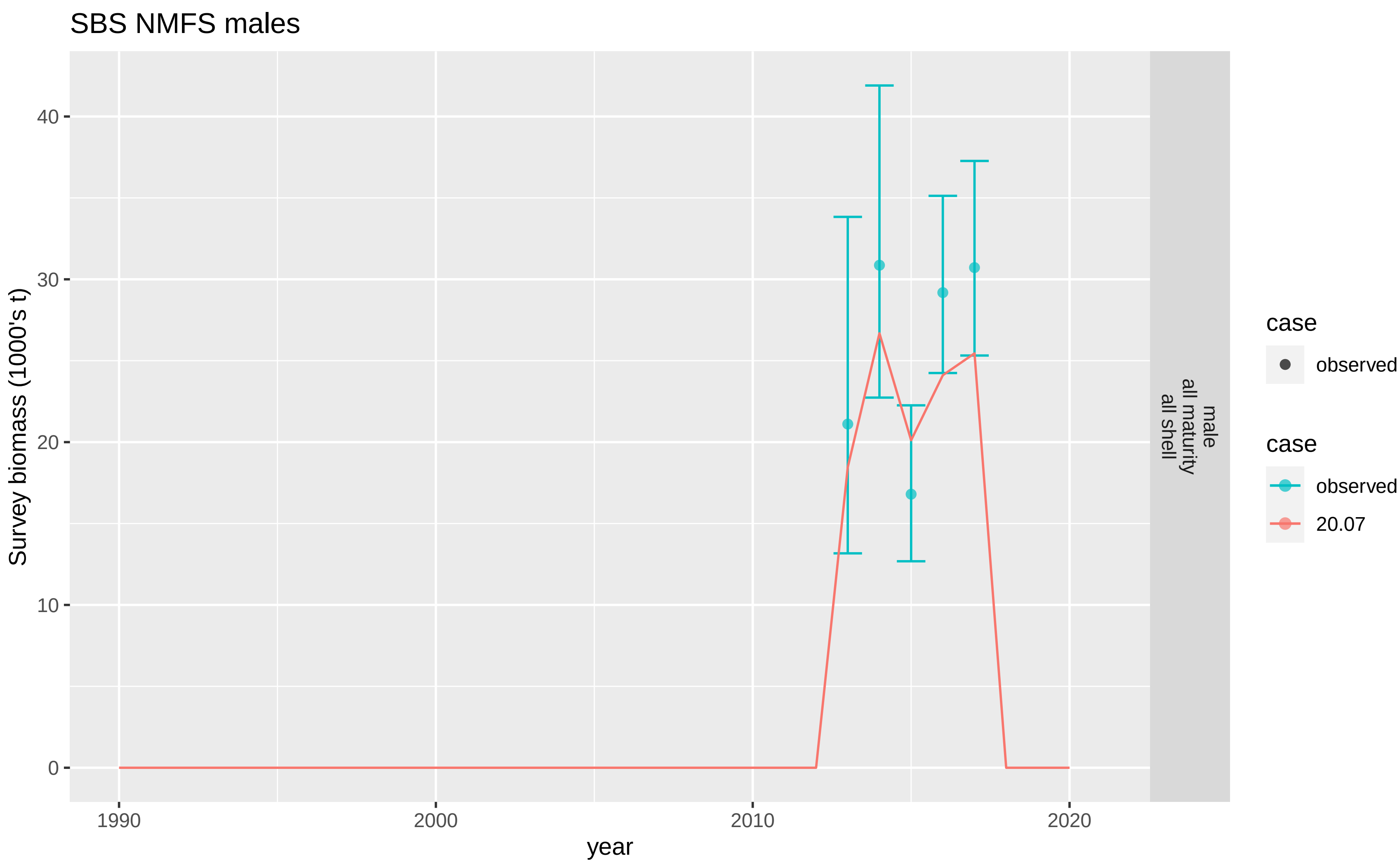

Figure 9: Comparison of observed and predicted male survey biomass for SBS NMFS males. Recent time period.

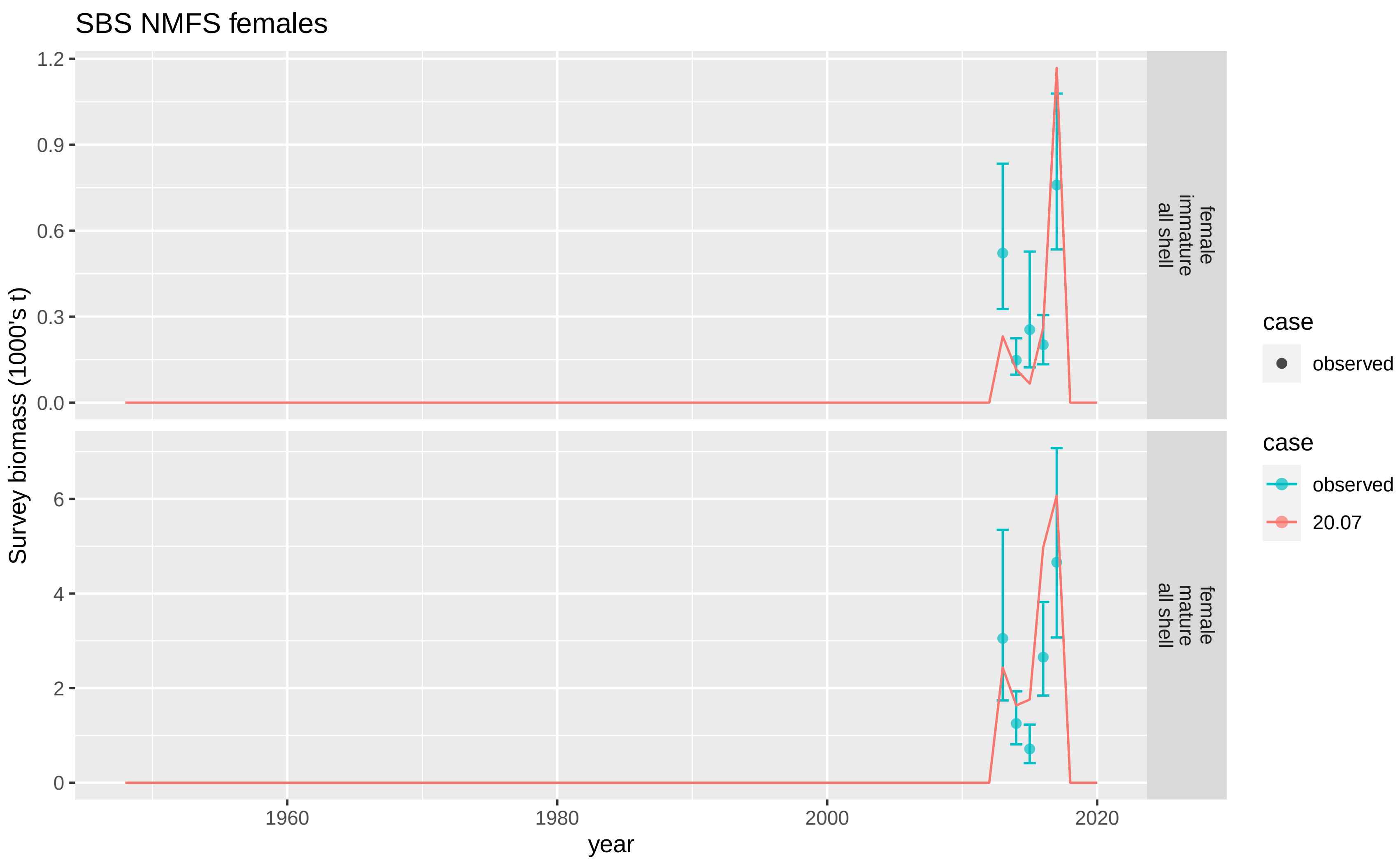

Figure 10: Comparison of observed and predicted female survey biomass for SBS NMFS females.

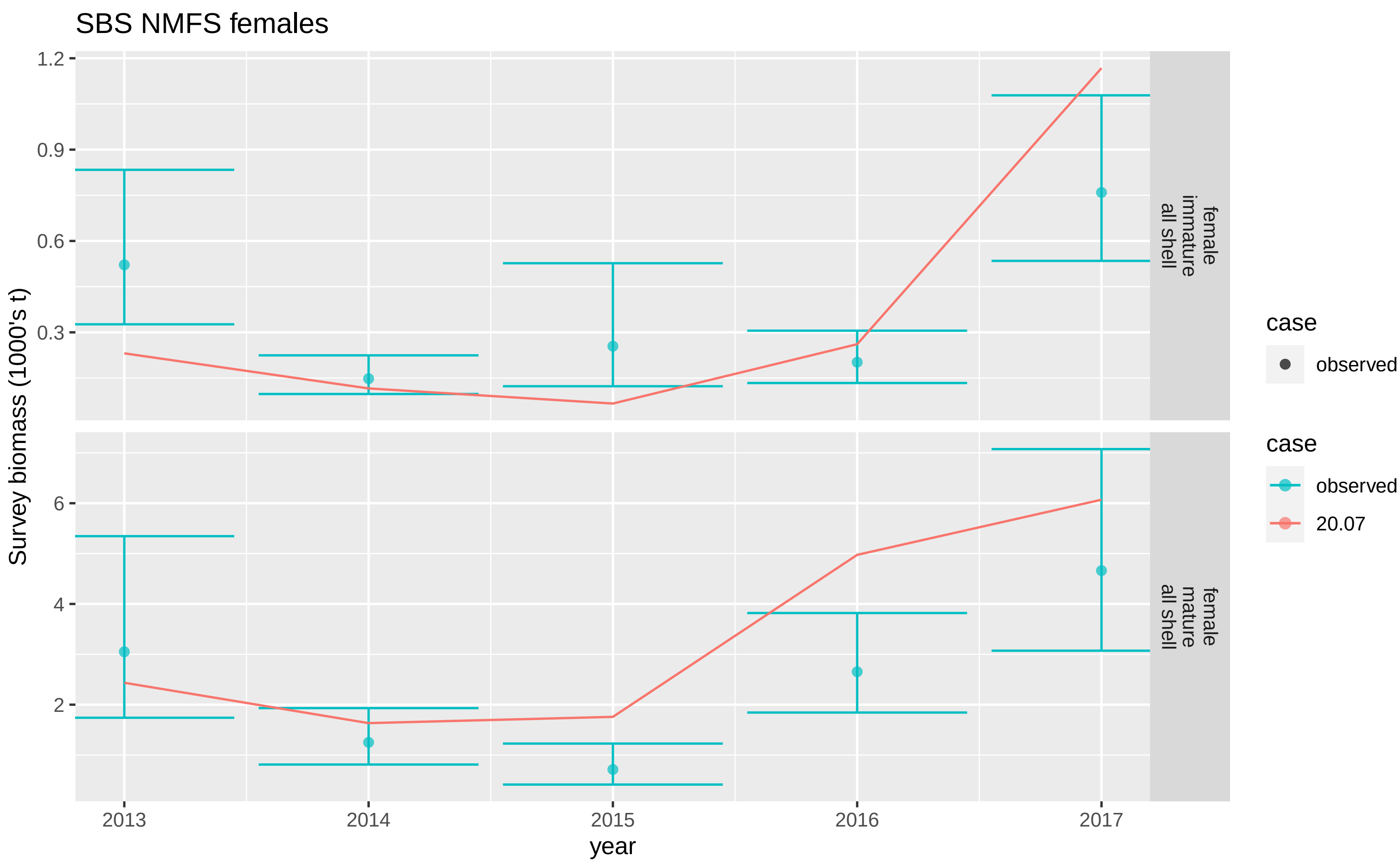

Figure 11: Comparison of observed and predicted female survey biomass for SBS NMFS females. Observed time period.

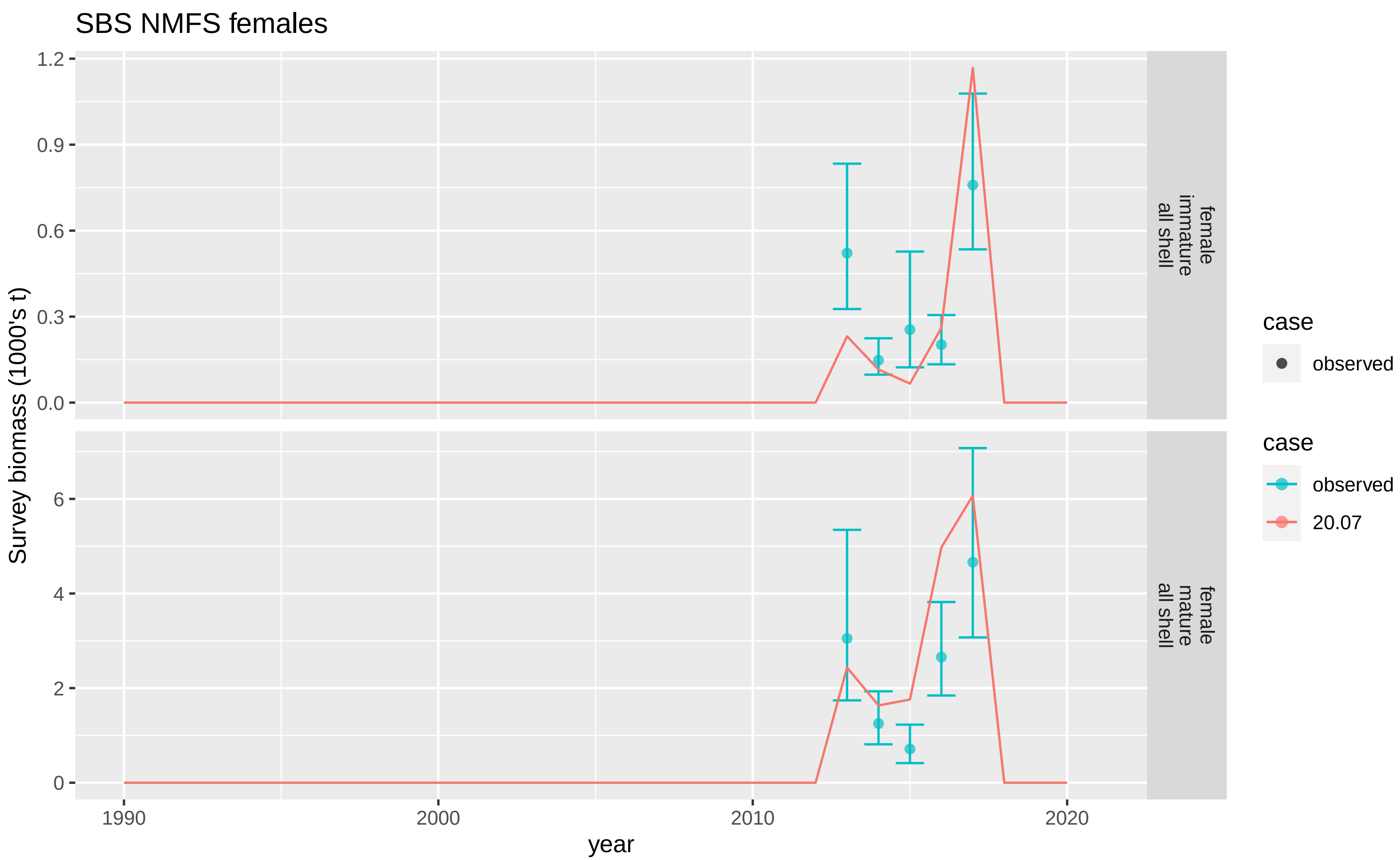

Figure 12: Comparison of observed and predicted female survey biomass for SBS NMFS females. Recent time period.

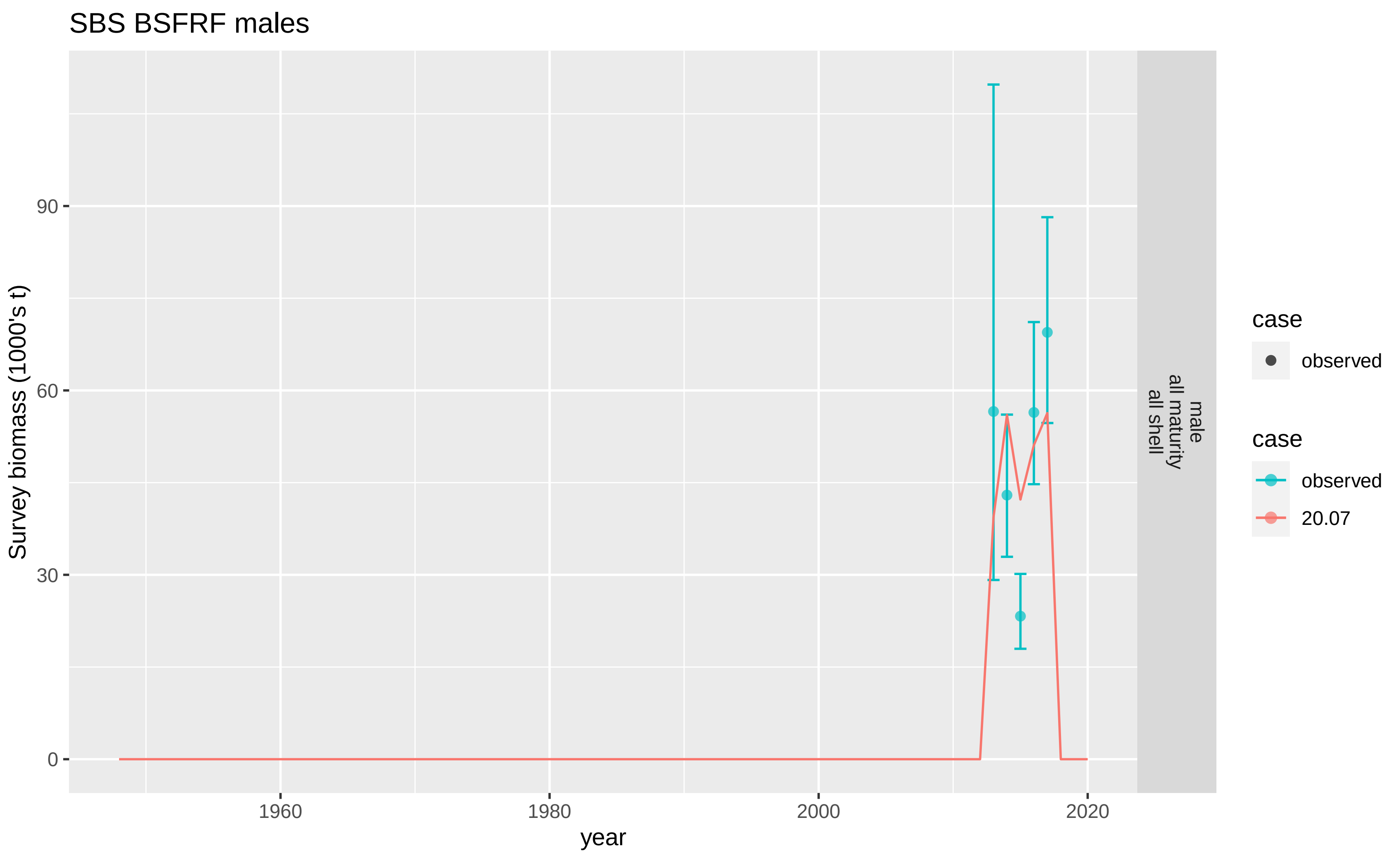

Figure 13: Comparison of observed and predicted male survey biomass for SBS BSFRF males.

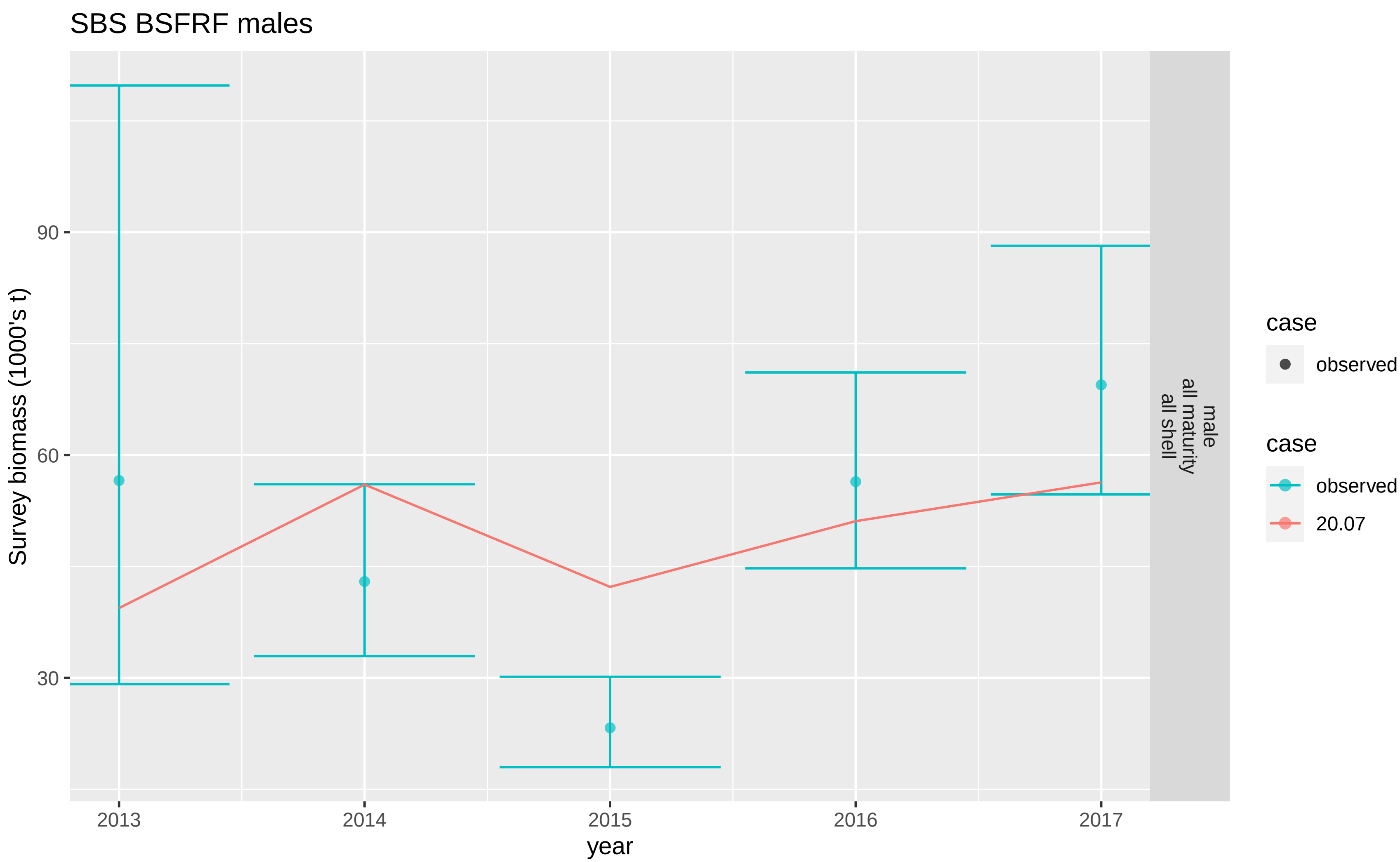

Figure 14: Comparison of observed and predicted male survey biomass for SBS BSFRF males. Observed time period.

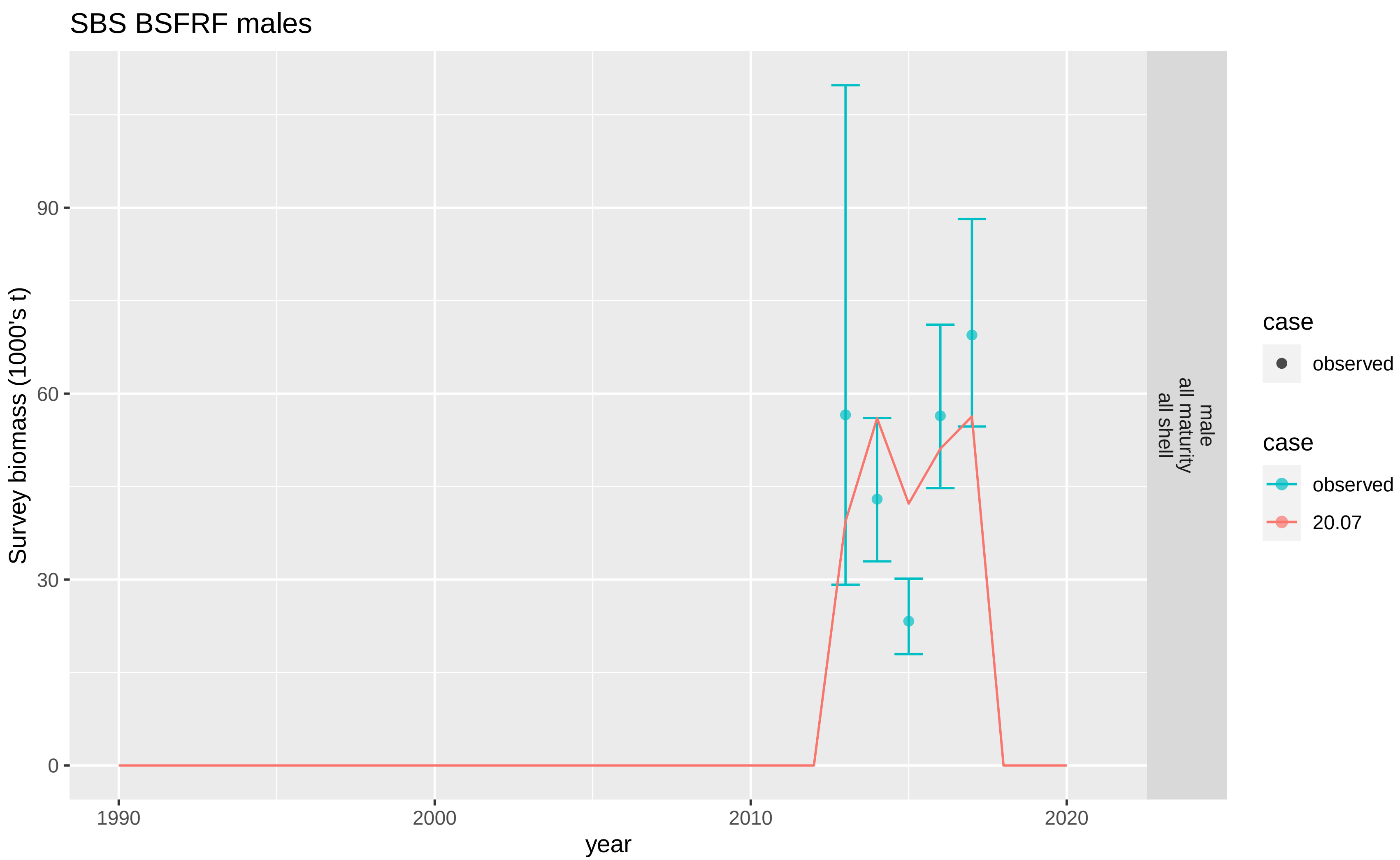

Figure 15: Comparison of observed and predicted male survey biomass for SBS BSFRF males. Recent time period.

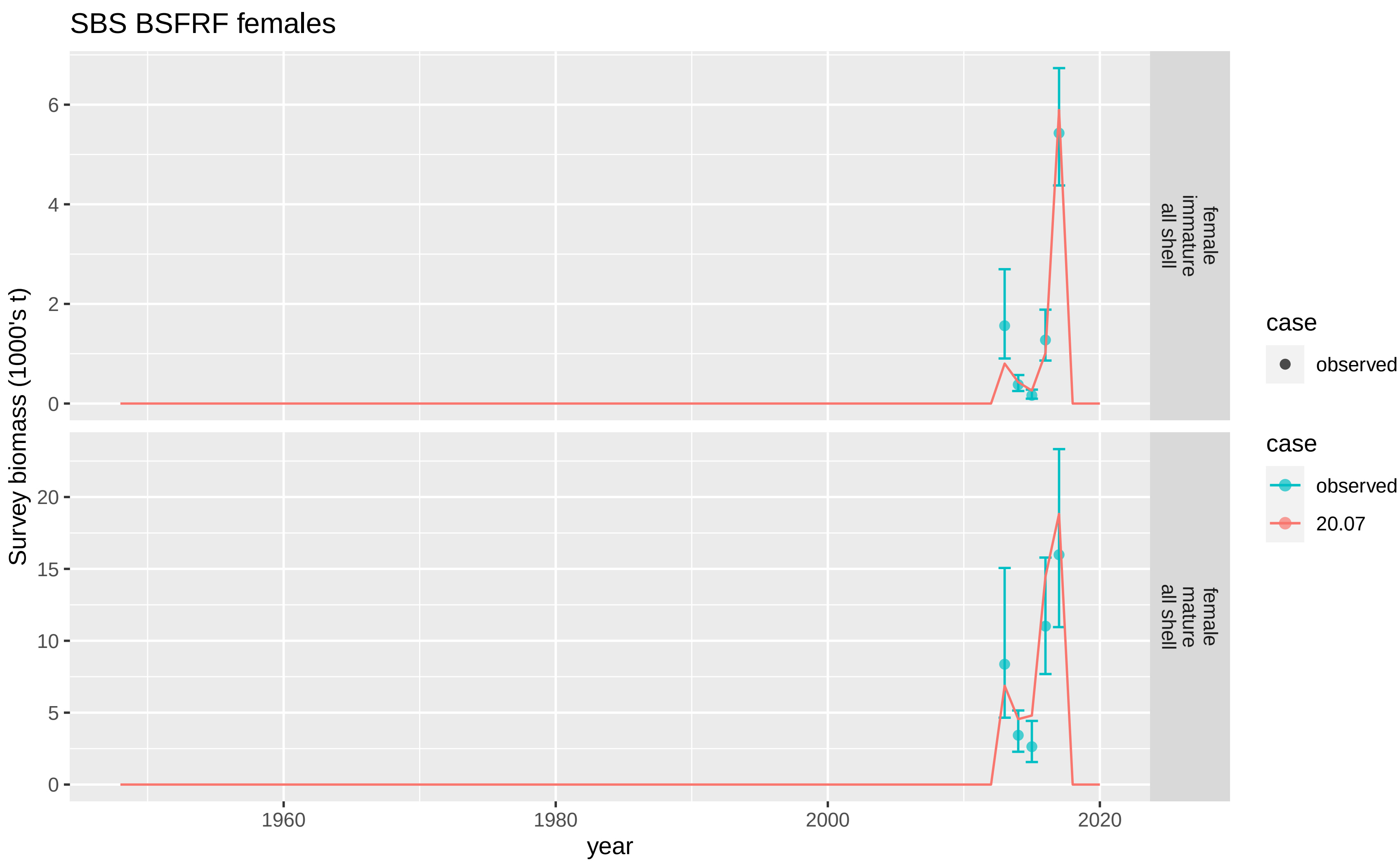

Figure 16: Comparison of observed and predicted female survey biomass for SBS BSFRF females.

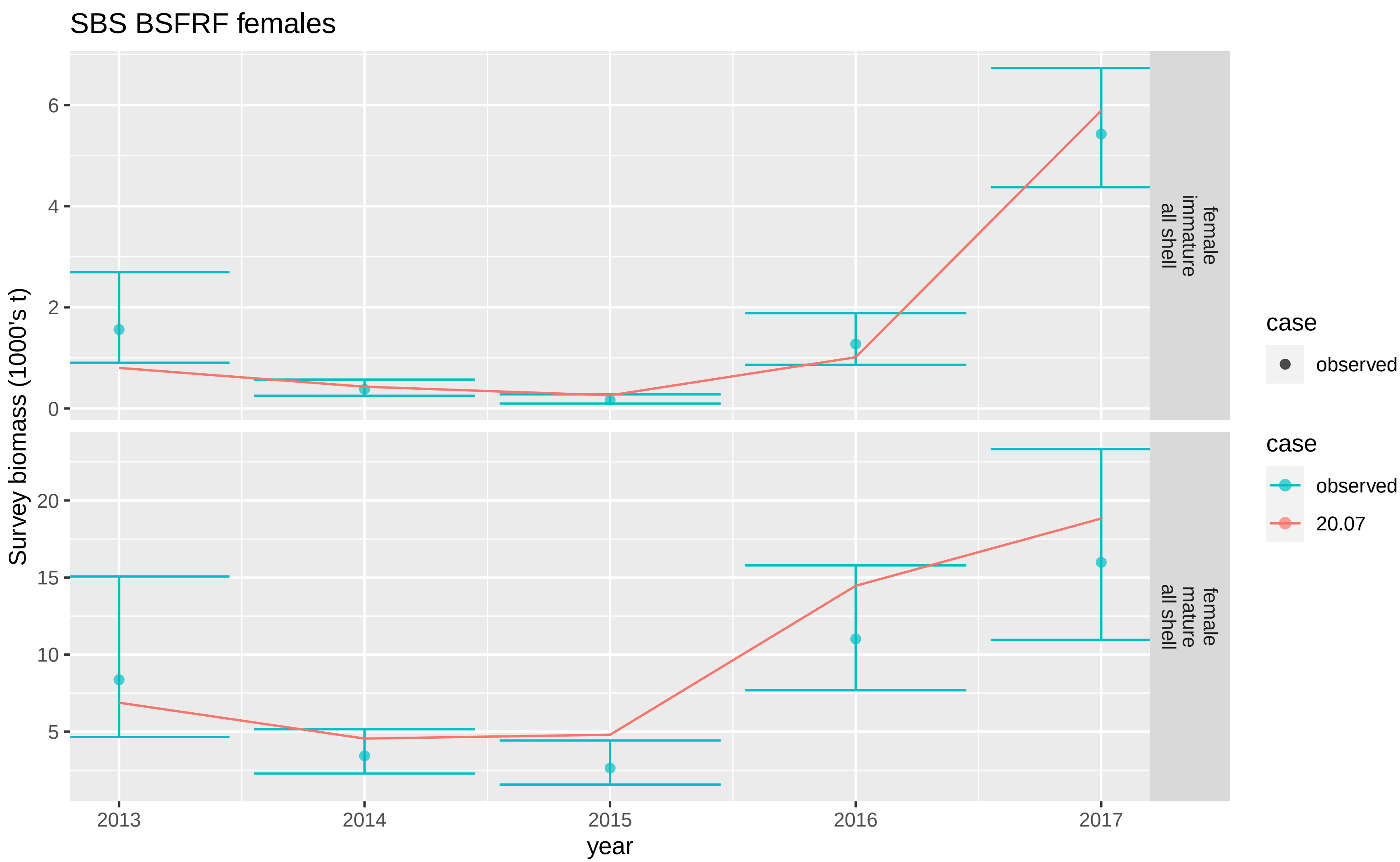

Figure 17: Comparison of observed and predicted female survey biomass for SBS BSFRF females. Observed time period.

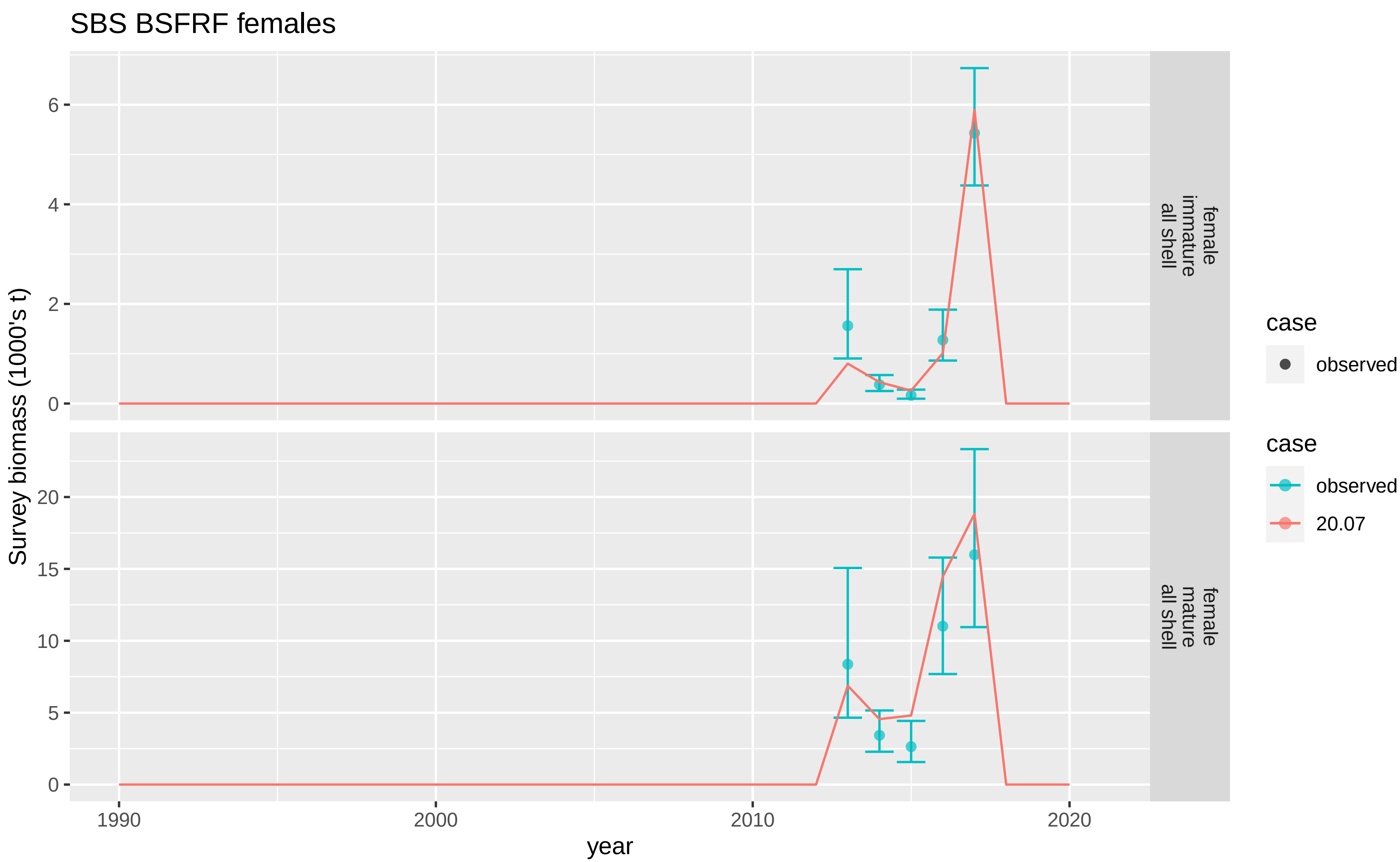

Figure 18: Comparison of observed and predicted female survey biomass for SBS BSFRF females. Recent time period.

Z-scores

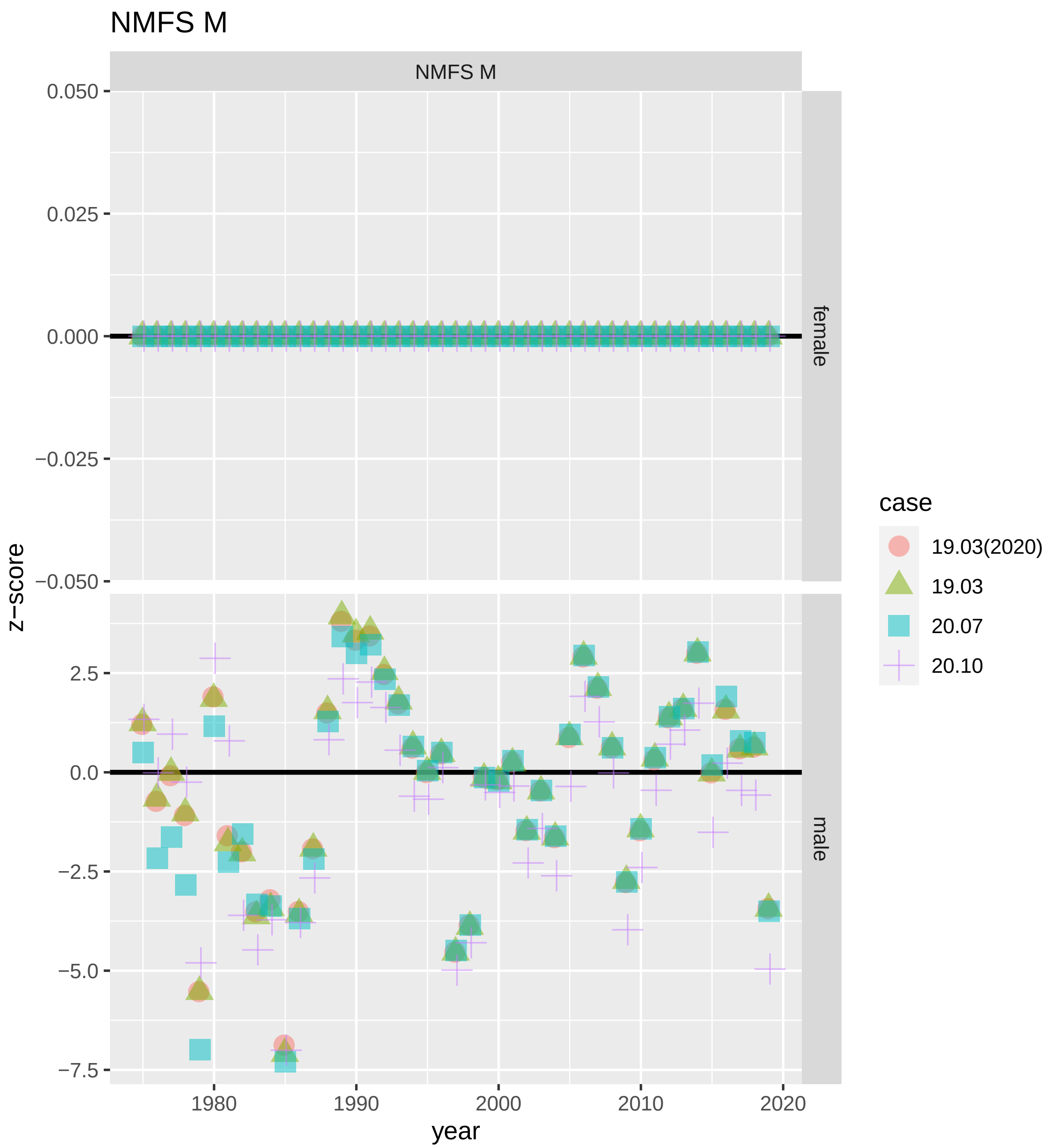

Figure 19: Z-scores for index catch biomass in NMFS M.

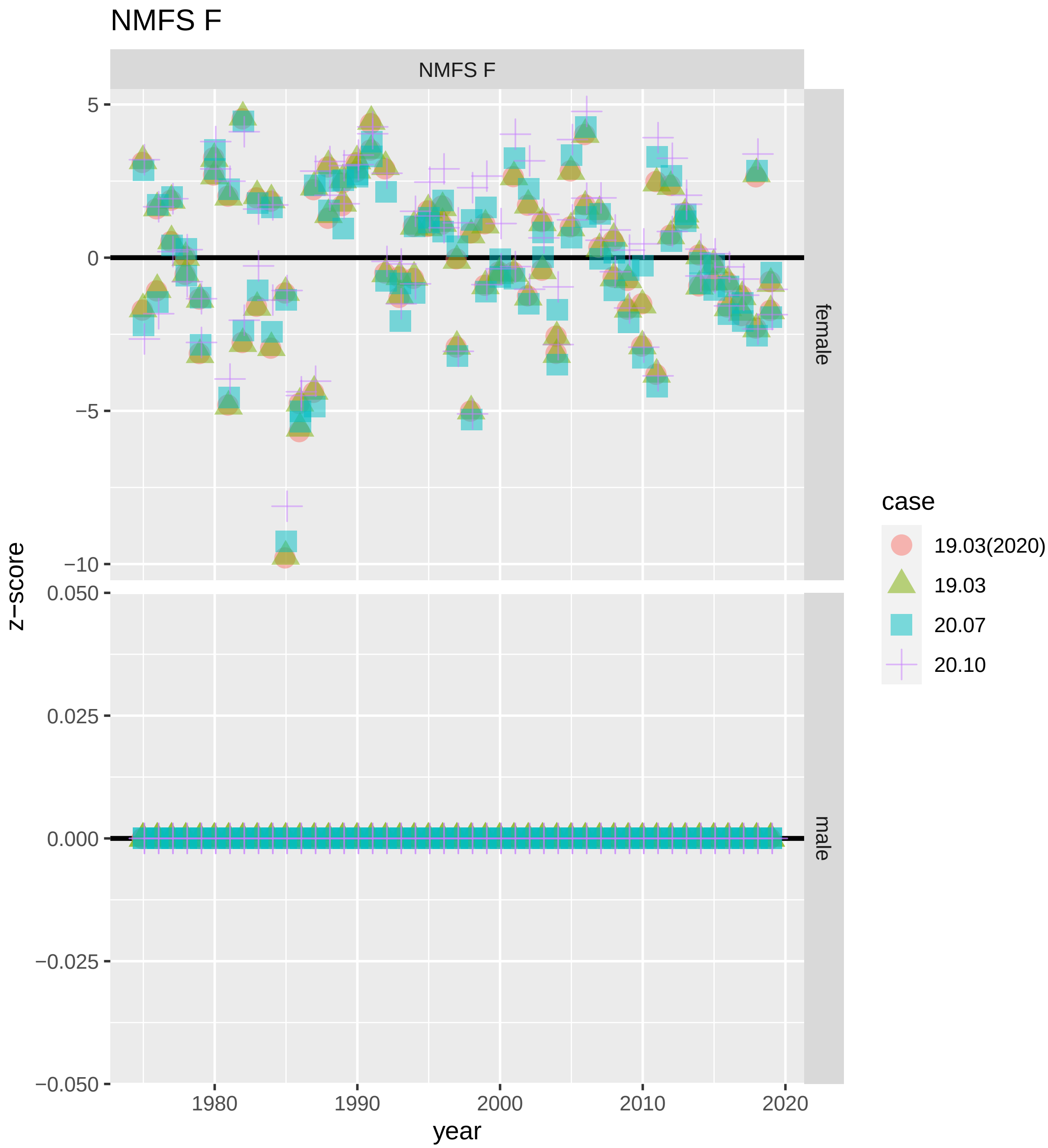

Figure 20: Z-scores for index catch biomass in NMFS F.

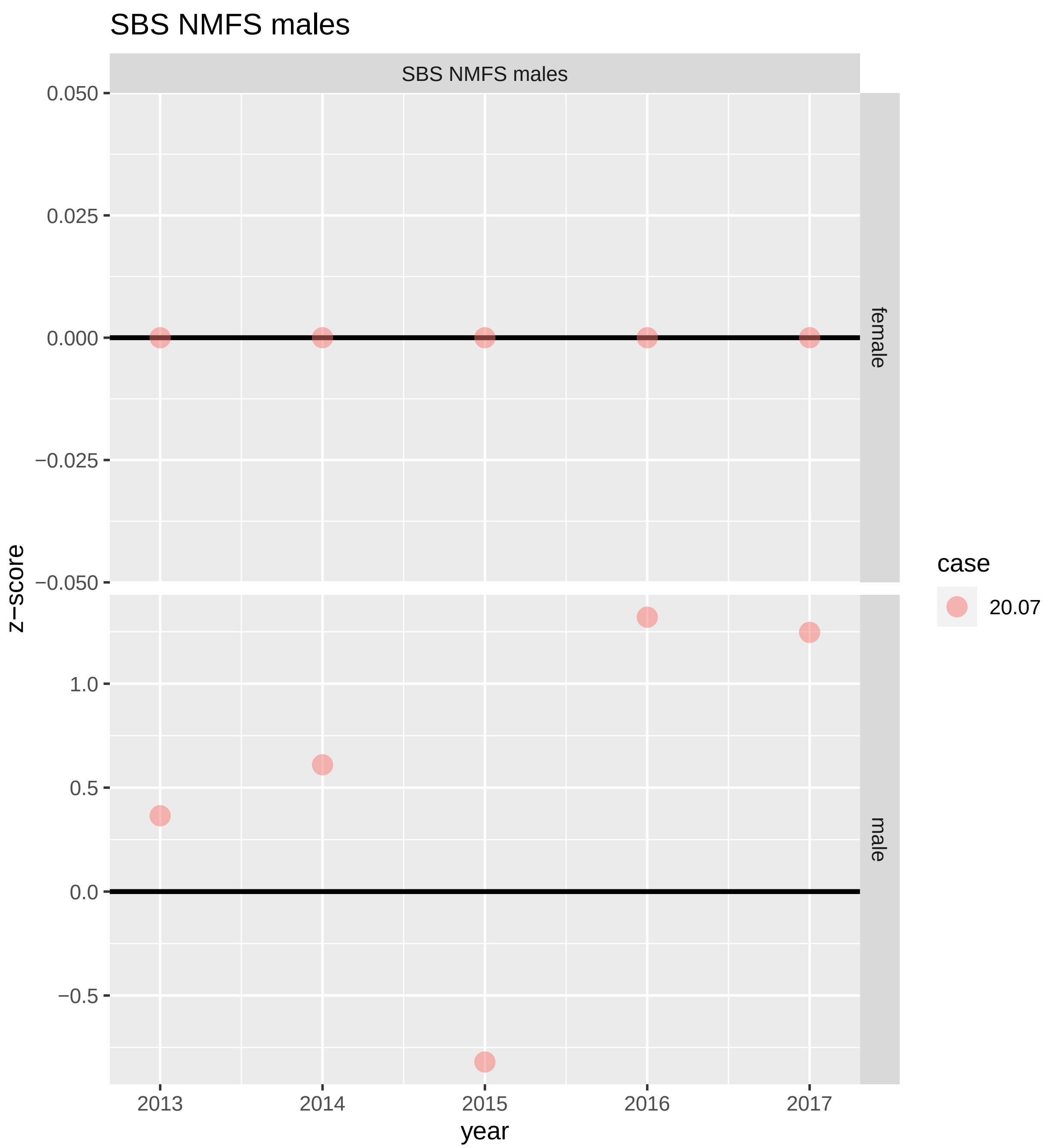

Figure 21: Z-scores for index catch biomass in SBS NMFS males.

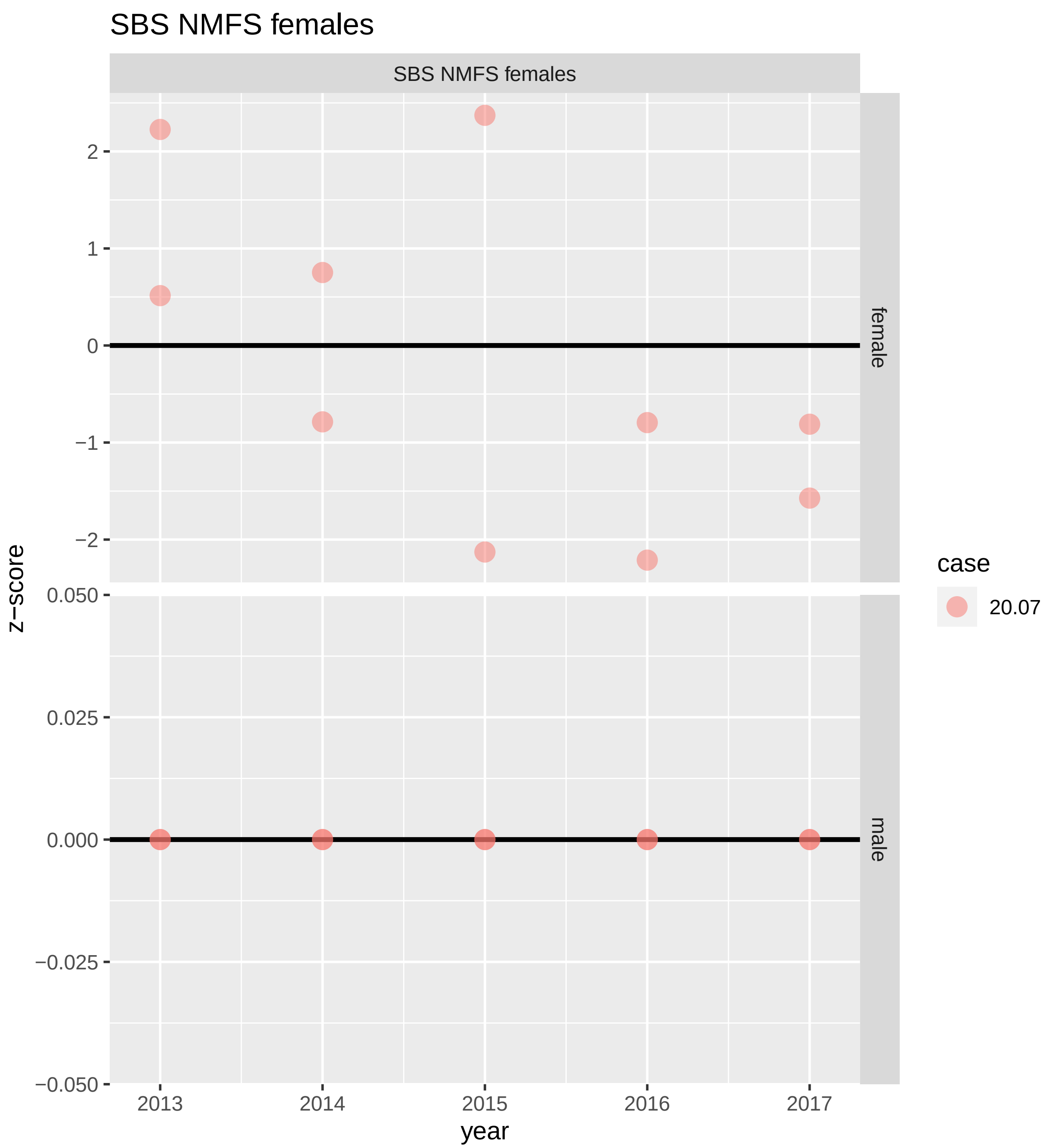

Figure 22: Z-scores for index catch biomass in SBS NMFS females.

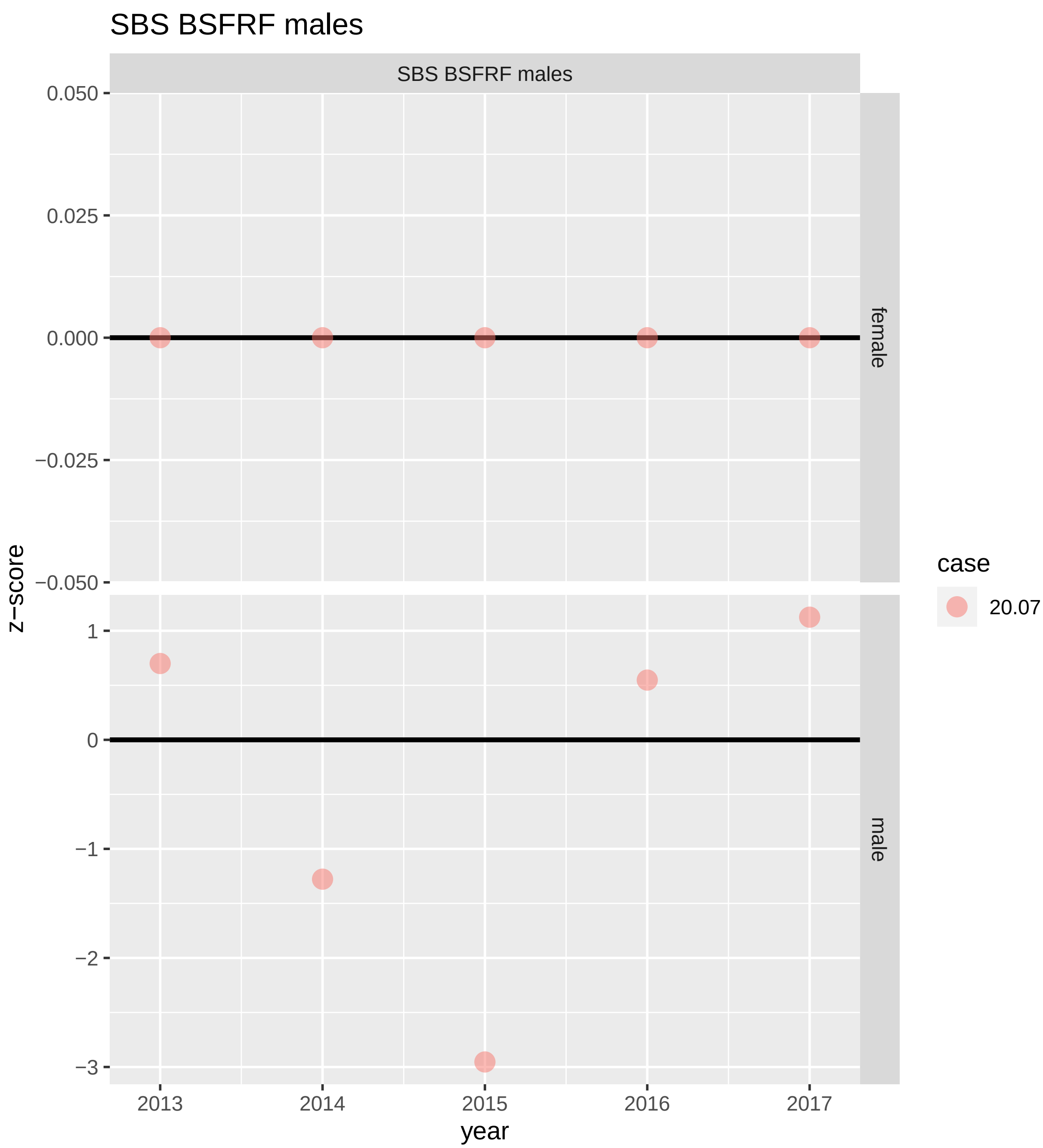

Figure 23: Z-scores for index catch biomass in SBS BSFRF males.

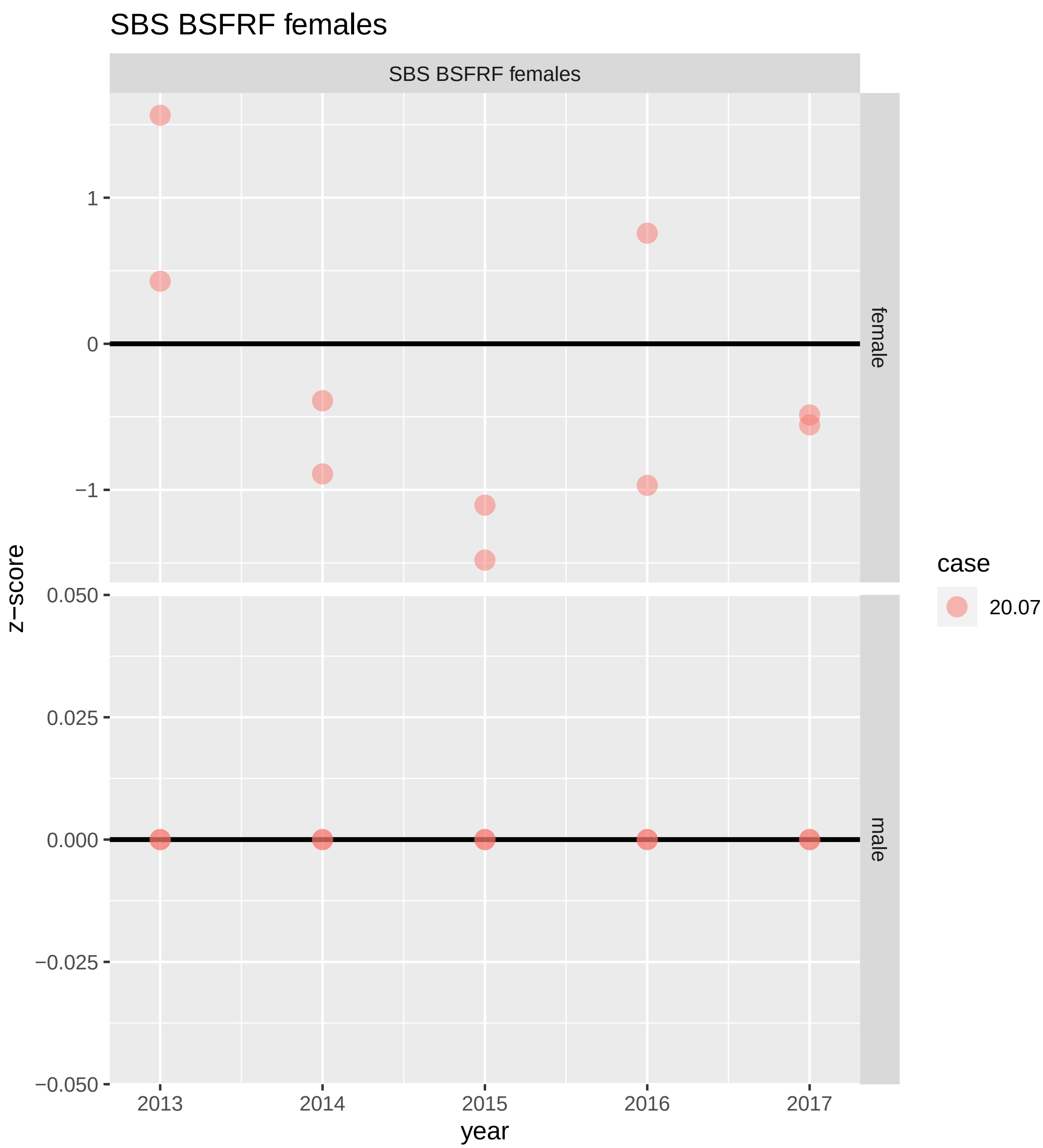

Figure 24: Z-scores for index catch biomass in SBS BSFRF females.

Survey abundance

Fits

Figure 25: Comparison of observed and predicted male survey abundance for NMFS M.

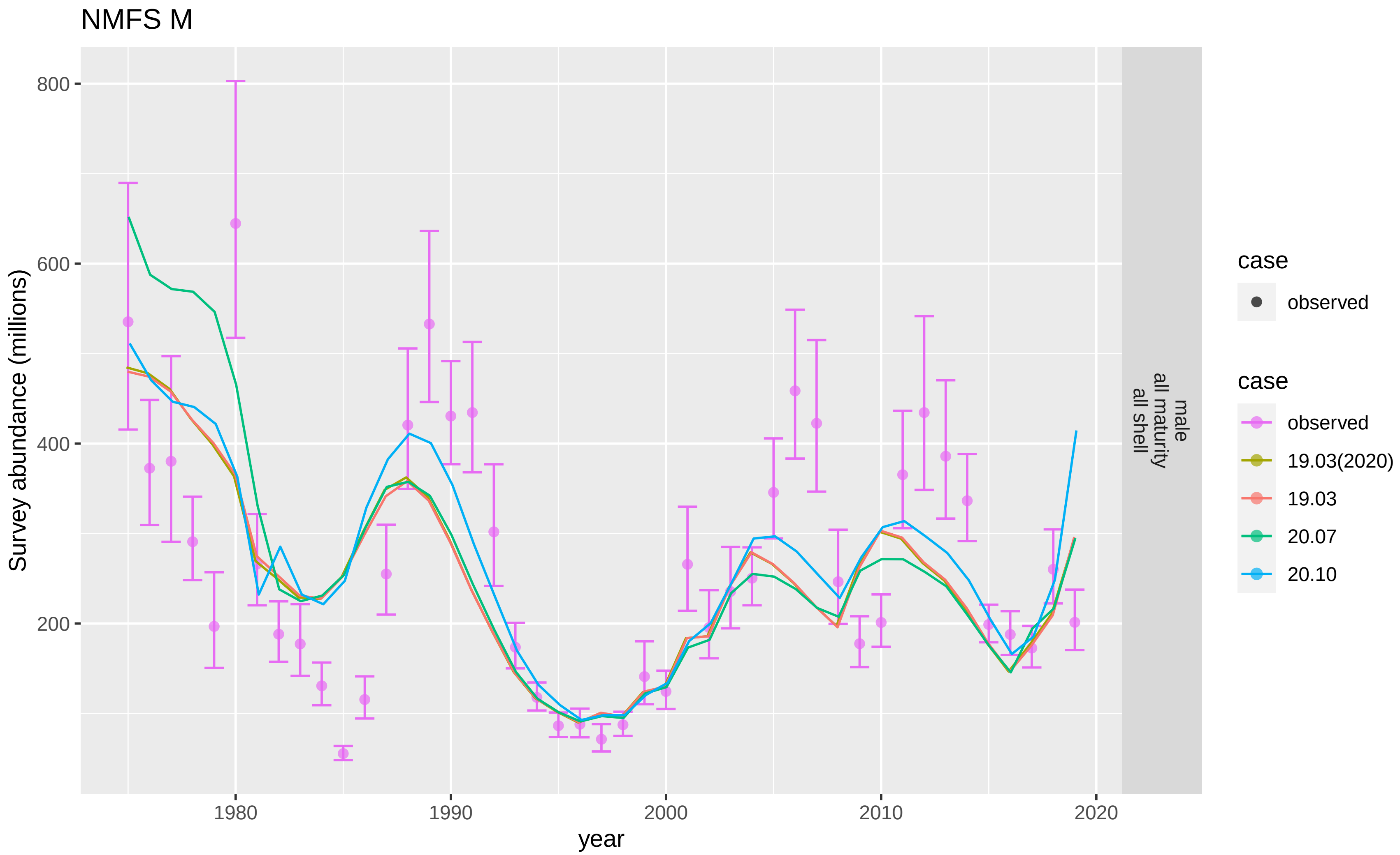

Figure 26: Comparison of observed and predicted male survey abundance for NMFS M. Observed time period.

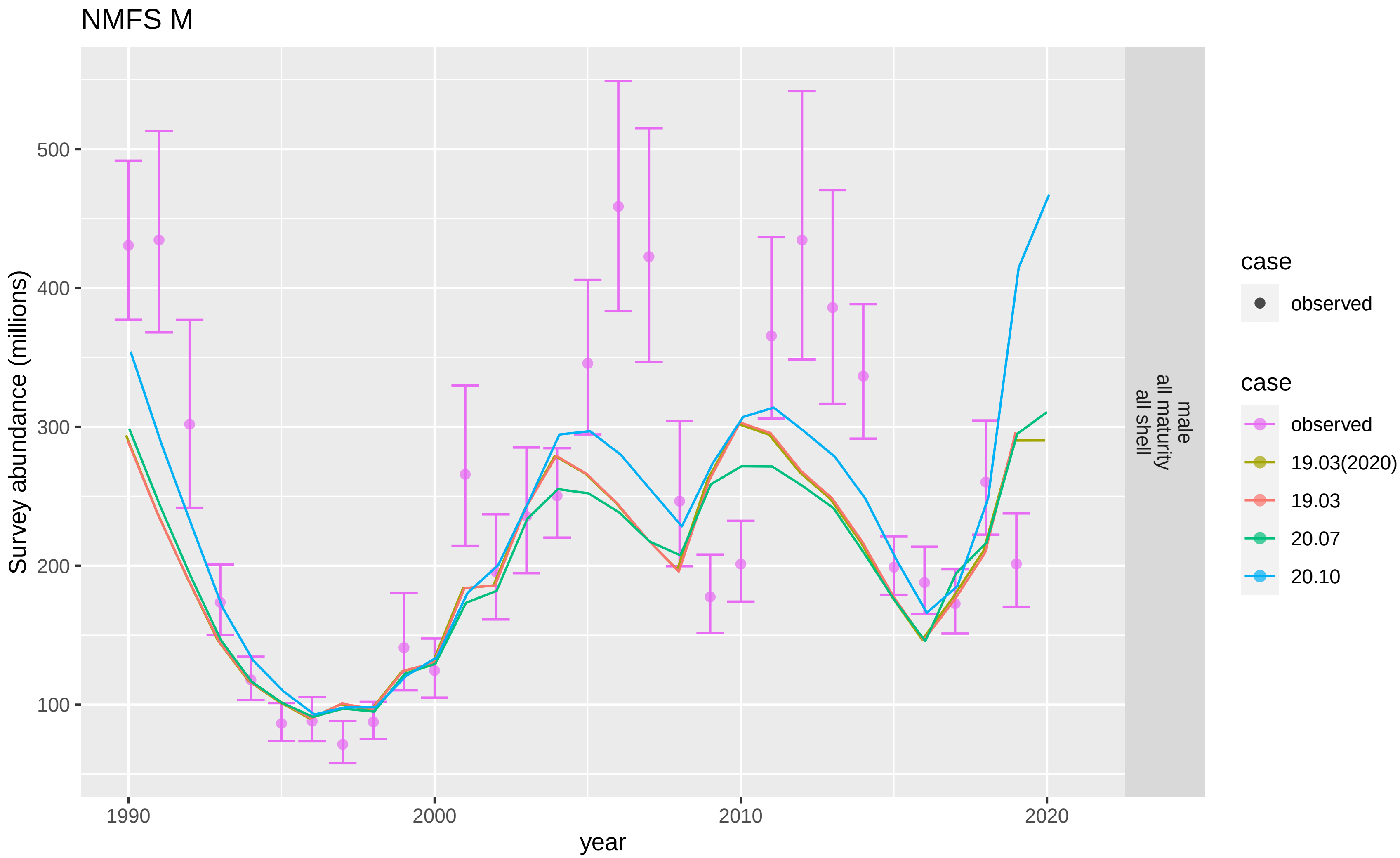

Figure 27: Comparison of observed and predicted male survey abundance for NMFS M. Recent time period.

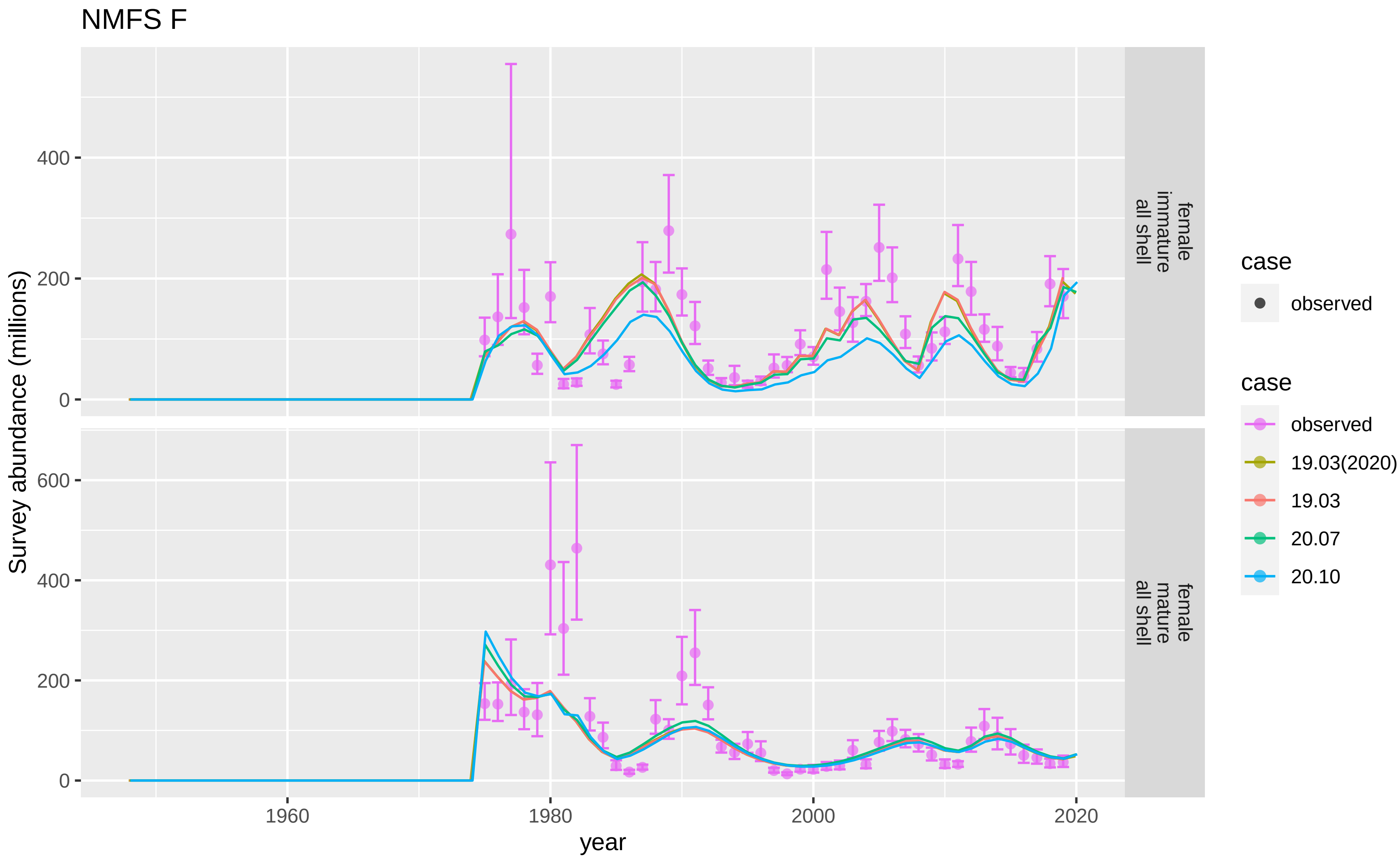

Figure 28: Comparison of observed and predicted female survey abundance for NMFS F.

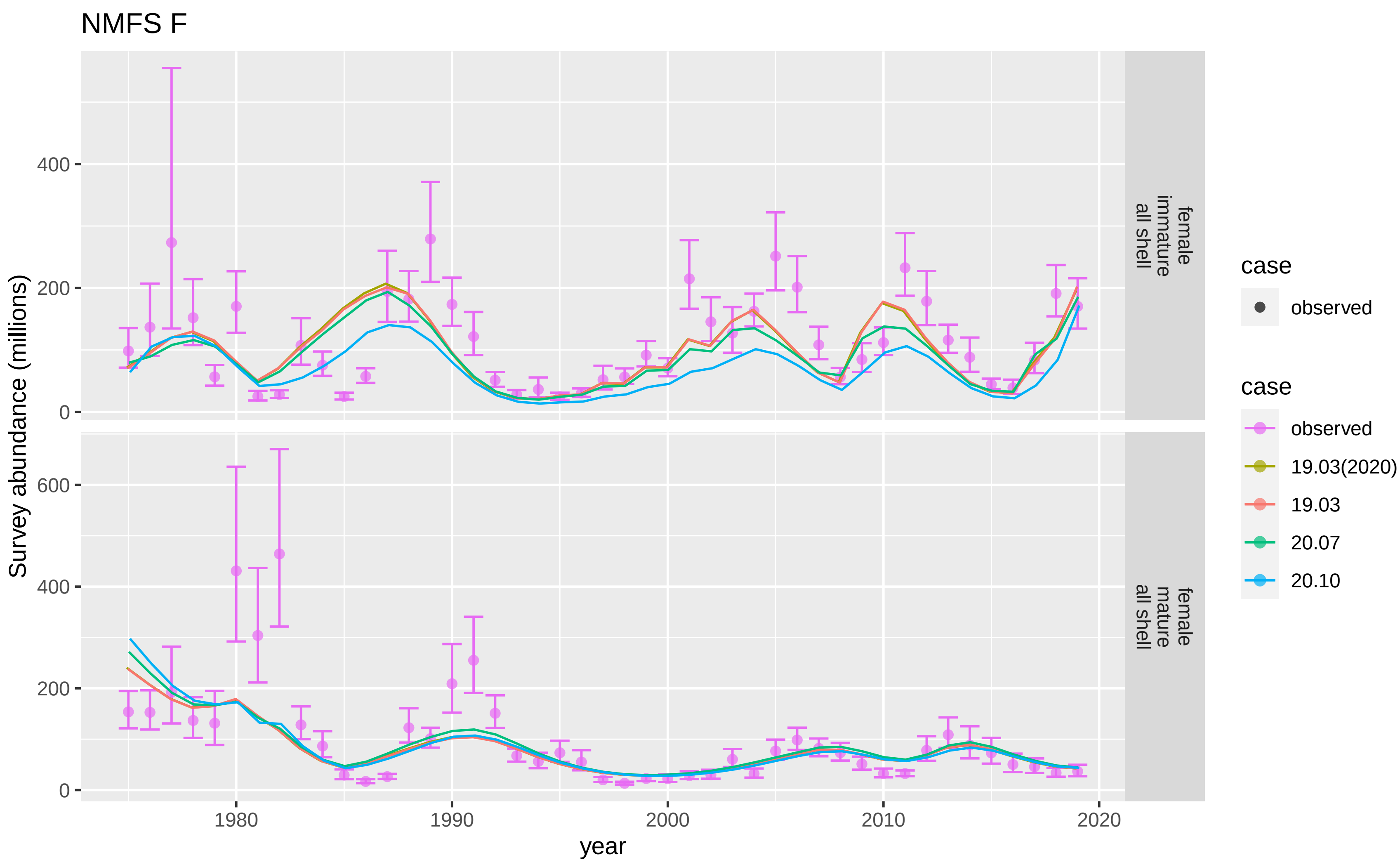

Figure 29: Comparison of observed and predicted female survey abundance for NMFS F. Observed time period.

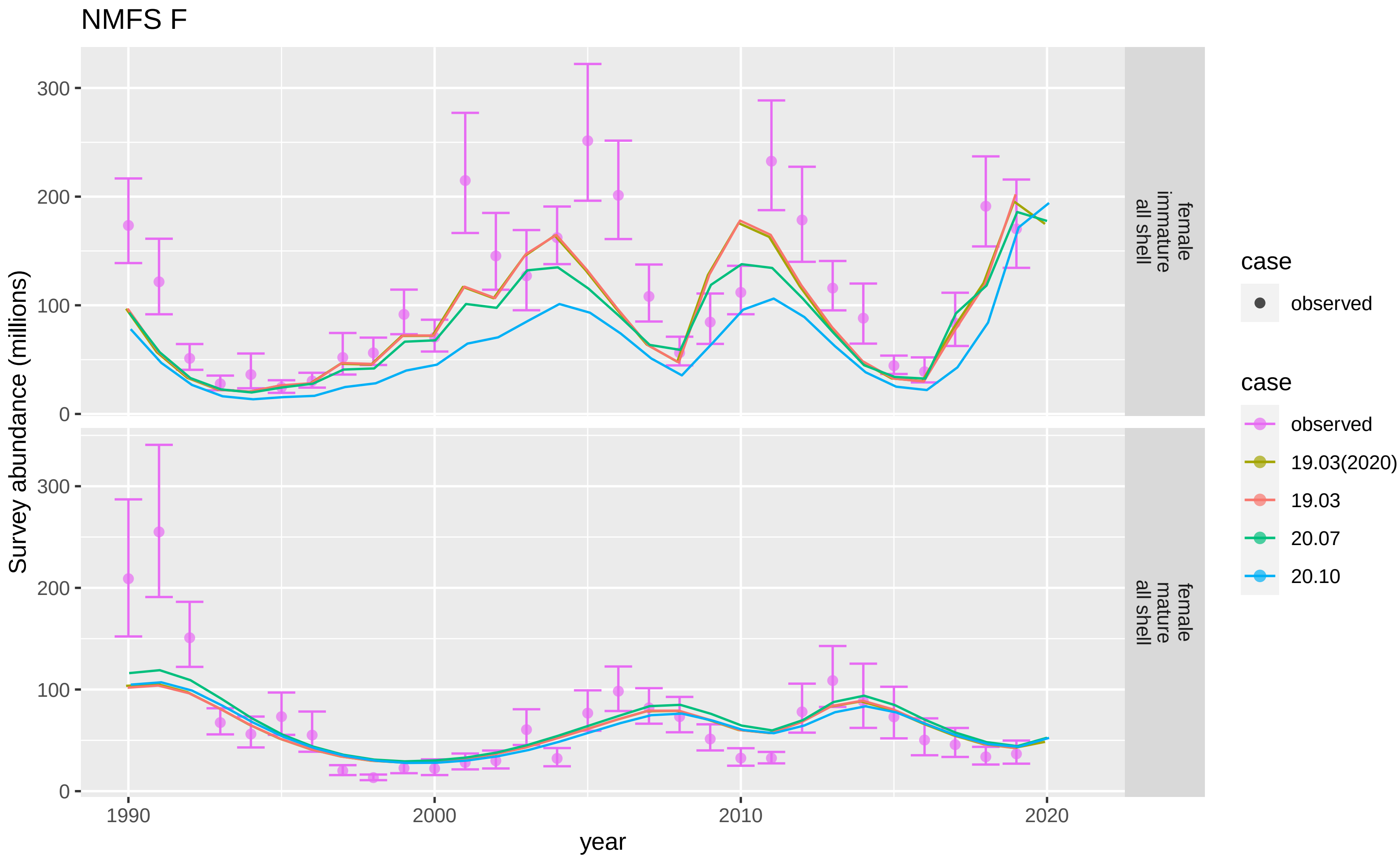

Figure 30: Comparison of observed and predicted female survey abundance for NMFS F. Recent time period.

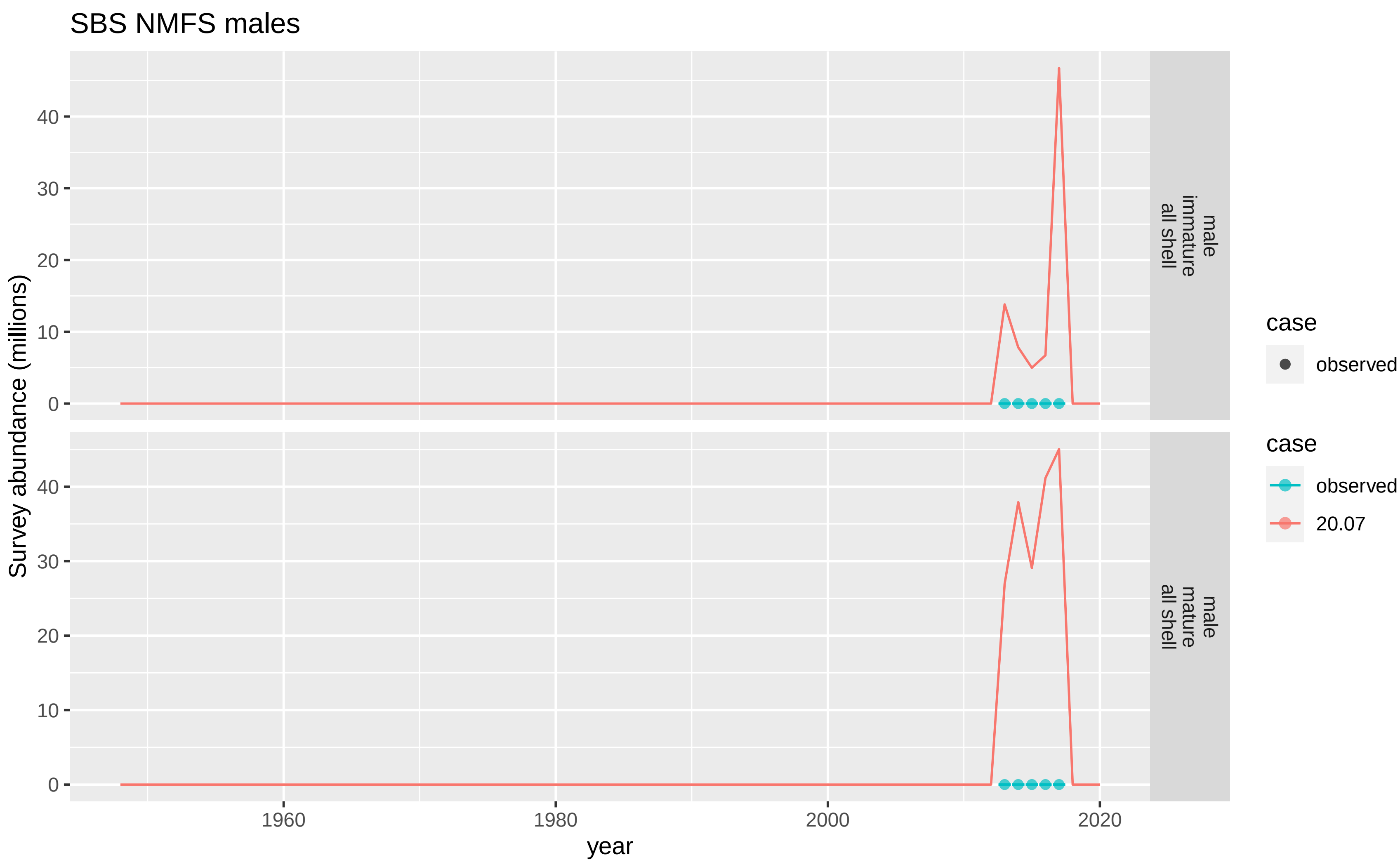

Figure 31: Comparison of observed and predicted male survey abundance for SBS NMFS males.

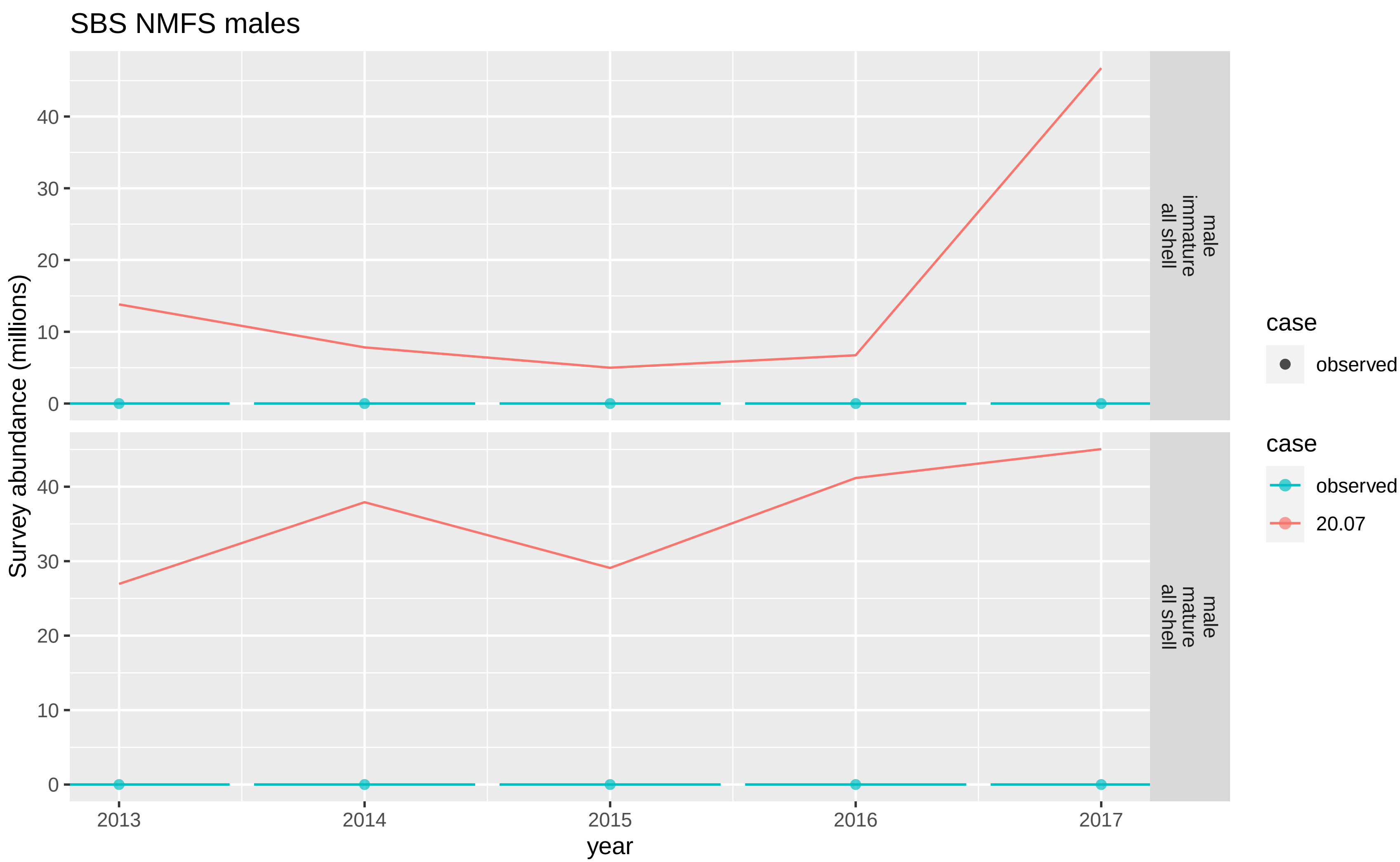

Figure 32: Comparison of observed and predicted male survey abundance for SBS NMFS males. Observed time period.

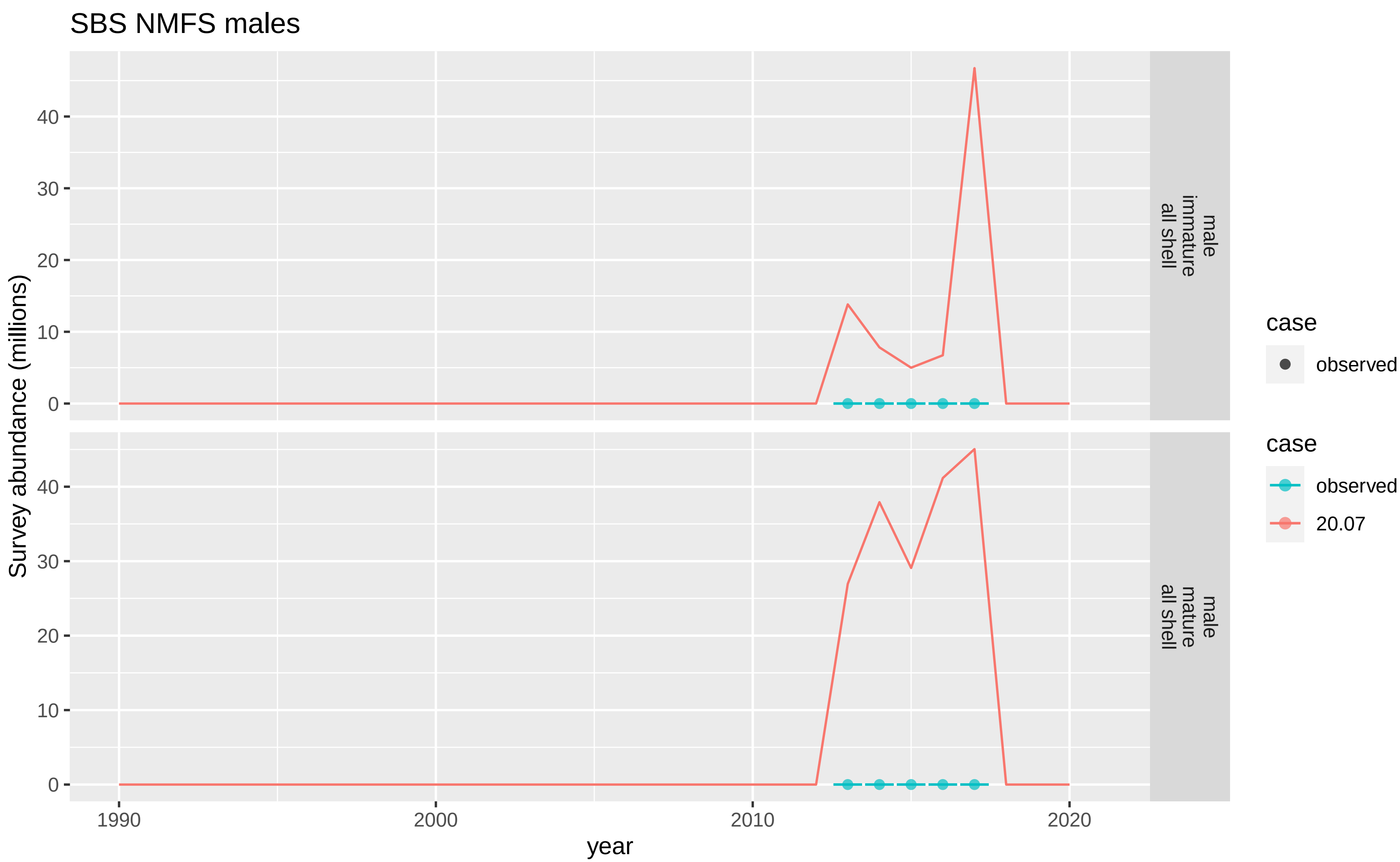

Figure 33: Comparison of observed and predicted male survey abundance for SBS NMFS males. Recent time period.

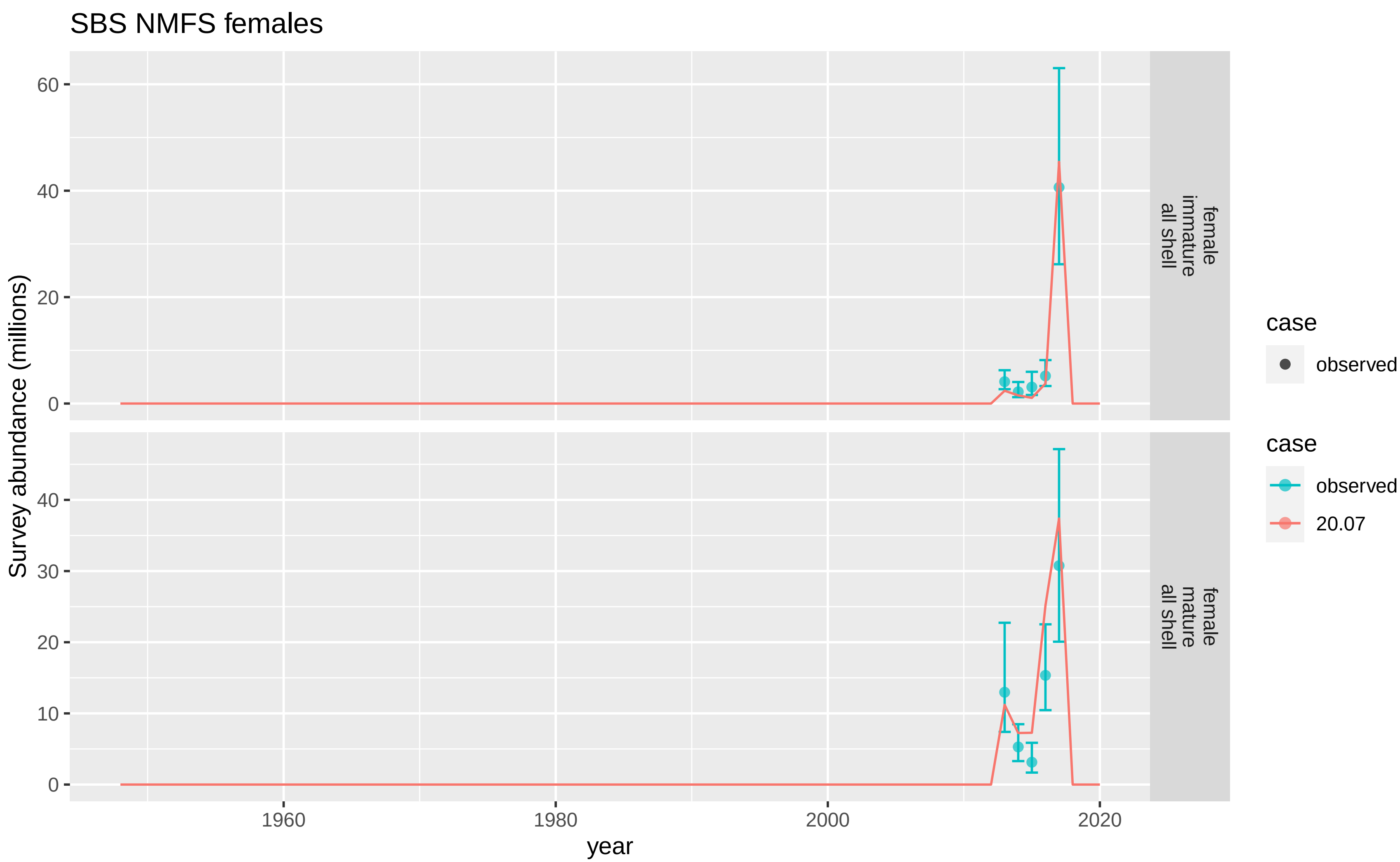

Figure 34: Comparison of observed and predicted female survey abundance for SBS NMFS females.

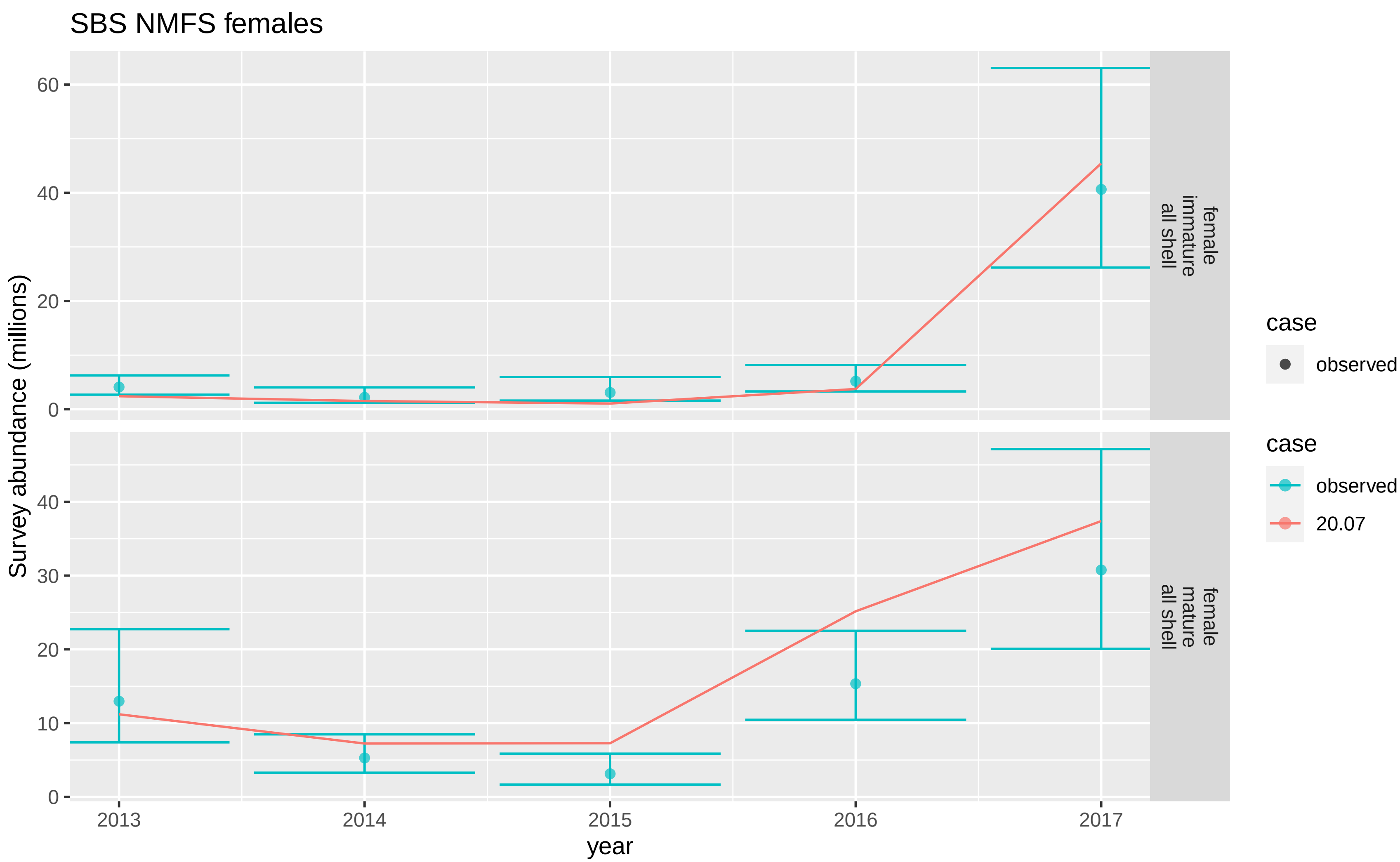

Figure 35: Comparison of observed and predicted female survey abundance for SBS NMFS females. Observed time period.

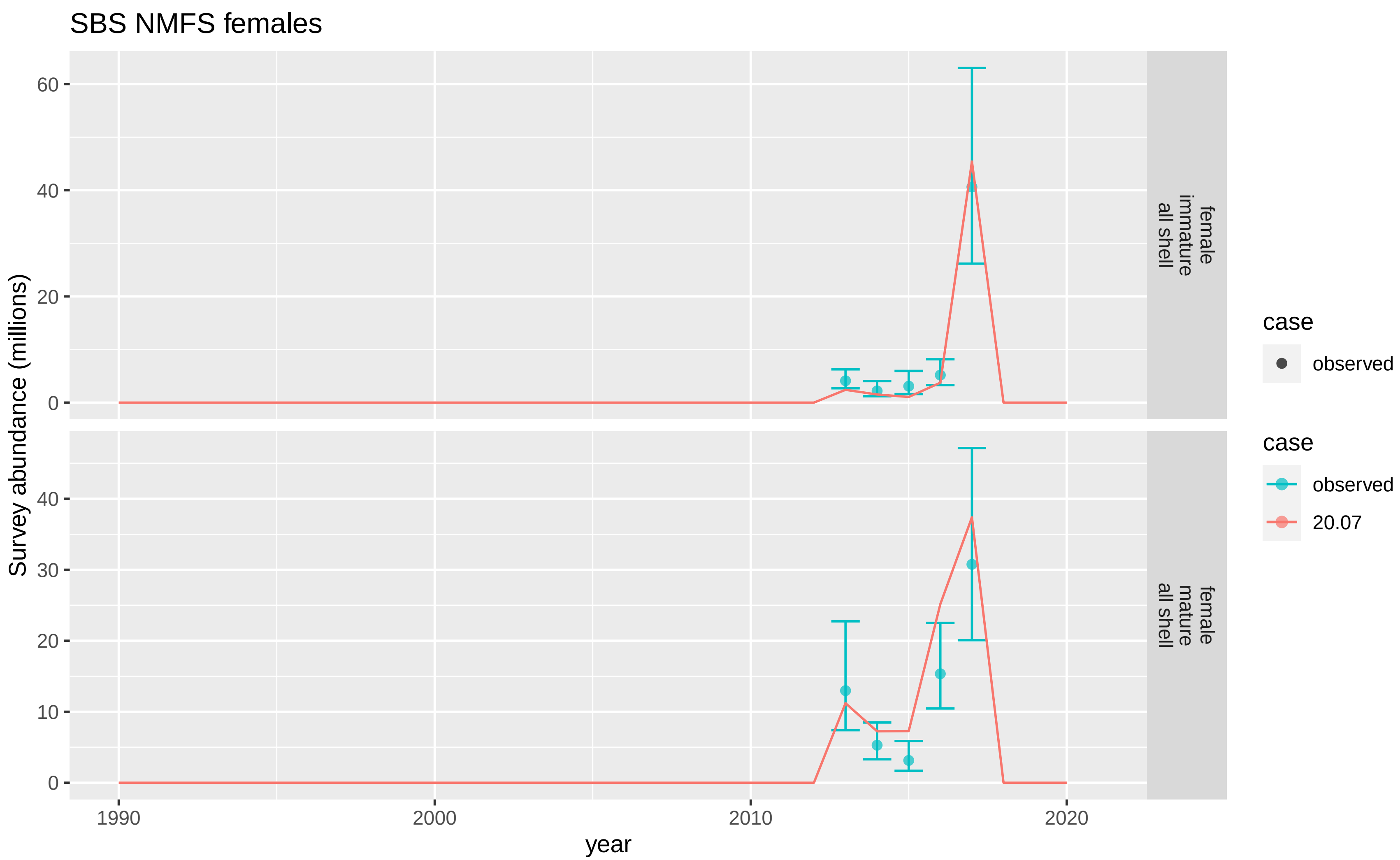

Figure 36: Comparison of observed and predicted female survey abundance for SBS NMFS females. Recent time period.

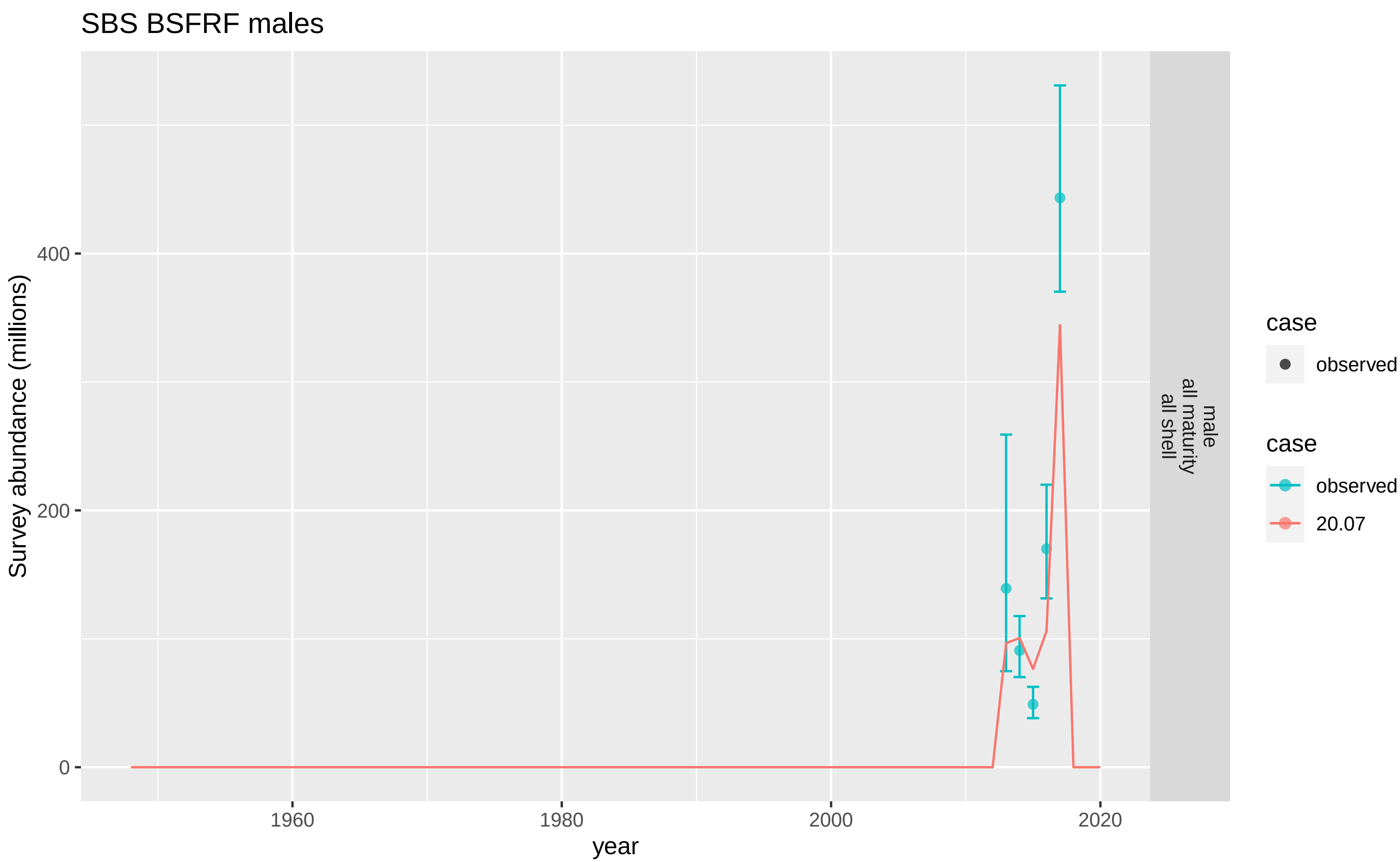

Figure 37: Comparison of observed and predicted male survey abundance for SBS BSFRF males.

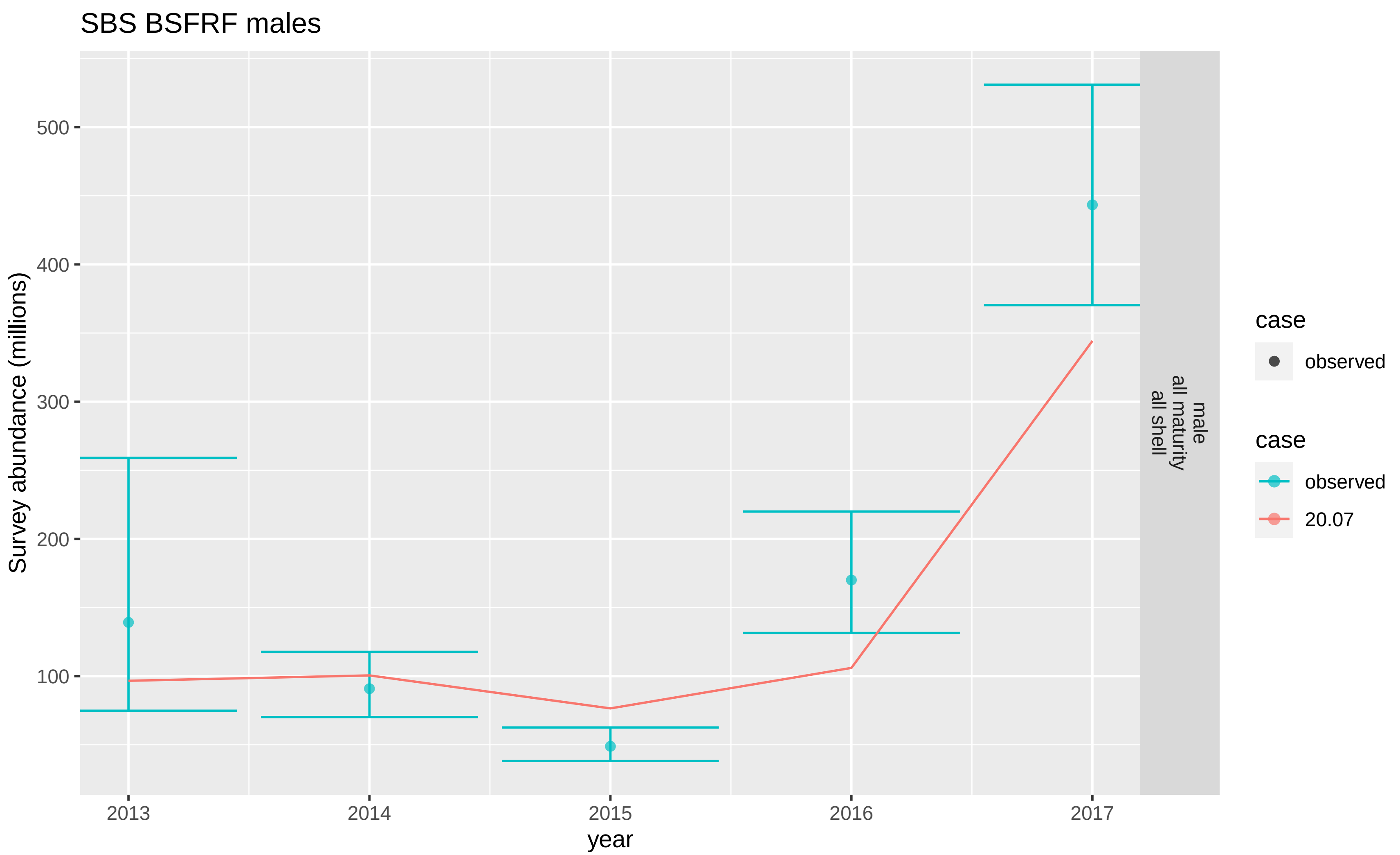

Figure 38: Comparison of observed and predicted male survey abundance for SBS BSFRF males. Observed time period.

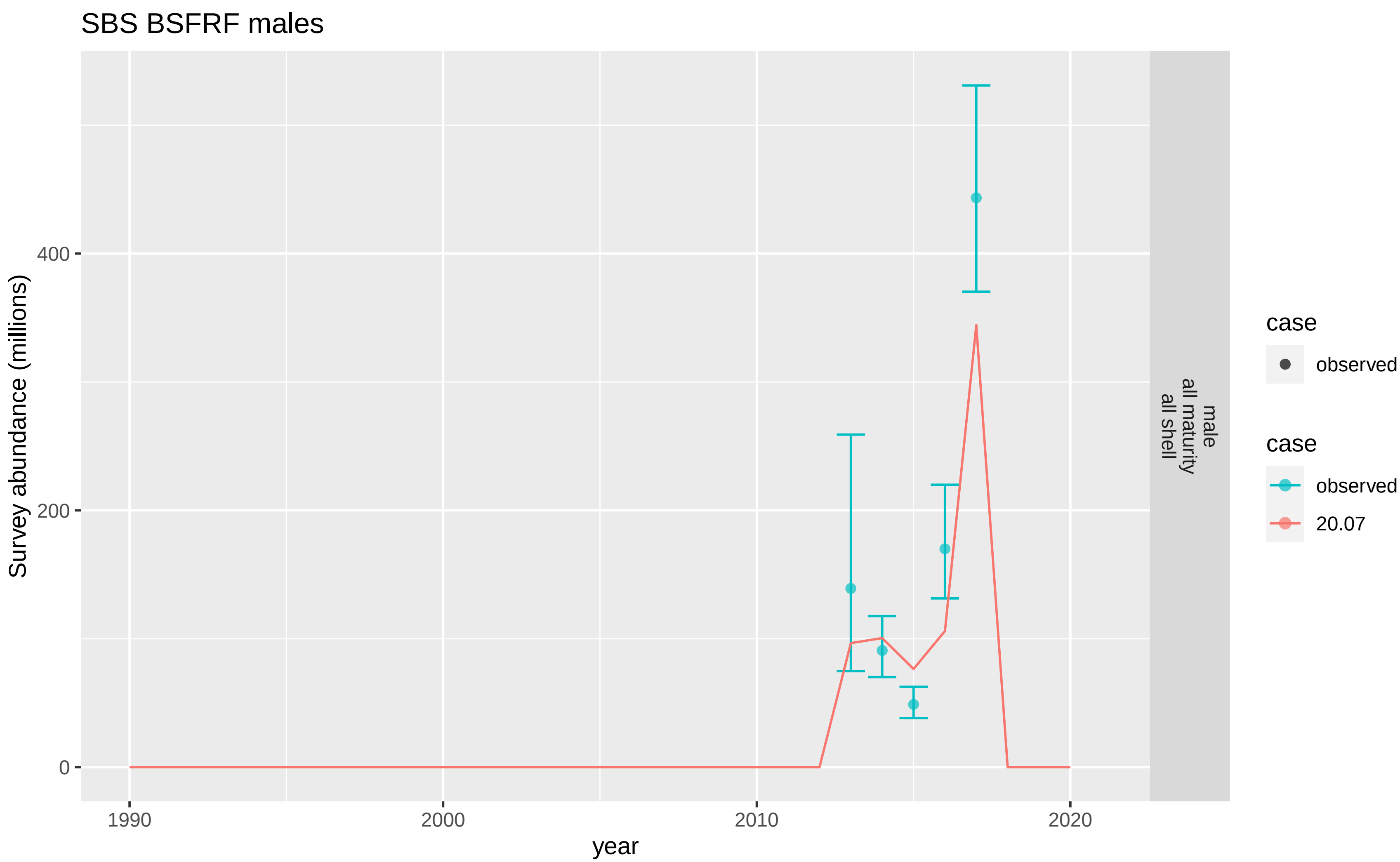

Figure 39: Comparison of observed and predicted male survey abundance for SBS BSFRF males. Recent time period.

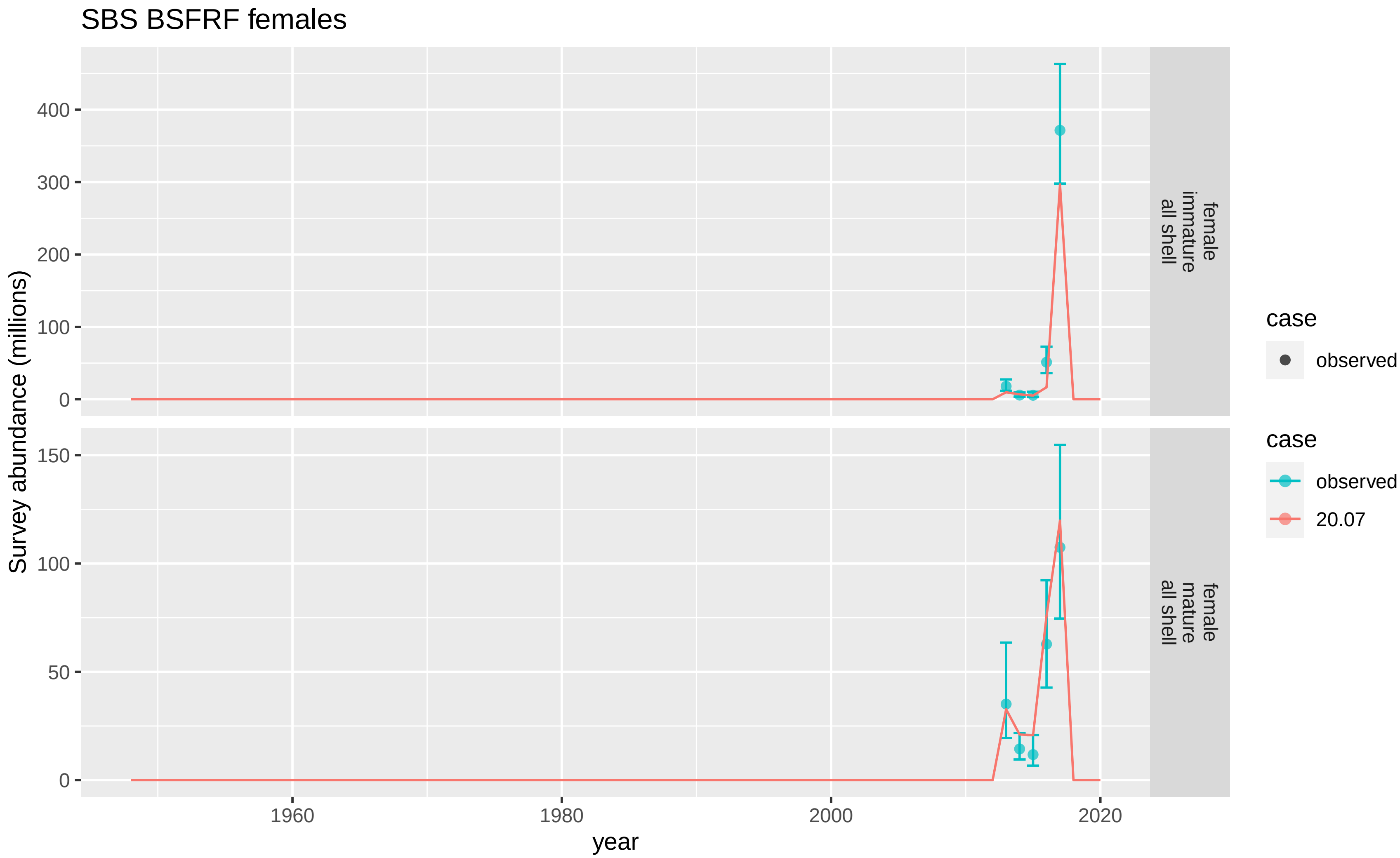

Figure 40: Comparison of observed and predicted female survey abundance for SBS BSFRF females.

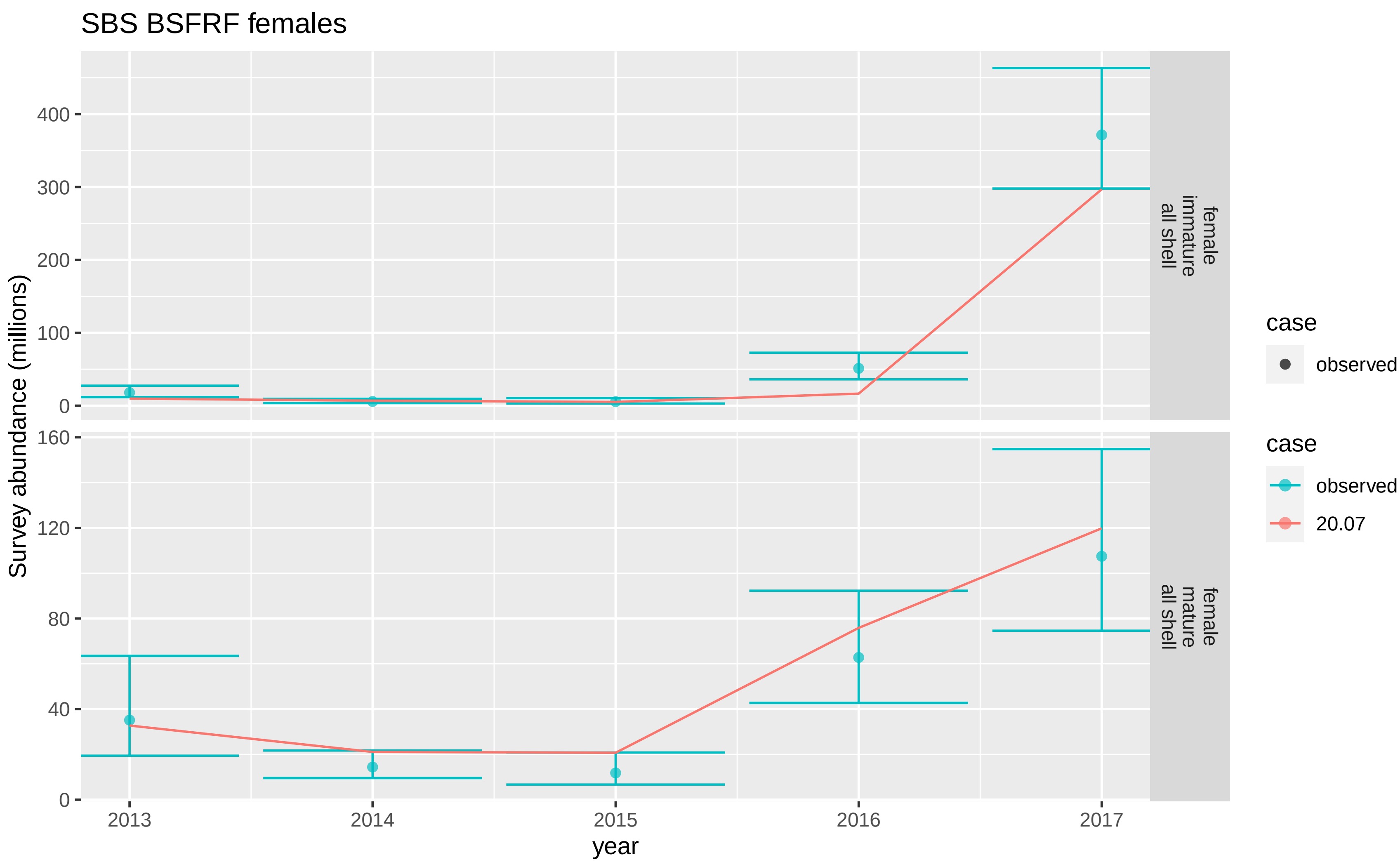

Figure 41: Comparison of observed and predicted female survey abundance for SBS BSFRF females. Observed time period.

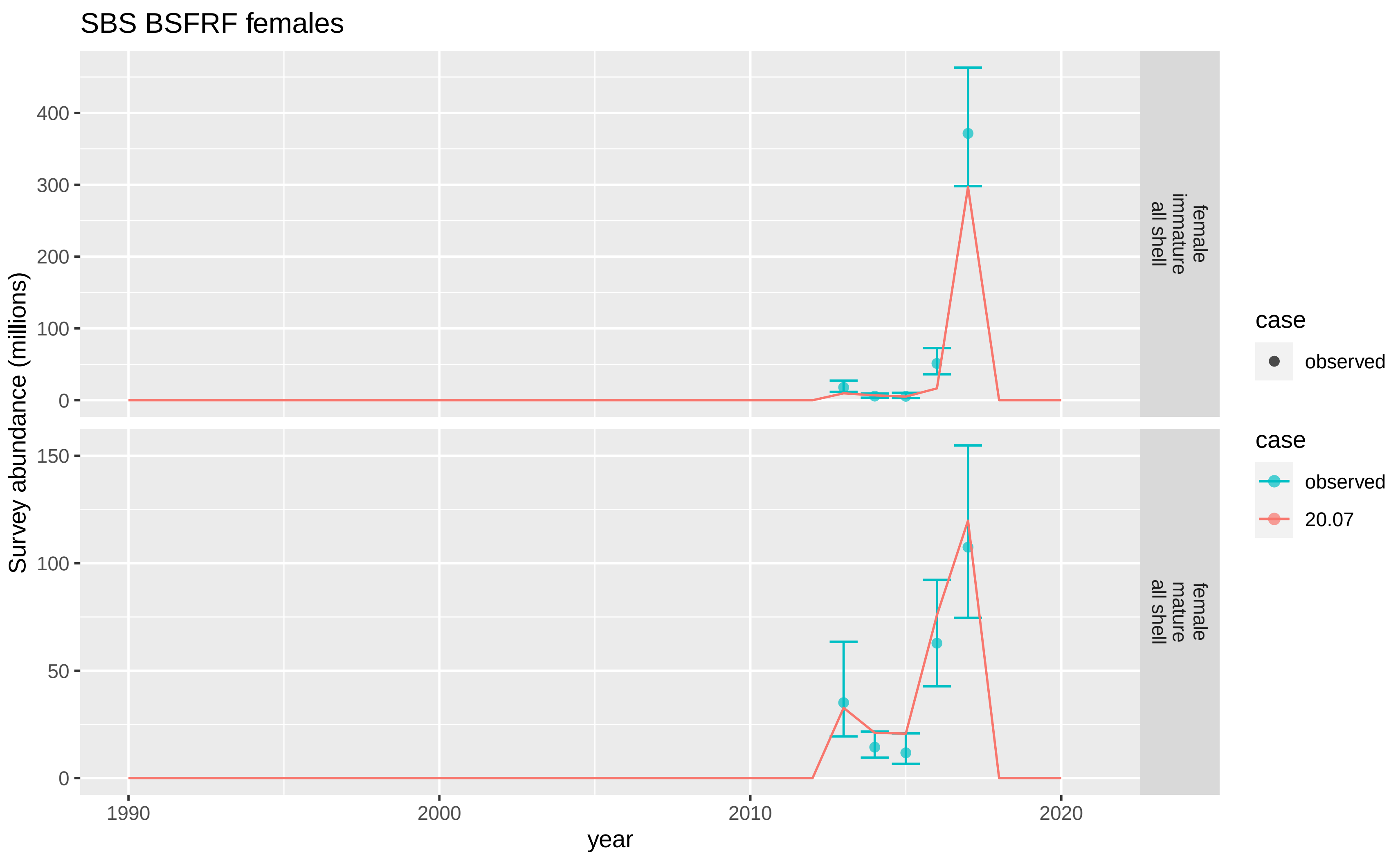

Figure 42: Comparison of observed and predicted female survey abundance for SBS BSFRF females. Recent time period.

Z-scores

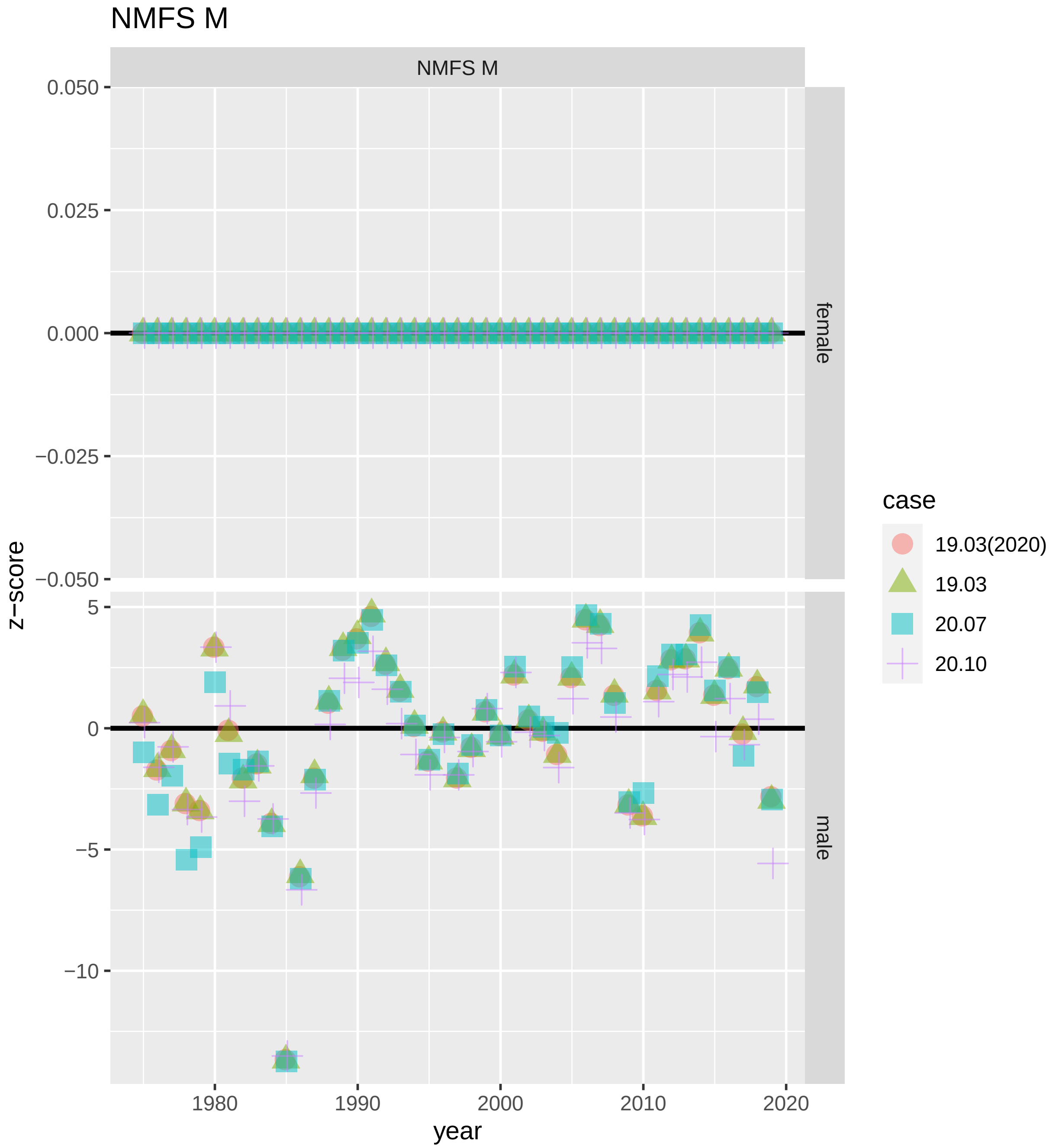

Figure 43: Z-scores for index catch abundance in NMFS M.

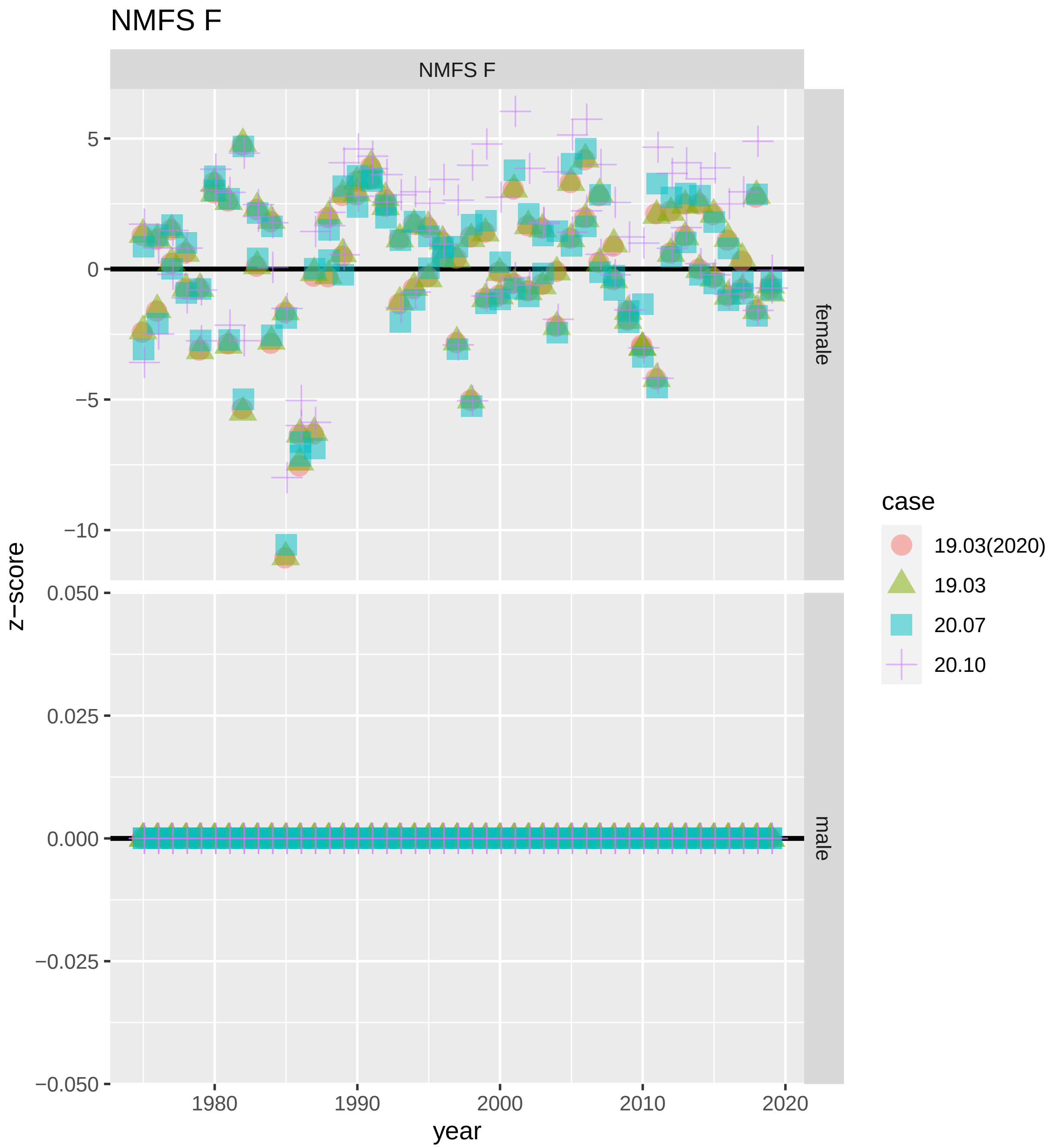

Figure 44: Z-scores for index catch abundance in NMFS F.

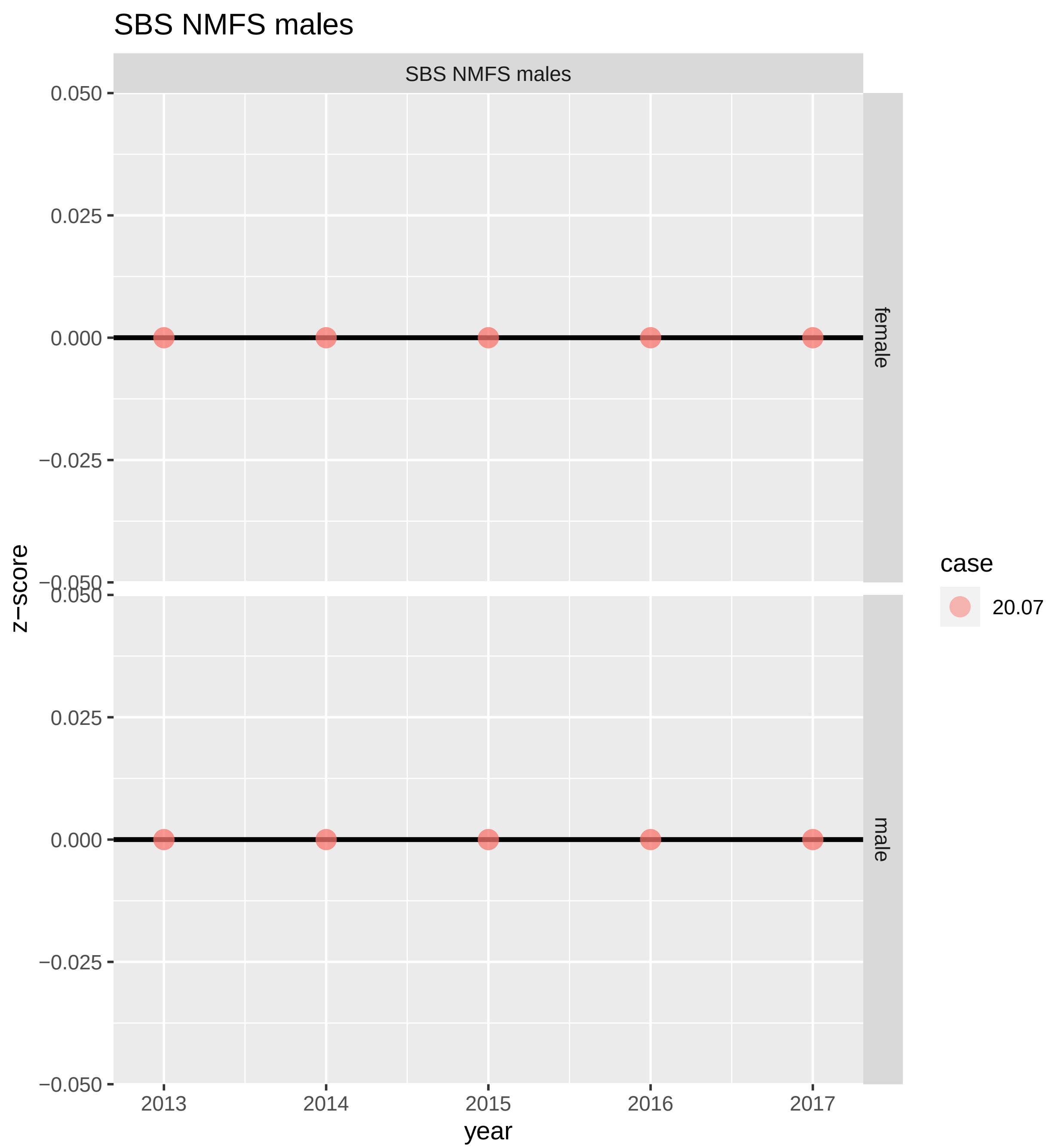

Figure 45: Z-scores for index catch abundance in SBS NMFS males.

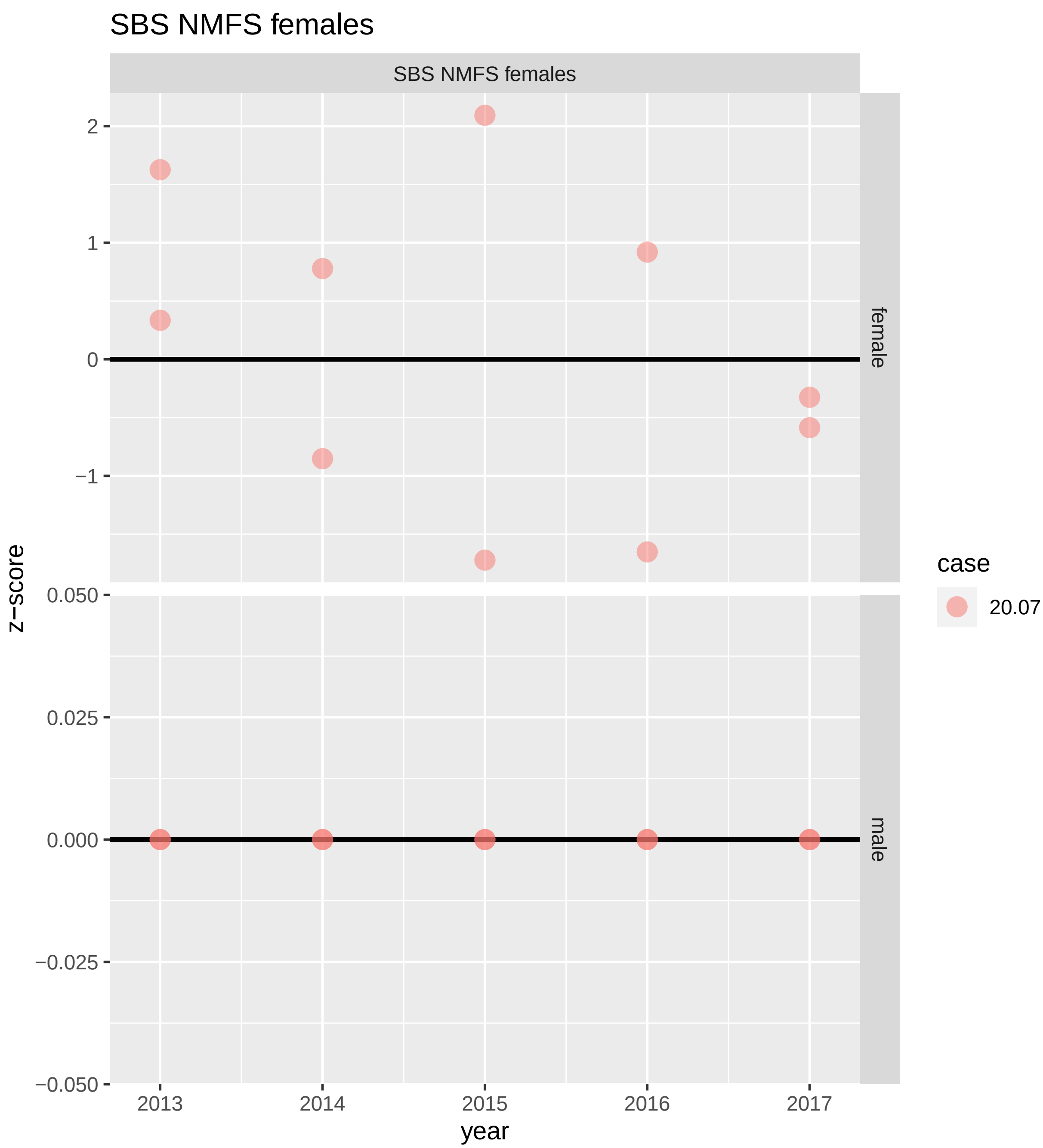

Figure 46: Z-scores for index catch abundance in SBS NMFS females.

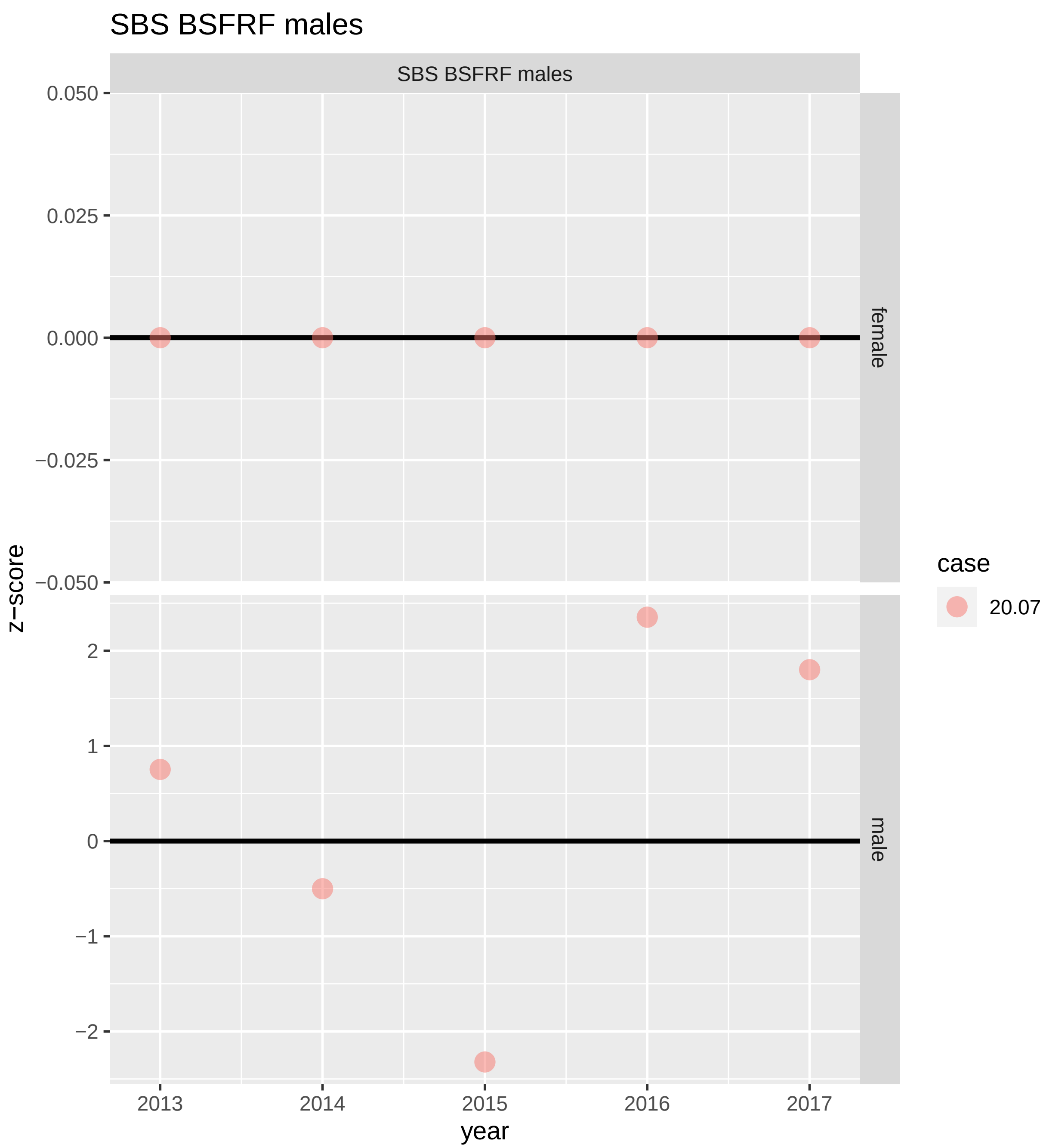

Figure 47: Z-scores for index catch abundance in SBS BSFRF males.

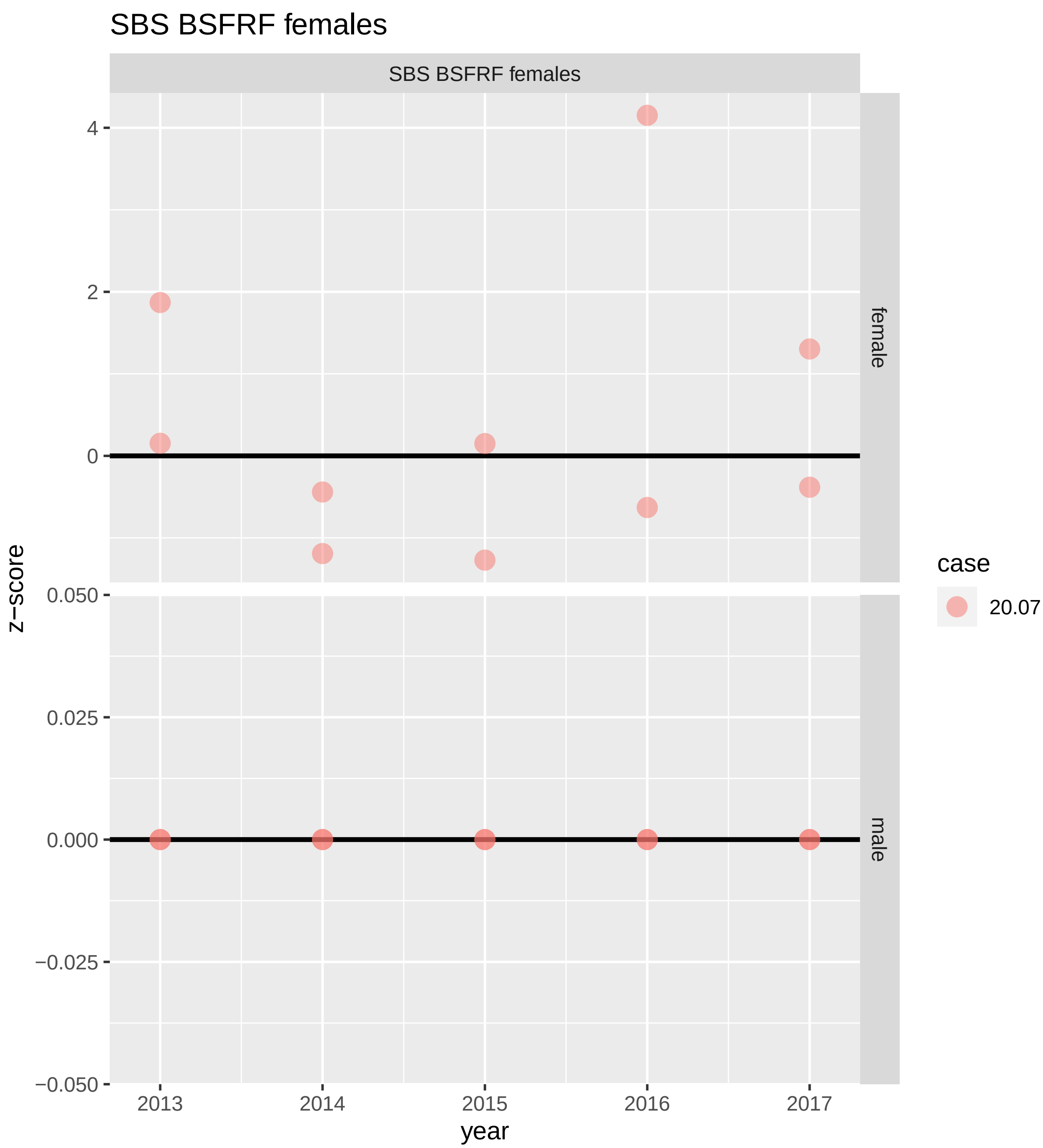

Figure 48: Z-scores for index catch abundance in SBS BSFRF females.

Appendix 7: Fits to "Other" Data – 19.03(2020) vs 19.03 vs 20.07 vs 20.10

William Stockhausen

01 September, 2020

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Model fits to "other" data

Fits to growth data and male maturity datasets by the model(s) are presented in this section. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Growth data

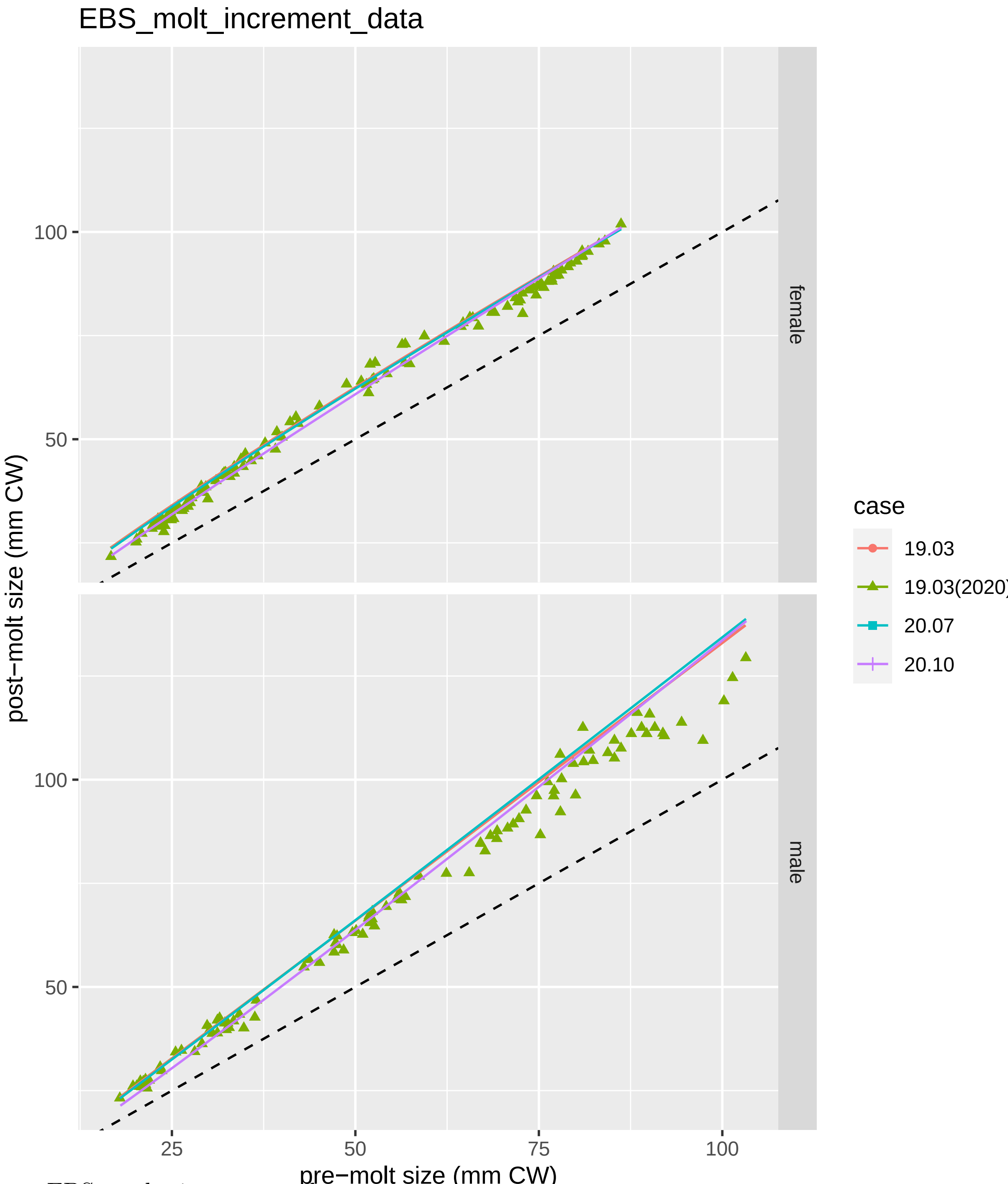

Figure 1. Model fits to EBS_molt_increment_data.

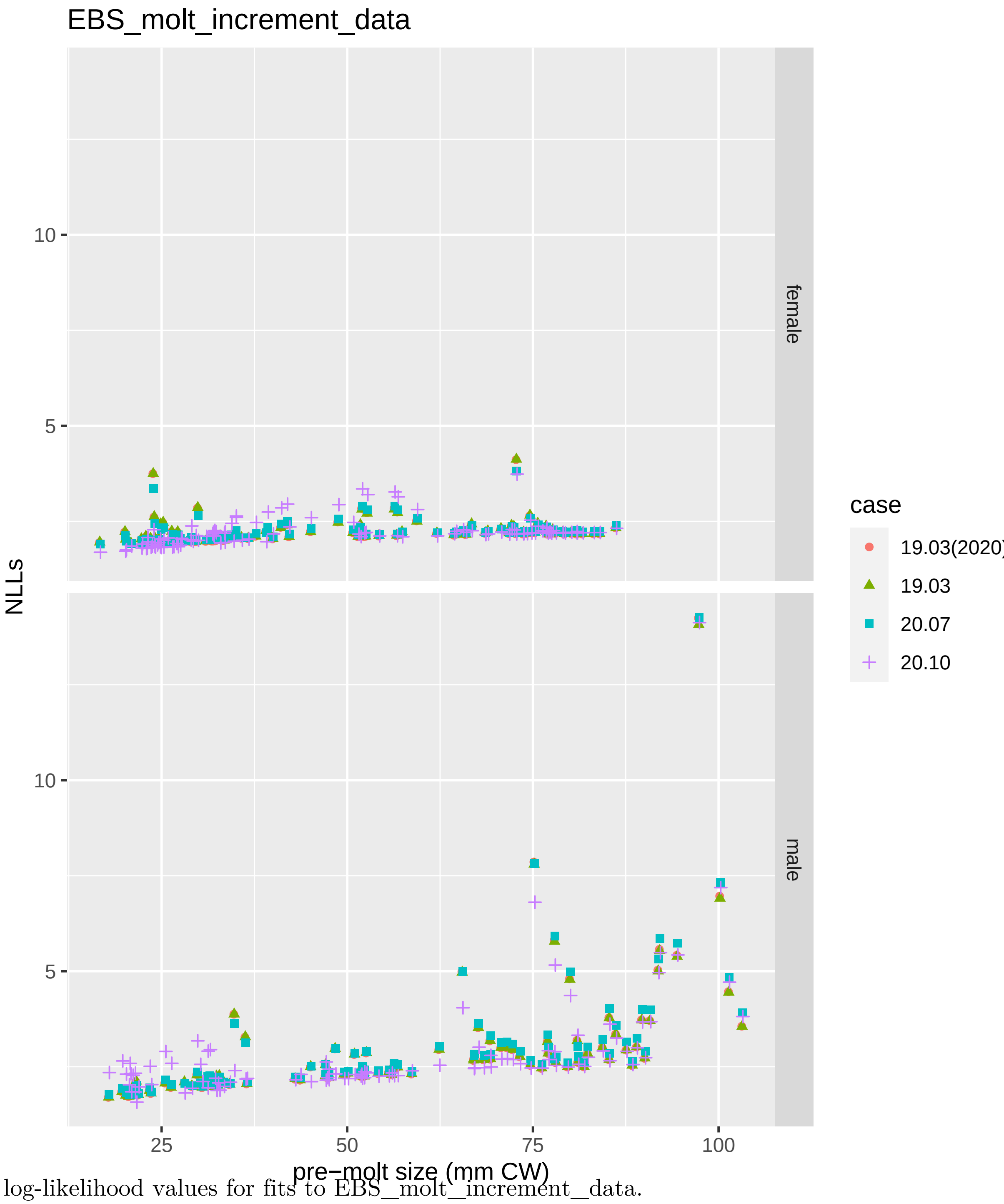

Figure 2. Negative log-likelihood values for fits to EBS_molt_increment_data.

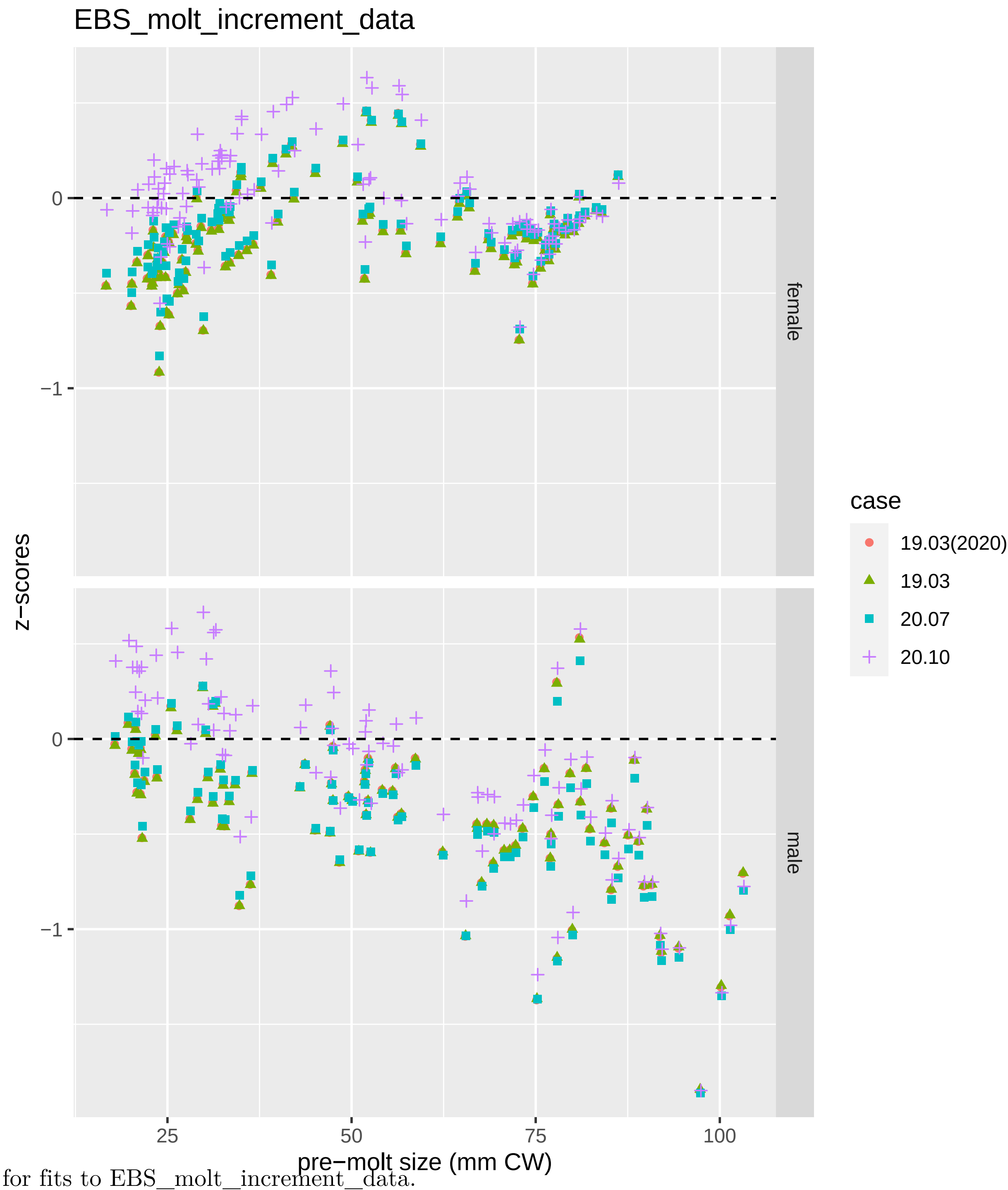

Figure 3. Z-scores for fits to EBS_molt_increment_data.

Maturity ogive data

In the male maturity dataset used in this assessment, a number of male crab less than 60 mm CW were classified as mature based on their chela height-to-carapace width ratios. For the purposes of fitting the data, these crab were assumed to be misclassified and to actually be immature. Consequently, data from size bins less than 60 mm CW, although shown in the following plots comparing model predictions to observations, were not included in the likelihood used for model optimization and are not shown in the NLL and z-score plots.

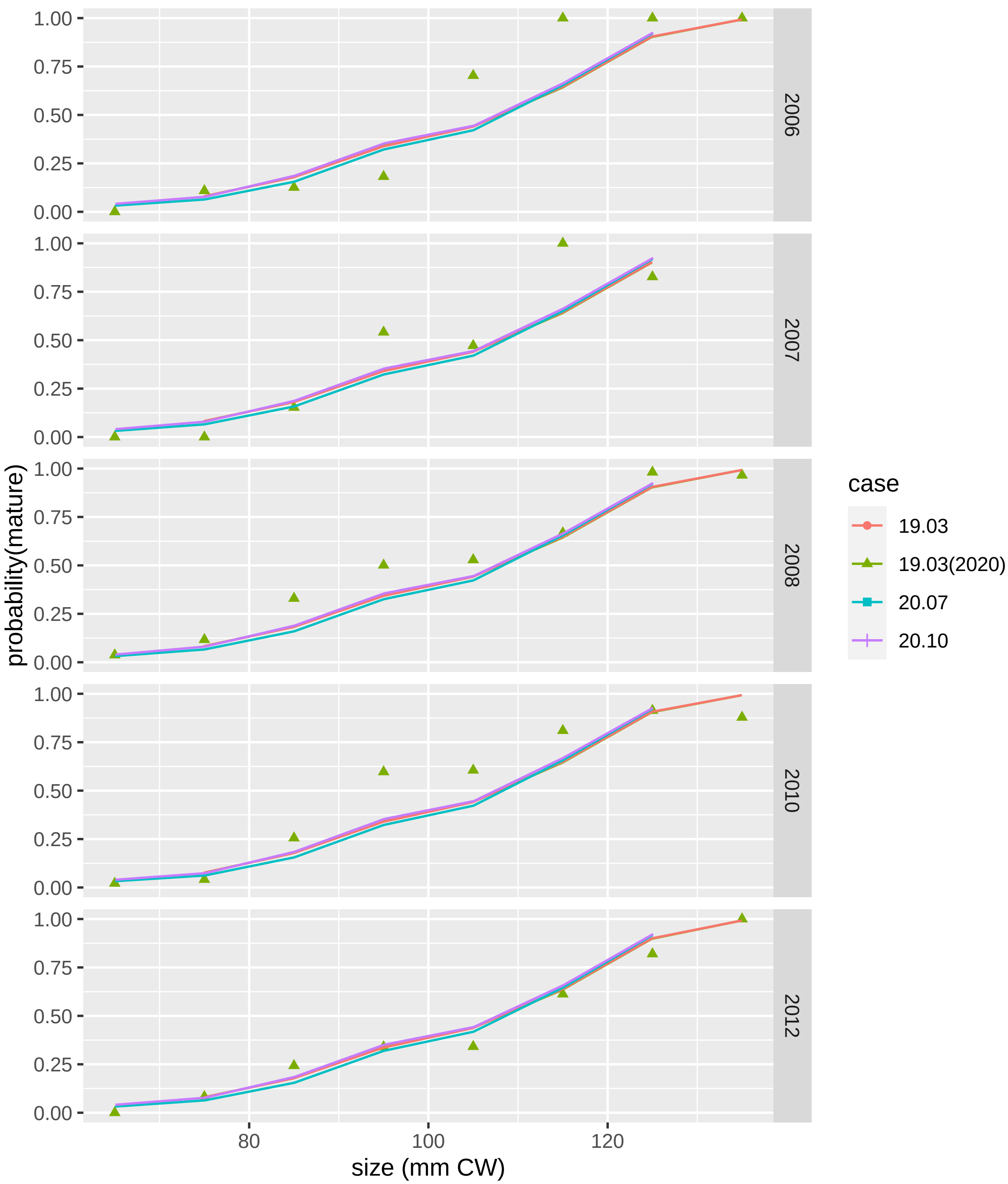

Figure 4: Model fits to EBS male maturity ogives for 2006 to 2012.

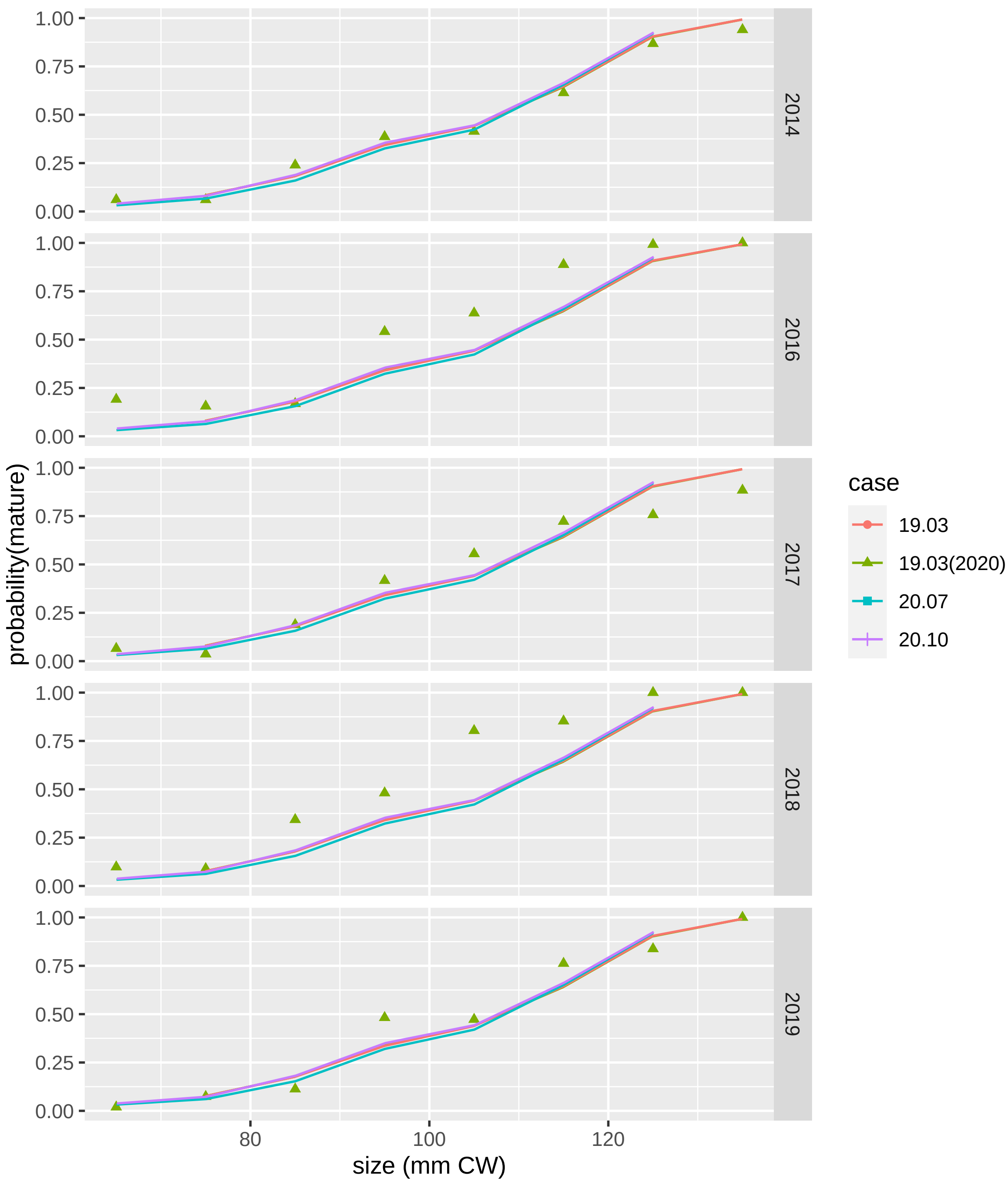

Figure 5: Model fits to EBS male maturity ogives for 2014 to 2019.

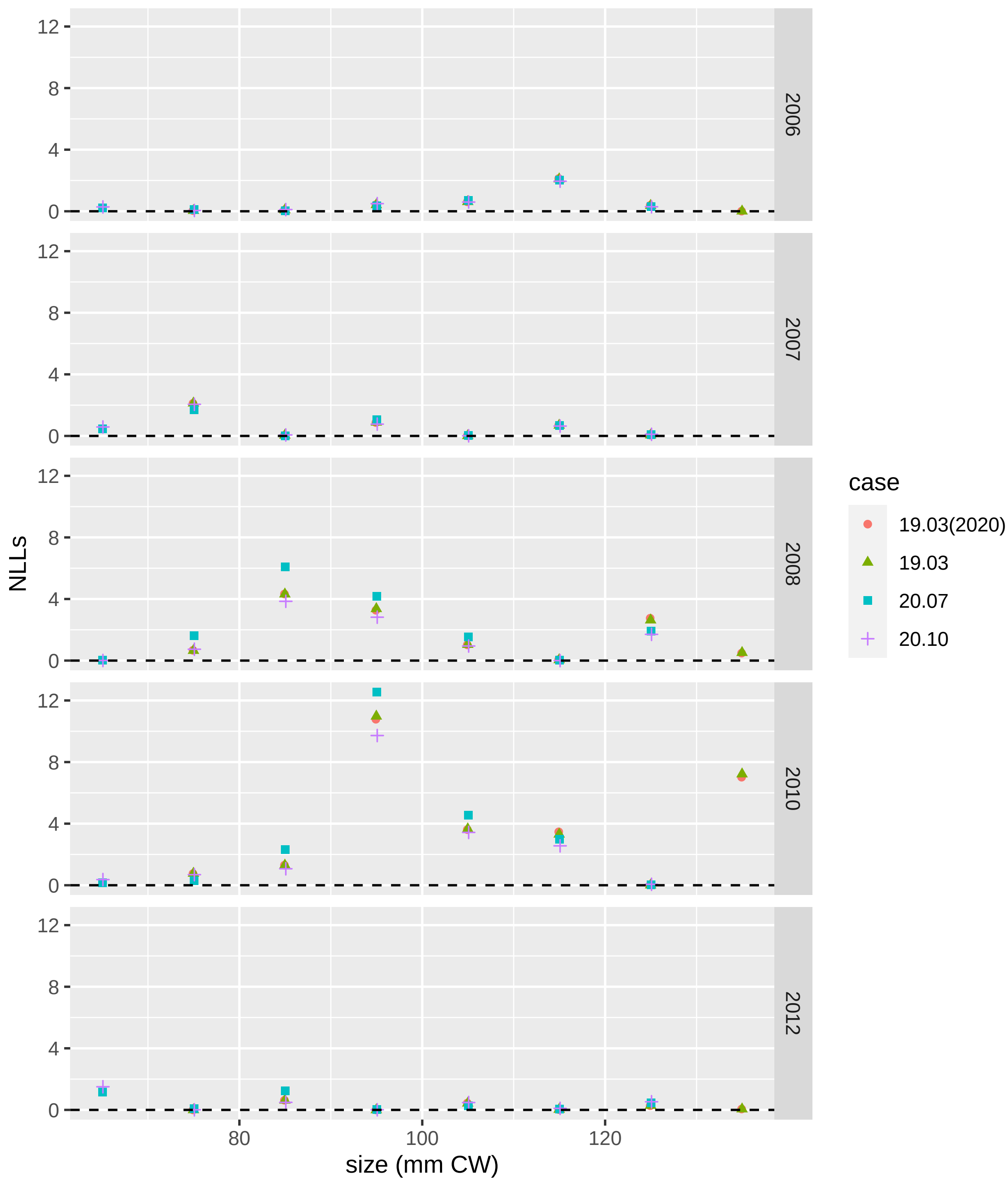

Figure 6: Negative log-likelihood values for fits to EBS male maturity ogives for 2006 to 2012.

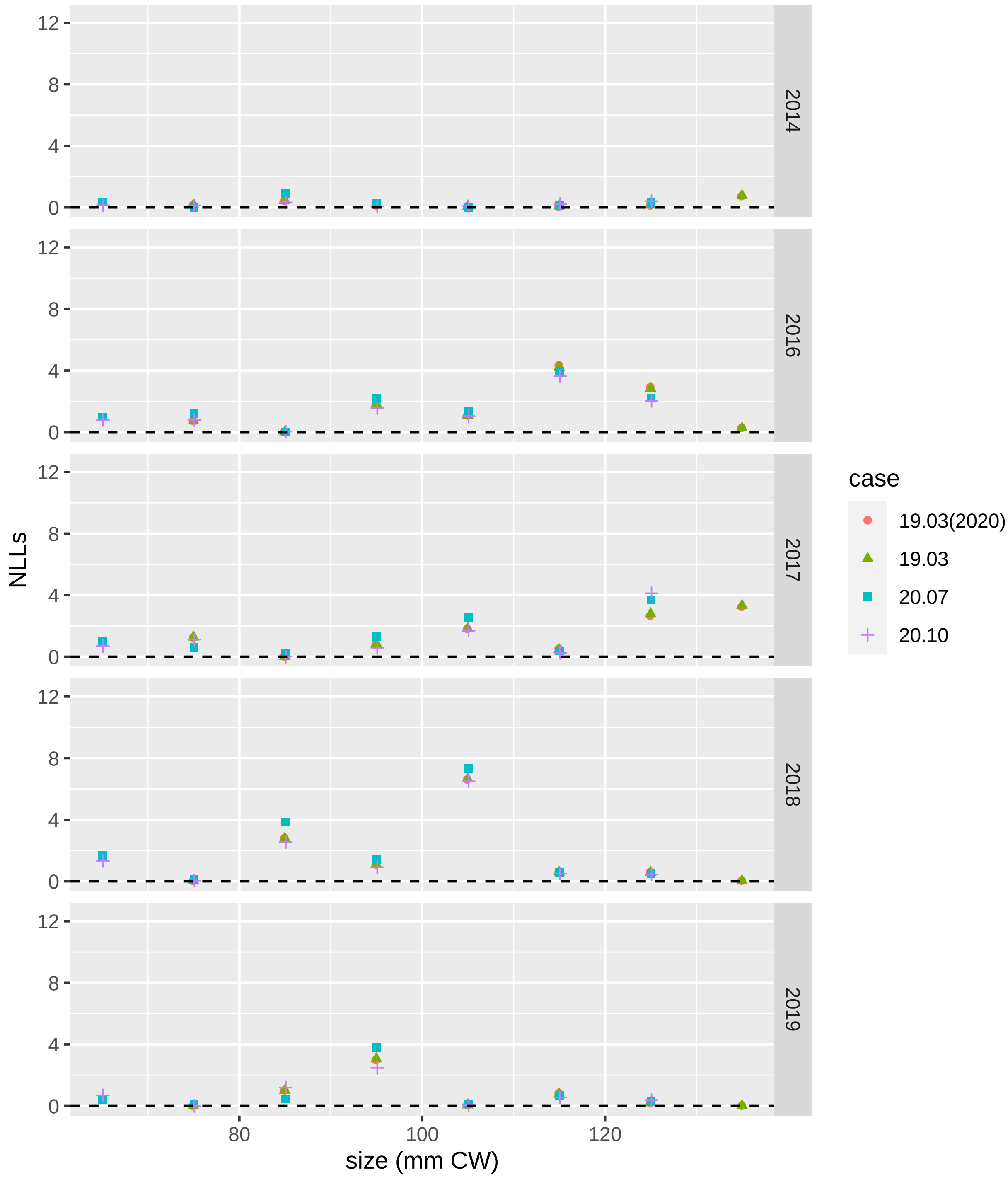

Figure 7: Negative log-likelihood values for fits to EBS male maturity ogives for 2014 to 2019.

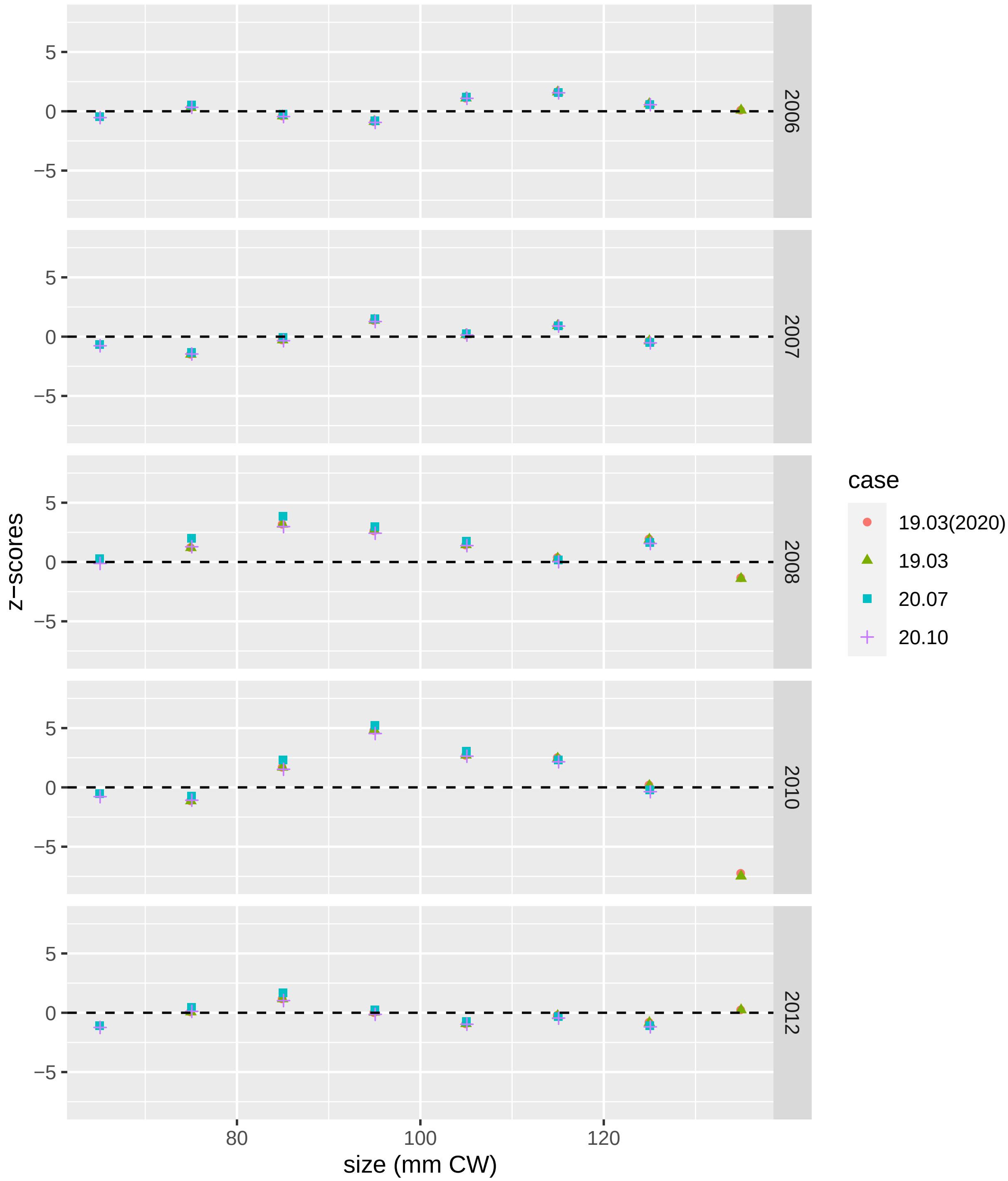

Figure 8: Z-scores for fits to EBS male maturity ogives for 2006 to 2012.

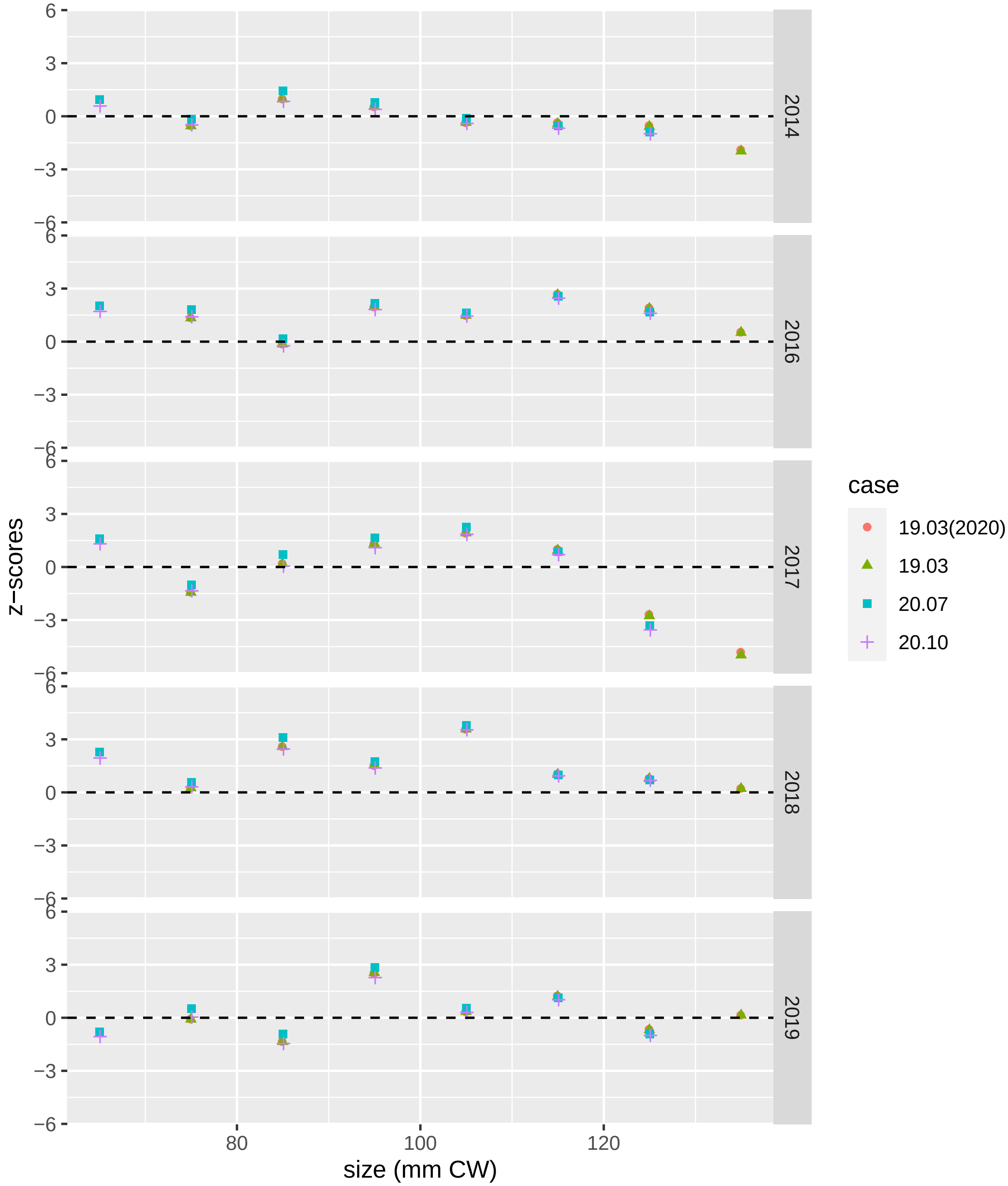

Figure 9: Z-scores for fits to EBS male maturity ogives for 2014 to 2019.

Appendix 8: Fits to All Size Composition Data – 19.03(2020) vs 19.03 vs 20.07 vs 20.10

William Stockhausen

01 September, 2020

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Model fits to size compositions, by year

Fits to the size composition data available to the model(s) are presented in this section as line plots by year. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Survey size compositions

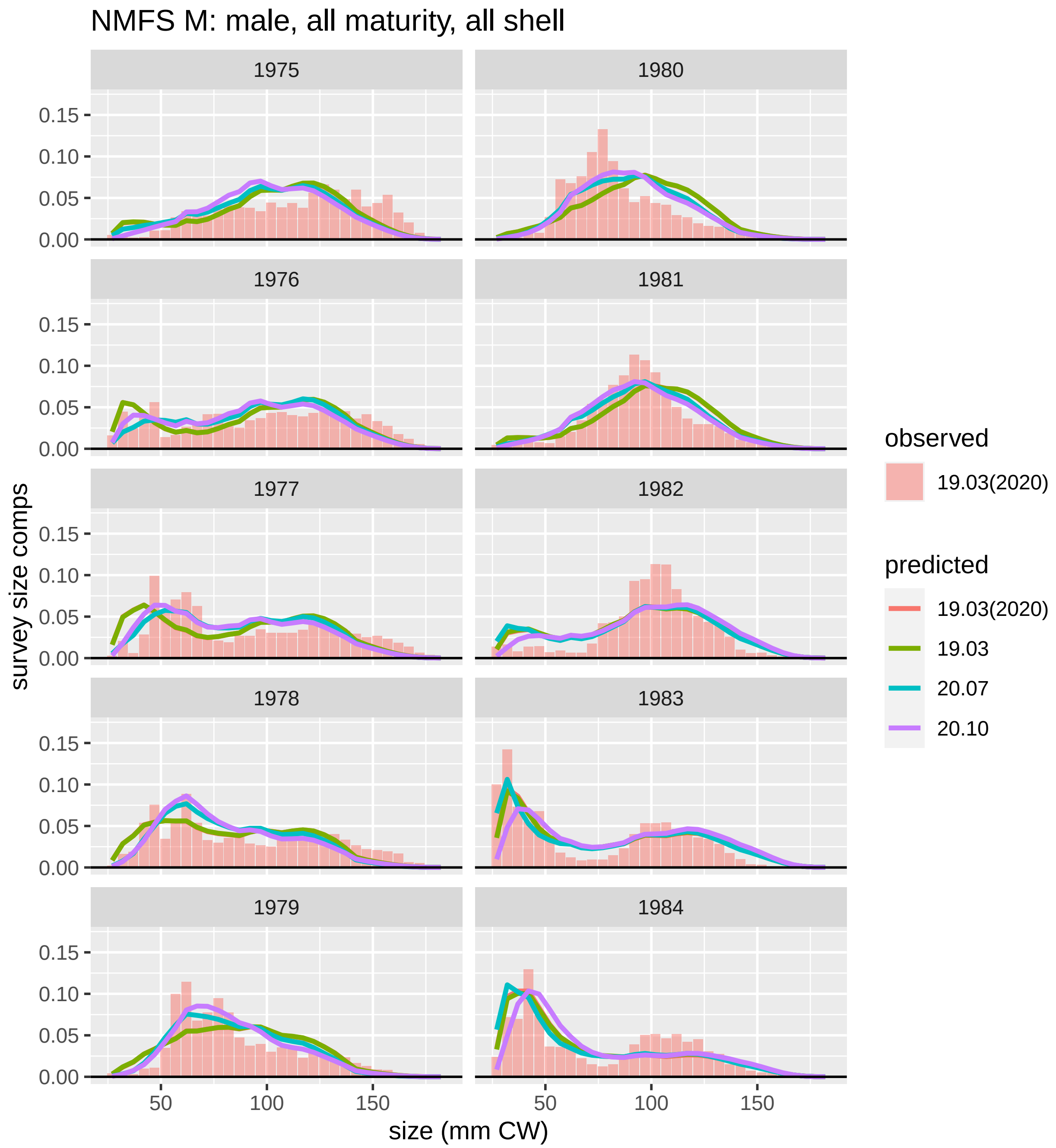


Figure 1: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 1 of 5.

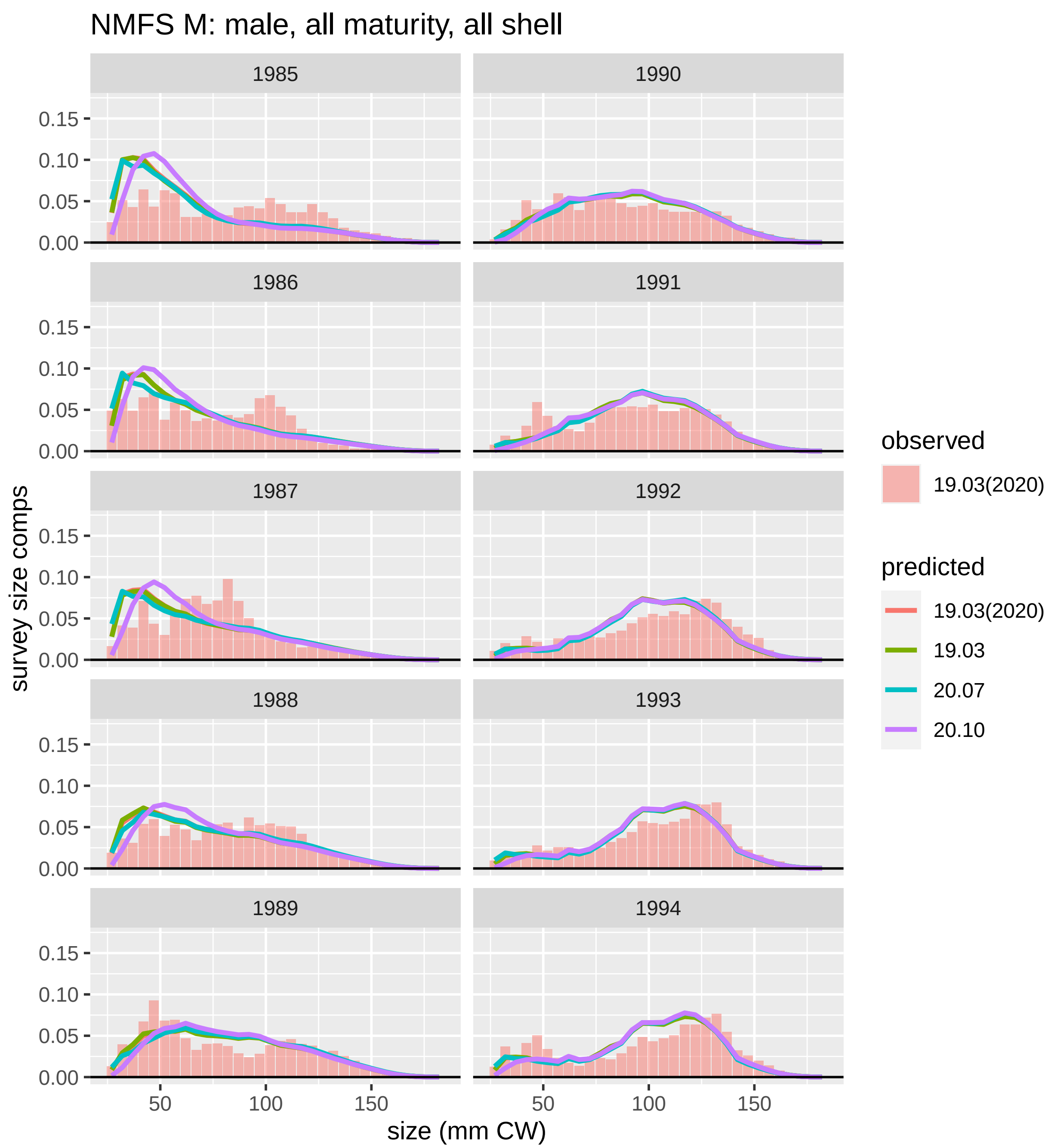


Figure 2: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 2 of 5.

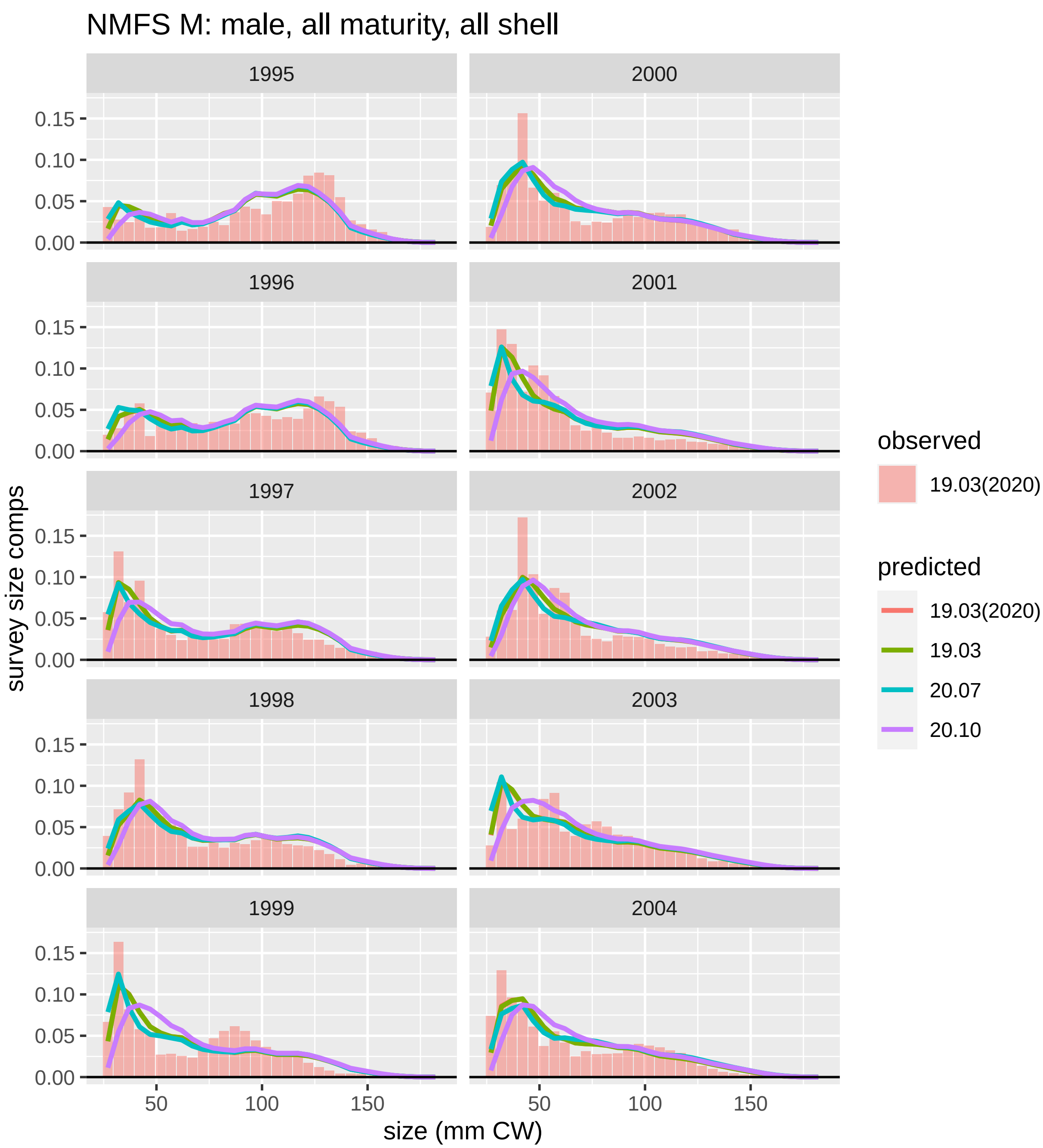


Figure 3: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 3 of 5.

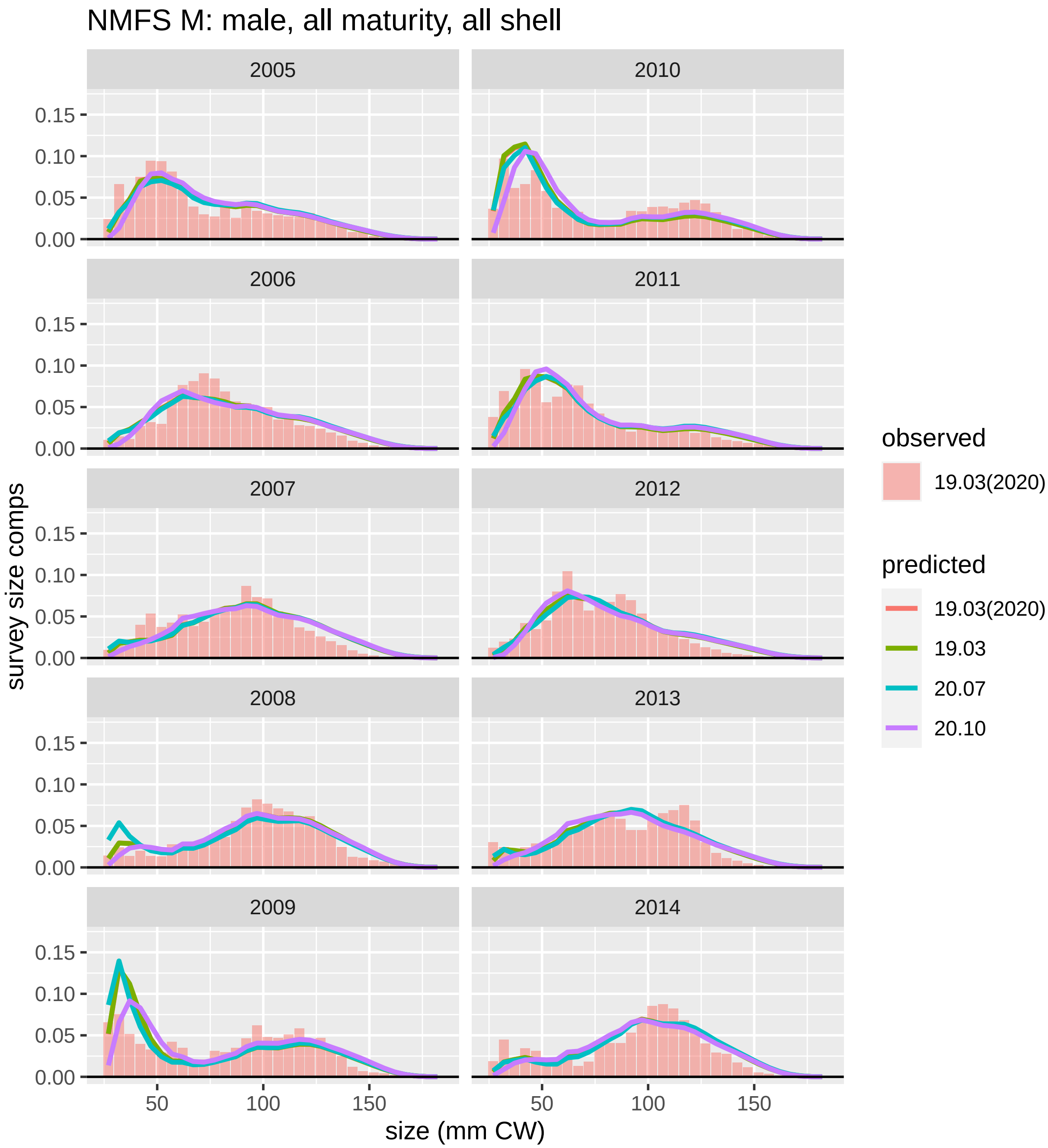


Figure 4: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 4 of 5.

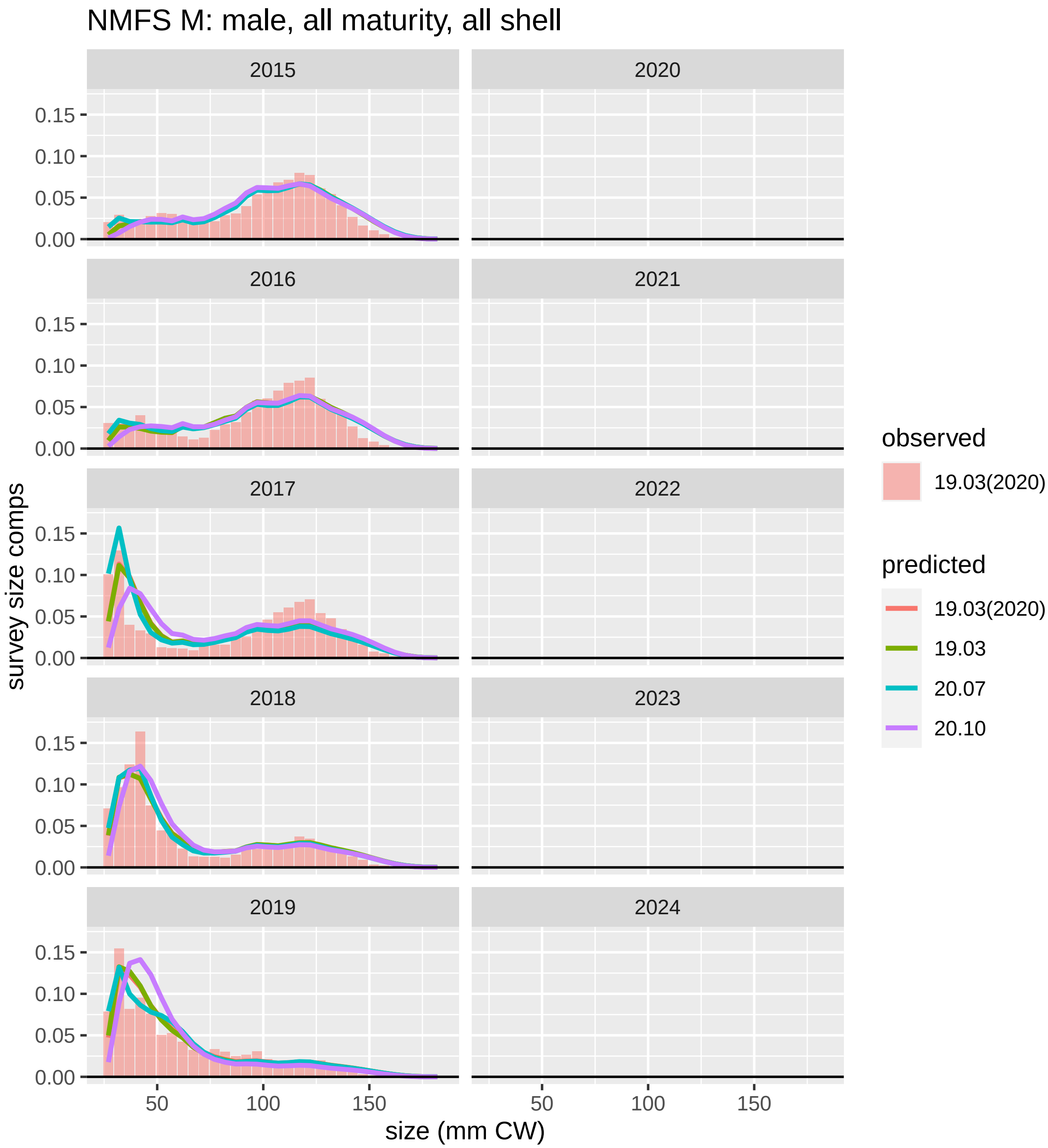


Figure 5: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 5 of 5.

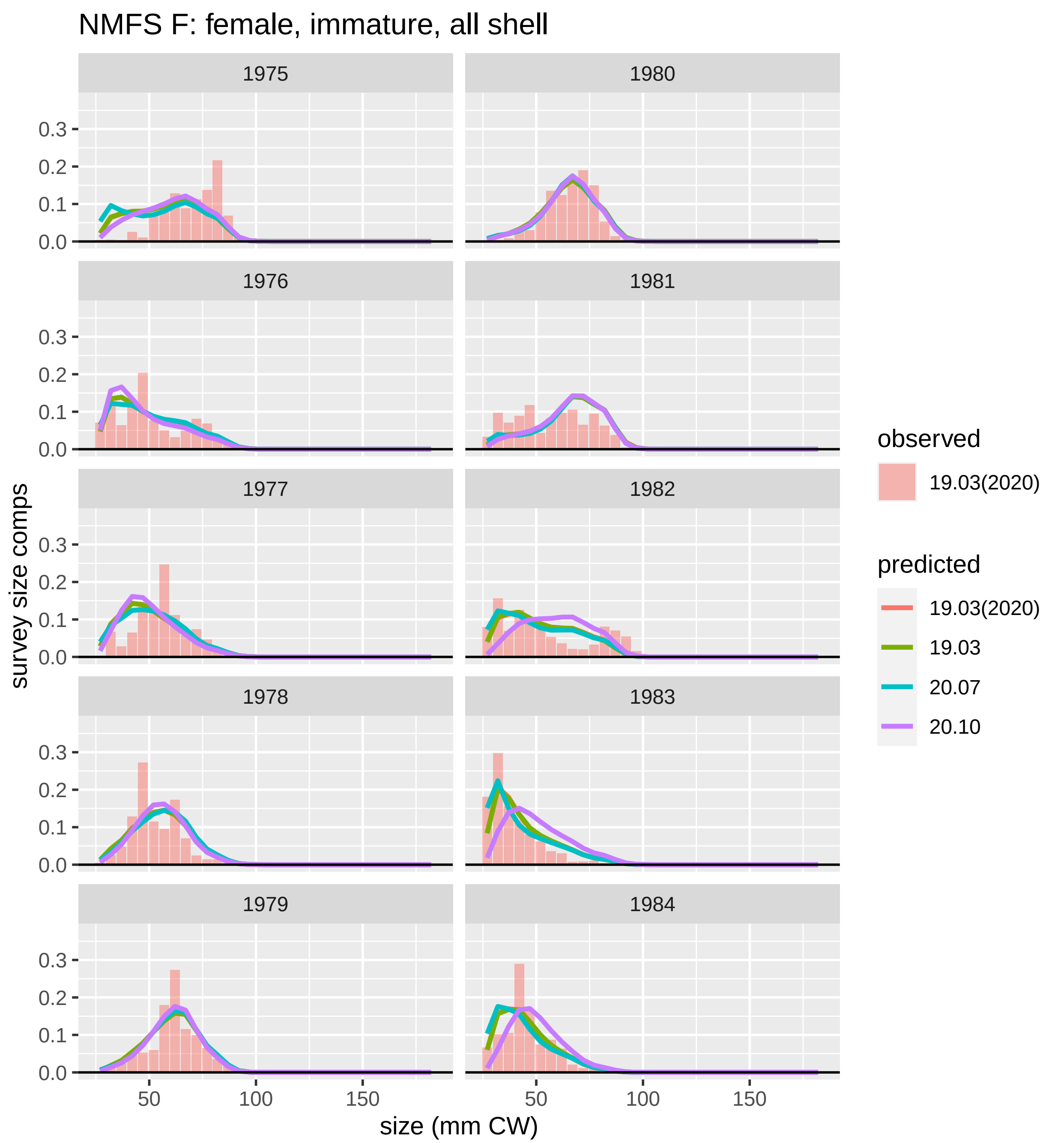


Figure 6: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 1 of 5.

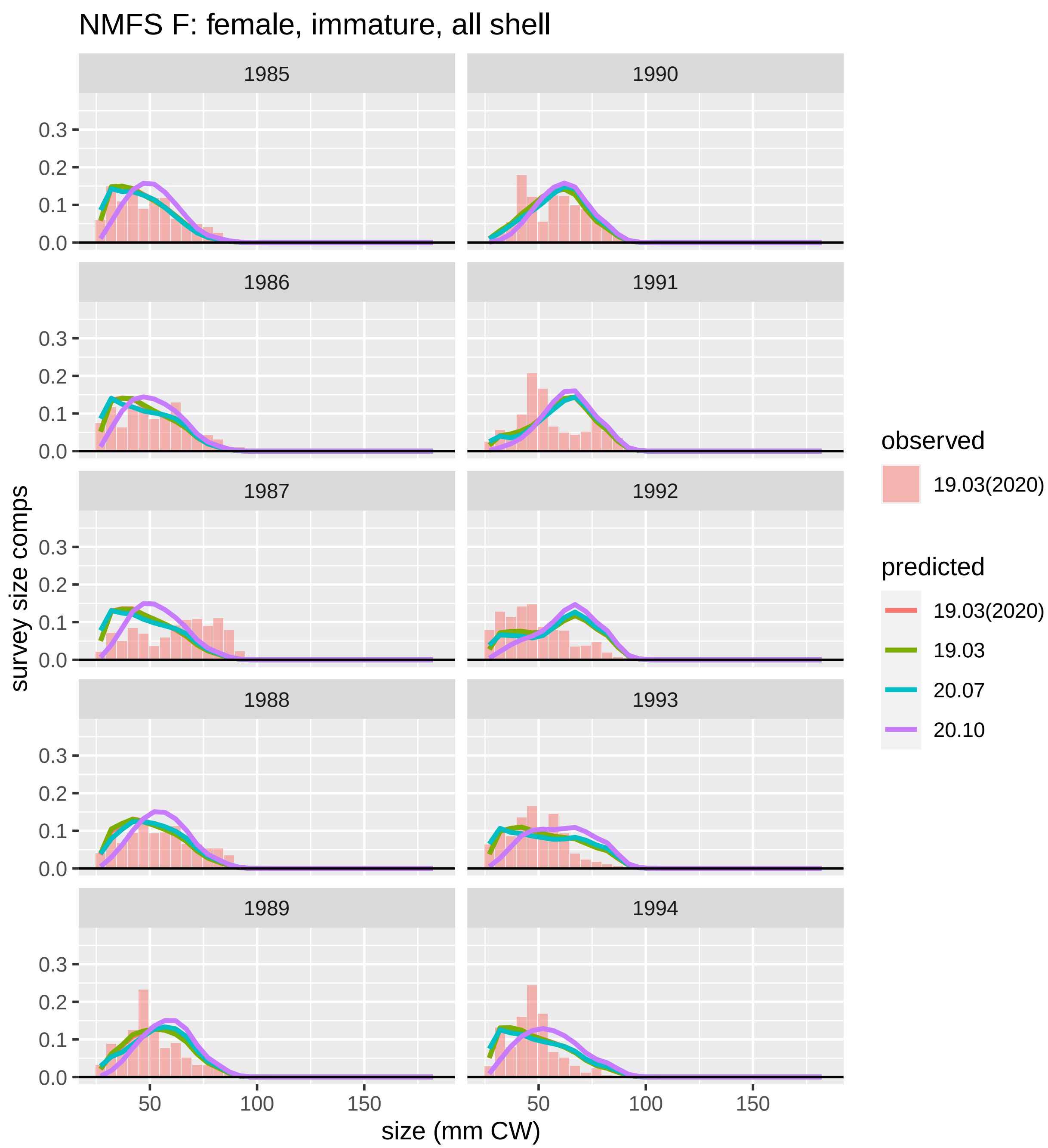


Figure 7: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 2 of 5.

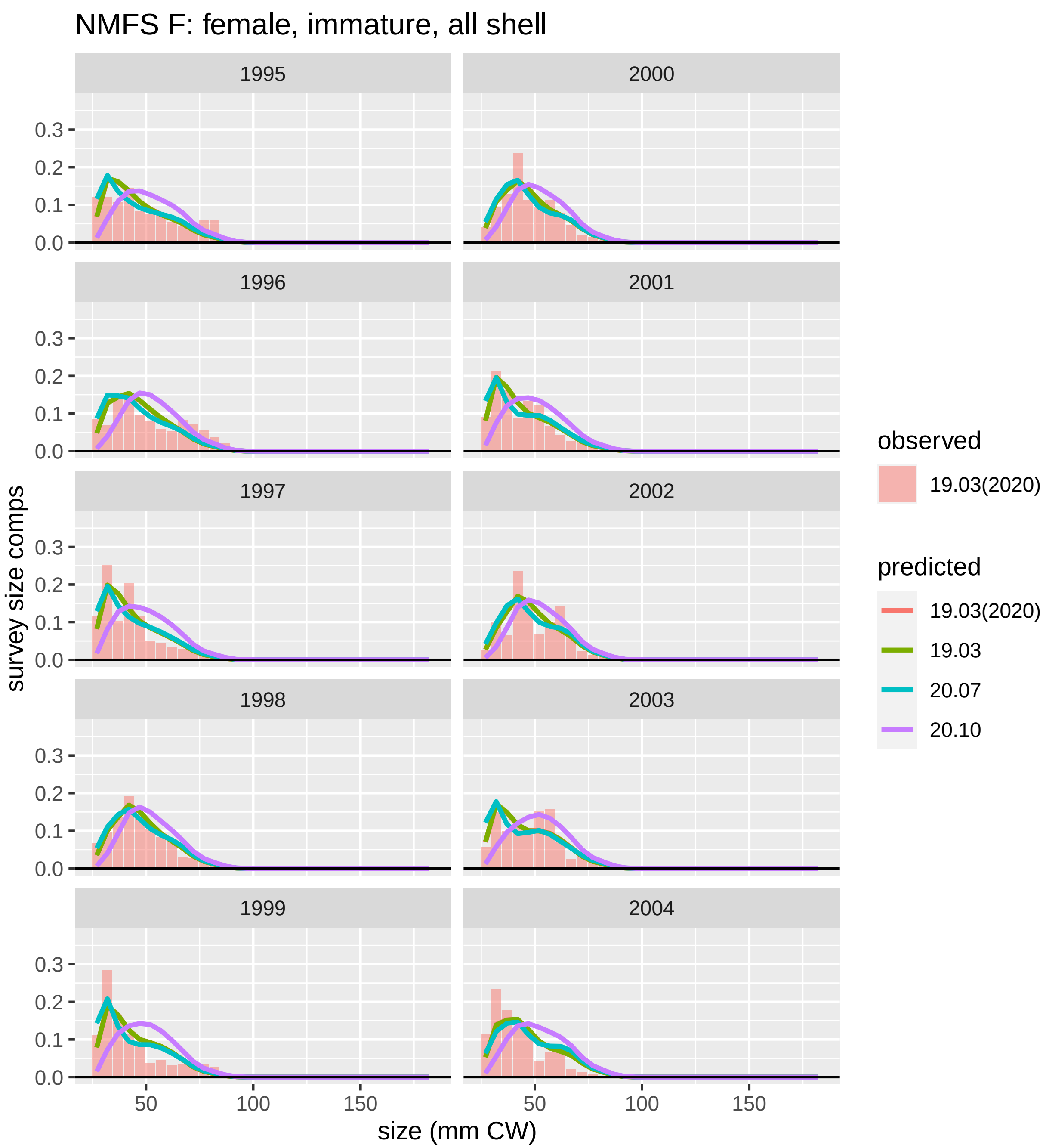


Figure 8: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 3 of 5.

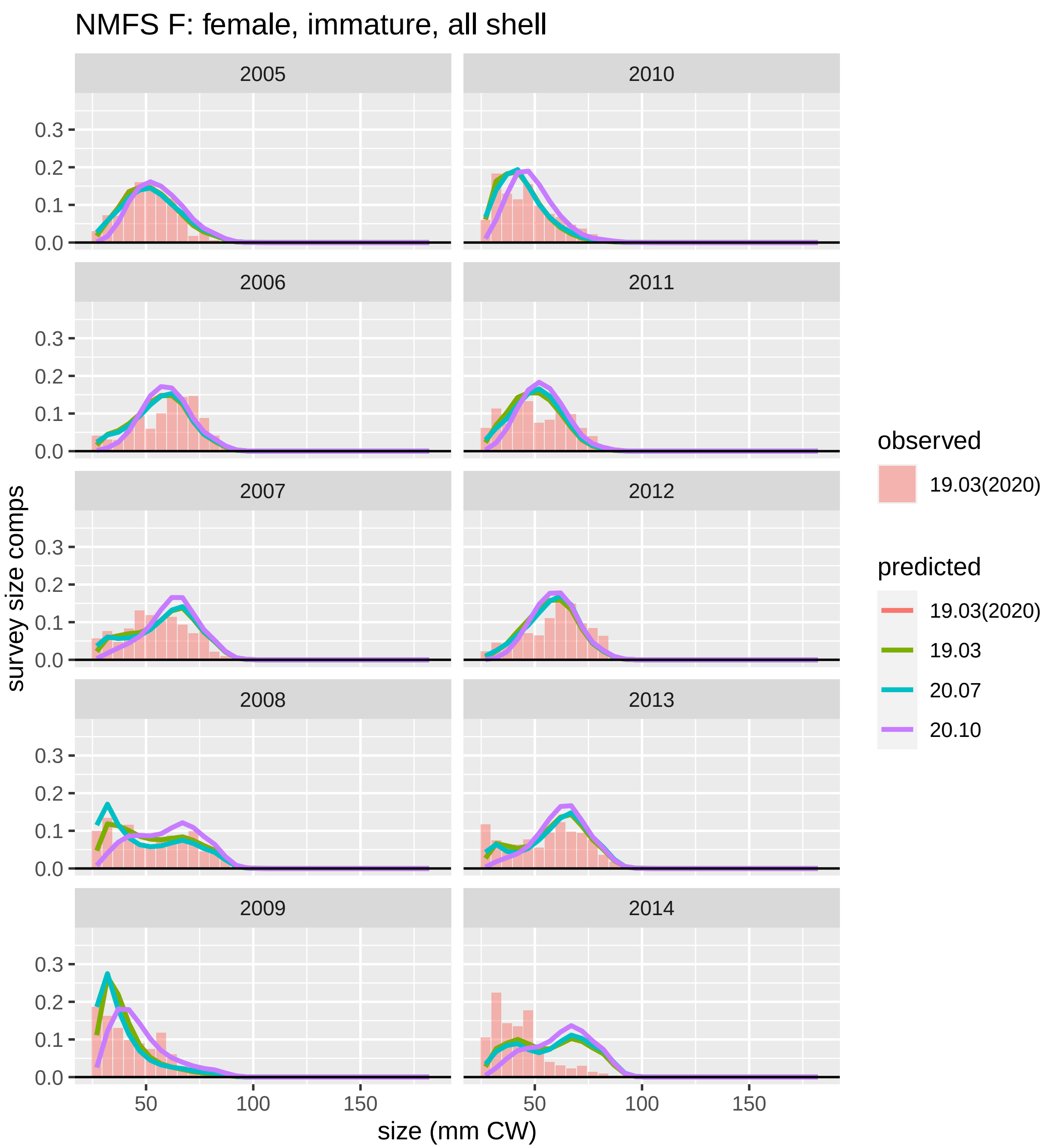


Figure 9: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 4 of 5.

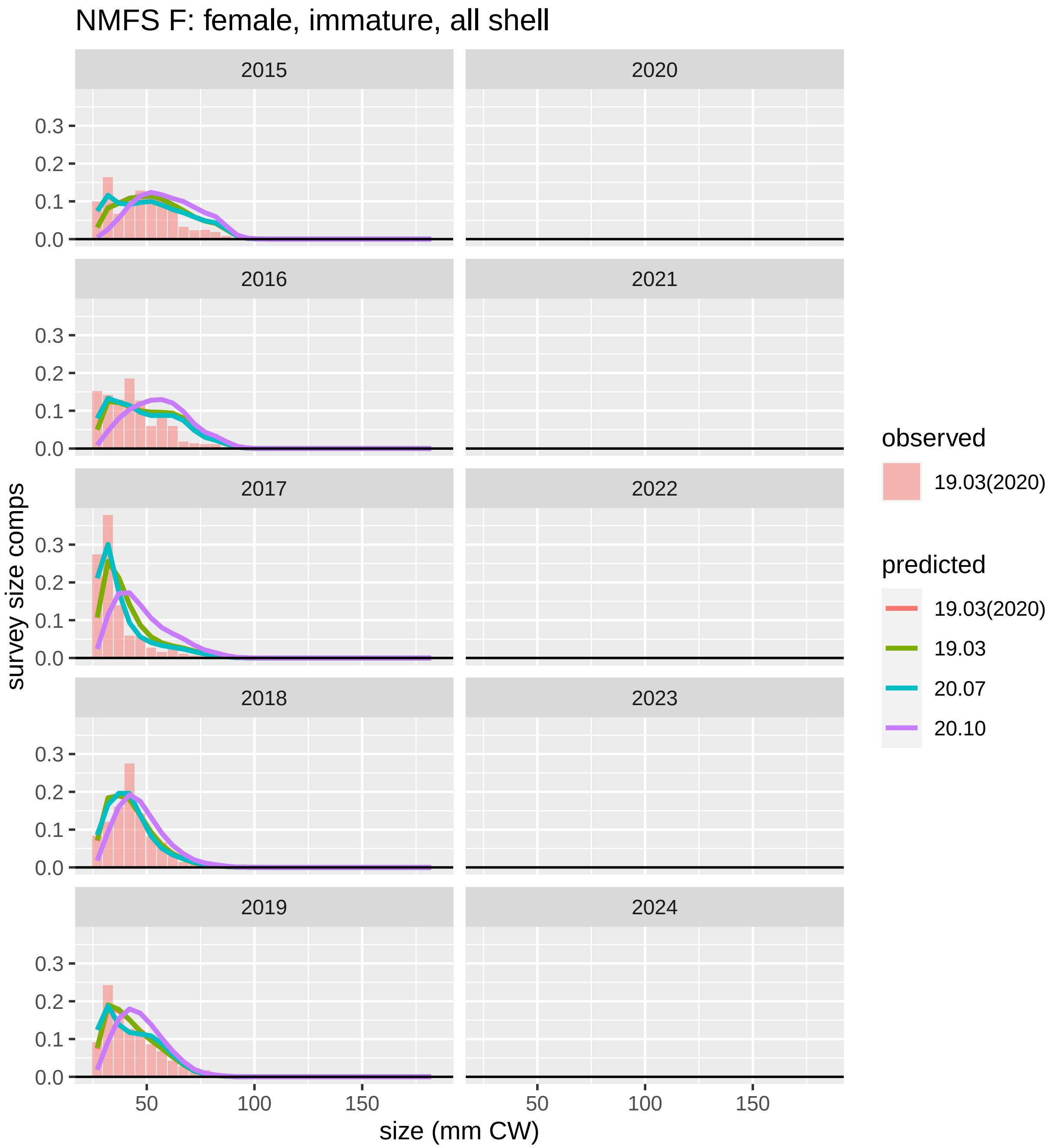


Figure 10: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 5 of 5.

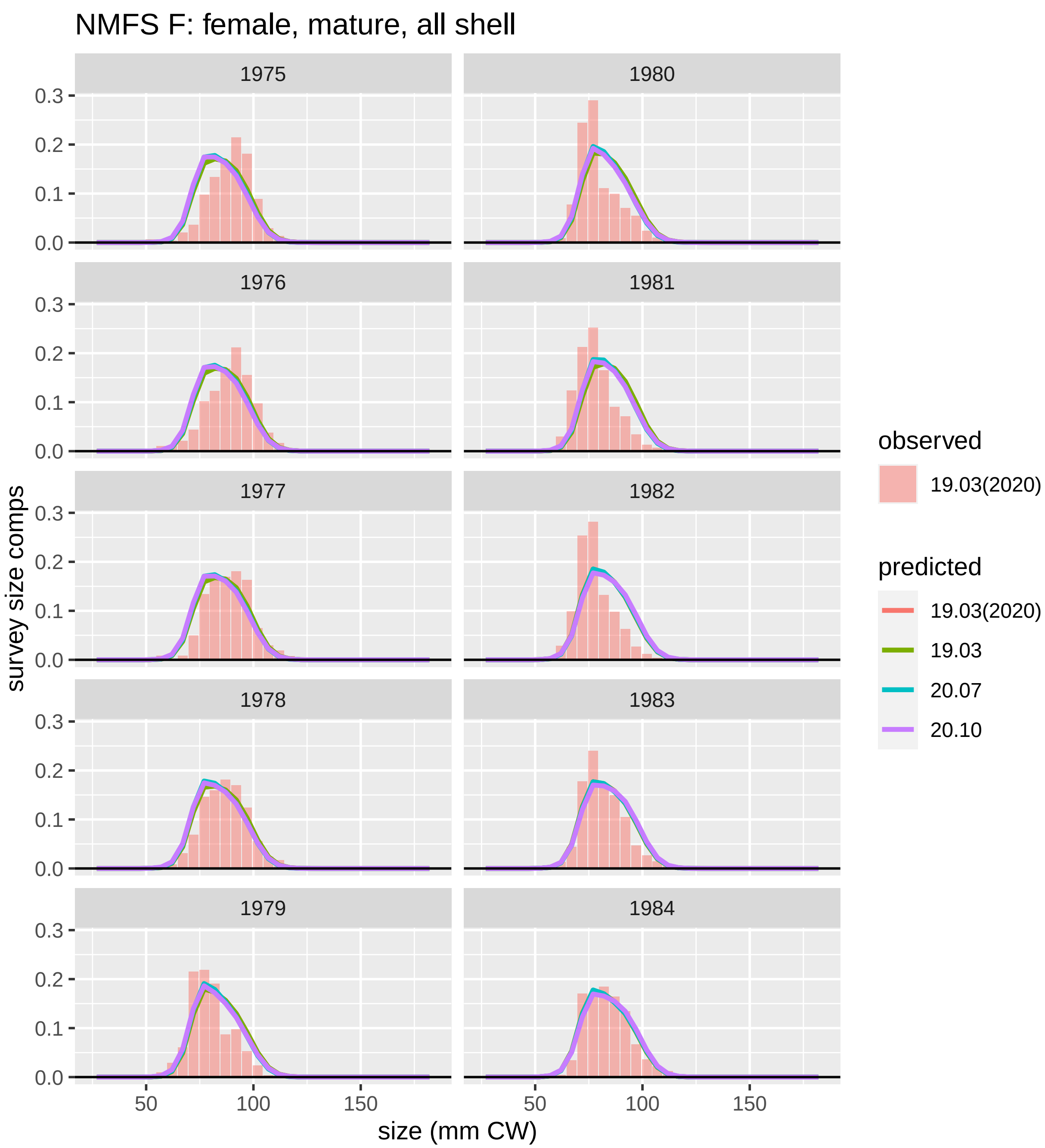


Figure 11: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 1 of 5.

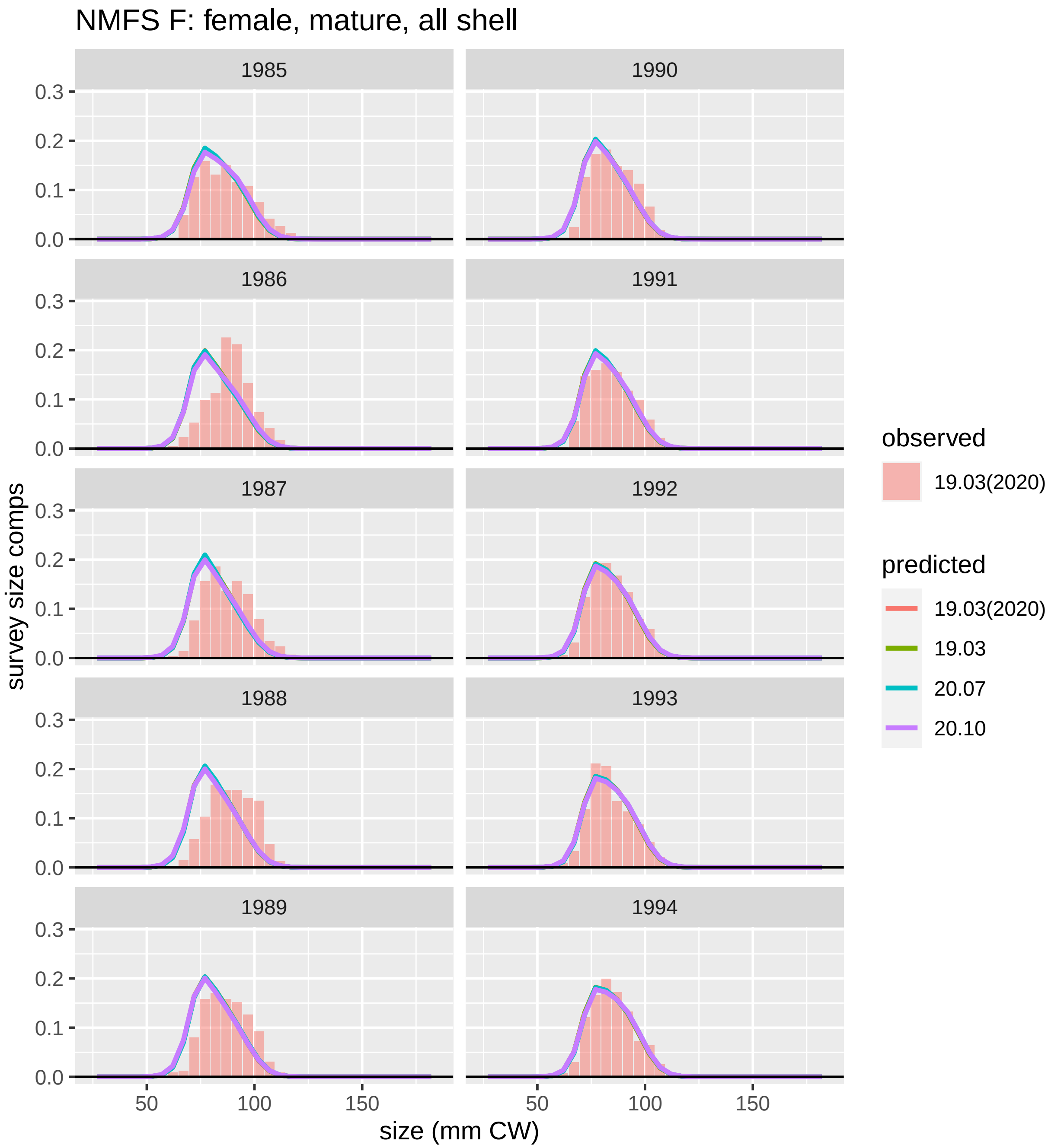


Figure 12: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 2 of 5.

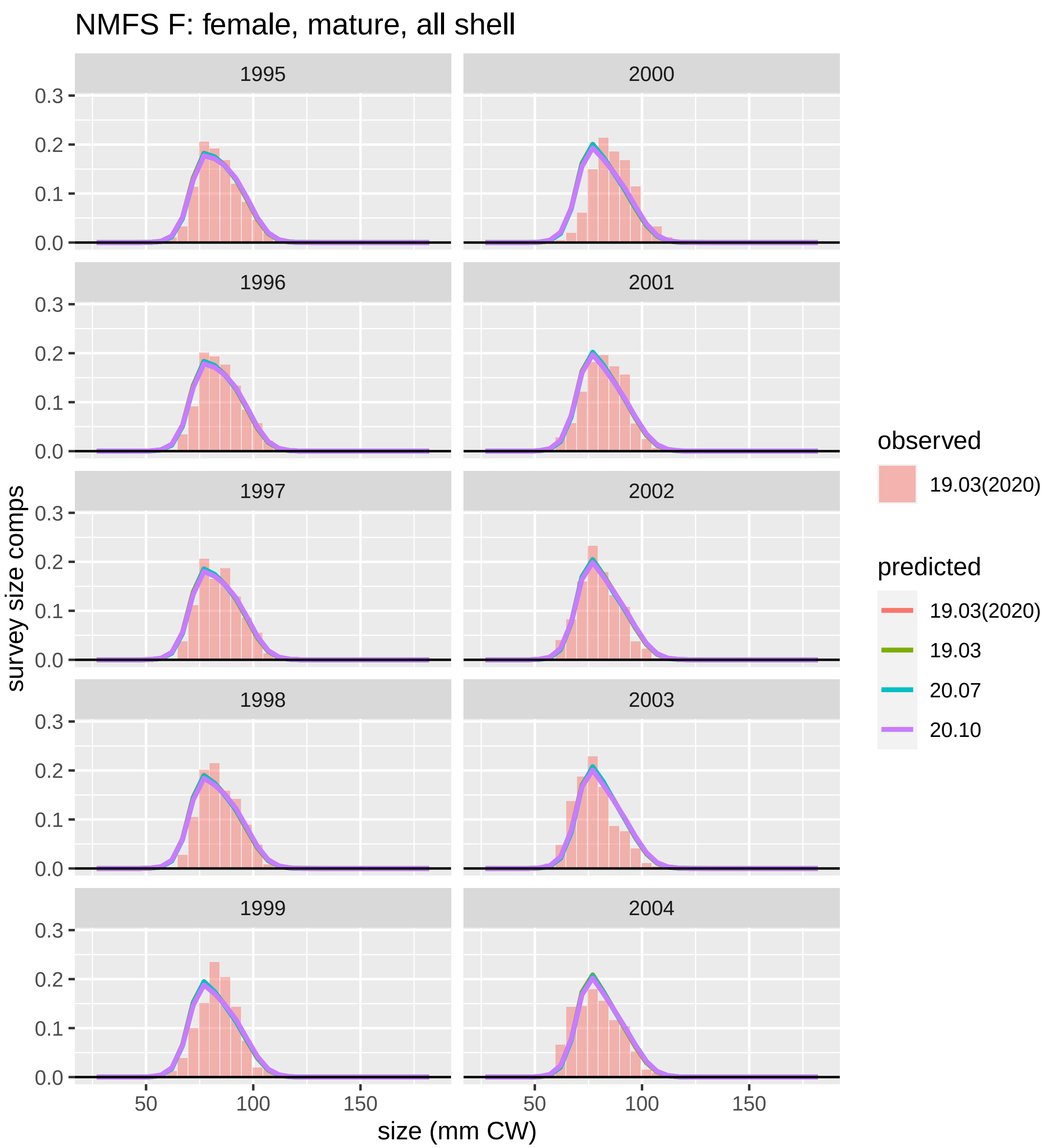


Figure 13: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 3 of 5.

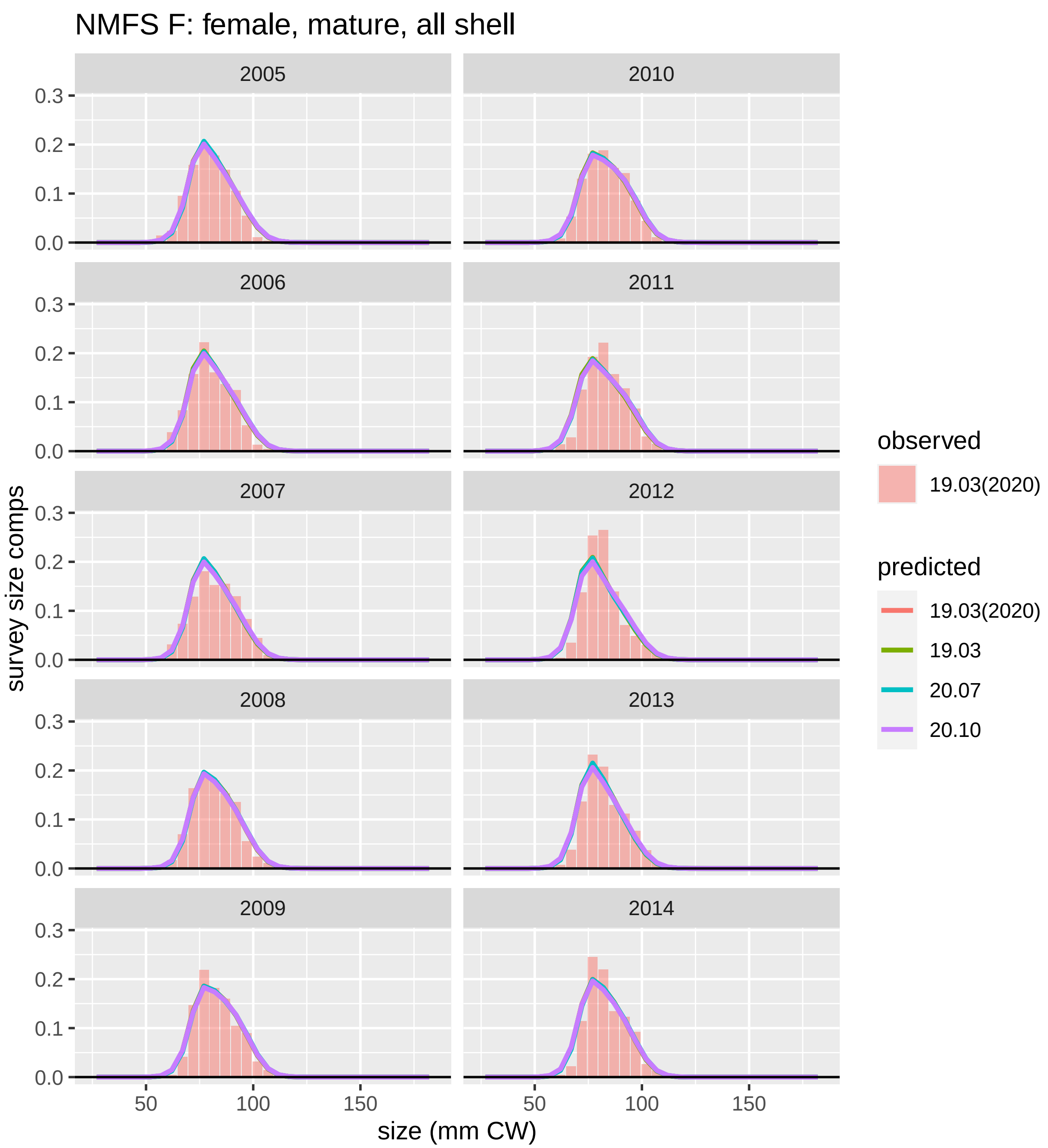


Figure 14: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 4 of 5.

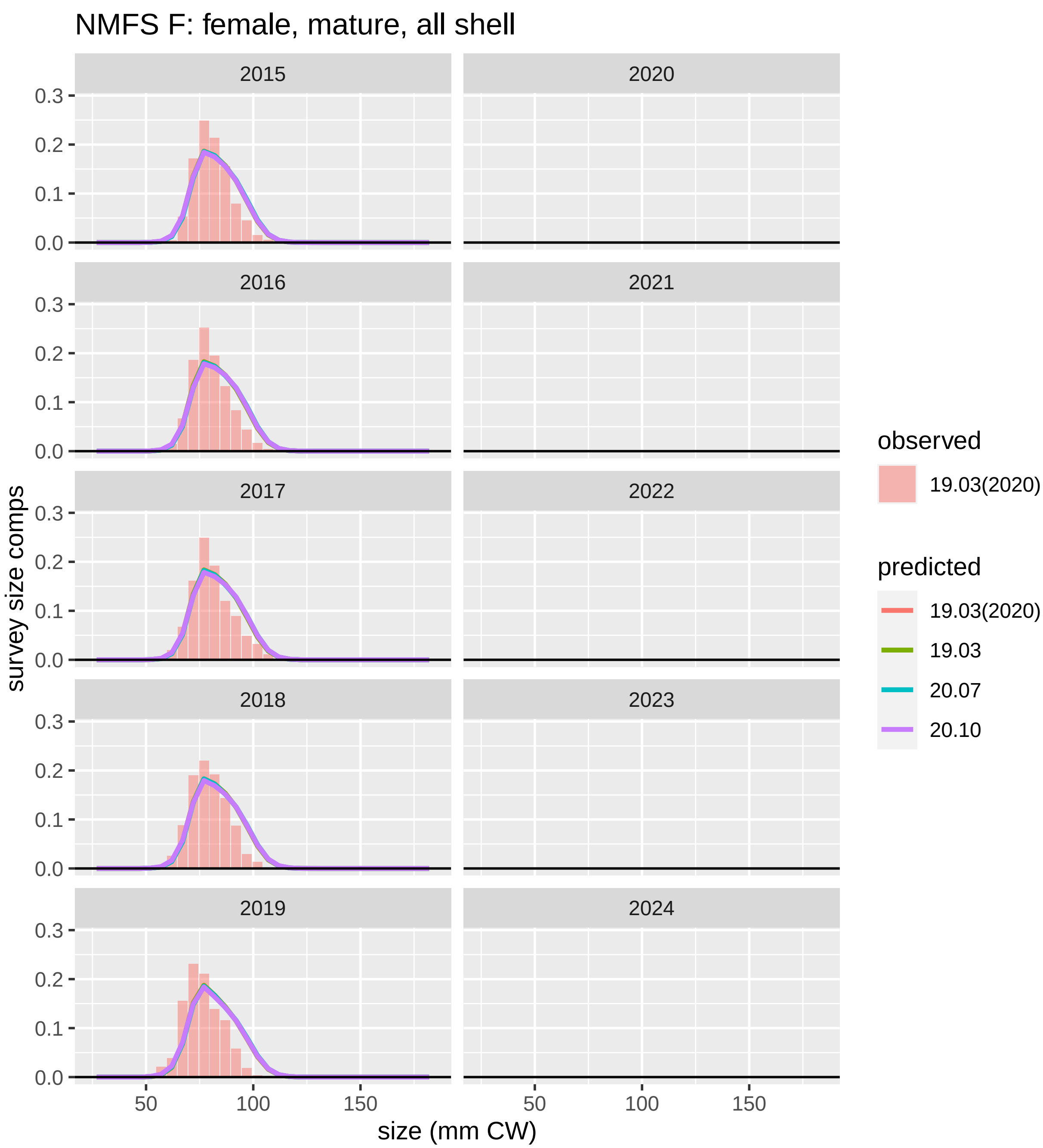


Figure 15: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 5 of 5.

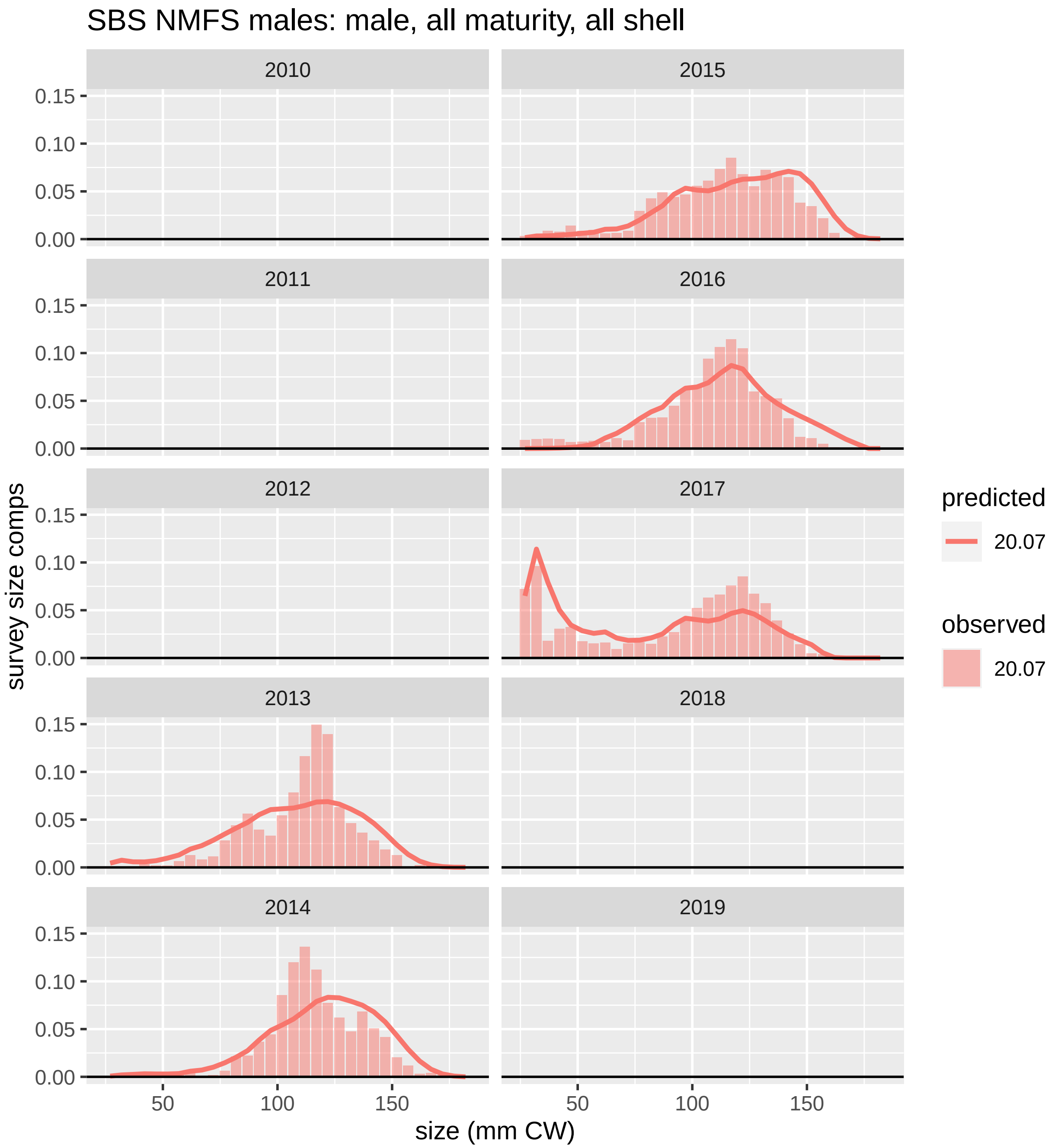


Figure 16: Comparison of observed and predicted male, all maturity, all shell survey size comps for SBS NMFS males. Page 1 of 1.

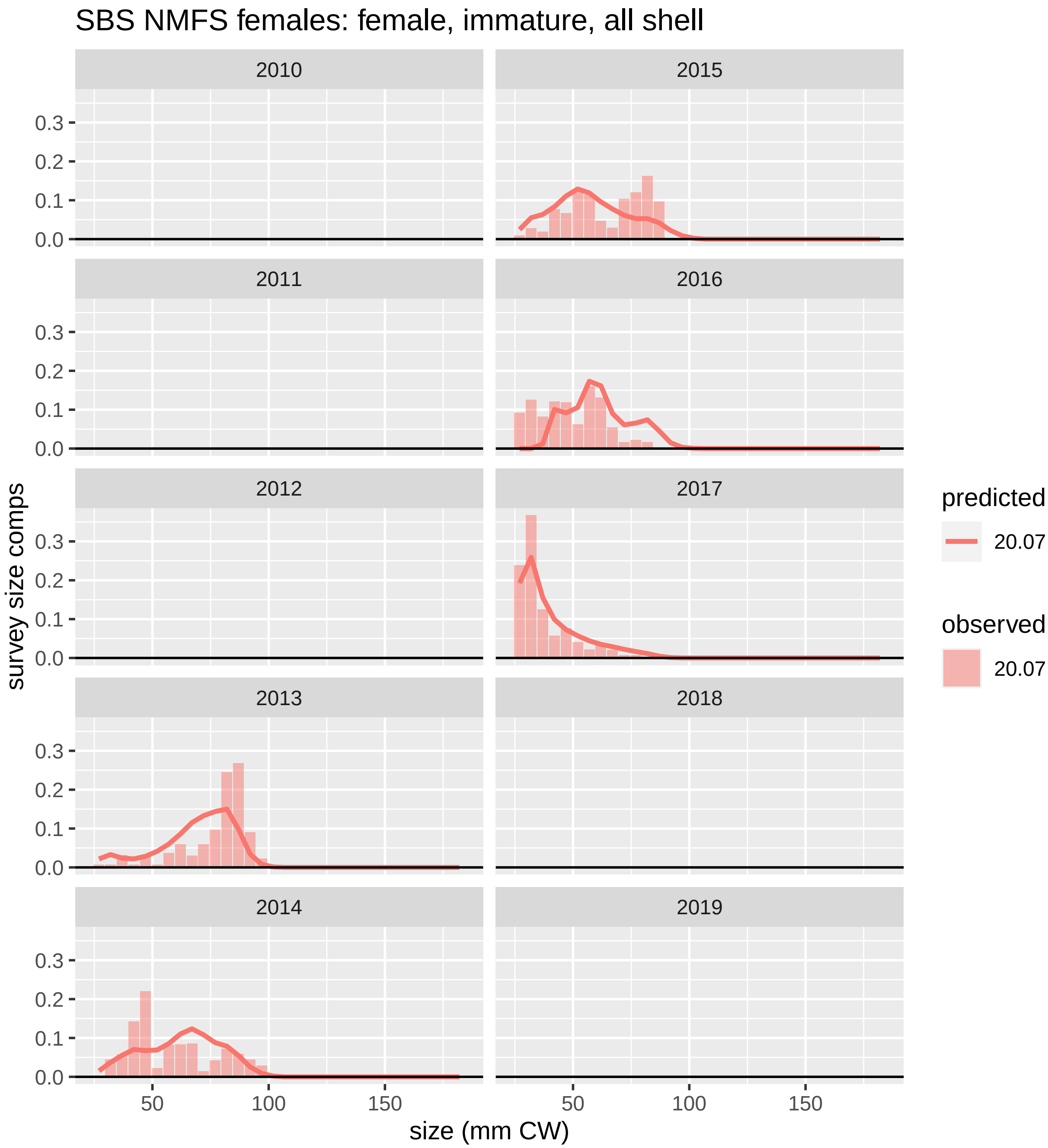


Figure 17: Comparison of observed and predicted female, immature, all shell survey size comps for SBS NMFS females. Page 1 of 1.

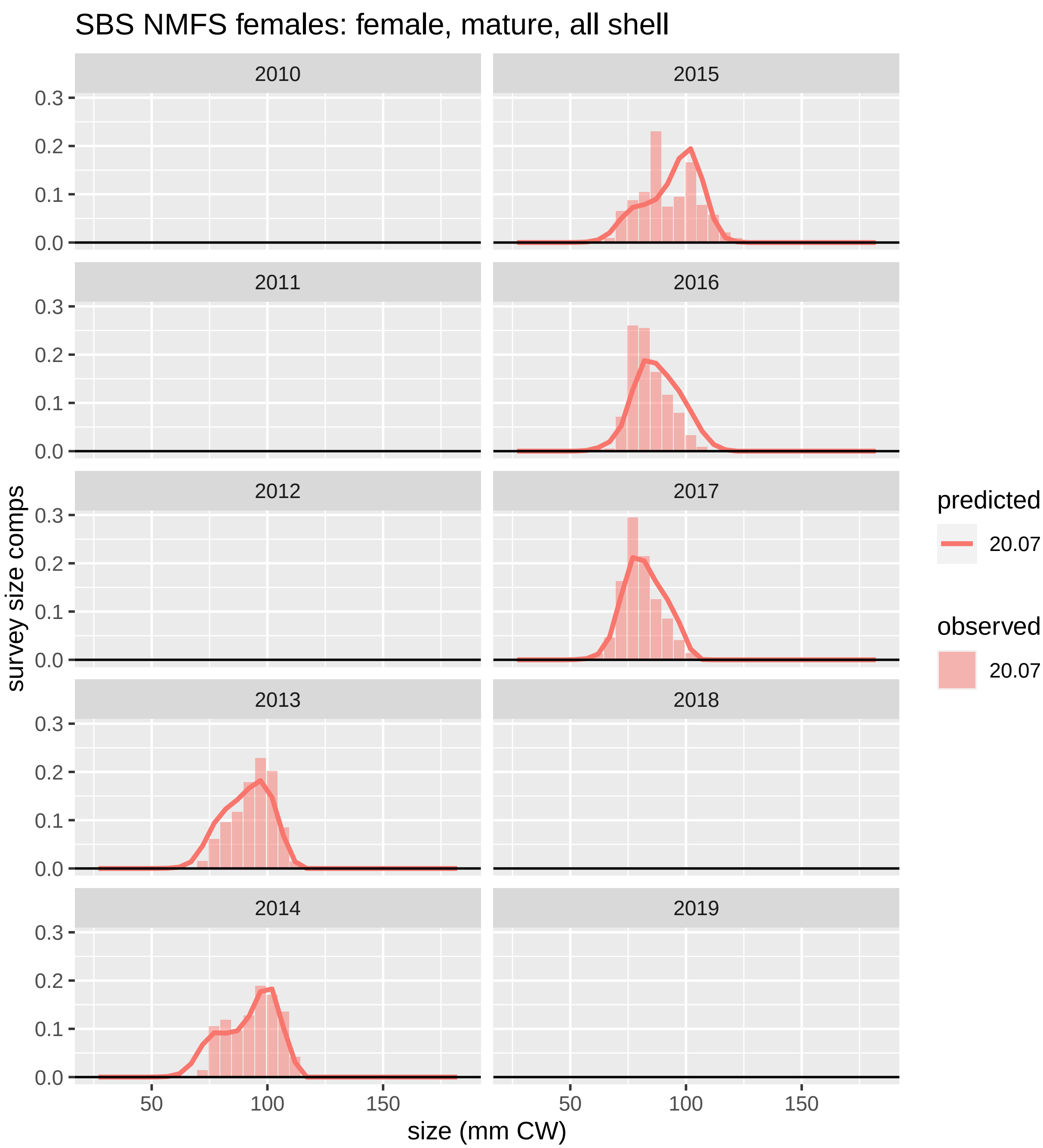


Figure 18: Comparison of observed and predicted female, mature, all shell survey size comps for SBS NMFS females. Page 1 of 1.

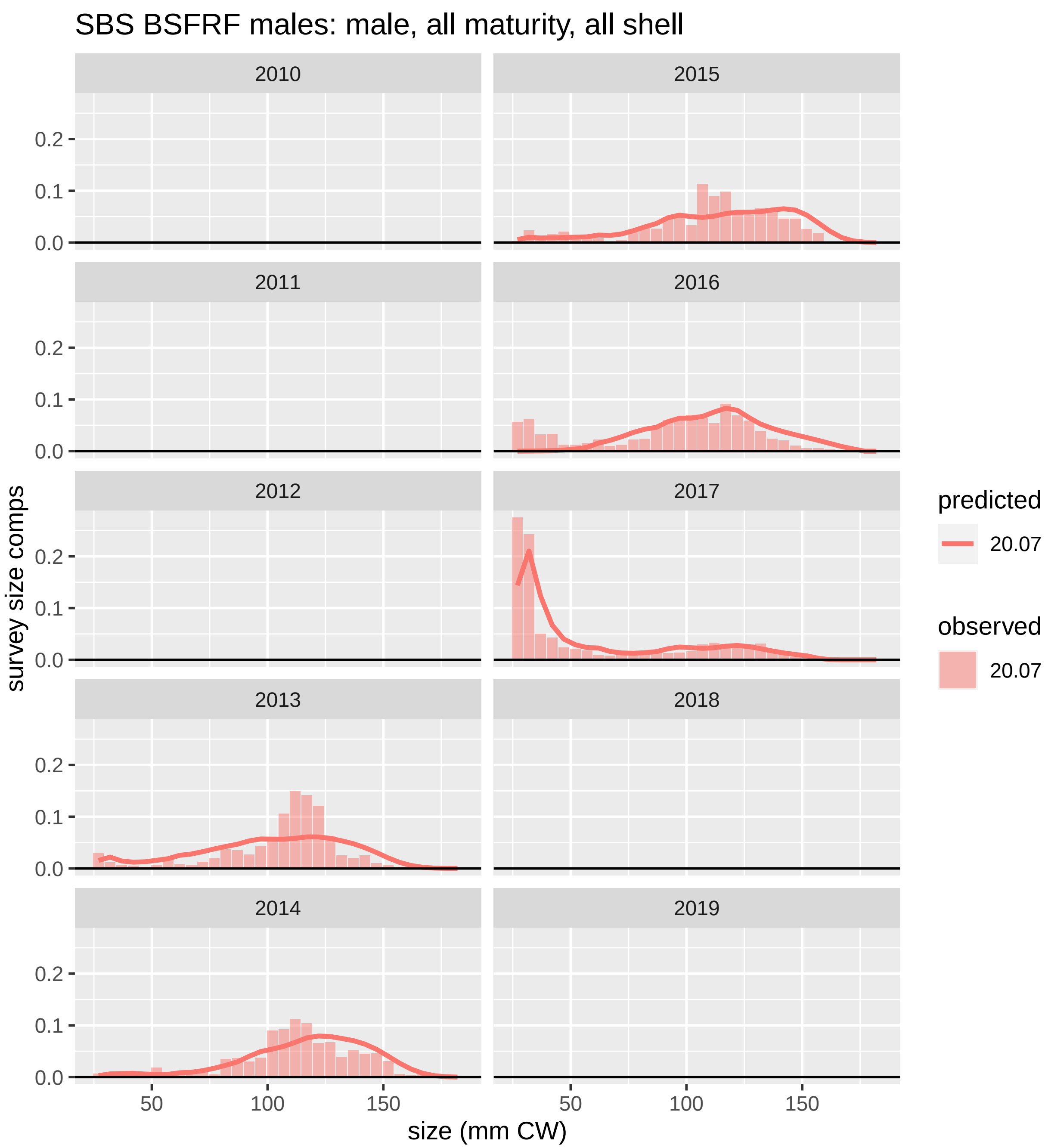


Figure 19: Comparison of observed and predicted male, all maturity, all shell survey size comps for SBS BSFRF males. Page 1 of 1.

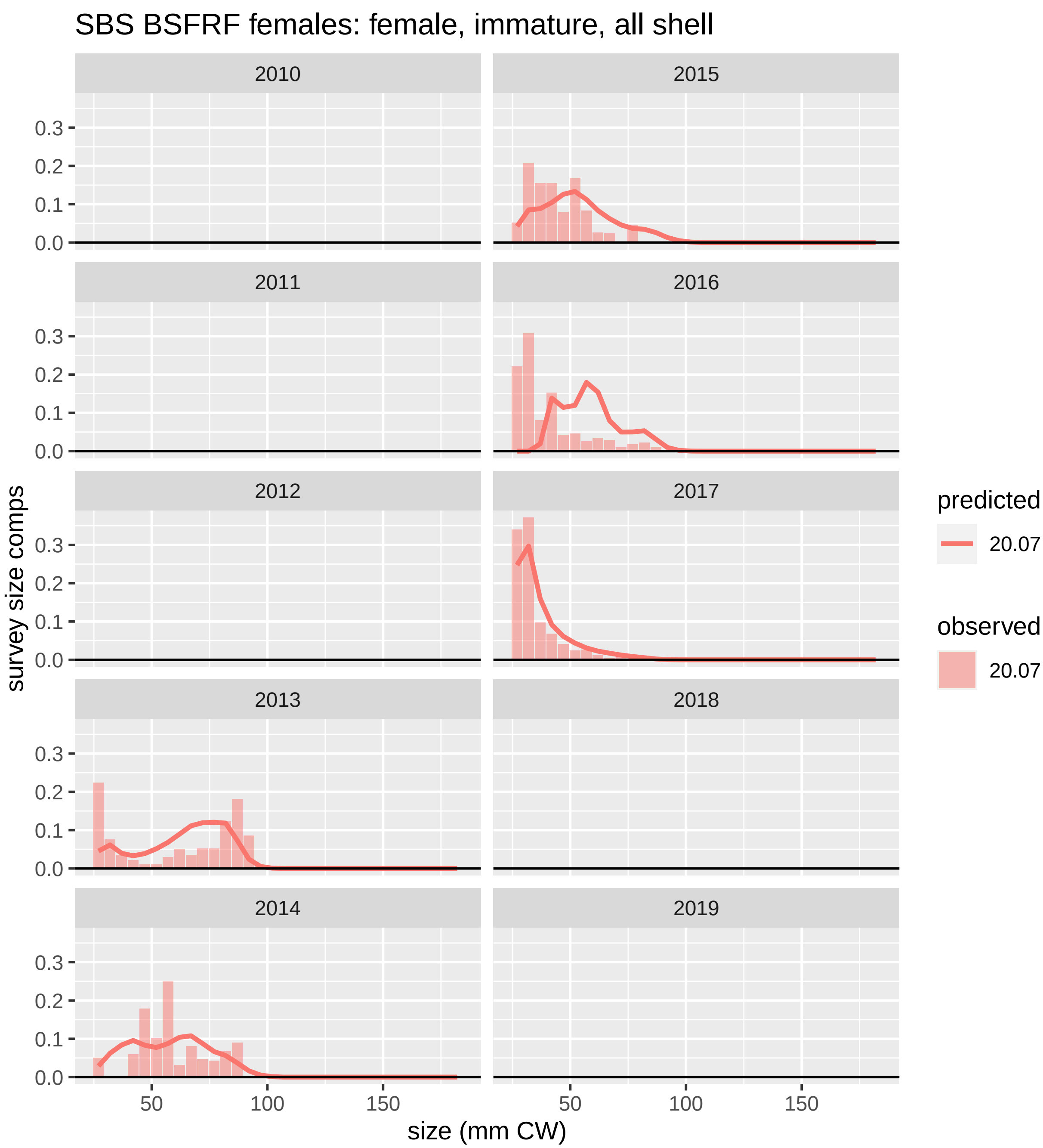


Figure 20: Comparison of observed and predicted female, immature, all shell survey size comps for SBS BSFRF females. Page 1 of 1.

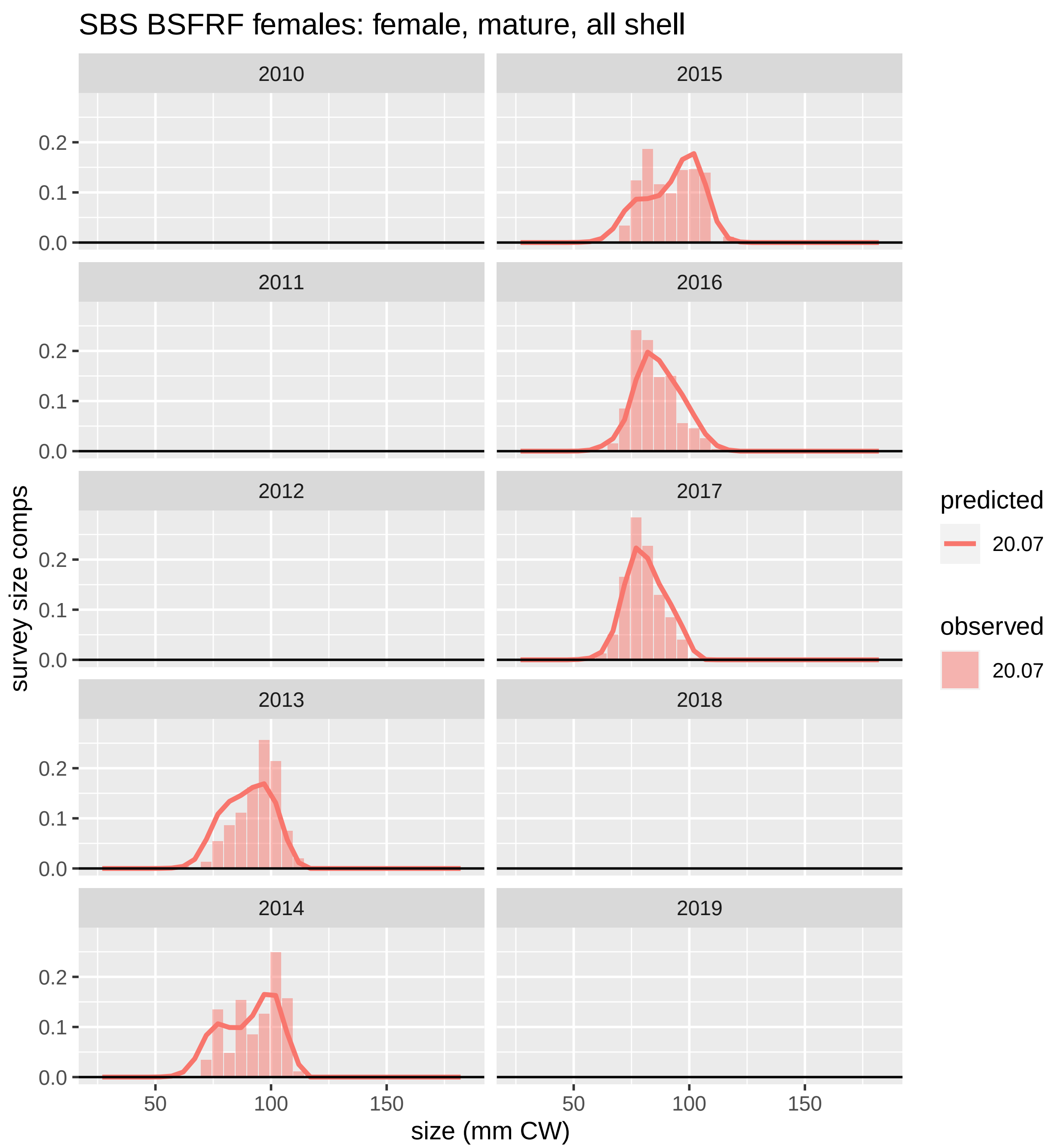


Figure 21: Comparison of observed and predicted female, mature, all shell survey size comps for SBS BSFRF females. Page 1 of 1.

Fishery retained catch size compositions

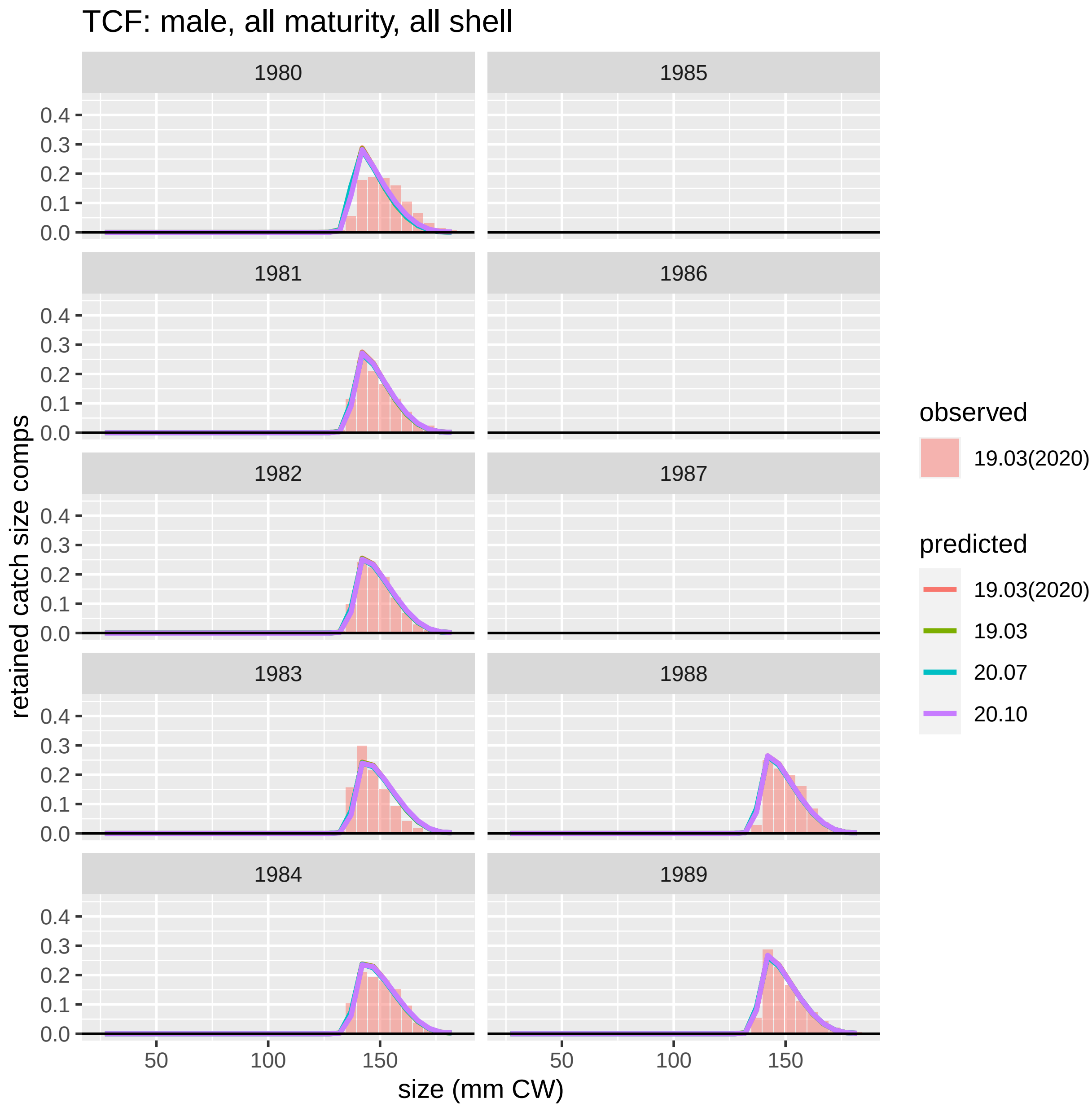


Figure 22: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 1 of 4.

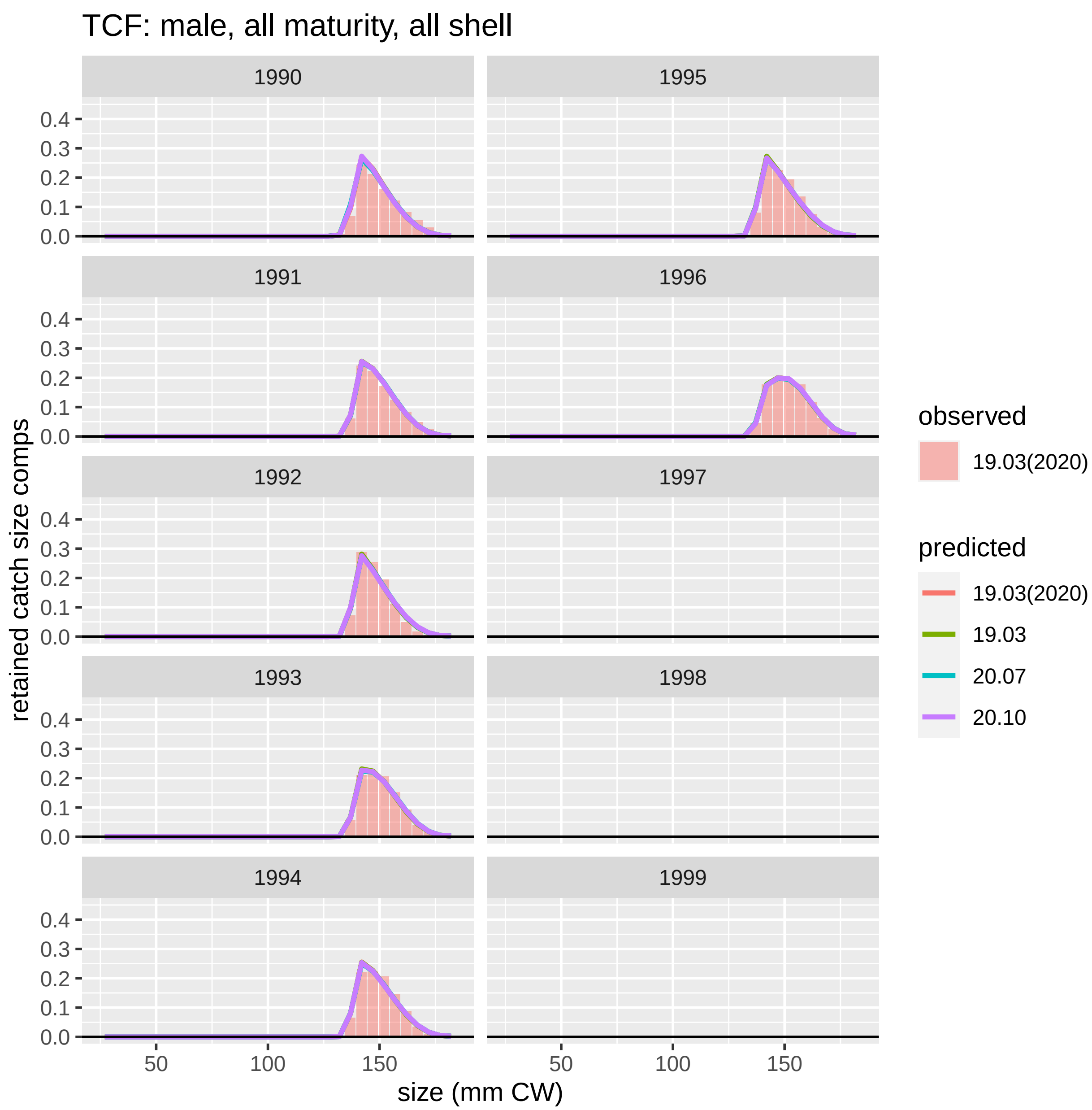


Figure 23: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 2 of 4.

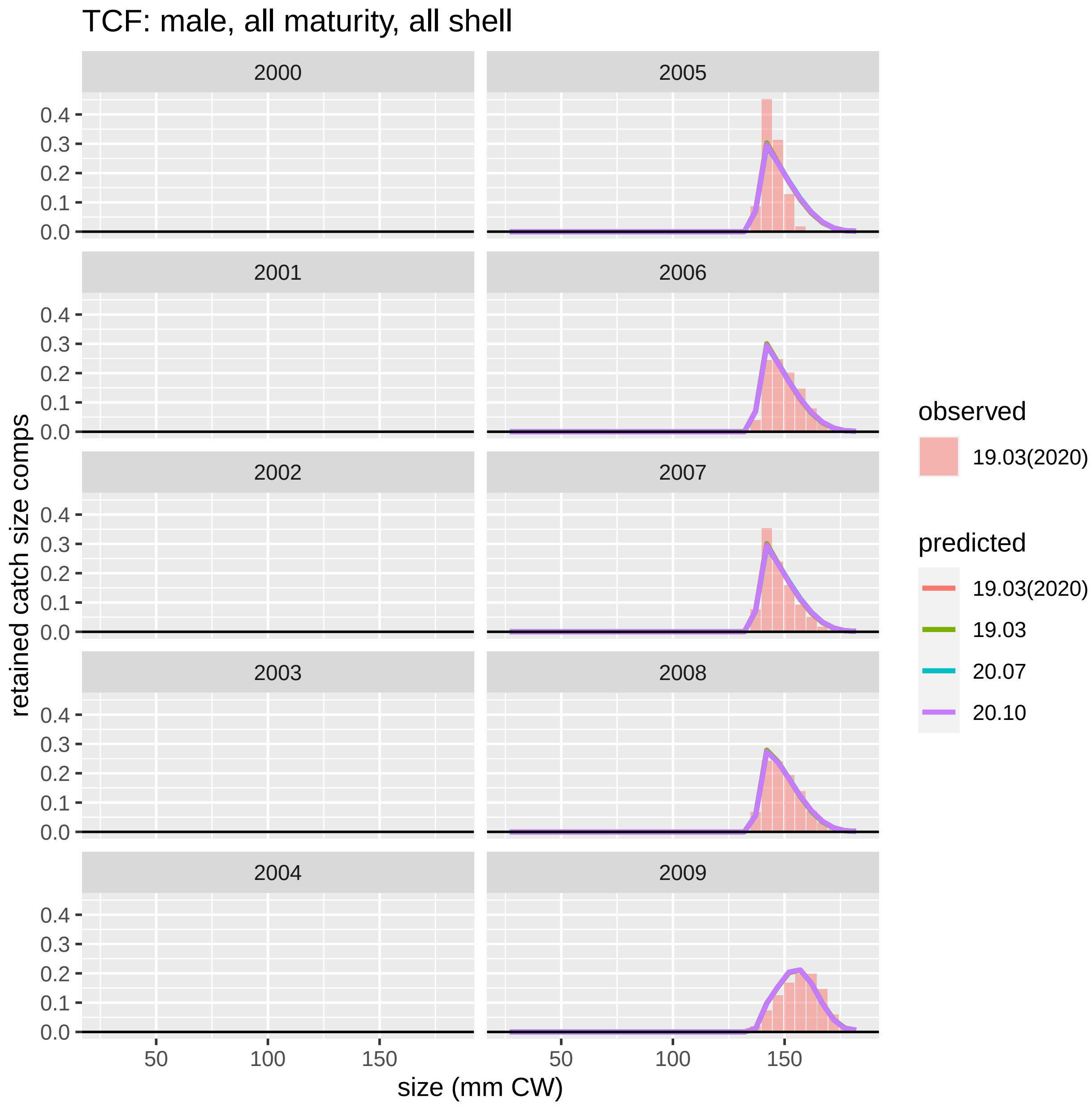


Figure 24: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 3 of 4.

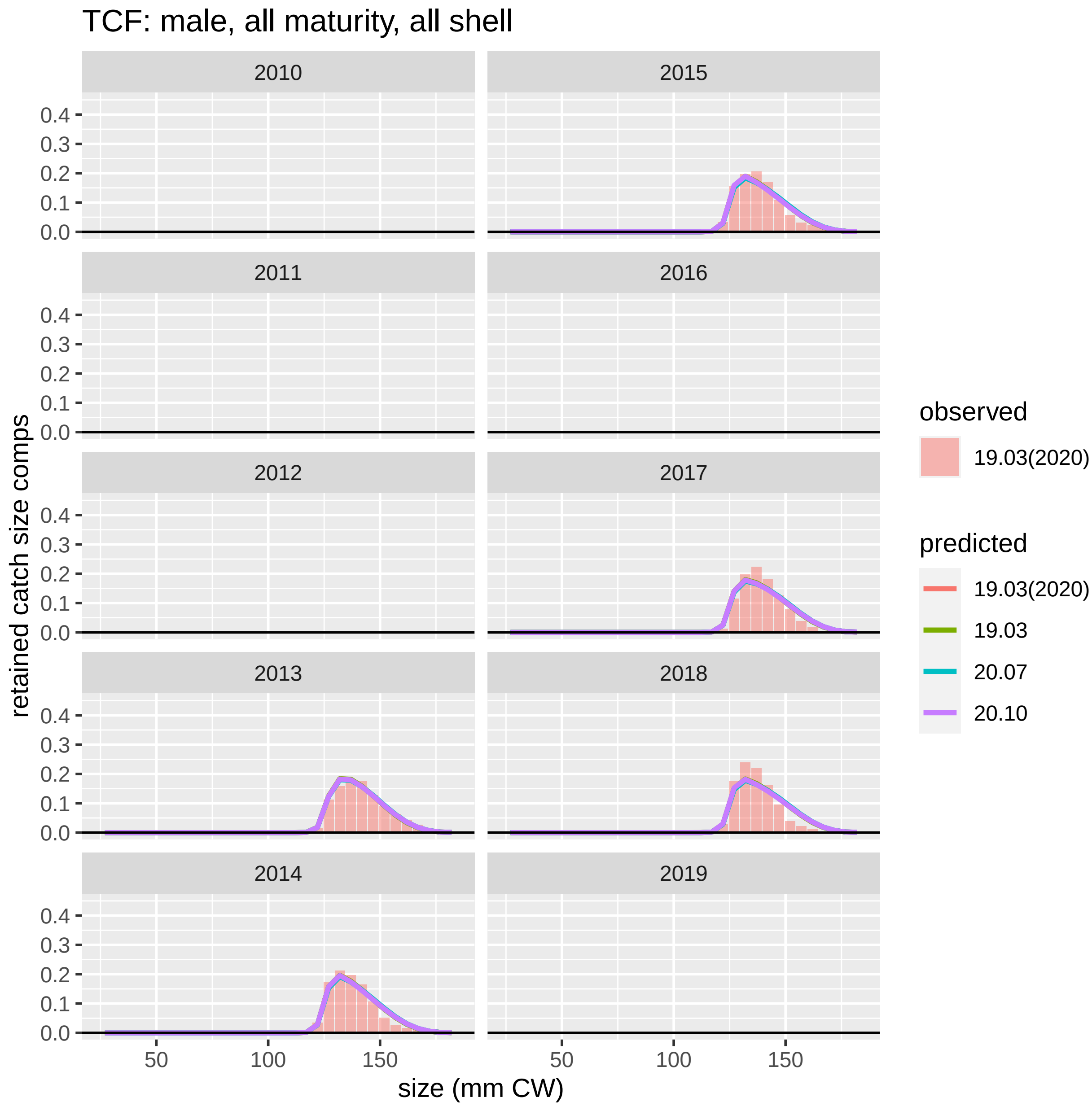


Figure 25: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 4 of 4.

Fishery total catch size compositions

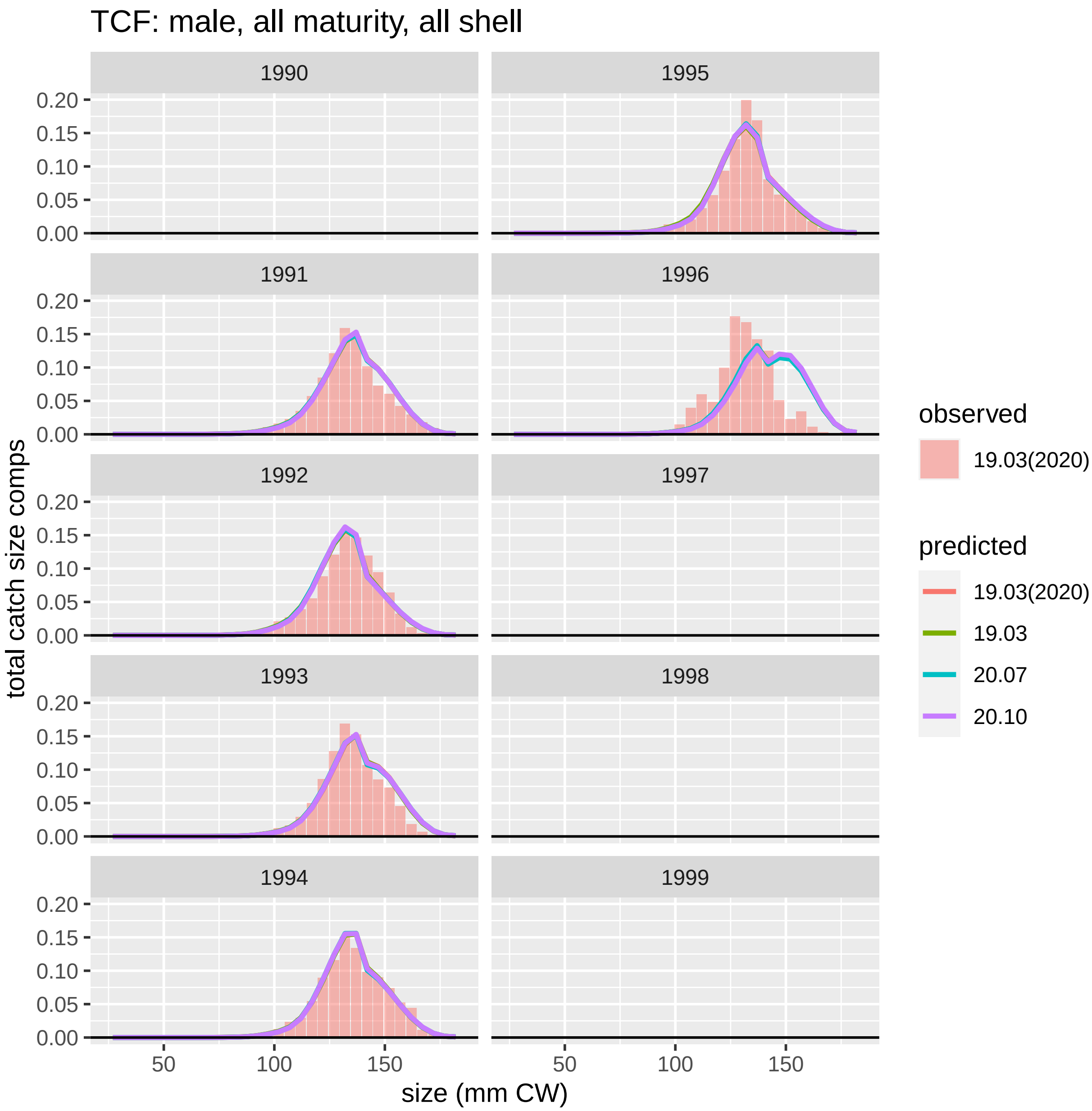


Figure 26: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

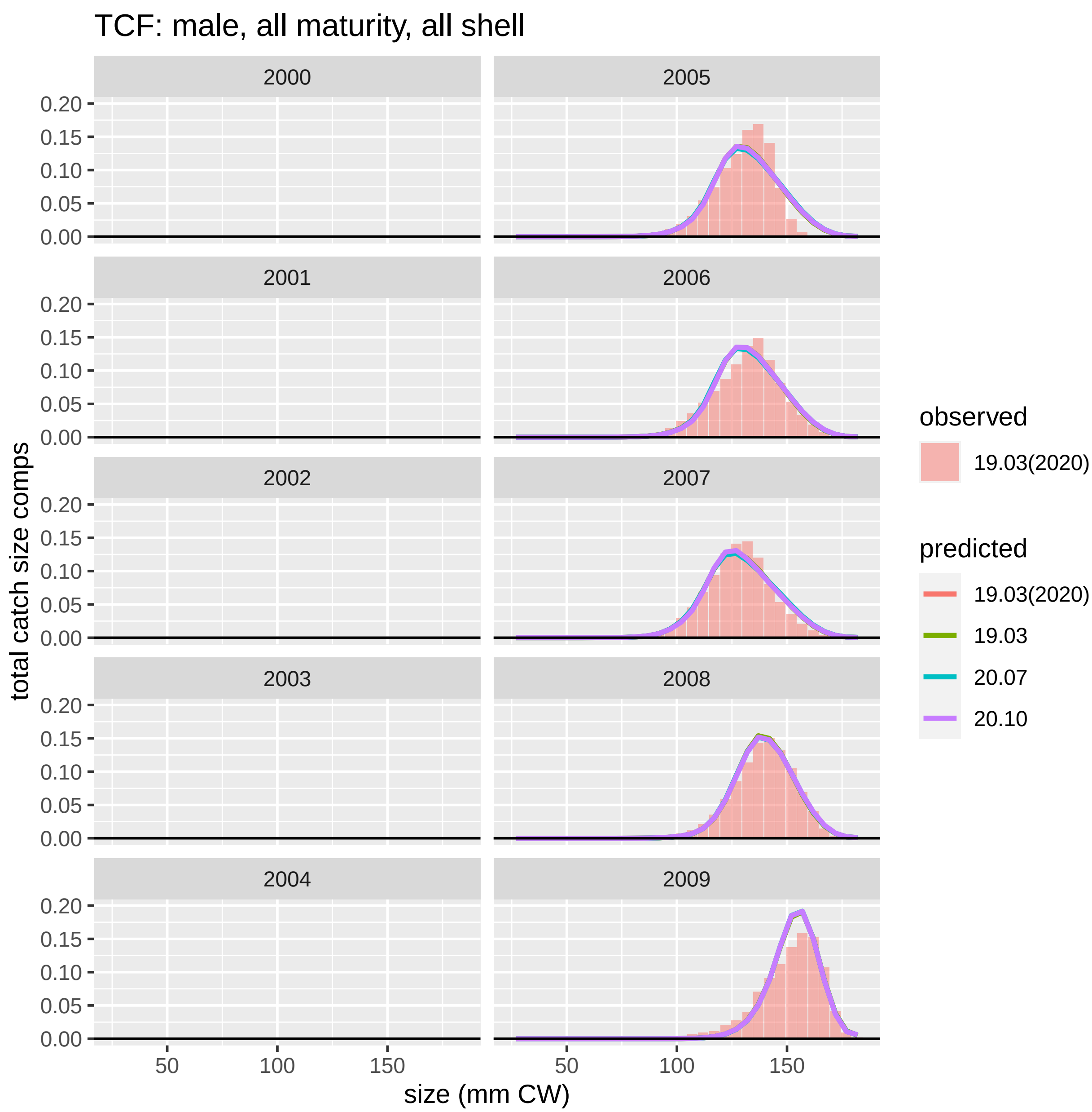


Figure 27: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

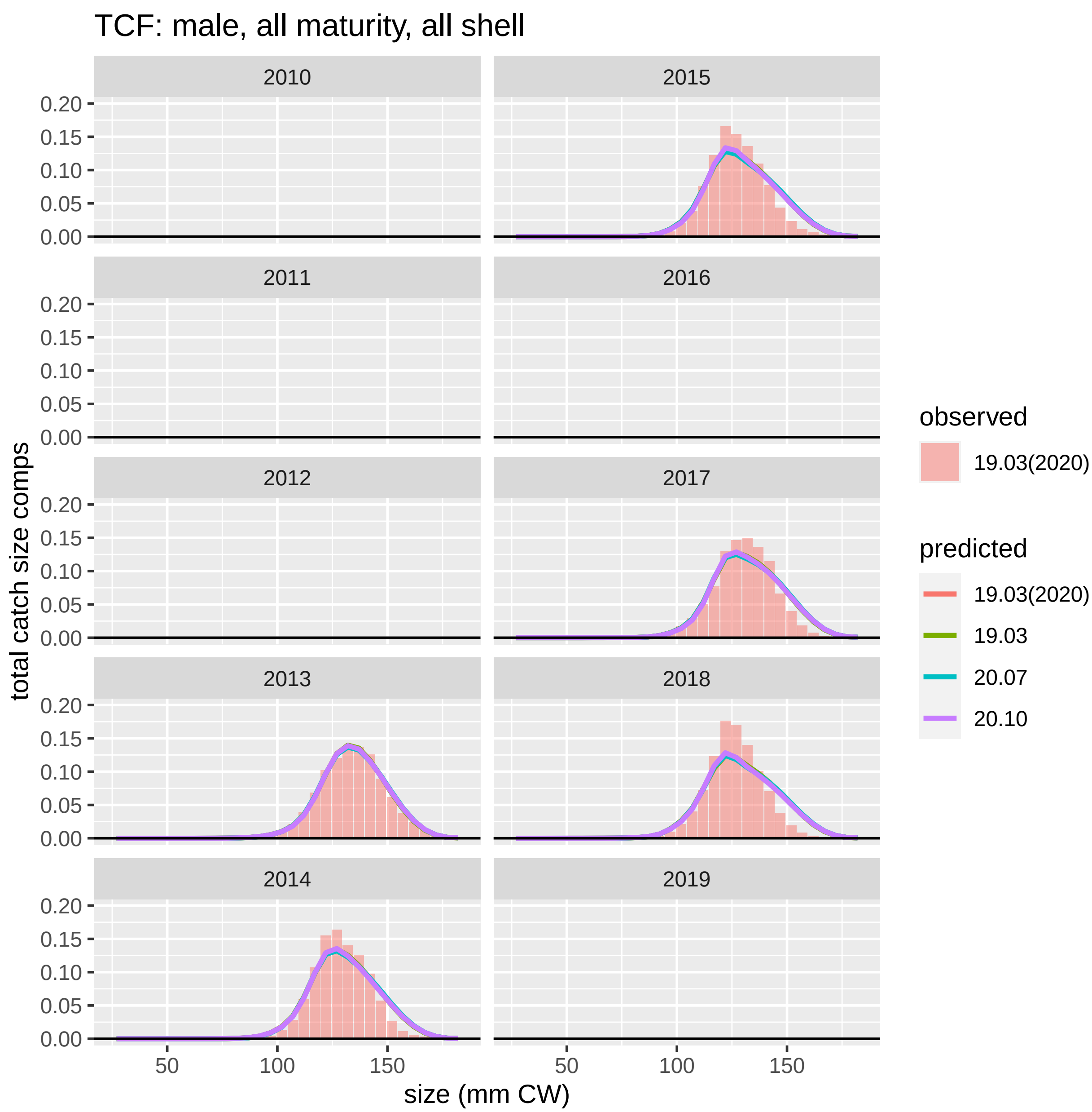


Figure 28: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

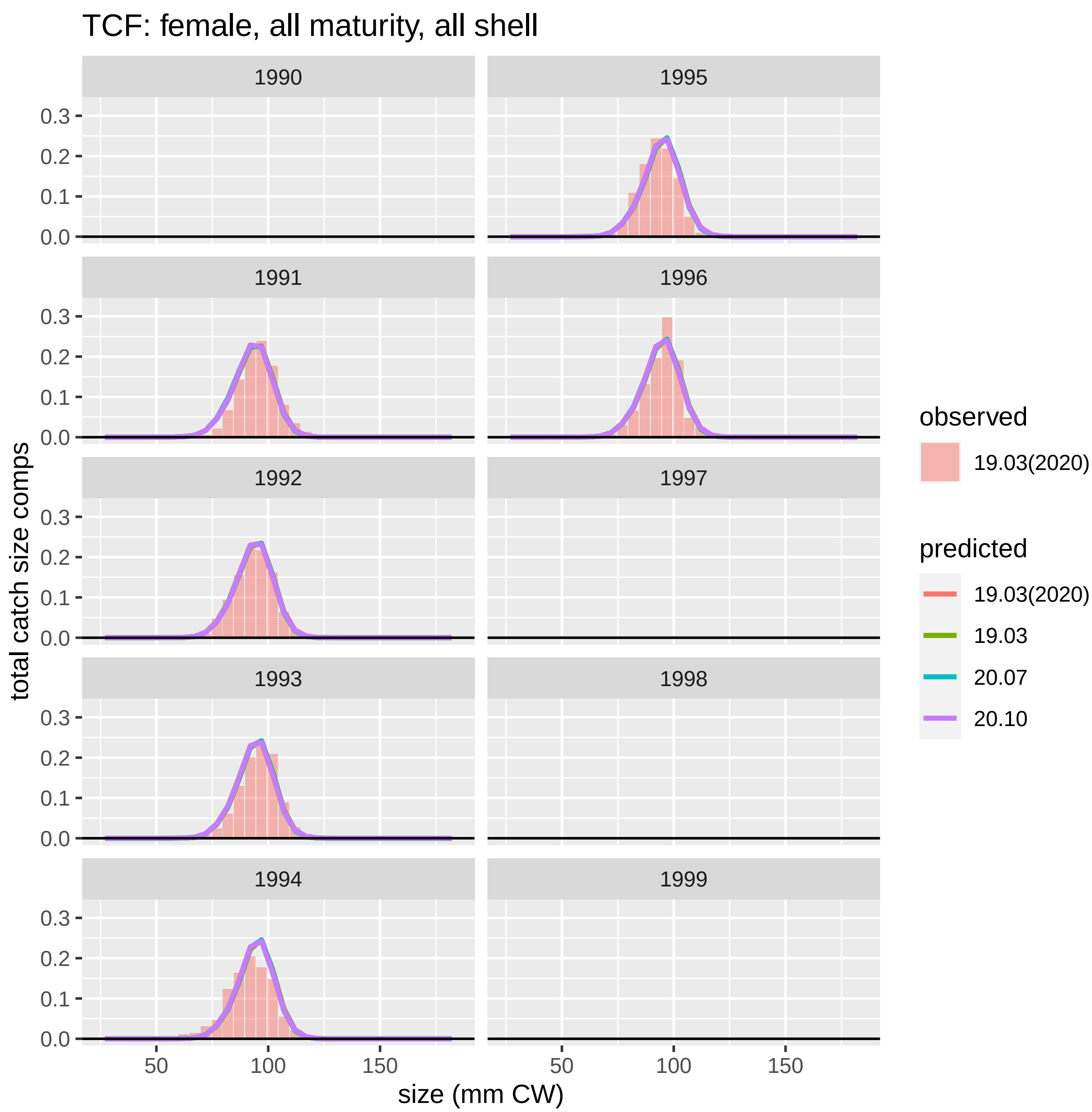


Figure 29: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

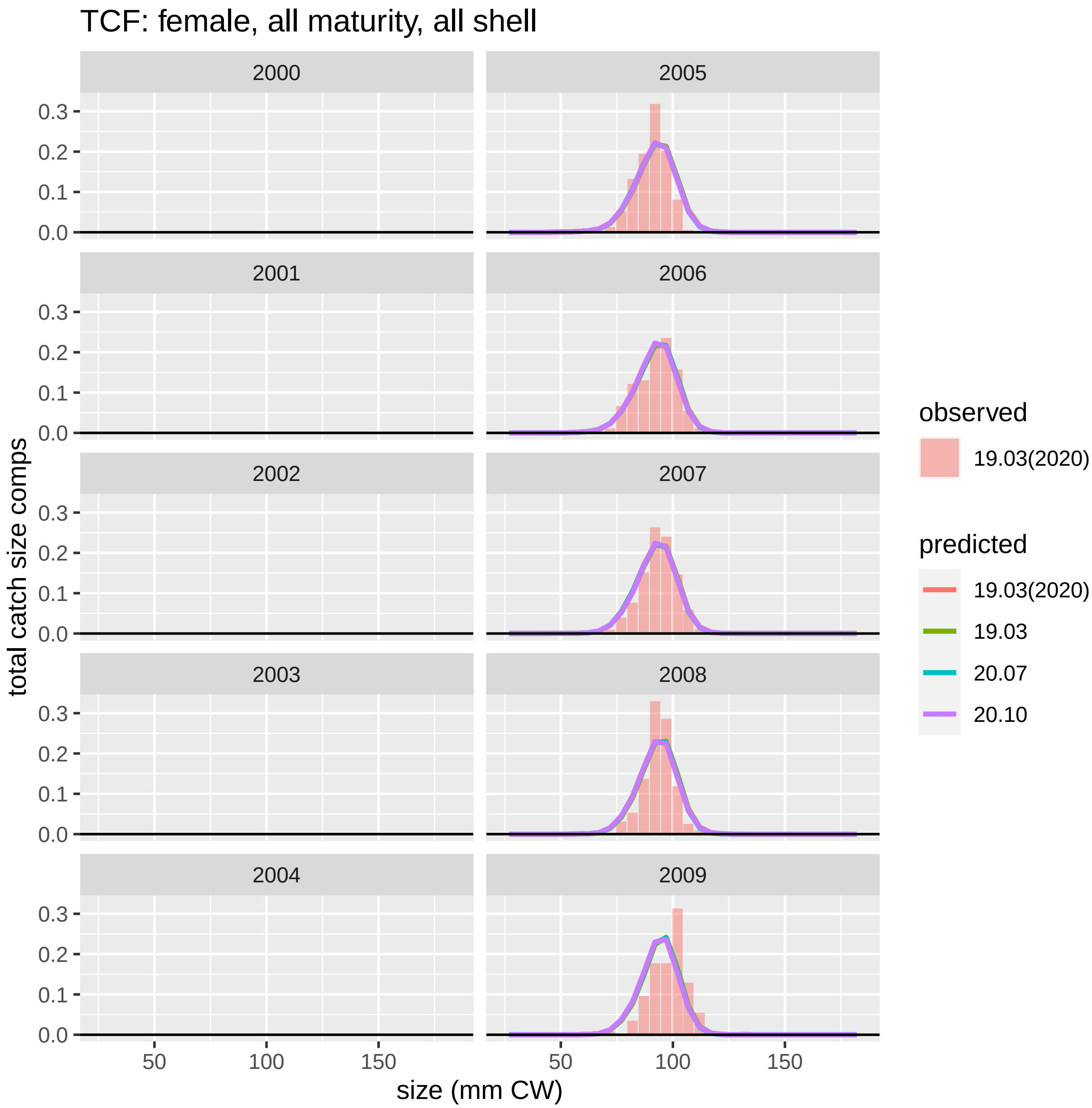


Figure 30: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

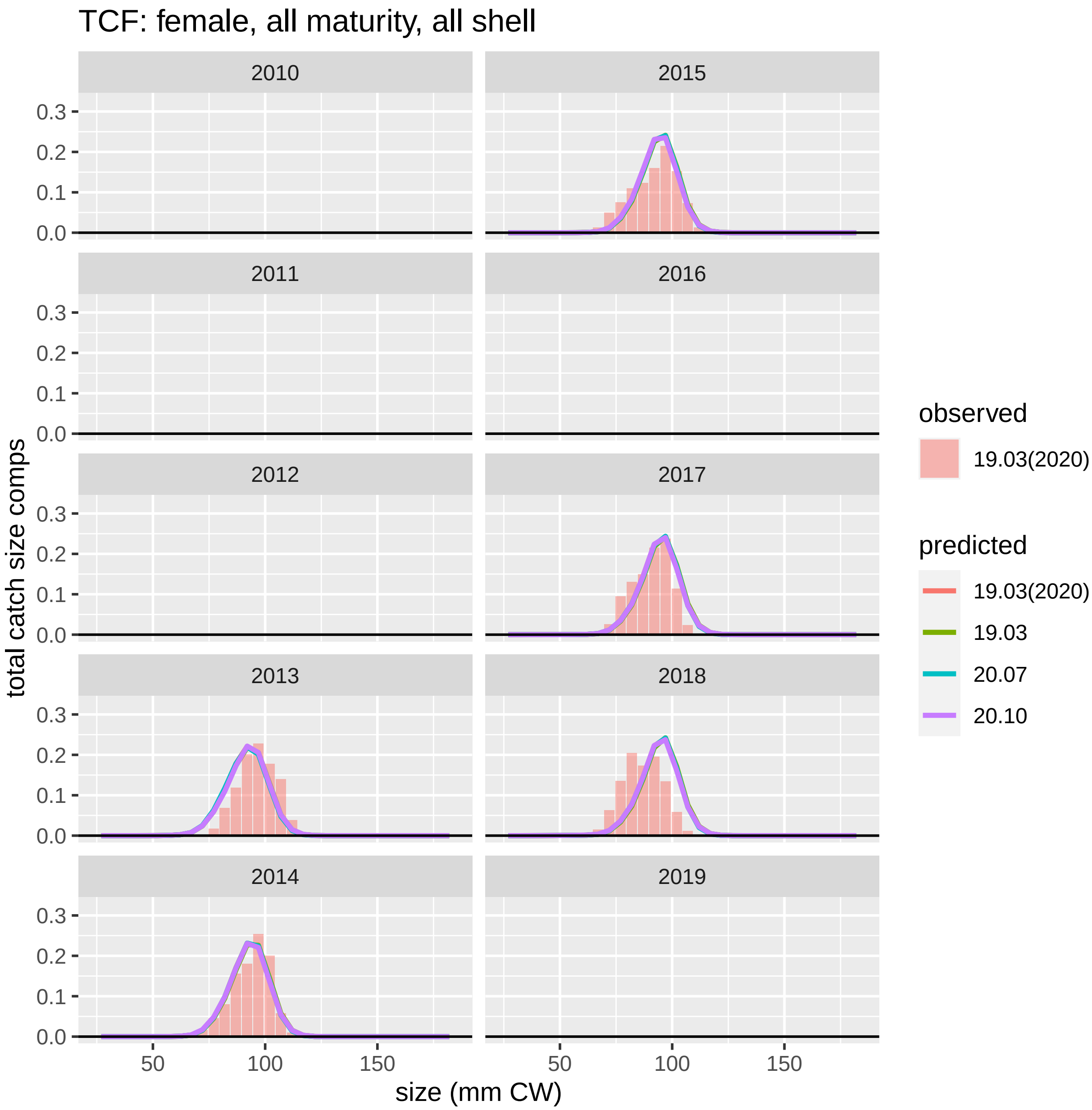


Figure 31: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

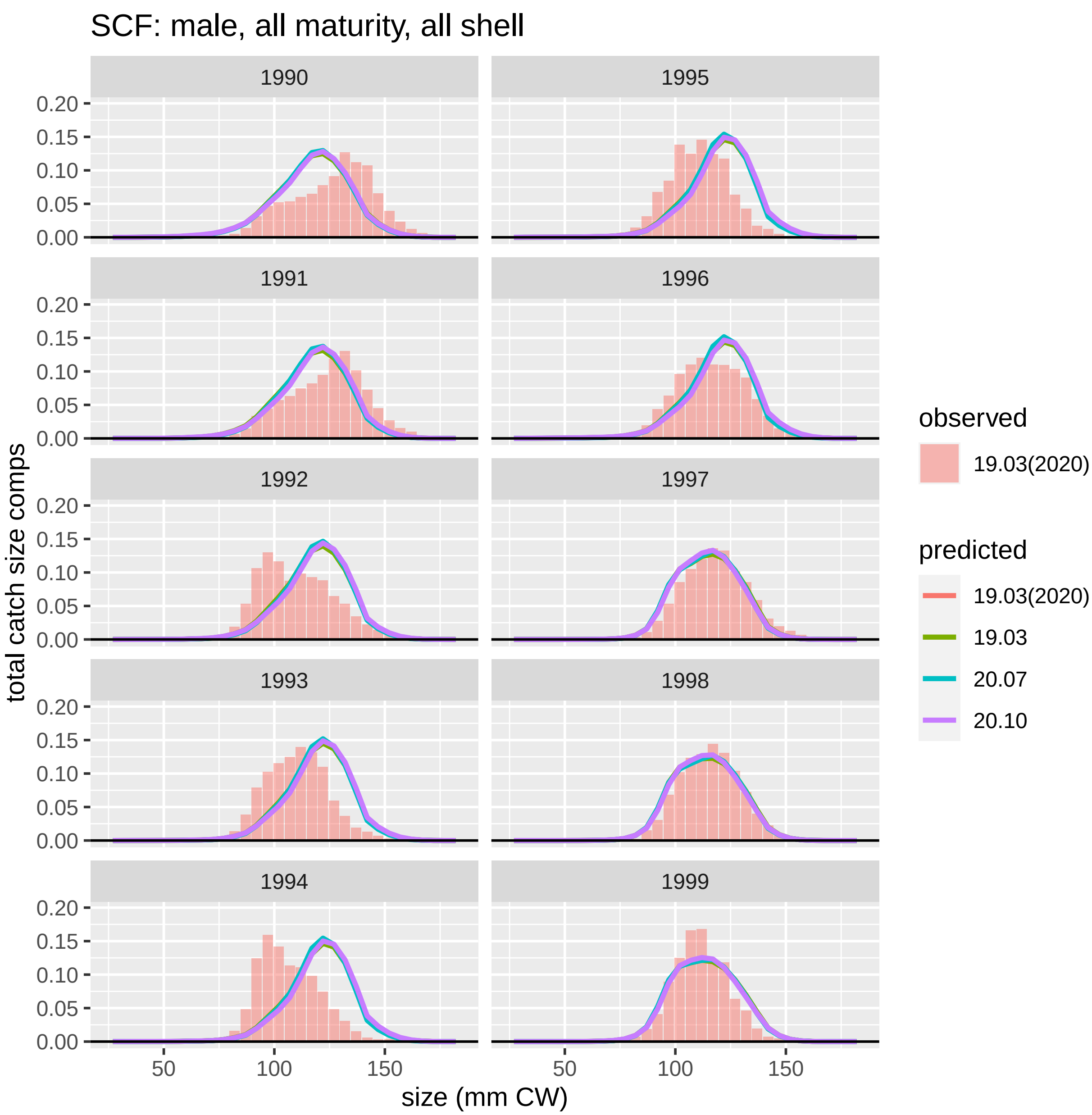


Figure 32: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

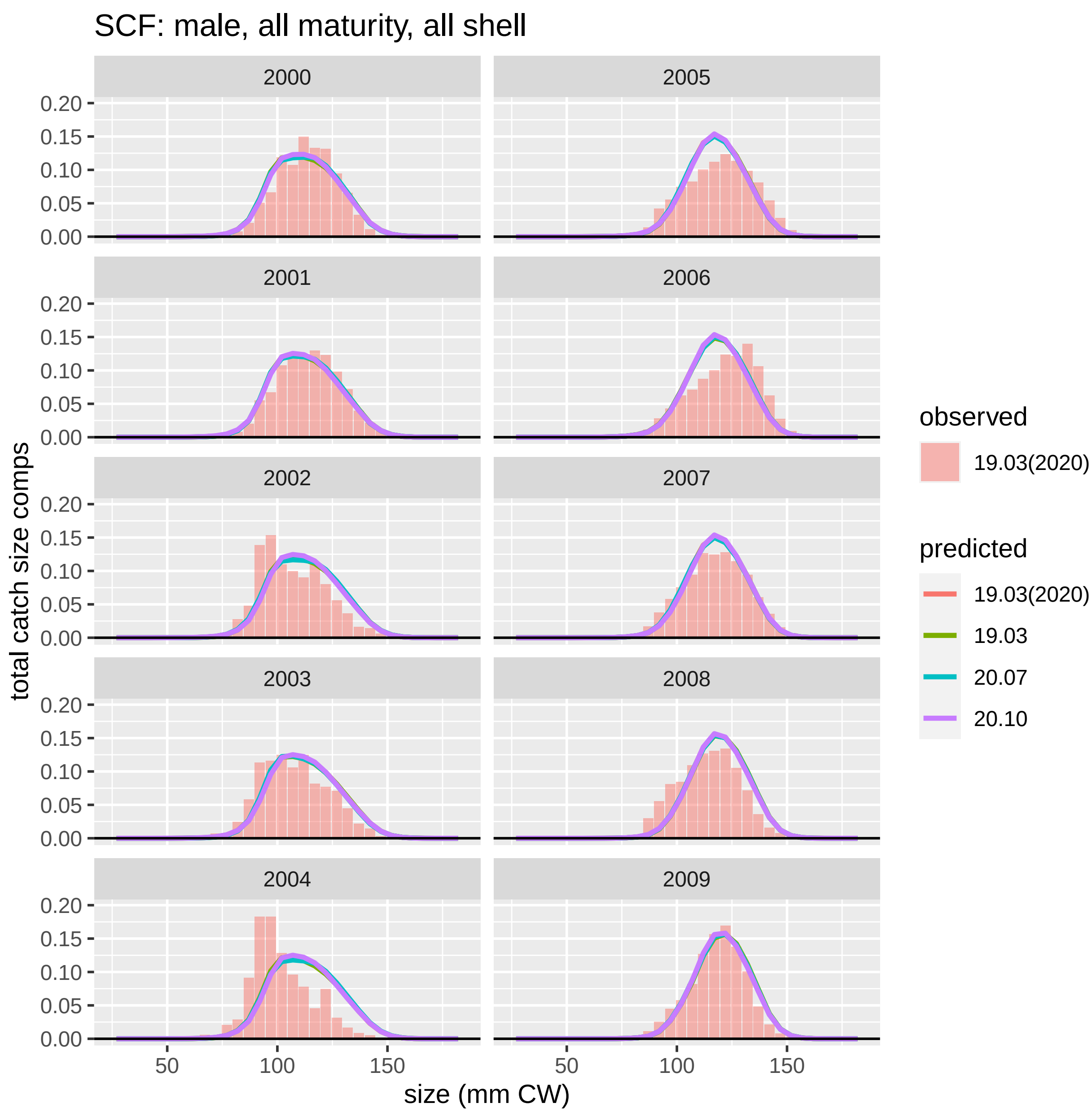


Figure 33: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

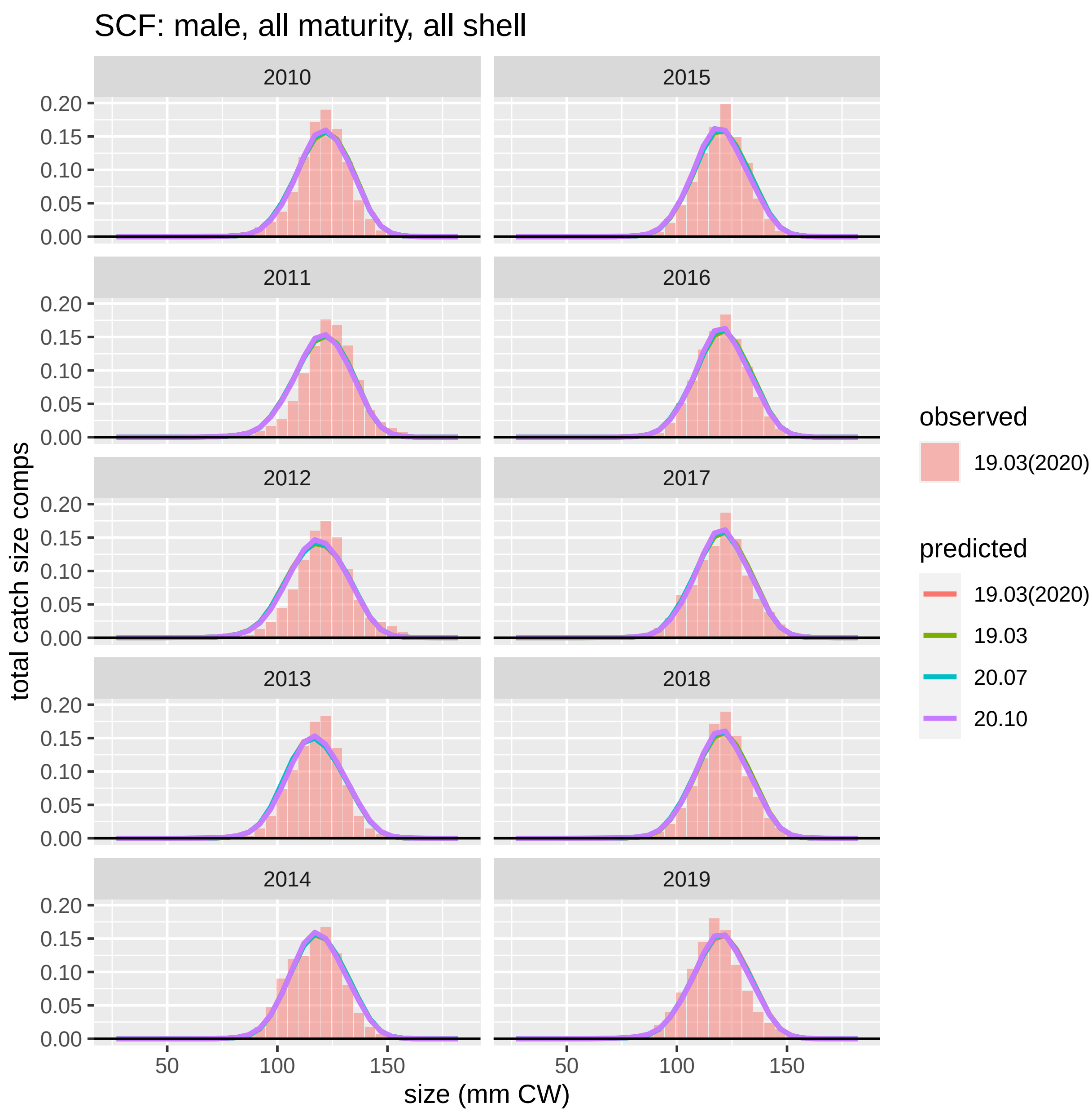


Figure 34: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

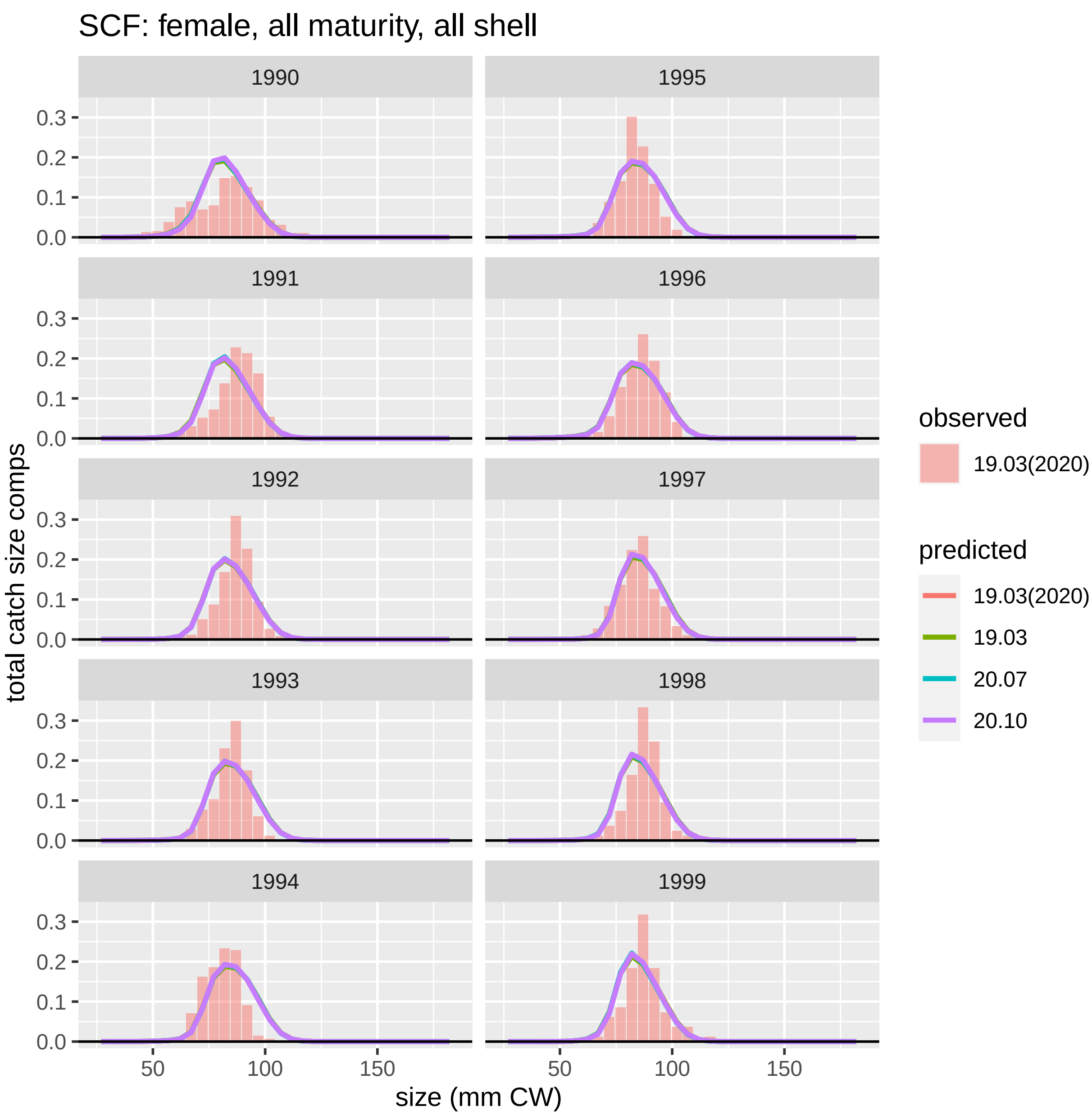


Figure 35: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

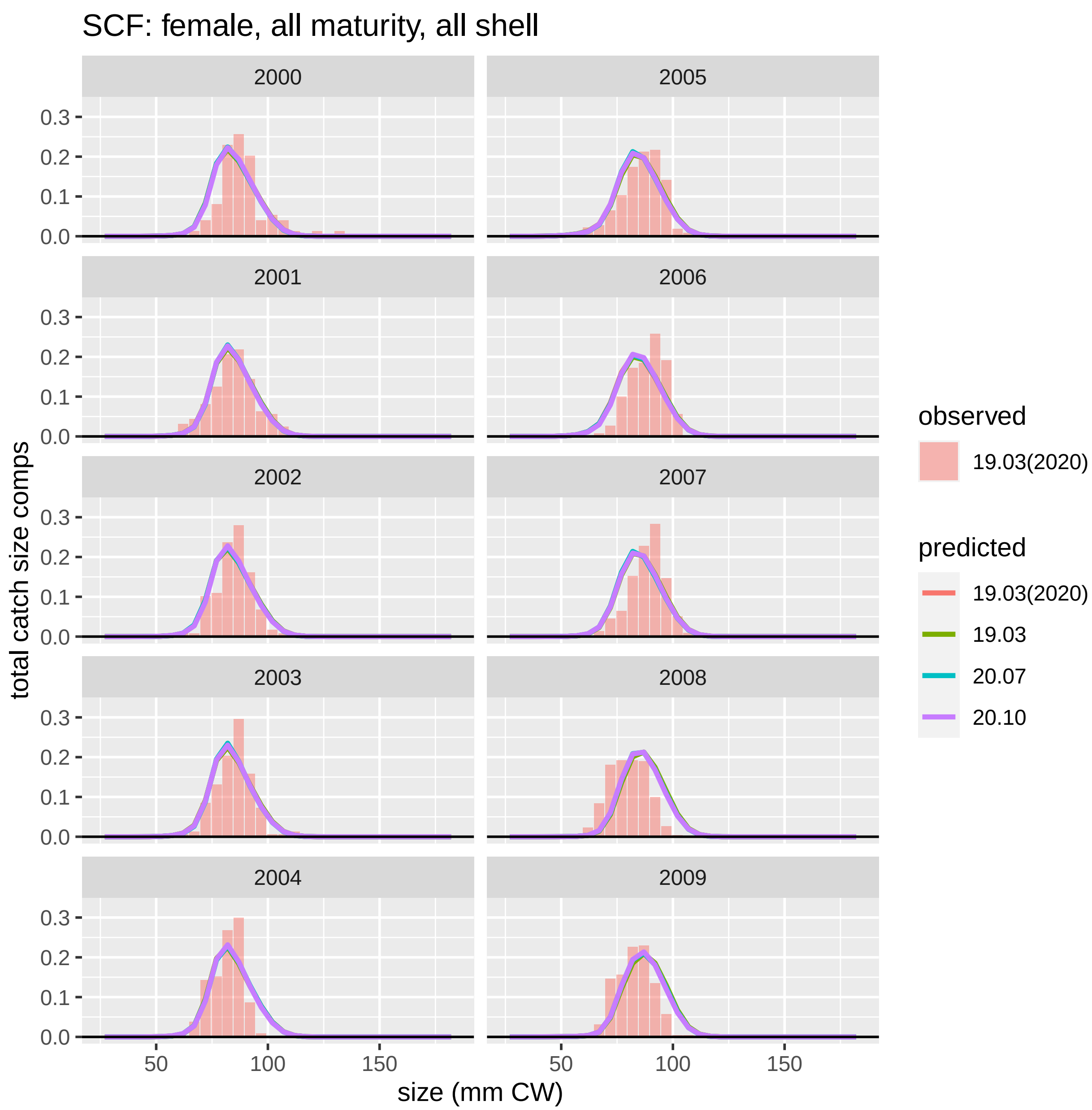


Figure 36: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

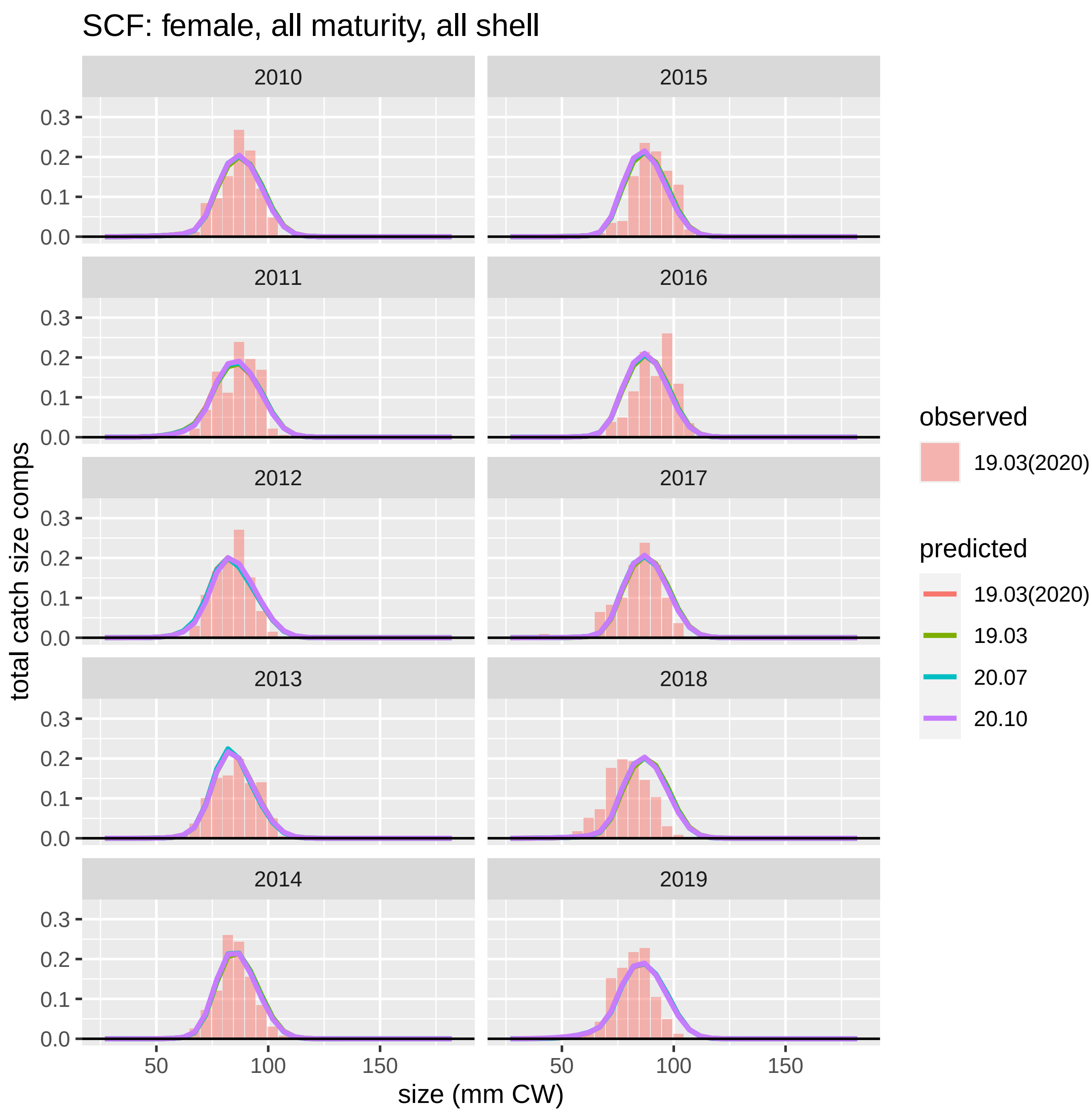


Figure 37: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

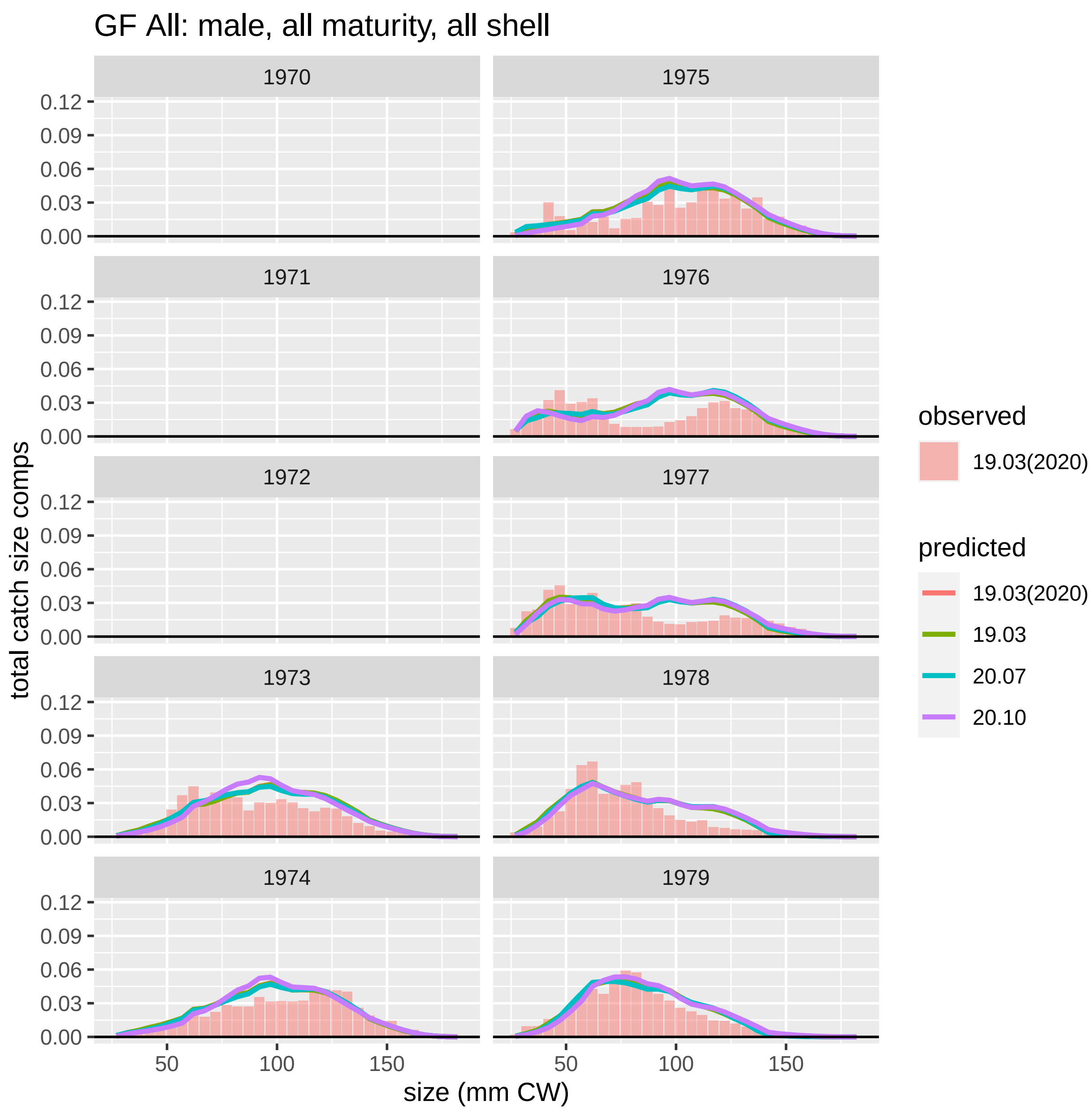


Figure 38: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GF All. Page 1 of 5.

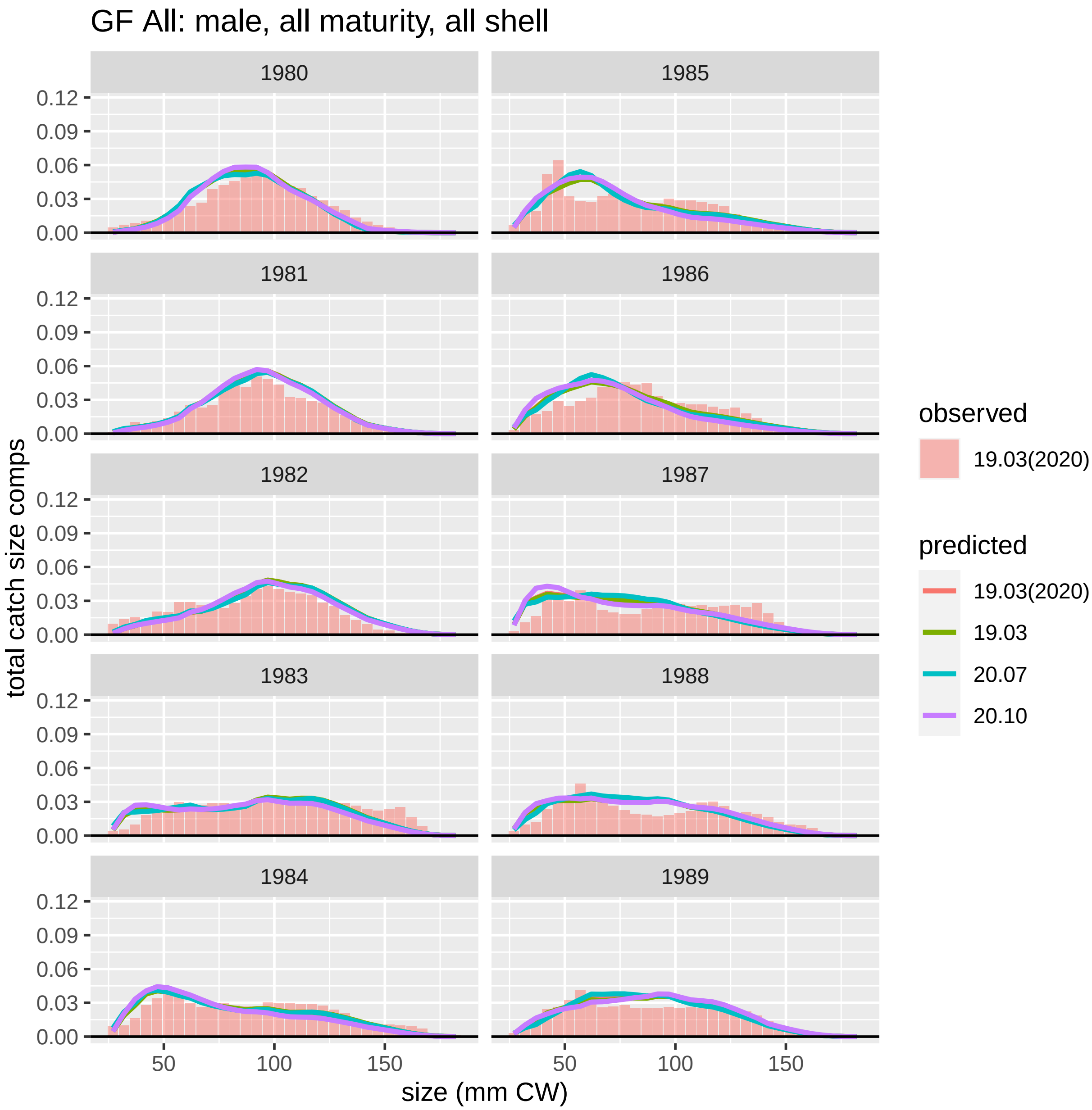


Figure 39: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GF All. Page 2 of 5.

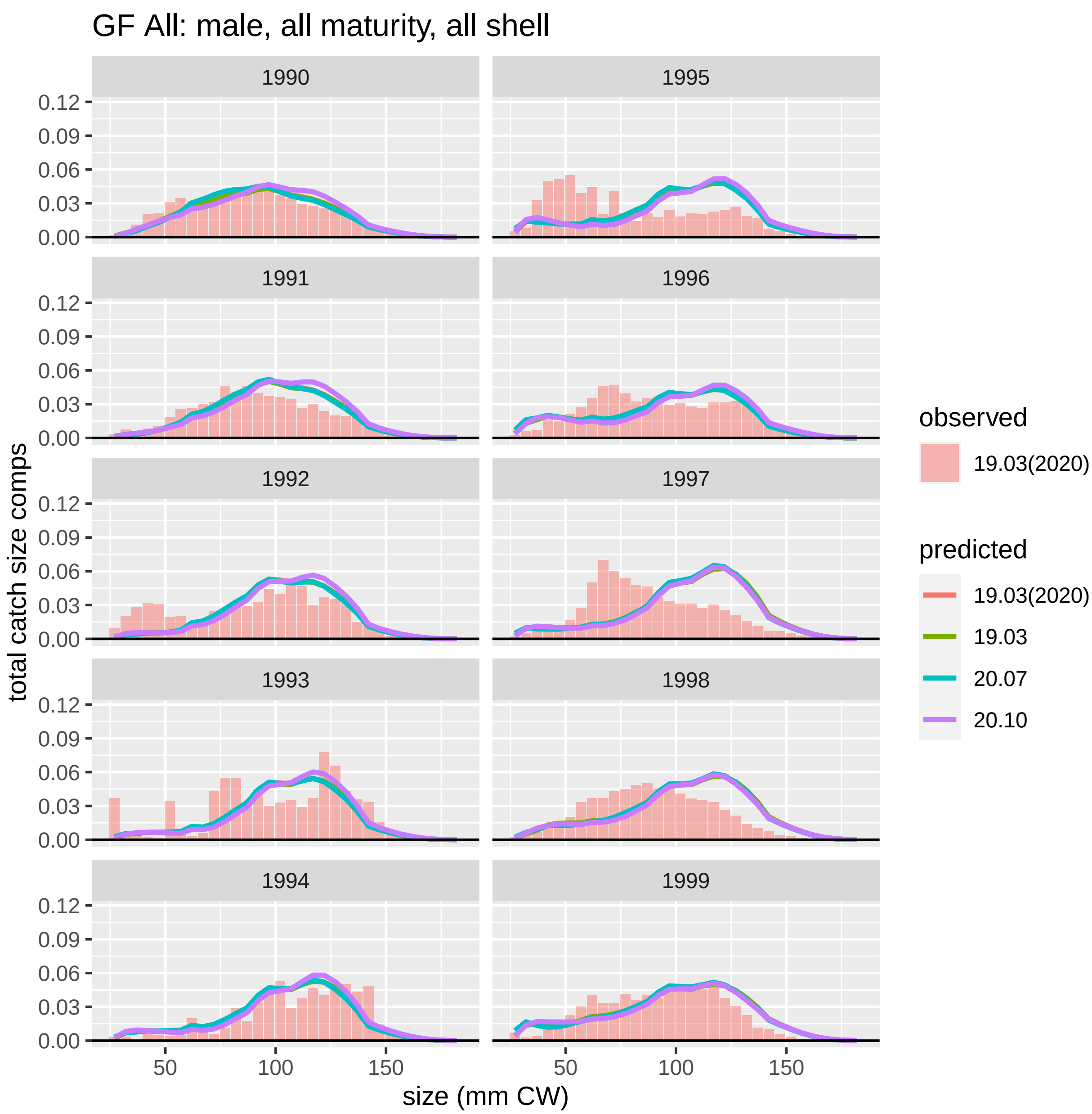


Figure 40: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GF All. Page 3 of 5.

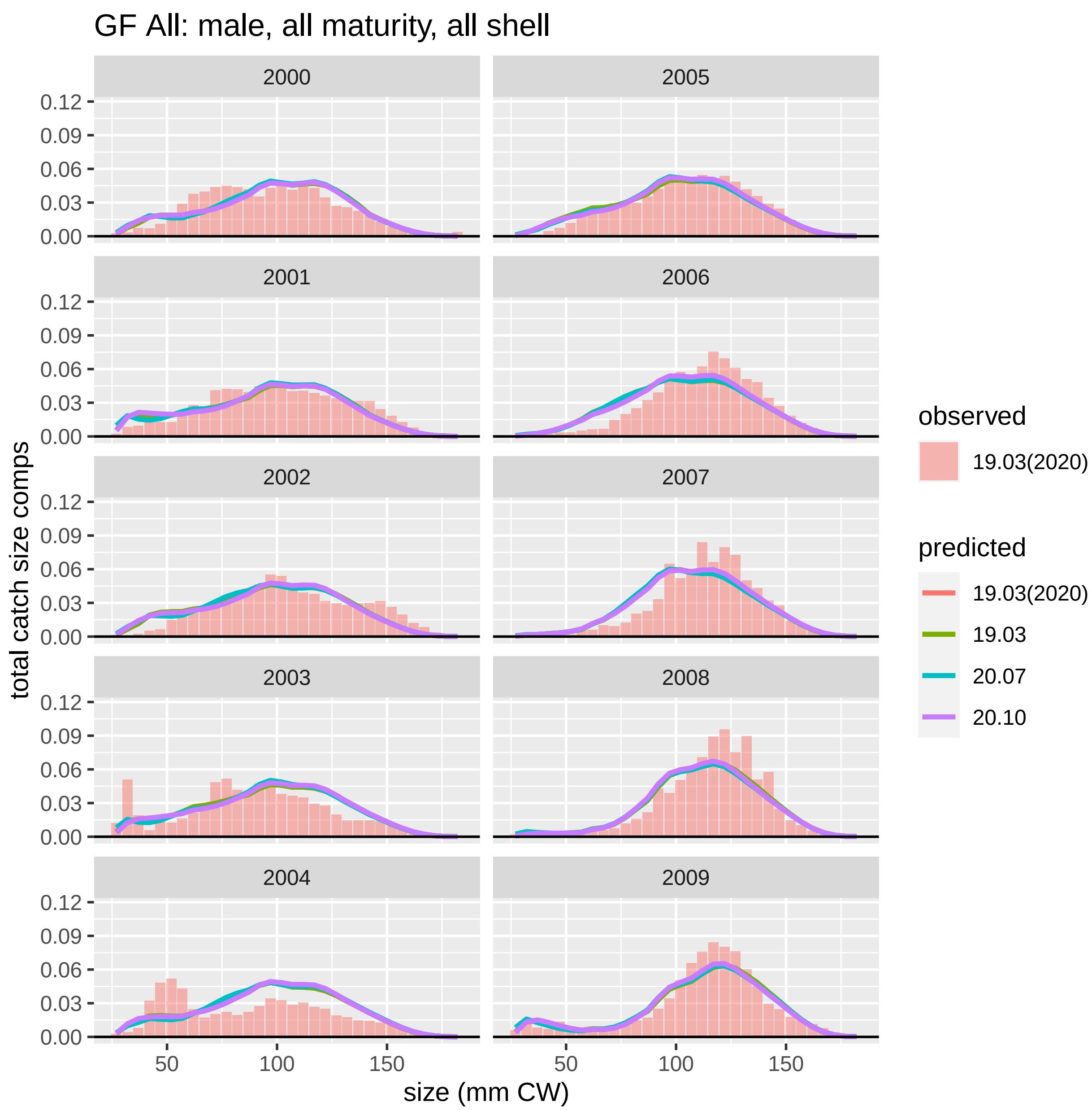


Figure 41: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GF All. Page 4 of 5.

Figure 42: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GF All. Page 5 of 5.

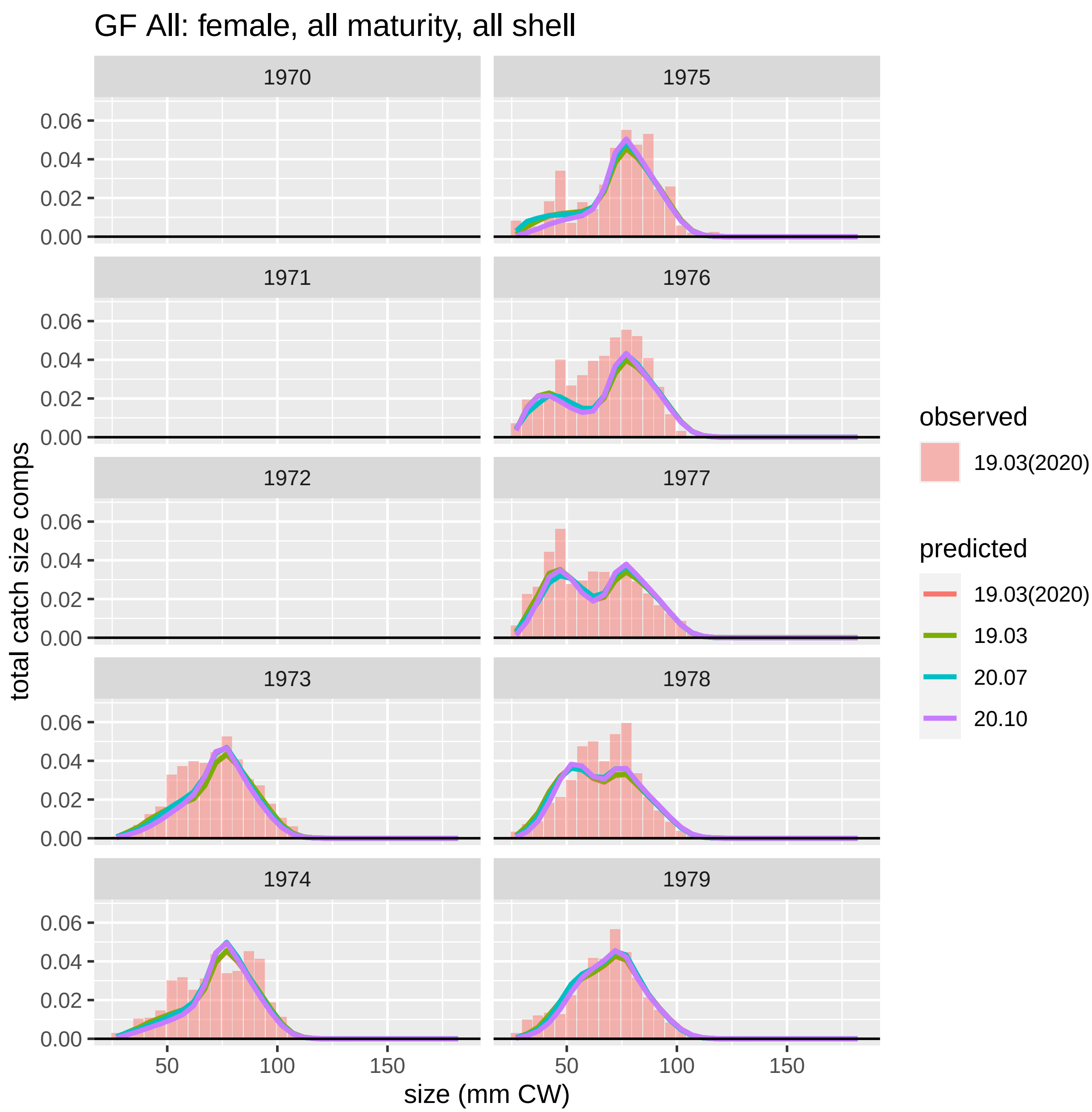


Figure 43: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GF All. Page 1 of 5.

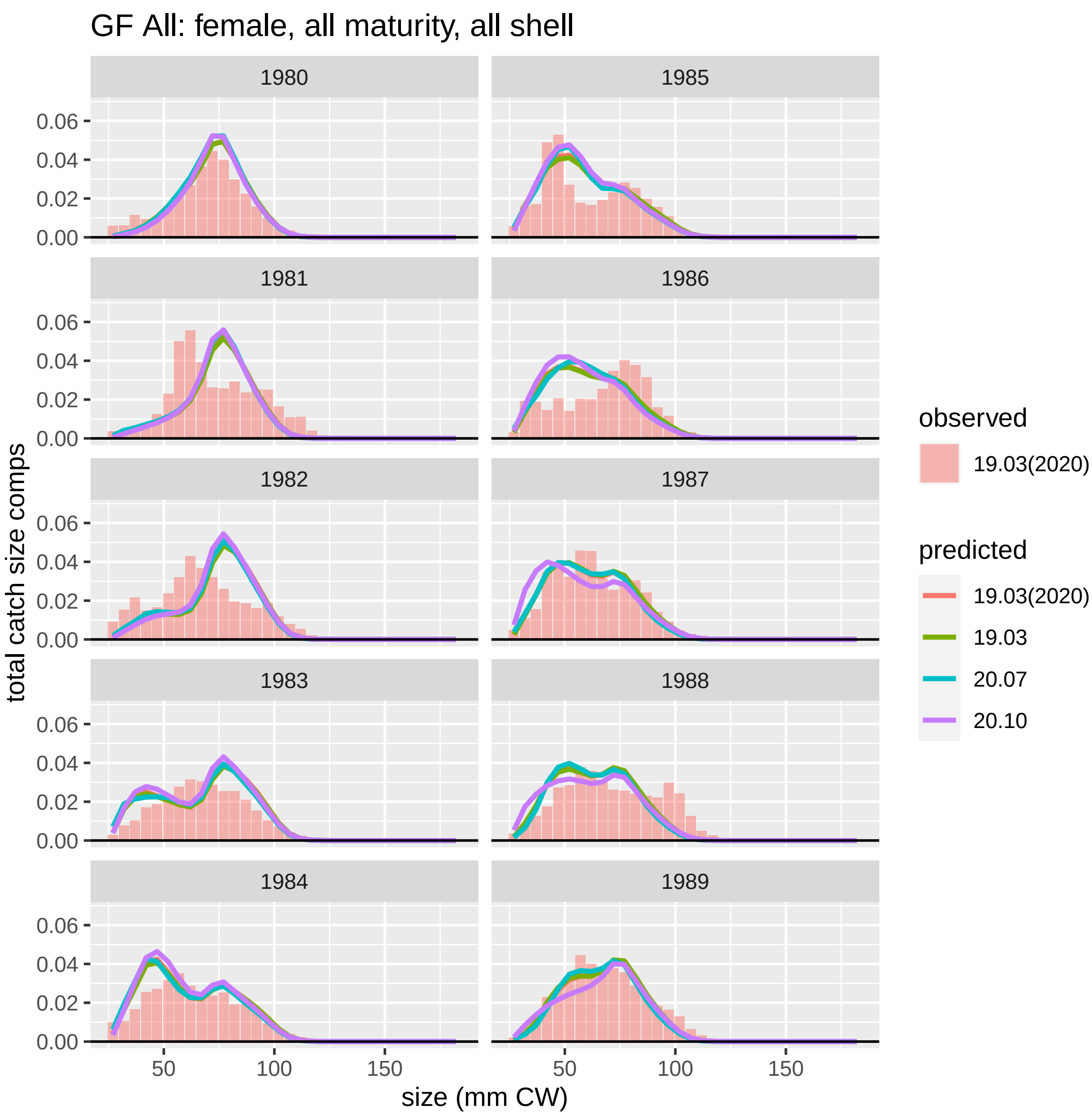


Figure 44: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GF All. Page 2 of 5.

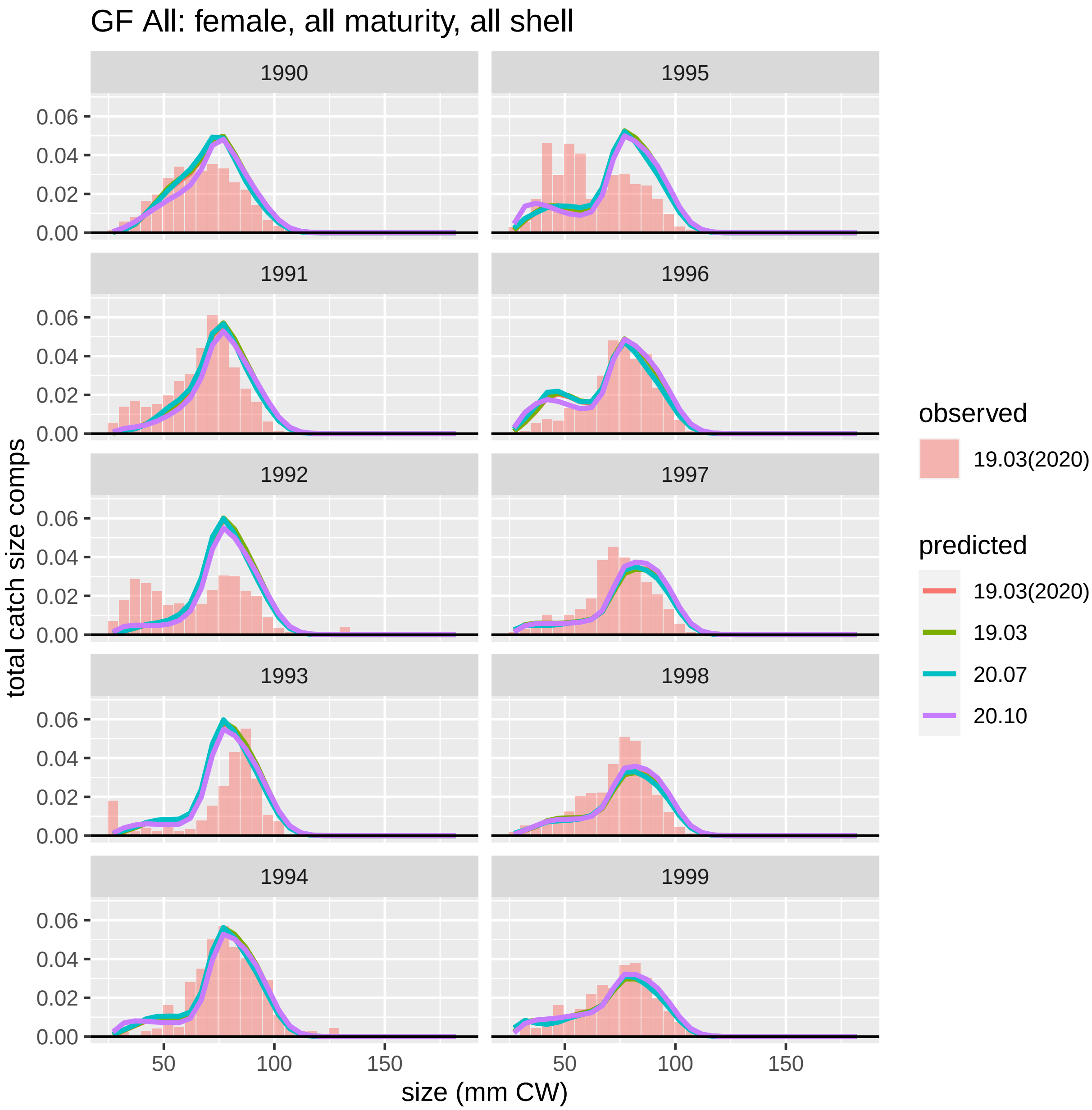


Figure 45: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GF All. Page 3 of 5.

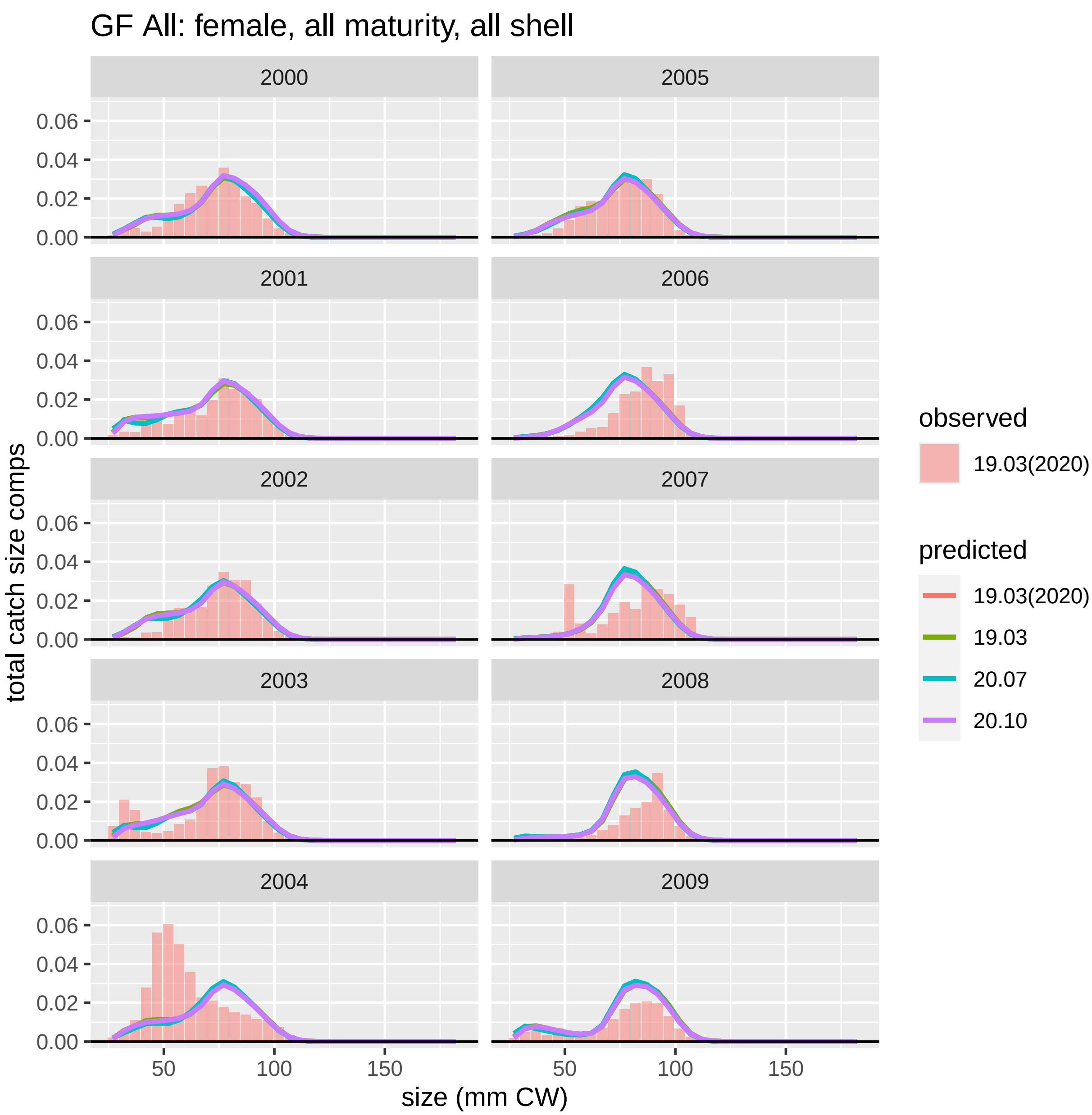


Figure 46: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GF All. Page 4 of 5.

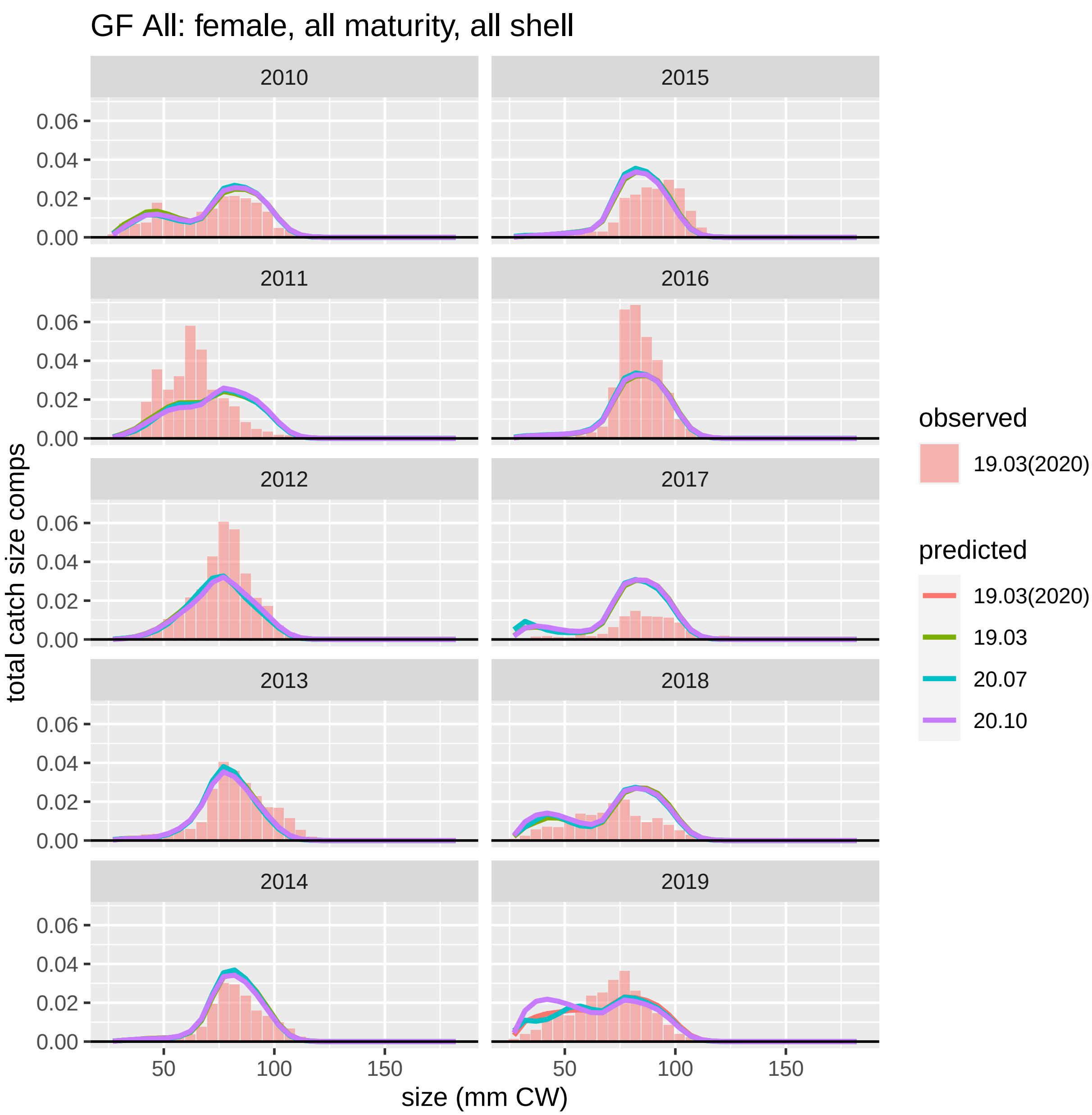


Figure 47: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GF All. Page 5 of 5.

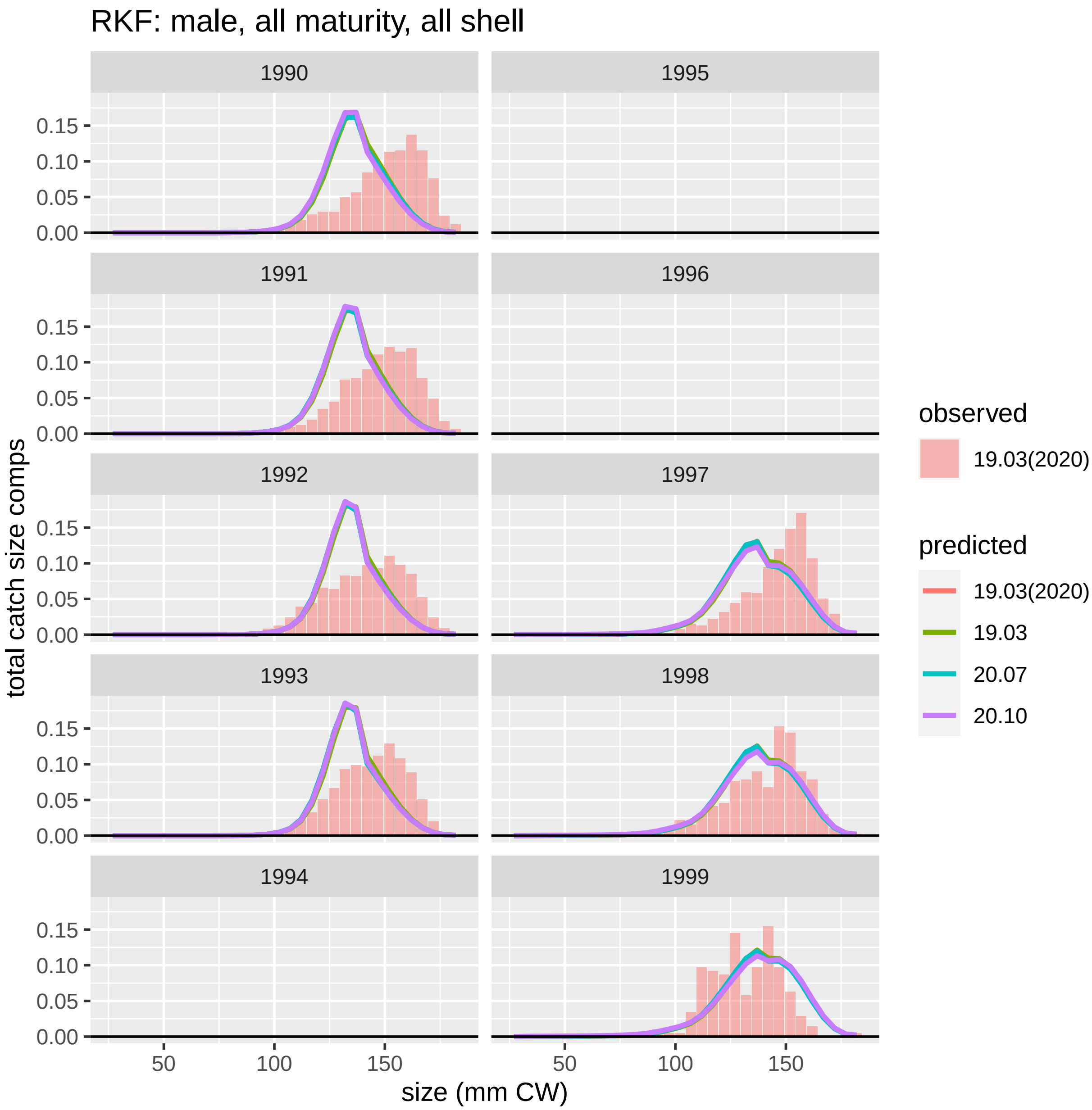


Figure 48: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

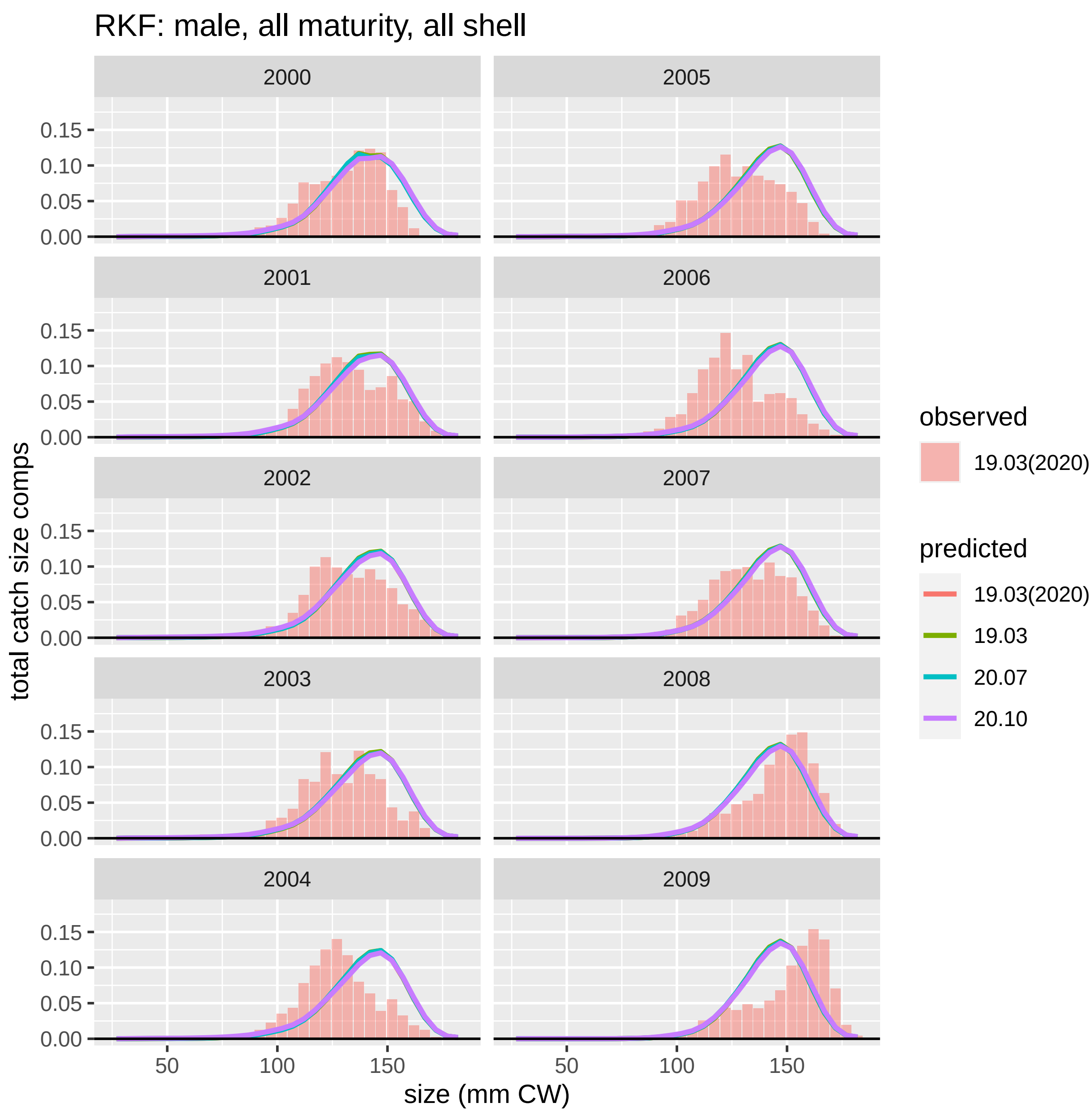


Figure 49: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

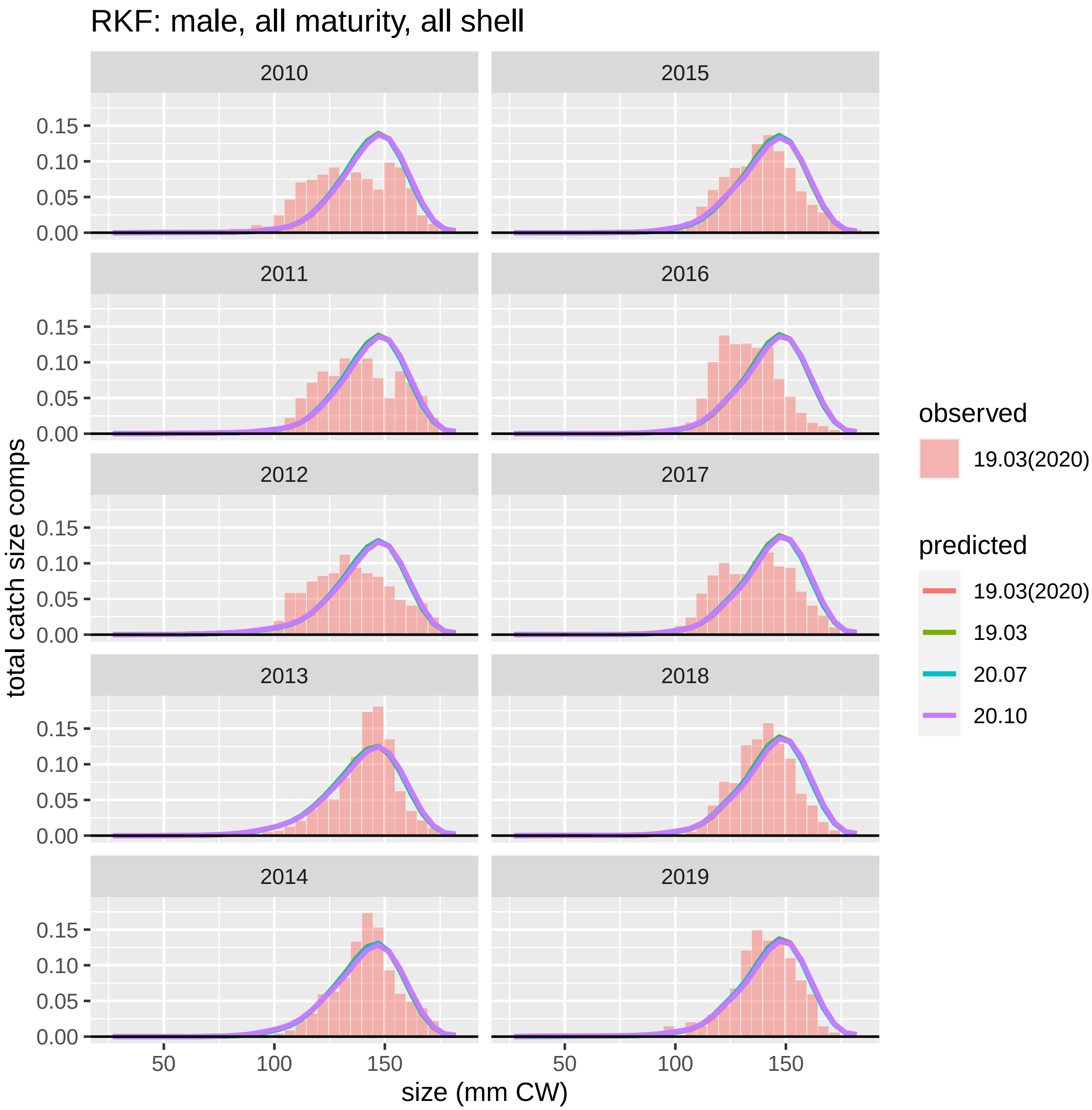


Figure 50: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

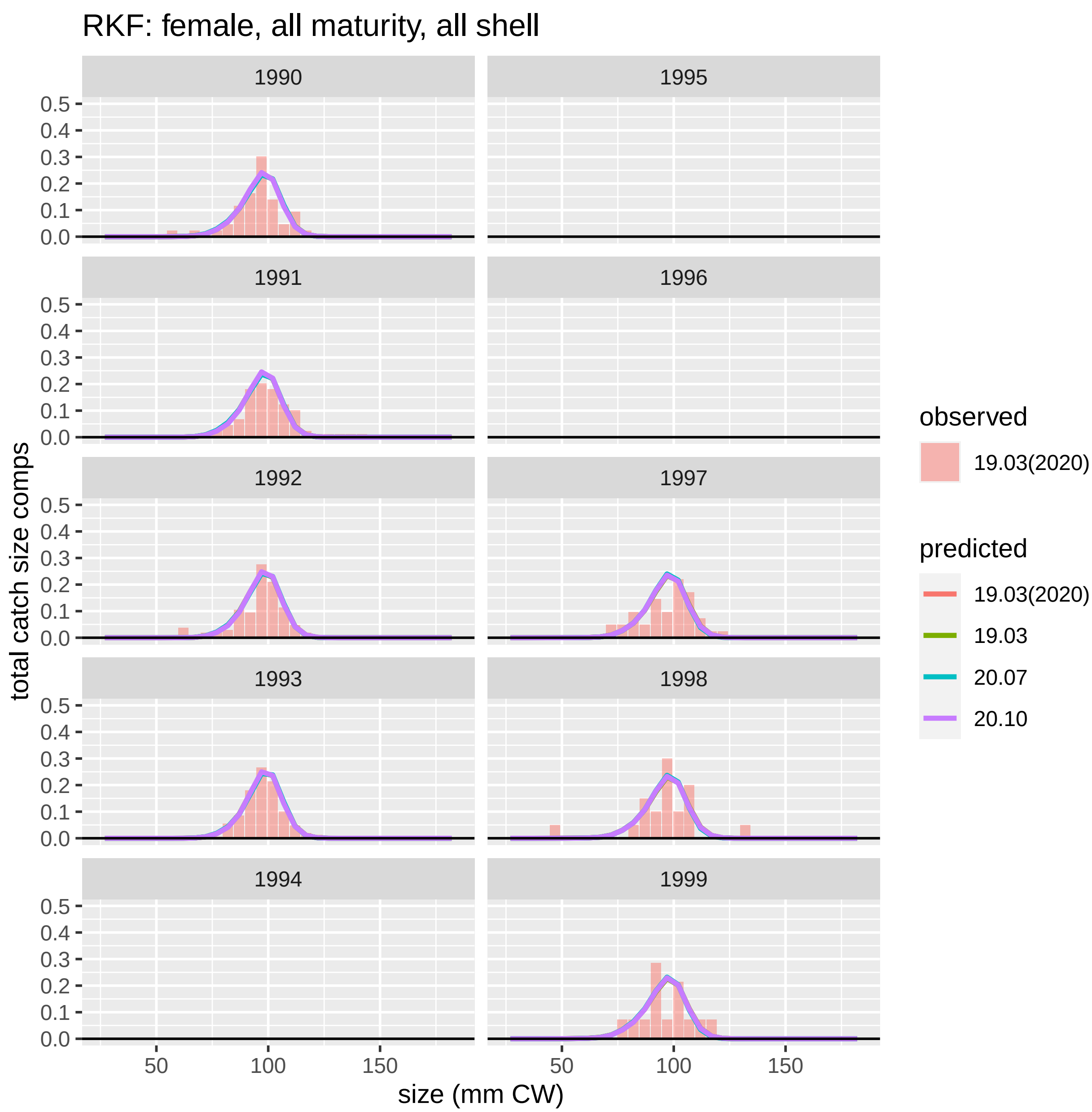


Figure 51: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

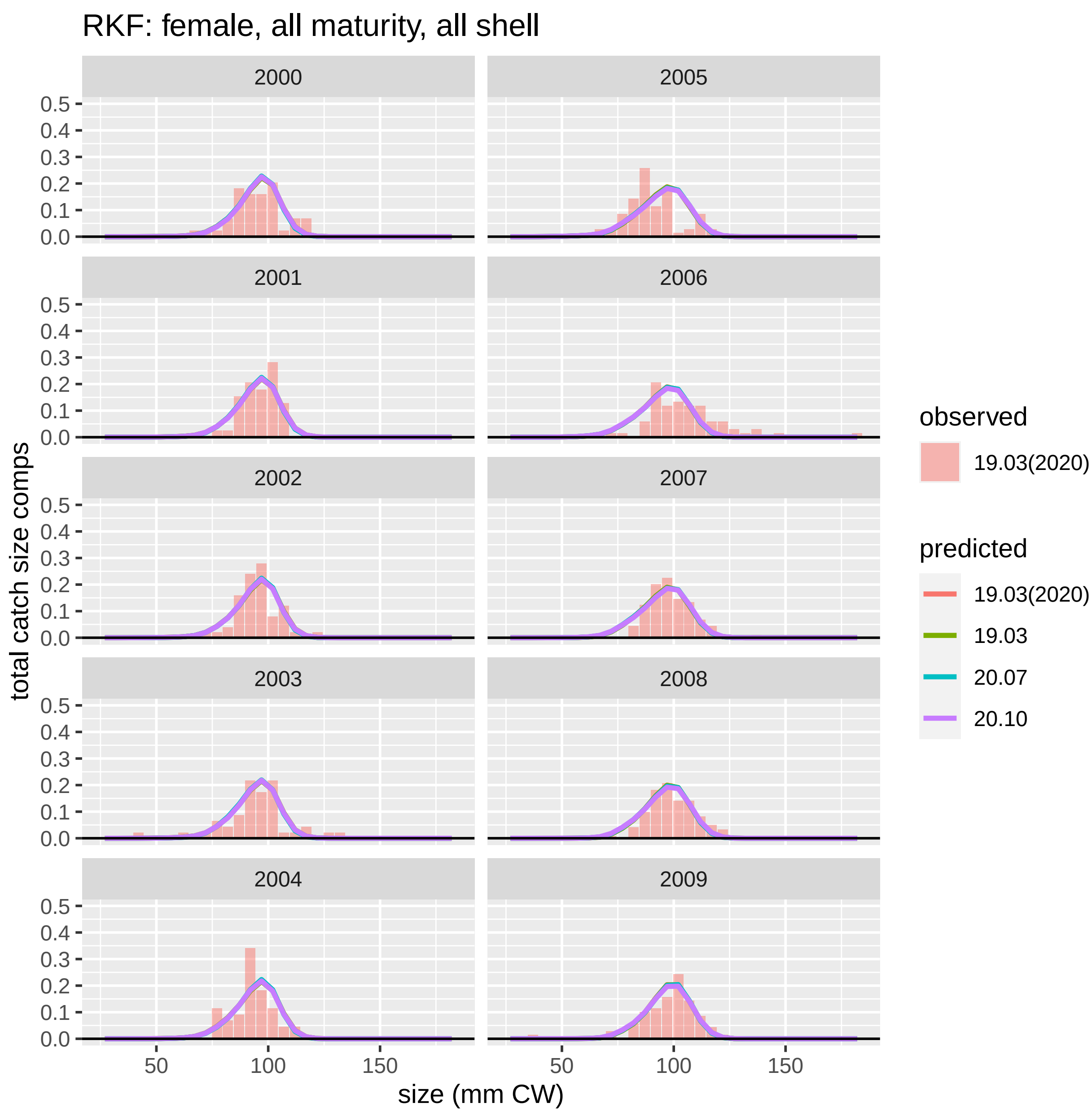


Figure 52: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

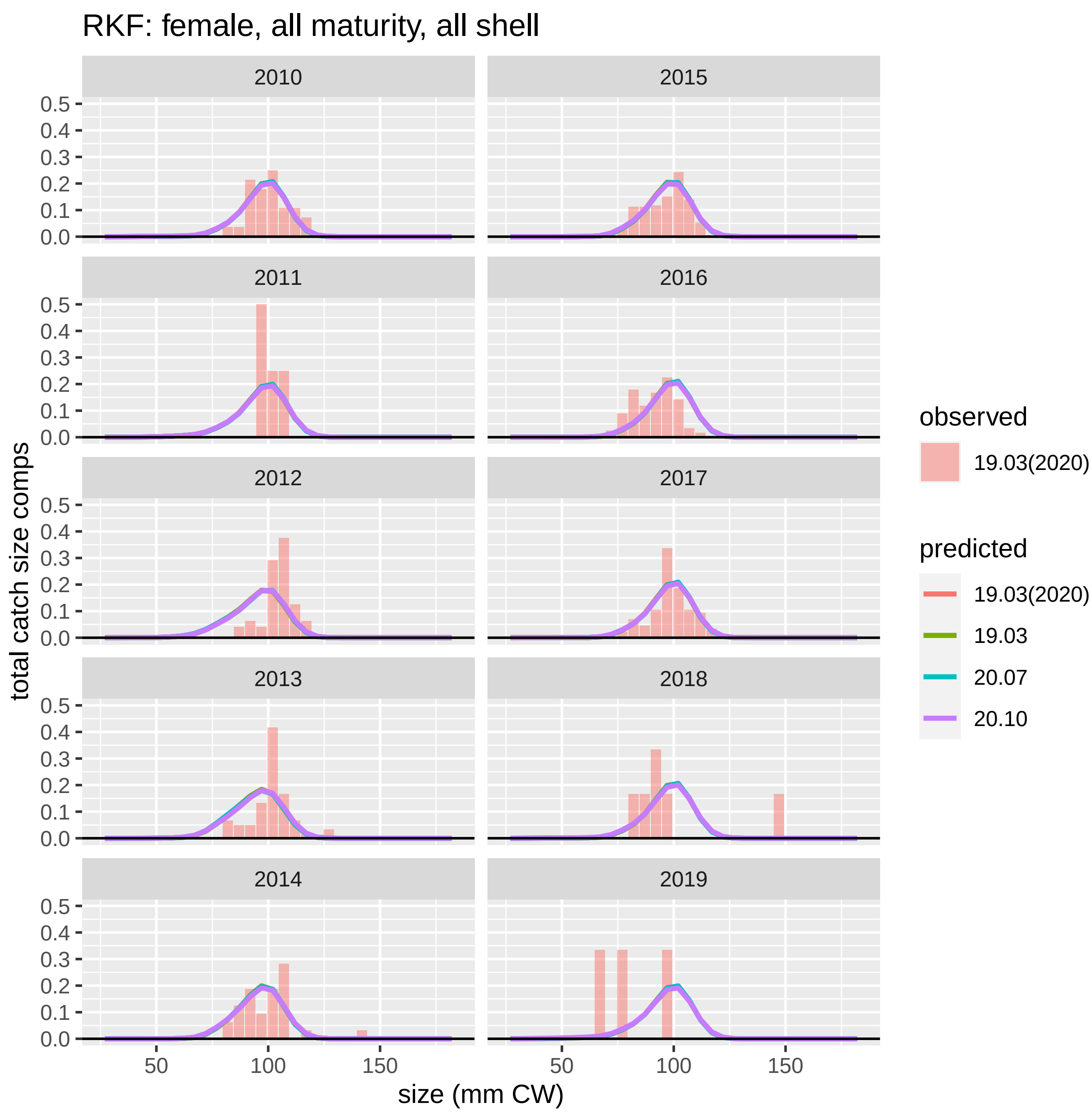


Figure 53: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

Appendix 9: Diagnostics for Fits to Fisheries Size Composition Data –19.03(2020) vs 19.03 vs 20.07 vs 20.10

William Stockhausen

01 September, 2020

Contents

Introduction

Fits to fishery retained catch and total catch size composition data available to the model(s) are presented in this section. Included are plots of mean fits to size compositions, Pearson's residuals as bubble plots, and effective sample sizes. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Retained catch mean size compositions

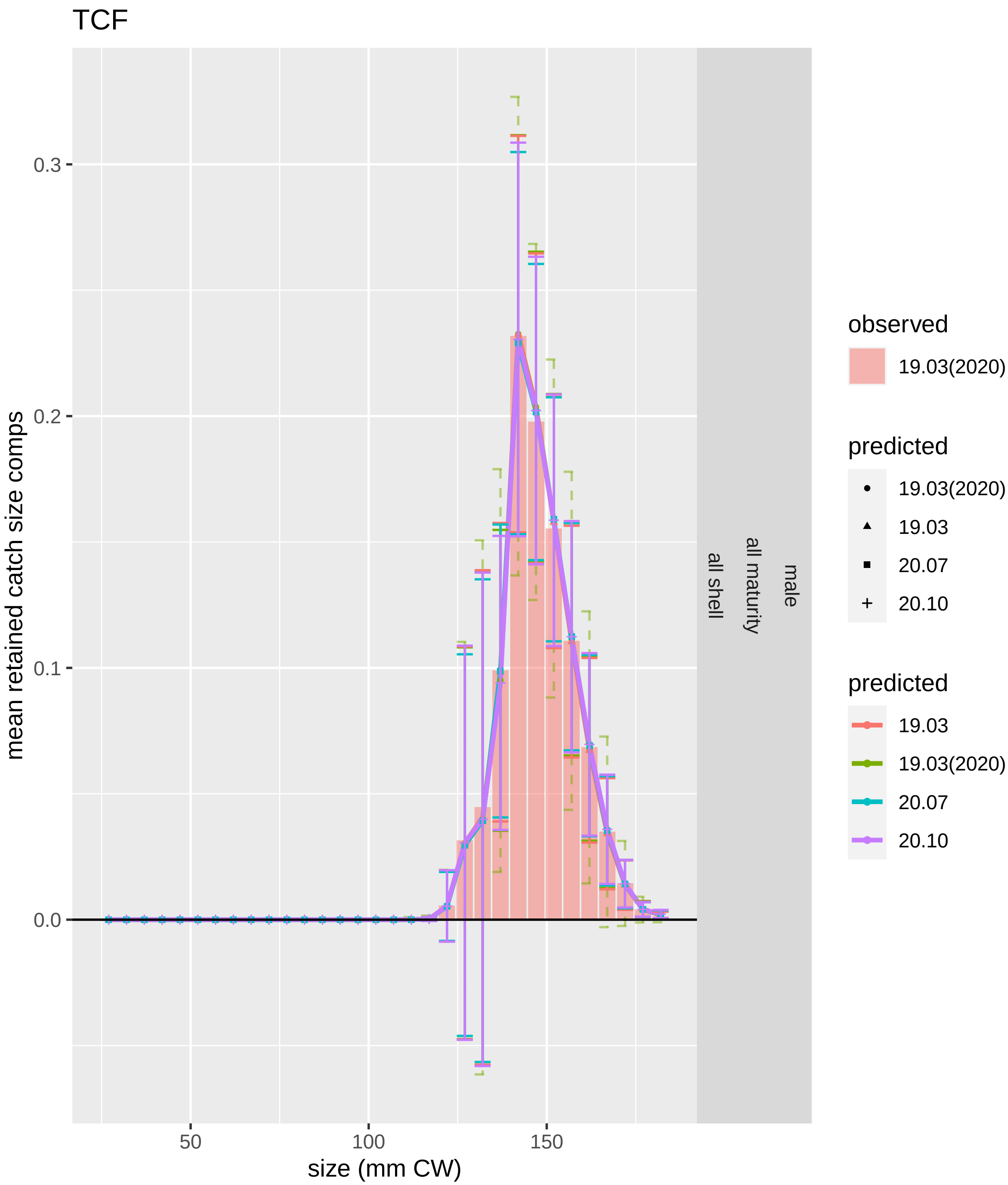


Figure 1: Comparison of observed and predicted mean retained catch size comps for TCF.

Total catch mean size compositions

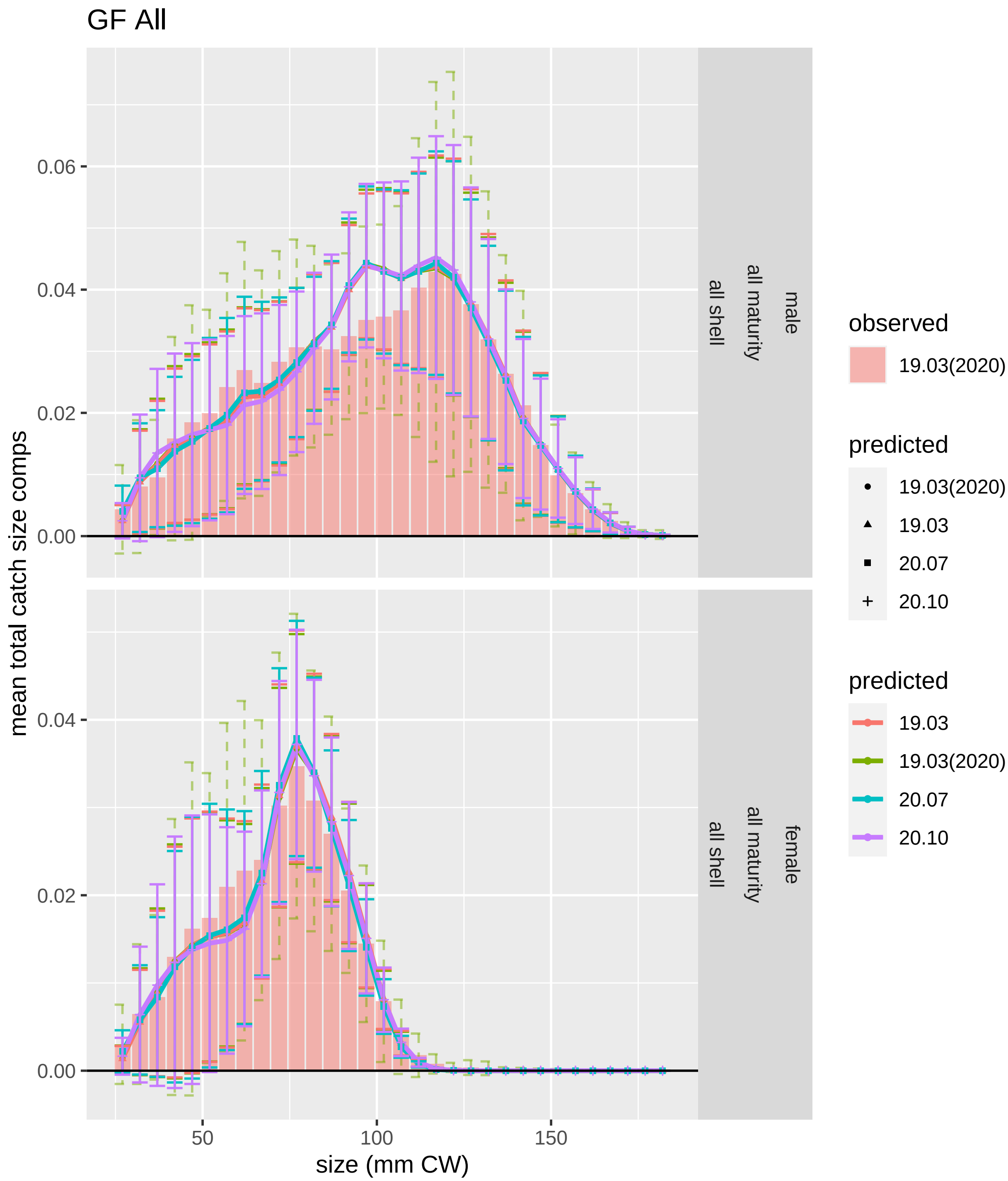


Figure 2: Comparison of observed and predicted mean total catch size comps for GF All.

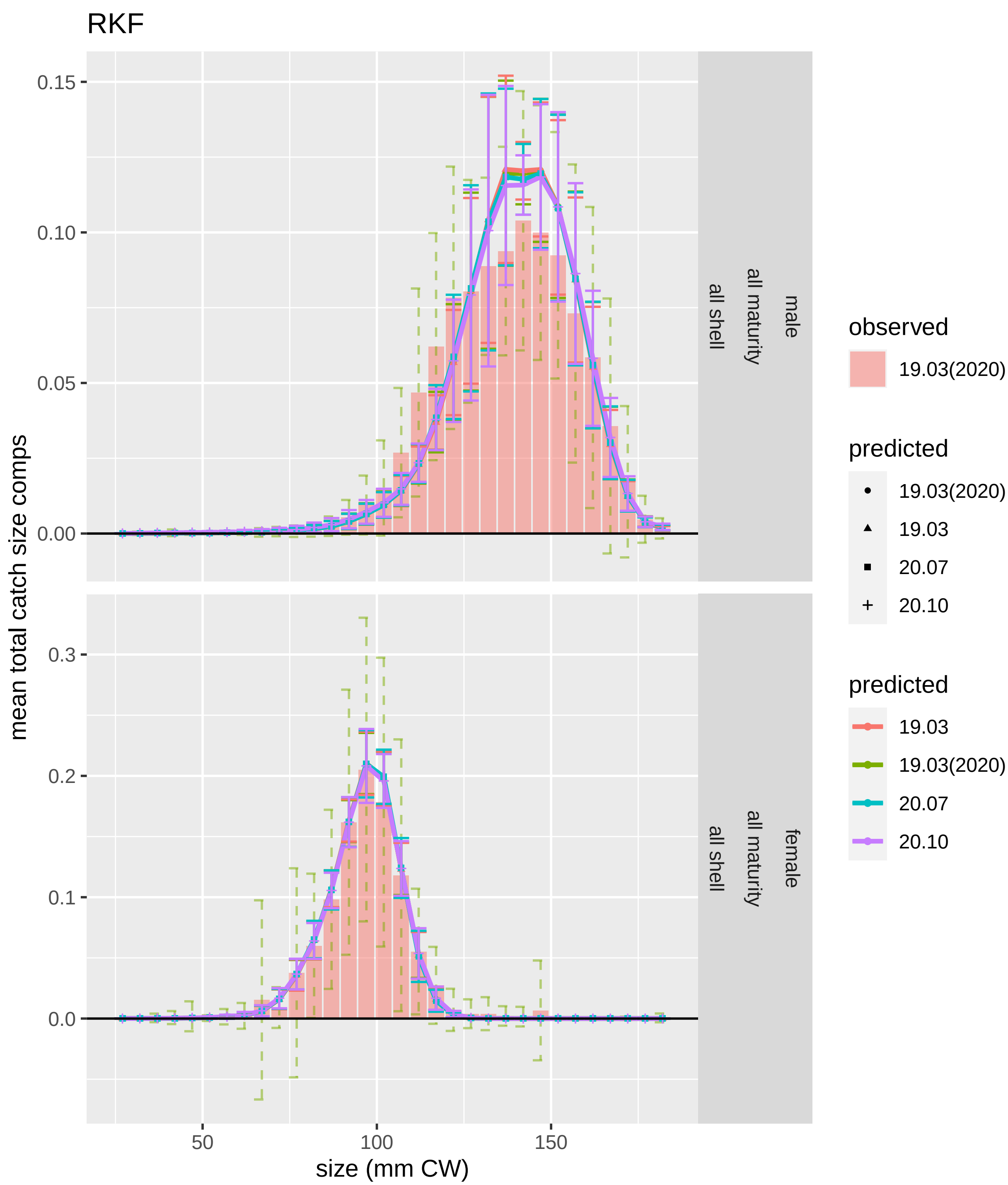


Figure 3: Comparison of observed and predicted mean total catch size comps for RKF.

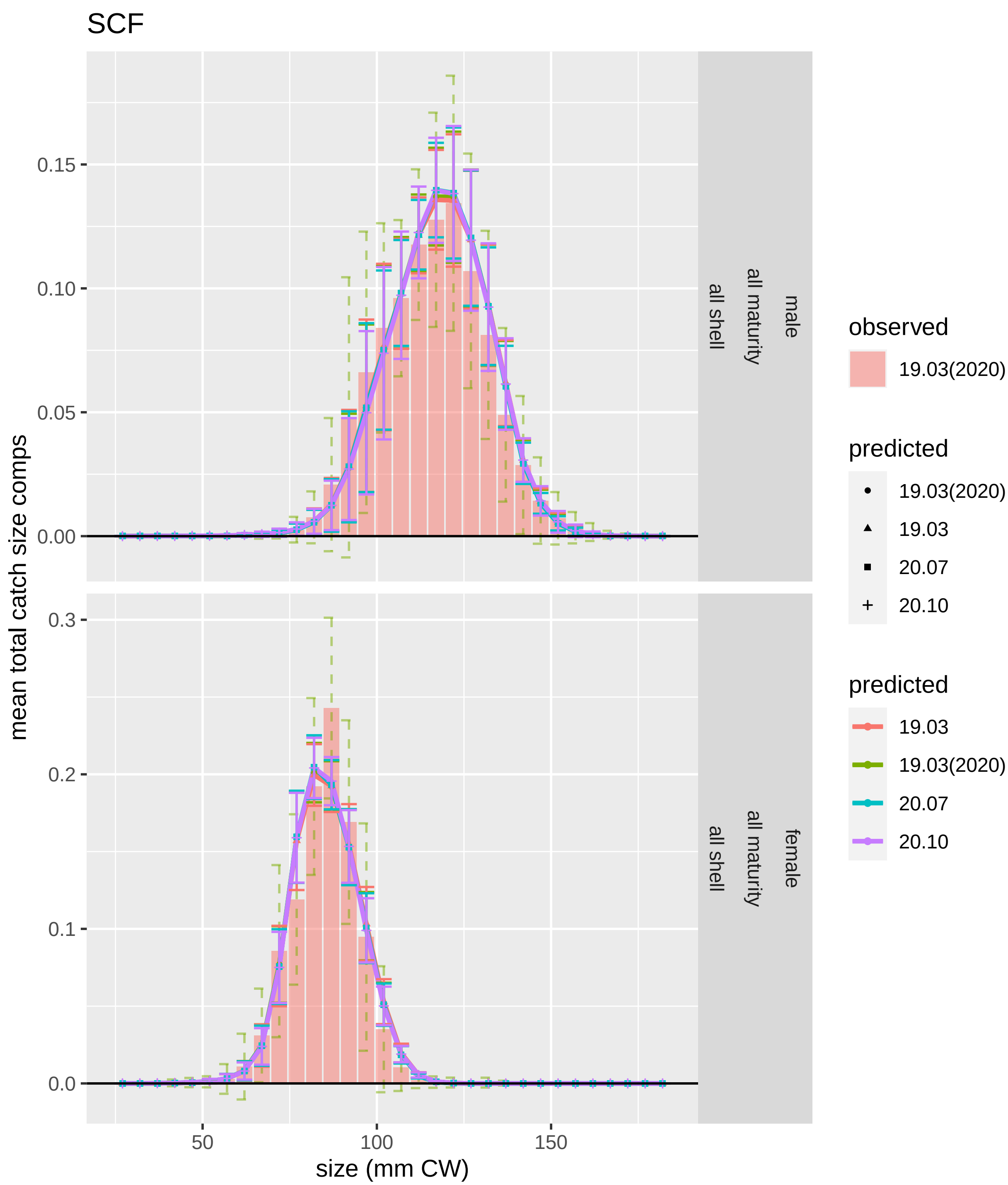


Figure 4: Comparison of observed and predicted mean total catch size comps for SCF.

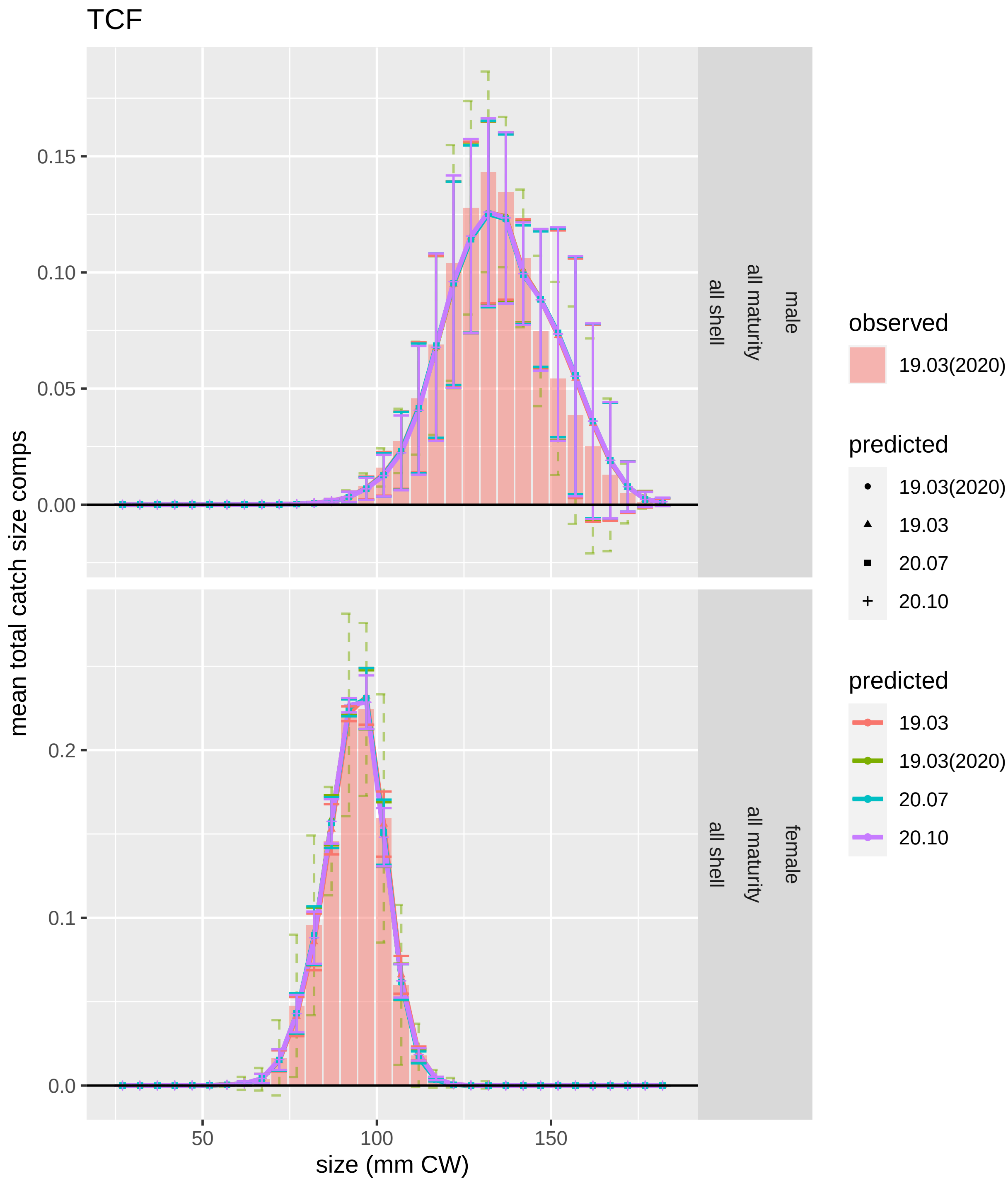


Figure 5: Comparison of observed and predicted mean total catch size comps for TCF.

Fishery retained catch size composition residuals

Figure 6: Pearson's residuals for male proportions-at-size from the TCF for scenario 19.03(2020).

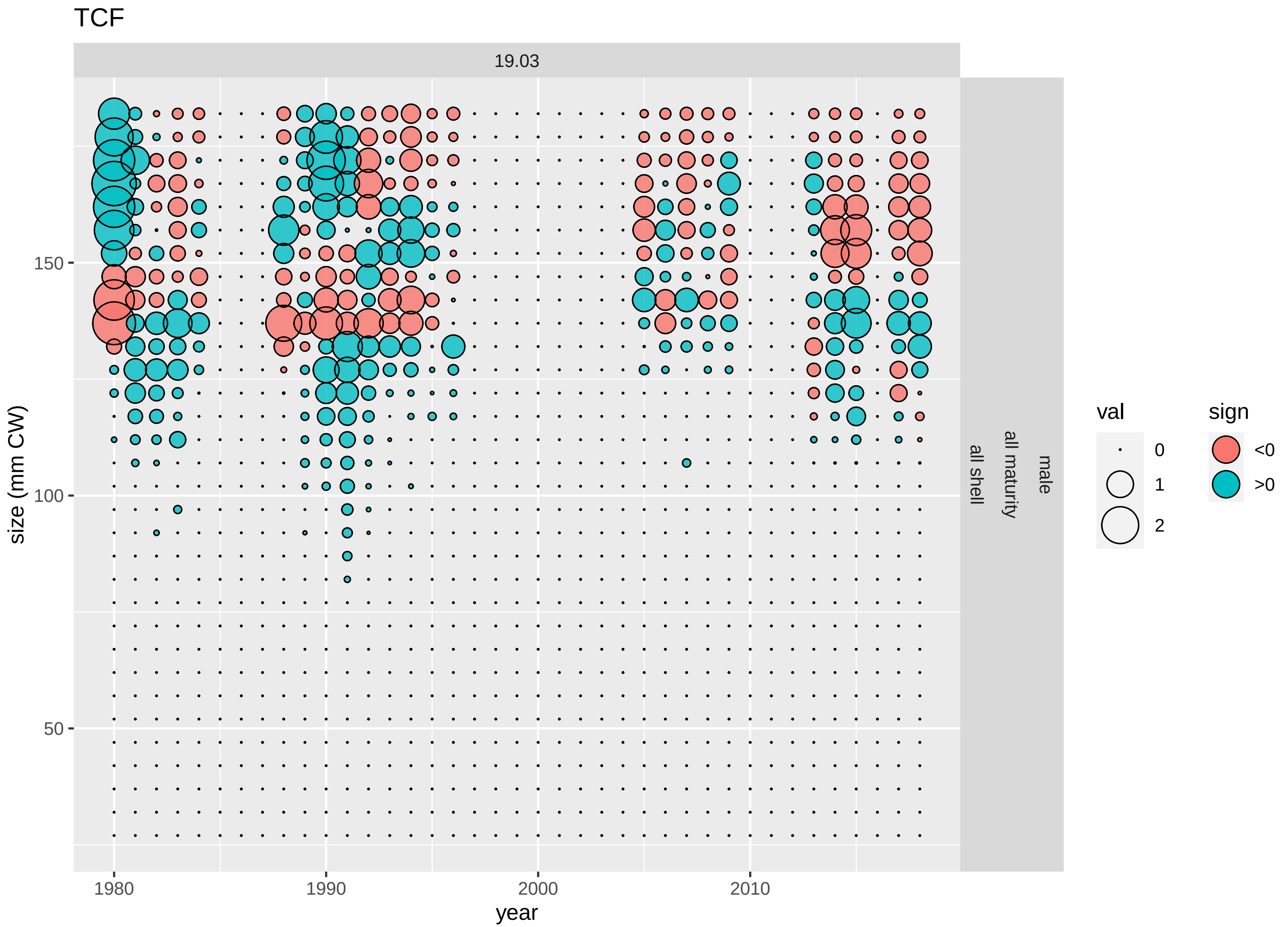


Figure 7: Pearson's residuals for male proportions-at-size from the TCF for scenario 19.03.

Figure 8: Pearson's residuals for male proportions-at-size from the TCF for scenario 20.07.

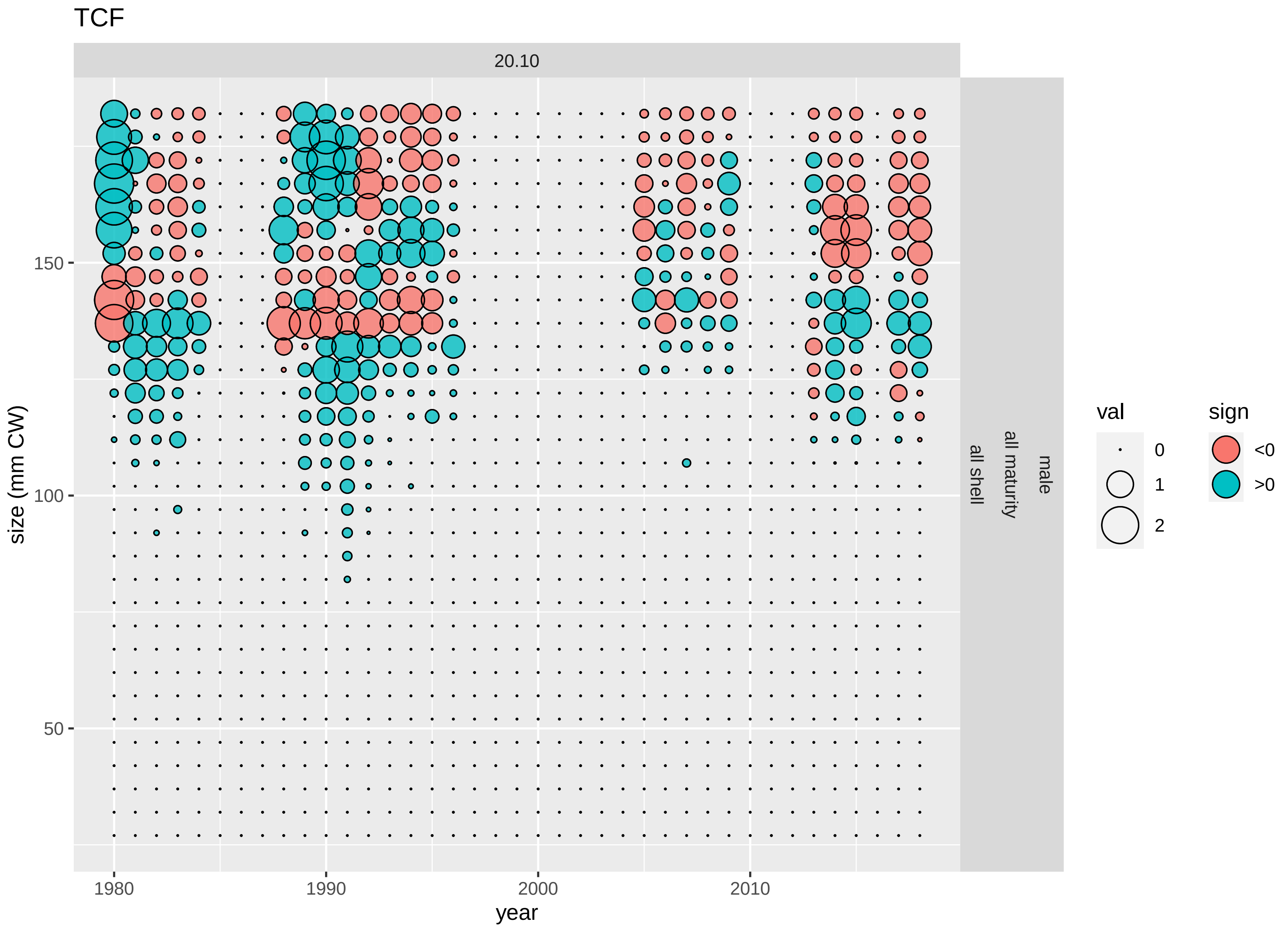


Figure 9: Pearson's residuals for male proportions-at-size from the TCF for scenario 20.10.

Effective Ns for retained catch size compositions

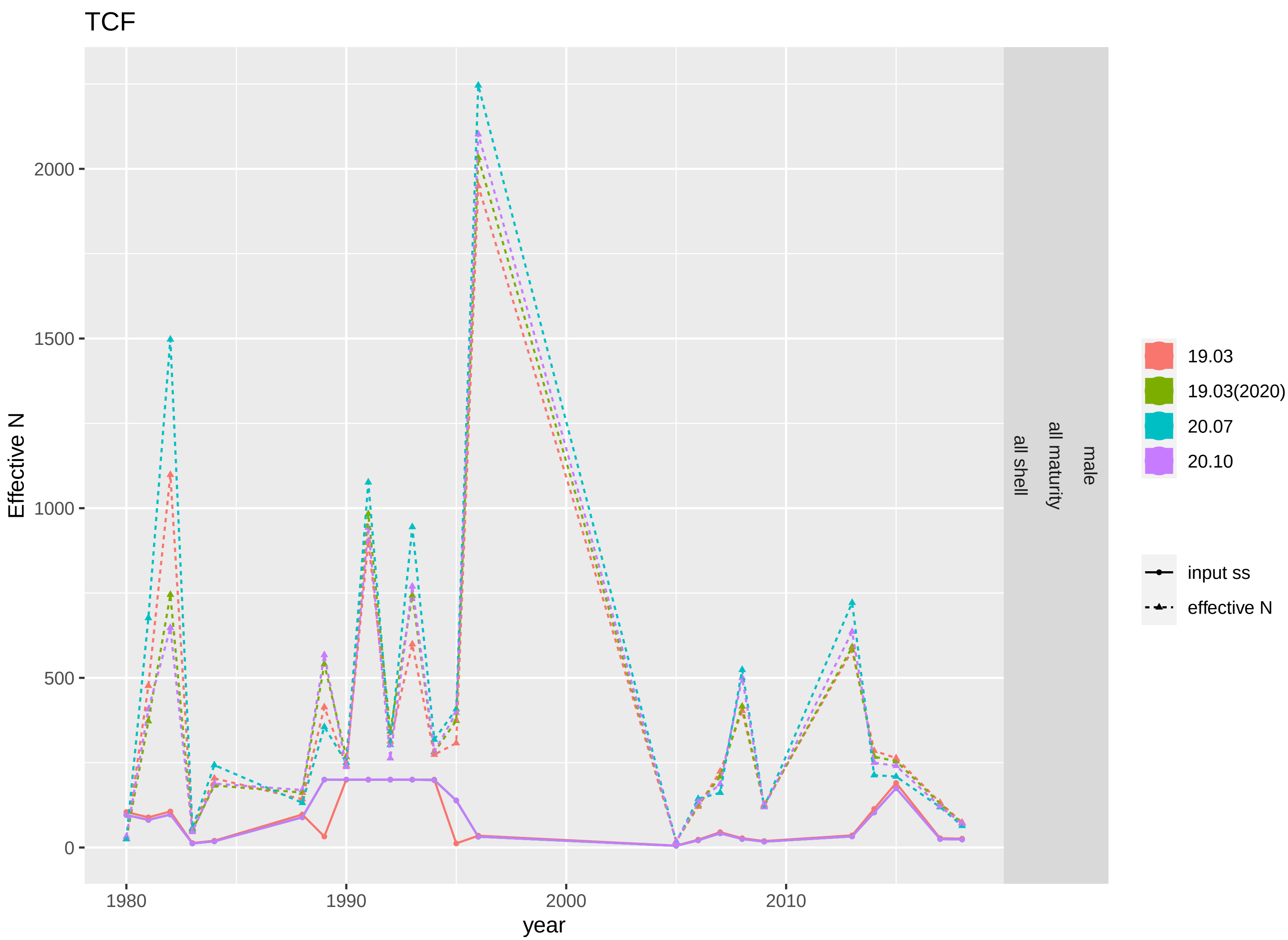


Figure 10: Input and effective sample sizes from retained catch size compositions from the TCF fishery.

Total catch size composition residuals

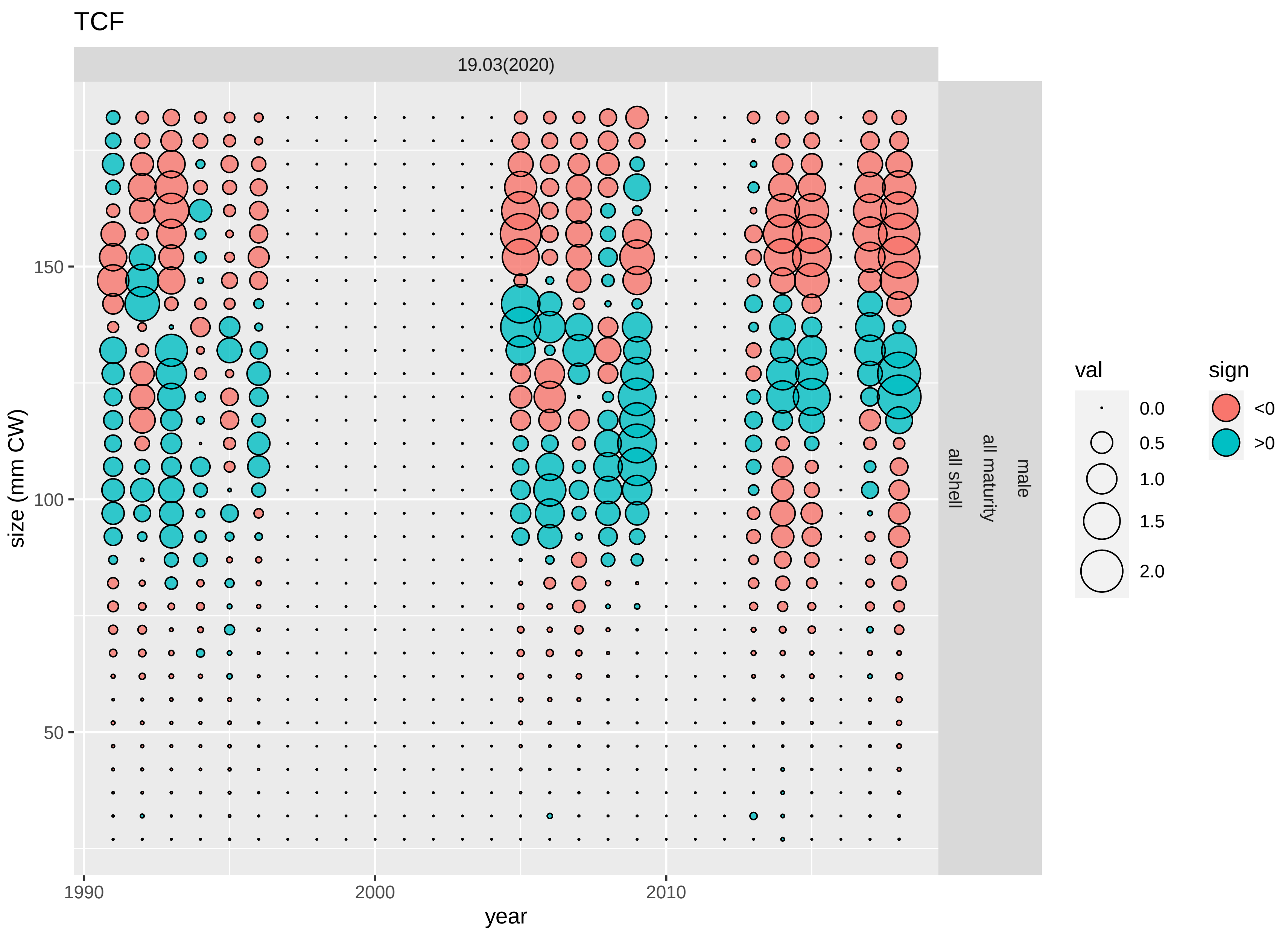


Figure 11: Pearson's residuals for male proportions-at-size from the TCF for scenario 19.03(2020).

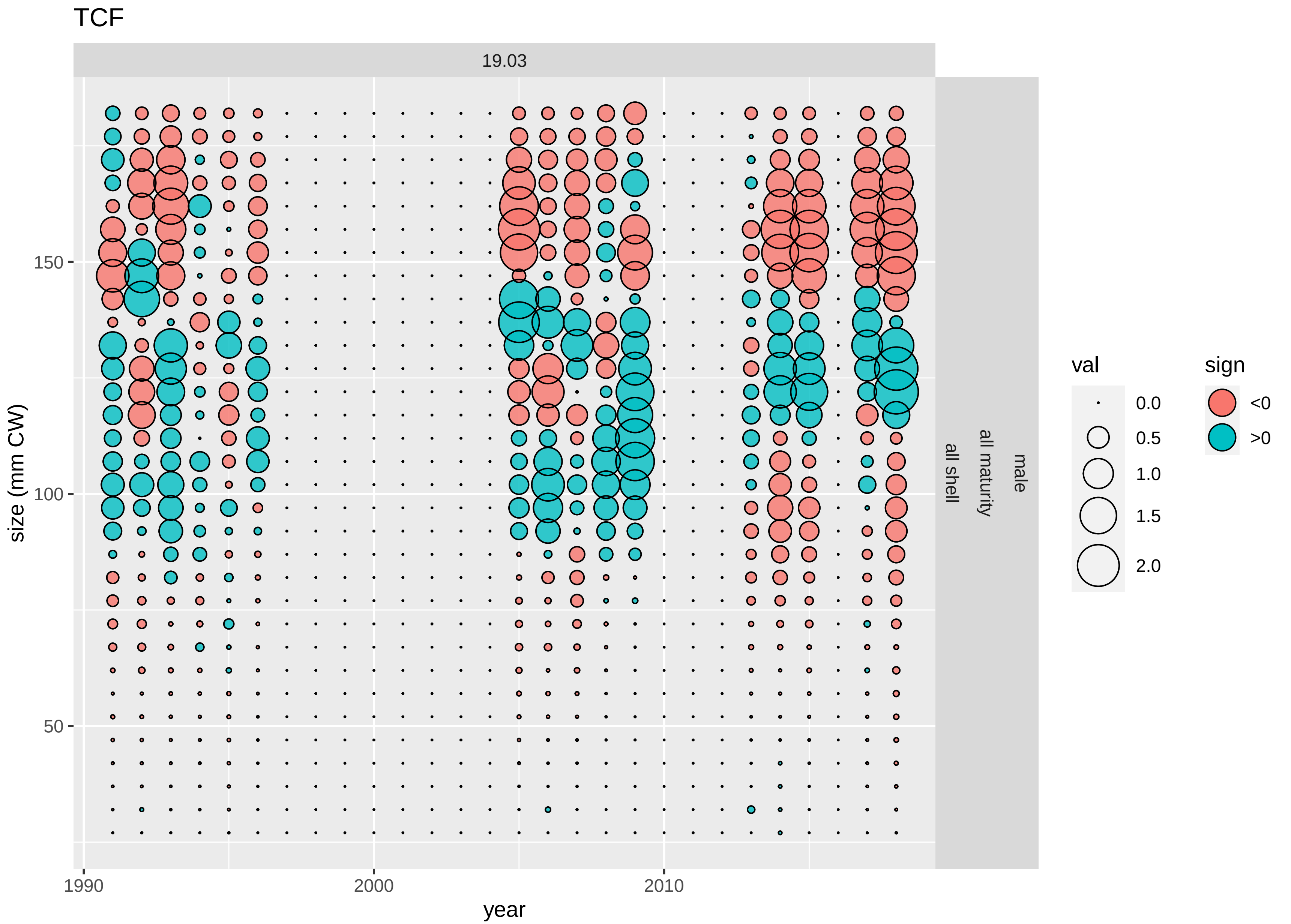


Figure 12: Pearson's residuals for male proportions-at-size from the TCF for scenario 19.03.

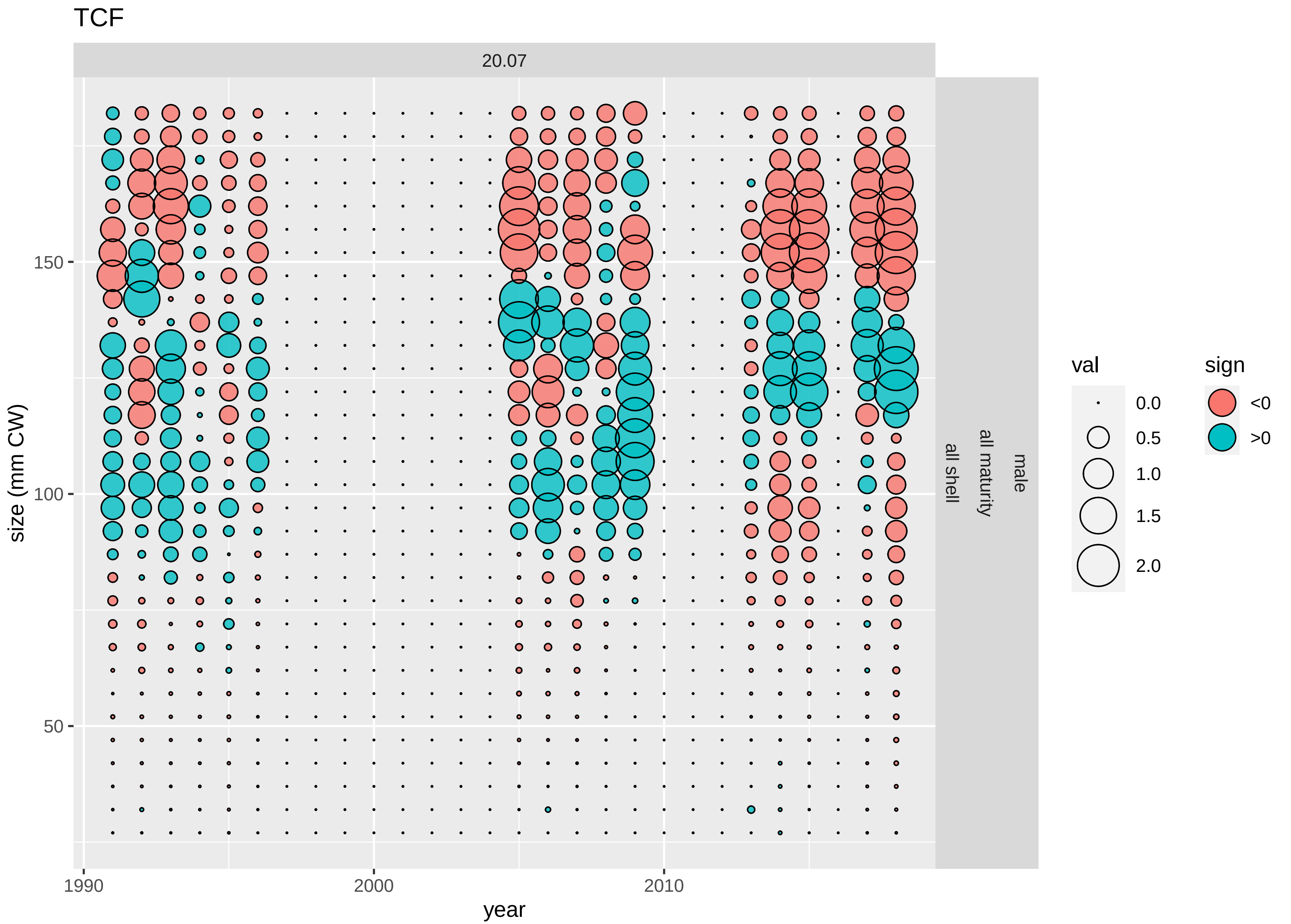


Figure 13: Pearson's residuals for male proportions-at-size from the TCF for scenario 20.07.

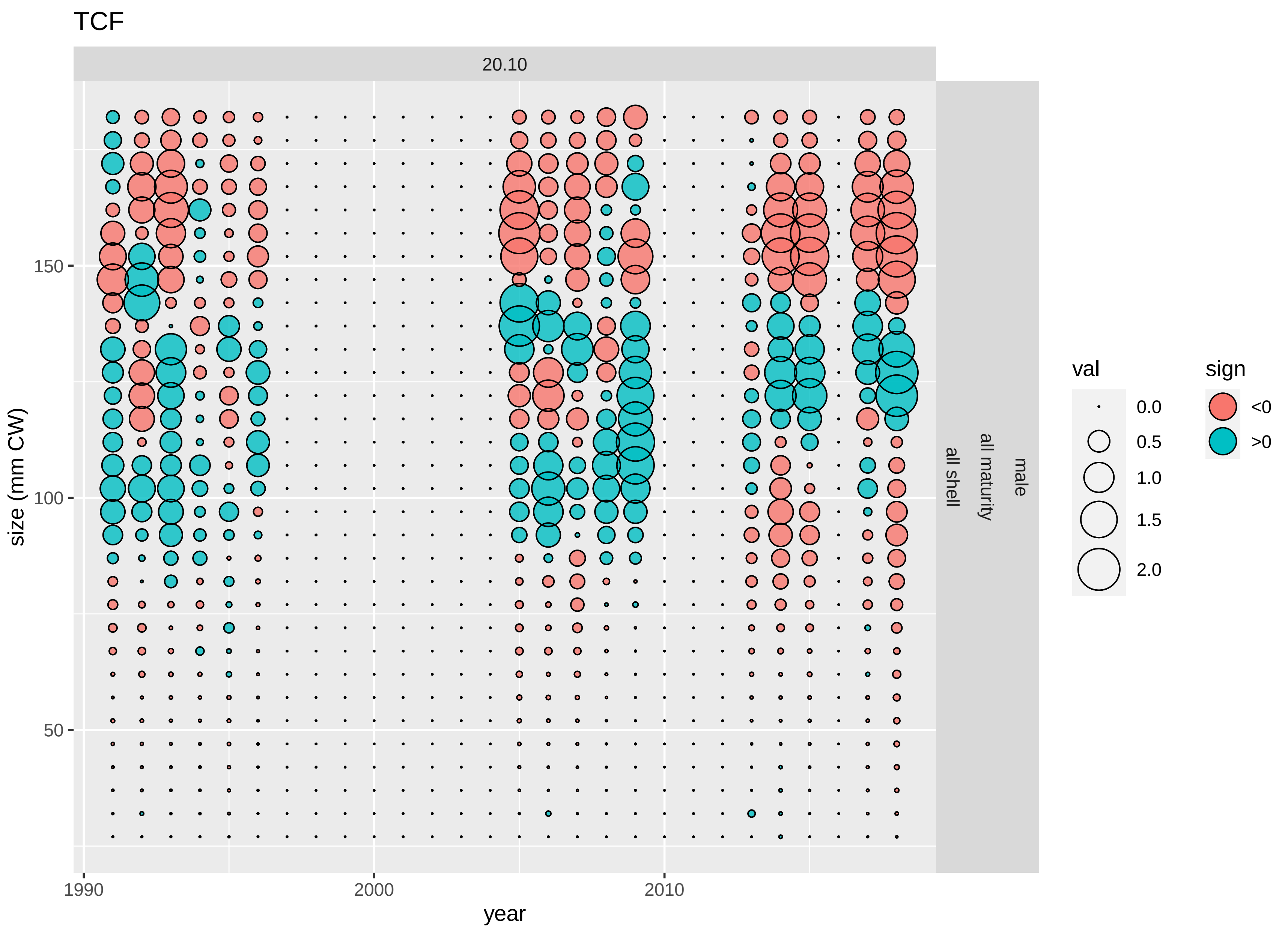


Figure 14: Pearson's residuals for male proportions-at-size from the TCF for scenario 20.10.

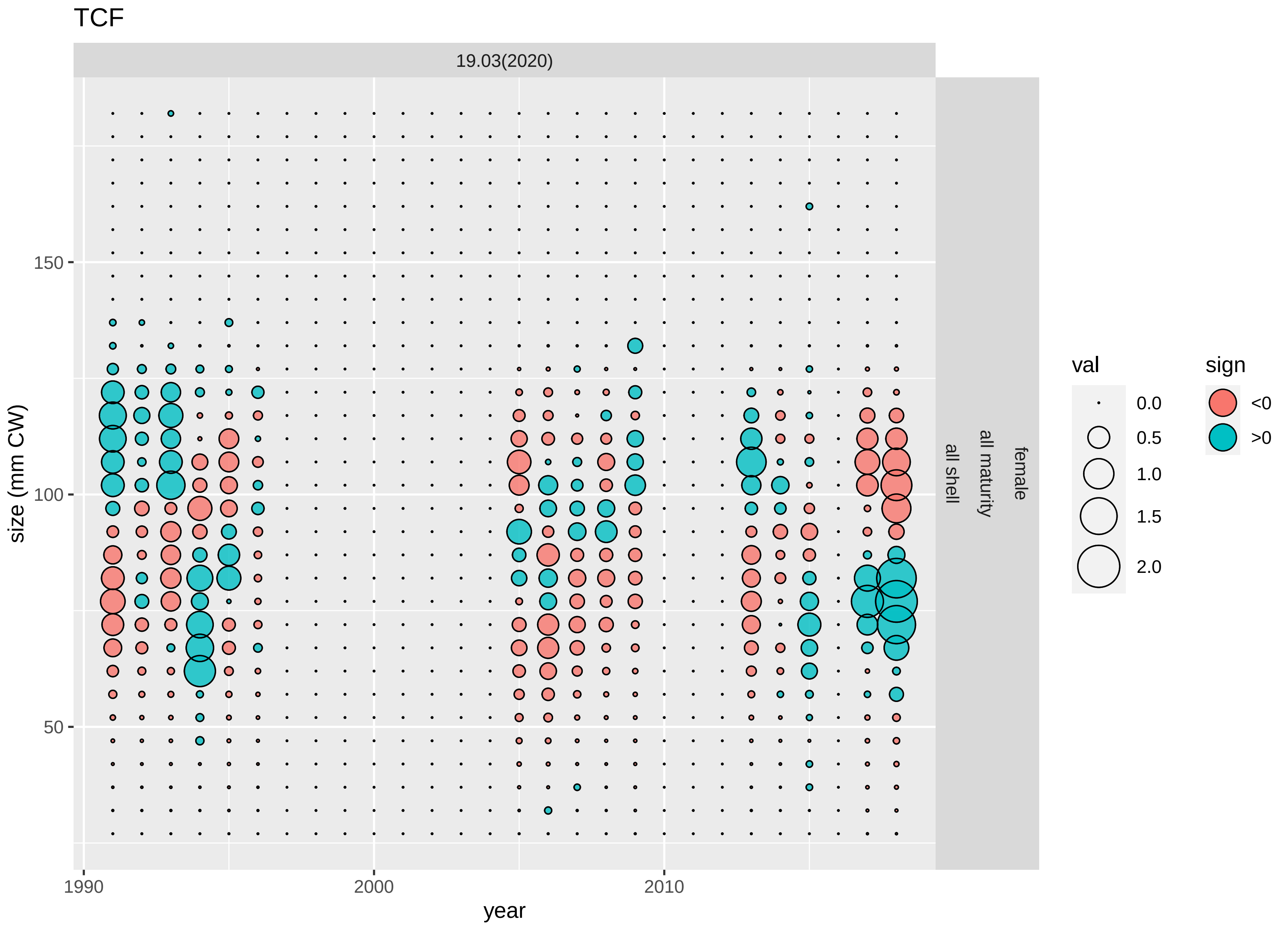


Figure 15: Pearson's residuals for female proportions-at-size from the TCF for scenario 19.03(2020).

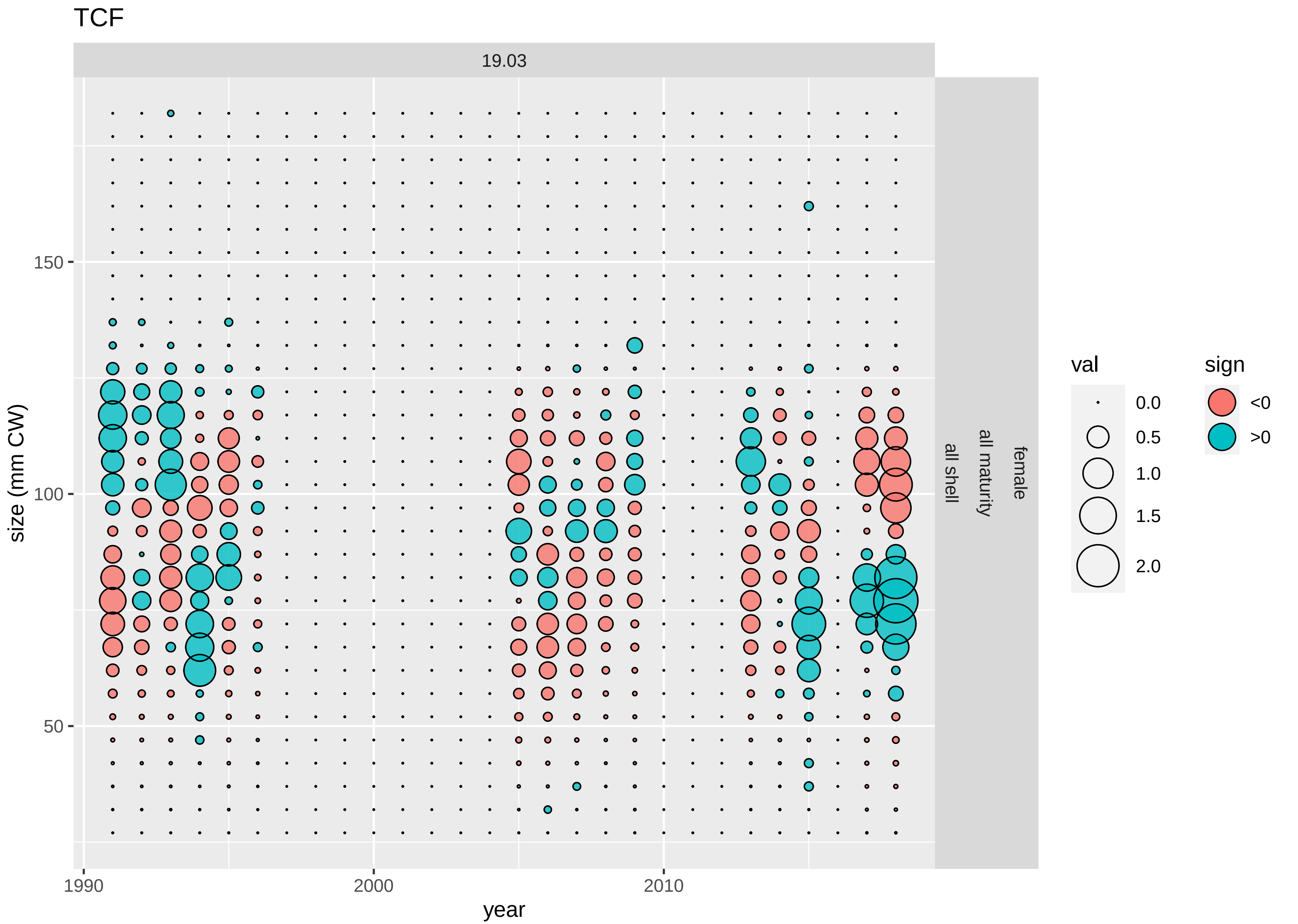


Figure 16: Pearson's residuals for female proportions-at-size from the TCF for scenario 19.03.

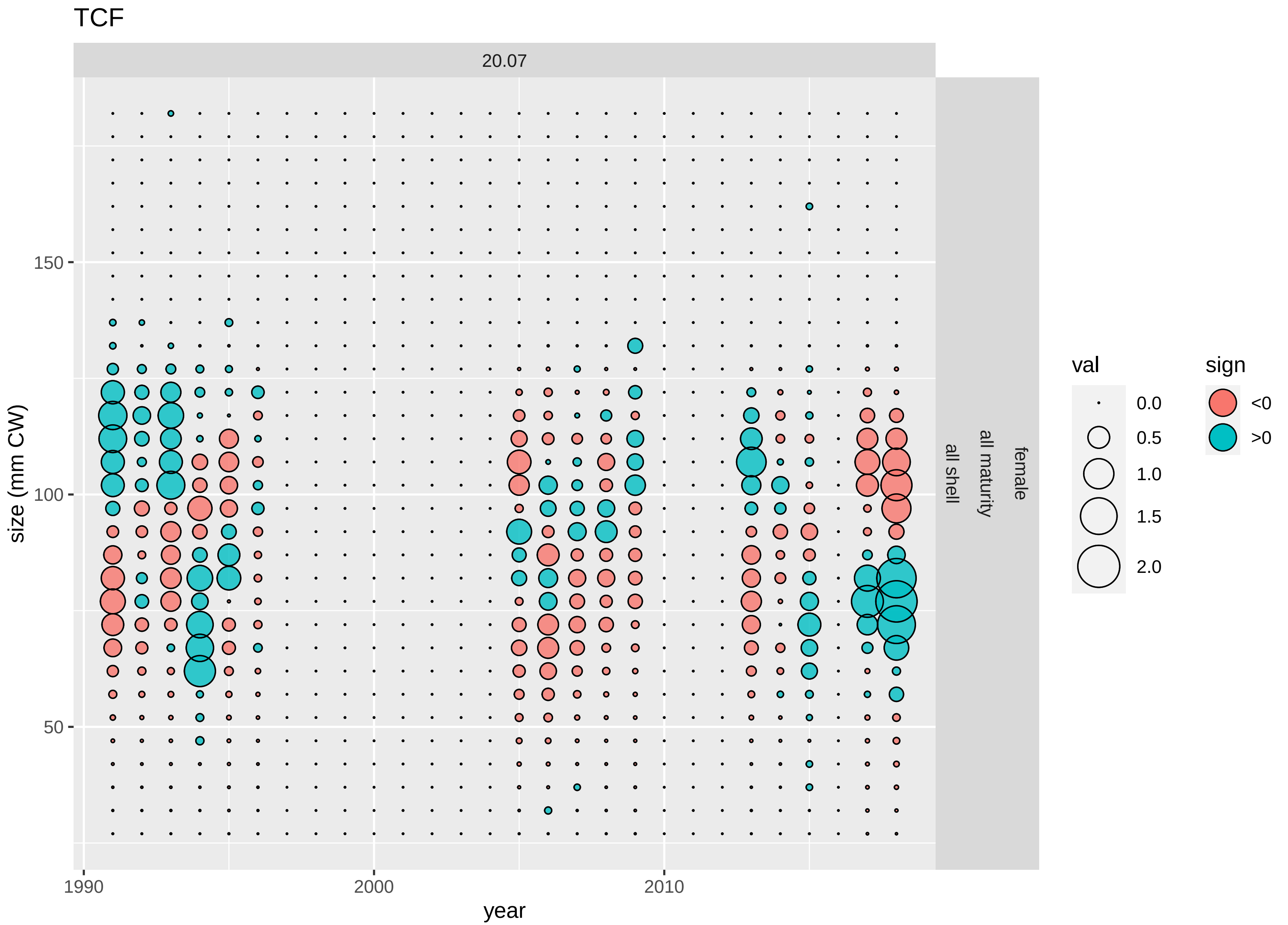


Figure 17: Pearson's residuals for female proportions-at-size from the TCF for scenario 20.07.

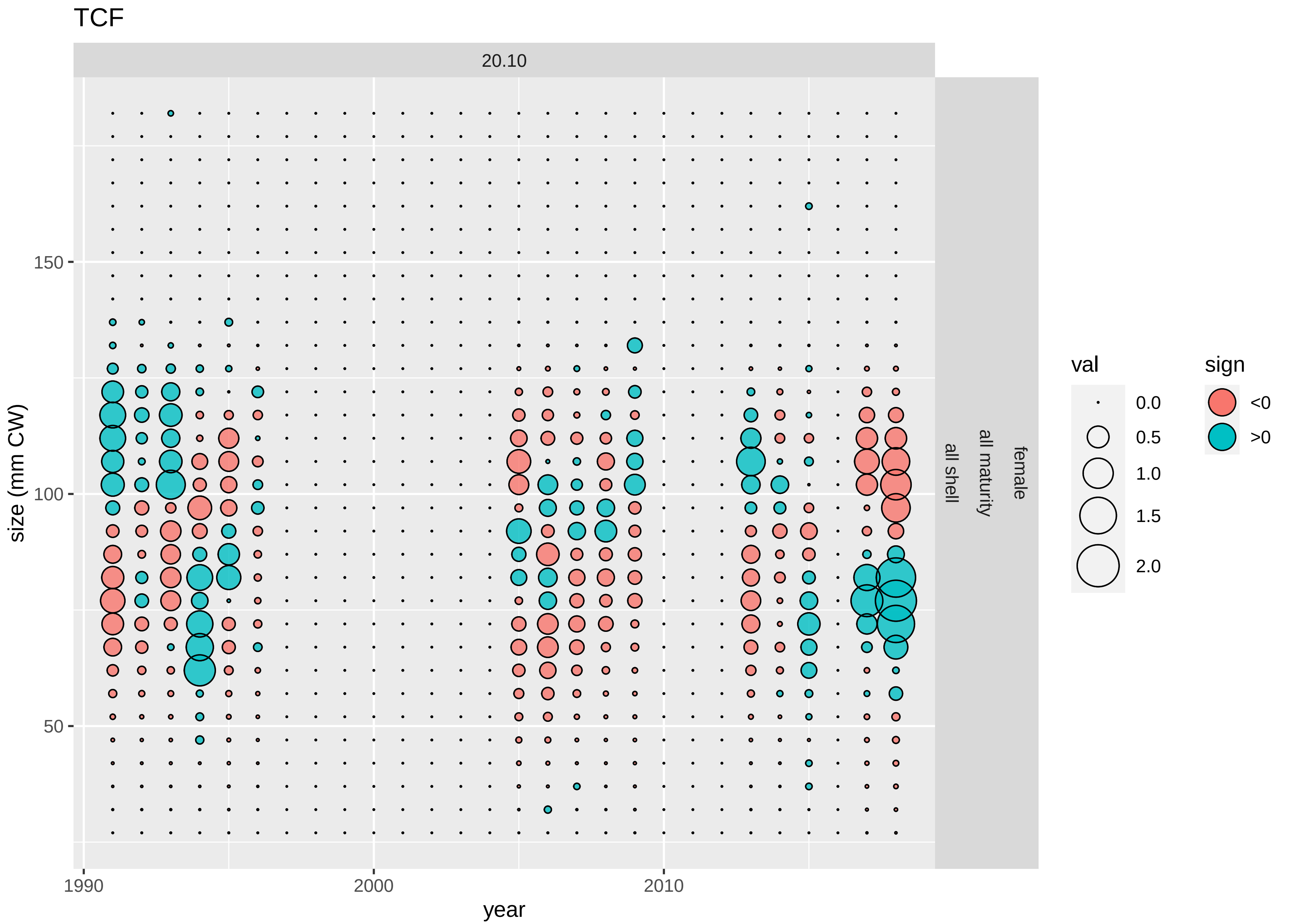


Figure 18: Pearson's residuals for female proportions-at-size from the TCF for scenario 20.10.

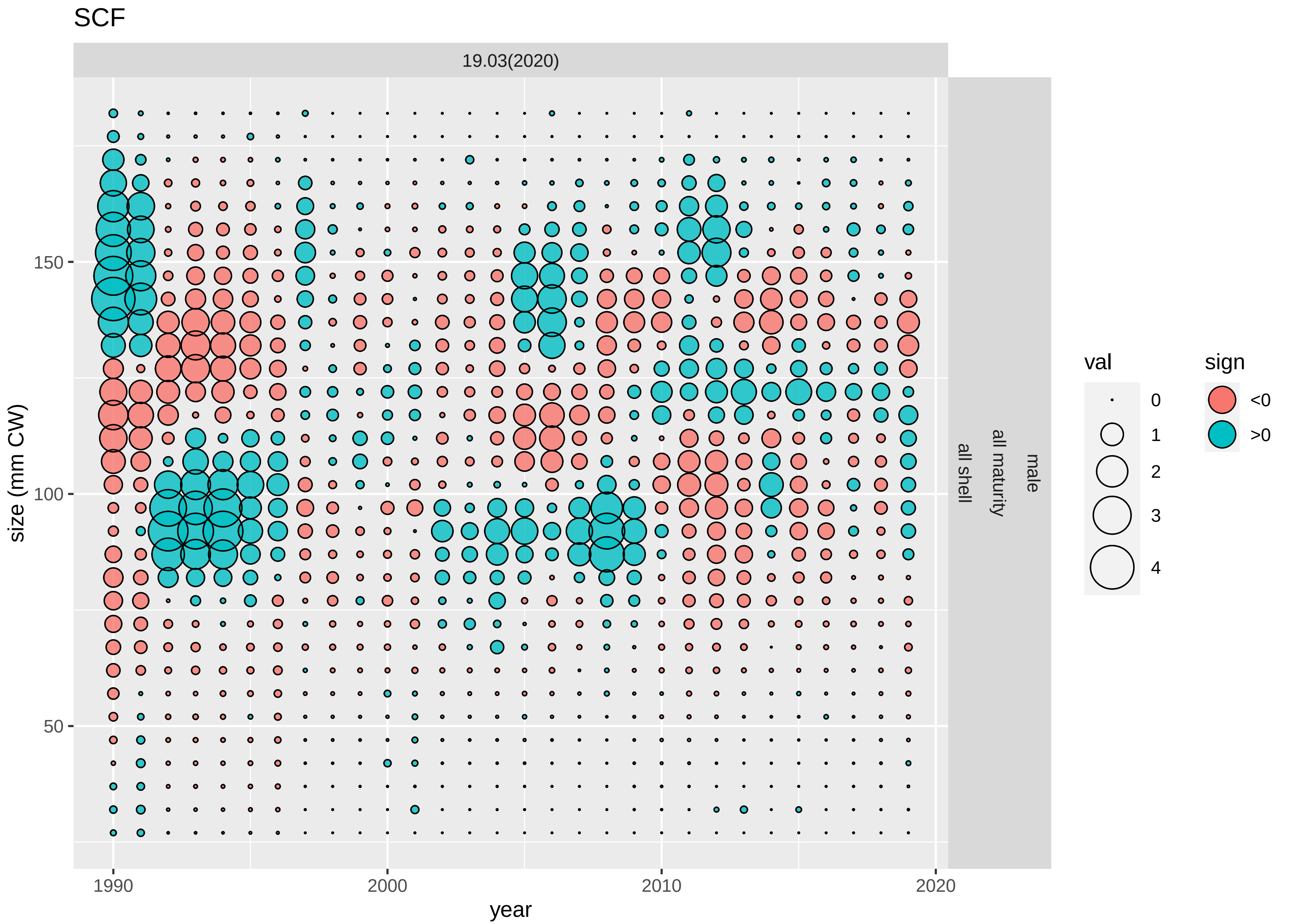


Figure 19: Pearson's residuals for male proportions-at-size from the SCF for scenario 19.03(2020).

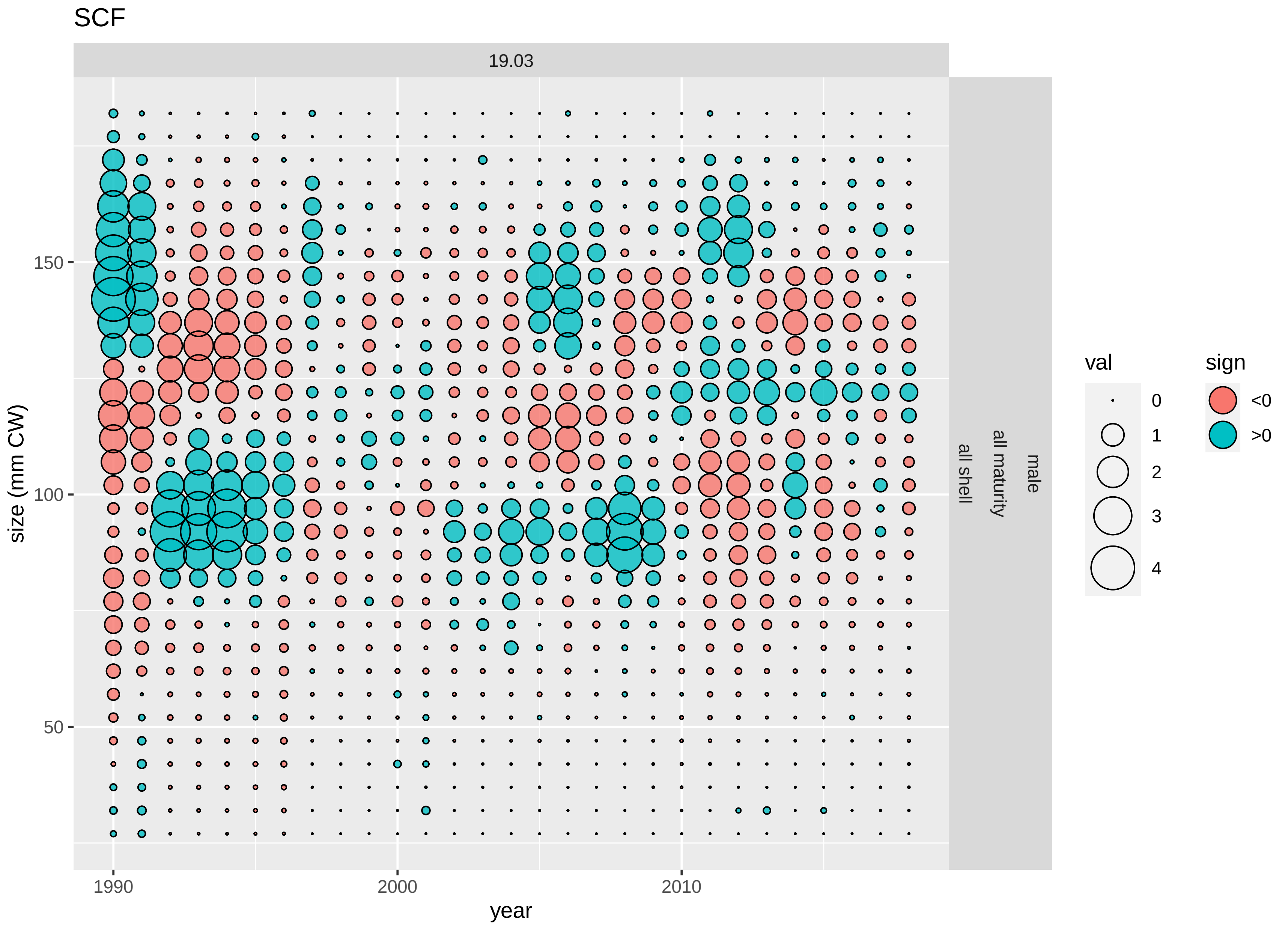


Figure 20: Pearson's residuals for male proportions-at-size from the SCF for scenario 19.03.

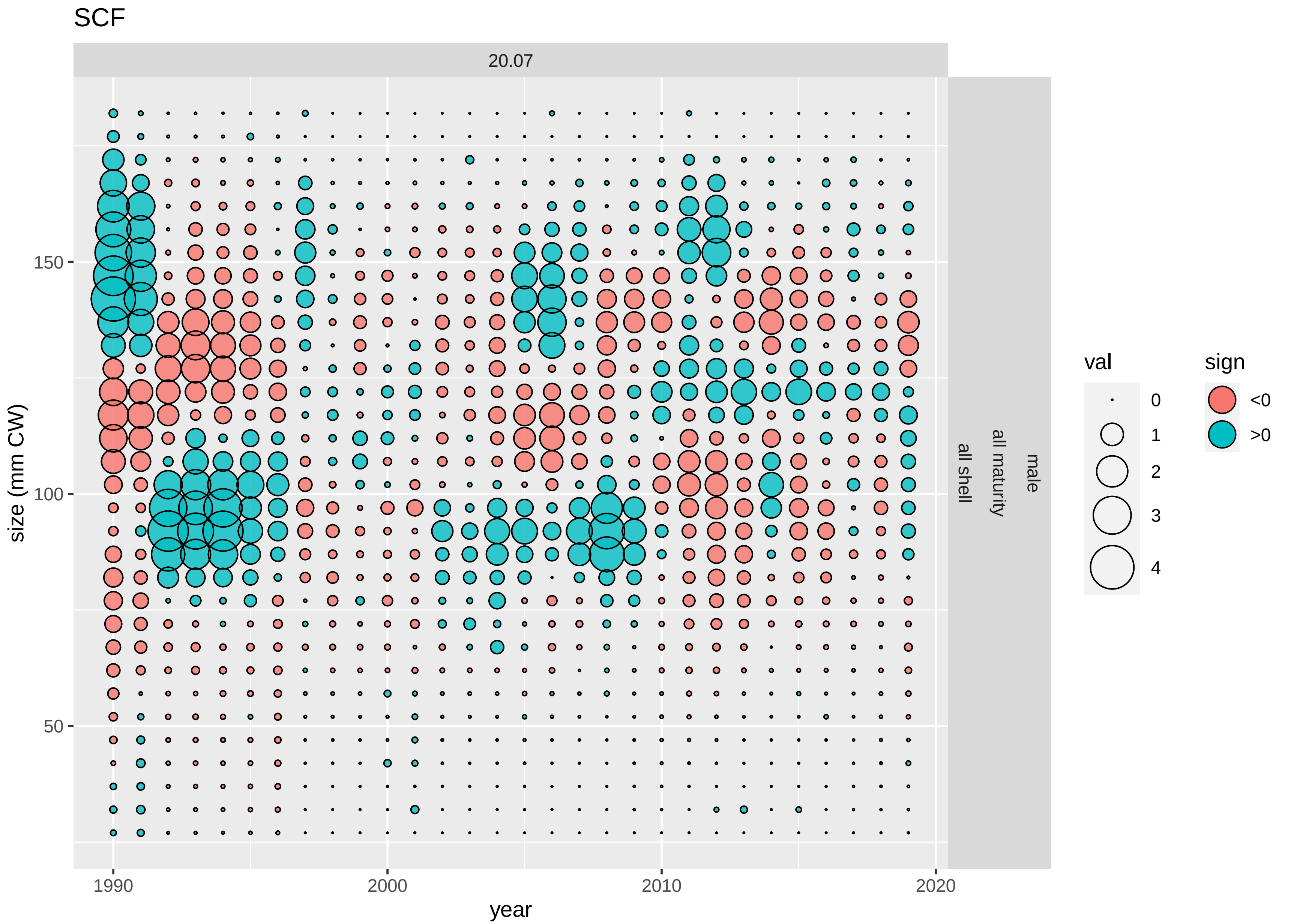


Figure 21: Pearson's residuals for male proportions-at-size from the SCF for scenario 20.07.

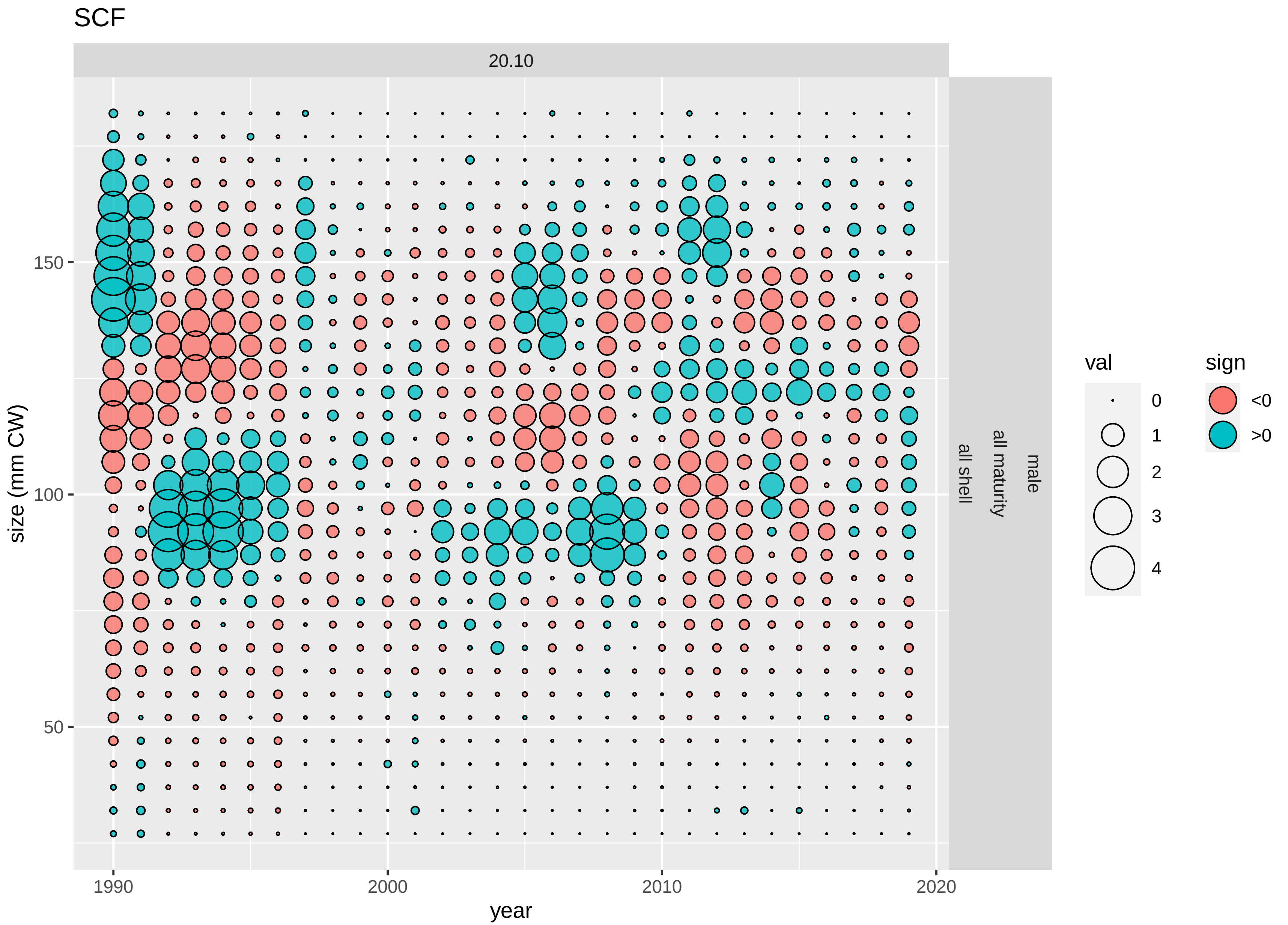


Figure 22: Pearson's residuals for male proportions-at-size from the SCF for scenario 20.10.

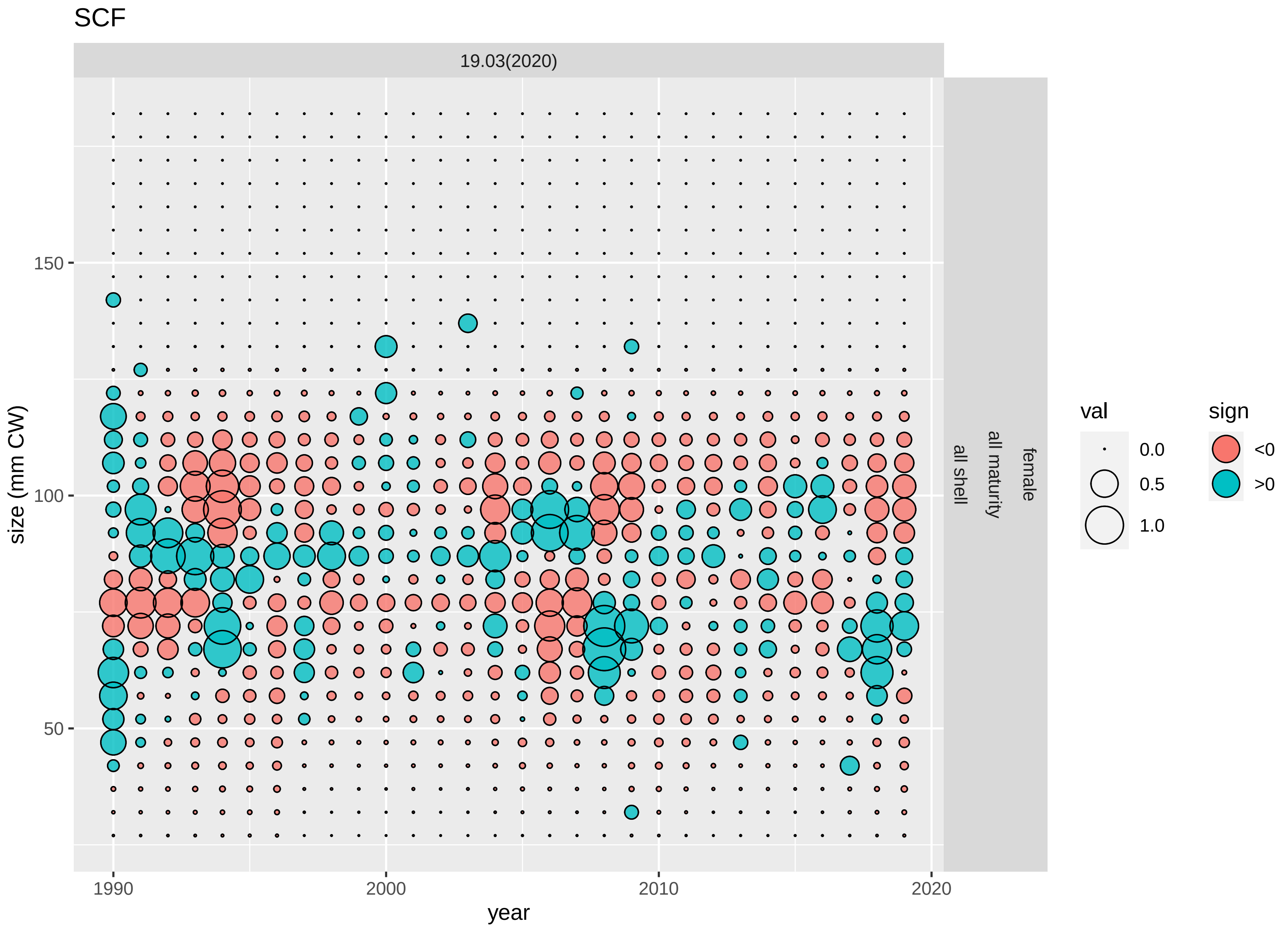


Figure 23: Pearson's residuals for female proportions-at-size from the SCF for scenario 19.03(2020).

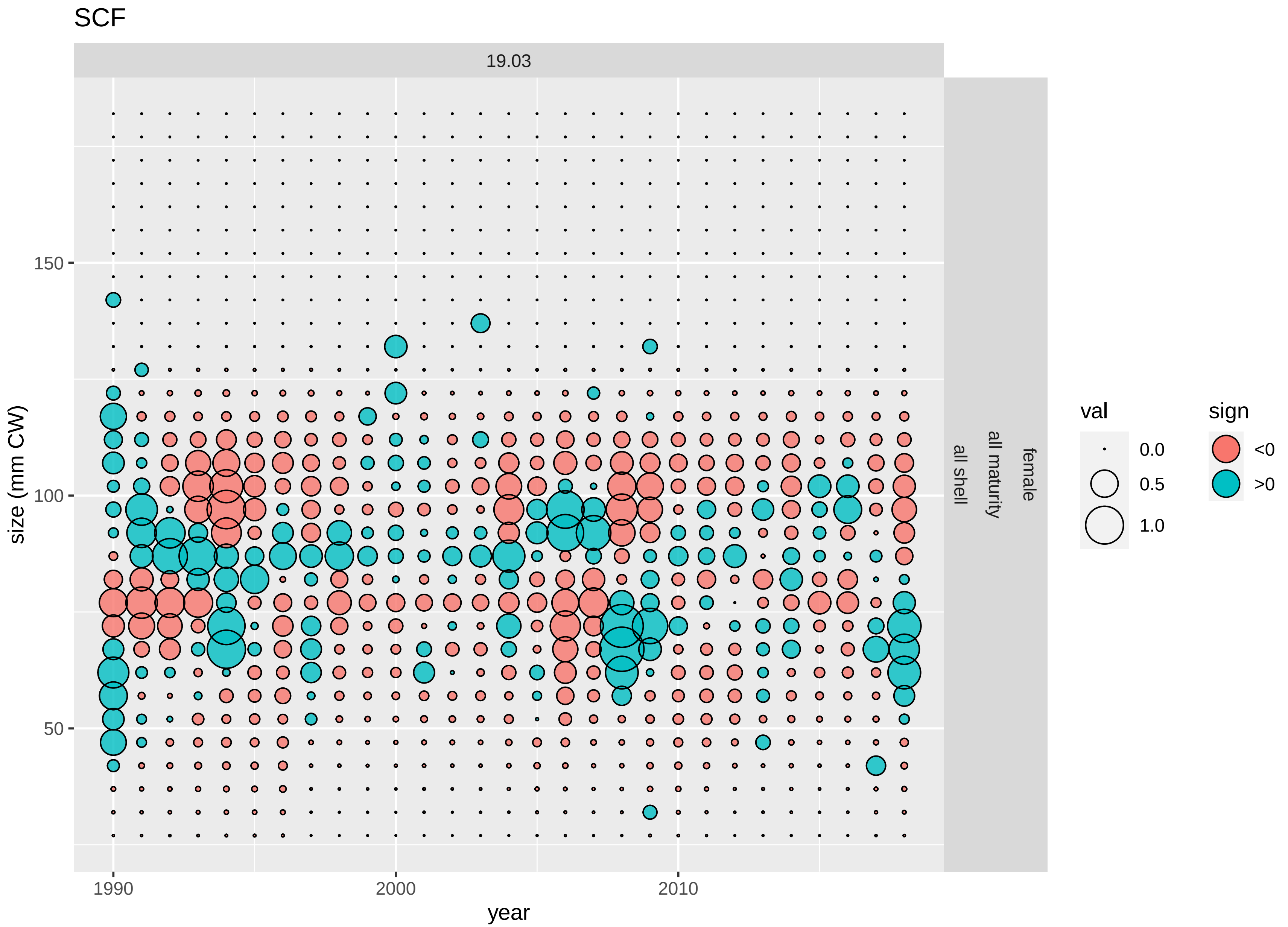


Figure 24: Pearson's residuals for female proportions-at-size from the SCF for scenario 19.03.

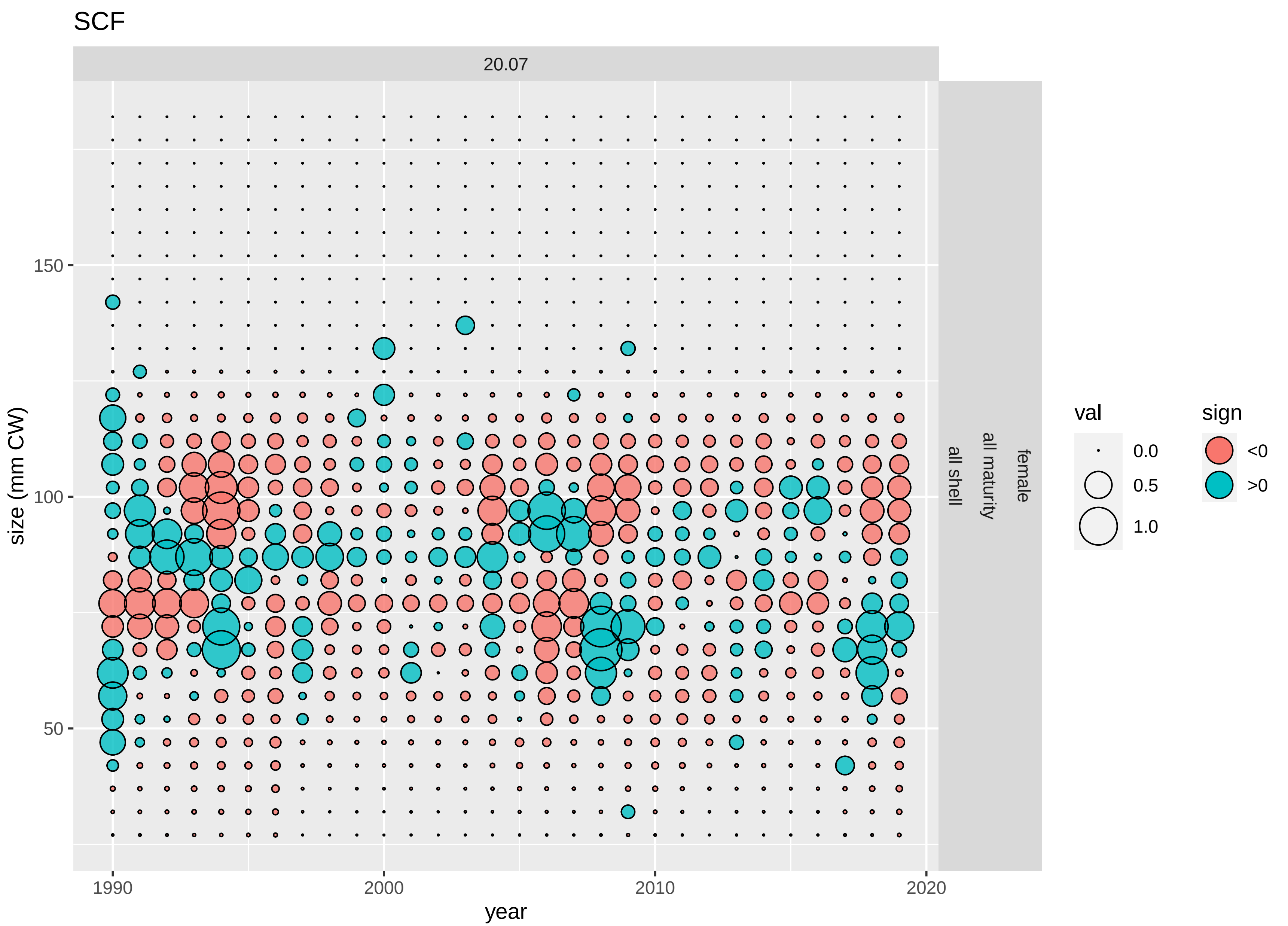


Figure 25: Pearson's residuals for female proportions-at-size from the SCF for scenario 20.07.

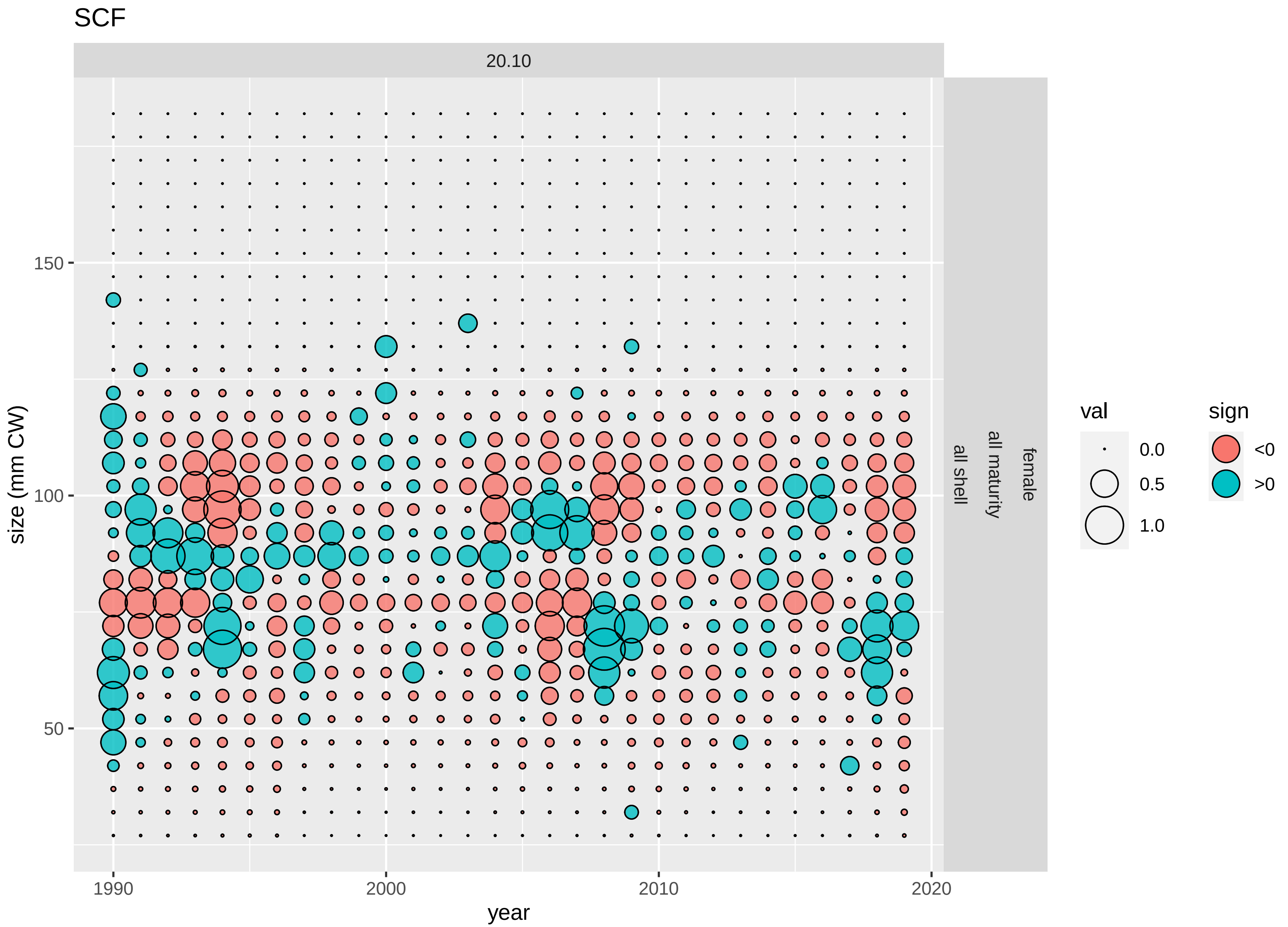


Figure 26: Pearson's residuals for female proportions-at-size from the SCF for scenario 20.10.

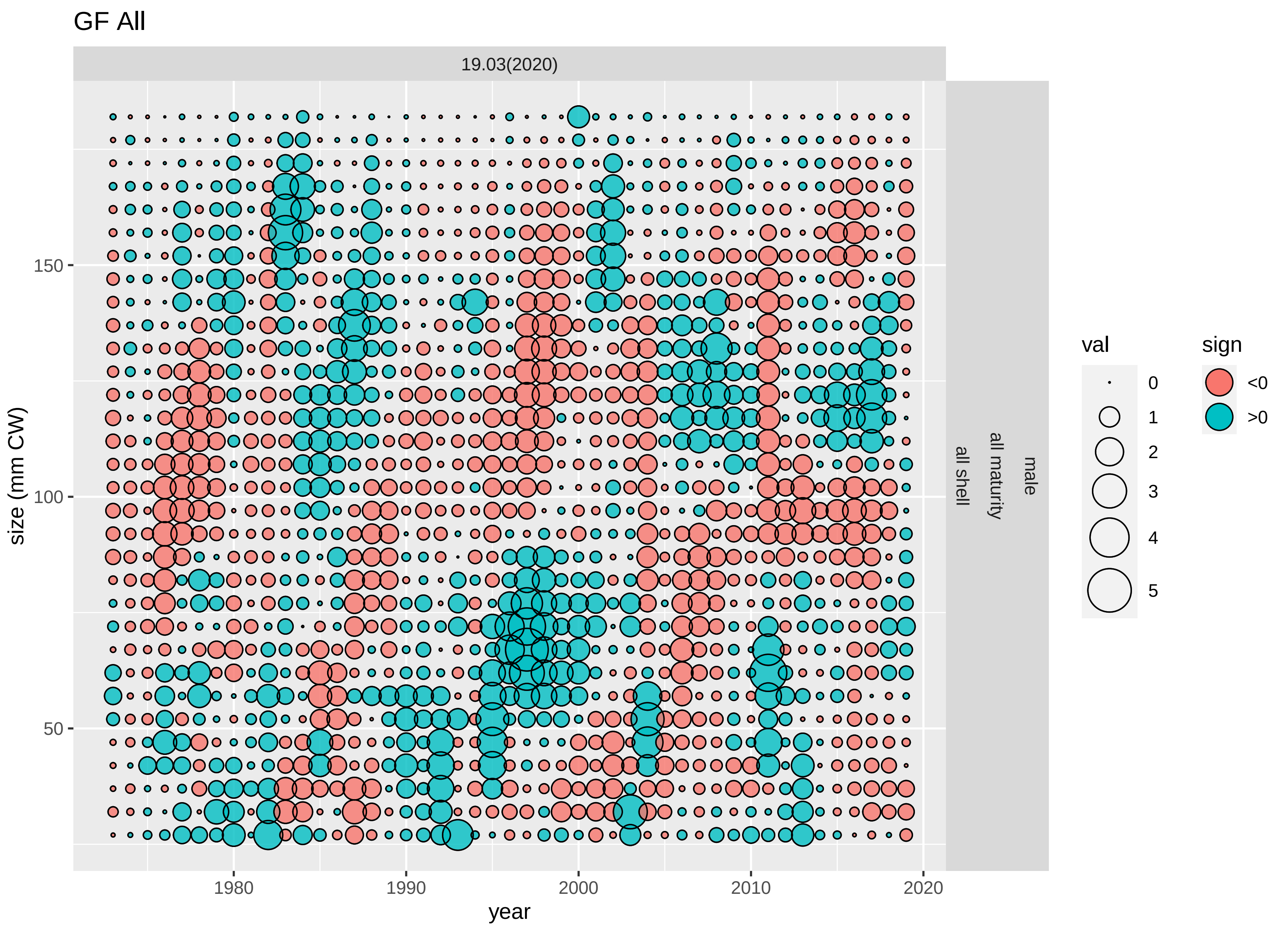


Figure 27: Pearson's residuals for male proportions-at-size from the GF All for scenario 19.03(2020).

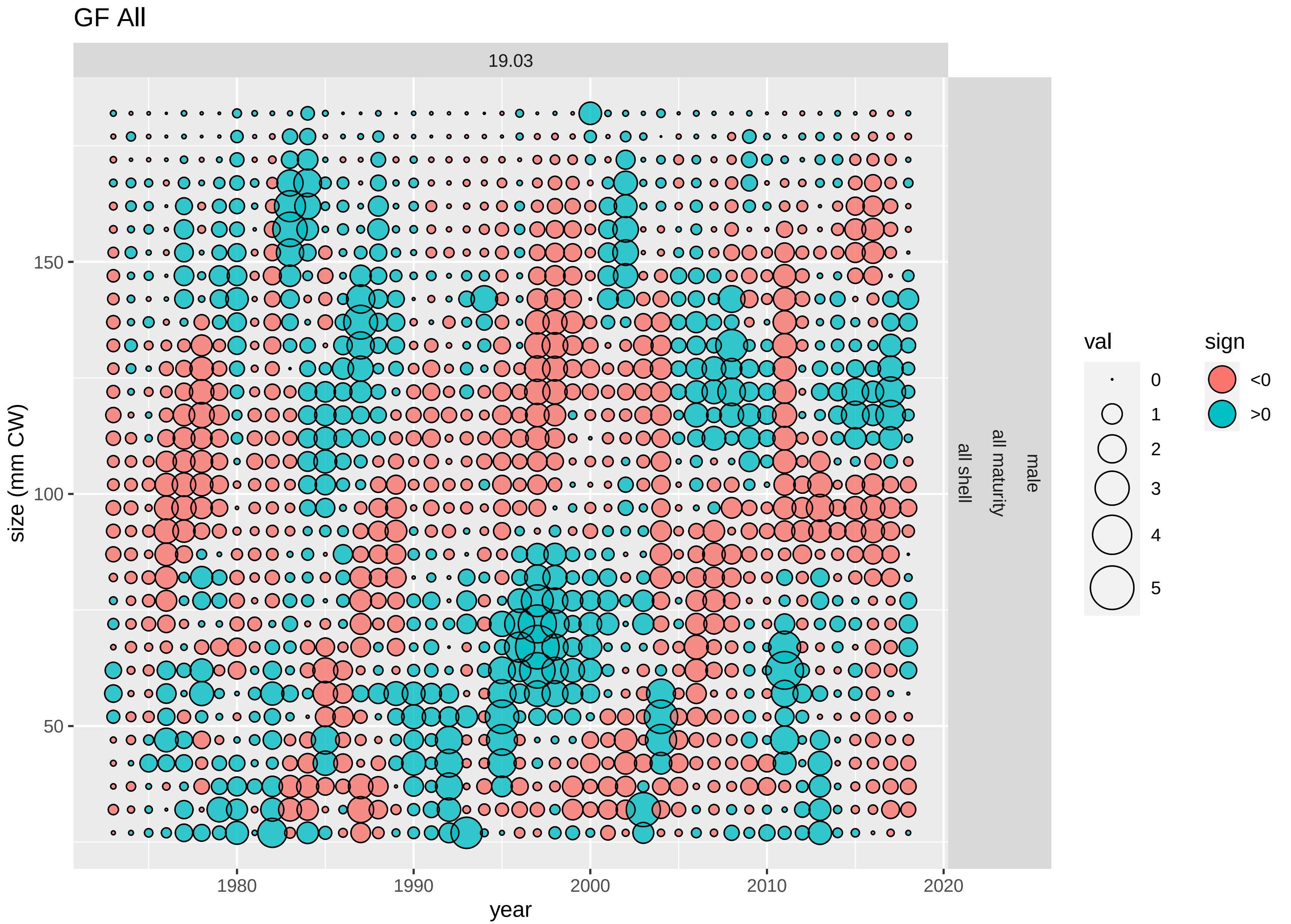


Figure 28: Pearson's residuals for male proportions-at-size from the GF All for scenario 19.03.

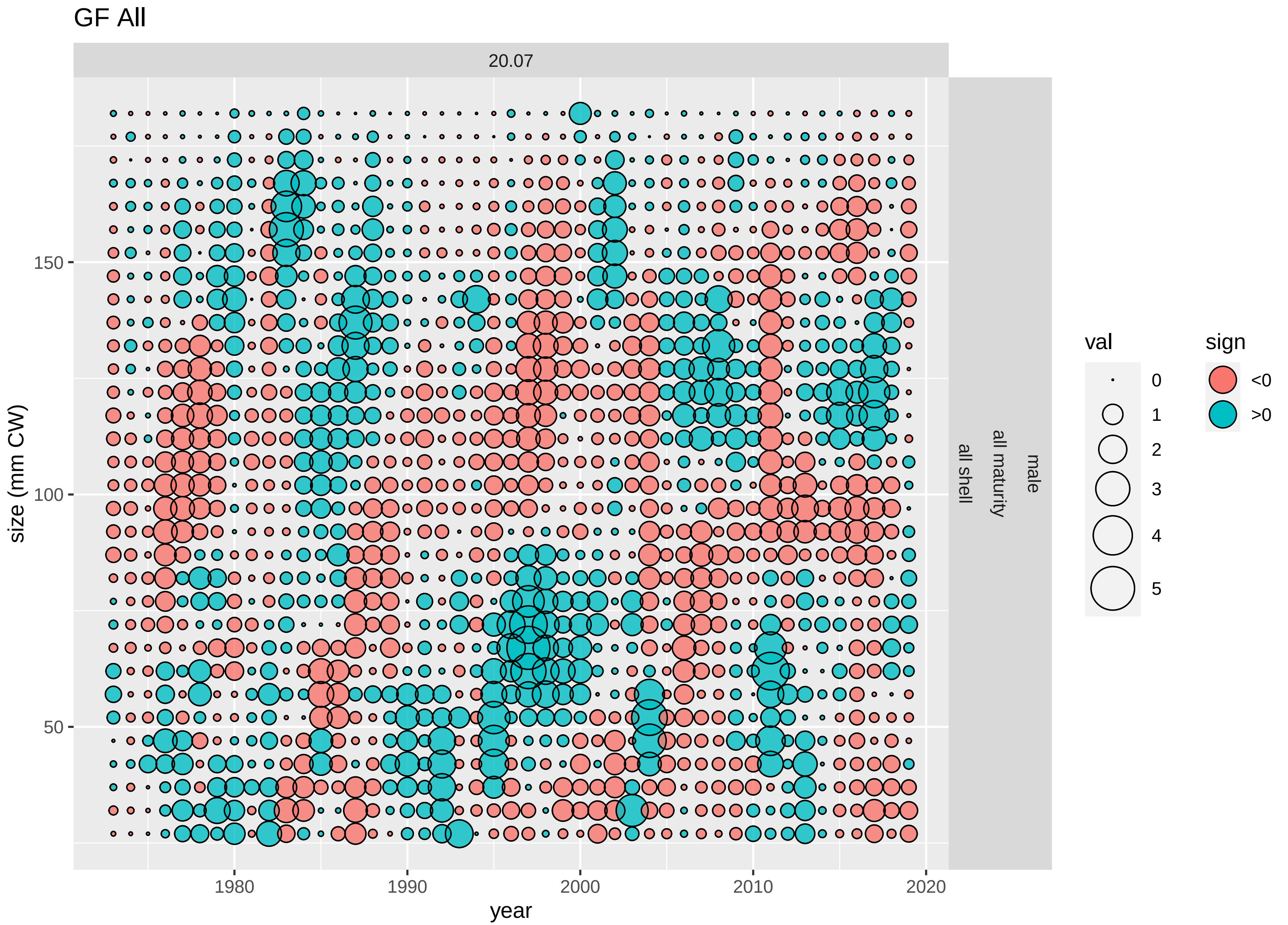


Figure 29: Pearson's residuals for male proportions-at-size from the GF All for scenario 20.07.

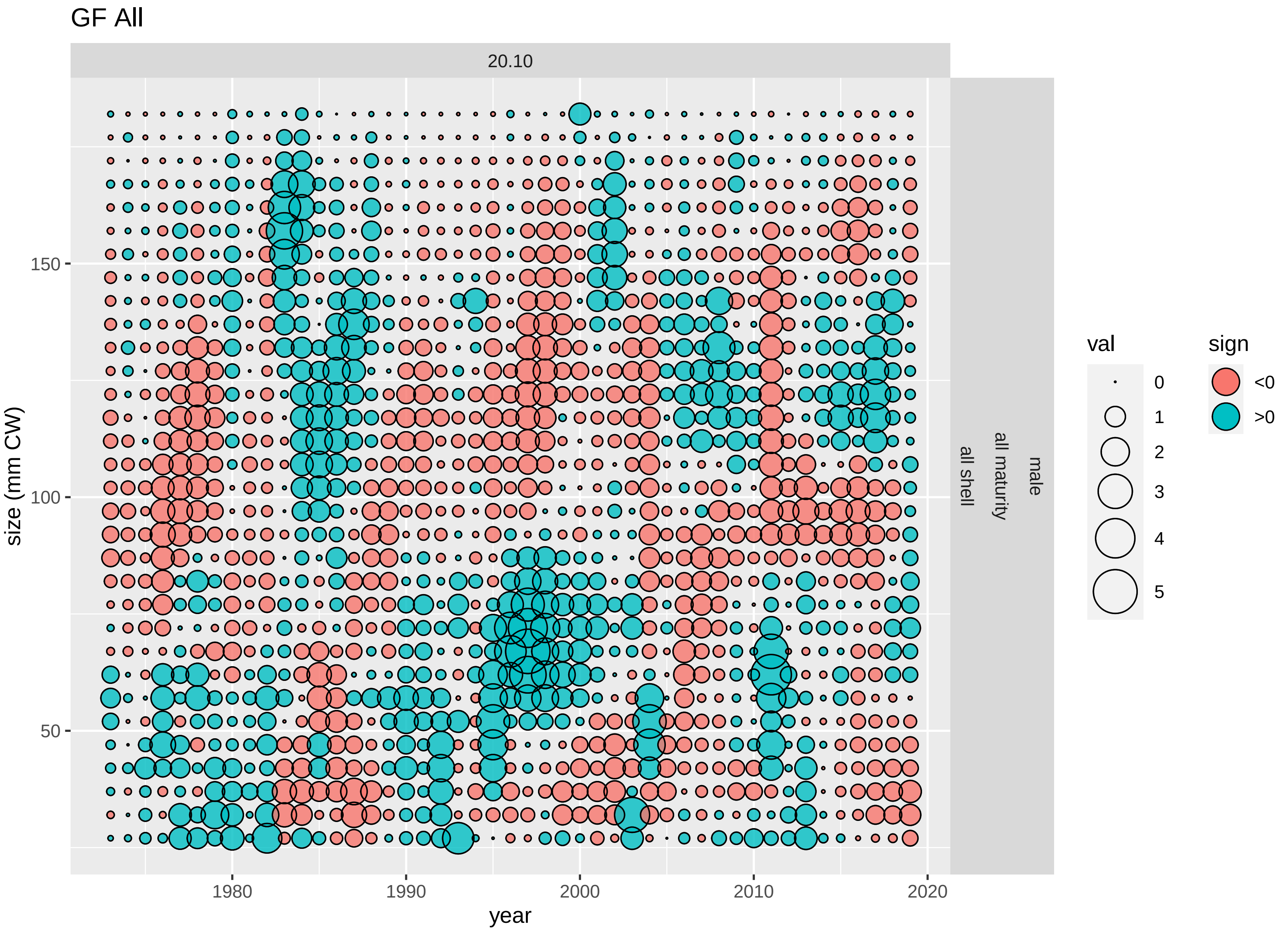


Figure 30: Pearson's residuals for male proportions-at-size from the GF All for scenario 20.10.

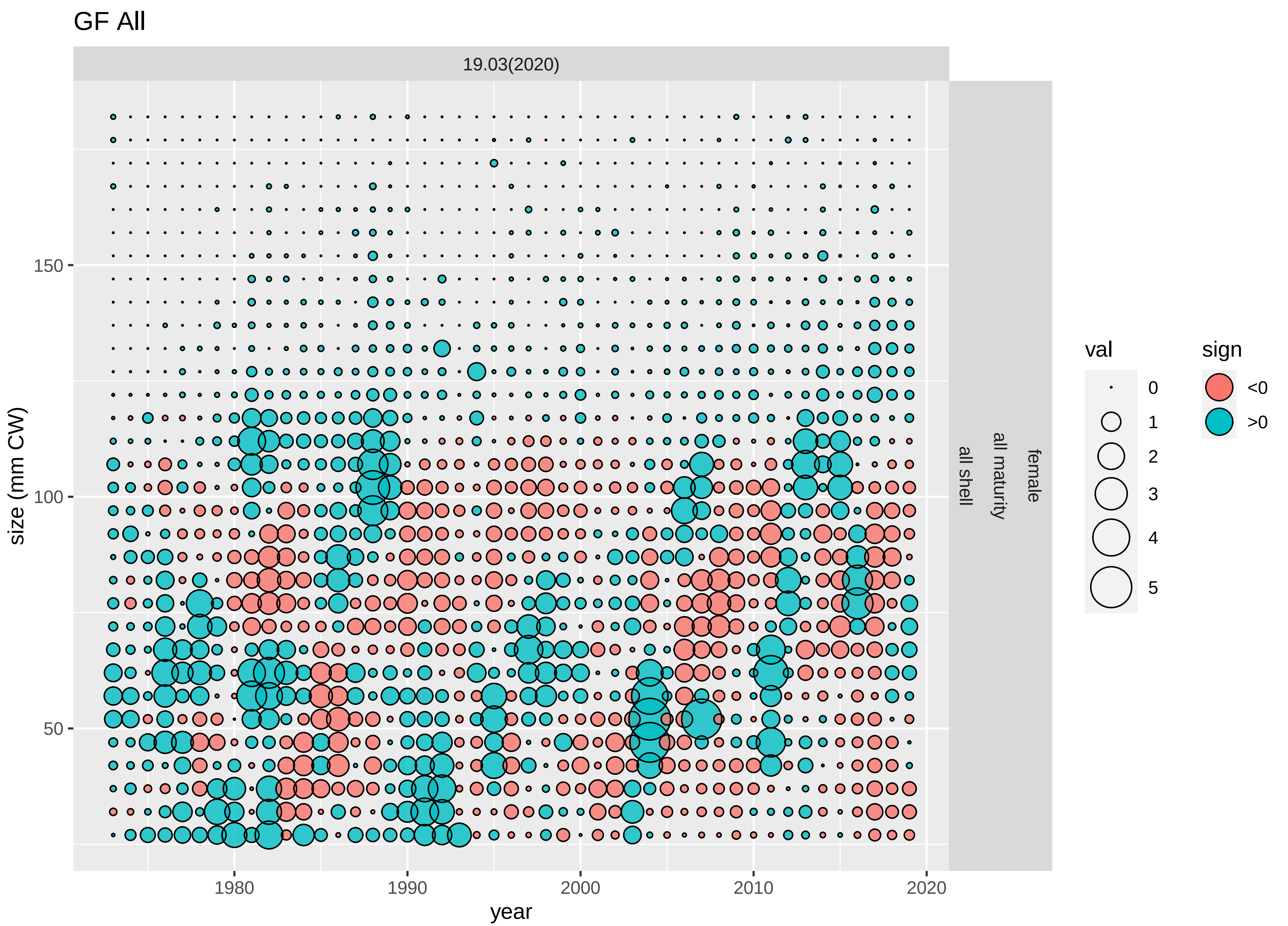


Figure 31: Pearson's residuals for female proportions-at-size from the GF All for scenario 19.03(2020).

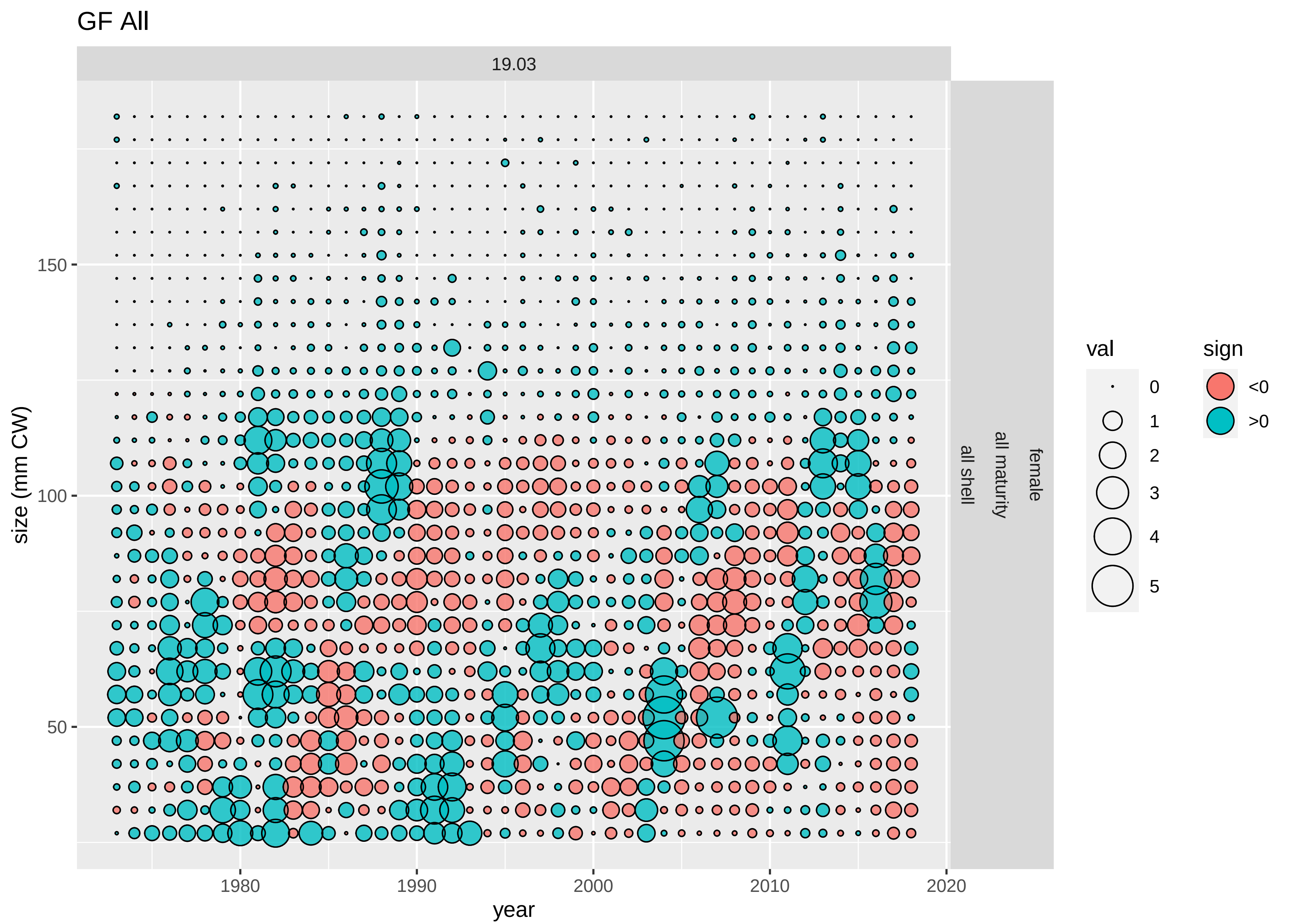


Figure 32: Pearson's residuals for female proportions-at-size from the GF All for scenario 19.03.

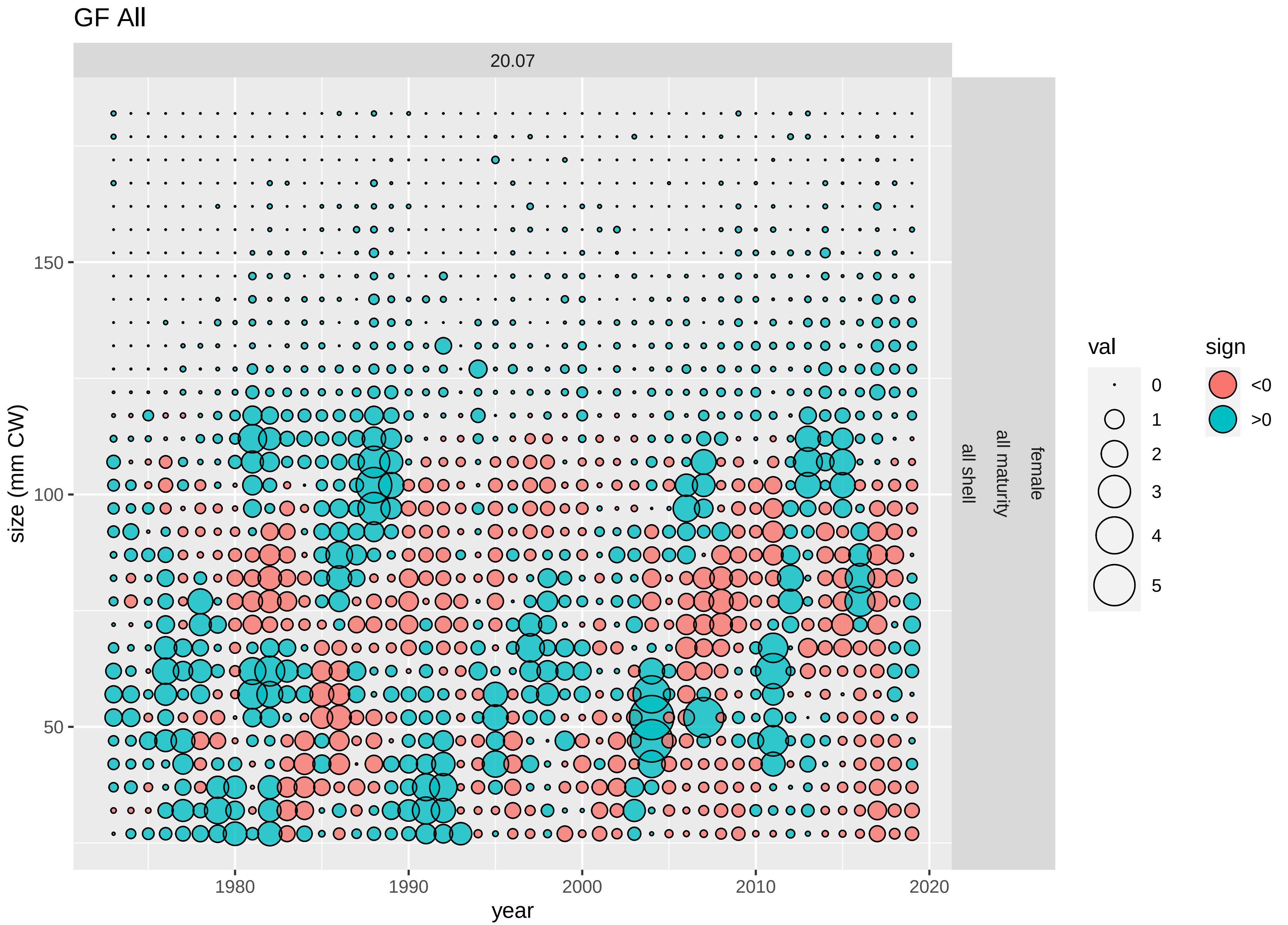


Figure 33: Pearson's residuals for female proportions-at-size from the GF All for scenario 20.07.

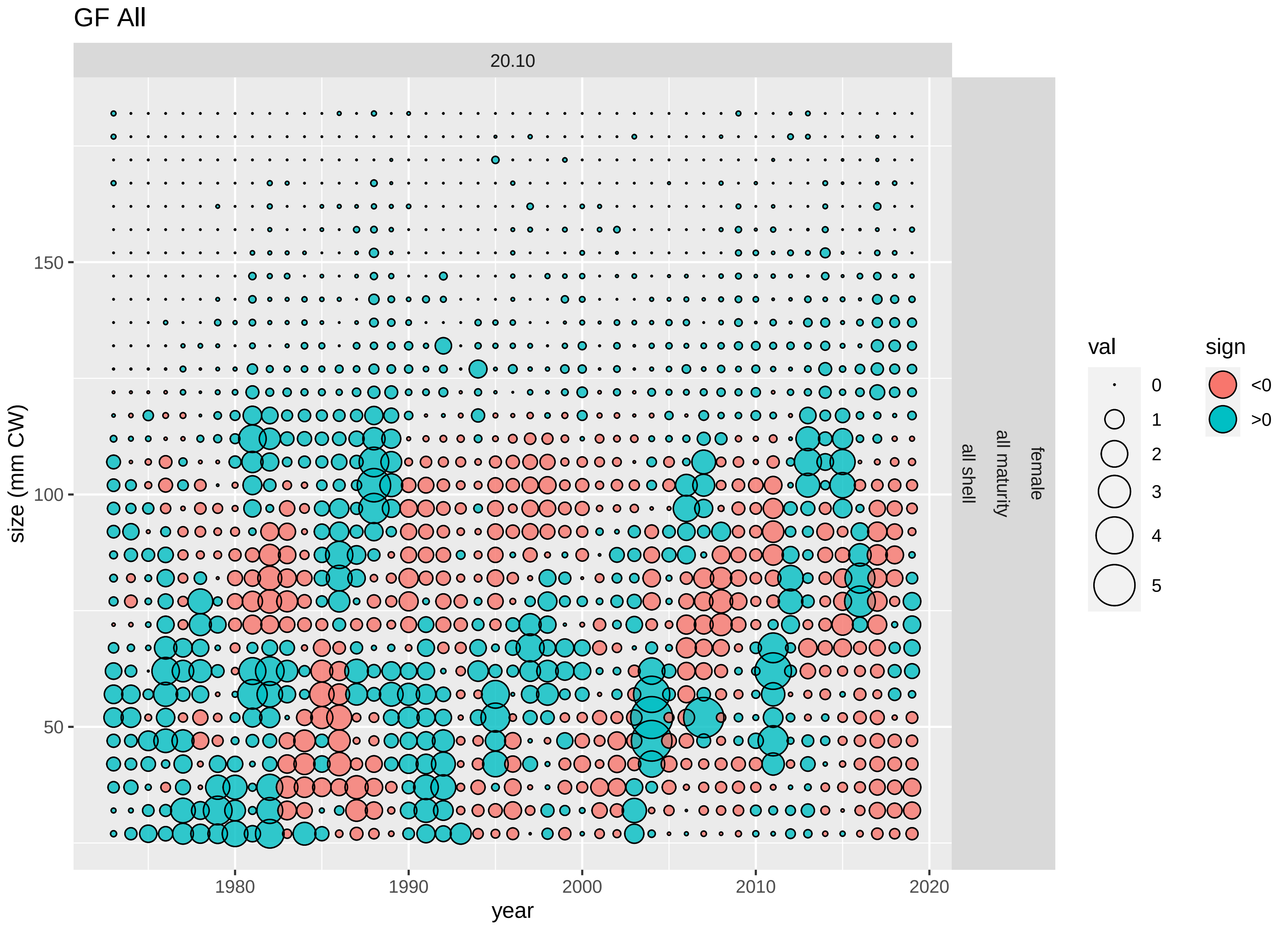


Figure 34: Pearson's residuals for female proportions-at-size from the GF All for scenario 20.10.

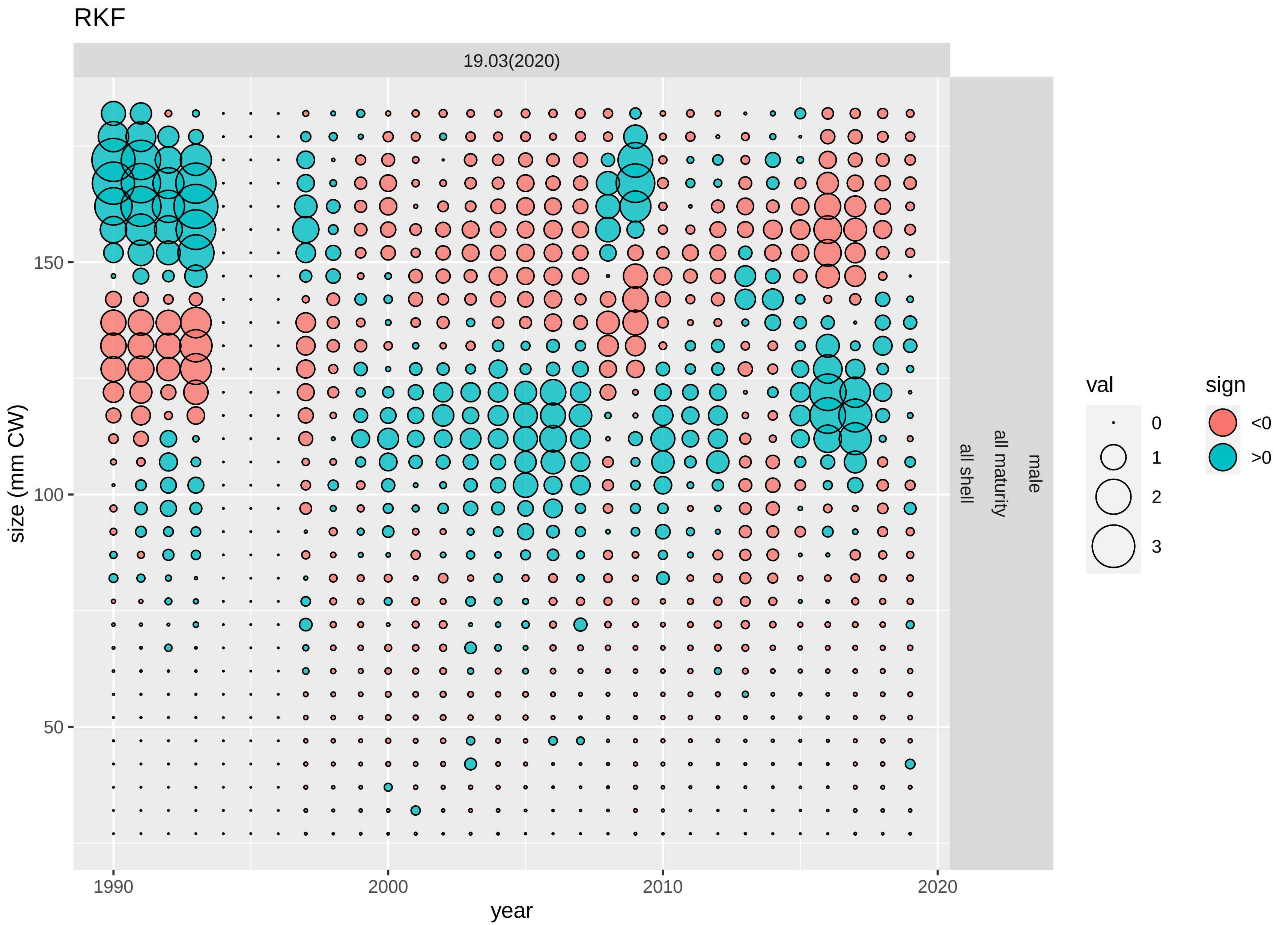


Figure 35: Pearson's residuals for male proportions-at-size from the RKF for scenario 19.03(2020).

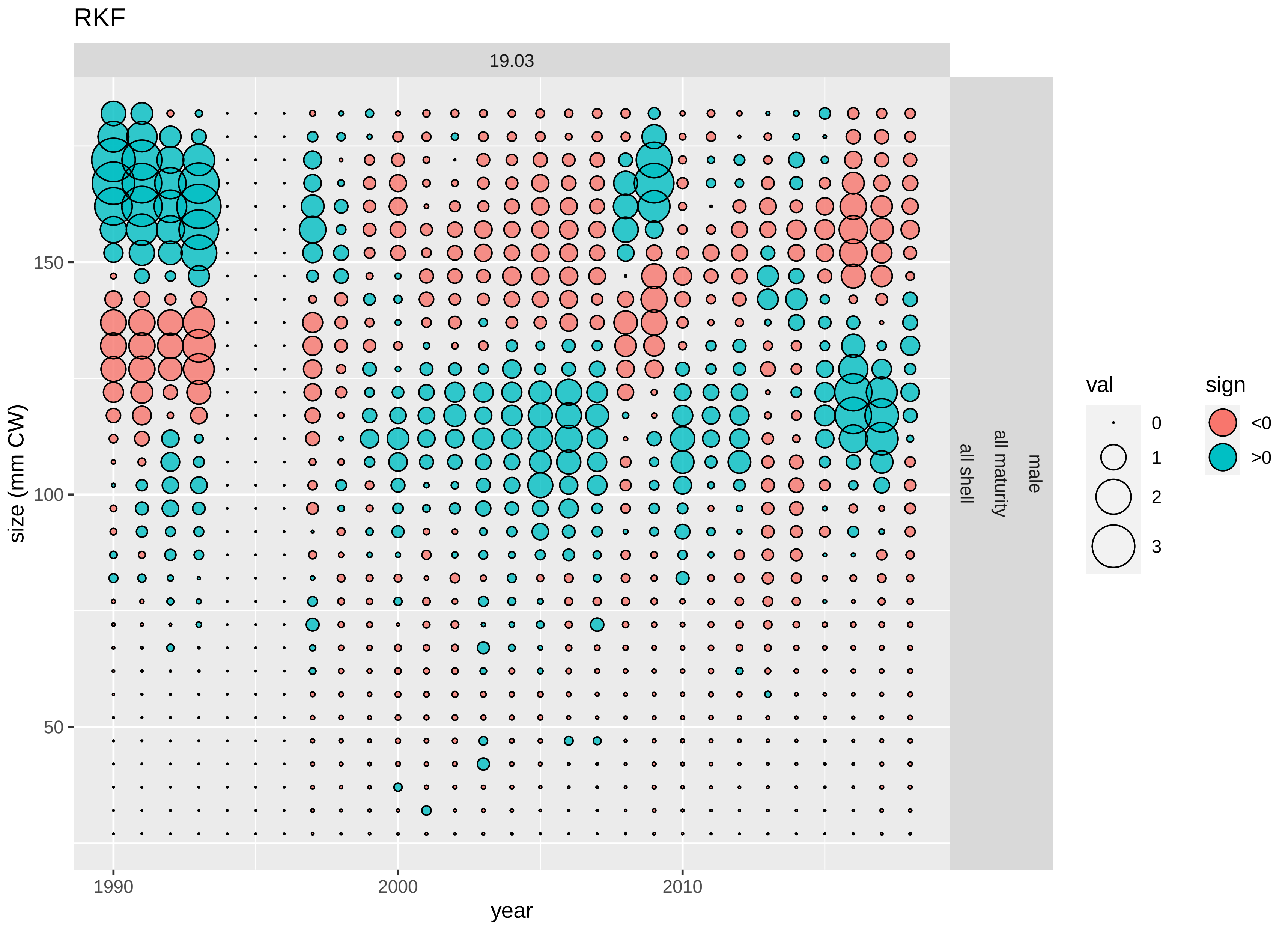


Figure 36: Pearson's residuals for male proportions-at-size from the RKF for scenario 19.03.

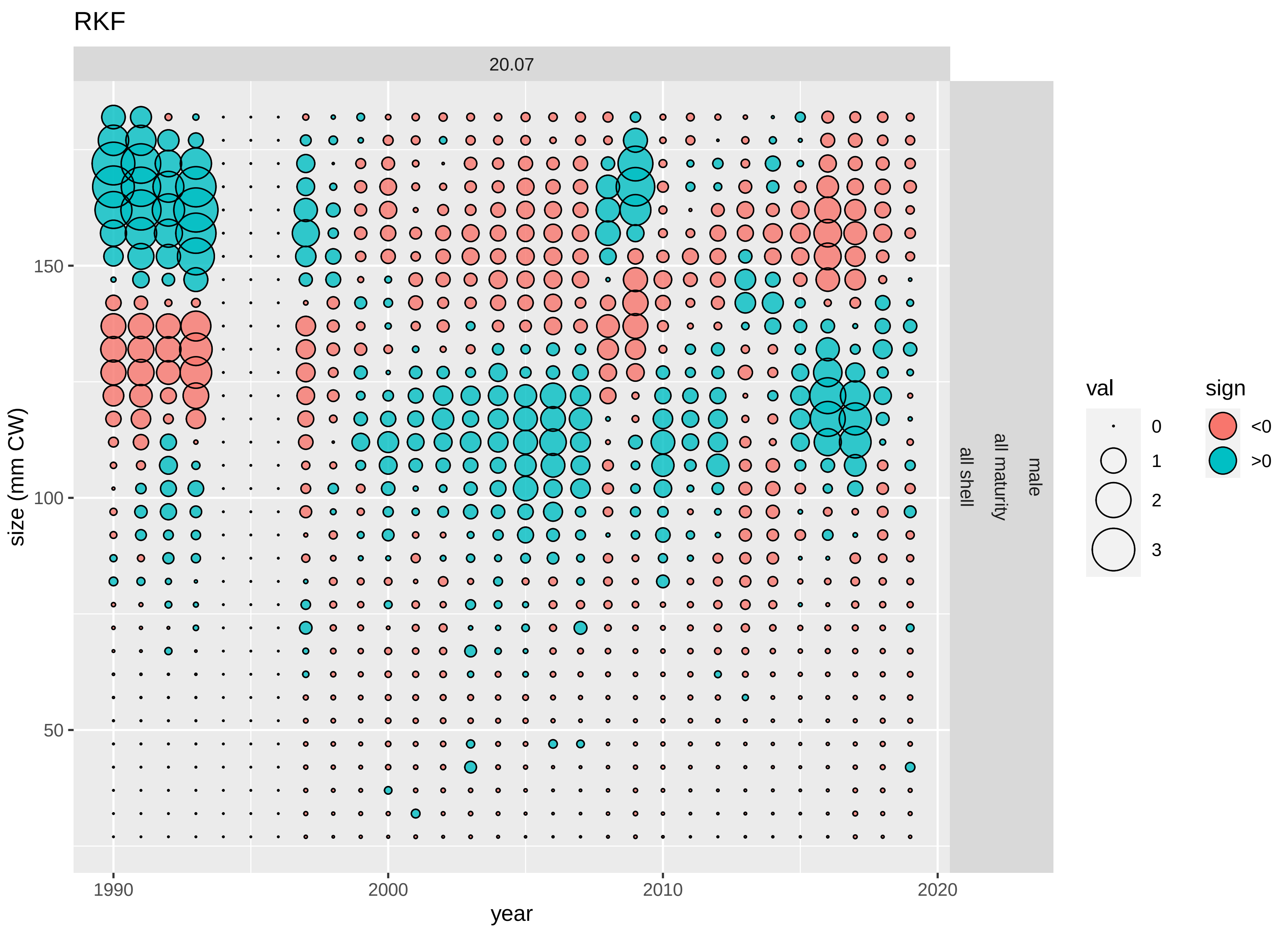


Figure 37: Pearson's residuals for male proportions-at-size from the RKF for scenario 20.07.

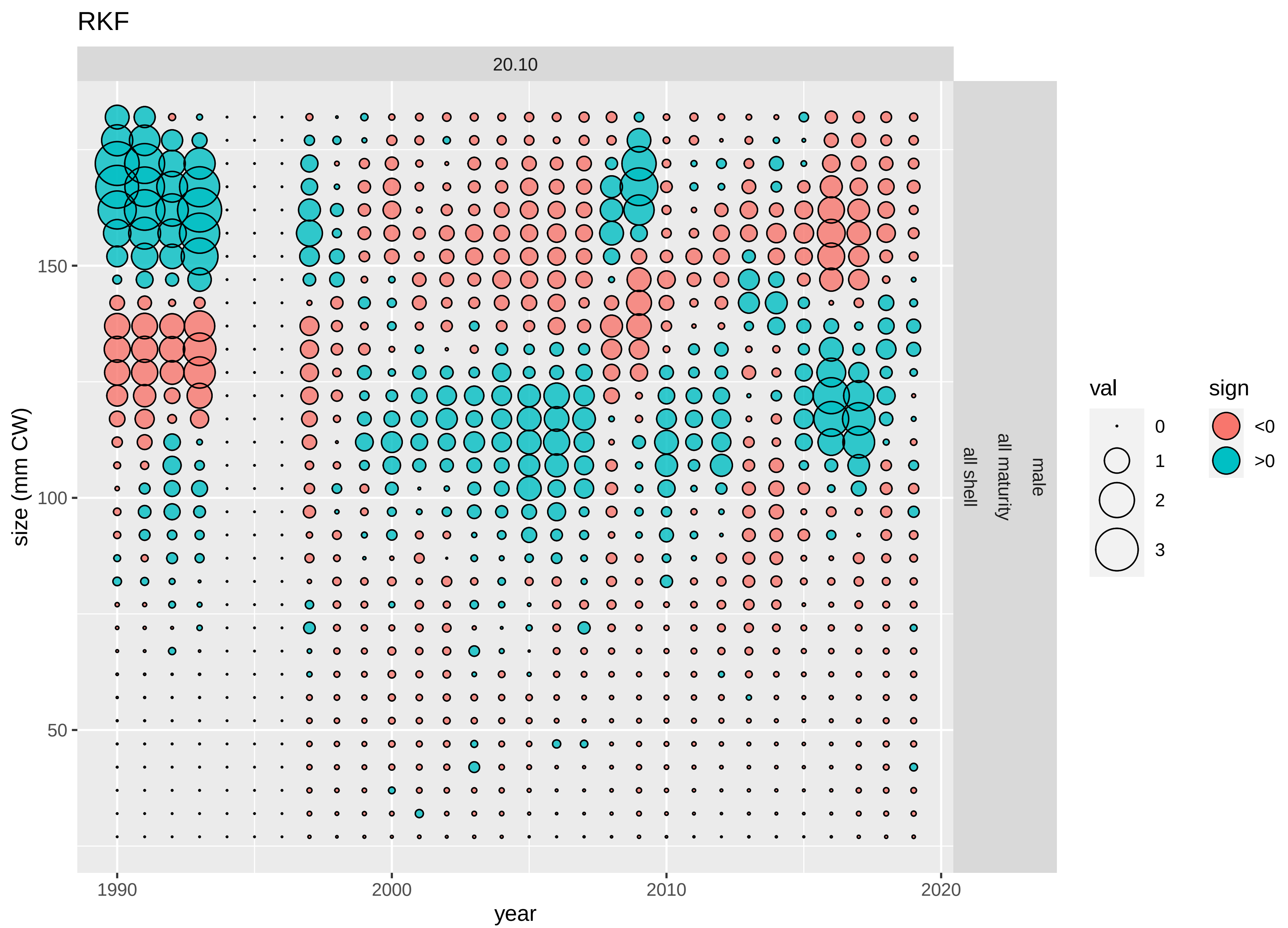


Figure 38: Pearson's residuals for male proportions-at-size from the RKF for scenario 20.10.

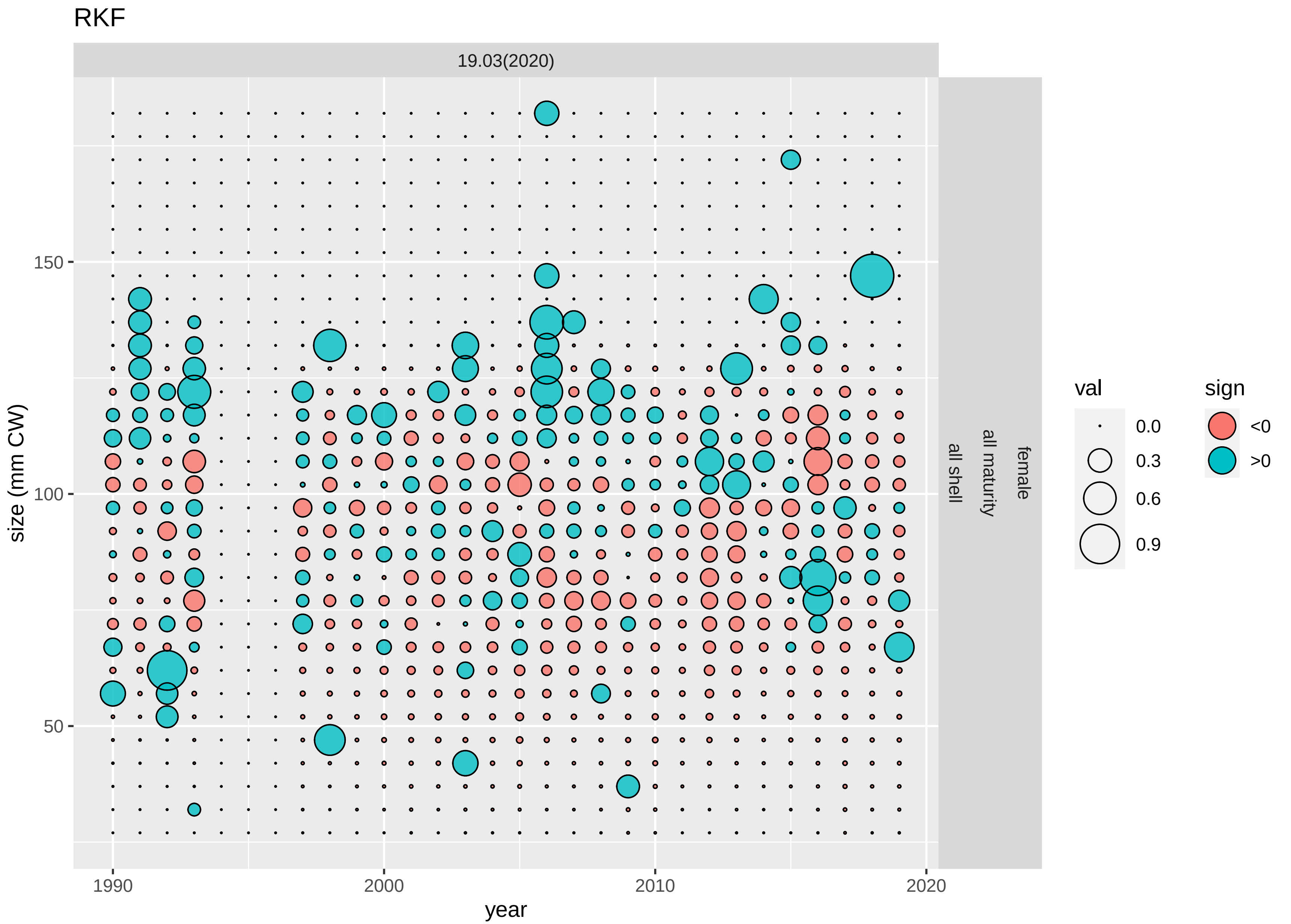


Figure 39: Pearson's residuals for female proportions-at-size from the RKF for scenario 19.03(2020).

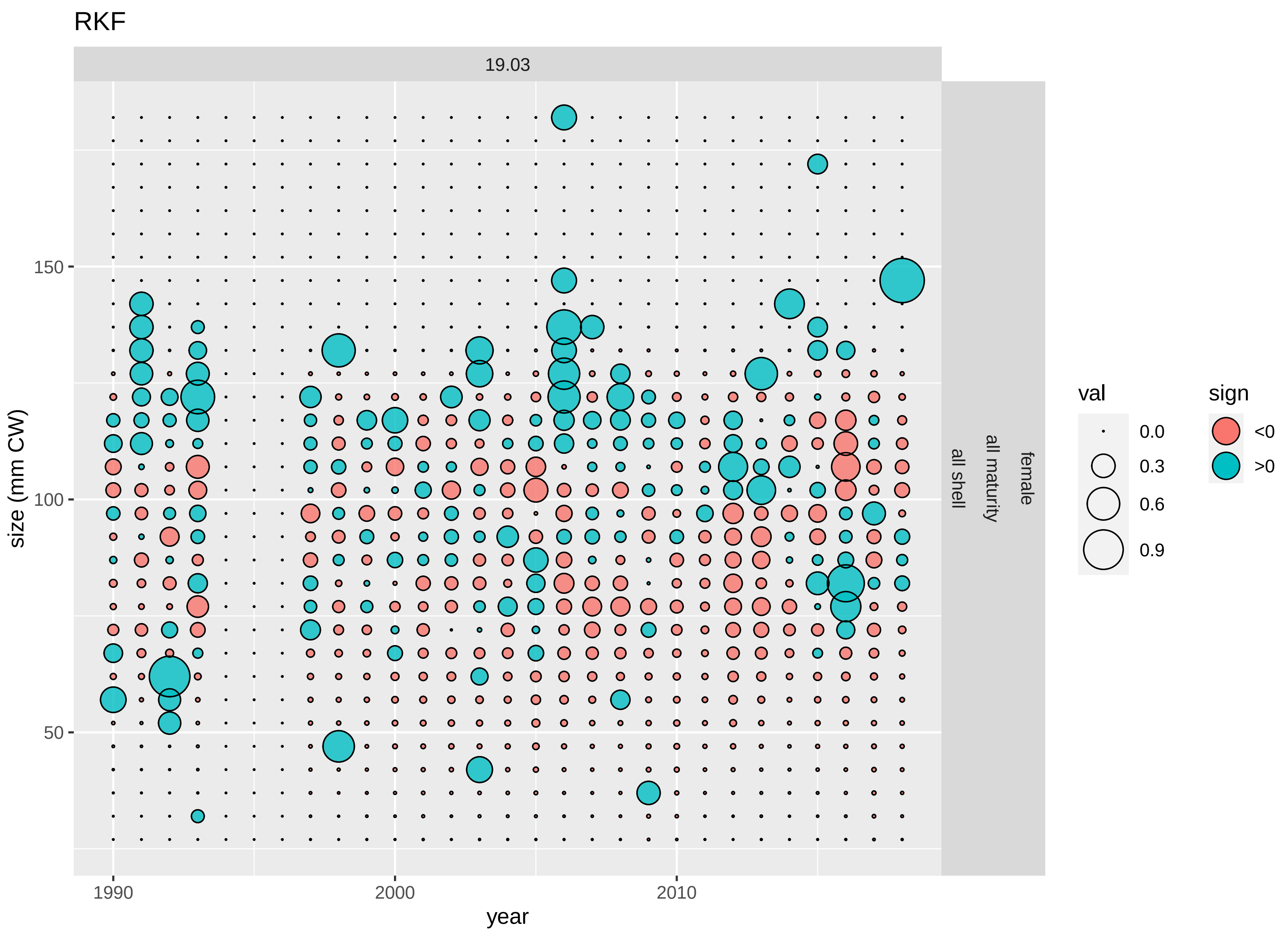


Figure 40: Pearson's residuals for female proportions-at-size from the RKF for scenario 19.03.

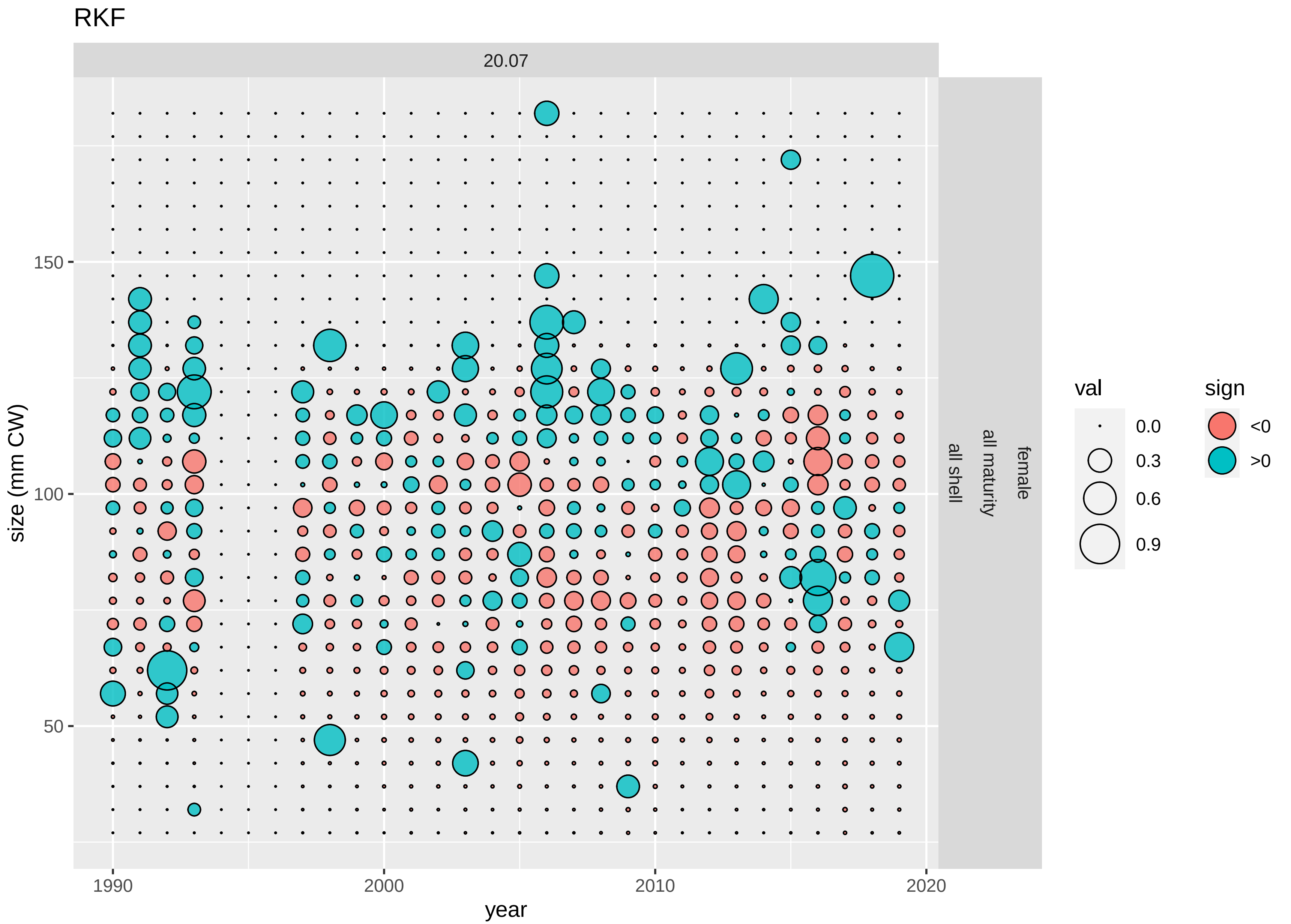


Figure 41: Pearson's residuals for female proportions-at-size from the RKF for scenario 20.07.

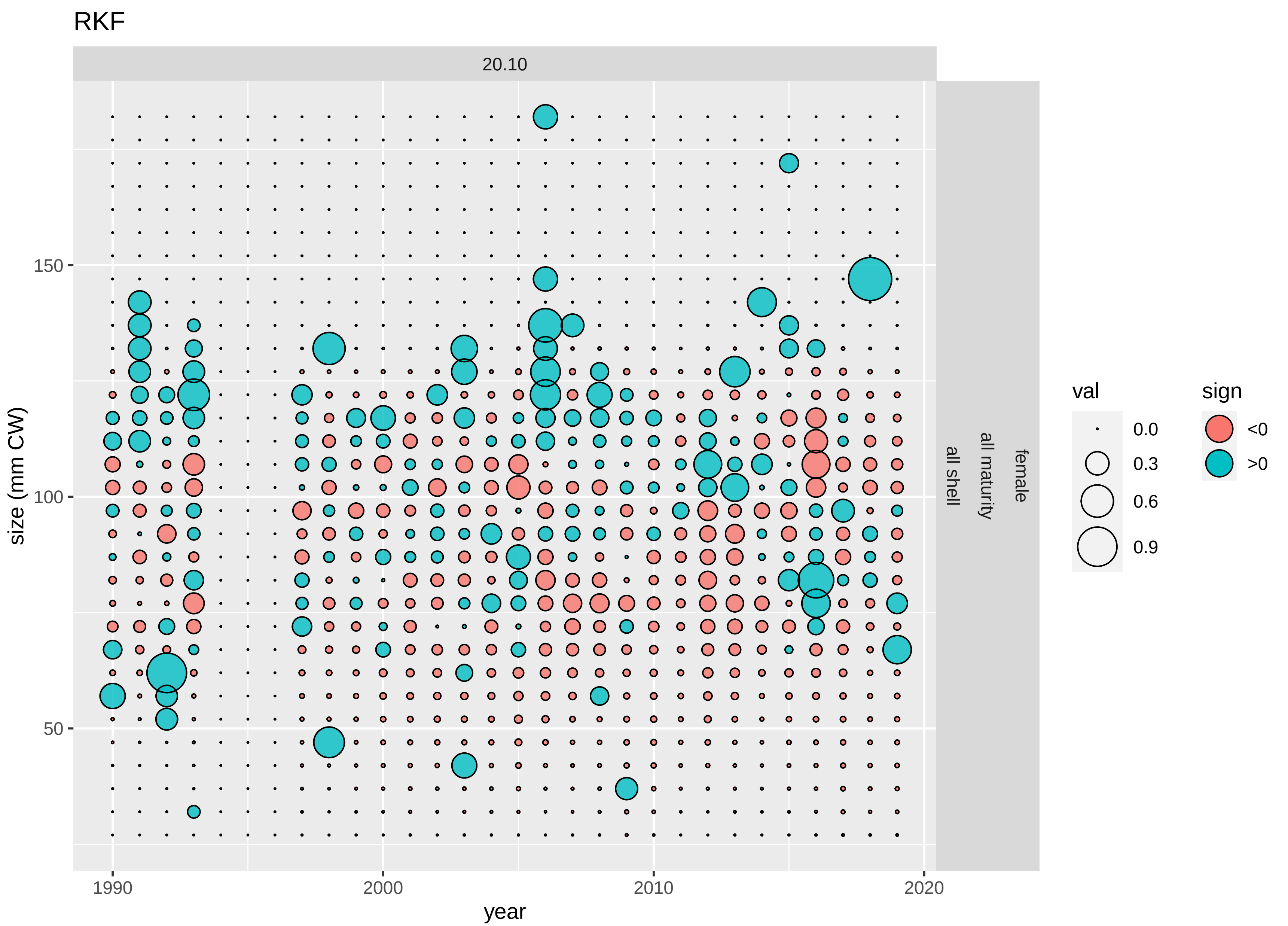


Figure 42: Pearson's residuals for female proportions-at-size from the RKF for scenario 20.10.

Effective Ns for total catch size compositions

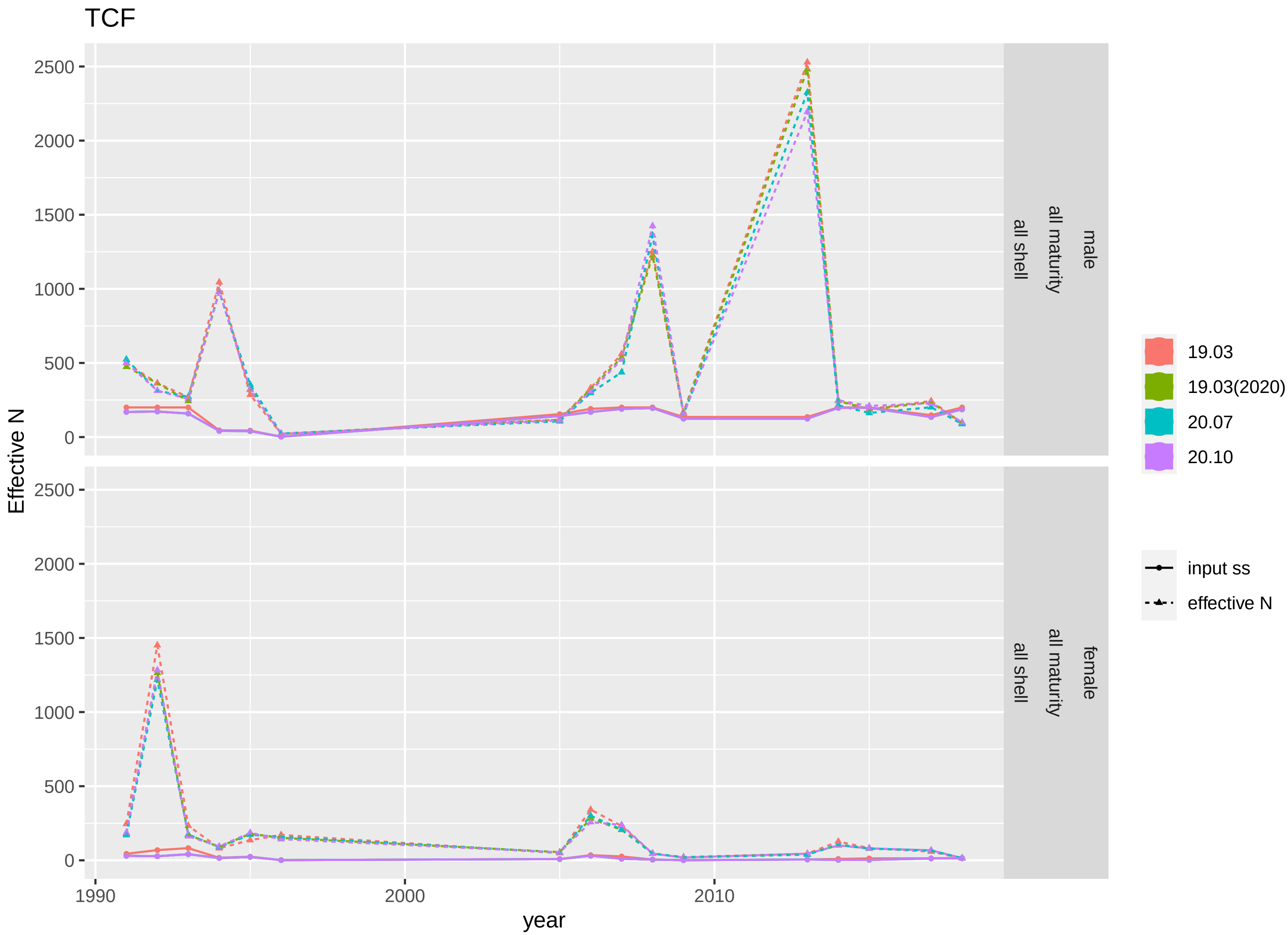


Figure 43: Input and effective sample sizes from total catch size compositions from the TCF fishery.

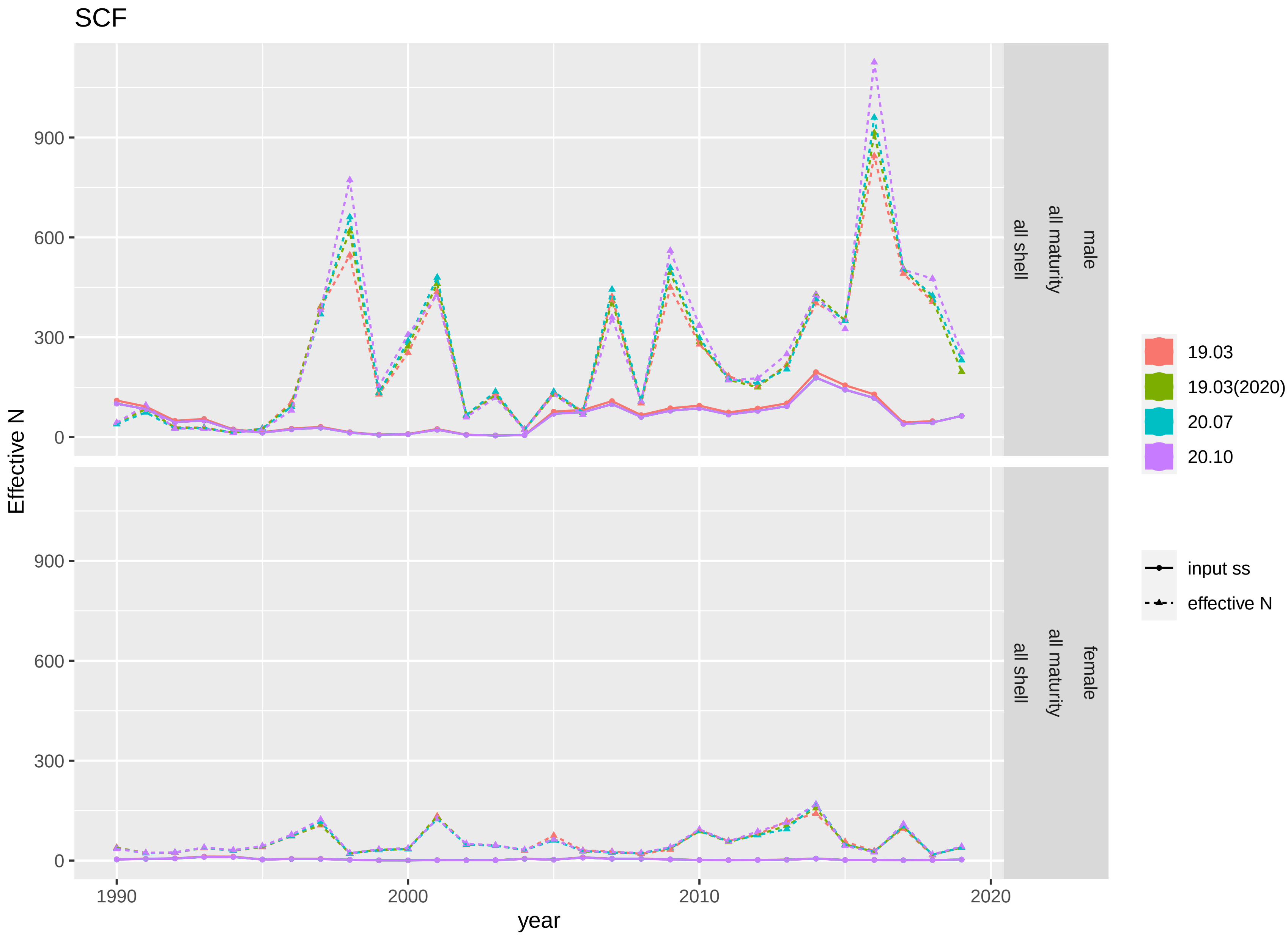


Figure 44: Input and effective sample sizes from total catch size compositions from the SCF fishery.

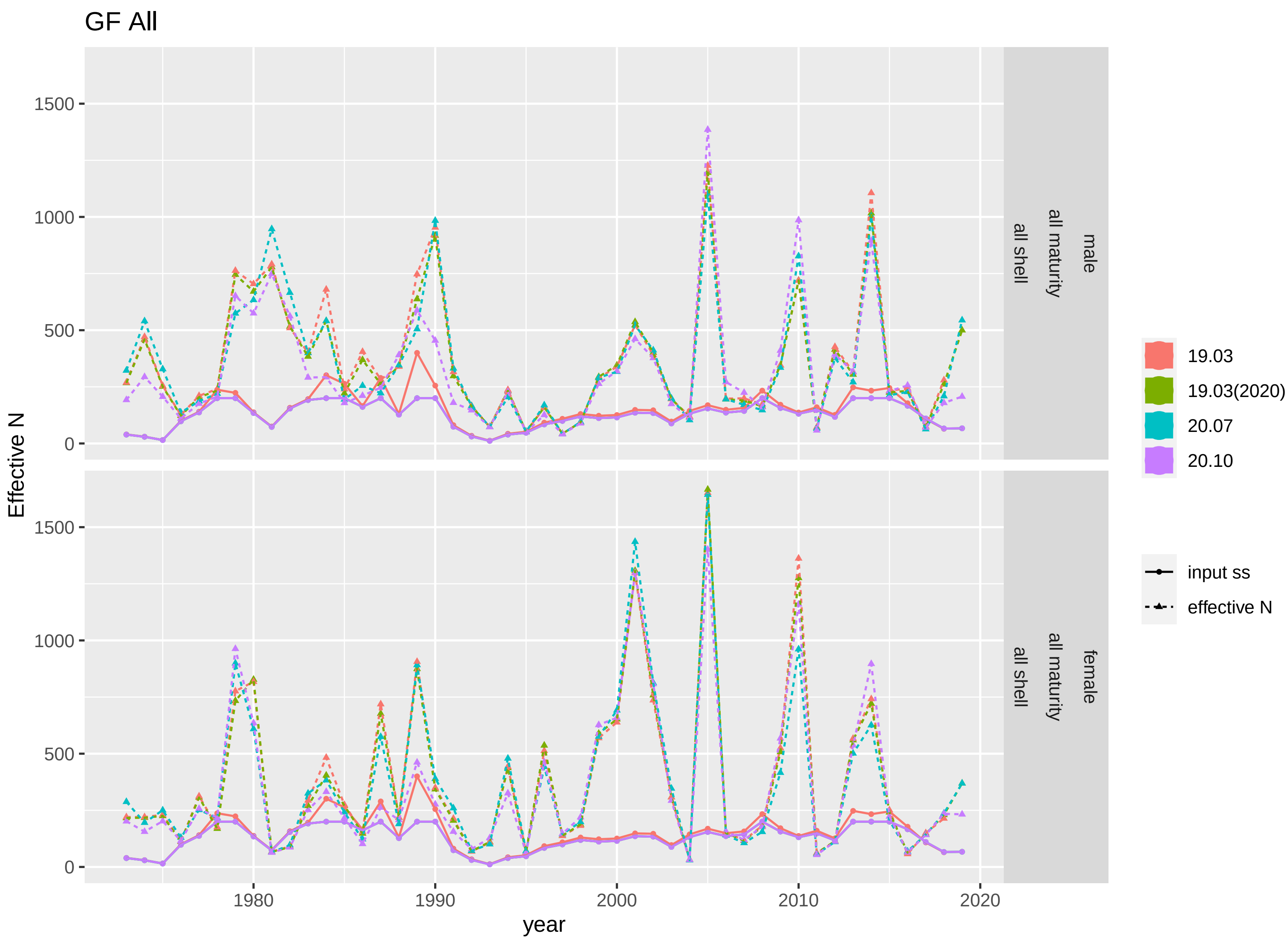


Figure 45: Input and effective sample sizes from total catch size compositions from the GF All fishery.

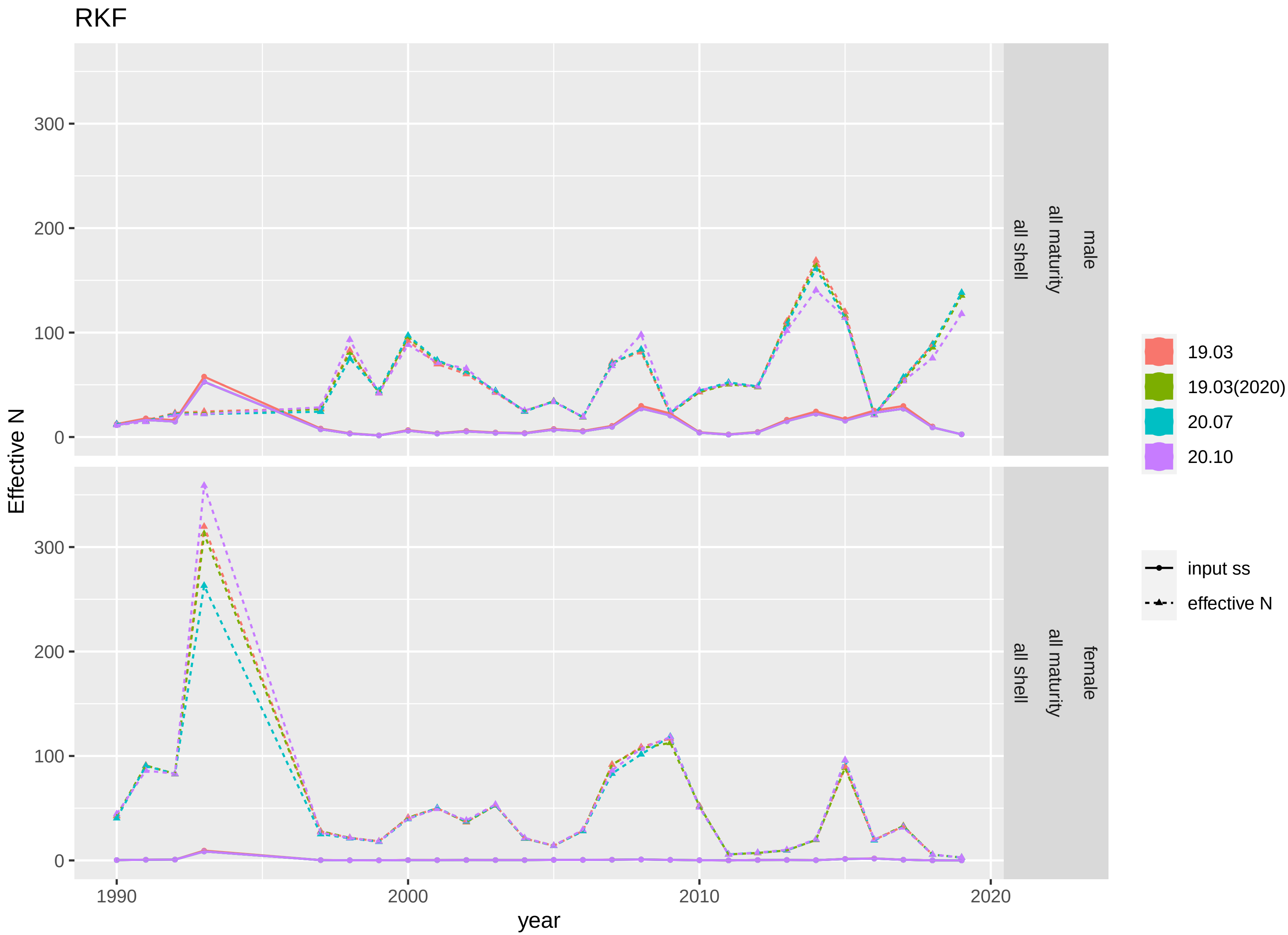


Figure 46: Input and effective sample sizes from total catch size compositions from the RKF fishery.

Appendix 10: Diagnostics for Fits to Surveys Size Composition Data –19.03(2020) vs 19.03 vs 20.07 vs 20.10

William Stockhausen

01 September, 2020

Contents

Introduction

Fits to survey size composition data available to the model(s) are presented in this section. Included are plots of mean fits to size compositions, Pearson's residuals as bubble plots, and effective sample sizes. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Mean survey size compositions

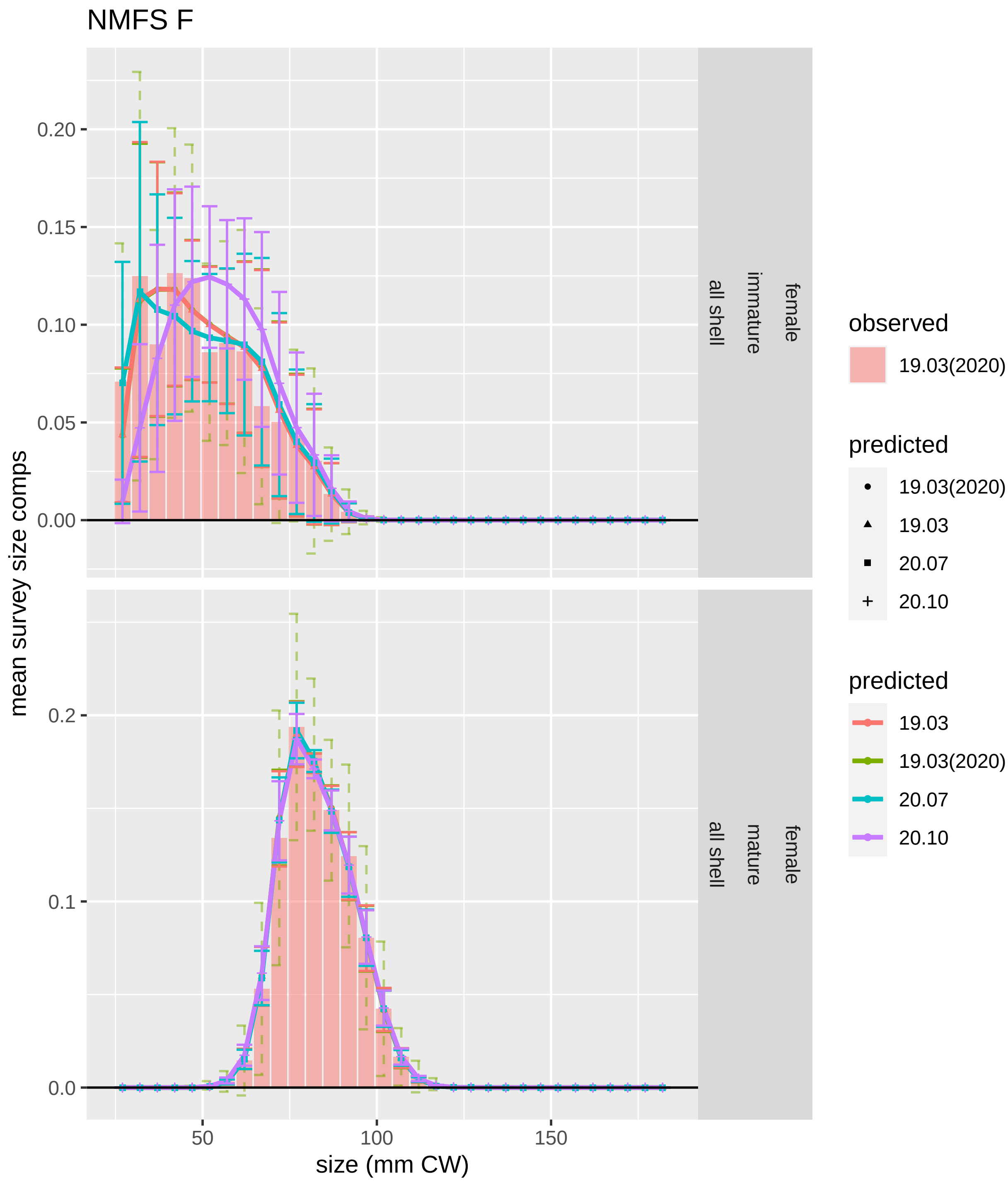


Figure 1: Comparison of observed and predicted mean survey size comps for NMFS F.

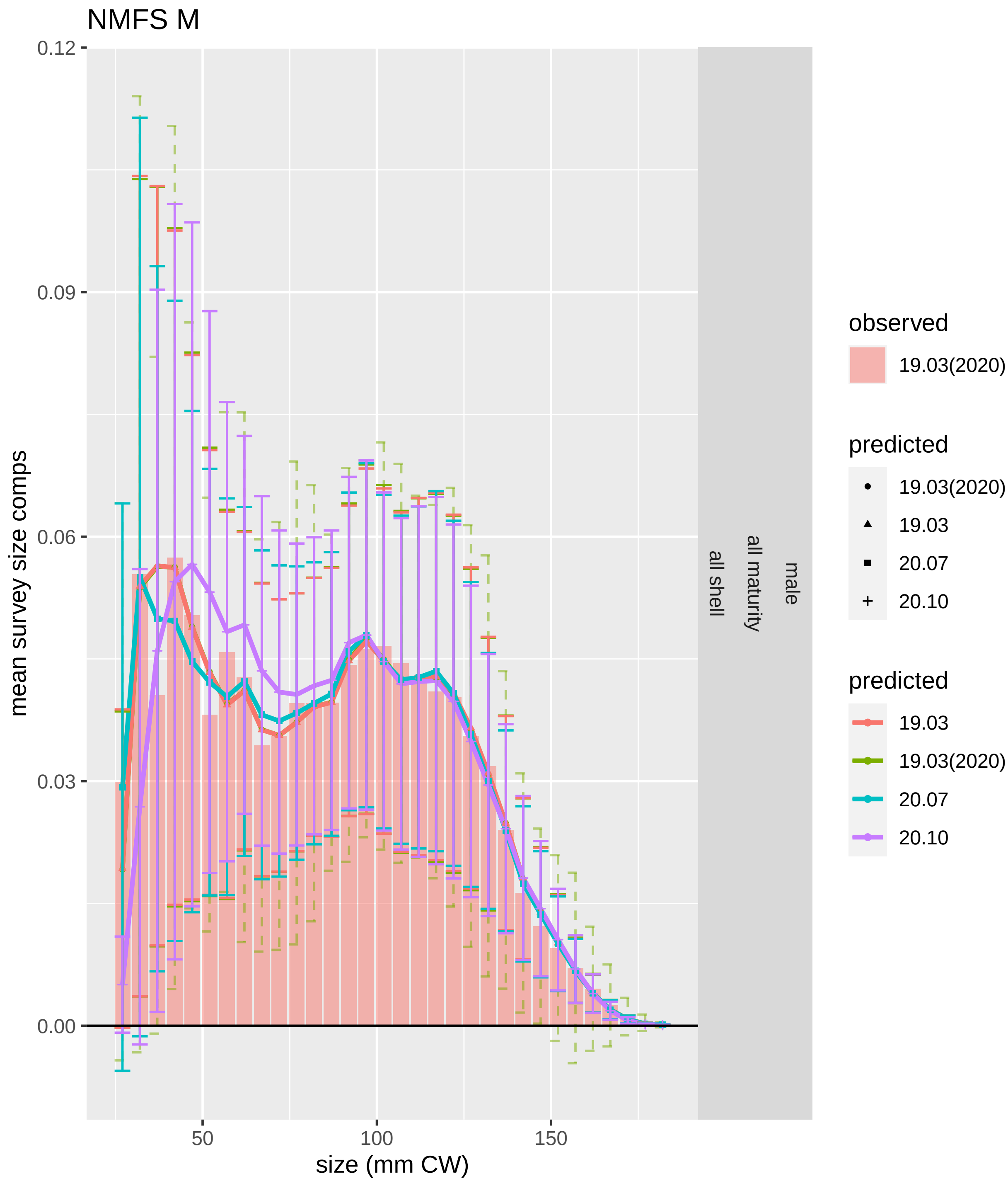


Figure 2: Comparison of observed and predicted mean survey size comps for NMFS M.

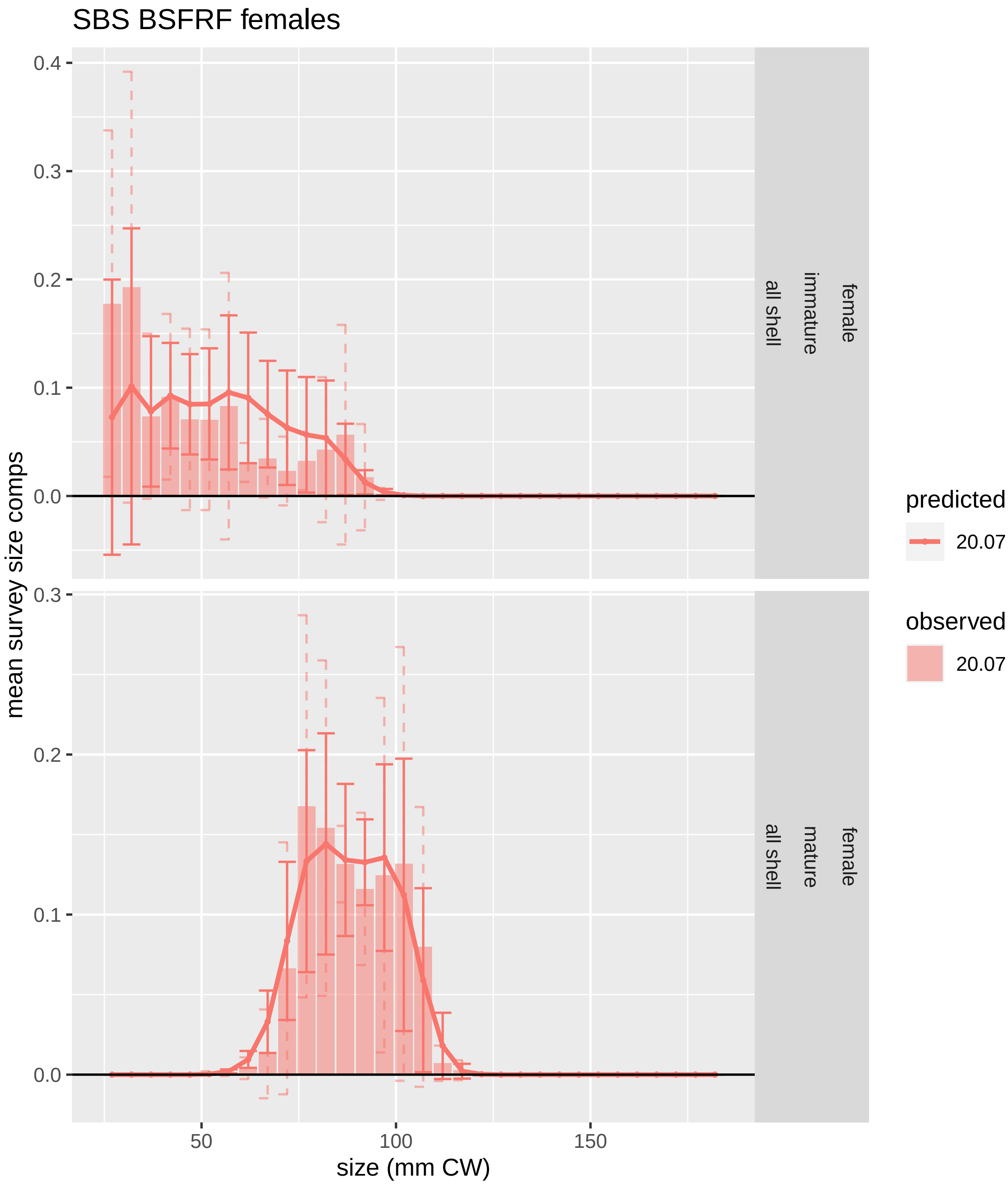


Figure 3: Comparison of observed and predicted mean survey size comps for SBS BSFRF females.

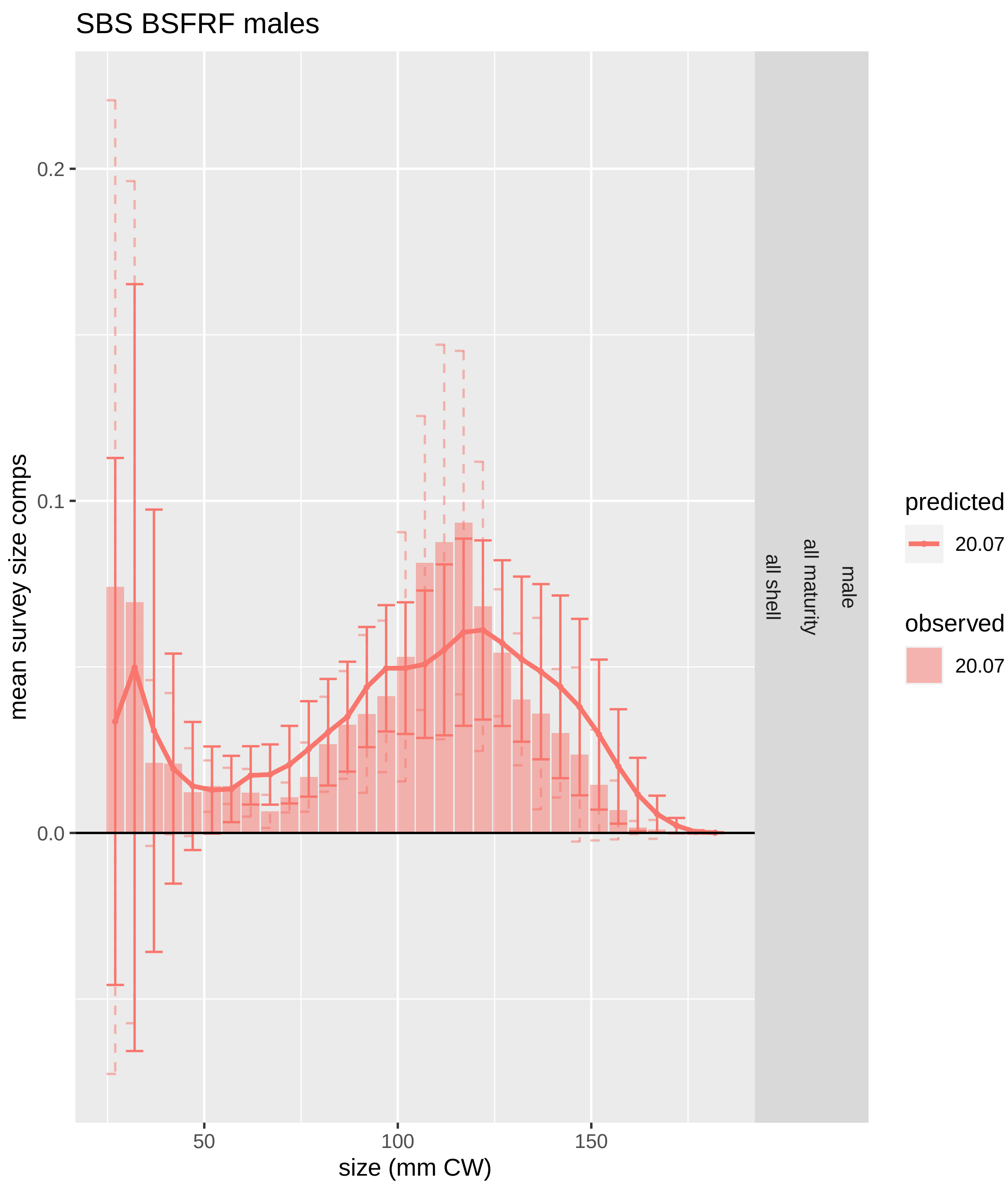


Figure 4: Comparison of observed and predicted mean survey size comps for SBS BSFRF males.

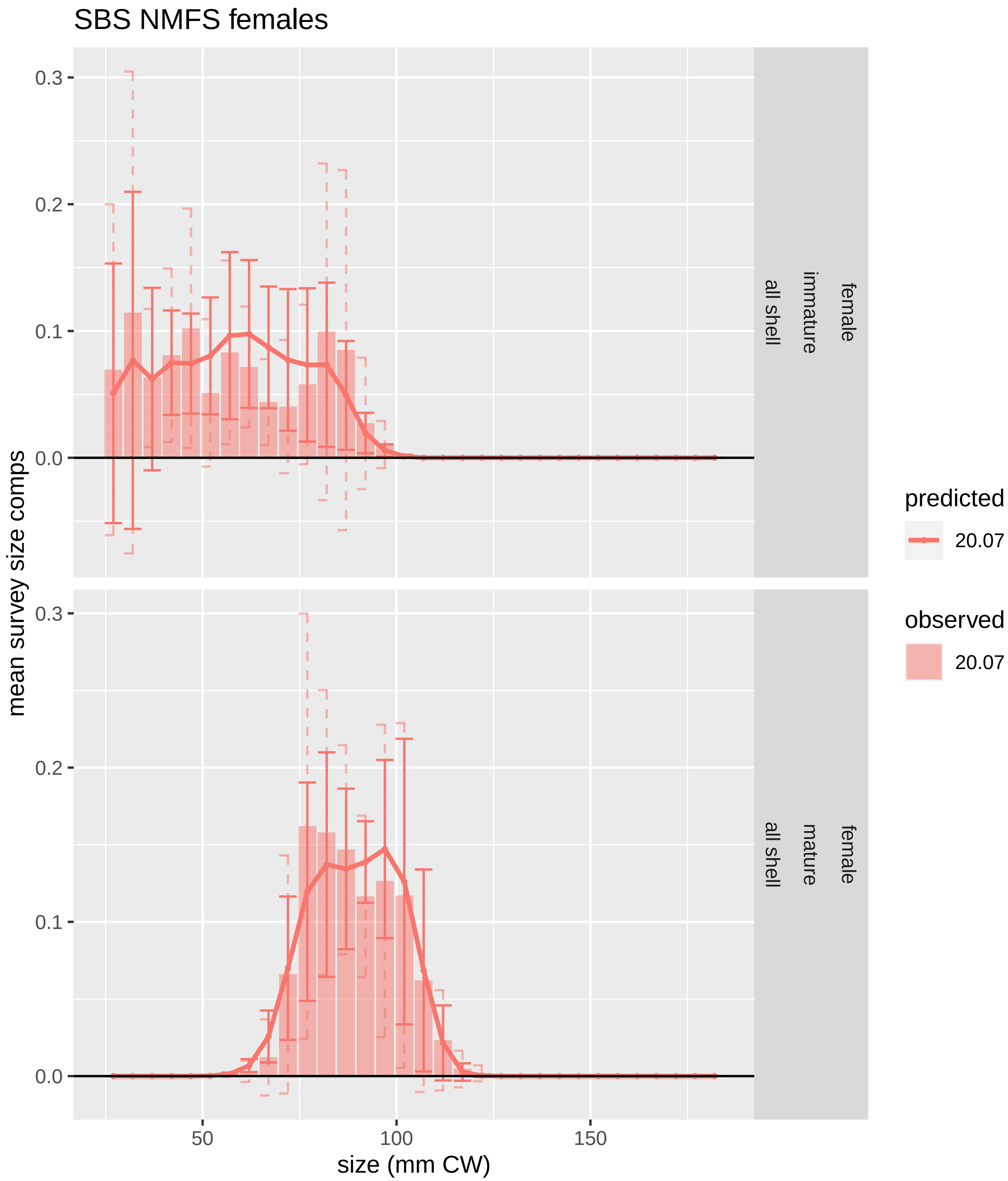


Figure 5: Comparison of observed and predicted mean survey size comps for SBS NMFS females.

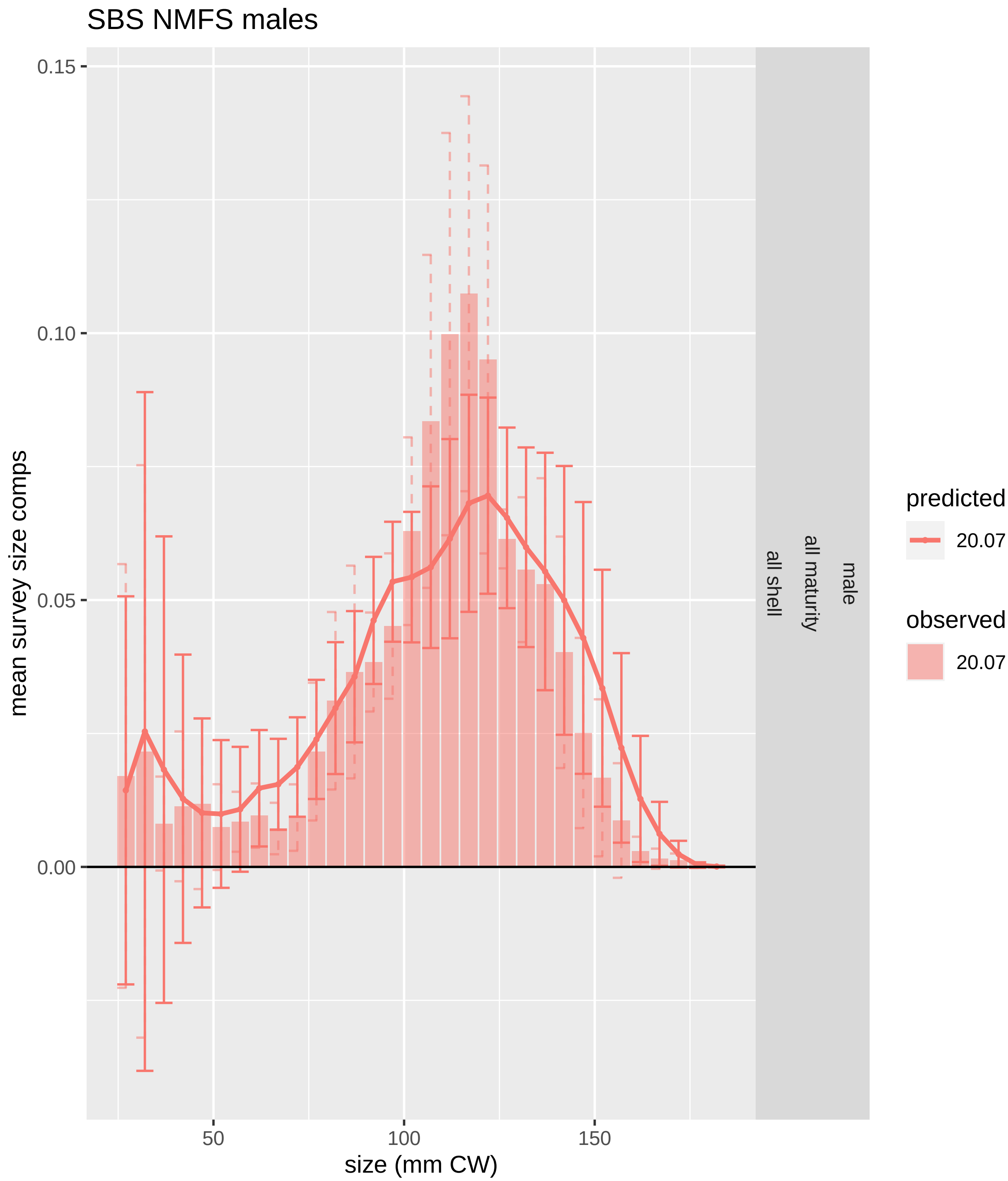
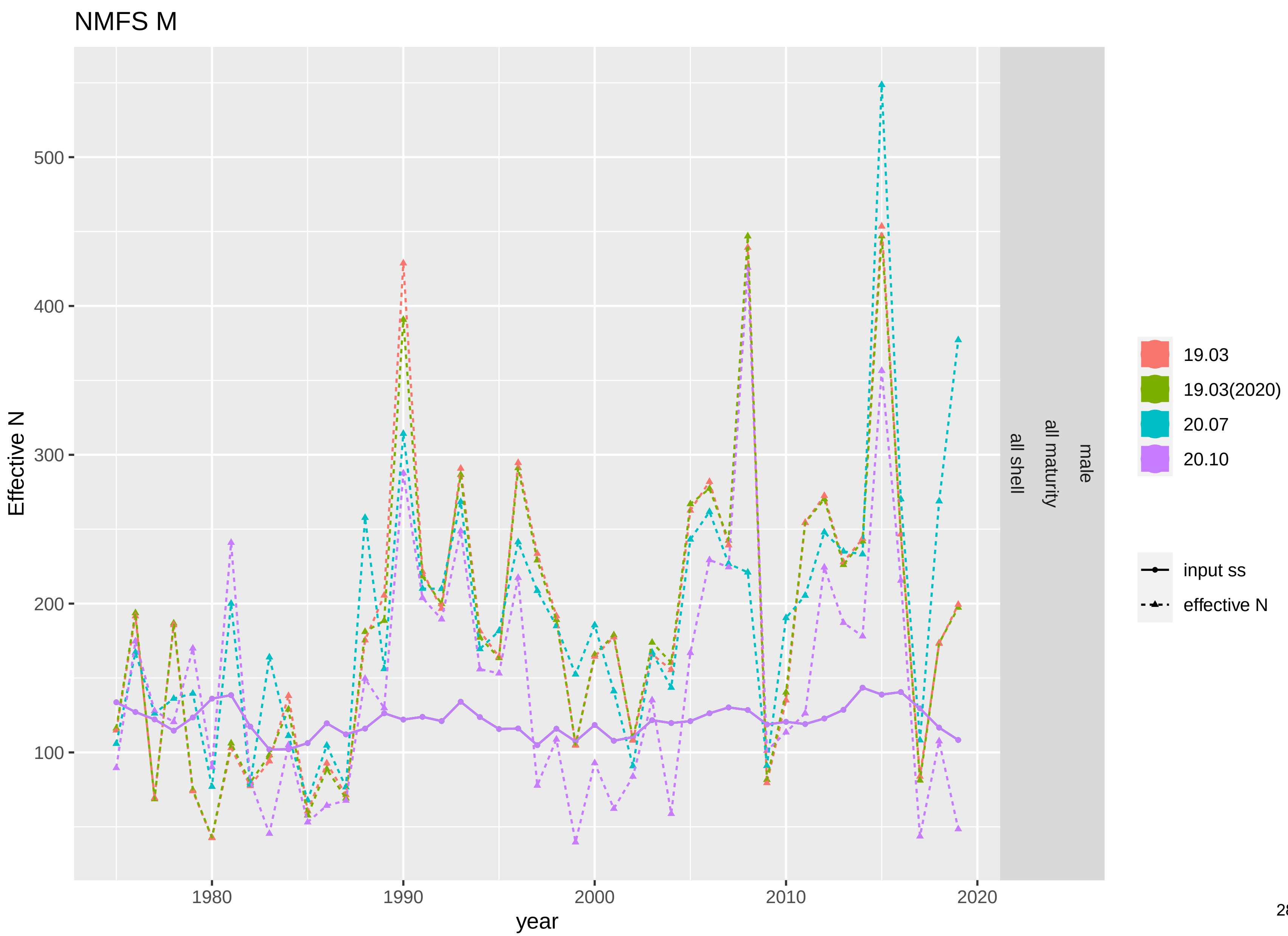


Figure 6: Comparison of observed and predicted mean survey size comps for SBS NMFS males.

Residuals to survey size composition data

Effective sample sizes for survey size compositions



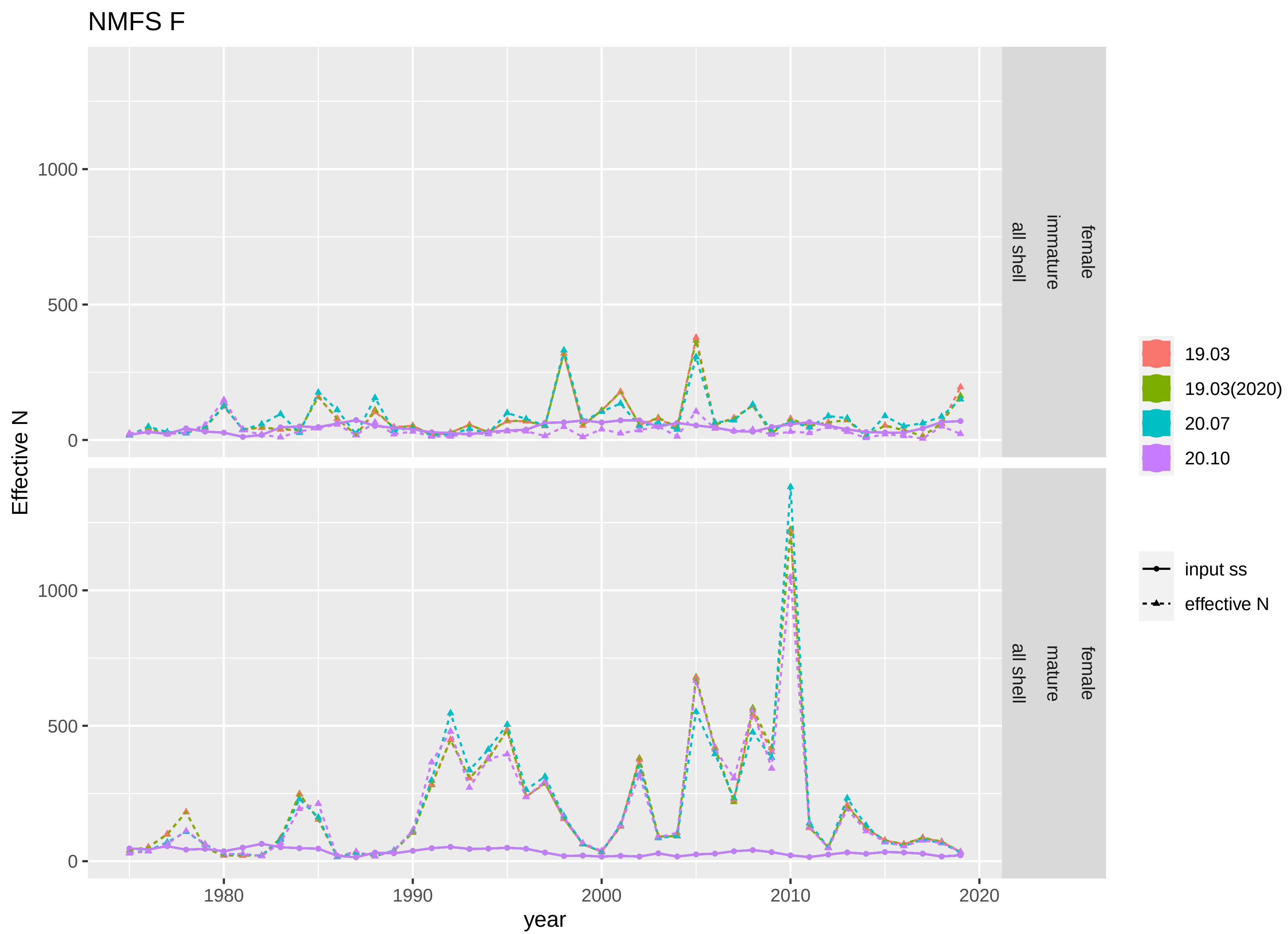


Figure 8: Input and effective sample sizes from retained catch size compositions from the NMFS F.

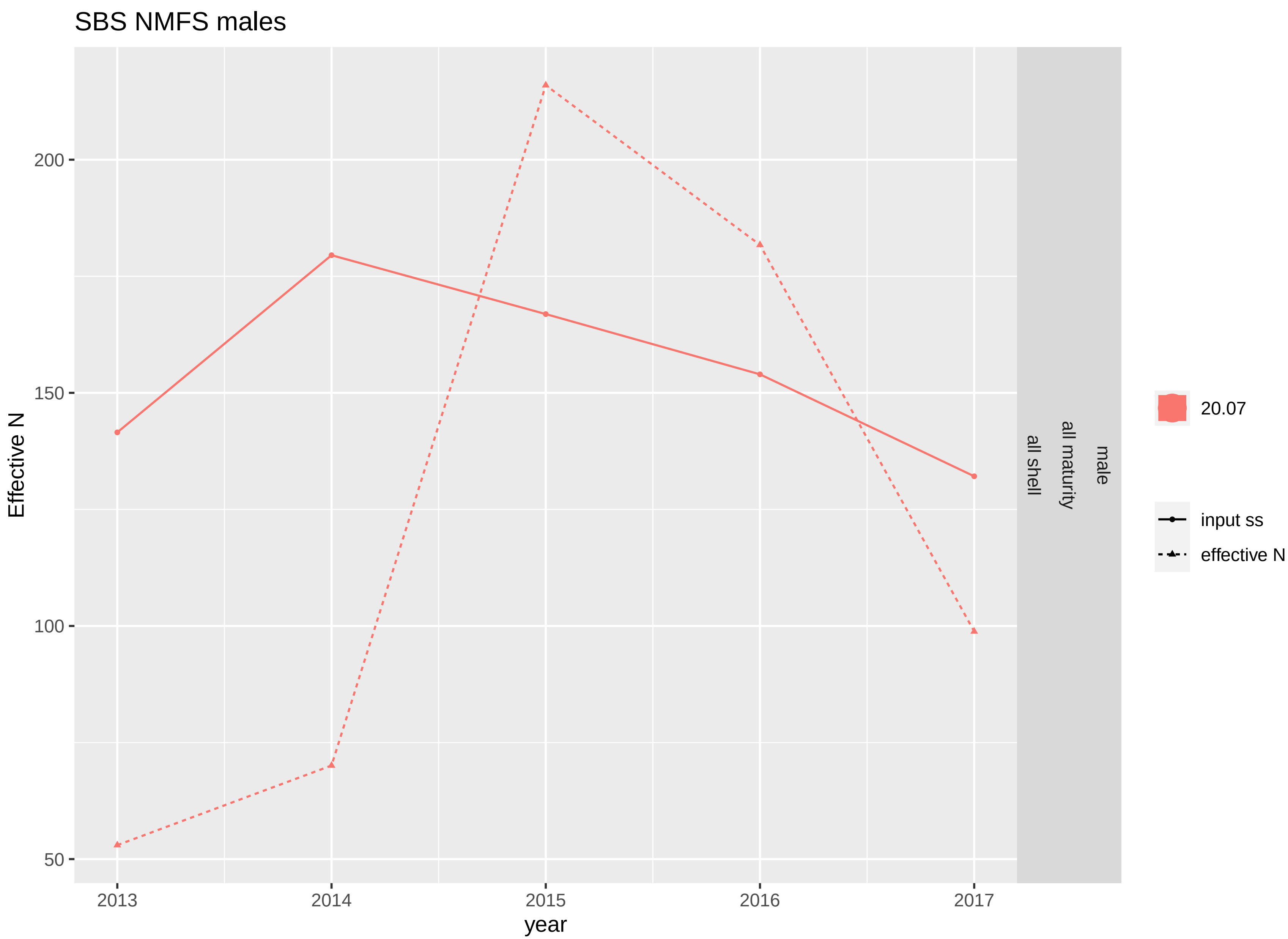


Figure 9: Input and effective sample sizes from retained catch size compositions from the SBS NMFS males.

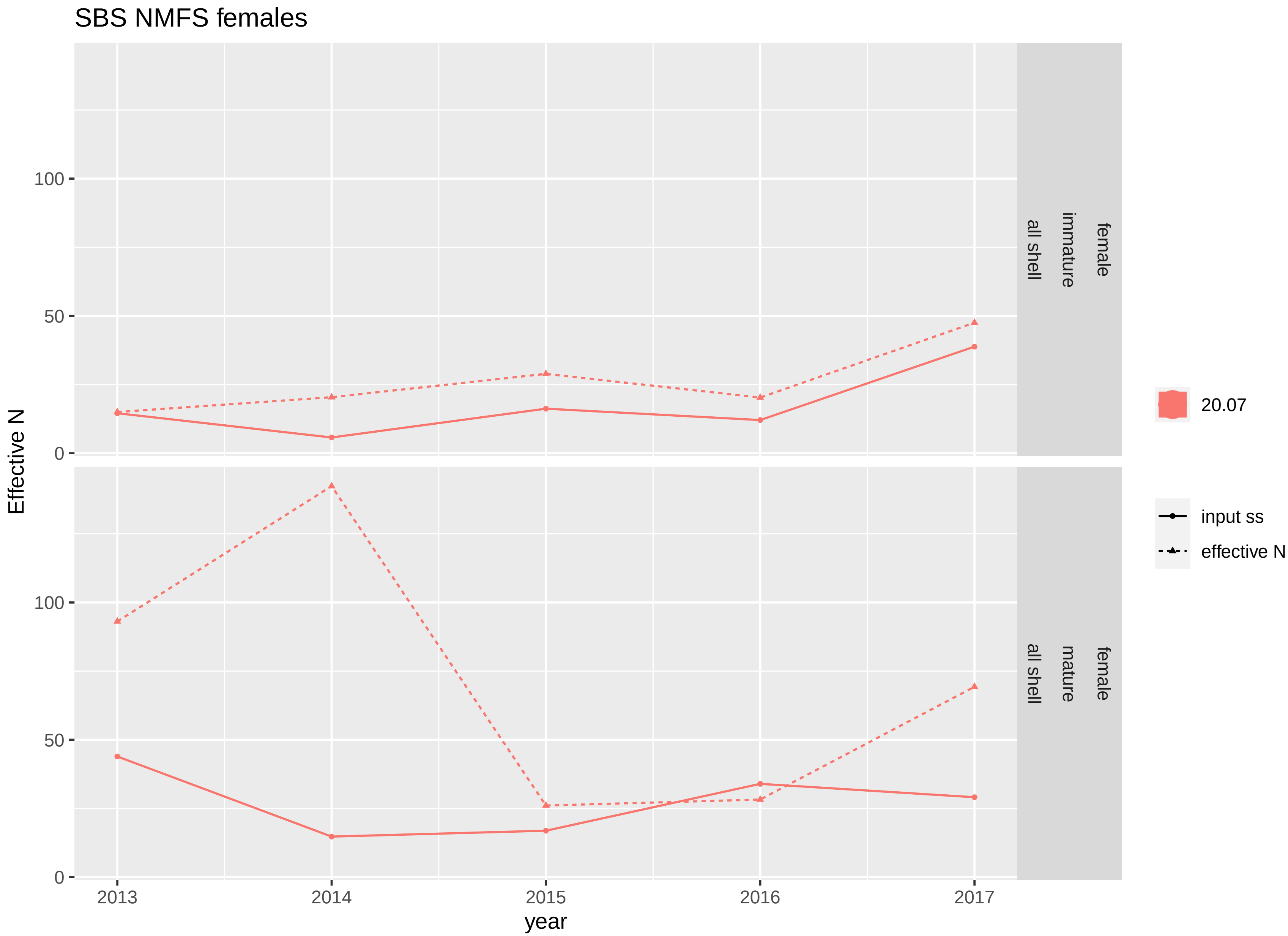


Figure 10: Input and effective sample sizes from retained catch size compositions from the SBS NMFS females.

Figure 11: Input and effective sample sizes from retained catch size compositions from the SBS BSFRF males.

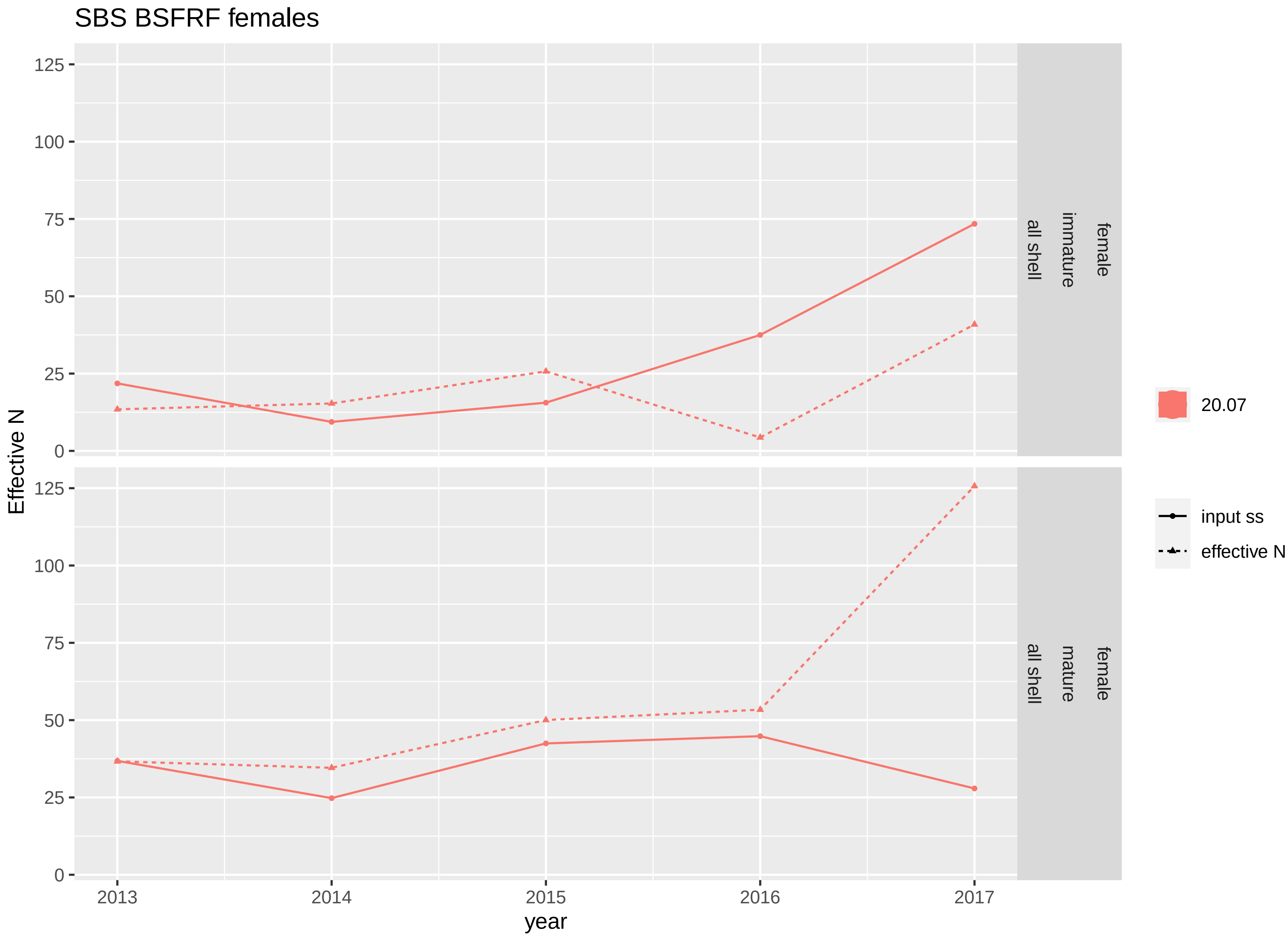


Figure 12: Input and effective sample sizes from retained catch size compositions from the SBS BSFRF females.