2019 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

William T. Stockhausen
Alaska Fisheries Science Center
10 September 2019

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY

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]).

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. 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 ~3,000 t for the 5-year period 2013/14-2017/18. Bycatch in the snow crab fishery in 2018/19 was 888 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 325 t. Bycatch in the groundfish fisheries in 2018/19 was 191 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 202 t over the 5-year time period. In 2018/19, this fishery accounted for only 74 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 using trawl gear 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 (M19F03), estimated MMB for 2018/19 was 79.5 thousand t (Table 47; Figure 61). MMB has been on a declining trend since 2014/15 when it peaked at 135.8 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). However, it is considerably below model-estimated historical levels in the late 1970s (1975-1980 average: 215.9 thousand t) before it declined through 1985.

4. Recruitment: trends and current levels relative to virgin or historic levels.
From the author's preferred model (M19F03), the estimated total recruitment for 2018/19 (the number of crab entering the population on July 1) is 1,234.9 million crab (Table 50; Figure 59). Although this value is highly uncertain, it follows two years of similarly high estimates for 2016/17 and 2017/18 (647 and 677 million crab, respectively). The average 5-year recruitment prior to 2016/17 was only 108 million crab while the longterm (1982+) mean is 394 million crab.

5. Management performance
Historical status and catch specifications for eastern Bering Sea Tanner crab.

(a) in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	12.82	73.93	8.92	8.91	11.38	27.19	21.75
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		39.55				28.86	23.09

(b) in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	28.27	162.99	19.67	19.64	25.09	59.94	47.95
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				46.01	36.82
2019/20		87.18				63.62	50.89

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[A]	B_{MSY}[A]	Current MMB[A]	B/B_{MSY}[A]	F_{OFL}[A] (yr^{-1})	Years to define B_{MSY}[A]	Natural Mortality[A,B] (yr^{-1})
2015/16	3a	26.79	53.70	2.00	0.58	1982-2015	0.23
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

b) in millions lbs.

Year	Tier[A]	B_{MSY}[A]	Current MMB[A]	B/B_{MSY}[A]	F_{OFL}[A] (yr^{-1})	Years to define B_{MSY}[A]	Natural Mortality[A,B] (yr^{-1})
2015/16	3a	59.06	118.38	2.00	0.58	1982-2015	0.23
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

A—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 2019/20.
B—Nominal rate of natural mortality. Actual rates used in the assessment are estimated and may be different.

Current male spawning stock biomass (MMB), as projected for 2019/20, is estimated at 39.55 thousand t. B_{MSY} for this stock is calculated to be 41.07 thousand t, so MSST is 20.54 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 2018/19 was 1.90

thousand t, which was less than the OFL for 2017/18 (20.97 thousand t); consequently **overfishing did not occur**. The OFL for 2019/20 based on the author's preferred model (M19F03) is 28.86 thousand t. The ABC_{max} for 2019/20, based on the p^* ABC, is 28.79 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 23.09 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.
At the March, 2015 SOA Board of Fish (BOF) meeting, the Board adopted a revised harvest strategy for Tanner crab in the Bering Sea District[1], wherein the TAC for the area east of 166ºW longitude would be based on a minimum preferred harvest size of 127 mm CW (5.0 inches), including the lateral spines. Formerly, this calculation was based on a minimum preferred size of 140 mm CW (5.5 inches). The TAC in the area west of 166ºW longitude continues to be based on a minimum preferred harvest size of 127 mm CW (including lateral spines).

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 has since been prosecuted in 2017/18 and 2018/19.

2. Changes to the input data
The following table summarizes data sources that have been updated for this assessment:

[1] https://aws.state.ak.us/OnlinePublicNotices/Notices/Attachment.aspx?id=100244

Updated data sources.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	recalculated, new	NMFS
	size compositions	1975-2019	recalculated, new	
	male maturity data	2006+	new	
NMFS/BSFRF	molt-increment data	2015-17, 2019	same as 2017	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	new	BSFRF
	size compositions	2013-17	new	
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	updated, new	ADFG
	retained catch size compositions	2013/14-2018/19	updated, new	ADFG
	total catch (abundance, biomass)	1991/92-2017/18	revised, new	ADFG
	total catch size compositions	1991/92-2017/18	revised, new	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	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)	1991/92-2017/18	revised, new	NMFS/AKFIN
	total bycatch size compositions	1991/92-2017/18	updated, new	

Changes of note include the incorporation of BSFRF bottom trawl survey data from the “side-by-side” (SBS) catchability studies jointly conducted with the NMFS EBS bottom trawl survey in 2013-2017, the addition of new molt increment (growth) data, and the use of revised estimates by ADFG of total catch/bycatch data from at-sea observer sampling in the crab fisheries. Otherwise, the changes consist of finalized catch data for 2017/18 and new catch data for 2018/19.

3. Changes to the assessment methodology.

Following a considerable development effort and substantial review by the CPT at the January 2017 Modeling Workshop and the May 2017 CPT Meeting, with additional review by the SSC at its February and June 2017 meetings, a new modeling “framework”, TCSAM02, was recommended by the CPT at its May 2017 meeting (and approved by the SSC at its June 2017 meeting) for use in the 2017/18 assessment. This framework was used again in 2018/19 and is the basis for this assessment. TCSAM02, while based on the previous assessment model (TCSAM2013), constitutes a completely rewritten code library for the Tanner crab assessment model. Results presented at the May 2017 CPT meeting demonstrated that TCSAM02 could be configured to exactly match results from the TCSAM2013 code, thus providing continuity with the old model code.

The 2017 assessment model (“B2b” in that assessment), built on the 2016 model by: 1) fitting EBS model-increment data inside the model to inform growth parameters, b) estimating separate retention functions for three time periods (pre-1997/98, 2005/06-2009/10, and 2013/14-2015/16), and c) estimating the asymptotic value for the fraction of male crab retained in the directed fishery (in the same three time periods as (b)), rather than assuming it was 1 (i.e., 100% retention at large sizes). This was also the model (with updated data for 2017/18, referred to in that assessment as “18AM17”) selected by the CPT and SSC for the 2018 assessment. This model is referred to here as “M19F00” as the base model scenario for this assessment.

The author-recommended model scenario proposed here, "M19F03", differs 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 fits the 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.

4. Changes to the assessment results
Revisions to the input crab fishery data used in the assessment model have had a large effect (almost 2x) on the estimated scale of the population, although the trends are very similar. Average recruitment (1982-present) was estimated at 224 million in last year's model, whereas it is estimated at 394 million in the author's preferred model this year. F_{MSY} is larger this year (1.18 yr^{-1} this year vs. 0.74 yr^{-1} last year), as is B_{MSY} (40.75 thousand t vs. 30.29 thousand t). The stock remains in Tier 3, but it is now classified as "3b" rather than "3a" (its classification last year) because the ratio of projected MMB to B_{MSY} is 0.95, i.e. less than 1. Last year the ratio was 1.19.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets of SSC and CPT comments on assessments in general.

June 2019 SSC Meeting
SSC Comment: The SSC reminded authors to use the model numbering protocols that allow the SSC to understand the year in which a particular version of the model was first introduced.
Response: The Tanner crab assessment has not fully implemented this suggestion. The 2018 assessment model was labeled 18AM17, which does not follow the guidelines. Here, that model is referred to as M19F00 ("00" designating the base model from which other scenarios proceed in the 2019 assessment, "F" denoting the "final" scenarios proposed in May). This also does not reflect the requested model numbering. However, the model numbering adopted herein should allow subsequent model numbering to follow the guidelines (so that the author's preferred model M19F03 would become 19.03 in the future).

May 2019 Crab Plan Team Meeting
No general comments.

October 2018 SSC Meeting
SSC Comment: The SSC reminded authors to use the model numbering protocols that allow the SSC to understand the year in which a particular version of the model was first introduced.
Response: Model numbering was consistent with this guideline for the model scenarios presented by the author to the CPT in September 2018. However, the CPT recommended a model based on the 2017 assessment which was labeled 18AM17 to designate the 2017 assessment model updated with 2018 data, which did not follow the guidelines.

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/
Response: The Tanner crab assessment does not yet use VAST-based estimates of survey biomass.

September 2018 Crab Plan Team Meeting
No general comments.

2. Responses to the most recent two sets 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 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).
Response: 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
The CPT accepted the author's recommended models for presentation in September 2019.
Response: The model runs with the recommended scenarios were run for this assessment, and the results are presented herein. The CPT (and assessment author) referred to these "final scenarios" as 19F.0, 19F.0a, 19F.1, 19F.2, 19F.3, 19F.4, and 19F.5. Here, they are referred to as M19F00, M19F00a, M19F01, M19F02, M19F03, M19F04, and M19F05 (which allowed for additional scenarios while maintaining folder/scenario order on computer disk).

CPT comment: compare the estimated selectivity to the ratio of NMFS to BSFRF numbers at length. Is estimated and empirical catchability/availability/selectivity the same? Does the empirical selectivity look logistic?"
Response: The model-estimated availability of Tanner crab to the survey gears in the side-by-side (SBS) study areas was compared to "empirical" estimates of availability using the ratio of numbers-at-size in the NMFS SBS datasets to those form the full NMFS EBS survey. The results are shown in Figure 53. While there are some similarities between the two sets, there are also substantial differences when conceptually they should be the same. Results for the empirical size-specific relative catchability (the ratio of NMFS to BSFRF estimated abundance at size) are shown in Figure 65, but are not compared directly to the estimated selectivity. The mean curves appear reasonably logistic, with approximate asymptotes of ~0.6 for males and ~0.4 for females. If the BSFRF surveys are regarded as providing estimates of absolute abundance (catchability=1 for all sizes), this would suggest fully-selected NMFS survey "q"'s are ~0.6 for males and ~0.4 for females--which are about 50% higher than the estimates (0.43 and 0.24, respectively) from the assessment model, but within the 95% confidence intervals for males (0.37-0.49) (but not females: 0.19-0.29).

CPT comment: show the fits to the BSFRF length composition data by year as well as in aggregate.
Response: These fits are shown in Appendix B.

CPT comment: check the bounds of parameters when estimating the BSFRF data.
Response: Fitting the BSFRF data results in no better, or worse, performance in terms of parameters hitting their bounds.

CPT comment: indicate whether or not Hessians were produced.
Response Hessians were produced for the "best" model runs for all scenarios and .std files were obtained.

CPT comment: Suggest rationale for chosen weighting for the second difference smoothing on the availability curve.
Response: The rationale for the selected weighting is that it reflects a preference toward a smoothly-varying function, reflecting an assumption that crab of similar sizes would tend to be found together with no abrupt dichotomies (which would justify a smaller smoothing weight) in spatial distribution with size. However, this assumption has not been examined in detail.

CPT comment: Compare trends in largest crab to fishing pressure and area occupied by stock.
Response: This is a good suggestion that, time permitting, will be addressed before the January 2020 CPT meeting.

CPT comment: Compare the maximum sizes seen in the fishery to the survey.
Response: Another good suggestion that, time permitting, will be addressed before the January 2020 CPT meeting.

CPT comment: Consider blocking for estimation of growth and probability of maturing.
Response: 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: Make incorporating chela height data in the assessment a priority because this might address changes in the probability of maturing over time
Response: Chela height data, in the form of male maturity ogives based on collections of chela heights since 2006, is incorporated in several model scenarios examined here, including the author-preferred scenario.

CPT comment: Provide retrospective analysis and calculate Mohn's rho for MMB
Response: Retrospective analyses for Tanner crab are complicated given the recent fishery closures and short time frames for molt increment and maturity ogive data. Time did not permit making retrospective analyses for the model scenarios considered herein. However, a retrospective analysis for the CPT-selected assessment model could be presented at the January 2020 CPT meeting.

October 2018 SSC Meeting
Comment: The SSC supports "the author's plans to investigate the sensitivity of the model to just a few early years of catch data".
Response: As described in Section 3.2, the apparent sensitivity of the model to changes in the early 1990s crab observer data was instead due to using erroneous input sample sizes for several years of fishery size composition data. After correcting these errors, the results using the revised crab fishery data are more reasonable, with less inflation of estimated population sizes. However, these sizes are still substantially larger than those obtained using the out-of-date fishery catch data. The author recommended adopting the revised crab fishery data, which was based on a painstaking reclassification of directed vs. incidental effort in the early Tanner and snow crab fisheries that more closely reflects current ADFG practices. Both the CPT and SSC concurred in May/June 2019 with this recommendation.

Comment: *"The SSC continues to recommend that the authors try to resolve the parameters on the bounds issue by either simplifying the model or experimenting with removing the bounds".*
Response: A number of formerly-estimated parameters related to the sex- and size-specific probability of undergoing the terminal molt to maturity have been eliminated because they were, unsurprisingly, estimated at their bounds (implying a probability of 0 for a terminal molt of very small immature crab or 1 for very large immature crab). This had no discernable effect on the MLE solution.

Comment: *"The author should justify fitting both abundance and biomass indices in the model or fit only one index".*
Response: The author sees no justification for fitting both abundance and biomass indices in the current model configuration and so will only include fits to one index (biomass) in the model optimization. Fits to the other index may provide a diagnostic capability.

Comment: *"The team looks forward to seeing the BSFRF work included in the future If the catchability study is to be used to inform selectivity and catchability estimates in the model, it could be as a prior instead of as fixed inputs".*
Response: After preliminary examination of this for the May 2019 CPT meeting, two model scenarios incorporating the BSFRF side-by-side (SBS) tow studies are considered in this assessment, using an approach similar to that used in the snow crab model. The use of the catchability study as a prior is an intriguing idea but would require substantial additional model development and remains to be explored. An alternative approach to the one applied here, which assumes that selectivity in the BSFRF studies is 1 and estimates availability curves that are applied to both the BSFRF and NMFS SBS simultaneously, is to

use the NMFS SBS data to estimate the availability curves outside the model using size-specific ratios between the NMFS SBS and full NMFS estimates of abundance-at-size. These could then be applied inside the model and would eliminate ~50 additional parameters per year of SBS data. However, issues associated with unobserved size ranges would need to be addressed.

September 2018 CPT Meeting
Comment: None

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). Somerton (1981b) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

Although the State of Alaska's (SOA) harvest strategy and management controls for this stock are different east and west of 166ºW, the unit stock of Tanner crab in the EBS appears to encompass both regions and comprises crab throughout the geographic range of the NMFS bottom trawl survey. Strong evidence is lacking that the EBS shelf is home to two distinct, non-intermixing, non-interbreeding stocks that should be assessed and managed separately (G. Johnson, presentation at the May 2019 CPT meeting).

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 166°W, 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 166°W), 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.

The Rugolo-Turnock classification approach is referred to herein as the "Rugolo-Turnock male maturity ogive". In this and previous assessments, the Rugolo-Turnock maturity ogive has been used to fix the proportions of immature and mature, new shell male crab in size composition data from the entire NMFS EBS bottom trawl survey dataset and to subsequently provide survey biomass estimates of abundance and biomass aggregated over all size classes. The NMFS survey datasets that use this approach to characterize male maturity outside the assessment model are identified here as "NMFS 0". The assessment model has used the resulting annual estimates of immature and new shell mature male crab abundance, biomass and size compositions as "data" to inform the model's estimates of population size and processes, including the probability of immature male crab within a given model size bin undergoing the terminal molt to maturity. This is somewhat circular in nature, and several model scenarios in this assessment fit directly to annual observed (i.e., classifying crab based on CH:CW ratios) proportions of new shell mature males to all new shell males by size bin without classifying new shell males as immature or mature outside the model.

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. If 20 years was assumed to represent the 95% percentile of the distribution of ages in the unexploited stock, the estimate for M was 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 new 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" (138 mm CW) 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 166ºW 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 strategy and total allowable catch (TAC) calculations are based on assumed minimum 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. In 2015, following a petition by the crab industry, the BOF revised the minimum preferred size for TAC calculations in the area east of 166º W longitude to 5" (127 mm CW), the same as that in the western area. These new "preferred" sizes were used to set the TAC for the 2015/16 fishery season.

In assessments prior to 2016, the term "legal males" was used to refer to male crab ≥ 138 mm CW (not including the lateral spines), although this was not strictly correct as it referred to the industry's "preferred" crab size in the east region, as well as to the minimum size in the east used in the SOA's harvest strategy for TAC setting. In subsequent assessments (and this one), the term "legal males" is used to refer to male crab 125 mm CW (the current minimum "preferred" size for both eastern and western areas used in the SOA's harvest strategy) and larger.

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 2). 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 3). 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 reopened 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; Figure 2). 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.

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 3). 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 mode of discard losses occurred in the early-1990s. In the early-1970s, the groundfish fisheries contributed significantly 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

For several years now, NMFS has annually provided a standardized version of the EBS bottom trawl survey for Tanner and other crab stocks for surveys from 1975 to the present. Similarly, estimates from the NMFS Regional Office for crab bycatch in the groundfish fisheries since 1990 have been provided by AKFIN. Standard procedure in this assessment has been to update all the data used in the assessment model based on these sources each year, so that the data used in the assessment remains consistent with the survey and groundfish bycatch data provided by NMFS and AKFIN (see below).

However, this was not done with the retained catch and bycatch data provided annually by ADFG due mainly to inconsistency between years in the formats in which the data were provided. More recently

(starting in 2017), ADFG has provided datasets in more consistent formats, allowing development of stable R code to extract the data required for the assessment in a repeatable fashion, rather than doing it by hand or in "one-off" code for a particular assessment. Thus, prior to 2018 the corresponding data in the assessment tended to be added for the current and only updated for the previous year (if necessary). Following the 2017 assessment in the course of developing R code to extract the data to a format compatible with the assessment, it was noted that discrepancies had accrued primarily between the total catch biomass data used in the assessment and those provided by ADFG for fisheries conducted in the 1990s, although there were also some (much smaller) discrepancies later in the time series and in the retained catch data as well (Tables 4-7). The discrepancies in the total catch estimates in the 1990s were traced back to a substantial reclassification of directed fishing effort and at-sea observer sampling by Doug Pengilly in 2015 that primarily affected the expansion of sampled catch by at-sea observers to total catch estimates in the early 1990s; these had not been updated in the assessment (pending a review). The smaller discrepancies later in the time series may have been due to a change in the size-weight relationships used to calculate average catch weight when CPUE was expanded to total catch biomass. The main discrepancies in retained catch occurred in 2013/14 and 2014/15 and were the result of incidental retained catch of Tanner crab in the snow and BBRKC fisheries inadvertently not being aggregated into the values for the directed fishery provided to the assessment author (Table 8). For the 2018 assessment, the "current" crab fisheries data differed from "historical" data (i.e., used in the 2017 assessment) as summarized in the following table:

data type	**years not updated**	**years updated**
effort in the BBRKC fishery	1953/54-1989/90	1990/91 to present
effort in the snow crab fishery	1978/79-1989/90	1990/91 to present
retained catch abundance, biomass	1965/66-1996/97	2005/06 to present
retained catch size compositions	1980/81-1989/90	1990/91 to present
total catch abundance, biomass (all fisheries)	--	1990/91 to present
total catch size compositions (all fisheries)	--	1990/91 to present

Unfortunately, the CPT and SSC did not have the opportunity to approve the use of the "current" version of data from the crab fisheries prior to the 2018 assessment; thus, the 2018 assessment was based on the "historical" version, with the addition of 2017/18 data. However, the "current" version was reviewed by the CPT in May 2019 and approved for use in this assessment (to which the SSC concurred at the June 2019 Council meeting).

1. Summary of new information
ADFG provided revised values for retained catch abundance and biomass from fish ticket data for 2005/06-2017/18, with new values for 2018/19. This included a breakout of incidental retained Tanner crab catch in the snow crab and BBRKC fisheries; prior to the 2018/19 assessment only total retained catch (assumed taken in the directed fishery) had been provided. 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. Revised retained catch size composition data from "dockside" observer sampling in the directed fishery were provided by ADFG last year for 1989/90-2017/18 and updated by ADFG this year for 2013/14-2017/18, with new data for 2018/19.

Revised estimates of total Tanner crab catch and bycatch in the directed, snow crab, and BBRKC fisheries provided by ADFG for 1990/91-2017/18 were incorporated into the assessment. ADFG provided updated values for total catch in the crab fisheries for 2017/18 and new values for 2018/19.

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.

Swept-area abundance, biomass and size composition data from the 2019 NMFS EBS Bottom Trawl Survey were added to the assessment. Survey results for the assessment were calculated directly from the survey "crab haul" data files and station strata file to incorporate assessment criteria (e.g., excluding crab < 25 mm CW, aggregating crab > 185 mm CW into the upper-most size bin in size compositions) and facilitate comparisons across multiple areas and population categories.

Molt increment data from growth studies conducted in the EBS as cooperative research by NMFS and BSFRF are fit in the model scenarios included in this assessment, with new data from studies in 2017 and 2019 included in this assessment.

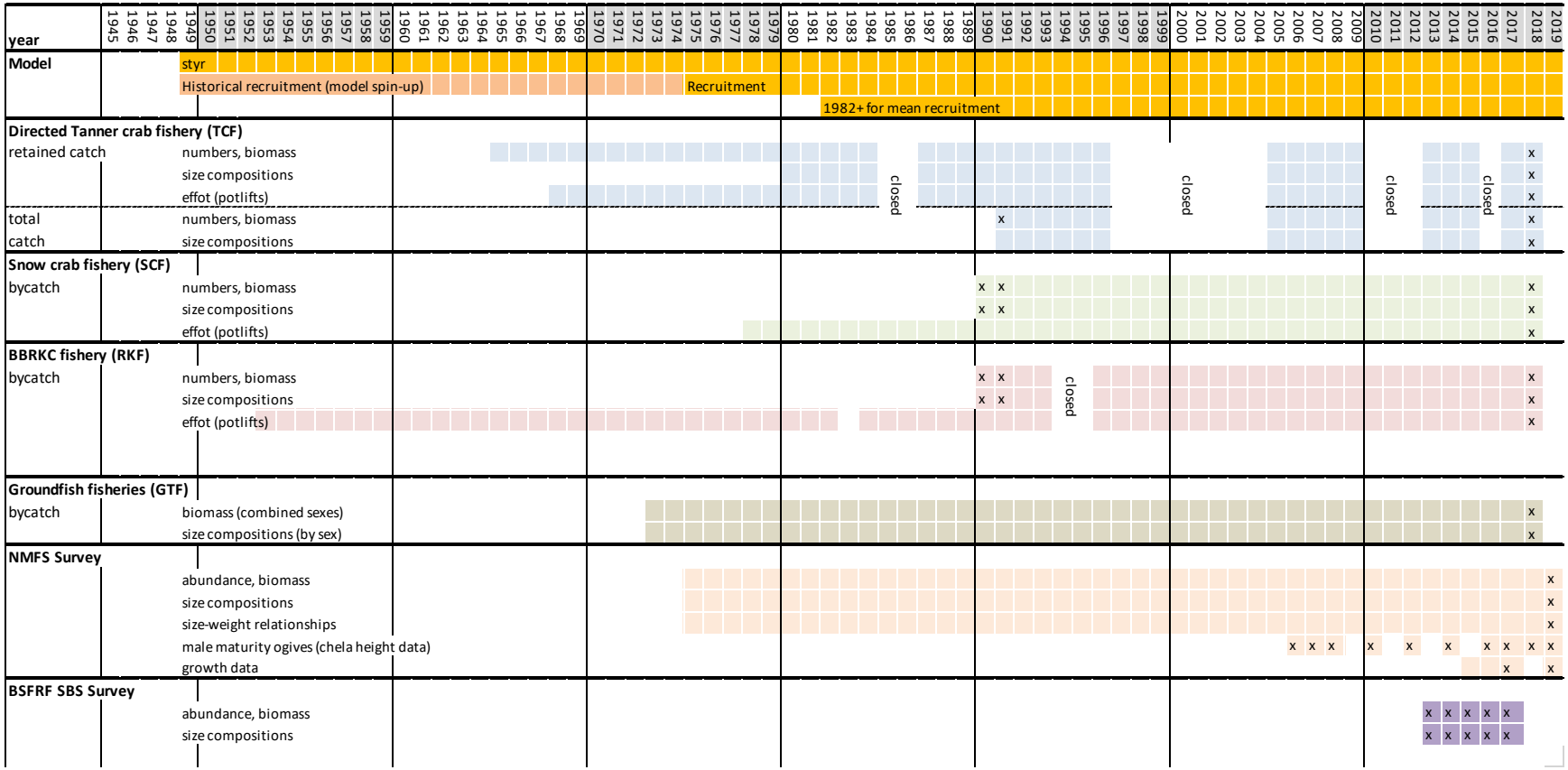
Annual male maturity ogives based on classification of male crab in the NMFS EBS bottom trawl survey using CH:CW ratios are fit in a number of the model scenarios considered in this assessment. Existing and new (2019) chela height data sets were analyzed to provide estimates of the fraction of new shell mature males to all new shell male crab by 10 mm size bin (J. Richar, NMFS, pers. comm.). Data from collections since 2006, when chela heights were first measured to 0.1 mm, are included in the assessment.

Finally, data for Tanner crab from the joint BSFRF-NMFS comparative catchability ("side-by-side") studies in 2013-2017 are included in the assessment for the first time.

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

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	recalculated, new	NMFS
	size compositions	1975-2019	recalculated, new	
	male maturity data	2006+	new	
NMFS/BSFRF	molt-increment data	2015-17, 2019	same as 2017	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	new	BSFRF
	size compositions	2013-17	new	
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	updated, new	ADFG
	retained catch size compositions	2013/14-2018/19	updated, new	ADFG
	total catch (abundance, biomass)	1991/92-2017/18	revised, new	ADFG
	total catch size compositions	1991/92-2017/18	revised, new	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	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)	1991/92-2017/18	revised, new	NMFS/AKFIN
	total bycatch size compositions	1991/92-2017/18	updated, new	

The following table summarizes the data coverage in the assessment model (color shading highlights different model time periods and data components):



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 2 and 3 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 again 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 166°W longitude.

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 3 and Figure 4 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. In previous assessments, estimates of "discards" were provided rather than estimates for "total catch", which allowed mortality associated with the handling process to be estimated outside the assessment model. While this generally remains true for bycatch in the groundfish and non-directed crab fisheries (most or all Tanner crab bycatch is discarded), "discard mortality" cannot be estimated outside the assessment model for males in the directed fishery.

Estimated bycatch mortality in the groundfish fisheries (without distinguishing gear type) was highest (~15,000 t) in the early 1970s, but was substantially reduced 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 a gradual decline until 2008, after which it has fluctuated annually below ~300 t to the present (150 t in 2018/19).

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 5 by fishery region and shell condition since the fishery re-opened in 2013/14. These appear to indicate a shift to retaining somewhat smaller minimum sizes since 2013/14, compared with 2005/06-2009/10 (Stockhausen, 2017). In fact, the BOF in 2014/15, in response to a petition by industry, 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.

Normalized total catch (retained + discards) size compositions from at-sea crab fishery observer sampling are presented by sex and fishery in Figures 6-11. 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 Figures 112-13 for 1991/92 to 2018/19. 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 in Figure 12).

Raw and input sample sizes (number of individuals measured) for the various fisheries are presented in Tables 9-13.

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 14-15, Figures14-15). 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 14). 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 currently at its lowest point (28,000 t) since 2000 (Table 14). 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 166°W longitude), although the magnitudes differ (Figure 14). Preferred-size male survey biomass has been declining east of 166°W (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 15, Figure 15). 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 16, while estimates of area-swept biomass for the study areas are compared in Figure 17 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 18. 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 19), 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 19, 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 16. 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 Figures 20-22 for immature males, mature males, immature females, mature females and legal males. 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 23 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 17).

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 24) 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 25.

c. Size distribution at recruitment

The assumed size distribution for recruits to the population in the assessment model is presented in Figure 26.

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 have been made 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[2].

A new 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. The new 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 new frame work incorporates new data types (e.g., molt increment data, male maturity ogives), new survey data (e.g., the BSFRF surveys), and new fishery data (e.g., bycatch in the groundfish fisheries by gear type). The new model 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 Markov Chain Monte Carlo (MCMC) evaluation of a model's posterior probability distribution.

Most recently, the model code has been modified to allow fitting to molt increment observations, chela height data, and male maturity ogives. It has also been restructured to function in a management strategy evaluation (MSE) mode. The code for the TCSAM02 model framework is publicly available on GitHub[3].

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 A.

In brief, crab enter the modeled population as recruits following the size distribution in Figure 26. 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 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

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

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

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 function in a management strategy evaluation mode, with specific computational routes defined for use as an operational model and as an estimation model. Fits to annual male maturity ogives were incorporated into the model last year, but with the assumption that these data would be aggregated to the same size bins as used in the model and other data. Now, this requirement has been loosened and the model can now fit ogives given using any size bin width. Finally, the model now allows specification and estimation of "availability" functions, similar to selectivity functions, that reflect the size-specific fraction of a section of the population (defined by sex, maturity state and shell condition) that can be encountered within a specific survey collection. This was necessary to incorporate the BSFRF SBS data into the assessment framework because these collections, in contrast to the complete NMFS EBS bottom trawl survey, do not encompass the entire Tanner crab stock.

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 2018 assessment (Model 18AM17 from Stockhausen, 2018) provides the baseline model configuration for subsequent alternative model scenarios evaluated in this assessment. Here, the 2018 assessment model is designated "M19F00". The following tables provide a summary of the baseline model configuration, M19F00, for this assessment.

Model M19F00: 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 M19F00: 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 M19F00: Description of model likelihood components.

Component	Type	included in optimization	Distribution	Likelihood
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 "0" survey	abundance	no	lognormal	by sex
	biomass	yes	lognormal	by sex, for mature crab only
	size comp.s	yes	multinomial	by sex/maturity
	chela height data	no	--	--
NMFS "M" survey (males only, no maturity)	abundance	no	lognormal	all males
	biomass	no	lognormal	all males
	size comp.s	no	multinomial	all males
NMFS "F" survey (females only, w/ maturity)	abundance	no	lognormal	by maturity classification
	biomass	no	lognormal	by maturity classification
	size comp.s	no	multinomial	by maturity classification
growth data	EBS only	yes	gamma	by sex

The NMFS “0” survey refers to the “flavor” of the NMFS EBS bottom trawl survey data which has been fit in previous assessment models: maturity state (immature/mature) is determined outside the model for females based on morphological identification and for males on a size-dependent proportional basis using the Rugolo-Turnock maturity ogive. The NMFS “M” survey refers to a new, 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 “0” survey data configured as a separate data file to accompany the NMFS “M” survey data file.

As per CPT recommendation, the following model scenarios were evaluated as part of this assessment:

model scenario	number of parameters	objective function value	max gradient	Jitter runs	# runs converged to MLE	scenario description
M19F00	357	2,962.17	0.0004	--	--	2018 assessment model (18AM17)
M19F00a	357	3,025.43	0.0003	--	--	M19F00 with revised ADFG data for 1990+ crab fisheries
M19F01	363	3,368.11	0.0002	3,000	94	M19F00a updated for 2018/19 (base model for 2019)
M19F02	363	3,521.89	0.0004	--	--	M19F01 + 2006+ observed male maturity data
M19F03	343	3,467.75	0.0013	3,000	72	M19F02 - male maturity characterized by Rugolo/Turnock maturity ogive
M19F04	628	3,578.47	0.0004	3,000	7	M19F01 + 2013-2017 BSFRF/NMFS side-by-side data
M19F05	608	3,674.61	0.0004	3,000	5	M19F03 + 2013-2017 BSFRF/NMFS side-by-side data

As noted previously, M19F00 is the 2018 assessment model and data ("18AM17" in the 2018 assessment). For M19F00a, the "historical" crab fishery catch data is replaced with the "current" data provided by ADFG through 2017/18. This represents a bridging scenario to the 2019 assessment and allows a characterization of the effects of the changes in fishery data on model outcomes without the confounding effects of new data for 2018/19. M19F01 is M19F00a updated with 2018/19 data. It represents "business as usual" in terms of the development of the assessment model. M19F02 includes fits to the male maturity ogive data developed from 2006-onward chela height data collections during the NMFS EBS bottom trawl survey. It also, however, fits the male data in the NMFS "0" dataset with male maturity determined outside the assessment model using the Rugolo-Turnock maturity ogive. This is a bridging scenario that provides a transition to M19F03, which drops the fits to the male data in the NMFS "0" dataset and relies strictly on the male maturity ogive data (and the size composition data) to inform the model estimates of the size-specific probability of terminal molt for males. M19F04 constitutes a different development "fork" based on M19F01, and includes fits to the biomass and size composition data from 2013-2017 BSFRF and NMFS side-by-side studies. In this scenario, the BSFRF survey is assumed to be fully-selected across the size ranges in the model (> 25 mm CW) and thus provides estimates of absolute size-specific abundance within a given study area. Sex-specific "availability" functions are estimated in the model to relate the size-specific study-area abundance estimates to population abundance. The final scenario, M19F05, reflects a merging of the M19F01-M19F02-M19F03 fork with the M19F01-M19F04 fork.

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 as well in the table above. The total objective function values, however, cannot be directly compared between scenarios because each scenario fits different datasets. Convergence for the four scenarios under consideration for status determination and OFL-setting (M19F01, M19F03, M19F04, and M19F05) was evaluated using parameter jittering, with a total of 3,000 runs initiated for each scenario. Of these runs, generally a large number failed to converge at all and a smaller number converged to local minima smaller than the maximum likelihood (ML) solution. About 3% of the runs found the (presumed) ML solution in M19F01, about 2.4% for M19F03, and only about 0.2% in M19F04 and M19F05. In the interest of time and computing resources, the bridging scenarios were not jittered but instead were initialized using the final parameter estimates from the base scenario in the bridge.

M19F03 is the author's preferred model, as explained below.

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

The following table summarizes basic model results from the 2018 assessment model (M19F00) and the 6 scenarios considered here (results from the author's preferred model are highlighted):

Model Scenario	average recruitment	Final MMB	B0	Bmsy	Fmsy	MSY	Fofl	OFL	projected MMB	projected MMB / Bmsy
	millions	1000's t	1000's t	1000's t		1000's t		1000's t	1000's t	
M19F00	223.63	66.64	86.55	30.29	0.74	12.75	0.74	20.87	35.95	1.19
M19F00a	284.28	82.05	94.24	32.99	0.89	14.58	0.89	27.90	41.52	1.26
M19F01	316.79	68.79	100.85	35.30	0.81	15.58	0.81	22.54	35.66	1.01
M19F02	367.48	71.54	105.59	36.96	1.11	17.89	1.03	24.75	34.63	0.94
M19F03	393.84	82.61	118.96	41.64	1.18	19.49	1.12	29.48	39.68	0.95
M19F04	377.28	74.03	106.76	37.37	0.87	16.87	0.87	24.87	37.50	1.00
M19F05	418.73	80.33	116.44	40.75	1.21	19.40	1.14	28.58	38.42	0.94

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

It was noted at the May 2018 CPT meeting that it was not biologically realistic that male Tanner crab less than 60 mm CW had undergone their terminal molt, although there were a few males collected in the NMFS EBS bottom trawl surveys below 60 mm CW that were classified as mature using the chela height data. It was similarly recognized that it was probably biologically unrealistic for female crab less than 40 mm CW to have undergone terminal molt. This actually resulted in simpler, but more realistic models, in scenarios where these constraints were implemented (scenarios M19F03 and M19F05).

A future avenue for exploration in this regard is to estimate the "availability" functions outside the model that are required to allow the SBS data to inform NMFS survey catchability, rather than estimating these functions inside the model. Because the availability functions are estimated in the model using a non-parametric approach to allow for an arbitrary, but smoothly-varying, shape, this adds 48 additional parameters per included SBS study (32 for the male availability function, 16 for the female one). Instead, the availability functions can be estimated outside the model using the size-specific ratios of the size composition data from each NMFS SBS dataset to the corresponding data from the full NMFS dataset, perhaps with a smoothing penalty applied to the resulting curve. In this respect, there would be no need to fit the NMFS SBS data within the model (as is done now) at all.

d. Convergence status and convergence criteria

As noted above, convergence in all non-bridging models was assessed by running each model 3,000 times with randomly-selected ("jittered") initial parameter values for each run. For each model, a number of these jitter runs failed, primarily because the initial values for the growth parameters resulted in the mean post-molt size being smaller than the pre-molt size. 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 would 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, many more runs converged to the final (presumably) ML solution for scenarios M19F01 and M19F03 than for M19F04 and M19F05, but this is not too surprising given the much larger number of estimated parameters for the latter two scenarios.

e. Sample sizes assumed for the compositional data

Input sample sizes used for compositional data are listed in Tables 9-13 for fishery-related size compositions. Input sample sizes for all survey size compositions were set to 200, which was also the

maximum allowed for the fishery-related sample sizes. Otherwise, input sample sizes were scaled as described in Stockhausen (2014, Appendix 5):

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

where $\overline{SS}$ was 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 Tables 18 and 19. 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. The logit-scale parameter describing the retention of male crab at large (asymptotic) sizes prior to 1997 was estimated at its upper bound (15) in all model scenarios. Because retention can only go as high as 1 on the arithmetic scale, and a logit-scale value of 15 corresponds to an arithmetic scale value of 0.9999997, this parameter should be fixed in future models. In a similar fashion, the logit-scale parameter describing the probability of terminal molt for males in the largest size bin (180+ mm CW) reached its bound of 15 in scenarios M19F00a, M19F01, M19F02, and M19F04 while that describing the probability of terminal molt for females in the smallest size bin (25-30 mm CW) reached its lower bound (-15). These were fixed in M19F03 and M19F05, based on assumptions of minimum and maximum sizes for immature crab at terminal molt, such that the corresponding probabilities of terminal molt in these size bins were 1 or 0.

Survey catchability parameters for the 1975-1981 time period (pQ[1] and pQ[3]) 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).

Estimates of parameter uncertainty, approximations calculated by inverting the model hessian and using the "delta" method, were obtained from each converged model's ADMB "std" file (Tables 20-33). Extremely large uncertainties were obtained for parameters related to the NMFS trawl survey selectivity for females after 1981 for all scenarios that estimated these parameters, unless the estimates hit one of the bounds (Table19). A number of other selectivity-related parameters, while not at one of their bounds, have large uncertainties associated with the estimates (e.g., the 95%-selected size for female bycatch in the BBRKC fishery, Table 31). These may reflect indeterminacy between the estimated capture rates for fully-selected crab and these parameters in determining the effective capture rates on large crab.

Unweighted negative log-likelihoods (NLLs) and their associated (weighted) components in the model objective function are compared for fits to data for the scenarios with 2018/19 data in Tables 34-36. Comparison of the unweighted versions gives some insight into the tradeoffs between fitting to different datasets in the model scenarios. For example, M19F03 doesn't actually fit the NMFS "0" dataset mature male biomass (i.e., the likelihood is not included in the objective function that is optimized) whereas M19F00 does, while the latter doesn't fit the NMFS "M" dataset biomass and the former does. The NLL for M19F00 from the NMFS "0" biomass is ~17 likelihood units better than that for M19F03 but the NLL for M19F03 is ~50 likelihood units better than that for M19F00. Another way of assessing model fit is to examine the average root mean square errors (RMSE) associated with differences between observed and predicted values (Table 38). In this regard, M19F03 fits NMFS "0" male size compositions (rmse=490.64) slightly worse than M19F01 (rmse=487.07) but fits the NMFS "M" size compositions better (185.98 vs. 195.51).

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

None of the model scenarios evaluated in this assessment were directly comparable using likelihood criteria because different combinations of datasets were fit in each scenario. Consequently, the criteria used to evaluate the alternative models were based primarily on: 1) goodness of fit (assessed using the unweighted NLLs and RMSEs for different datasets, even when the datasets were not included in the likelihood), 2) parameter sensibility, and 3) 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.

i. Evaluation of the model(s)

All scenarios fit their respective catch biomass data quite well (noting that different crab fishery data is fit in M19F00 and the other scenarios; Figures 27-30), although scenarios M19F01-M19F05 slightly underestimate total bycatch biomass in the groundfish fisheries from 1991-2013. The model fits to fishery size compositions are similar in quality to what has been obtained in previous assessments: not terrible, but not really great either. The fits to retained catch size compositions are the best overall and are essentially identical for all the scenarios excluding M19F00 (Appendix B, Figures 42-45). Some less good fits seem to be associated with a closure of one of the management areas (e.g., 2005, 2009, 2018). Fits to total catch size compositions in the directed fishery (Appendix B, Figures 46-51) are reasonably

good (except for 1996, when sample sizes were very small) but continue to somewhat overestimate the catch of large males since 2013. Again, however, the fits are almost identical among the scenarios. The fits to the total catch size compositions from the snow crab fishery are somewhat worse, particularly in the early 1990s, than those for the directed fishery—to be expected given the differences in the numbers of crab sampled. Some slight differences can be seen among the scenarios in the fits to the total catch size compositions form the groundfish fisheries (Appendix B, Figures 58-67), but the fits themselves are not particularly good. Selectivity functions for the groundfish fisheries are estimated for three different time periods between 1973 and the present, but underlying changing in areas targeted and gear composition may occur on shorter time scales that contribute to the lack of fit. The fits to total catch in the BBRKC fishery (Appendix B, Figures 68-73) are the poorest, consistent with the low observer sample sizes for Tanner crab, particularly females, in this fishery. However, the disagreement between predicted and observed male compositions in the early 1990s is rather puzzling.

The fits to survey biomass (Figures 31-34) are somewhat poorer than those to fishery catch biomass, a not unexpected result because fitting to the fishery catch biomass data was weighted heavily (20x) in the model objective functions. The most notable differences among the fits are that scenarios M19F03 and M19F05 (which fit the male maturity ogive data) both follow the low female biomasses in the 1980's better than the other scenarios do. While all the scenarios estimate declining trends in mature survey biomass starting in 2014, all are biased somewhat high relative to the data.

In general, the predicted survey size compositions are remarkably similar among the scenarios (Appendix B, Figures 1-41), but scenarios that fit the male maturity ogive data (M19F02, M19F03, and M19F05) tend to estimate slightly higher proportions of "mature" (as categorized by the Rugolo-Turnock maturity ogive) males at smaller sizes, lower proportions of immature females at small sizes, and lower proportions of mature females at larger sizes, than occurs in the other scenarios. Somewhat surprisingly, the proportions for "immature" males are almost identical among the scenarios. The two scenarios that fit the SBS datasets also estimate almost identical size compositions which fit the observed ones fairly well for both the NMFS and BSFRF data. In particular, the models capture the recruitment event in 2017 well in both datasets, although it occurs much more strongly in the BSFRF dataset.

All the scenarios fit female growth equally well, but over-predict male molt increments at larger sizes, with M19F03 and M19F05 being the most biased (Figure 35). In contrast, M19F03 and M19F05 fit the male maturity ogive data better than the other scenarios, but all scenarios tend to underestimate the fraction mature in any size bin, although this is not true in all cases (Figure 36).

Estimated capture rates in the directed fishery (Figure 37) follow the same temporal patterns in all scenarios, with the largest peak in 1979 and a lesser peak in 1991 or 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 38-41) or retention functions (Figure 42), which are essentially identical (the differences between M19F00 and M19F00a in 1990 and 1991 are primarily due to changes in the underlying snow crab data).

Estimated capture rates in the snow crab (Figure 43) also exhibited similar temporal patterns. Scenarios M19F00 and M19F00a differ substantially in level due to changes in the underlying crab data, which changes the selectivity function estimated for the early 1990s, as well as differences in recruitment. The capture rates estimated in the other scenarios are much more similar to one another, and primarily reflect smaller differences in estimated recruitment. Estimated selectivity functions for these scenarios were almost identical for the three time periods in which they were estimated, with the only substantial difference being that the curves estimated in M19F04 and M19F05 for the pre-1997 time period were right-shifted to larger sizes by one or two size bins (Figure 44).

Estimated capture rates in the BBRKC fishery (Figure 45) exhibited similar temporal patterns among the scenarios, as well. Scenarios M19F00 and M19F00a were much more similar in level than was the case for the snow crab fishery because the underlying data was not substantially changed. The levels of the capture rates for females in scenarios M19F00a-M19F05 appear fairly variable, but the absolute scale is very small (on the order of 0.04 relative to 0.5 for the directed fishery) and the variability is primarily due to the small scale of the associated catches. The estimated selectivity functions (Figure 46) were also slightly different among the scenarios for females, while those for males were basically identical.

As with the other fisheries, estimated capture rates in the groundfish fisheries (Figure 47) exhibited similar temporal patterns in all scenarios but differed somewhat in absolute level. In addition, M19F00a exhibited substantially higher levels in the 1991-2012 time period than did scenarios M19F01-M19F05, which were all quite similar in level. Estimated male selectivity curves exhibited a fair amount of variation among scenarios during the 1997-2004 time period, while the selectivity curves for both males and females in the 2005+ period exhibited somewhat less variability and those in the pre-1997 period were essentially the same (Figure 48).

The change in the crab fishery data had fairly large effects on estimates of survey catchability and selectivity functions (Figures 49-51). Although estimated catchability was the same for scenarios M19F00 and M19F00a in the pre-1982 time period, the estimated size-at-50% selected for the male and female selectivity functions shifted substantially to larger sizes (more so for males than females) such that many more small and intermediate size crab were "invisible" to the survey during this time period. In the 1982+ time period, catchability was estimated to be smaller in M19F00a while the selectivity functions remained similar (the male function was slightly shifted toward larger sizes), with the result that crab of *all* sizes were effectively invisible to the survey in M19F00a. Survey catchability in the pre-1982 time period did not change in the M19F01-M19F05 scenarios, no did the male selectivity function, but the female selectivity function shifted to somewhat larger sizes in scenarios M19F03 and M19F05. Survey catchabilities did change in all of these scenarios in the 1982+ time period for both males and females, with the largest values estimated in M19F00a while the smallest value for females was estimated in M19F02 and the smallest for males in M19F03. In general, including the male maturity ogive data in the model fit decreased the catchability for both sexes. Selectivity for males in the pre-1982 time period was essentially unchanged among M19F01-M19F05 scenarios, while including the male maturity ogive data shifted female selectivity ~ 5 mm to larger sizes. The selectivity functions for both sexes differed among these scenarios for the 1982+ time period, shifting the 50%-selected size substantially to larger size for females in scenarios M19F03, M19F04, and M19F05 but only slightly to larger size for males.

Survey availability, estimated in scenarios M19F04 and M19F05 for the SBS datasets, were similar to one another (Figure 52). Curves for females were fairly similar for 2013-15, increasing with size, but different from those for 2016 and 2017, which decreased with size. For males, larger males in the 100-150 mm CW range tended to be most available to the survey. In 2013-15, small males were mostly unavailable while in 2016-17 the smallest were much more available while intermediate-sized males were relatively less available. It is possible to estimate empirical versions for the availability functions using the ratio of crab abundance in the NMFS SBS dataset to that in the NMFS "0" dataset by size bin. These empirical availability functions provide a check on the estimated versions. However, they do not particularly resemble the estimated versions (Figure 53), except for females in 2013.

Another effect of the revised crab fishery data is to slightly increase the estimated rate of M on mature mature females and to slightly decrease them on males, outside the 1980-84 "enhanced mortality" period when the effect is to increase the rates for both sexes (M19F00a compared with M19F00; Figure 54). Fitting the male maturity ogive data rather than mature male survey biomass based on the Rugolo-Turnock maturity ogive (M19F03, M19F05) results in a much reduced estimate of M on mature males in the enhanced mortality period while it is elevated for mature females.

The estimated probability of terminal molt by size is almost the same for all scenarios, but is shifted to smaller sizes by ~5 mm CW for the scenarios that fit the male maturity ogive data (scenarios M19F02, M19F03, and M19F05; Figure 55). Mean growth, as well, is similar across all scenarios for females while the scenarios that fit the male maturity ogive data yield slightly higher estimates of growth for males at large pre-molt sizes (Figure 56).

Estimated recruitment time series exhibit similar temporal patterns in all scenarios, but differ in overall scale, with the largest difference occurring between M19F00 (the 2018 assessment model) and M19F00a, the 2018 assessment model with the revised crab fishery data (Figures 57-58). The good news for the stock a few years in the future is that all the scenarios estimate recruitment during 2016-18 was much larger than during 2011-2015. The bad news is that all the scenarios estimated a declining trend in mature male and female biomass (MMB and MFB, evaluated on Feb. 15 for each year) over the past 4-5 years since a recent high in 2014 (or 2015, depending on scenario; Figures 59-60). Across the time series, the estimated trajectories for mature biomass also follow similar temporal trends but differ in scale. Unsurprisingly, similar trends were also estimated for the mature components of population biomass (evaluated on July 1 for each year; Figure 61). However, trends in immature biomass reflect the estimated recent recruitment trends and have been increasing in all scenarios for the past two years following a low point not seen since the early 1990s.

The author's preferred model, M19F03, fits all of the datasets reasonably well and includes fits to "observed" new shell male maturity ogives derived for years after 2005 when chela height data was collected in the NMFS EBS bottom trawl survey. It also drops the fits to immature/mature male categories created by applying the Rugolo-Turnock maturity ogive to male abundance and biomass by size outside the model. It does not fit the BSFRF SBS datasets, but doing so (i.e. M19F04, M19F05) does not seem to substantially change the estimates of catchability for the NMFS EBS bottom trawl survey or population quantities such as recruitment and mature biomass in the manner one would expect (higher estimates of catchability, lower estimates for population quantities). In addition, the manner in which "availability" is handled in the scenarios that fit the SBS data is somewhat problematic in terms of potential confounding between the ability to estimate availabilities for the BSFRF surveys and the ability to estimate catchabilities for the NMFS surveys. Finally, the estimated availability functions are somewhat inconsistent with empirical versions derived from the full NMFS survey and the NMFS SBS studies.

4. Results (best model(s))

Scenario M19F03 was selected as the author's preferred model for the 2019 assessment.

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

Input and effective sample sizes for size composition data fit in the model are listed in Tables 40-45 from the 2018 assessment model and scenario M19F03. 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 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 20-34.

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

Estimates for mature survey biomass, by sex, are listed in Table 46and for mature biomass at mating, by sex, in Table 47 for the 2018 assessment model and the author's preferred model, M19F03. 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 (see Tables 48 and 49, respectively).

iii. Recruitment time series

The estimated recruitment time series from the 2018 assessment and M19F03 are listed in Table 50.

iv. Time series of catch divided by biomass.

A comparison of catch divided by biomass (i.e., exploitation rate) from the 2017 assessment and 18C2a is listed in Table 51.

c. Graphs of estimates

Graphs of estimates from the preferred scenario, M19F03 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 curves for the directed fishery are shown in Figures 39-42, for the snow crab fishery in Figure 45, for the BBRKC fishery in Figure 47, and for the groundfish fisheries in Figure 49. Estimated retention curves are shown in Figure 43. Graphs of selectivity curves for the NMFS survey are shown Figure 51; graphs of estimated availability curves from the NMFS SBS studies are shown in Figure 53. Natural mortality estimates are shown in Figure 55, terminal molt probabilities are shown in Figure 56, and mean growth rates (molt increments) are shown in Figure 57.

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 38, 44, 46, and 48.

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 62. Mature male and female biomass trends (MMB and MFB) are shown in Figures 60 and 61.

iv. Estimated fishing mortality versus estimated spawning stock biomass

See Figure 65.

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

Not available.

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 Figure 26 for retained and total catch in the directed fishery and in Figures 27-29 for total catch in the snow crab, BBRKC, and groundfish fisheries. Fits to NMFS survey biomass are shown for mature crab and all males and females by maturity state in Figures 30 and 31, respectively. Fits to survey biomass in the SBS studies are shown in Figures 32 and 33.

ii. Graphs of model fits to survey numbers

Not available.

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

See Appendix B for model fits to annual catch proportions by size class.

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

See Appendix B for model fits to annual survey proportions by size class.

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

See Appendices C and D for marginal distributions of fits to the compositional data.

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

See Appendices C and D for plots of implied and input sample sizes. For the most part, the implied effective sample sizes tend to be substantially larger than the input values.

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

RMSEs for fits to various datasets are provided in Tables 37-39.

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.

Due to time constraints, quantile-quantile (q-q) plots and histograms of residuals were not completed for the 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).

Due to time constraints, retrospective analyses were not completed for the assessment.

ii. Historical analysis (plot of actual estimates from current and previous assessments).

Due to time constraints, an historical analysis was not completed for the assessment.

g. Uncertainty and sensitivity analyses

MCMC runs were completed for scenario M19F03 to explore model uncertainty. The model was run for four chains, which 10 million iterations each, with a burn-in period of 1,000,000 iterations and keeping results from every 1,000th iteration to reduce serial autocorrelation, which yielded 4000 samples per chain. Mixing appeared to be sufficient, but this can be difficult to evaluate. This run provides empirical posterior distributions for model parameters and selected derived quantities, including OFL-related quantities.

Time constraints (the MCMC run took several days to complete) did not allow a full exploration of the MCMC results. Summary results for the objective function and OFL-related quantities (Figure 62) indicates that they are reasonably well-behaved and normally-distributed, and do not exhibit unexpected correlation structures (e.g., F_{OFL} and F_{MSY} are expected to be highly correlated, so this is not cause for concern).

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 2018/19 was 20.87 thousand t while the total catch mortality was 1.90 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 2018/19. 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 63):

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

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 2019/20 require estimates of $B = MMB_{2019/20}$ (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 19). 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.

In 2015, the SOA's Board of Fish, under petition from the commercial Tanner crab fishing industry, changed the minimum preferred size for crab in the area east of 166ºW longitude in calculations used for setting TACs from 138 mm CW (not including lateral spines) to 125 mm CW. The minimum preferred size in the area west of 166ºW remained the same (125 mm CW). In assessments before 2017, an attempt was made to account for retention of slightly (10 mm CW) smaller crab in the directed fishery in the western area. Because the preferred size is now the same in both areas, the OFL is calculated assuming both selectivity (as previously) and retention (new) curves are the same in both areas.

In assessments before 2017, a separate "projection model" was used to determine OFL based on results from the assessment model. The estimated coefficient of variation for the estimate of final MMB was used to characterize model uncertainty and provided a calculational basis for determining an empirical probability density function (pdf) for OFL based on sampling final MMB from its assumed pdf. Since the transition to TCSAM02 in 2017, the OFL is calculated within the assessment model based on equilibrium calculations for F_{OFL} 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) incorporating full model uncertainty.

To calculate the F_{OFL}, 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. This calculation also depends on the assumed bycatch F's on Tanner crab in the snow crab, BBRKC and groundfish fisheries. As with last year, 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).

Selectivity curves in the bycatch fisheries were set using the average curves over the last 5 years for each fishery, the same approach as in previous assessments (Stockhausen 2017).

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+. This issue was revisited at the May 2018 CPT meeting with regard to the final year to be included in the calculation, but no definitive were made. 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. The value of $\bar{R}$ for this period from MCMC runs of the author's preferred model is 373.96 million. The estimates of average recruitment from the author's preferred model (M19F03), as well as all the other models based on the "current" ADFG fishery data, are substantially higher than from the 2018 assessment model (224 million; see Table 52). The value of B_{MSY}=$B_{35\%}$ for $\bar{R}$ is 41.07 thousand t, which is larger than that from the 2018 assessment (21.87 thousand t).

Once F_{OFL} is determined using the control rule (Figure 63), the (total catch) OFL can be calculated based on projecting the population forward one year assuming that $F = F_{OFL}$. 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 when fishing at $F = F_{OFL}$.

The total catch (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, 2019 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 2019/20 were calculated based on resulting model parameter values. This would be repeated a large number of times to approximate the distribution of OFL given the full model uncertainty. For this assessment, four chains of 10 million MCMC steps were generated, with the OFL and associated quantities calculated at each step. The chain was initialized from the converged model state using a "burn in" of 2,000,000 steps and subsequently thinned by a factor of 1,000 to reduce serial autocorrelation in the MCMC sampling. This resulted in about 20,000 MCMC samples with which to characterize the distribution of the OFL. **The median value**

of this distribution was taken as the OFL for 2019/20. The OFL for 2019/20 from the author's preferred model (Model M19F03) is 28.86 thousand t (Figure 64)**.**

The B_{MSY} proxy, $B_{35\%}$, from the author's preferred model is 41.07 thousand t, so MSST = 0.5 B_{MSY} = 20.54 thousand t. Because current projected B = 39.55 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 1965/66-2018/19 in Figure 65 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.

For the author's preferred scenario, M19F03, the P* ABC (ABC_{max}) is 28.79 thousand t while the 20% Buffer ABC is 23.09 thousand t. 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 23.09 thousand t**.

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 is 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 166°W longitude should be explicitly represented in the assessment model should 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. There appears to be conflicting information from the NMFS and BSFRF SBS surveys regarding "availability" relative to the full NMFS survey, so estimating availability in the assessment model by fitting SBS data from both surveys (as was done here in Scenarios M19F04 and M19F05) may not be the best approach to incorporating the BSFRF surveys, which are assumed to provide absolute estimates of crab abundance within the area(s) in which the SBS surveys are conducted.

Development of a Gmacs version of the Tanner crab model is also a priority, but will await development of a Gmacs snow crab model.

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

J. Literature Cited

Adams, A. E. and A. J. Paul. 1983. Male parent size, sperm storage and egg production in the Crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). International Journal of Invertebrate Reproduction. 6:181-187.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. NOAA Tech. Memo. NMFS-AFSC-178. 298 p.

Brown, R. B. and G. C. Powell. 1972. Size at maturity in the male Alaskan Tanner crab, *Chionoecetes bairdi*, as determined by chela allometry, reproductive tract weights, and size of precopulatory males. Journal of the Fisheries Research Board of Canada. 29:423-427.

Bowers, F.R., M. Schwenzfeier, S. Coleman, B. Failor-Rounds, K. Milani, K. Herring, M. Salmon and M. Albert. 2008. Annual Management Report for the Commercial and Subsistence Shellfish Fisheries of the Aleutian Islands, Bering Sea and the Westward Regionss Shellfish Observer Program, 2006/07. Fishery Management Report No. 08-02. 242 p.

Daly, B., C. Armistead and R. Foy. 2014. The 2014 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. NOAA Technical Memorandum NMFS-AFSC-282 172 p.

Daly, B., C. Armistead and R. Foy. in prep. The 2015 Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Results for Commercial Crab Species. NOAA Technical Memorandum NMFS-AFSC-XX 172 p.

Donaldson, W .E. and D. M. Hicks. 1977. Technical report to industry on the Kodiak crab population surveys. Results, life history, information, and history of the fishery for Tanner crab. Alaska Dept. Fish and Game, Kodiak Tanner crab research. 46 p.

Donaldson, W. E., and A. A. Adams. 1989. Ethogram of behavior with emphasis on mating for the Tanner crab *Chionoecetes bairdi* Rathbun. Journal of Crustacean Biology. 9:37-53.

Donaldson, W. E., R. T. Cooney, and J. R. Hilsinger. 1981. Growth, age, and size at maturity of Tanner crab *Chionoecetes bairdi* M. J. Rathbun, in the northern Gulf of Alaska. Crustaceana. 40:286-302.

Haynes, E., J. F. Karinen, J. Watson, and D. J. Hopson. 1976. Relation of number of eggs and egg length to carapace width in the brachyuran crabs *Chionoecetes baridi* and *C. opilio* from the southeastern Bering Sea and *C. opilio* from the Gulf of St. Lawrence. J. Fish. Res. Board Can. 33:2592-2595.

Hilsinger, J. R. 1976. Aspects of the reproductive biology of female snow crabs, *Chionoecetes bairdi*, from Prince William Sound and the adjacent Gulf of Alaska. Marine Science Communications. 2:201-225.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

Hosie, M. J. and T. F. Gaumer. 1974. Southern range extension of the Baird crab *(Chionoecetes bairdi* Rathbun). Calif. Fish and Game. 60:44-47.

Karinen, J. F. and D. T. Hoopes. 1971. Occurrence of Tanner crabs (*Chionoecetes* sp.) in the eastern Bering Sea with characteristics intermediate between *C. bairdi* and *C. opilio*. Proc. Natl. Shellfish Assoc. 61:8-9.

Kon, T. 1996. Overview of Tanner crab fisheries around the Japanese Archipelago, p. 13-24. *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, Universityof Alaska Fairbanks.

Martel, S and D. Stram. 2011. Report on the North Pacific Fishery Management Council's Crab Modeling Workshop, 16-18 February 2011, Alaska Fisheries Science Center, Seattle WA.

McLaughlin, P. A. and 39 coauthors. 2005. Common and scientific names of aquatic invertebrates from the United States and Canada: crustaceans. American Fisheries Society Special Publication 31. 545 p.

Munk, J. E., S. A. Payne, and B. G. Stevens. 1996. Timing and duration of the mating and molting season for shallow water Tanner crab (*Chionoecetes bairdi*), p. 341 (abstract only). *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.

Nevisi, A., J. M. Orensanz, A. J. Paul, and D. A. Armstrong. 1996. Radiometric estimation of shell age in *Chionoecetes* spp. from the eastern Bering Sea, and its use to interpret shell condition indices: preliminary results, p. 389-396. *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.

NMFS. 2004. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, P.O. Box 21668, Juneau, AK 99802-1668.

NPFMC. 2011. Fishery Management Plan for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite, 306, Anchorage, AK 99501.

NPFMC. 2007. Initial Review Draft Environmental Assessment, Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner crabs to Revise Overfishing Definitions. North Pacific Fishery Management Council, 605 W. 4th Avenue, 306, Anchorage, AK 99501.

Otto, R. S. 1998. Assessment of the eastern Bering Sea snow crab, *Chionoecetes opilio*, stock under the terminal molting hypothesis, p. 109-124. *In* G. S. Jamieson and A. Campbell, (editors), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Canadian Special Publication of Fisheries and Aquatic Sciences.

Paul, A. J. 1982. Mating frequency and sperm storage as factors affecting egg production in multiparous *Chionoecetes bairdi,* p. 273-281. *In* B. Melteff (editor), Proceedings of the International Symposium on the Genus *Chionoecetes:* Lowell Wakefield Symposium Series, Alaska Sea Grant Report, 82-10. University of Alaska Fairbanks.

Paul, A. J. 1984. Mating frequency and viability of stored sperm in the Tanner crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). Journal of Crustacean Biology. 4:375-381.

Paul, A. J. and J. M. Paul. 1992. Second clutch viability of *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) inseminated only at the maturity molt. Journal of Crustacean Biology. 12:438-441.

Paul, A. J. and J. M. Paul. 1996. Observations on mating of multiparous *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) held with different sizes of males and one-clawed males. Journal of Crustacean Biology. 16:295-299.

Rathbun, M. J. 1924. New species and subspecies of spider crabs. Proceedings of U.S. Nat. Museum. 64:1-5.

Rodionov, S., and J. E. Overland. 2005. Application of a sequential regime shift detection method to the Bering Sea ecosystem. ICES Journal of Marine Science, 62: 328-332.

Rugolo L,J. and B.J. Turnock. 2010. 2010 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Draft Report to the North Pacific Fishery Management Council, Crab Plan Team. 61 p.

Rugolo, L.J. and B.J. Turnock. 2011a. Length-Based Stock Assessment Model of eastern Bering Sea Tanner Crab. Report to Subgroup of NPFMC Crab Plan Team. 61p.

Rugolo L,J. and B.J. Turnock. 2011b. 2011 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. Draft Report to the North Pacific Fishery Management Council, Crab Plan Team. 70 p.

Rugolo, L.J. and B.J. Turnock. 2012a. Length-Based Stock Assessment Model of eastern Bering Sea Tanner Crab. Report to Subgroup of NPFMC Crab Plan Team. 69p.

Rugolo L,J. and B.J. Turnock. 2012b. 2012 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2012 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 267-416.

Slizkin, A. G. 1990. Tanner crabs *(Chionoecetes opilio*, *C. bairdi*) of the northwest Pacific: distribution, biological peculiarities, and population structure, p. 27-33. *In* Proceedings of the International Symposium on King and Tanner Crabs. Lowell Wakefield Fisheries Symposium Series, Alaska Sea Grant College Program Report 90-04. University of Alaska Fairbanks.

Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Can. J. Fish. Aquat. Sci. 37:1488-1494.

Somerton, D. A. 1981a. Life history and population dynamics of two species of Tanner crab, *Chionoecetes bairdi* and *C. opilio*, in the eastern Bering Sea with implications for the management of the commercial harvest, PhD Thesis, University of Washington, 220 p.

Somerton, D. A. 1981b. Regional variation in the size at maturity of two species of Tanner Crab (*Chionoecetes bairdi* and *C. opilio*) in the eastern Bering Sea, and its use in defining management subareas. Canadian Journal of Fisheries and Aquatic Science. 38:163-174.

Somerton, D. A. and W. S. Meyers. 1983. Fecundity differences between primiparous and multiparous female Alaskan Tanner crab (*Chionoecetes bairdi*). Journal of Crustacean Biology. 3:183-186.

Somerton, D. A. and R. S. Otto. 1999. Net efficiency of a survey trawl for snow crab, *Chionoecetes opilio,* and Tanner crab, *C. bairdi.* Fish. Bull. 97:617-625.

Stevens, B. G. 2000. Moonlight madness and larval launch pads: tidal synchronization of Mound Formation and hatching by Tanner crab, *Chionoecetes bairdi*. Journal of Shellfish Research. 19:640-641.

Stockhausen, W., L. Rugolo and B. Turnock. 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2013 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-478.

Stockhausen, W. 2014. 2014 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2014 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 324-545.

Stockhausen, W. 2015. 2015 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2015 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.

Stockhausen, W. 2016. 2016 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2016 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.

Stockhausen, W. 2017a. 2017 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2017 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.

Stockhausen, W. 2017b. Tanner Crab Assessment Report for the May 2017 CPT Meeting. North Pacific Fishery Management Council. Anchorage, AK.

Stockhausen, W. 2018a. 2018 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2018 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.

Stockhausen, W. 2018b. Tanner Crab Assessment Report for the May 2018 CPT Meeting. North Pacific Fishery Management Council. Anchorage, AK.

Stone, R.P., M.M. Masuda and J.Clark. 2003. Growth of male Tanner crabs, *Chionoecetes bairdi,* in a Southeast Alaska Estuary. Draft document to Alaska Department of Fish and Game Headquarters. 36p.

Tamone, S. L., S. J. Taggart, A. G. Andrews, J. Mondragon, and J. K. Nielsen. 2007. The relationship between circulating ecdysteroids and chela allometry in male Tanner crabs: Evidence for a terminal molt in the genus *Chionoecetes*. J. Crust. Biol. 27:635-642.

Thompson, G. and R Lauth. 2012. Chapter 2: Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands Area. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, 245-544 p.

Turnock, B. and L. Rugolo. 2011. Stock assessment of eastern Bering Sea snow crab (*Chionoecetes opilio*). Report to the North Pacific Fishery Management Council, Crab Plan Team. 146 p.

Williams, A. B., L. G. Abele, D. L. Felder, H. H. Hobbs, Jr., R. B. Manning, P. A. McLaughlin, and I. Perez Farfante. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. American Fisheries Society Special Publication 17. 77 p.

Zheng, J. and G.H. Kruse, 1999. Evaluation of harvest strategies for Tanner crab stocks that exhibit periodic recruitment. J. Shellfish Res., 18(2):667-679.

Zheng, J. and M.S.M. Siddeek. 2012. Bristol Bay Red King Crab Stock Assessment In Fall 2012. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2012 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 161-266.

Table captions

Table 1. Retained catch (males) in directed Tanner crab fisheries (1965/66-2000/01). Catch units are metric tons. Asterisks denote a closure of the directed domestic fishery. 53
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. Number of crabs caught and harvest includes 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. 55
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. 56
Table 4. Comparison of retained catch abundance and biomass used in the previous assessment ("historical") with "current" catch abundance and biomass. Only values since 2005 (highlighted in grey) have been changed. 58
Table 5. Comparison of total catch biomass in the directed Tanner crab fisheries used in the previous assessment ("historical") with "current" catch biomass dataset. See text for details. 59
Table 6. Comparison of Tanner crab bycatch biomass in the snow crab fisheries used in the previous assessment ("historical") with the "current" catch biomass dataset. See text for details..... 60
Table 7. Comparison of Tanner crab bycatch biomass in the BBRKC fishery used in the previous assessment ("historical") with the "current" catch biomass dataset. See text for details..... 61
Table 8. 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, and in 2016/17. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch. 62
Table 9. Sample sizes for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment. The directed fishery was closed in 2016/17. 62
Table 10. Sample sizes for total catch-at-size in the directed fishery from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment. 63
Table 11. Sample sizes for total bycatch-at-size in the snow crab fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment. 64
Table 12. Sample sizes for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment. 65
Table 13. 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..... 66
Table 14. Trends in Tanner crab biomass (metric tons) in the NMFS EBS summer bottom trawl survey, by sex and area. 67
Table 15. Trends in biomass for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (in metric tons). 69
Table 16. 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. 71
Table 17. 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. 73
Table 18.Non-selectivity parameters from all model scenarios that were estimated within 1% of bounds. 75
Table 19.Selectivity-related parameters from all model scenarios estimated within 1% of bounds. 76
Table 20. Estimated growth, natural mortality, and non-vector recruitment parameters for all model scenarios. 78
Table 21. Historical recruitment devs estimates (1948-1974) for all model scenarios. 79
Table 22. Current recruitment devs estimates (1975-2019) for all model scenarios. 80

Table 23. Logit-scale parameters for the probability of terminal molt for males for all model scenarios. The (arithmetic) probability of terminal molt was fixed at 0 for males less than 60 mm CW and at 1 for males greater than 145 mm CW in Scenarios M19F03 and M19F05. 81
Table 24. Logit-scale parameters for the probability of terminal molt for females for all model scenarios. The (arithmetic) probability of terminal molt was fixed at 0 for females less than 50 mm CW in Scenarios M19F03 and M19F05 and at 1 for females greater than 105 mm CW for all scenarios..... 82
Table 25. Log-scale NMFS survey catchability and selectivity parameters for all model scenarios. 83
Table 26. BSFRF SBS (side-by-side) male availability parameters for all model scenarios in which they were estimated. 84
Table 27. BSFRF SBS (side-by-side) female availability parameters for all model scenarios. in which they were estimated. 85
Table 28. Mean capture rate, selectivity and retention parameter estimates for the directed fishery (TCF) for all model scenarios. 86
Table 29. Log-scale male capture rate dev parameter estimates for the directed fishery (TCF) for all model scenarios. 87
Table 30. Comparison of mean capture rate, ln-scale capture rate devs, and selectivity parameter estimates for the snow crab fishery (SCF) for all model scenarios..... 88
Table 31. Comparison of mean capture rate, ln-scale capture rate devs, and selectivity parameters estimates for the BBRKC fishery (RKF) for all model scenarios. 89
Table 32. Comparison of mean capture rate and selectivity parameters estimates for the groundfish fisheries (GTF). 90
Table 33. Log-scale capture rate dev parameter estimates for the groundfish fisheries (GTF) for all model scenarios. 91
Table 34. (Unweighted) negative log-likelihoods and (weighted) objective function values for fishery-related data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries. 92
Table 35. (Unweighted) negative log-likelihoods and (weighted) objective function values for survey-related data components from the model scenarios. Rows consisting of all zero values indicate a data component which was not included in any of the models. Blank cells indicate a data component (row) that was not included in the associated scenario (column). 93
Table 36. (Unweighted) negative log-likelihoods and (weighted) objective function values for fits to growth (molt increment) and male maturity ogive data components from the model scenarios. 93
Table 37. Root mean square errors (RMSE) for fishery-related data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries. Rows consisting of all zero values indicate a data component which was not included in any of the models. 94
Table 38. Average root mean square errors (RMSE) for survey-related data components from the model scenarios. Rows consisting of all zero values indicate a data component which was not included in any of the models. Blank cells indicate a data component (row) that was not included in the likelihood in the associated scenario (column). 95
Table 39. Root mean square errors (RMSE) for fits to growth (molt increment) and male maturity ogive data components from the model scenarios. 95
Table 40. Effective sample sizes used for NMFS 0 EBS trawl survey size composition data for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach. Note that, while effective N's were calculated for this dataset in MF1903, it was not included in the model objective function (the weight in the likelihood was set to 0). Input sample sizes were set at 200. 96
Table 41. Effective sample sizes used for retained catch size composition data from the directed fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach. 97

Table 42. Effective sample sizes used for total catch size composition data from the directed fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach. 98
Table 43. Effective sample sizes used for bycatch size composition data from the snow crab fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach. 99
Table 44. Effective sample sizes used for bycatch size composition data from the BBRKC fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03. Effective sample sizes were estimated using the McAllister-Ianelli approach. 100
Table 45. Effective sample sizes used for bycatch size composition data from the groundfish fisheries for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach. 101
Table 46. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03). 102
Table 47. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03). 103
Table 48. Estimated population size (millions) for females on July 1 of year. from the author's preferred model, Model M19F03. 103
Table 49. Estimated population size (millions) for males on July 1 of year. from the author's preferred mode, Model M19F03. 103
Table 50. Comparison of estimates of recruitment (in millions) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03). 104
Table 51. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03). 105
Table 52. 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. Results from the author's preferred model (M19F03) are highlighted in green. 106

Figure captions

Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008)..... 107
Figure 2. 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 from 1996/97 to 2004/05, from 2010/11 to 2012/13, and in 2016/17. 108
Figure 3. Time series of retained catch biomass (1000's t) in the directed Tanner crab (TCF: red; eastern area: triangles; western area: circles; all EBS: squares), snow crab (SCF: green), and BBRKC (RFF: blue) fisheries since 2005. The directed fishery was closed from 2010/11 to 2012/13, and in 2016/17. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch. 109
Figure 4. 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 1992 for the crab fisheries. Lower: detail since 2005. 110
Figure 5. Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14 (red: western area, green: eastern area; blue: all EBS)..... 111
Figure 6. Total catch (retained + discards) size compositions for males, normalized by fleet, during 1990/91-1999/2000 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab)..... 112
Figure 7. Total catch (retained + discards) size compositions for males, normalized by fleet, during 2000/01-2009/10 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). The directed fishery was closed in 2000/01-2004/05 and was open only in the western area in 2005/06 and in the eastern area in 2009/10..... 113
Figure 8. Total catch (retained + discards) size compositions for males, normalized by fleet, during 2010/11-2018/19 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). The directed fishery was closed in 2010/11-2012/13 and 206/17, and was open only in the western area in 2017/18 and 2018/19..... 114
Figure 9. Bycatch size compositions for females, normalized by fleet, during 1990/91-1999/2000 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). 115
Figure 10. Bycatch size compositions for females, normalized by fleet, during 2000/01-2009/10 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). 116
Figure 11. Bycatch size compositions for females, normalized by fleet, during 2010/11-2018/19 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). 117
Figure 12. Annual bycatch size compositions in the groundfish fisheries by sex, expanded to total bycatch, during 1991/92-2006/07. Red lines: females; green lines: males..... 118
Figure 13. Annual bycatch size compositions in the groundfish fisheries by sex, expanded to total bycatch, during 2007/08-2018/19. Red lines: females; green lines: males..... 119
Figure 14. 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..... 120
Figure 15. 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..... 121

Figure 16. 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). 122
Figure 17. 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. 123
Figure 18. Size compositions from the NMFS EBS bottom trawl survey for 1975-2019. 124
Figure 19. Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2015. Red lines: BSFRF; green lines: NMFS. 125
Figure 20. 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. 127
Figure 21. 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. 128
Figure 22. 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. 129
Figure 23. 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.. 130
Figure 24. Molt increment data collected collaboratively by NMFS, BSFRF, and ADFG. 130
Figure 25. Size-weight relationships developed from NMFS EBS summer trawl survey data. 131
Figure 26. Assumed size distribution for recruits entering the population. 131
Figure 27. Fits to retained and total catch biomass in the directed fishery from all model scenarios. 132
Figure 28. Fits to total catch biomass in the snow crab fishery from all scenarios. 133
Figure 29. Fits to total catch biomass in the BBRKC fishery from all scenarios. 133
Figure 30. Fits to total catch biomass in the groundfish fisheries for all scenarios. 134
Figure 31. Fits to mature biomass from the NMFS “0” EBS bottom trawl survey data for all. Note that scenarios M19F03 and M19F05 do not include the mature male component in the likelihood (they fit total male biomass) and fit both mature and immature biomass for females. 135
Figure 32. Fits to mature biomass from the NMFS “M” and NMFS “F” EBS bottom trawl survey data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05. Note that only scenarios M19F03 and M19F05 include these data components in the model objective function. 136
Figure 33. Fits to survey biomass from the NMFS SBS bottom trawl survey data for scenarios M19F04 and M19F05. 137
Figure 34. Fits to survey biomass from the BSFRF SBS bottom trawl survey data for scenarios M19F04 and M19F05. 138
Figure 35. Fits to molt increment data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05 139
Figure 36. Fits to male maturity ogive data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05. Note that only scenarios M1902, M19F03, and M19F05 include the data in the likelihood. 140
Figure 37. Directed fishery catchability (capture rates) from all model scenarios. 141
Figure 38. Directed fishery selectivity curves from all scenarios for the pre-1991 time period and 1991-1994. The 50%-selected parameter varies annually for 1991+. 142
Figure 39. Directed fishery selectivity curves from all scenarios for 1995-1996 and 2005-2007. The 50%-selected parameter varies annually for 1991+. 143

Figure 40. Directed fishery selectivity curves from all scenarios for 2008-2009 and 2013-2015. The 50%-selected parameter varies annually for 1991+. 144
Figure 41. Directed fishery selectivity curves from all scenarios for 2008-2009 and 2013-2015. The 50%-selected parameter varies annually for 1991+. 145
Figure 42. Directed fishery retention curves from all scenarios for the pre-1991, 1991-1996, and post-2004 time periods 146
Figure 43. Snow crab fishery catchability (capture rates) from all scenarios. 147
Figure 44. Snow crab fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+. 148
Figure 45. BBRKC fishery catchability (capture rates) from all scenarios. 149
Figure 46. BBRKC fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+. 150
Figure 47. Catchability (capture rates) in the groundfish fisheries from all scenarios. 151
Figure 48. Groundfish fisheries selectivity curves from all scenarios estimated for 3 time periods: pre-1987, 1987-1996, 1997+. 152
Figure 49. NMFS “0” survey catchabilities for all scenarios for the 1975-1981 and 1982+ time periods. 153
Figure 50. NMFS “0” survey selectivity functions for all scenarios for the 1975-1981 and 1982+ time periods. 154
Figure 51. NMFS “0” survey capture probabilities (i.e., catchability *x* selectivity) for all scenarios for the 1975-1981 and 1982+ time periods. 155
Figure 52. Survey availabilities from scenarios M19F04 and M19F05 for the 2013-2017 SBS studies.. 156
Figure 53. Comparison of empirical “observed” and predicted availability in the 2013-2017 SBS studies from scenario M19F04. The “observed” availability is the ratio of abundance in the NMFS SBS survey to that in the full NMFS survey by size bin. Observed: red points, lines. Red fills are from loess smoothing of the observed availability. Predicted: green points, lines. 157
Figure 54. Estimates of natural mortality from all scenarios. 158
Figure 55. Estimates of the probability of terminal molt from all scenarios. 159
Figure 56. Estimates of mean growth from all scenarios. Dashed line is 1:1. 160
Figure 57. Estimated recruitment time series from all scenarios. 161
Figure 58. Estimated recent recruitment time series from all scenarios. 162
Figure 59. Estimated (Feb. 15) mature biomass time series from all scenarios. 163
Figure 60. Estimated recent (Feb. 15) mature biomass time series from all scenarios. 164
Figure 61. Estimated (July 1) biomass time series by population category for all scenarios. 165
Figure 62. MCMC results from scenario M19F03, the author’s preferred model, for OFL-related quantities. 166
Figure 63. The F_{OFL} harvest control rule. 167
Figure 64. The OFL and ABC from the author’s preferred model, scenario M19F03. 167
Figure 65. Quad plot for the author’s preferred model, scenario M19F03. 168
Figure 65. The ratio of estimated abundance by size from the NMFS and BSFRF side-by-side catchability studies. The heavy green line is the size-specific mean over the 5 years. These represent simple empirical estimates of the size-specific catchability of the NMFS survey gear relative to the BSFRF gear. If the BSFRF survey gear is assumed to capture all crab within the area swept, these curves represent empirical estimates of the size-specific NMFS survey gear catchability (i.e., fully selected catchability [q] *x* selectivity). 169

Tables

Table 1. Retained catch (males) in directed Tanner crab fisheries (1965/66-2000/01). Catch units are metric tons. Asterisks denote 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
1985*	0	0	0	0
1986*	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
1997*	0	0	0	0
1998*	0	0	0	0
1999*	0	0	0	0
2000*	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
2001*	0	0	0	0
2002*	0	0	0	0
2003*	0	0	0	0
2004*	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
2010*	1	0	0	1
2011*	2	0	0	2
2012*	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
2016*	1	0	0	1
2017	1,133	0	0	1,133
2018	1,107	0	0	1,107

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. Number of crabs caught and harvest includes 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

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
1985*	–	–	–	–	–	–	–	–	0.3992	0.3992
1986*	–	–	–	–	–	–	–	–	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
1997*	–	–	–	–	1.9637	0.0927	0.1601	0.0017	1.1800	3.3981
1998*	–	–	–	–	0.6559	0.0804	0.1152	0.0017	0.9350	1.7882
1999*	–	–	–	–	0.1318	0.0112	0.0751	0.0022	0.6306	0.8509
2000*	–	–	–	–	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
2001*	–	–	–	–	0.545308	0.020530	0.042200	0.000963	1.185191	1.794192
2002*	–	–	–	–	0.167178	0.013815	0.061253	0.001580	0.719068	0.962894
2003*	–	–	–	–	0.064743	0.007011	0.054937	0.001847	0.423801	0.552339
2004*	–	–	–	–	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
2010*	–	–	–	–	1.453261	0.009179	0.031920	0.000553	0.231367	1.726280
2011*	–	–	–	–	2.141349	0.013272	0.017470	0.000072	0.203984	2.376147
2012*	–	–	–	–	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
2016*	–	–	–	–	2.575704	0.016695	0.175692	0.004222	0.310121	3.082434
2017	1.362519	0.038489	–	–	1.081659	0.006841	0.183555	0.001433	0.167927	2.842423
2018	1.598424	0.034668	–	–	0.879726	0.008857	0.074017	0.000131	0.190972	2.786795

Table 4. Comparison of retained catch abundance and biomass used in the previous assessment ("historical") with "current" catch abundance and biomass. Only values since 2005 (highlighted in grey) have been changed.

	abundance (num. crab)		biomass (millions lbs)	
year	historical	current	historical	current
1965	1,558,362	1,558,362	4.24	4.24
1966	1,981,280	1,981,280	5.39	5.39
1967	11,032,652	11,032,652	29.98	29.98
1968	14,576,228	14,576,228	39.69	39.69
1969	22,394,986	22,394,986	60.60	60.60
1970	22,004,597	22,004,597	56.20	56.20
1971	17,820,914	17,820,914	45.66	45.66
1972	14,906,645	14,906,645	37.27	37.27
1973	12,000,825	12,000,825	28.72	28.72
1974	13,404,770	13,404,770	33.60	33.60
1975	15,603,036	15,603,036	38.92	38.92
1976	26,120,508	26,120,508	66.17	66.17
1977	26,821,995	26,821,995	78.32	78.32
1978	18,780,962	18,780,962	46.50	46.50
1979	16,805,611	16,805,611	41.90	41.90
1980	12,928,112	12,928,112	29.60	29.60
1981	4,830,980	4,830,980	11.00	11.00
1982	2,286,756	2,286,756	5.27	5.27
1983	516,877	516,877	1.21	1.21
1984	1,272,501	1,272,501	3.15	3.15
1987	957,318	957,318	2.20	2.20
1988	2,894,480	2,894,480	7.01	7.01
1989	10,672,607	10,672,607	24.50	24.50
1990	16,609,286	16,609,286	40.10	40.10
1991	12,924,102	12,924,102	31.80	31.80
1992	15,265,865	15,265,865	35.10	35.10
1993	7,236,054	7,236,054	16.90	16.90
1994	3,351,639	3,351,639	7.80	7.80
1995	1,881,525	1,881,525	4.23	4.23
1996	734,303	734,303	1.81	1.81
2005	443,865	443,977	0.95	0.95
2006	926,101	926,103	2.12	2.12
2007	927,164	927,164	2.11	2.11
2008	830,363	830,369	1.94	1.94
2009	485,963	485,963	1.33	1.33
2013	1,426,670	1,445,768	2.75	2.79
2014	7,442,931	7,522,844	13.58	13.70
2015	10,856,418	10,856,418	19.64	19.64
2017	1,340,394	1,340,394	2.50	2.50
2018	--	1,381,008	--	2.44

Table 5. Comparison of total catch biomass in the directed Tanner crab fisheries used in the previous assessment ("historical") with "current" catch biomass dataset. See text for details.

	biomass (millions lbs)			
	males		females	
year	historical	current	historical	current
1991	--	56.92	--	4.16
1992	48.71	81.59	2.21	3.76
1993	25.43	26.13	2.27	2.20
1994	14.70	16.13	2.80	1.86
1995	10.32	11.17	3.88	2.35
1996	2.07	0.66	0.10	0.12
2005	1.97	1.51	0.10	0.05
2006	5.14	3.77	0.78	0.27
2007	6.61	5.42	0.21	0.10
2008	2.89	2.86	0.03	0.02
2009	1.49	1.47	0.01	0.01
2013	3.60	3.70	0.05	0.05
2014	19.12	18.44	0.09	0.09
2015	26.35	26.96	0.13	0.13
2017	4.66	3.00	0.13	0.08
2018	--	3.52	--	0.08

Table 6. Comparison of Tanner crab bycatch biomass in the snow crab fisheries used in the previous assessment ("historical") with the "current" catch biomass dataset. See text for details.

	biomass (millions lbs)			
	males		females	
year	historical	current	historical	current
1990	--	15.61	--	0.23
1991	--	18.43	--	0.32
1992	56.79	5.48	3.94	0.36
1993	32.03	6.34	4.00	0.88
1994	15.71	2.97	2.80	0.43
1995	10.58	2.25	3.88	0.27
1996	1.84	4.32	0.51	0.26
1997	3.86	4.33	0.50	0.20
1998	4.38	1.45	0.39	0.18
1999	1.53	0.29	0.32	0.02
2000	0.32	0.69	0.05	0.01
2001	0.71	1.20	0.02	0.05
2002	1.23	0.37	0.08	0.03
2003	0.43	0.14	0.06	0.02
2004	0.17	0.30	0.03	0.09
2005	2.13	2.56	0.09	0.04
2006	3.22	3.37	0.37	0.19
2007	4.13	4.10	0.22	0.11
2008	2.47	2.43	0.11	0.05
2009	2.92	3.44	0.03	0.03
2010	2.96	3.20	0.03	0.02
2011	4.67	4.72	0.03	0.03
2012	2.62	3.45	0.02	0.02
2013	4.04	4.06	0.03	0.03
2014	11.87	11.75	0.11	0.11
2015	8.64	8.64	0.04	0.04
2016	5.68	5.68	0.04	0.04
2017	2.45	2.38	0.02	0.02
2018	--	1.94	--	0.02

Table 7. Comparison of Tanner crab bycatch biomass in the BBRKC fishery used in the previous assessment ("historical") with the "current" catch biomass dataset. See text for details.

	biomass (millions lbs)			
	males		females	
year	historical	current	historical	current
1990	--	8.21	--	0.08
1991	--	4.34	--	0.06
1992	2.62	2.90	0.06	0.04
1993	6.54	6.90	0.44	0.33
1996	0.06	0.60	0.01	0.01
1997	0.36	0.35	0.01	0.00
1998	0.26	0.25	0.01	0.00
1999	0.17	0.17	0.01	0.00
2000	0.15	0.15	0.01	0.00
2001	0.09	0.09	0.00	0.00
2002	0.14	0.14	0.01	0.00
2003	0.12	0.12	0.01	0.00
2004	0.11	0.11	0.01	0.00
2005	0.09	0.09	0.00	0.00
2006	0.06	0.07	0.01	0.00
2007	0.12	0.13	0.02	0.00
2008	0.59	0.62	0.01	0.01
2009	0.33	0.41	0.00	0.00
2010	0.07	0.07	0.00	0.00
2011	0.04	0.04	0.00	0.00
2012	0.09	0.09	0.00	0.00
2013	0.25	0.28	0.00	0.00
2014	0.65	0.67	0.00	0.00
2015	0.45	0.45	0.01	0.01
2016	0.39	0.39	0.01	0.01
2017	0.40	0.40	0.00	0.00
2018	--	0.16	--	0.00

Table 8. 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, and in 2016/17. 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	376,080	365,110	0	0	376,080	365,110	67,897	67,112	0	0
2006	333,508	320,187	583,650	633,937	917,158	954,124	7,115	6,784	1,830	1,883
2007	232,345	228,829	679,137	711,640	911,482	940,469	9,328	8,761	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

Table 9. Sample sizes for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment. The directed fishery was closed in 2016/17.

year	new + old shell	
	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
1992/93	125,193	200.0
1993/94	71,622	200.0
1994/95	27,658	200.0
1995/96	1,525	12.0
1996/97	4,430	34.8
2005/06	705	5.5
2006/07	2,940	23.1
2007/08	6,935	45.2
2008/09	3,490	27.4
2009/10	2,417	19.0
2013/14	4,760	35.8
2014/15	14,055	113.7
2015/16	24,420	190.3
2016/17	--	--
2017/18	3,470	27.3
2018/19	3,306	26.0

Table 10. Sample sizes for total catch-at-size in the directed fishery from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

	N		N'	
year	males	females	males	females
1991/92	31,252	5,605	200.0	44.0
1992/93	54,836	8,755	200.0	68.8
1993/94	40,388	10,471	200.0	82.3
1994/95	5,792	2,132	45.5	16.7
1995/96	5,589	3,119	43.9	24.5
1996/97	352	168	2.8	1.3
2005/06	19,715	1,107	154.9	8.7
2006/07	24,226	4,432	190.3	34.8
2007/08	61,546	3,318	200.0	26.1
2008/09	29,166	646	200.0	5.1
2009/10	17,289	147	135.8	1.2
2013/14	17,291	710	135.8	5.6
2014/15	85,116	1,191	200.0	9.4
2015/16	119,843	1,622	200.0	12.8
2016/17	--	--	--	--
2017/18	18,785	1,721	147.6	13.5
2018/19	28,338	2,036	200.0	16.0

Table 11. Sample sizes for total bycatch-at-size in the snow crab fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1990/91	14,032	478	110.2	3.8
1991/92	11,708	686	92.0	5.4
1992/93	6,280	859	49.3	6.7
1993/94	6,969	1,542	54.7	12.1
1994/95	2,982	1,523	23.4	12.0
1995/96	1,898	428	14.9	3.4
1996/97	3,265	662	25.6	5.2
1997/98	3,970	657	31.2	5.2
1998/99	1,911	324	15.0	2.5
1999/00	976	82	7.7	0.6
2000/01	1,237	74	9.7	0.6
2001/02	3,113	160	24.5	1.3
2002/03	982	118	7.7	0.9
2003/04	688	152	5.4	1.2
2004/05	833	707	6.5	5.6
2005/06	9,807	368	77.0	2.9
2006/07	10,391	1,256	81.6	9.9
2007/08	13,797	728	108.4	5.7
2008/09	8,455	722	66.4	5.7
2009/10	11,057	474	86.9	3.7
2010/11	12,073	250	94.8	2.0
2011/12	9,453	189	74.3	1.5
2012/13	11,004	270	86.4	2.1
2013/14	12,935	356	101.6	2.8
2014/15	24,878	804	195.4	6.3
2015/16	19,839	230	155.9	1.8
2016/17	16,369	262	128.6	2.1
2017/18	5,598	109	44.0	0.9
2018/19	6,145	233	48.3	1.8

Table 12. Sample sizes for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1990/91	1,580	43	12.4	0.3
1991/92	2,273	89	17.9	0.7
1992/93	2,056	105	16.2	0.8
1993/94	7,359	1,196	57.8	9.4
1997/98	1,030	41	8.1	0.3
1998/99	457	20	3.6	0.2
1999/00	207	14	1.6	0.1
2000/01	845	44	6.6	0.3
2001/02	456	39	3.6	0.3
2002/03	750	50	5.9	0.4
2003/04	555	46	4.4	0.4
2004/05	487	44	3.8	0.3
2005/06	983	70	7.7	0.5
2006/07	746	68	5.9	0.5
2007/08	1,360	89	10.7	0.7
2008/09	3,797	121	29.8	1.0
2009/10	2,871	70	22.6	0.5
2010/11	582	28	4.6	0.2
2011/12	323	4	2.5	0.0
2012/13	618	48	4.9	0.4
2013/14	2,110	60	16.6	0.5
2014/15	3,110	32	24.4	0.3
2015/16	2,175	186	17.1	1.5
2016/17	3,220	246	25.3	1.9
2017/18	3,782	86	29.7	0.7
2018/19	1,283	6	10.1	0.0

Table 13. 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	N		N'	
	males	females	males	females
1973/74	3,155	2,277	24.8	17.9
1974/75	2,492	1,600	19.6	12.6
1975/76	1,251	839	9.8	6.6
1976/77	6,950	6,683	54.6	52.5
1977/78	10,685	8,386	83.9	65.9
1978/79	18,596	13,665	146.1	107.4
1979/80	19,060	11,349	149.7	89.2
1980/81	12,806	5,917	100.6	46.5
1981/82	6,098	4,065	47.9	31.9
1982/83	13,439	8,006	105.6	62.9
1983/84	18,363	8,305	144.3	65.2
1984/85	27,403	13,771	200.0	108.2
1985/86	23,128	12,728	181.7	100.0
1986/87	14,860	7,626	116.7	59.9
1987/88	23,508	15,857	184.7	124.6
1988/89	10,586	7,126	83.2	56.0
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	185.0	88.1
1991/92	6,817	3,479	53.6	27.3
1992/93	3,128	1,175	24.6	9.2
1993/94	1,217	358	9.6	2.8
1994/95	3,628	1,820	28.5	14.3
1995/96	3,904	2,669	30.7	21.0
1996/97	8,306	3,400	65.3	26.7
1997/98	9,949	3,900	78.2	30.6
1998/99	12,105	4,440	95.1	34.9
1999/00	11,053	4,522	86.8	35.5
2000/01	12,895	3,087	101.3	24.3
2001/02	15,788	3,083	124.0	24.2
2002/03	15,401	3,249	121.0	25.5
2003/04	9,572	2,733	75.2	21.5
2004/05	13,844	4,460	108.8	35.0
2005/06	17,785	3,709	139.7	29.1
2006/07	15,903	3,047	124.9	23.9
2007/08	16,148	3,819	126.9	30.0
2008/09	26,171	4,235	200.0	33.3
2009/10	19,075	2,704	149.9	21.2
2010/11	15,131	2,275	118.9	17.9
2011/12	16,119	4,244	126.6	33.3
2012/13	12,987	3,083	102.0	24.2
2013/14	28,782	6,064	200.0	47.6
2014/15	39,119	4,212	200.0	33.1
2015/16	27,428	5,735	200.0	45.1
2016/17	18,313	4,299	143.9	33.8
2017/18	12,541	1,229	98.5	9.7
2018/19	7,004	1,227	55.0	9.6

Table 14. 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 14 (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 15. 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 15 (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 16. 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

Table16 (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.

year	number of hauls	females						males					
		immature new shell		mature new shell		mature old shell		immature new shell		mature new shell		mature old shell	
		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 17. 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.

	SCF	RKF
year	all EBS	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 17 (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.

	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

Table 18.Non-selectivity parameters from all model scenarios that were estimated within 1% of bounds.

category	name	index	scenario	which?	bound	description
fisheries	pLgtRet[1]	1	M19F00	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F00a	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F01	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F02	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F03	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F04	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F05	at upper bound	15	TCF: logit-scale max retention (pre-1997)
population processes	pvLgtPrM2M[1]	32	M19F00	at upper bound	15	males (entire model period)
			M19F00a	at upper bound	15	males (entire model period)
			M19F01	at upper bound	15	males (entire model period)
			M19F02	at upper bound	15	males (entire model period)
			M19F04	at upper bound	15	males (entire model period)
	pvLgtPrM2M[2]	1	M19F00	at lower bound	-15	females (entire model period)
			M19F00a	at lower bound	-15	females (entire model period)
			M19F01	at lower bound	-15	females (entire model period)
			M19F02	at lower bound	-15	females (entire model period)
			M19F04	at lower bound	-15	females (entire model period)
surveys	pQ[1]	1	M19F00	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F00a	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F01	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F02	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F03	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F04	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F05	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
	pQ[3]	1	M19F00	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F00a	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F01	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F02	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F03	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F04	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F05	at lower bound	0.5	NMFS trawl survey: females, 1975-1981

Table 19.Selectivity-related parameters from all model scenarios estimated within 1% of bounds.

	name		scenario	which?	bound	description
selectivity	pS1[1]	1	M19F00a	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F01	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F02	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F03	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F04	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F05	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
	pS1[20]	1	M19F00	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F00a	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F01	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F02	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F03	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F04	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F05	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
	pS1[23]	1	M19F00	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F00a	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F01	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F02	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F03	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F04	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F05	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
	pS1[24]	1	M19F00	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F00a	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F01	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F02	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F03	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F04	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F05	at upper bound	180	z95 for RKF selectivity (males, 2005+)
	pS1[27]	1	M19F00	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F00a	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F01	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F02	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F03	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F04	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F05	at upper bound	140	z95 for RKF selectivity (females, 2005+)
	pS2[10]	1	M19F00a	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
			M19F01	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)

Table 19 (cont.).Selectivity-related parameters from all model scenarios estimated within 1% of bounds.

name		scenario	which?	bound	description
		M19F02	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
		M19F03	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
		M19F04	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
		M19F05	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
pS2[2]	1	M19F01	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F02	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F03	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F04	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F05	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
pS2[4]	1	M19F00	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F00a	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F01	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F02	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F03	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F04	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F05	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
pS4[1]	1	M19F00	at upper bound	0.5	descending slope for SCF selectivity (males, pre-1997)
		M19F00a	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F01	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F02	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F03	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F04	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F05	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)

Table 20. Estimated growth, natural mortality, and non-vector recruitment parameters for all model scenarios.

						M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
process	description	parameter		phase	scale	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev
growth	both sexes	pGrBeta[1]	1	5	ARITHMETIC	$8.116e-01$	0.12597	$5.441e-01$	0.07594	$5.822e-01$	0.06559	$7.936e-01$	0.09799	$9.035e-01$	0.11392	$5.651e-01$	0.06168	$9.061e-01$	0.11105
	females	pGrA[2]	1	4	ARITHMETIC	$3.446e+01$	0.42304	$3.389e+01$	0.35337	$3.326e+01$	0.25176	$3.367e+01$	0.29993	$3.399e+01$	0.33574	$3.320e+01$	0.24548	$3.396e+01$	0.33400
		pGrB[2]	1	4	ARITHMETIC	$1.151e+02$	0.84195	$1.151e+02$	0.77050	$1.152e+02$	0.59572	$1.151e+02$	0.65401	$1.149e+02$	0.64756	$1.152e+02$	0.55714	$1.149e+02$	0.61193
	males	pGrA[1]	1	4	ARITHMETIC	$3.309e+01$	0.35045	$3.268e+01$	0.26962	$3.258e+01$	0.23545	$3.235e+01$	0.26033	$3.274e+01$	0.29222	$3.245e+01$	0.23171	$3.261e+01$	0.28179
		pGrB[1]	1	4	ARITHMETIC	$1.670e+02$	1.07890	$1.634e+02$	1.10110	$1.612e+02$	1.02490	$1.657e+02$	0.86298	$1.666e+02$	0.92085	$1.612e+02$	0.98847	$1.670e+02$	0.94701
natural mortality	1980-1984 multiplier for mature females	pDM2[2]	1	4	ARITHMETIC	$1.307e+00$	0.09981	$1.440e+00$	0.10786	$1.380e+00$	0.10693	$1.353e+00$	0.10385	$1.873e+00$	0.15471	$1.356e+00$	0.10445	$1.893e+00$	0.15211
	1980-1984 multiplier for mature males	pDM2[1]	1	4	ARITHMETIC	$2.587e+00$	0.24183	$2.843e+00$	0.25788	$2.798e+00$	0.25750	$2.620e+00$	0.22434	$2.231e+00$	0.21496	$2.720e+00$	0.24396	$2.286e+00$	0.21422
	base ln-scale M	pM[1]	1	-1	LOG	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA
	multiplier for immature crab	pDM1[1]	1	4	ARITHMETIC	$1.002e+00$	0.05044	$9.997e-01$	0.05066	$9.901e-01$	0.05042	$9.756e-01$	0.05022	$9.839e-01$	0.05149	$1.064e+00$	0.04820	$1.048e+00$	0.04979
	multiplier for mature females	pDM1[3]	1	4	ARITHMETIC	$1.386e+00$	0.03557	$1.341e+00$	0.03710	$1.328e+00$	0.03635	$1.348e+00$	0.03688	$1.316e+00$	0.03885	$1.327e+00$	0.03567	$1.327e+00$	0.03811
	multiplier for mature males	pDM1[2]	1	4	ARITHMETIC	$1.152e+00$	0.03952	$1.221e+00$	0.04087	$1.230e+00$	0.03938	$1.352e+00$	0.03742	$1.292e+00$	0.04001	$1.262e+00$	0.03864	$1.318e+00$	0.03873
recruitment	current recruitment period	pLnR[2]	1	1	ARITHMETIC	$5.138e+00$	0.07180	$5.414e+00$	0.07889	$5.484e+00$	0.08083	$5.615e+00$	0.08148	$5.691e+00$	0.08257	$5.630e+00$	0.06936	$5.740e+00$	0.06904
	fixed value	pRa[1]	1	-1	LOG	$2.442e+00$	NA	$2.442e+00$	NA	$2.442e+00$	NA	$2.442e+00$	NA	$2.442e+00$	NA	$2.442e+00$	NA	$2.442e+00$	NA
		pRb[1]	1	-1	LOG	$1.386e+00$	NA	$1.386e+00$	NA	$1.386e+00$	NA	$1.386e+00$	NA	$1.386e+00$	NA	$1.386e+00$	NA	$1.386e+00$	NA
	full model period	pRCV[1]	1	-1	LOG	$-6.931e-01$	NA	$-6.931e-01$	NA	$-6.931e-01$	NA	$-6.931e-01$	NA	$-6.931e-01$	NA	$-6.931e-01$	NA	$-6.931e-01$	NA
		pRX[1]	1	-1	LOGIT	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA
	historical recruitment period	pLnR[1]	1	1	ARITHMETIC	$5.662e+00$	0.40017	$6.039e+00$	0.38683	$6.185e+00$	0.37589	$6.251e+00$	0.39915	$6.281e+00$	0.41654	$6.315e+00$	0.37471	$6.341e+00$	0.41554

Table 21. Historical recruitment devs estimates (1948-1974) for all model scenarios.

			M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
index			value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev
1	1	ARITHMETIC	−1.4120	1.4764	−1.2802	1.4628	−1.21227	1.4492	−1.21416	1.4817	−1.39338	1.5043	−1.19404	1.4508	−1.381738	1.5055
2	1	ARITHMETIC	−1.4120	1.3270	−1.2826	1.3122	−1.21620	1.2978	−1.21685	1.3320	−1.38912	1.3562	−1.19841	1.2993	−1.378240	1.3574
3	1	ARITHMETIC	−1.4105	1.1914	−1.2858	1.1758	−1.22223	1.1611	−1.22085	1.1953	−1.37960	1.2206	−1.20533	1.1624	−1.370257	1.2216
4	1	ARITHMETIC	−1.4057	1.0721	−1.2877	1.0561	−1.22784	1.0417	−1.22425	1.0745	−1.36341	1.0997	−1.21230	1.0428	−1.356370	1.1006
5	1	ARITHMETIC	−1.3949	0.9712	−1.2851	0.9552	−1.22960	0.9417	−1.22430	0.9714	−1.33850	0.9956	−1.21587	0.9423	−1.334528	0.9963
6	1	ARITHMETIC	−1.3746	0.8894	−1.2738	0.8738	−1.22273	0.8615	−1.21710	0.8872	−1.30189	0.9094	−1.21124	0.8616	−1.301728	0.9098
7	1	ARITHMETIC	−1.3393	0.8260	−1.2476	0.8107	−1.20041	0.7997	−1.19696	0.8213	−1.24913	0.8408	−1.19151	0.7994	−1.253493	0.8409
8	1	ARITHMETIC	−1.2817	0.7781	−1.1977	0.7631	−1.15263	0.7532	−1.15541	0.7712	−1.17347	0.7877	−1.14656	0.7525	−1.182986	0.7877
9	1	ARITHMETIC	−1.1899	0.7418	−1.1101	0.7266	−1.06393	0.7173	−1.07919	0.7330	−1.06415	0.7470	−1.06065	0.7164	−1.079357	0.7469
10	1	ARITHMETIC	−1.0453	0.7126	−0.9619	0.6970	−0.90858	0.6882	−0.94640	0.7028	−0.90325	0.7152	−0.90753	0.6871	−0.924438	0.7150
11	1	ARITHMETIC	−0.8151	0.6883	−0.7120	0.6736	−0.64015	0.6662	−0.71771	0.6798	−0.65848	0.6912	−0.63979	0.6654	−0.685503	0.6910
12	1	ARITHMETIC	−0.4383	0.6726	−0.2871	0.6623	−0.18242	0.6572	−0.32434	0.6683	−0.27087	0.6796	−0.18059	0.6566	−0.302887	0.6792
13	1	ARITHMETIC	0.1660	0.6670	0.3730	0.6568	0.50326	0.6510	0.29986	0.6641	0.32880	0.6782	0.50615	0.6503	0.293606	0.6774
14	1	ARITHMETIC	0.9679	0.6525	1.1497	0.6391	1.24659	0.6320	1.07202	0.6488	1.08913	0.6671	1.24599	0.6312	1.055489	0.6660
15	1	ARITHMETIC	1.6257	0.6254	1.6449	0.6127	1.65040	0.6070	1.62078	0.6236	1.67036	0.6444	1.64471	0.6067	1.646939	0.6433
16	1	ARITHMETIC	1.7976	0.6055	1.6724	0.6031	1.60834	0.6017	1.69296	0.6102	1.79168	0.6301	1.60010	0.6018	1.778654	0.6288
17	1	ARITHMETIC	1.6191	0.6125	1.4503	0.6111	1.36579	0.6077	1.47538	0.6164	1.61024	0.6355	1.35947	0.6078	1.604503	0.6347
18	1	ARITHMETIC	1.3692	0.6187	1.2196	0.6105	1.13831	0.6030	1.22210	0.6170	1.37666	0.6359	1.13637	0.6025	1.379250	0.6358
19	1	ARITHMETIC	1.2090	0.6091	1.0895	0.5948	1.01064	0.5864	1.05644	0.6040	1.22342	0.6216	1.01261	0.5853	1.238470	0.6212
20	1	ARITHMETIC	1.1875	0.5888	1.0640	0.5771	0.96832	0.5732	0.99256	0.5871	1.17131	0.6028	0.96827	0.5718	1.201936	0.6004
21	1	ARITHMETIC	1.2546	0.5708	1.0303	0.5654	0.89237	0.5599	0.95314	0.5733	1.13925	0.5929	0.87968	0.5582	1.179838	0.5890
22	1	ARITHMETIC	1.2263	0.5399	0.8766	0.5246	0.75151	0.5121	0.86630	0.5379	0.99302	0.5659	0.73357	0.5109	1.027757	0.5635
23	1	ARITHMETIC	1.0762	0.4826	0.8502	0.4642	0.72676	0.4560	0.80345	0.4809	0.77987	0.5114	0.70422	0.4560	0.797451	0.5113
24	1	ARITHMETIC	0.6695	0.4841	0.4802	0.4726	0.32334	0.4703	0.43006	0.4935	0.37588	0.5176	0.28941	0.4715	0.382385	0.5187
25	1	ARITHMETIC	0.2508	0.4985	0.1363	0.4876	0.06273	0.4829	0.09607	0.5049	−0.01844	0.5223	0.04545	0.4837	−0.006806	0.5232
26	1	ARITHMETIC	0.1002	0.4463	0.1744	0.4312	0.23064	0.4218	0.15639	0.4445	−0.04595	0.4561	0.23782	0.4209	−0.027946	0.4570

Table 22. Current recruitment devs estimates (1975-2019) for all model scenarios.

			M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
index			value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev
1	1	ARITHMETIC	1.325987	0.21947	1.26031	0.25829	1.1945	0.30320	1.15328	0.30225	0.86809	0.32553	1.11503	0.31661	0.873803	0.33236
2	1	ARITHMETIC	1.999511	0.14193	2.10527	0.14112	2.1559	0.14562	2.11267	0.15067	1.92607	0.15117	2.11699	0.14489	1.948271	0.15060
3	1	ARITHMETIC	1.741158	0.15634	1.79450	0.15903	1.7409	0.17475	1.74449	0.17805	1.64245	0.17117	1.67740	0.17631	1.647896	0.17221
4	1	ARITHMETIC	0.914330	0.25716	0.91906	0.26315	0.8178	0.29703	0.87446	0.30204	0.94441	0.26110	0.73860	0.30411	0.938347	0.26352
5	1	ARITHMETIC	0.060257	0.39606	0.15632	0.37163	0.1218	0.40566	0.07721	0.44154	−0.06675	0.43056	0.06231	0.41081	−0.073395	0.43698
6	1	ARITHMETIC	−0.436228	0.47983	−0.29754	0.43368	−0.2936	0.46888	−0.41781	0.53348	−0.57721	0.51730	−0.33556	0.47194	−0.565462	0.51549
7	1	ARITHMETIC	0.057849	0.25068	0.08108	0.25329	0.1607	0.25902	0.07293	0.27445	−0.10833	0.26401	0.11128	0.26485	−0.121861	0.26766
8	1	ARITHMETIC	−0.518498	0.33685	−0.40743	0.32326	−0.4401	0.36189	−0.54060	0.37438	−0.25303	0.24297	−0.45249	0.35993	−0.258598	0.24387
9	1	ARITHMETIC	1.068860	0.10832	1.06916	0.10705	1.1744	0.10699	1.09664	0.10918	0.84628	0.11017	1.15444	0.10700	0.837807	0.11057
10	1	ARITHMETIC	0.874922	0.14305	0.91568	0.13217	0.9568	0.13703	0.86325	0.14717	0.75097	0.14269	0.92987	0.13732	0.744673	0.14369
11	1	ARITHMETIC	1.172213	0.13044	0.85682	0.14854	0.7990	0.16062	0.93231	0.15232	0.95242	0.13655	0.76898	0.16024	0.962625	0.13501
12	1	ARITHMETIC	1.134704	0.13537	0.95193	0.13239	1.0451	0.12651	0.98791	0.14234	0.94857	0.14102	1.03449	0.12446	0.961474	0.14092
13	1	ARITHMETIC	1.127278	0.13076	0.94278	0.12646	0.8736	0.14097	0.97327	0.13736	0.98944	0.13308	0.83020	0.14230	0.993998	0.13253
14	1	ARITHMETIC	0.737460	0.15415	0.41544	0.15996	0.3241	0.17331	0.47560	0.17379	0.69924	0.15395	0.29543	0.17444	0.694339	0.15454
15	1	ARITHMETIC	0.004827	0.18563	−0.13141	0.18008	−0.1839	0.19135	−0.14532	0.20310	−0.17150	0.21099	−0.20957	0.19309	−0.187352	0.21377
16	1	ARITHMETIC	−1.180975	0.38180	−1.40841	0.40897	−1.5941	0.48663	−1.52964	0.50361	−1.32340	0.40960	−1.63103	0.49750	−1.339677	0.41479
17	1	ARITHMETIC	−1.404156	0.33220	−1.51656	0.33544	−1.5957	0.35933	−1.53360	0.36485	−1.42398	0.32064	−1.62032	0.36386	−1.435798	0.32304
18	1	ARITHMETIC	−1.526055	0.29294	−1.53753	0.28809	−1.5417	0.29511	−1.53361	0.30441	−1.39119	0.25789	−1.55755	0.29720	−1.397713	0.25815
19	1	ARITHMETIC	−1.529904	0.27300	−1.48781	0.27121	−1.4885	0.28543	−1.53198	0.29714	−1.48169	0.27427	−1.50814	0.28884	−1.500872	0.27647
20	1	ARITHMETIC	−1.259841	0.22362	−1.19852	0.22551	−1.1435	0.23061	−1.19402	0.23688	−1.25593	0.24584	−1.15282	0.23121	−1.269587	0.24563
21	1	ARITHMETIC	−1.004762	0.19234	−0.91708	0.19233	−0.8269	0.19186	−0.87836	0.19708	−0.72265	0.17359	−0.84062	0.19226	−0.740183	0.17330
22	1	ARITHMETIC	−1.078268	0.22288	−1.01880	0.22794	−1.0485	0.24793	−1.05749	0.24727	−1.01225	0.23320	−1.07560	0.25020	−1.036970	0.23392
23	1	ARITHMETIC	−0.008056	0.10696	0.05202	0.10829	0.1272	0.10884	0.11232	0.10896	0.02733	0.11155	0.11215	0.10864	0.009917	0.11119
24	1	ARITHMETIC	−0.920764	0.20125	−0.85936	0.20485	−0.8502	0.21716	−0.90117	0.22133	−0.84470	0.20866	−0.86471	0.21773	−0.860841	0.20859
25	1	ARITHMETIC	0.289723	0.10549	0.38974	0.10445	0.4616	0.10480	0.41001	0.10665	0.41959	0.10446	0.44562	0.10465	0.396694	0.10416
26	1	ARITHMETIC	−0.366276	0.20085	−0.29864	0.20562	−0.2978	0.21995	−0.34294	0.22357	−0.29201	0.21269	−0.30902	0.22019	−0.306770	0.21209
27	1	ARITHMETIC	0.815665	0.09646	0.86132	0.09686	0.9013	0.09881	0.90922	0.09894	0.93503	0.09762	0.89129	0.09891	0.914377	0.09759
28	1	ARITHMETIC	−0.324659	0.23741	−0.26477	0.23954	−0.2525	0.25385	−0.30239	0.26489	−0.24681	0.25659	−0.25004	0.25371	−0.252331	0.25580
29	1	ARITHMETIC	0.782948	0.11247	0.85807	0.10883	0.8867	0.11053	0.90219	0.11281	1.03049	0.10797	0.88050	0.11109	1.011588	0.10834
30	1	ARITHMETIC	0.754406	0.10830	0.72155	0.11167	0.6930	0.11698	0.76029	0.11716	0.84219	0.11706	0.69958	0.11696	0.839696	0.11671
31	1	ARITHMETIC	−0.561822	0.24624	−0.52333	0.24261	−0.6105	0.26630	−0.62183	0.28186	−0.46522	0.25987	−0.60852	0.26952	−0.477087	0.26272
32	1	ARITHMETIC	−0.827576	0.27219	−0.88981	0.29428	−0.9527	0.31647	−0.90211	0.31438	−0.84391	0.30278	−0.94964	0.32136	−0.845306	0.30424
33	1	ARITHMETIC	−1.079504	0.31525	−0.98223	0.31350	−0.9470	0.32000	−0.99731	0.33015	−0.97928	0.31748	−0.93565	0.32438	−0.983900	0.31895
34	1	ARITHMETIC	−0.651014	0.26285	−0.45404	0.25695	−0.3760	0.25660	−0.50319	0.26709	−0.50286	0.26369	−0.30953	0.25406	−0.506445	0.26382
35	1	ARITHMETIC	1.219595	0.10001	1.32960	0.09379	1.3675	0.09161	1.36945	0.09620	1.34668	0.10032	1.41816	0.08972	1.378909	0.09736
36	1	ARITHMETIC	1.079563	0.10839	1.00232	0.11536	0.8413	0.12839	0.96347	0.12734	1.07831	0.12005	0.81370	0.13253	1.059373	0.12192
37	1	ARITHMETIC	0.165279	0.17803	0.04304	0.18429	−0.1110	0.19518	−0.01554	0.19961	0.01705	0.19485	−0.01670	0.18271	0.052942	0.18644
38	1	ARITHMETIC	−1.429645	0.46100	−1.35238	0.43217	−1.5650	0.48335	−1.58832	0.52578	−1.55216	0.46028	−1.62522	0.50258	−1.629746	0.47288
39	1	ARITHMETIC	−0.447087	0.18059	−0.46539	0.18595	−0.5666	0.18716	−0.48835	0.18585	−0.53477	0.17530	−0.46516	0.15891	−0.459241	0.15041
40	1	ARITHMETIC	−0.834498	0.21397	−0.83214	0.21754	−1.0070	0.23089	−0.94203	0.23099	−1.01823	0.22108	−1.03765	0.21588	−1.077281	0.20752
41	1	ARITHMETIC	−1.244014	0.27292	−1.22138	0.27541	−1.3175	0.28034	−1.31779	0.28752	−1.30915	0.25684	−1.31331	0.24850	−1.357546	0.23090
42	1	ARITHMETIC	−0.893146	0.24196	−0.86516	0.24412	−0.8876	0.23938	−0.86864	0.23975	−0.92572	0.23069	−0.73199	0.18381	−0.840550	0.17699
43	1	ARITHMETIC	0.959708	0.14287	0.99193	0.14244	0.8948	0.13040	0.91736	0.13034	0.78189	0.12072	1.08909	0.11217	0.928495	0.10095
44	1	ARITHMETIC	1.240503	0.22169	1.21181	0.22408	0.8241	0.19598	0.86635	0.19511	0.82803	0.17921	0.91640	0.19794	0.823768	0.18082

Table 23. Logit-scale parameters for the probability of terminal molt for males for all model scenarios. The (arithmetic) probability of terminal molt was fixed at 0 for males less than 60 mm CW and at 1 for males greater than 145 mm CW in Scenarios M19F03 and M19F05.

scenario:	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
size bin	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
27.5	-12.03	7.44	-12.06	7.42	-12.04	7.39	-12.48	7.59	--	--	-11.92	7.22	--	--
32.5	-10.85	5.62	-10.84	5.60	-10.82	5.57	-11.15	5.73	--	--	-10.70	5.43	--	--
37.5	-9.66	4.02	-9.62	4.00	-9.61	3.99	-9.82	4.11	--	--	-9.48	3.86	--	--
42.5	-8.48	2.68	-8.40	2.67	-8.39	2.66	-8.49	2.74	--	--	-8.27	2.56	--	--
47.5	-7.31	1.63	-7.19	1.61	-7.19	1.61	-7.17	1.64	--	--	-7.06	1.53	--	--
52.5	-6.16	0.91	-6.01	0.88	-6.01	0.88	-5.87	0.87	--	--	-5.89	0.84	--	--
57.5	-5.11	0.54	-4.92	0.52	-4.92	0.51	-4.65	0.46	--	--	-4.81	0.49	--	--
62.5	-4.49	0.36	-4.27	0.36	-4.24	0.35	-3.82	0.28	-2.91	0.28	-4.20	0.35	-2.95	0.28
67.5	-4.10	0.29	-3.95	0.29	-3.92	0.29	-3.48	0.22	-3.29	0.29	-3.98	0.29	-3.37	0.30
72.5	-3.46	0.22	-3.34	0.23	-3.39	0.22	-3.04	0.19	-2.86	0.25	-3.40	0.22	-2.86	0.25
77.5	-2.93	0.17	-2.71	0.17	-2.76	0.17	-2.50	0.14	-2.17	0.16	-2.68	0.17	-2.14	0.15
82.5	-2.50	0.14	-2.26	0.14	-2.24	0.14	-1.92	0.12	-1.66	0.14	-2.19	0.13	-1.67	0.13
87.5	-2.03	0.12	-1.90	0.12	-1.90	0.12	-1.53	0.10	-1.41	0.12	-1.91	0.11	-1.43	0.12
92.5	-1.44	0.11	-1.42	0.11	-1.48	0.10	-1.00	0.09	-0.86	0.11	-1.50	0.10	-0.86	0.10
97.5	-0.95	0.09	-0.95	0.10	-1.07	0.10	-0.57	0.08	-0.47	0.10	-1.07	0.10	-0.47	0.09
102.5	-0.68	0.09	-0.59	0.09	-0.67	0.09	-0.39	0.08	-0.32	0.10	-0.65	0.09	-0.34	0.09
107.5	-0.53	0.09	-0.47	0.09	-0.45	0.08	-0.23	0.08	-0.15	0.10	-0.41	0.08	-0.14	0.09
112.5	-0.06	0.10	-0.12	0.09	-0.15	0.09	0.20	0.09	0.30	0.11	-0.13	0.08	0.30	0.10
117.5	0.56	0.13	0.41	0.11	0.34	0.10	0.77	0.11	0.90	0.13	0.37	0.10	0.95	0.14
122.5	1.44	0.20	1.09	0.14	0.98	0.13	1.55	0.16	1.76	0.19	0.99	0.13	1.80	0.19
127.5	2.81	0.36	1.88	0.29	1.55	0.20	2.81	0.30	3.11	0.31	1.54	0.20	3.16	0.30
132.5	5.06	0.59	3.95	0.61	3.17	0.55	4.17	0.34	4.35	0.34	3.16	0.54	4.40	0.35
137.5	7.20	1.06	6.22	0.91	5.44	0.79	6.01	0.65	6.12	0.73	5.45	0.77	6.15	0.74
142.5	9.01	1.68	8.21	1.42	7.54	1.21	7.80	1.17	8.03	1.54	7.55	1.20	8.05	1.55
147.5	10.50	2.32	9.85	2.03	9.29	1.79	9.35	1.77	--	--	9.31	1.78	--	--
152.5	11.69	2.85	11.18	2.57	10.73	2.35	10.64	2.33	--	--	10.75	2.34	--	--
157.5	12.63	3.19	12.24	2.95	11.87	2.75	11.71	2.73	--	--	11.89	2.75	--	--
162.5	13.36	3.26	13.06	3.07	12.78	2.92	12.59	2.90	--	--	12.80	2.91	--	--
167.5	13.91	3.01	13.71	2.88	13.50	2.77	13.32	2.76	--	--	13.52	2.77	--	--
172.5	14.35	2.42	14.21	2.33	14.08	2.27	13.95	2.26	--	--	14.09	2.26	--	--
177.5	14.69	1.44	14.63	1.40	14.56	1.37	14.49	1.36	--	--	14.57	1.37	--	--
182.5	15.00	0.00	15.00	0.00	15.00	0.00	15.00	0.00	--	--	15.00	0.00	--	--

Table 24. Logit-scale parameters for the probability of terminal molt for females for all model scenarios. The (arithmetic) probability of terminal molt was fixed at 0 for females less than 50 mm CW in Scenarios M19F03 and M19F05 and at 1 for females greater than 105 mm CW for all scenarios.

scenario:	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
size bin	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
27.5	-15.00	0.00	-15.00	0.00	-15.00	0.00	-15.00	0.00	--	--	-15.00	0.00	--	--
32.5	-13.77	0.78	-13.78	0.78	-13.79	0.78	-13.79	0.78	--	--	-13.81	0.78	--	--
37.5	-12.48	1.18	-12.50	1.18	-12.53	1.18	-12.52	1.18	--	--	-12.56	1.18	--	--
42.5	-11.09	1.29	-11.12	1.29	-11.15	1.28	-11.13	1.28	--	--	-11.20	1.28	--	--
47.5	-9.53	1.15	-9.56	1.15	-9.60	1.15	-9.58	1.15	--	--	-9.66	1.14	--	--
52.5	-7.76	0.86	-7.79	0.86	-7.83	0.86	-7.80	0.86	-6.82	0.99	-7.90	0.86	-6.89	1.00
57.5	-5.75	0.52	-5.78	0.53	-5.81	0.52	-5.78	0.52	-5.05	0.45	-5.88	0.52	-5.11	0.45
62.5	-3.58	0.24	-3.60	0.24	-3.63	0.24	-3.60	0.24	-3.34	0.21	-3.70	0.24	-3.39	0.20
67.5	-1.77	0.11	-1.78	0.11	-1.81	0.11	-1.78	0.11	-1.79	0.11	-1.87	0.11	-1.85	0.11
72.5	-0.43	0.09	-0.44	0.08	-0.48	0.08	-0.44	0.08	-0.51	0.09	-0.52	0.08	-0.54	0.09
77.5	0.31	0.09	0.28	0.09	0.24	0.08	0.29	0.09	0.22	0.09	0.26	0.08	0.27	0.09
82.5	0.59	0.10	0.59	0.10	0.56	0.09	0.59	0.10	0.55	0.10	0.55	0.09	0.56	0.09
87.5	1.28	0.16	1.23	0.15	1.20	0.14	1.26	0.15	1.18	0.14	1.03	0.12	1.04	0.12
92.5	2.58	0.35	2.36	0.29	2.36	0.27	2.53	0.31	2.26	0.25	2.08	0.22	2.12	0.22
97.5	4.03	0.67	3.61	0.50	3.67	0.49	3.96	0.60	3.48	0.47	3.50	0.41	3.53	0.43
102.5	5.52	1.27	4.91	0.99	5.03	1.00	5.42	1.18	4.78	0.99	5.02	0.87	5.06	0.93

Table 25. Log-scale NMFS survey catchability and selectivity parameters for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	phase	scale	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pQ[1]	**NMFS trawl survey: males, 1975-1981**	5	LOG	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000
pQ[2]	**NMFS trawl survey: males, 1982+**	5	LOG	-0.450	0.054	-0.635	0.065	-0.708	0.063	-0.757	0.065	-0.848	0.069	-0.702	0.053	-0.766	0.055
pQ[3]	**NMFS trawl survey: females, 1975-1981**	5	LOG	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.001	-0.693	0.000	-0.693	0.001
pQ[4]	**NMFS trawl survey: females, 1982+**	5	LOG	-0.922	0.073	-1.185	0.086	-1.268	0.084	-1.432	0.086	-1.437	0.105	-1.291	0.076	-1.357	0.099
pS1[1]	**z50 for NMFS survey selectivity (males, pre-1982)**	1	ARITHMETIC	52.441	2.125	90.000	0.001	90.000	0.000	90.000	0.000	90.000	0.000	90.000	0.000	90.000	0.000
pS1[2]	**z50 for NMFS survey selectivity (males, 1982+)**	1	ARITHMETIC	34.262	4.137	40.160	6.282	40.369	5.641	48.332	5.272	46.976	5.617	51.811	4.538	55.732	4.697
pS1[3]	**z50 for NMFS survey selectivity (females, pre-1982)**	1	ARITHMETIC	56.408	2.854	76.838	3.071	77.775	2.969	82.307	3.326	92.150	4.946	79.502	2.969	92.970	4.820
pS1[4]	**z50 for NMFS survey selectivity (females, 1982+)**	1	ARITHMETIC	-35.492	30.433	-33.961	30.933	-36.975	32.573	-47.549	41.643	-0.042	18.679	-4.632	15.305	18.651	14.067
pS2[1]	**z95-z50 for NMFS survey selectivity (males, pre-1982)**	1	ARITHMETIC	23.612	3.514	86.141	6.981	84.091	6.598	81.019	6.068	92.616	7.614	80.670	6.020	89.255	7.012
pS2[2]	**z95-z50 for NMFS survey selectivity (males, 1982+)**	1	ARITHMETIC	75.233	10.334	99.001	17.736	100.000	0.003	100.000	0.001	100.000	0.000	100.000	0.007	100.000	0.000
pS2[3]	**z95-z50 for NMFS survey selectivity (females, pre-1982)**	1	ARITHMETIC	40.090	5.841	59.809	6.261	59.360	5.973	65.786	6.834	68.015	8.994	60.215	5.987	67.834	8.860
pS2[4]	**z95-z50 for NMFS survey selectivity (females, 1982+)**	1	ARITHMETIC	100.000	0.002	100.000	0.002	100.000	0.002	100.000	0.003	100.000	0.001	100.000	0.001	100.000	0.000

Table 26. BSFRF SBS (side-by-side) male availability parameters for all model scenarios in which they were estimated.

	BSFRF availability (males, 2013)				BSFRF availability (males, 2014)				BSFRF availability (males, 2015)				BSFRF availability (males, 2016)				BSFRF availability (males, 2017)			
	M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05	
index	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1	-3.297	0.615	-3.255	0.614	-3.608	0.708	-3.590	0.700	-3.084	0.588	-3.030	0.578	-0.591	0.477	-0.438	0.488	0.113	0.340	0.321	0.352
2	-3.463	0.509	-3.428	0.510	-3.558	0.569	-3.558	0.563	-3.057	0.465	-3.021	0.457	-0.848	0.390	-0.716	0.399	-0.433	0.298	-0.234	0.308
3	-3.606	0.443	-3.578	0.446	-3.505	0.466	-3.523	0.463	-3.032	0.381	-3.015	0.376	-1.082	0.344	-0.971	0.351	-0.901	0.292	-0.717	0.301
4	-3.709	0.407	-3.690	0.412	-3.445	0.401	-3.481	0.400	-3.002	0.331	-3.006	0.330	-1.271	0.326	-1.185	0.332	-1.204	0.299	-1.046	0.306
5	-3.764	0.388	-3.753	0.394	-3.374	0.366	-3.430	0.365	-2.970	0.308	-2.999	0.308	-1.400	0.324	-1.347	0.327	-1.356	0.311	-1.235	0.316
6	-3.764	0.375	-3.763	0.381	-3.292	0.347	-3.368	0.347	-2.932	0.298	-2.992	0.297	-1.458	0.326	-1.444	0.326	-1.394	0.326	-1.319	0.328
7	-3.713	0.363	-3.722	0.368	-3.205	0.334	-3.302	0.333	-2.872	0.292	-2.968	0.291	-1.440	0.327	-1.476	0.323	-1.347	0.342	-1.328	0.340
8	-3.618	0.349	-3.638	0.354	-3.107	0.320	-3.225	0.318	-2.775	0.287	-2.910	0.283	-1.350	0.327	-1.443	0.318	-1.241	0.357	-1.283	0.350
9	-3.476	0.334	-3.505	0.339	-2.987	0.302	-3.125	0.300	-2.632	0.279	-2.803	0.274	-1.193	0.326	-1.346	0.312	-1.091	0.369	-1.197	0.356
10	-3.283	0.321	-3.320	0.326	-2.829	0.283	-2.984	0.280	-2.446	0.267	-2.647	0.262	-0.974	0.323	-1.189	0.305	-0.907	0.379	-1.076	0.360
11	-3.048	0.310	-3.092	0.316	-2.623	0.263	-2.794	0.260	-2.242	0.254	-2.465	0.248	-0.706	0.321	-0.979	0.297	-0.699	0.386	-0.925	0.360
12	-2.792	0.304	-2.843	0.309	-2.367	0.245	-2.551	0.241	-2.061	0.241	-2.298	0.235	-0.415	0.321	-0.740	0.292	-0.471	0.392	-0.749	0.360
13	-2.529	0.303	-2.589	0.307	-2.083	0.232	-2.276	0.227	-1.924	0.230	-2.164	0.224	-0.125	0.322	-0.485	0.290	-0.228	0.396	-0.544	0.358
14	-2.244	0.306	-2.315	0.310	-1.774	0.224	-1.969	0.217	-1.828	0.222	-2.060	0.215	0.141	0.325	-0.235	0.291	0.023	0.398	-0.317	0.356
15	-1.899	0.312	-1.979	0.315	-1.437	0.218	-1.625	0.211	-1.756	0.215	-1.965	0.208	0.362	0.327	-0.002	0.292	0.270	0.396	-0.074	0.353
16	-1.484	0.320	-1.574	0.322	-1.097	0.216	-1.267	0.208	-1.684	0.209	-1.858	0.204	0.527	0.326	0.199	0.292	0.498	0.390	0.170	0.348
17	-1.044	0.327	-1.143	0.329	-0.824	0.216	-0.977	0.208	-1.605	0.203	-1.745	0.199	0.624	0.320	0.348	0.290	0.689	0.380	0.391	0.341
18	-0.668	0.334	-0.776	0.337	-0.660	0.219	-0.806	0.210	-1.557	0.199	-1.672	0.195	0.642	0.309	0.422	0.283	0.820	0.366	0.563	0.333
19	-0.445	0.343	-0.560	0.345	-0.618	0.224	-0.763	0.215	-1.540	0.197	-1.637	0.193	0.573	0.295	0.411	0.274	0.877	0.350	0.669	0.323
20	-0.419	0.353	-0.533	0.355	-0.648	0.230	-0.797	0.220	-1.540	0.196	-1.623	0.192	0.413	0.280	0.305	0.265	0.850	0.332	0.696	0.311
21	-0.566	0.362	-0.671	0.364	-0.683	0.234	-0.836	0.222	-1.514	0.195	-1.586	0.192	0.174	0.265	0.116	0.256	0.734	0.315	0.637	0.300
22	-0.807	0.367	-0.895	0.368	-0.693	0.234	-0.851	0.223	-1.453	0.193	-1.516	0.191	-0.119	0.252	-0.134	0.247	0.533	0.302	0.492	0.293
23	-1.086	0.368	-1.155	0.370	-0.670	0.233	-0.835	0.222	-1.395	0.193	-1.454	0.191	-0.451	0.245	-0.432	0.244	0.258	0.300	0.271	0.297
24	-1.385	0.374	-1.432	0.376	-0.655	0.236	-0.831	0.224	-1.369	0.196	-1.430	0.194	-0.814	0.256	-0.768	0.256	-0.073	0.318	-0.010	0.320
25	-1.703	0.395	-1.731	0.397	-0.672	0.249	-0.862	0.236	-1.391	0.206	-1.458	0.203	-1.198	0.296	-1.132	0.294	-0.441	0.368	-0.332	0.372
26	-2.037	0.445	-2.044	0.447	-0.735	0.283	-0.941	0.268	-1.461	0.231	-1.538	0.227	-1.589	0.371	-1.507	0.366	-0.831	0.453	-0.678	0.458
27	-2.381	0.530	-2.369	0.532	-0.831	0.347	-1.055	0.328	-1.576	0.281	-1.664	0.276	-1.987	0.481	-1.889	0.473	-1.230	0.573	-1.035	0.576
28	-2.730	0.650	-2.698	0.652	-0.941	0.444	-1.183	0.421	-1.726	0.364	-1.825	0.357	-2.388	0.624	-2.276	0.612	-1.633	0.725	-1.397	0.725
29	-3.080	0.803	-3.029	0.803	-1.055	0.572	-1.315	0.546	-1.886	0.482	-1.999	0.472	-2.792	0.794	-2.666	0.779	-2.038	0.904	-1.761	0.902
30	-3.431	0.983	-3.360	0.983	-1.171	0.730	-1.450	0.700	-2.049	0.630	-2.175	0.618	-3.195	0.987	-3.055	0.969	-2.442	1.106	-2.125	1.101
31	-3.782	1.187	-3.692	1.186	-1.288	0.913	-1.586	0.880	-2.213	0.805	-2.353	0.790	-3.599	1.202	-3.445	1.181	-2.847	1.329	-2.489	1.321
32	-4.132	1.411	-4.024	1.409	-1.406	1.118	-1.722	1.081	-2.377	1.002	-2.531	0.985	-4.002	1.434	-3.835	1.411	-3.252	1.569	-2.853	1.560

Table 27. BSFRF SBS (side-by-side) female availability parameters for all model scenarios. in which they were estimated.

	BSFRF availability (females, 2013)				BSFRF availability (females, 2014)				BSFRF availability (females, 2015)				BSFRF availability (females, 2016)				BSFRF availability (females, 2017)			
	M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05	
index	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1	-3.376	0.599	-3.272	0.597	-4.290	0.862	-4.211	0.860	-3.616	0.647	-3.543	0.642	-0.314	0.558	-0.156	0.572	0.798	0.434	1.001	0.450
2	-3.735	0.510	-3.640	0.509	-4.212	0.720	-4.146	0.718	-3.681	0.545	-3.621	0.542	-0.674	0.472	-0.531	0.483	0.328	0.377	0.526	0.390
3	-4.061	0.458	-3.974	0.457	-4.132	0.608	-4.079	0.607	-3.748	0.477	-3.701	0.474	-1.014	0.416	-0.886	0.424	-0.093	0.351	0.094	0.362
4	-4.327	0.429	-4.250	0.429	-4.053	0.524	-4.014	0.522	-3.810	0.434	-3.778	0.431	-1.300	0.377	-1.190	0.382	-0.393	0.335	-0.228	0.344
5	-4.508	0.409	-4.442	0.409	-3.987	0.460	-3.962	0.458	-3.863	0.404	-3.848	0.402	-1.529	0.346	-1.441	0.349	-0.564	0.321	-0.427	0.327
6	-4.586	0.389	-4.532	0.389	-3.940	0.408	-3.930	0.406	-3.900	0.379	-3.903	0.377	-1.688	0.318	-1.625	0.318	-0.627	0.309	-0.525	0.313
7	-4.542	0.363	-4.503	0.362	-3.904	0.362	-3.909	0.359	-3.919	0.354	-3.940	0.352	-1.769	0.290	-1.734	0.289	-0.611	0.300	-0.548	0.300
8	-4.367	0.331	-4.344	0.330	-3.864	0.317	-3.886	0.314	-3.903	0.327	-3.942	0.325	-1.774	0.263	-1.770	0.260	-0.547	0.292	-0.524	0.290
9	-4.050	0.296	-4.045	0.295	-3.791	0.274	-3.833	0.271	-3.828	0.301	-3.884	0.299	-1.707	0.241	-1.734	0.237	-0.464	0.286	-0.481	0.281
10	-3.579	0.262	-3.595	0.261	-3.657	0.239	-3.721	0.236	-3.682	0.278	-3.754	0.277	-1.573	0.226	-1.632	0.222	-0.389	0.281	-0.447	0.275
11	-2.960	0.237	-3.002	0.237	-3.438	0.216	-3.530	0.213	-3.472	0.264	-3.563	0.263	-1.407	0.220	-1.497	0.216	-0.356	0.280	-0.455	0.272
12	-2.217	0.231	-2.291	0.230	-3.133	0.207	-3.255	0.205	-3.218	0.259	-3.331	0.258	-1.276	0.222	-1.398	0.217	-0.393	0.287	-0.534	0.275
13	-1.385	0.249	-1.499	0.248	-2.731	0.210	-2.891	0.207	-2.930	0.262	-3.069	0.260	-1.200	0.231	-1.355	0.224	-0.497	0.306	-0.679	0.290
14	-0.494	0.297	-0.652	0.294	-2.242	0.223	-2.444	0.219	-2.589	0.269	-2.759	0.267	-1.166	0.250	-1.353	0.240	-0.650	0.346	-0.874	0.325
15	0.440	0.375	0.236	0.372	-1.672	0.253	-1.921	0.246	-2.172	0.286	-2.378	0.281	-1.158	0.290	-1.380	0.276	-0.833	0.417	-1.100	0.391
16	1.389	0.486	1.138	0.483	-1.048	0.313	-1.352	0.300	-1.696	0.322	-1.943	0.313	-1.156	0.364	-1.414	0.345	-1.032	0.525	-1.340	0.494
17	2.340	0.629	2.042	0.626	-0.410	0.413	-0.772	0.393	-1.195	0.392	-1.488	0.378	-1.156	0.476	-1.450	0.452	-1.235	0.666	-1.586	0.631
18	3.292	0.800	2.946	0.797	0.227	0.550	-0.197	0.526	-0.693	0.501	-1.034	0.481	-1.156	0.622	-1.488	0.595	-1.439	0.837	-1.833	0.799
19	4.243	0.994	3.849	0.991	0.863	0.719	0.376	0.691	-0.188	0.645	-0.579	0.619	-1.155	0.796	-1.525	0.766	-1.643	1.032	-2.080	0.991
20	5.195	1.209	4.753	1.206	1.500	0.912	0.949	0.881	0.317	0.818	-0.124	0.788	-1.155	0.994	-1.563	0.961	-1.847	1.248	-2.327	1.205
21	6.146	1.442	5.656	1.439	2.136	1.126	1.523	1.092	0.822	1.015	0.332	0.981	-1.155	1.212	-1.600	1.176	-2.051	1.483	-2.574	1.438

Table 28. Mean capture rate, selectivity and retention parameter estimates for the directed fishery (TCF) for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	index	phase	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[1]	TCF: female offset	1	1	-2.351	0.300	-1.968	0.269	-2.002	0.265	-2.121	0.260	-2.202	0.225	-2.242	0.224	-2.365	0.209
pLgtRet[1]	TCF: logit-scale max retention (pre-1997)	1	3	14.999	2.211	14.999	4.414	14.999	4.355	14.999	4.757	14.999	5.155	14.999	4.336	14.999	4.561
pLgtRet[2]	TCF: logit-scale max retention (2005-2009)	1	3	2.101	1.305	14.210	996.790	14.919	337.810	14.863	526.220	14.993	39.551	14.868	479.580	14.928	322.800
pLgtRet[3]	TCF: logit-scale max retention (2013+)	1	3	4.031	2.222	14.633	619.480	14.990	45.731	14.980	78.614	14.987	57.716	14.977	88.452	14.984	66.741
pLnC[1]	TCF: base capture rate, pre-1965 (=0.05)	1	-1	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000
pLnC[2]	TCF: base capture rate, 1965+	1	1	-1.418	0.083	-1.580	0.085	-1.679	0.083	-1.634	0.083	-1.818	0.086	-1.678	0.081	-1.767	0.082
pDevsS1[1]	ln(z50 devs) for TCF selectivity (males, 1991+)	1	2	0.037	0.018	0.086	0.011	0.100	0.012	0.092	0.011	0.090	0.010	0.099	0.012	0.090	0.010
		2	2	0.124	0.012	0.040	0.011	0.050	0.011	0.044	0.010	0.038	0.010	0.049	0.011	0.041	0.010
		3	2	0.107	0.014	0.118	0.013	0.130	0.014	0.121	0.013	0.112	0.012	0.128	0.013	0.113	0.012
		4	2	0.088	0.021	0.070	0.018	0.081	0.018	0.075	0.017	0.066	0.017	0.079	0.018	0.068	0.017
		5	2	0.001	0.027	-0.002	0.026	0.002	0.027	0.009	0.025	0.005	0.024	0.001	0.026	0.008	0.023
		6	2	0.130	0.040	0.153	0.038	0.167	0.038	0.161	0.037	0.161	0.036	0.164	0.038	0.159	0.035
		7	2	-0.079	0.017	-0.076	0.016	-0.067	0.016	-0.064	0.015	-0.061	0.015	-0.066	0.016	-0.062	0.015
		8	2	-0.087	0.018	-0.080	0.016	-0.068	0.016	-0.067	0.015	-0.062	0.015	-0.066	0.016	-0.062	0.015
		9	2	-0.124	0.016	-0.122	0.015	-0.114	0.015	-0.108	0.014	-0.103	0.014	-0.113	0.015	-0.103	0.014
		10	2	0.019	0.014	0.018	0.014	0.029	0.013	0.027	0.013	0.030	0.013	0.029	0.013	0.029	0.013
		11	2	0.189	0.016	0.189	0.015	0.198	0.015	0.192	0.014	0.195	0.014	0.197	0.015	0.193	0.014
		12	2	-0.040	0.017	-0.035	0.015	-0.027	0.015	-0.022	0.015	-0.020	0.015	-0.025	0.015	-0.020	0.015
		13	2	-0.100	0.014	-0.096	0.013	-0.083	0.012	-0.085	0.012	-0.085	0.012	-0.082	0.012	-0.086	0.012
		14	2	-0.138	0.016	-0.142	0.014	-0.128	0.013	-0.124	0.013	-0.124	0.013	-0.126	0.013	-0.124	0.013
		15	2	-0.125	0.021	-0.122	0.019	-0.113	0.019	-0.103	0.017	-0.098	0.017	-0.112	0.019	-0.099	0.017
		16	2					-0.157	0.017	-0.147	0.016	-0.145	0.016	-0.156	0.017	-0.146	0.016
pS1[28]	z50 for TCF retention (2005-2009)	1	1	138.799	1.573	137.700	0.303	137.716	0.337	137.711	0.331	137.711	0.329	137.716	0.348	137.711	0.328
pS1[29]	z50 for TCF retention (2013+)	1	1	125.230	0.725	125.170	0.566	125.216	0.544	125.269	0.539	125.254	0.538	125.189	0.543	125.249	0.538
pS1[5]	z50 for TCF retention (pre-1991)	1	1	138.043	0.420	138.527	0.448	138.635	0.452	138.545	0.441	138.638	0.446	138.591	0.444	138.577	0.438
pS1[6]	z50 for TCF retention (1991-1996)	1	1	137.483	0.250	138.337	0.331	138.378	0.340	138.418	0.347	138.475	0.357	138.380	0.339	138.438	0.352
pS1[8]	ln(z50) for TCF selectivity (males)	1	1	4.858	0.008	4.865	0.008	4.857	0.007	4.860	0.007	4.859	0.007	4.859	0.007	4.860	0.007
pS1[9]	z50 for TCF selectivity (females)	1	1	96.441	2.583	96.842	2.621	96.722	2.641	96.719	2.600	95.205	2.202	94.863	2.164	94.174	1.986
pS2[28]	slope for TCF retention (2005-2009)	1	1	0.865	0.634	2.000	0.507	2.000	0.649	2.000	0.628	2.000	0.618	1.999	0.691	2.000	0.614
pS2[29]	slope for TCF retention (2013+)	1	1	0.563	0.115	0.568	0.108	0.570	0.104	0.563	0.100	0.565	0.100	0.575	0.105	0.567	0.101
pS2[5]	slope for TCF retention (pre-1991)	1	1	0.687	0.125	0.686	0.118	0.687	0.115	0.678	0.115	0.689	0.116	0.692	0.116	0.694	0.117
pS2[6]	slope for TCF retention (1997+)	1	1	0.954	0.190	0.937	0.222	0.933	0.222	0.920	0.217	0.908	0.212	0.931	0.221	0.918	0.217
pS2[7]	slope for TCF selectivity (males, pre-1997)	1	1	0.118	0.006	0.112	0.006	0.110	0.006	0.114	0.006	0.116	0.006	0.111	0.006	0.117	0.006
pS2[8]	slope for TCF selectivity (males, 1997+)	1	1	0.155	0.008	0.156	0.008	0.158	0.008	0.160	0.007	0.159	0.007	0.158	0.007	0.159	0.007
pS2[9]	slope for TCF selectivity (females)	1	1	0.185	0.019	0.184	0.018	0.179	0.017	0.179	0.017	0.184	0.017	0.189	0.018	0.191	0.018

Table 29. Log-scale male capture rate dev parameter estimates for the directed fishery (TCF) for all model scenarios.

	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
year	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1965	-0.548	0.463	-0.569	0.459	-0.588	0.456	-0.561	0.459	-0.494	0.460	-0.590	0.456	-0.501	0.460
1966	-0.773	0.369	-0.775	0.365	-0.785	0.362	-0.769	0.364	-0.724	0.365	-0.786	0.362	-0.729	0.365
1967	0.449	0.336	0.460	0.329	0.459	0.325	0.466	0.328	0.494	0.327	0.459	0.324	0.492	0.328
1968	0.294	0.315	0.322	0.308	0.333	0.304	0.330	0.306	0.353	0.307	0.334	0.304	0.350	0.308
1969	0.474	0.304	0.504	0.298	0.518	0.294	0.514	0.295	0.532	0.296	0.517	0.295	0.528	0.298
1970	0.332	0.303	0.356	0.295	0.369	0.290	0.370	0.290	0.375	0.291	0.366	0.291	0.370	0.294
1971	0.138	0.293	0.159	0.283	0.172	0.277	0.182	0.276	0.169	0.276	0.168	0.277	0.160	0.280
1972	-0.033	0.261	-0.005	0.251	0.016	0.244	0.036	0.245	0.001	0.242	0.010	0.244	-0.015	0.246
1973	-0.281	0.199	-0.227	0.193	-0.191	0.188	-0.161	0.191	-0.220	0.185	-0.197	0.188	-0.247	0.187
1974	-0.094	0.136	0.002	0.136	0.055	0.134	0.090	0.137	0.008	0.130	0.052	0.133	-0.028	0.130
1975	0.130	0.103	0.271	0.108	0.340	0.106	0.373	0.109	0.281	0.104	0.340	0.105	0.240	0.102
1976	0.908	0.096	1.064	0.103	1.142	0.103	1.187	0.105	1.085	0.101	1.148	0.100	1.046	0.098
1977	1.711	0.113	1.812	0.124	1.885	0.123	2.007	0.131	1.827	0.117	1.901	0.121	1.797	0.115
1978	2.041	0.150	1.966	0.166	2.017	0.161	2.250	0.175	1.996	0.152	2.042	0.159	1.980	0.151
1979	2.818	0.229	2.383	0.225	2.407	0.205	2.703	0.229	2.488	0.220	2.443	0.201	2.483	0.223
1980	2.015	0.178	2.066	0.172	2.242	0.175	2.133	0.167	2.073	0.162	2.290	0.175	2.071	0.161
1981	0.207	0.112	0.357	0.116	0.534	0.119	0.353	0.110	0.390	0.108	0.565	0.118	0.386	0.108
1982	-0.791	0.123	-0.750	0.123	-0.667	0.123	-0.705	0.122	-0.641	0.122	-0.652	0.123	-0.637	0.122
1983	-1.796	0.244	-1.801	0.245	-1.768	0.246	-1.733	0.248	-1.708	0.248	-1.760	0.246	-1.692	0.249
1984	-0.779	0.174	-0.771	0.176	-0.759	0.175	-0.675	0.176	-0.715	0.176	-0.752	0.175	-0.680	0.177
1987	-1.338	0.208	-1.271	0.211	-1.230	0.211	-1.189	0.211	-1.120	0.213	-1.214	0.212	-1.116	0.214
1988	-0.527	0.105	-0.407	0.105	-0.336	0.103	-0.361	0.103	-0.224	0.103	-0.320	0.103	-0.224	0.104
1989	0.669	0.081	0.772	0.078	0.820	0.076	0.821	0.077	0.998	0.077	0.832	0.076	0.999	0.078
1990	1.347	0.087	1.498	0.082	1.529	0.079	1.519	0.081	1.669	0.082	1.540	0.079	1.680	0.082
1991	1.352	0.105	1.762	0.118	1.823	0.119	1.742	0.116	1.826	0.115	1.835	0.119	1.852	0.116
1992	2.049	0.142	1.933	0.115	1.938	0.113	1.856	0.110	1.875	0.108	1.944	0.112	1.910	0.109
1993	1.442	0.147	1.576	0.143	1.594	0.144	1.491	0.140	1.428	0.136	1.596	0.143	1.470	0.135
1994	0.932	0.193	0.800	0.160	0.794	0.160	0.748	0.157	0.696	0.150	0.790	0.158	0.743	0.150
1995	0.340	0.178	0.222	0.166	0.168	0.161	0.219	0.166	0.204	0.161	0.163	0.158	0.251	0.161
1996	0.055	0.378	-0.370	0.409	-0.381	0.411	-0.356	0.407	-0.381	0.402	-0.383	0.409	-0.339	0.402
2005	-2.086	0.189	-2.210	0.206	-2.172	0.206	-2.208	0.206	-2.159	0.207	-2.173	0.206	-2.156	0.207
2006	-1.490	0.123	-1.715	0.138	-1.660	0.137	-1.704	0.137	-1.650	0.137	-1.660	0.137	-1.645	0.137
2007	-1.473	0.110	-1.653	0.119	-1.614	0.117	-1.652	0.117	-1.618	0.117	-1.625	0.116	-1.617	0.117
2008	-1.826	0.154	-1.819	0.155	-1.743	0.154	-1.800	0.154	-1.786	0.154	-1.746	0.154	-1.782	0.154
2009	-1.198	0.265	-1.147	0.263	-1.049	0.264	-1.125	0.258	-1.091	0.260	-1.046	0.265	-1.087	0.260
2013	-1.821	0.136	-1.705	0.137	-1.621	0.135	-1.652	0.136	-1.647	0.136	-1.638	0.135	-1.656	0.136
2014	-0.623	0.089	-0.581	0.093	-0.463	0.090	-0.558	0.088	-0.546	0.087	-0.503	0.089	-0.568	0.087
2015	-0.363	0.088	-0.359	0.090	-0.249	0.087	-0.309	0.085	-0.278	0.084	-0.300	0.085	-0.295	0.084
2017	-1.864	0.125	-2.151	0.143	-2.042	0.140	-2.037	0.141	-1.983	0.141	-2.097	0.139	-1.995	0.140
2018	--	--	--	--	-1.836	0.135	-1.833	0.135	-1.784	0.134	-1.894	0.133	-1.798	0.133

Table 30. Comparison of mean capture rate, ln-scale capture rate devs, and selectivity parameter estimates for the snow crab fishery (SCF) for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	index	phase	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[2]	**SCF: female offset**	1	2	-1.749	0.150	-3.361	0.619	-3.388	0.621	-3.521	0.622	-3.394	0.616	-3.403	0.618	-3.415	0.611
pDevsLnC[2]	**SCF: 1992+**	1	2	1.945	0.091	0.572	0.105	0.586	0.105	0.571	0.105	0.512	0.104	0.583	0.105	0.516	0.104
		2	2	1.641	0.093	0.897	0.098	0.904	0.098	0.889	0.098	0.807	0.097	0.900	0.097	0.816	0.097
		3	2	1.241	0.097	0.331	0.181	0.330	0.180	0.332	0.181	0.242	0.179	0.325	0.180	0.255	0.179
		4	2	1.170	0.104	0.290	0.237	0.285	0.236	0.303	0.238	0.199	0.234	0.280	0.237	0.218	0.234
		5	2	-0.271	0.244	1.203	0.144	1.194	0.143	1.229	0.144	1.099	0.140	1.194	0.142	1.123	0.140
		6	2	0.784	0.211	0.919	0.160	0.895	0.163	0.909	0.162	0.901	0.161	0.915	0.160	0.912	0.159
		7	2	0.999	0.203	-0.136	0.354	-0.147	0.352	-0.122	0.351	-0.134	0.351	-0.133	0.353	-0.123	0.351
		8	2	-0.035	0.336	-0.995	0.551	-1.000	0.548	-0.976	0.550	-0.982	0.548	-0.991	0.551	-0.975	0.549
		9	2	-0.982	0.513	-0.731	0.495	-0.733	0.493	-0.717	0.491	-0.718	0.492	-0.724	0.496	-0.711	0.492
		10	2	-0.834	0.441	-0.447	0.384	-0.448	0.382	-0.447	0.379	-0.419	0.384	-0.437	0.384	-0.413	0.384
		11	2	-0.614	0.358	-1.148	0.497	-1.155	0.495	-1.152	0.493	-1.115	0.500	-1.148	0.496	-1.112	0.500
		12	2	-1.311	0.453	-1.422	0.497	-1.426	0.496	-1.428	0.494	-1.390	0.501	-1.420	0.497	-1.389	0.500
		13	2	-1.652	0.465	-1.470	0.467	-1.472	0.467	-1.476	0.465	-1.435	0.470	-1.466	0.467	-1.435	0.469
		14	2	-0.540	0.229	-0.107	0.205	-0.109	0.204	-0.118	0.204	-0.079	0.204	-0.090	0.204	-0.076	0.204
		15	2	-0.251	0.170	0.041	0.164	0.030	0.163	0.030	0.163	0.069	0.163	0.046	0.163	0.070	0.163
		16	2	-0.144	0.145	0.136	0.142	0.138	0.141	0.116	0.141	0.124	0.141	0.151	0.141	0.124	0.140
		17	2	-0.729	0.202	-0.490	0.207	-0.483	0.207	-0.499	0.206	-0.494	0.206	-0.473	0.206	-0.495	0.206
		18	2	-0.504	0.181	-0.105	0.160	-0.107	0.159	-0.103	0.159	-0.085	0.159	-0.102	0.159	-0.087	0.159
		19	2	-0.330	0.181	-0.017	0.170	-0.022	0.169	-0.001	0.169	0.014	0.169	-0.017	0.169	0.013	0.169
		20	2	0.256	0.136	0.530	0.130	0.531	0.129	0.559	0.129	0.568	0.128	0.537	0.129	0.568	0.128
		21	2	-0.386	0.200	0.189	0.163	0.210	0.162	0.212	0.162	0.215	0.161	0.210	0.161	0.206	0.161
		22	2	-0.269	0.148	0.081	0.144	0.130	0.143	0.089	0.143	0.101	0.142	0.121	0.142	0.082	0.142
		23	2	0.646	0.099	0.953	0.093	1.005	0.091	0.971	0.091	1.005	0.089	0.986	0.090	0.984	0.088
		24	2	0.423	0.107	0.702	0.100	0.753	0.098	0.729	0.098	0.773	0.096	0.728	0.097	0.754	0.096
		25	2	0.202	0.125	0.463	0.119	0.514	0.117	0.502	0.117	0.548	0.115	0.483	0.116	0.530	0.115
		26	2	-0.457	0.208	-0.240	0.216	-0.182	0.217	-0.187	0.216	-0.148	0.217	-0.210	0.216	-0.163	0.216
		27	2					-0.221	0.258	-0.215	0.258	-0.177	0.260	-0.248	0.257	-0.189	0.259
pLnC[3]	**SCF: base capture rate, pre-1978 (=0.01)**	1	-2	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000
pLnC[4]	**SCF: base capture rate, 1992+**	1	2	-2.862	0.102	-3.428	0.123	-3.505	0.124	-3.526	0.122	-3.732	0.116	-3.557	0.113	-3.693	0.106
pS1[10]	**ascending z50 for SCF selectivity (males, pre-1997)**	1	2	87.648	1.558	113.170	2.039	113.617	1.991	115.440	1.911	113.499	1.864	113.489	1.947	113.866	1.836
pS1[11]	**ascending z50 for SCF selectivity (males, 1997-2004)**	1	2	95.647	3.832	94.504	3.036	94.623	3.059	95.940	3.096	95.758	3.008	94.609	2.975	95.734	2.961
pS1[12]	**ascending z50 for SCF selectivity (males, 2005+)**	1	2	105.452	1.410	105.556	1.188	105.657	1.180	106.572	1.149	106.295	1.103	105.846	1.165	106.315	1.097
pS1[13]	**ascending z50 for SCF selectivity (females, pre-1997)**	1	2	70.333	4.978	74.138	4.872	74.155	4.844	74.154	4.851	73.422	4.650	74.086	4.752	73.547	4.635
pS1[14]	**ascending z50 for SCF selectivity (females, 1997-2004)**	1	2	76.365	4.529	76.921	4.483	76.928	4.439	76.865	4.458	76.348	4.447	76.990	4.394	76.484	4.427
pS1[15]	**ascending z50 for SCF selectivity (females, 2005+)**	1	2	84.942	5.484	81.126	4.013	80.715	4.017	80.706	4.030	79.972	3.937	80.666	3.847	80.056	3.826
pS2[10]	**ascending slope for SCF selectivity (males, pre-1997)**	1	2	0.376	0.131	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000
pS2[11]	**ascending slope for SCF selectivity (males, 1997-2004)**	1	2	0.209	0.064	0.224	0.065	0.225	0.066	0.209	0.056	0.211	0.056	0.227	0.066	0.212	0.056
pS2[12]	**ascending slope for SCF selectivity (males, 2005+)**	1	2	0.175	0.015	0.182	0.013	0.181	0.013	0.180	0.013	0.182	0.013	0.180	0.013	0.182	0.013
pS2[13]	**slope for SCF selectivity (females, pre-1997)**	1	2	0.221	0.127	0.162	0.065	0.163	0.065	0.162	0.065	0.170	0.068	0.164	0.064	0.170	0.066
pS2[14]	**slope for SCF selectivity (females, 1997-2004)**	1	2	0.263	0.128	0.257	0.119	0.259	0.119	0.259	0.120	0.264	0.126	0.259	0.117	0.262	0.123
pS2[15]	**slope for SCF selectivity (females, 2005+)**	1	2	0.157	0.049	0.193	0.057	0.190	0.055	0.190	0.055	0.193	0.058	0.193	0.054	0.194	0.056
pS4[1]	**descending slope for SCF selectivity (males, pre-1997)**	1	2	0.500	0.001	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000
pS4[2]	**descending slope for SCF selectivity (males, 1997-2004)**	1	2	0.126	0.081	0.164	0.093	0.157	0.090	0.167	0.103	0.168	0.103	0.164	0.096	0.171	0.107
pS4[3]	**descending slope for SCF selectivity (males, 2005+)**	1	2	0.182	0.024	0.191	0.024	0.189	0.023	0.193	0.025	0.196	0.025	0.192	0.024	0.197	0.025

Table 31. Comparison of mean capture rate, ln-scale capture rate devs, and selectivity parameters estimates for the BBRKC fishery (RKF) for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	index	phase	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[4]	**RKF: female offset**	1	2	-0.834	3.018	-1.153	3.735	-1.278	3.713	-1.430	3.589	-1.832	2.062	-1.686	2.318	-1.950	1.864
pDevsLnC[4]	**RKF: 1992+**	1	2	0.845	0.275	0.565	0.191	0.548	0.190	0.522	0.189	0.466	0.185	0.548	0.190	0.474	0.185
		2	2	2.220	0.213	1.589	0.129	1.566	0.126	1.539	0.125	1.433	0.121	1.564	0.125	1.447	0.122
		3	2	-0.044	0.381	0.162	0.344	0.120	0.338	0.143	0.346	0.088	0.330	0.121	0.338	0.105	0.333
		4	2	0.010	0.396	0.294	0.425	0.260	0.418	0.268	0.424	0.282	0.421	0.265	0.419	0.287	0.424
		5	2	-0.012	0.392	0.256	0.425	0.227	0.419	0.236	0.424	0.255	0.424	0.233	0.421	0.258	0.426
		6	2	-0.028	0.389	0.219	0.419	0.194	0.415	0.202	0.419	0.222	0.419	0.200	0.417	0.224	0.421
		7	2	-0.035	0.387	0.195	0.412	0.173	0.409	0.179	0.412	0.196	0.412	0.178	0.411	0.197	0.413
		8	2	-0.052	0.381	0.145	0.398	0.129	0.397	0.128	0.397	0.145	0.397	0.135	0.398	0.145	0.398
		9	2	-0.060	0.376	0.098	0.379	0.089	0.380	0.082	0.378	0.106	0.381	0.095	0.382	0.106	0.382
		10	2	-0.083	0.368	0.027	0.361	0.019	0.362	0.015	0.361	0.041	0.364	0.024	0.363	0.041	0.365
		11	2	-0.126	0.355	-0.070	0.341	-0.069	0.343	-0.076	0.342	-0.053	0.344	-0.064	0.344	-0.053	0.344
		12	2	-0.161	0.345	-0.146	0.323	-0.140	0.326	-0.146	0.325	-0.128	0.326	-0.132	0.327	-0.127	0.326
		13	2	-0.218	0.333	-0.250	0.306	-0.236	0.310	-0.247	0.309	-0.233	0.309	-0.227	0.311	-0.233	0.309
		14	2	-0.229	0.326	-0.292	0.296	-0.280	0.299	-0.284	0.299	-0.278	0.299	-0.274	0.300	-0.277	0.299
		15	2	-0.125	0.319	-0.191	0.282	-0.167	0.287	-0.184	0.285	-0.195	0.282	-0.161	0.287	-0.195	0.282
		16	2	-0.236	0.314	-0.320	0.278	-0.295	0.282	-0.298	0.282	-0.306	0.280	-0.291	0.282	-0.306	0.280
		17	2	-0.280	0.318	-0.399	0.285	-0.385	0.288	-0.362	0.291	-0.361	0.290	-0.383	0.288	-0.360	0.290
		18	2	-0.239	0.328	-0.323	0.296	-0.312	0.299	-0.277	0.304	-0.274	0.304	-0.310	0.299	-0.272	0.304
		19	2	-0.196	0.336	-0.235	0.307	-0.221	0.310	-0.190	0.316	-0.189	0.314	-0.218	0.311	-0.188	0.314
		20	2	-0.189	0.329	-0.193	0.303	-0.160	0.309	-0.166	0.309	-0.174	0.306	-0.161	0.309	-0.181	0.305
		21	2	-0.139	0.311	-0.188	0.278	-0.125	0.288	-0.167	0.282	-0.175	0.280	-0.134	0.286	-0.188	0.278
		22	2	-0.233	0.307	-0.345	0.273	-0.280	0.281	-0.304	0.278	-0.302	0.277	-0.297	0.279	-0.312	0.276
		23	2	-0.221	0.314	-0.343	0.277	-0.280	0.285	-0.279	0.285	-0.266	0.286	-0.299	0.282	-0.274	0.285
		24	2	-0.168	0.327	-0.255	0.288	-0.193	0.296	-0.174	0.299	-0.156	0.301	-0.212	0.293	-0.164	0.299
		25	2					-0.183	0.313	-0.162	0.317	-0.145	0.319	-0.200	0.310	-0.152	0.318
pLnC[7]	**RKF: base capture rate, pre-1953 (=0.02)**	1	-2	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000
pLnC[8]	**RKF: base capture rate, 1992+**	1	2	-4.012	0.159	-3.595	0.117	-3.663	0.118	-3.626	0.120	-3.758	0.120	-3.665	0.115	-3.702	0.115
pS1[22]	**z95 for RKF selectivity (males, pre-1997)**	1	3	157.784	6.506	151.838	4.156	152.477	4.147	152.695	4.047	151.025	4.078	152.312	4.110	151.034	4.047
pS1[23]	**z95 for RKF selectivity (males, 1997-2004)**	1	3	180.000	0.005	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001
pS1[24]	**z95 for RKF selectivity (males, 2005+)**	1	3	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000
pS1[25]	**z95 for RKF selectivity (females, pre-1997)**	1	3	121.870	39.215	125.661	42.789	125.322	41.346	125.189	40.260	118.660	23.645	119.762	27.833	116.967	22.375
pS1[26]	**z95 for RKF selectivity (females, 1997-2004)**	1	3	122.103	56.686	123.545	50.295	124.984	56.212	125.454	57.613	121.229	48.066	120.998	50.369	119.121	45.518
pS1[27]	**z95 for RKF selectivity (females, 2005+)**	1	3	140.000	0.037	140.000	0.034	140.000	0.036	140.000	0.035	140.000	0.103	140.000	0.040	140.000	0.107
pS2[22]	**ln(z95-z50) for RKF selectivity (males, pre-1997)**	1	3	3.070	0.163	2.930	0.134	2.943	0.133	2.931	0.129	2.914	0.133	2.935	0.132	2.908	0.133
pS2[23]	**ln(z95-z50) for RKF selectivity (males, 1997-2004)**	1	3	3.550	0.086	3.458	0.074	3.452	0.074	3.439	0.072	3.433	0.072	3.447	0.073	3.431	0.071
pS2[24]	**ln(z95-z50) for RKF selectivity (males, 2005+)**	1	3	3.516	0.041	3.435	0.038	3.428	0.036	3.413	0.035	3.408	0.035	3.418	0.036	3.405	0.035
pS2[25]	**ln(z95-z50) for RKF selectivity (males, pre-1997)**	1	3	2.789	0.697	2.830	0.607	2.825	0.599	2.823	0.590	2.743	0.529	2.759	0.565	2.719	0.544
pS2[26]	**ln(z95-z50) for RKF selectivity (males, 1997-2004)**	1	3	2.859	0.909	2.866	0.781	2.883	0.795	2.892	0.799	2.865	0.860	2.849	0.872	2.840	0.895
pS2[27]	**ln(z95-z50) for RKF selectivity (males, 2005+)**	1	3	2.985	0.212	2.970	0.205	2.971	0.204	2.972	0.204	3.026	0.201	2.999	0.203	3.039	0.201

Table 32. Comparison of mean capture rate and selectivity parameters estimates for the groundfish fisheries (GTF).

		M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[3]	GTF: female offset	-0.957	0.072	-0.981	0.087	-1.081	0.079	-1.231	0.081	-1.002	0.083	-1.137	0.078	-1.048	0.082
pLnC[6]	GTF: base capture rate, ALL YEARS	-4.408	0.067	-4.611	0.073	-4.830	0.066	-4.804	0.068	-4.992	0.069	-4.843	0.060	-4.948	0.061
pS1[16]	z50 for GF.AllGear selectivity (males, pre-1987)	55.070	1.852	57.435	2.141	59.312	2.273	61.798	2.619	57.543	2.499	60.814	2.316	59.036	2.555
pS1[17]	z50 for GF.AllGear selectivity (males, 1987-1996)	59.005	4.849	60.873	6.670	68.343	6.466	78.079	6.766	68.399	5.326	71.569	6.318	70.533	5.218
pS1[18]	z50 for GF.AllGear selectivity (males, 1997+)	80.710	2.123	86.047	2.398	87.470	2.298	93.086	2.404	92.847	2.489	89.264	2.235	93.451	2.401
pS1[19]	z50 for GF.AllGear selectivity (males, pre-1987)	41.206	1.659	41.987	1.914	41.429	1.744	40.562	1.645	41.453	1.663	41.795	1.711	41.970	1.654
pS1[20]	z50 for GF.AllGear selectivity (males, 1987-1996)	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.002
pS1[21]	z50 for GF.AllGear selectivity (males, 1997+)	76.232	2.497	79.614	2.733	77.468	2.549	78.569	2.695	85.086	3.036	77.762	2.492	84.499	2.955
pS2[16]	slope for GF.AllGear selectivity (males, pre-1987)	0.104	0.010	0.094	0.009	0.088	0.008	0.084	0.008	0.093	0.010	0.087	0.008	0.091	0.009
pS2[17]	slope for GF.AllGear selectivity (males, 1987-1996)	0.057	0.012	0.049	0.013	0.041	0.007	0.037	0.005	0.046	0.007	0.040	0.006	0.046	0.006
pS2[18]	slope for GF.AllGear selectivity (males, 1997+)	0.075	0.004	0.069	0.004	0.067	0.003	0.063	0.003	0.061	0.003	0.068	0.003	0.062	0.003
pS2[19]	slope for GF.AllGear selectivity (females, pre-1987)	0.137	0.022	0.124	0.021	0.130	0.021	0.139	0.022	0.138	0.020	0.130	0.020	0.138	0.020
pS2[20]	slope for GF.AllGear selectivity (females, 1987-1996)	0.185	0.038	0.189	0.038	0.184	0.039	0.182	0.039	0.168	0.038	0.182	0.039	0.167	0.038
pS2[21]	slope for GF.AllGear selectivity (females, 1997+)	0.073	0.006	0.070	0.005	0.073	0.005	0.071	0.005	0.063	0.005	0.075	0.005	0.064	0.005

Table 33. Log-scale capture rate dev parameter estimates for the groundfish fisheries (GTF) for all model scenarios.

scenario:	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
year	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1973	1.312	0.098	1.352	0.099	1.524	0.092	1.496	0.097	1.428	0.097	1.519	0.091	1.397	0.097
1974	1.703	0.077	1.764	0.081	1.945	0.073	1.916	0.076	1.853	0.077	1.943	0.071	1.819	0.075
1975	0.856	0.072	0.924	0.077	1.110	0.069	1.081	0.071	1.036	0.072	1.111	0.066	1.002	0.069
1976	0.319	0.079	0.376	0.084	0.562	0.077	0.542	0.078	0.519	0.080	0.565	0.074	0.487	0.077
1977	0.009	0.100	0.033	0.104	0.217	0.098	0.210	0.099	0.203	0.100	0.223	0.097	0.175	0.098
1978	-0.254	0.130	-0.270	0.134	-0.085	0.130	-0.087	0.130	-0.070	0.131	-0.075	0.129	-0.094	0.130
1979	0.369	0.098	0.289	0.101	0.482	0.094	0.467	0.095	0.520	0.095	0.497	0.092	0.497	0.093
1980	-0.009	0.126	-0.094	0.126	0.099	0.121	0.063	0.121	0.132	0.121	0.115	0.120	0.118	0.120
1981	-0.201	0.158	-0.276	0.158	-0.103	0.156	-0.129	0.156	-0.058	0.156	-0.089	0.155	-0.059	0.156
1982	-0.969	0.353	-1.029	0.350	-0.893	0.357	-0.895	0.358	-0.836	0.361	-0.883	0.358	-0.826	0.362
1983	-0.418	0.302	-0.457	0.300	-0.328	0.303	-0.306	0.305	-0.260	0.306	-0.320	0.303	-0.239	0.307
1984	-0.203	0.326	-0.211	0.325	-0.093	0.329	-0.056	0.331	-0.030	0.334	-0.088	0.329	-0.001	0.336
1985	-0.615	0.425	-0.605	0.423	-0.495	0.434	-0.462	0.435	-0.452	0.446	-0.489	0.433	-0.432	0.450
1986	-0.461	0.321	-0.439	0.318	-0.308	0.323	-0.295	0.321	-0.254	0.331	-0.303	0.322	-0.243	0.332
1987	-0.659	0.319	-0.606	0.319	-0.421	0.325	-0.381	0.324	-0.363	0.329	-0.407	0.325	-0.356	0.330
1988	-1.066	0.363	-0.997	0.364	-0.818	0.375	-0.796	0.374	-0.769	0.379	-0.806	0.375	-0.768	0.380
1989	-0.874	0.295	-0.782	0.295	-0.594	0.300	-0.584	0.299	-0.560	0.301	-0.583	0.300	-0.562	0.301
1990	-0.532	0.231	-0.448	0.233	-0.250	0.235	-0.258	0.234	-0.252	0.233	-0.240	0.235	-0.254	0.233
1991	0.569	0.104	0.630	0.108	0.518	0.070	0.477	0.071	0.405	0.069	0.524	0.070	0.406	0.069
1992	0.869	0.097	0.893	0.101	0.798	0.067	0.752	0.069	0.666	0.066	0.803	0.067	0.670	0.066
1993	0.704	0.134	0.668	0.136	0.431	0.082	0.391	0.084	0.291	0.082	0.435	0.082	0.300	0.082
1994	1.168	0.117	1.072	0.120	0.952	0.071	0.927	0.073	0.821	0.071	0.956	0.071	0.833	0.071
1995	1.155	0.150	1.015	0.152	0.886	0.080	0.881	0.081	0.758	0.080	0.889	0.079	0.773	0.079
1996	1.440	0.145	1.287	0.147	1.002	0.083	1.012	0.084	0.877	0.083	1.006	0.082	0.896	0.082
1997	1.415	0.190	1.311	0.190	1.429	0.079	1.459	0.080	1.445	0.080	1.447	0.079	1.463	0.080
1998	1.186	0.252	1.110	0.250	1.321	0.089	1.360	0.090	1.348	0.089	1.340	0.089	1.367	0.089
1999	0.740	0.370	0.684	0.367	0.689	0.136	0.729	0.137	0.729	0.136	0.709	0.136	0.748	0.136
2000	0.816	0.308	0.785	0.312	0.674	0.127	0.711	0.128	0.729	0.127	0.694	0.127	0.747	0.127
2001	1.129	0.197	1.129	0.199	0.801	0.100	0.832	0.101	0.863	0.100	0.819	0.100	0.879	0.100
2002	0.455	0.304	0.459	0.308	0.073	0.159	0.104	0.160	0.140	0.160	0.088	0.159	0.155	0.159
2003	-0.162	0.418	-0.157	0.425	-0.318	0.190	-0.293	0.190	-0.267	0.190	-0.305	0.189	-0.253	0.190
2004	0.001	0.310	0.026	0.314	-0.011	0.127	0.003	0.128	0.025	0.127	-0.002	0.127	0.036	0.127
2005	-0.246	0.323	-0.213	0.327	-0.367	0.155	-0.359	0.156	-0.343	0.156	-0.361	0.155	-0.333	0.156
2006	-0.232	0.285	-0.204	0.288	-0.386	0.148	-0.385	0.149	-0.378	0.149	-0.383	0.148	-0.370	0.149
2007	-0.344	0.287	-0.316	0.290	-0.110	0.116	-0.116	0.116	-0.116	0.116	-0.112	0.115	-0.110	0.116
2008	-0.593	0.333	-0.572	0.337	-0.434	0.155	-0.440	0.155	-0.439	0.155	-0.441	0.154	-0.436	0.155
2009	-0.780	0.394	-0.776	0.398	-0.821	0.223	-0.817	0.223	-0.812	0.223	-0.834	0.222	-0.811	0.223
2010	-0.900	0.455	-0.904	0.459	-1.113	0.294	-1.101	0.294	-1.100	0.294	-1.125	0.293	-1.098	0.294
2011	-0.905	0.476	-0.895	0.482	-0.682	0.204	-0.667	0.205	-0.662	0.204	-0.696	0.204	-0.664	0.204
2012	-1.074	0.486	-1.032	0.495	-1.234	0.295	-1.232	0.295	-1.219	0.295	-1.251	0.294	-1.226	0.295
2013	-0.944	0.405	-0.877	0.413	-0.863	0.201	-0.881	0.201	-0.858	0.201	-0.888	0.200	-0.871	0.201
2014	-0.908	0.366	-0.850	0.371	-0.811	0.193	-0.841	0.194	-0.809	0.193	-0.844	0.193	-0.824	0.193
2015	-0.953	0.399	-0.922	0.401	-0.946	0.244	-0.974	0.244	-0.938	0.244	-0.985	0.243	-0.952	0.244
2016	-0.891	0.428	-0.873	0.430	-0.800	0.253	-0.818	0.253	-0.782	0.253	-0.843	0.252	-0.794	0.253
2017	-1.021	0.496	-1.003	0.499	-1.213	0.374	-1.222	0.375	-1.186	0.377	-1.259	0.371	-1.201	0.376
2018	0.000	0.000	0.000	0.000	-1.015	0.346	-1.019	0.347	-0.976	0.349	-1.071	0.343	-0.995	0.348

Table 34. (Unweighted) negative log-likelihoods and (weighted) objective function values for fishery-related data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries.

				NLLs					Objective function values				
fleet	catch.type	data.type	x	M19F01	M19F02	M19F03	M19F04	M19F05	M19F01	M19F02	M19F03	M19F04	M19F05
GTF	total catch	abundance	all sexes	0.15	0.15	0.16	0.15	0.16	2.99	3.03	3.19	3.04	3.23
		biomass	all sexes	1.24	1.28	1.48	1.26	1.49	24.71	25.60	29.69	25.11	29.78
		n.at.z	female	293.88	293.59	274.46	290.59	273.66	293.88	293.59	274.46	290.59	273.66
			male	288.00	294.90	285.09	291.02	287.46	288.00	294.90	285.09	291.02	287.46
RKF	total catch	abundance	female	21,939.76	25,053.62	28,472.19	18,960.49	30,238.99	0.00	0.00	0.00	0.00	0.00
			male	8,919.09	8,498.83	8,786.52	8,885.16	8,754.89	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.07	0.07	0.07
			male	1.20	1.23	1.36	1.22	1.36	23.99	24.60	27.22	24.34	27.28
		n.at.z	female	3.16	3.16	3.06	3.24	3.13	3.16	3.16	3.06	3.24	3.13
			male	75.34	72.80	74.43	75.72	75.27	75.34	72.80	74.43	75.72	75.27
SCF	total catch	abundance	female	267.01	271.11	367.66	280.76	363.74	0.00	0.00	0.00	0.00	0.00
			male	100.24	101.77	96.25	98.78	96.11	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.10	0.10	0.10	0.10	0.10	1.92	1.92	1.92	1.92	1.92
			male	1.12	1.04	0.89	1.12	0.89	22.35	20.89	17.75	22.37	17.76
		n.at.z	female	15.07	15.10	15.69	15.88	16.30	15.07	15.10	15.69	15.88	16.30
			male	133.09	129.50	124.76	132.85	125.92	133.09	129.50	124.76	132.85	125.92
TCF	retained cat	abundance	female	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			male	226.68	224.71	218.46	227.25	219.40	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			male	0.44	0.41	0.37	0.44	0.39	8.75	8.19	7.35	8.72	7.74
		n.at.z	male	54.24	54.37	51.98	54.69	52.92	54.24	54.37	51.98	54.69	52.92
	total catch	abundance	female	13,346.33	13,369.84	17,446.24	13,835.53	15,990.44	0.00	0.00	0.00	0.00	0.00
			male	10.78	10.19	9.31	10.65	9.37	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.53	0.50	0.50	0.53	0.50	10.63	10.07	9.96	10.65	9.92
			male	0.21	0.20	0.19	0.21	0.19	4.19	3.99	3.77	4.18	3.80
		n.at.z	female	18.19	18.11	18.16	17.86	17.97	18.19	18.11	18.16	17.86	17.97
			male	89.01	88.69	88.13	87.57	87.80	89.01	88.69	88.13	87.57	87.80

Table 35. (Unweighted) negative log-likelihoods and (weighted) objective function values for survey-related data components from the model scenarios. Rows consisting of all zero values indicate a data component which was not included in any of the models. Blank cells indicate a data component (row) that was not included in the associated scenario (column).

			NLLs					Objective function values				
fleet	catch.type	data.type	M19F01	M19F02	M19F03	M19F04	M19F05	M19F01	M19F02	M19F03	M19F04	M19F05
NMFS 0	index catch	abundance	838.19	792.09	757.00	818.86	748.14	0.00	0.00	0.00	0.00	0.00
		biomass	250.88	234.17	267.37	251.37	264.97	250.88	234.17	0.00	251.37	0.00
		n.at.z	991.65	982.94	1,126.75	993.77	1,135.21	991.65	982.94	0.00	993.77	0.00
NMFS F	index catch	abundance	388.10	372.88	329.04	383.67	328.60	0.00	0.00	0.00	0.00	0.00
		biomass	320.69	307.61	278.83	324.17	278.68	0.00	0.00	278.83	0.00	278.68
		n.at.z	336.03	338.50	343.70	334.71	347.17	0.00	0.00	343.70	0.00	347.17
NMFS M	index catch	abundance	289.94	261.72	240.01	280.35	234.33	0.00	0.00	0.00	0.00	0.00
		biomass	151.12	131.45	141.07	147.12	136.47	0.00	0.00	141.07	0.00	136.47
		n.at.z	465.57	460.96	449.00	466.11	455.33	0.00	0.00	449.00	0.00	455.33
SBS BSFRF females	index catch	abundance				9.12	7.70				0.00	0.00
		biomass				2.86	2.88				2.86	2.88
		n.at.z				45.54	45.09				45.54	45.09
SBS BSFRF males	index catch	abundance				10.44	8.65				0.00	0.00
		biomass				1.99	2.24				1.99	2.24
		n.at.z				48.87	48.93				48.87	48.93
SBS NMFS females	index catch	abundance				7.92	8.40				0.00	0.00
		biomass				9.72	9.86				9.72	9.86
		n.at.z				23.26	22.53				23.26	22.53
SBS NMFS males	index catch	abundance				2.91	3.76				0.00	0.00
		biomass				3.67	4.62				3.67	4.62
		n.at.z				30.00	30.15				30.00	30.15

Table 36. (Unweighted) negative log-likelihoods and (weighted) objective function values for fits to growth (molt increment) and male maturity ogive data components from the model scenarios.

	NLLs					objective function values				
category	M19F01	M19F02	M19F03	M19F04	M19F05	M19F01	M19F02	M19F03	M19F04	M19F05
growth data	493.63	524.81	539.86	490.63	540.15	493.63	524.81	539.86	490.63	540.15
maturity ogive data	215.21	116.53	95.42	210.40	95.61	0.00	116.53	95.42	0.00	95.61

Table 37. Root mean square errors (RMSE) for fishery-related data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries. Rows consisting of all zero values indicate a data component which was not included in any of the models.

fleet	catch.type	data.type	x	M19F01	M19F02	M19F03	M19F04	M19F05
GTF	total catch	**abundance**	all sexes	0.10	0.10	0.11	0.10	0.11
		biomass	all sexes	0.23	0.24	0.25	0.23	0.25
		n.at.z	female	371.61	384.39	388.75	372.54	391.04
			male	373.16	358.55	369.45	371.28	366.79
RKF	total catch	**abundance**	female	40.31	43.08	45.92	37.48	47.33
			male	25.70	25.09	25.51	25.65	25.47
		biomass	female	0.02	0.02	0.02	0.02	0.02
			male	0.30	0.30	0.32	0.30	0.32
		n.at.z	female	48.67	48.79	54.10	48.20	52.53
			male	56.41	56.51	55.96	56.25	55.74
SCF	total catch	**abundance**	female	4.29	4.32	5.04	4.40	5.01
			male	2.63	2.65	2.58	2.61	2.57
		biomass	female	0.08	0.08	0.08	0.08	0.08
			male	0.28	0.27	0.25	0.28	0.25
		n.at.z	female	54.82	55.60	54.83	50.76	51.28
			male	227.18	232.72	235.32	224.44	235.23
TCF	retained catch	**abundance**	female	0.00	0.00	0.00	0.00	0.00
			male	3.37	3.35	3.30	3.37	3.31
		biomass	female	0.00	0.00	0.00	0.00	0.00
			male	0.15	0.14	0.14	0.15	0.14
		n.at.z	male	355.25	367.67	384.72	354.36	381.60
	total catch	**abundance**	female	40.84	40.88	46.70	41.59	44.71
			male	1.16	1.13	1.08	1.15	1.08
		biomass	female	0.26	0.25	0.25	0.26	0.25
			male	0.16	0.16	0.15	0.16	0.15
		n.at.z	female	182.37	188.63	208.21	194.75	231.22
			male	499.38	511.41	513.56	514.17	520.01

Table 38. Average root mean square errors (RMSE) for survey-related data components from the model scenarios. Rows consisting of all zero values indicate a data component which was not included in any of the models. Blank cells indicate a data component (row) that was not included in the likelihood in the associated scenario (column).

fleet	catch.type	data.type	x	M19F01	M19F02	M19F03	M19F04	M19F05
NMFS 0	index catch	abundance	female	2.92	2.86	2.69	2.90	2.69
			male	3.12	2.99	3.05	3.06	3.02
		biomass	female	2.32	2.29	2.30	2.34	2.31
			male	2.40	2.27	2.56	2.38	2.54
		n.at.z	female	373.93	385.98	356.45	364.22	344.26
			male	487.07	499.49	490.64	477.53	480.54
NMFS F	index catch	abundance	female	2.92	2.86	2.69	2.90	2.69
			male	0.00	0.00	0.00	0.00	0.00
		biomass	female	2.65	2.60	2.48	2.66	2.48
			male	0.00	0.00	0.00	0.00	0.00
		n.at.z	female	125.86	125.69	136.02	125.48	133.02
NMFS M	index catch	abundance	female	0.00	0.00	0.00	0.00	0.00
			male	3.59	3.41	3.27	3.53	3.23
		biomass	female	0.00	0.00	0.00	0.00	0.00
			male	2.59	2.42	2.50	2.56	2.46
		n.at.z	male	195.51	188.89	185.98	192.03	183.02
SBS BSFRF females	index catch	abundance	female				1.31	1.23
			male				0.00	0.00
		biomass	female				0.76	0.75
			male				0.00	0.00
		n.at.z	female				44.41	46.72
SBS BSFRF males	index catch	abundance	female				0.00	0.00
			male				2.04	1.86
		biomass	female				0.00	0.00
			male				0.89	0.95
		n.at.z	male				191.47	198.80
SBS NMFS females	index catch	abundance	female				1.17	1.22
			male				0.00	0.00
		biomass	female				1.25	1.28
			male				0.00	0.00
		n.at.z	female				48.92	53.02
SBS NMFS males	index catch	abundance	female				0.00	0.00
			male				1.08	1.23
		biomass	female				0.00	0.00
			male				1.21	1.36
		n.at.z	male				316.65	303.44

Table 39. Root mean square errors (RMSE) for fits to growth (molt increment) and male maturity ogive data components from the model scenarios.

category	M19F01	M19F02	M19F03	M19F04	M19F05
growth data	0.42	0.42	0.43	0.42	0.43
maturity ogive data	2.51	1.92	1.77	2.48	1.80

Table 40. Effective sample sizes used for NMFS 0 EBS trawl survey size composition data for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach. Note that, while effective N's were calculated for this dataset in MF1903, it was not included in the model objective function (the weight in the likelihood was set to 0). Input sample sizes were set at 200.

Sum of val	Column Labels			Sum of val	Column Labels	
year	M19F00	M19F03		year	M19F00	M19F03
1975	700.312702	479.8666701		1996	1935.626324	1479.261951
1976	835.8906704	679.480725		1997	1891.598819	1523.133367
1977	874.9223597	775.5274286		1998	2046.203568	1345.547918
1978	892.441064	1415.818871		1999	1158.80325	1541.437445
1979	1130.270061	802.0601696		2000	1589.385175	2628.510003
1980	1441.838602	1103.810405		2001	2168.1765	1789.809452
1981	1138.908258	723.7818753		2002	1943.798287	2242.190544
1982	518.8477363	480.801695		2003	1488.112154	2703.663841
1983	1067.859284	866.8946961		2004	978.9173627	1103.316885
1984	572.9407661	790.9737623		2005	3262.607163	4249.657685
1985	326.2645986	386.0794348		2006	1505.176736	2452.948118
1986	676.7917083	818.0047904		2007	1294.785121	1506.294676
1987	789.3102243	1520.471983		2008	2318.550309	2770.433117
1988	1107.233577	1722.63342		2009	1414.661594	2372.096875
1989	2579.165029	1673.448147		2010	12011.00017	4232.237577
1990	2756.786708	2063.757876		2011	1806.553577	2278.879216
1991	3162.992353	1499.878515		2012	1476.147611	1820.248354
1992	2697.685485	2936.358538		2013	2662.685394	2493.220045
1993	1972.898268	1429.015184		2014	1191.826672	1135.930166
1994	1603.111983	1219.109801		2015	2445.230566	1933.403136
1995	1758.283681	1208.444231		2016	1168.110952	1004.934831
				2017	1151.365149	1026.282821
				2018	2277.011147	1905.751709
				2019		4102.775173

Table 41. Effective sample sizes used for retained catch size composition data from the directed fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00		M19F03	
year	effective N	input ss	effective N	input ss
1980	24.8	97.8	24.8	104.6
1981	1466.9	83.1	476.1	88.9
1982	1992.2	99.3	1097.8	106.2
1983	52.4	12.3	55.6	13.2
1984	426.3	18.7	203.8	20.0
1988	128.0	91.0	142.5	97.3
1989	1429.7	30.3	413.9	32.4
1990	256.1	200.0	242.1	200.0
1991	144.3	200.0	903.1	200.0
1992	99.0	200.0	313.2	200.0
1993	131.3	200.0	599.2	200.0
1994	145.3	200.0	273.7	200.0
1995	175.6	11.2	307.6	12.0
1996	172.8	32.6	1951.4	34.8
2005	14.4	5.2	18.3	5.5
2006	301.0	21.6	120.6	23.1
2007	1641.2	51.0	224.3	45.2
2008	972.8	25.6	402.8	27.4
2009	128.9	17.8	126.5	19.0
2013	770.9	35.0	581.1	35.8
2014	219.2	103.3	285.1	113.7
2015	164.3	200.0	263.6	190.3
2017	104.0	25.5	132.4	27.3
2018			73.8	26.0

Table 42. Effective sample sizes used for total catch size composition data from the directed fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1991	421.1	41.2	1343.4	200.0	245.5	44.0	499.5	200.0
1992	555.0	64.3	121.7	200.0	1450.9	68.8	363.3	200.0
1993	307.9	76.9	267.9	200.0	232.8	82.3	270.1	200.0
1994	62.7	15.7	549.0	42.6	81.4	16.7	1044.4	45.5
1995	100.7	22.9	310.4	41.1	136.0	24.5	285.2	43.9
1996	249.3	2.5	31.3	5.0	171.1	1.3	22.3	2.8
2005	41.7	8.1	99.4	144.9	48.2	8.7	118.1	154.9
2006	442.5	32.6	285.3	178.0	341.9	34.8	330.7	190.3
2007	302.4	24.4	394.4	200.0	231.5	26.1	560.6	200.0
2008	46.3	4.7	1149.5	200.0	45.1	5.1	1250.6	200.0
2009	23.6	1.1	162.5	127.0	21.5	1.2	168.1	135.8
2013	59.7	5.2	1475.0	127.0	44.7	5.6	2528.6	135.8
2014	175.6	8.8	210.5	200.0	126.6	9.4	248.3	200.0
2015	75.3	11.9	133.0	200.0	81.9	12.8	189.4	200.0
2017	52.1	12.6	168.4	138.0	58.5	13.5	243.4	147.6
2018					13.7	16.0	94.3	200.0

Table 43. Effective sample sizes used for bycatch size composition data from the snow crab fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1990					38.9	3.8	42.9	110.2
1991					22.7	5.4	86.1	92.0
1992	18.3	6.3	186.3	46.1	24.0	6.7	29.7	49.3
1993	30.7	11.3	117.4	51.2	38.0	12.1	28.6	54.7
1994	40.7	11.2	37.3	21.9	30.0	12.0	13.9	23.4
1995	42.1	3.1	86.7	13.9	40.5	3.4	26.2	14.9
1996	46.2	4.9	289.1	24.0	73.2	5.2	104.5	25.6
1997	111.8	4.8	449.8	29.2	106.4	5.2	390.0	31.2
1998	21.5	2.4	1131.3	14.0	21.7	2.5	546.4	15.0
1999	30.3	0.6	132.8	7.2	32.1	0.6	128.9	7.7
2000	30.6	0.5	285.3	9.1	34.3	0.6	253.4	9.7
2001	121.8	1.2	565.8	22.9	132.8	1.3	436.8	24.5
2002	45.6	0.9	59.8	7.2	47.2	0.9	66.1	7.7
2003	45.1	1.1	110.1	5.1	45.7	1.2	130.5	5.4
2004	30.7	5.2	23.1	6.2	30.5	5.6	23.7	6.5
2005	154.2	2.7	123.0	72.0	75.2	2.9	134.4	77.0
2006	49.9	9.2	76.5	76.4	30.4	9.9	77.1	81.6
2007	44.2	5.3	384.9	101.4	27.3	5.7	421.7	108.4
2008	15.0	5.3	97.0	62.1	20.2	5.7	102.0	66.4
2009	21.2	3.5	470.9	81.2	33.1	3.7	449.5	86.9
2010	76.4	1.8	382.8	88.7	91.7	2.0	279.0	94.8
2011	62.1	1.4	228.2	69.5	58.9	1.5	183.2	74.3
2012	47.3	1.4	209.1	53.9	78.5	2.1	153.3	86.4
2013	203.9	2.6	248.0	95.0	117.9	2.8	216.7	101.6
2014	67.5	5.9	532.0	182.8	141.0	6.3	402.6	195.4
2015	107.8	1.7	520.2	146.5	56.6	1.8	354.9	155.9
2016	112.9	1.7	468.7	142.8	28.9	2.1	844.4	128.6
2017	63.6	0.8	709.0	41.1	96.2	0.9	491.4	44.0
2018					16.2	1.8	406.7	48.3

Table 44. Effective sample sizes used for bycatch size composition data from the BBRKC fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03. Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1990					42.5	0.3	12.6	12.4
1991					91.0	0.7	16.0	17.9
1992	83.1	0.8	33.2	15.1	82.5	0.8	23.1	16.2
1993	275.0	8.8	32.9	54.1	319.6	9.4	24.5	57.8
1996	3.4	0.0	12.6	0.8				
1997	25.2	0.3	19.6	7.6	27.8	0.3	27.4	8.1
1998	21.0	0.1	55.7	3.4	21.6	0.2	83.0	3.6
1999	17.5	0.1	51.2	1.5	18.3	0.1	41.9	1.6
2000	40.5	0.3	134.6	6.2	41.1	0.3	92.2	6.6
2001	51.1	0.3	113.6	3.4	50.0	0.3	69.8	3.6
2002	35.5	0.4	87.3	5.5	36.7	0.4	60.3	5.9
2003	53.3	0.3	58.2	4.1	52.7	0.4	42.5	4.4
2004	20.3	0.3	31.5	3.6	21.0	0.3	24.4	3.8
2005	12.6	0.5	44.3	7.2	14.1	0.6	34.5	7.7
2006	23.8	0.6	22.6	5.9	28.4	0.5	19.0	5.9
2007	102.5	0.7	91.4	10.3	91.7	0.7	71.7	10.7
2008	91.8	0.9	62.5	27.9	108.5	1.0	81.2	29.8
2009	109.0	0.5	19.3	24.9	116.8	0.6	22.5	22.6
2010	35.9	0.2	51.3	4.4	52.2	0.2	43.1	4.6
2011	6.0	0.0	68.6	2.5	5.8	0.0	50.9	2.5
2012	6.9	0.4	66.0	4.5	7.2	0.4	48.6	4.9
2013	9.7	0.4	86.1	15.5	9.6	0.5	110.8	16.6
2014	19.3	0.2	155.1	22.9	19.8	0.3	169.1	24.4
2015	86.3	1.3	195.1	16.1	89.9	1.5	119.9	17.1
2016	18.9	1.8	25.1	22.5	19.6	1.9	21.4	25.3
2017	34.0	0.6	76.0	27.8	32.7	0.7	55.7	29.7
2018					5.5	0.0	89.1	10.1

Table 45. Effective sample sizes used for bycatch size composition data from the groundfish fisheries for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1973	226.8	39.9	357.5	39.9	220.4	39.9	269.0	39.9
1974	209.7	30.1	726.4	30.1	220.2	30.1	470.6	30.1
1975	195.0	15.4	334.1	15.4	230.7	15.4	254.9	15.4
1976	107.3	100.2	178.4	100.2	114.1	100.2	125.7	100.2
1977	327.3	140.1	233.1	140.1	312.4	140.1	210.2	140.1
1978	193.1	237.1	249.6	237.1	175.7	237.1	239.9	237.1
1979	889.5	223.5	594.2	223.5	776.5	223.5	763.7	223.5
1980	419.3	137.6	1045.8	137.6	817.6	137.6	704.2	137.6
1981	56.1	74.7	1050.0	74.7	67.3	74.7	791.0	74.7
1982	62.1	157.6	529.6	157.6	90.6	157.6	509.7	157.6
1983	134.6	196.0	345.6	196.0	293.9	196.0	401.5	196.0
1984	235.0	301.2	354.6	301.2	482.9	301.2	679.8	301.2
1985	278.0	263.5	169.9	263.5	274.3	263.5	239.7	263.5
1986	193.5	165.2	281.7	165.2	155.0	165.2	405.1	165.2
1987	671.1	289.3	266.3	289.3	718.7	289.3	282.6	289.3
1988	224.1	130.2	404.9	130.2	218.5	130.2	339.5	130.2
1989	595.1	400.0	810.5	400.0	906.0	400.0	747.2	400.0
1990	308.5	255.4	997.0	255.4	349.5	255.4	953.5	255.4
1991	186.1	75.7	330.4	75.7	213.5	80.9	316.1	80.9
1992	63.6	31.6	177.7	31.6	68.4	33.8	166.4	33.8
1993	93.8	11.6	77.8	11.6	108.2	12.4	72.8	12.4
1994	429.9	40.0	238.3	40.0	442.7	42.8	236.5	42.8
1995	60.2	48.3	58.2	48.3	65.5	51.6	52.2	51.6
1996	597.2	86.0	176.8	86.0	512.7	92.0	158.0	92.0
1997	184.6	101.8	49.5	101.8	137.2	108.8	43.0	108.8
1998	303.0	121.6	119.1	121.6	182.3	130.0	93.1	130.0
1999	1011.6	114.4	441.8	114.4	569.3	122.4	288.5	122.4
2000	899.8	117.4	556.9	117.4	638.7	125.6	338.9	125.6
2001	1246.6	138.7	775.7	138.7	1297.3	148.2	523.1	148.2
2002	891.3	137.0	429.6	137.0	736.2	146.5	391.5	146.5
2003	300.1	90.4	196.9	90.4	307.9	96.7	196.2	96.7
2004	30.3	134.5	110.2	134.5	32.8	143.8	119.3	143.8
2005	1814.9	157.9	1545.9	157.9	1652.0	168.9	1226.6	168.9
2006	134.6	139.2	182.0	139.2	151.8	148.9	197.8	148.9
2007	106.0	146.7	187.6	146.7	117.7	156.9	199.2	156.9
2008	164.5	223.4	184.2	223.4	182.4	233.3	172.7	233.3
2009	536.6	160.0	313.3	160.0	524.9	171.1	345.8	171.1
2010	2097.5	127.9	628.5	127.9	1362.2	136.7	719.2	136.7
2011	66.8	149.6	83.2	149.6	61.7	160.0	71.3	160.0
2012	102.6	118.1	412.4	118.1	112.1	126.2	426.6	126.2
2013	433.7	244.6	359.5	244.6	567.0	247.6	314.9	247.6
2014	794.9	231.0	1037.7	231.0	741.6	233.1	1105.9	233.1
2015	203.2	242.1	219.3	242.1	250.8	245.1	232.4	245.1
2016	56.9	166.2	229.2	166.2	57.4	177.6	244.0	177.6
2017	173.8	98.6	80.6	98.6	149.8	108.2	75.1	108.2
2018					214.1	64.7	279.5	64.7

Table 46. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

	M19F00				M19F03			
	female		male		female		male	
year	observed	predicted	observed	predicted	observed	predicted	observed	predicted
1975	72.4	102.8	540.9	333.2	72.4	91.5	540.9	381.9
1976	68.7	91.6	283.3	295.7	68.7	80.3	283.3	328.2
1977	91.6	82.8	249.8	241.9	91.6	70.6	249.8	261.2
1978	58.3	80.2	176.2	192.1	58.3	64.8	176.2	201.2
1979	42.5	84.2	82.7	183.6	42.5	65.2	82.7	187.0
1980	141.1	87.3	239.3	186.2	141.1	68.5	239.3	201.0
1981	86.7	77.5	130.2	156.7	86.7	56.4	130.2	180.4
1982	130.0	56.1	117.5	160.0	130.0	43.7	117.5	161.6
1983	43.1	43.9	67.9	117.2	43.1	31.7	67.9	120.2
1984	32.1	35.4	56.3	83.5	32.1	23.8	56.3	85.0
1985	12.1	31.4	26.8	65.2	12.1	20.5	26.8	65.0
1986	9.4	33.5	34.9	81.9	9.4	23.9	34.9	77.6
1987	25.3	38.0	70.1	108.6	25.3	28.7	70.1	98.2
1988	60.9	42.4	160.2	139.6	60.9	33.5	160.2	122.5
1989	50.6	45.6	226.1	165.9	50.6	37.0	226.1	143.3
1990	85.2	46.2	230.3	172.2	85.2	38.8	230.3	151.2
1991	96.5	43.5	258.4	153.9	96.5	38.0	258.4	144.0
1992	54.4	37.7	233.1	132.8	54.4	34.5	233.1	134.1
1993	24.3	30.1	135.3	99.0	24.3	29.0	135.3	108.8
1994	20.9	23.2	92.2	72.9	20.9	23.3	92.2	86.7
1995	25.8	17.9	67.7	53.9	25.8	18.6	67.7	67.4
1996	20.6	14.1	58.3	40.7	20.6	15.1	58.3	53.3
1997	8.2	11.8	25.9	34.7	8.2	13.0	25.9	44.9
1998	6.5	10.5	25.9	32.0	6.5	11.7	25.9	40.0
1999	10.5	10.4	34.5	32.2	10.5	11.6	34.5	39.4
2000	10.7	11.0	40.2	35.9	10.7	12.2	40.2	42.1
2001	15.4	12.7	47.9	43.4	15.4	13.9	47.9	48.3
2002	14.4	14.4	46.4	51.8	14.4	15.7	46.4	56.3
2003	21.5	17.0	62.4	62.7	21.5	18.7	62.4	67.7
2004	13.5	20.2	65.9	77.0	13.5	22.3	65.9	82.4
2005	33.5	22.7	108.9	92.9	33.5	25.3	108.9	98.7
2006	43.1	24.5	169.4	106.8	43.1	27.9	169.4	114.2
2007	32.5	25.5	173.7	117.0	32.5	29.4	173.7	127.1
2008	26.2	24.6	150.0	124.6	26.2	28.8	150.0	135.2
2009	19.5	22.9	85.6	122.2	19.5	27.0	85.6	130.3
2010	14.7	21.8	88.1	110.2	14.7	25.3	88.1	115.4
2011	21.2	22.4	105.9	101.8	21.2	25.2	105.9	104.6
2012	36.4	25.5	122.3	105.2	36.4	27.8	122.3	107.7
2013	42.1	29.4	170.4	126.9	42.1	31.5	170.4	128.6
2014	32.2	30.1	191.3	150.1	32.2	32.2	191.3	148.9
2015	24.1	26.9	137.2	144.4	24.1	29.0	137.2	142.2
2016	16.4	22.5	131.2	118.1	16.4	24.4	131.2	116.2
2017	15.6	19.8	104.5	102.7	15.6	20.9	104.5	97.4
2018	14.9	19.0	86.8	90.4	14.9	19.0	86.8	82.8
2019					14.6	19.7	48.8	75.0

Table 47. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

	M19F00		M19F03				M19F00		M19F03	
year	female	male	female	male		year	female	male	female	male
1948	0	0	0	0		1981	62.61178291	75.56595728	82.26932357	131.5457245
1949	0	0	0	0		1982	51.87527796	70.87388133	63.4376148	120.0710505
1950	0.029290529	0.010148921	0.052876667	0.032672463		1983	39.72084346	54.03546272	44.82566346	91.63937955
1951	0.248247159	0.137859662	0.426265689	0.358680293		1984	29.98144143	35.0648082	31.06340546	60.86077393
1952	1.009797269	0.996117696	1.729951628	2.05994497		1985	25.60570341	33.03218917	27.90313734	55.15366568
1953	2.27389353	3.799354119	4.034889901	6.798217159		1986	26.02824674	39.80612176	31.91702343	64.05134402
1954	3.530051511	8.111411502	6.516424806	13.71206184		1987	29.57524959	52.15248396	39.27885587	80.65351304
1955	4.505292273	11.95069256	8.572618804	19.91123245		1988	34.25326965	69.06617841	47.76469389	102.1912584
1956	5.23017135	14.86119389	10.17885791	24.64490259		1989	38.49425689	75.18367028	55.51587713	112.8729649
1957	5.78636166	17.08319575	11.47760673	28.32425004		1990	40.93261177	69.26230859	61.27541543	111.8311327
1958	6.245965522	18.83845512	12.60903413	31.34932668		1991	40.45010837	66.70096787	63.29311168	116.5835973
1959	6.678762971	20.34192753	13.71131601	34.10406971		1992	36.03354495	57.41112499	59.78533715	108.7895289
1960	7.166650145	21.80054365	14.95040896	36.96211501		1993	29.65188903	49.3061425	51.56526726	100.0945072
1961	7.836129047	23.456348	16.58795884	40.38361165		1994	23.0563003	39.76180942	41.6729754	83.5553754
1962	8.952929857	25.7583941	19.17276358	45.27954043		1995	17.59936166	29.9848262	32.93880923	65.64733696
1963	11.20855208	29.68301023	24.08692299	53.71943121		1996	13.60743973	24.14996006	26.2383916	52.55986347
1964	16.36886723	37.82739217	34.63784649	71.00574611		1997	10.89988773	20.4377007	21.53158493	43.25608304
1965	27.65874111	55.00374857	56.44912529	107.3336525		1998	9.235893888	18.20281208	18.67026921	37.79694288
1966	47.58206403	93.89734099	93.53874708	180.1369655		1999	8.542129551	17.98680288	17.4372762	36.17624799
1967	72.62268113	148.279836	139.8721418	279.6484942		2000	8.83666402	19.51660887	17.74578088	37.62178453
1968	93.82954052	214.5323711	180.3751698	388.7986146		2001	9.692410669	23.12988283	19.18716563	42.12837696
1969	104.9105219	255.7631836	203.5673987	456.8869593		2002	11.02624145	28.07170871	21.7207241	49.14444027
1970	107.109204	271.41282	210.1384986	481.6364664		2003	12.9610676	34.12756344	25.48135684	58.66512211
1971	105.2731072	271.6575832	207.2362958	478.9748353		2004	15.62280239	42.27234237	30.63971212	71.66628579
1972	103.0811121	267.6417929	200.5408889	464.2391531		2005	18.32526828	51.63285385	36.34643336	86.95724602
1973	100.1838676	261.581255	190.297984	440.9478977		2006	20.8324607	60.09081306	42.1541279	102.2607715
1974	95.18617647	246.8464928	175.7955327	402.2135648		2007	23.30097298	67.36561163	47.78906901	116.9103724
1975	87.98656329	230.3186616	158.2999936	358.4925464		2008	23.64643945	76.38178815	49.26304162	130.6858117
1976	77.82978018	188.5578534	137.8142501	289.4207129		2009	21.09129729	76.86605777	44.74294322	128.1643334
1977	67.70984017	130.9737959	118.1804075	209.8222867		2010	17.86953558	68.49052925	38.25400266	111.6231267
1978	63.0060915	96.16056729	106.342965	163.6950948		2011	16.63246429	59.23689734	35.08159051	95.47813585
1979	65.72347908	74.32736881	107.0998424	142.6686239		2012	19.85647861	57.81165696	39.75256727	94.20587388
1980	67.71303871	70.16135116	98.82641083	131.1216495		2013	25.76424691	70.26742291	49.64969507	114.7756218
						2014	28.58151286	83.75361085	54.83740078	135.7892866
						2015	26.38078068	82.0122724	51.08625555	131.8573143
						2016	22.15777388	75.99847076	43.11401688	117.1288802
						2017	18.40263189	64.09196727	35.57943126	96.36555861
						2018			29.66231471	79.45494853

Table 48. Estimated population size (millions) for females on July 1 of year. from the author's preferred model, Model M19F03.
<<Table too large: available online in the zip file "TannerCrab.PopSizeStructure.csvs.zip".>>

Table 49. Estimated population size (millions) for males on July 1 of year. from the author's preferred mode, Model M19F03.
<<Table too large: available online as a zipped csv file "TannerCrab.PopSizeStructure.csvs.zip".>>

Table 50. Comparison of estimates of recruitment (in millions) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

year	M19F00	M19F03	year	M19F00	M19F03
1948	70.09251687	132.6537449	1981	101.416713	229.8722417
1949	70.09557738	133.2203853	1982	496.0095549	690.0962537
1950	70.19921793	134.4944439	1983	408.5677129	627.3626472
1951	70.53781202	136.6898133	1984	550.0166431	767.3734676
1952	71.30143949	140.1373441	1985	529.7681206	764.4249404
1953	72.76979101	145.363002	1986	525.8487112	796.315064
1954	75.37788738	153.237184	1987	356.0941501	595.7349193
1955	79.85259349	165.2823008	1988	171.1538503	249.3996718
1956	87.52520379	184.3743392	1989	52.28767878	78.81849366
1957	101.1405733	216.5609486	1990	41.82858297	71.27724516
1958	127.3271887	276.6196651	1991	37.02824035	73.65268281
1959	185.5896413	407.587403	1992	36.8859791	67.27971079
1960	339.6142312	742.4221286	1993	48.32235441	84.32008419
1961	757.2893156	1588.034161	1994	62.36311147	143.7247786
1962	1462.061345	2839.791915	1995	57.94345627	107.5877226
1963	1736.132801	3206.061429	1996	168.9628999	304.259962
1964	1452.379666	2674.087231	1997	67.82772625	127.2116239
1965	1131.170889	2117.061574	1998	227.5701775	450.4022196
1966	963.730419	1816.266851	1999	118.091505	221.0847323
1967	943.2576586	1724.0517	2000	385.0604766	754.1423021
1968	1008.697227	1669.653411	2001	123.1097967	231.3054485
1969	980.6227068	1442.516104	2002	372.6665098	829.6787085
1970	843.9469644	1165.600708	2003	362.1799899	687.2774432
1971	561.9043515	778.2159348	2004	97.11673458	185.9225205
1972	369.6842268	524.6240813	2005	74.45238686	127.3120944
1973	318.0087047	510.3866376	2006	57.8718913	111.1939148
1974	641.4445935	705.3119393	2007	88.82972036	179.0548001
1975	1257.959539	2031.682265	2008	576.7044896	1138.228615
1976	971.5504765	1529.970097	2009	501.346918	870.3214169
1977	424.9897994	761.2503091	2010	200.9415568	301.1484309
1978	180.9087231	276.9401217	2011	40.77585148	62.70194572
1979	110.113046	166.2250105	2012	108.9237585	173.4310903
1980	180.4735272	265.6626468	2013	73.93881264	106.9458916
			2014	49.09325854	79.9499305
			2015	69.72714155	117.3112392
			2016	444.7192575	647.0591576
			2017	588.8895622	677.6176162
			2018		1234.937393

Table 51. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

year	M19F00	M19F03	year	M19F00	M19F03
1949	0.001622787	0.000851594	1981	0.046786646	0.026757506
1950	0.002688423	0.001373949	1982	0.025203452	0.014146239
1951	0.004152346	0.00210409	1983	0.013099622	0.007026487
1952	0.006247527	0.003273033	1984	0.026017138	0.015184677
1953	0.009322445	0.00529258	1985	0.015433162	0.005593393
1954	0.01260007	0.007679072	1986	0.019326482	0.007141423
1955	0.014753304	0.009385377	1987	0.031682959	0.013068075
1956	0.015980555	0.010368409	1988	0.040555945	0.020050353
1957	0.016287354	0.010527445	1989	0.091529287	0.054189398
1958	0.016548995	0.010701976	1990	0.152834055	0.091491752
1959	0.016393883	0.0105286	1991	0.14575004	0.075020873
1960	0.01602232	0.010226125	1992	0.173127894	0.095630499
1961	0.015550666	0.009976282	1993	0.130835171	0.054998198
1962	0.014008919	0.009008863	1994	0.098005158	0.038802861
1963	0.01190419	0.007751795	1995	0.085254294	0.031793233
1964	0.010409007	0.006771504	1996	0.047280956	0.019457438
1965	0.015993162	0.009020895	1997	0.033563022	0.01697017
1966	0.015931948	0.009115647	1998	0.031137612	0.01149889
1967	0.043643679	0.025403963	1999	0.01512733	0.005898124
1968	0.048268751	0.028737808	2000	0.012987827	0.006044593
1969	0.063683821	0.038160681	2001	0.016821106	0.006725774
1970	0.059569187	0.035828691	2002	0.010714727	0.003631334
1971	0.050880748	0.030686751	2003	0.006018027	0.002625986
1972	0.045502754	0.028496504	2004	0.006466766	0.003153082
1973	0.055554121	0.035566735	2005	0.012287384	0.006120349
1974	0.074143668	0.048631197	2006	0.018752949	0.008653291
1975	0.064643017	0.04403133	2007	0.020865591	0.010646254
1976	0.100923862	0.070635583	2008	0.014201418	0.007946933
1977	0.140735249	0.098008396	2009	0.012001593	0.006769104
1978	0.118938682	0.075778039	2010	0.006272852	0.00328305
1979	0.152736347	0.085590706	2011	0.007820264	0.004469626
1980	0.093896849	0.05814116	2012	0.004964941	0.00300838
			2013	0.015086706	0.008840832
			2014	0.052987808	0.031389129
			2015	0.072375017	0.044605374
			2016	0.009963209	0.005834419
			2017	0.020021174	0.010205414
			2018		0.01100967

Table 52. 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. Results from the author's preferred model (M19F03) are highlighted in green.

Model Scenario	average recruitment millions	Final MMB 1000's t	B0 1000's t	Bmsy 1000's t	Fmsy	MSY 1000's t	Fofl	OFL 1000's t	projected MMB 1000's t	projected MMB / Bmsy
M19F00	223.63	66.64	86.55	30.29	0.74	12.75	0.74	20.87	35.95	1.19
M19F00a	284.28	82.05	94.24	32.99	0.89	14.58	0.89	27.90	41.52	1.26
M19F01	316.79	68.79	100.85	35.30	0.81	15.58	0.81	22.54	35.66	1.01
M19F02	367.48	71.54	105.59	36.96	1.11	17.89	1.03	24.75	34.63	0.94
M19F03	393.84	82.61	118.96	41.64	1.18	19.49	1.12	29.48	39.68	0.95
M19F04	377.28	74.03	106.76	37.37	0.87	16.87	0.87	24.87	37.50	1.00
M19F05	418.73	80.33	116.44	40.75	1.21	19.40	1.14	28.58	38.42	0.94

Figures

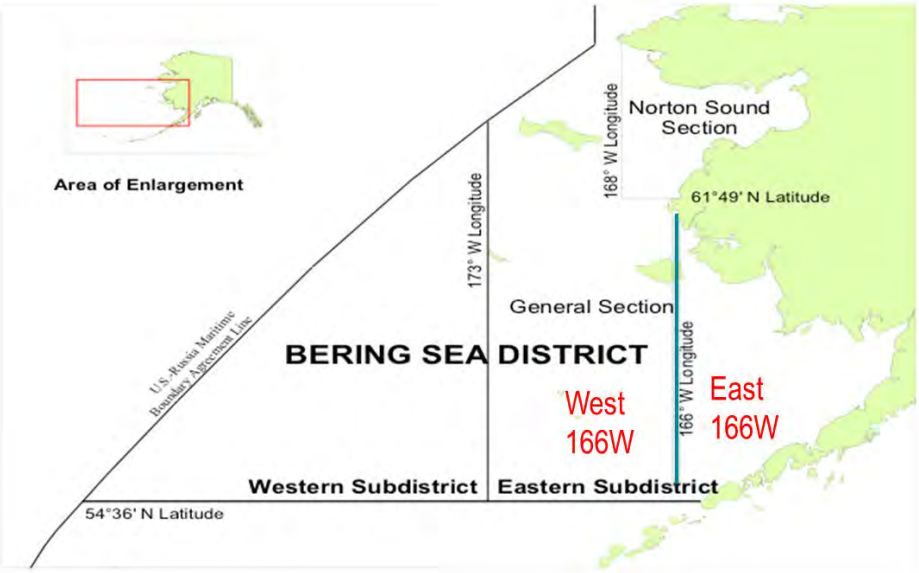


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

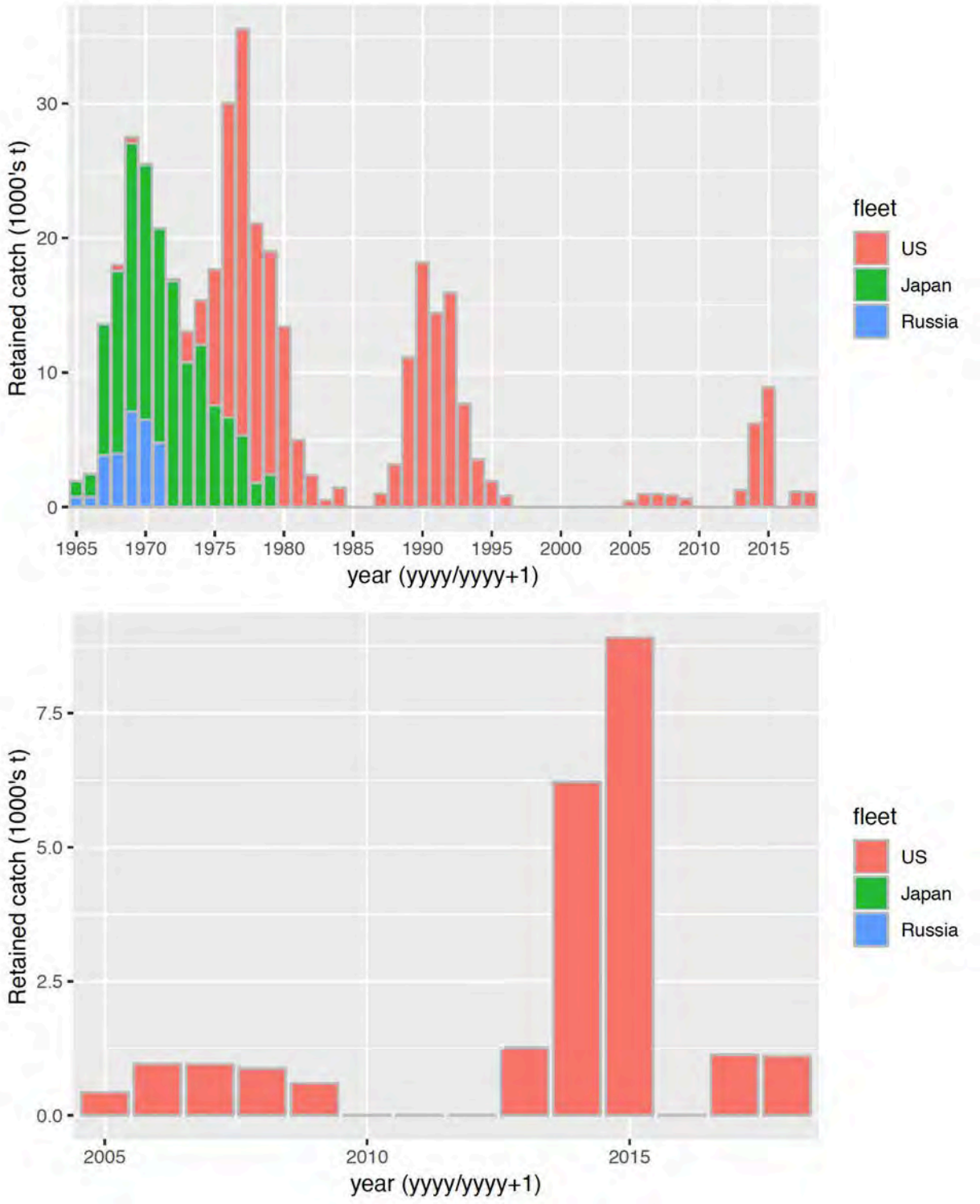


Figure 2. Upper: retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The directed fishery was closed from 1996/97 to 2004/05, from 2010/11 to 2012/13, and in 2016/17.

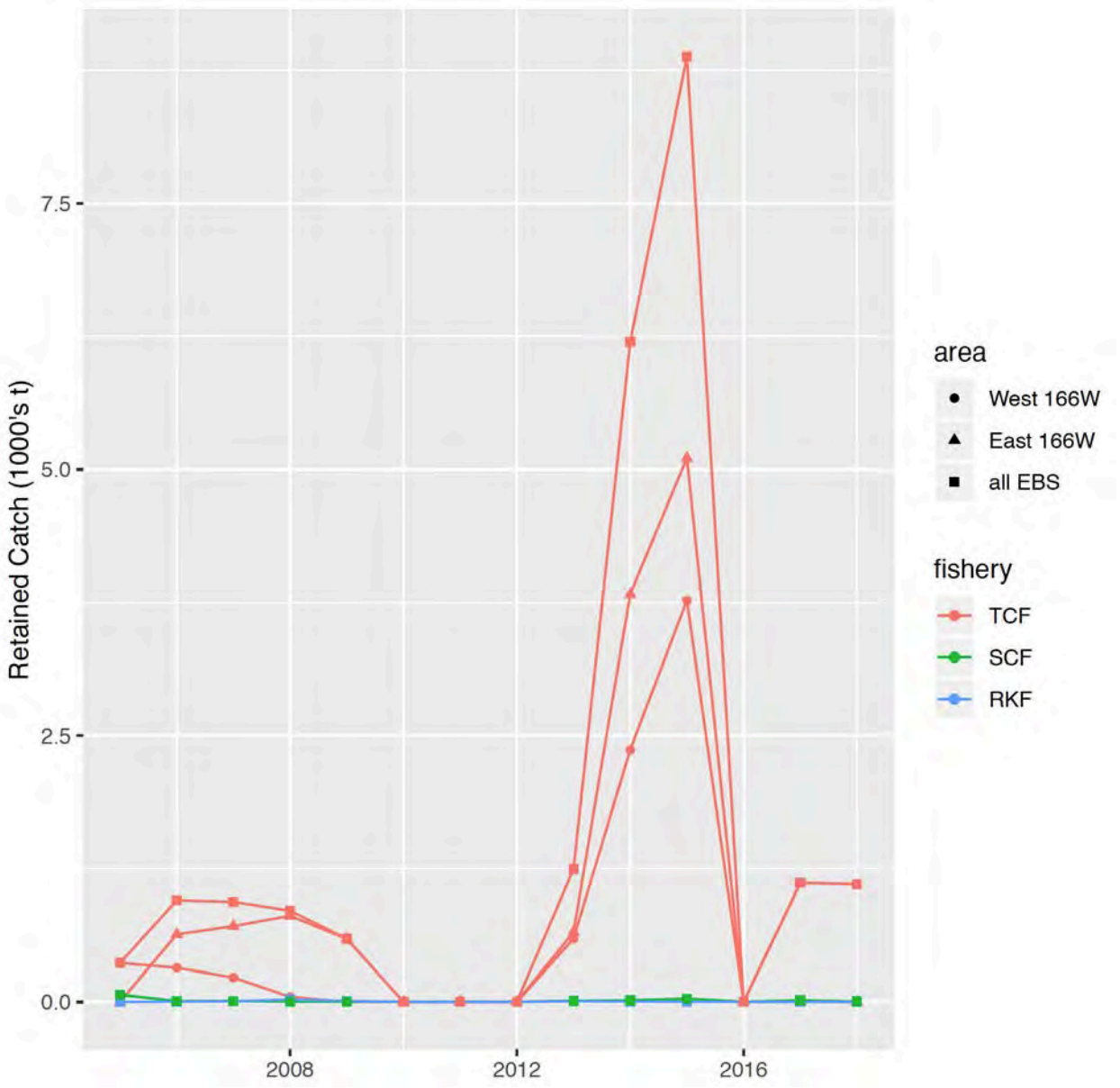


Figure 3. Time series of retained catch biomass (1000's t) in the directed Tanner crab (TCF: red; eastern area: triangles; western area: circles; all EBS: squares), snow crab (SCF: green), and BBRKC (RFF: blue) fisheries since 2005. The directed fishery was closed from 2010/11 to 2012/13, and in 2016/17. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch.

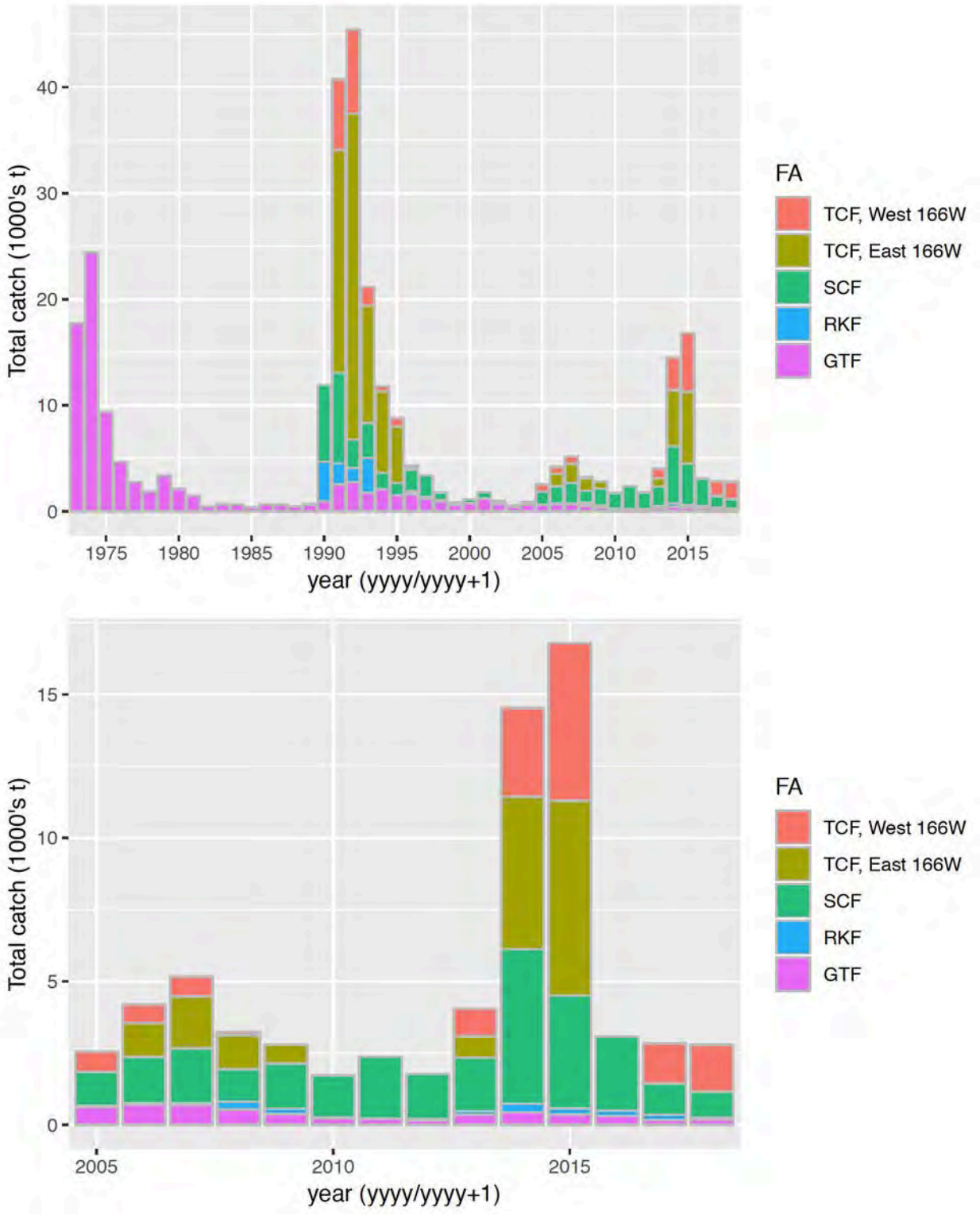


Figure 4. Upper: total catch (retained + discards) of Tanner crab (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Bycatch reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries. Lower: detail since 2005.

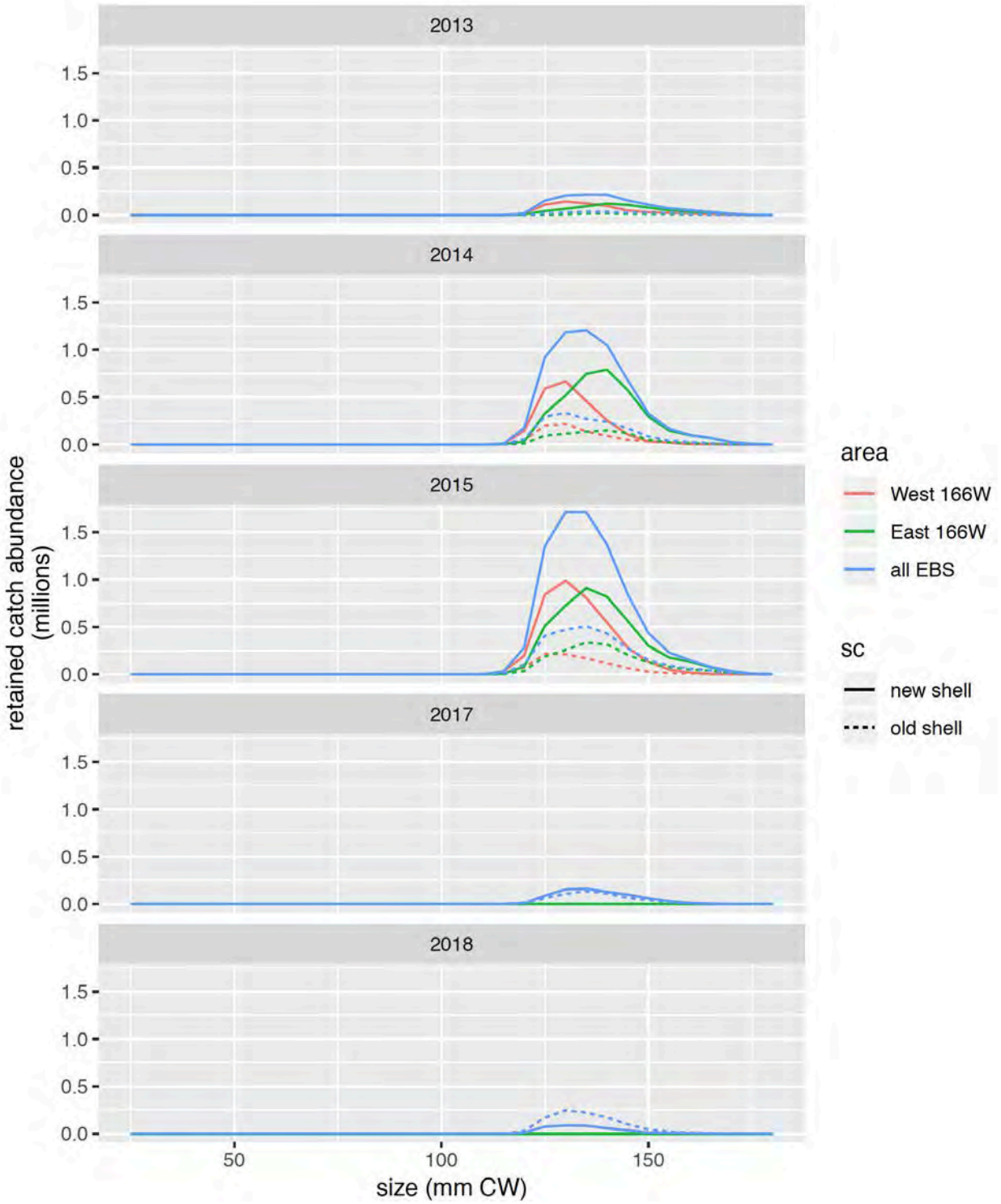


Figure 5. Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14 (red: western area, green: eastern area; blue: all EBS).

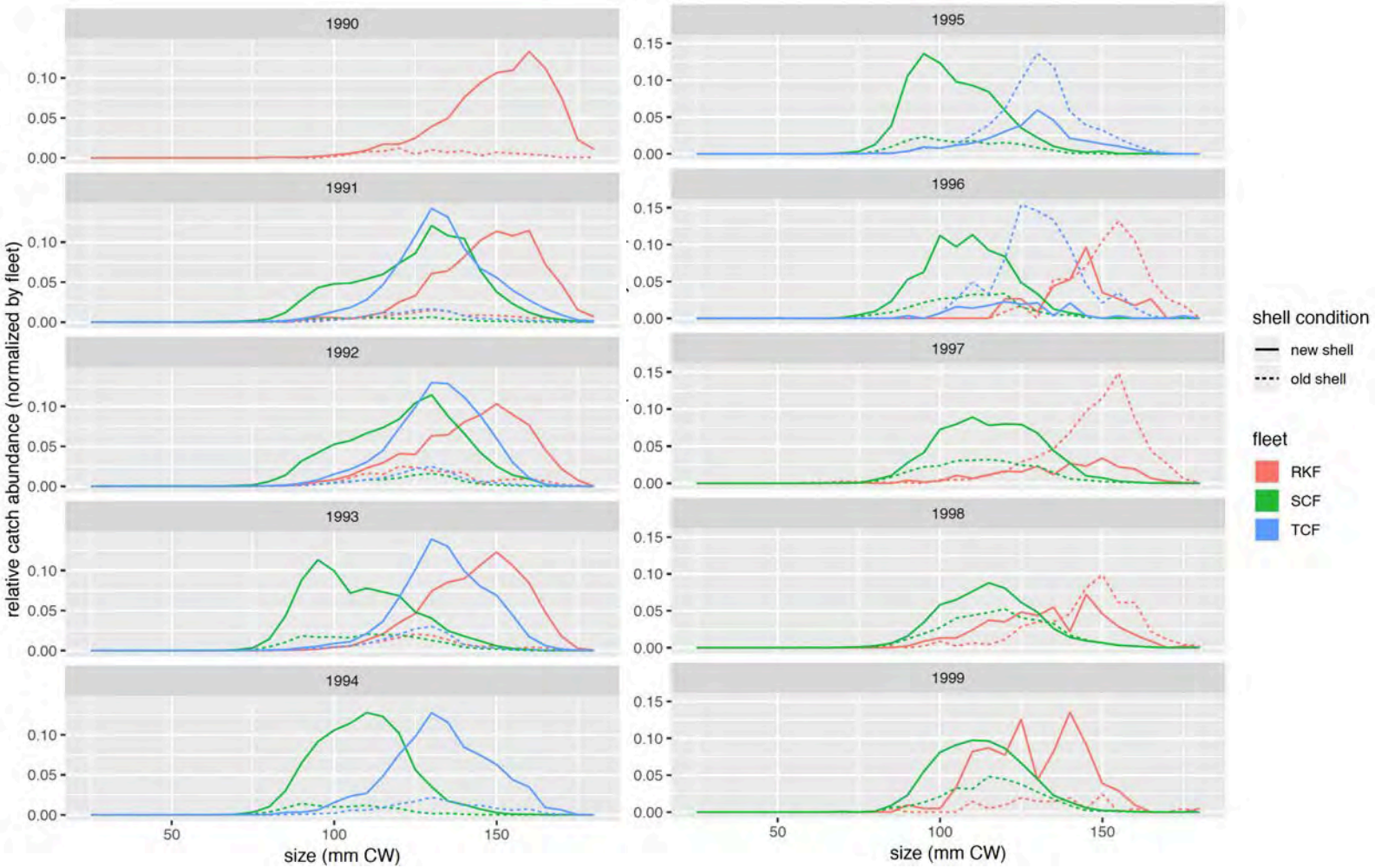


Figure 6. Total catch (retained + discards) size compositions for males, normalized by fleet, during 1990/91-1999/2000 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

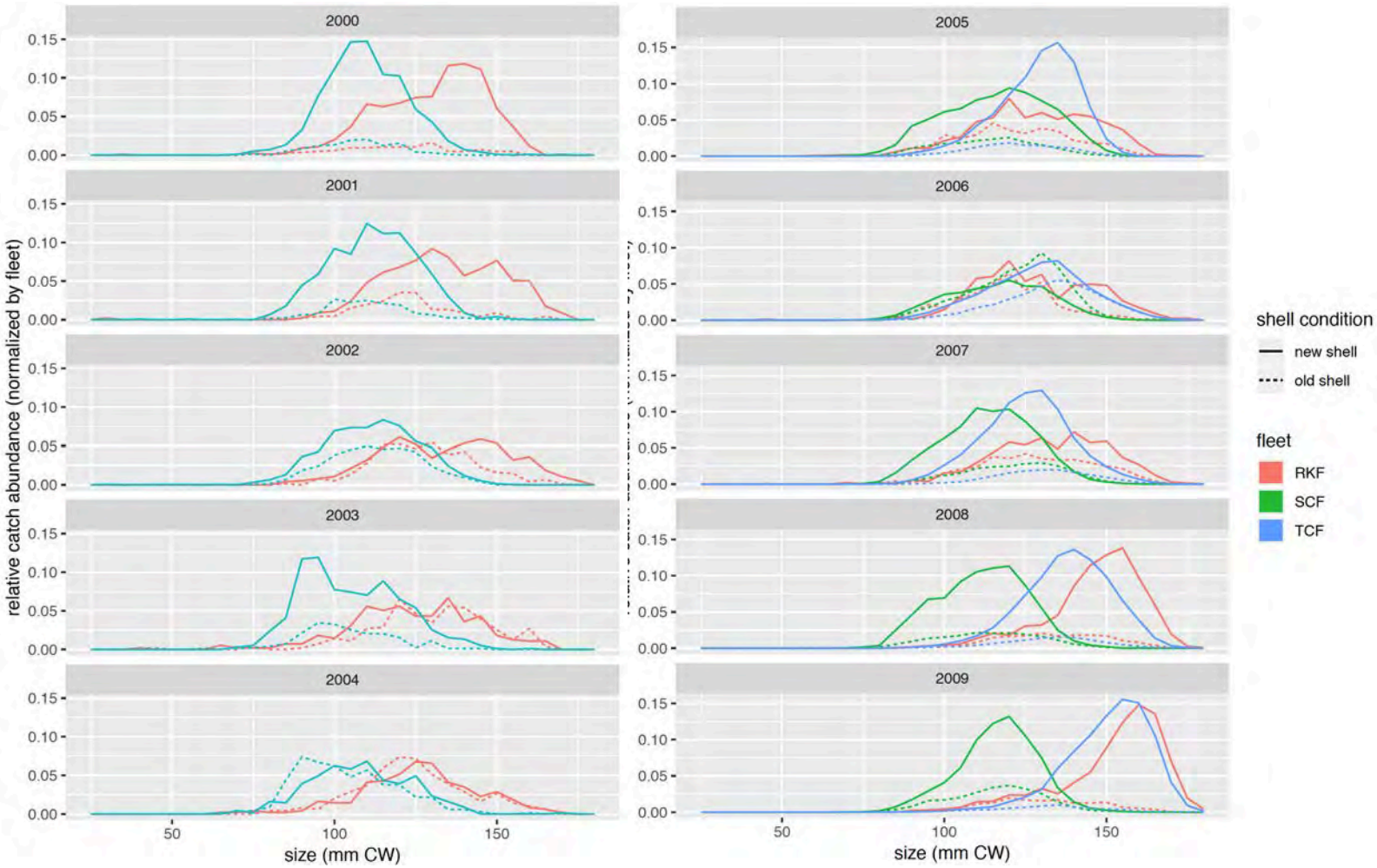


Figure 7. Total catch (retained + discards) size compositions for males, normalized by fleet, during 2000/01-2009/10 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). The directed fishery was closed in 2000/01-2004/05 and was open only in the western area in 2005/06 and in the eastern area in 2009/10.

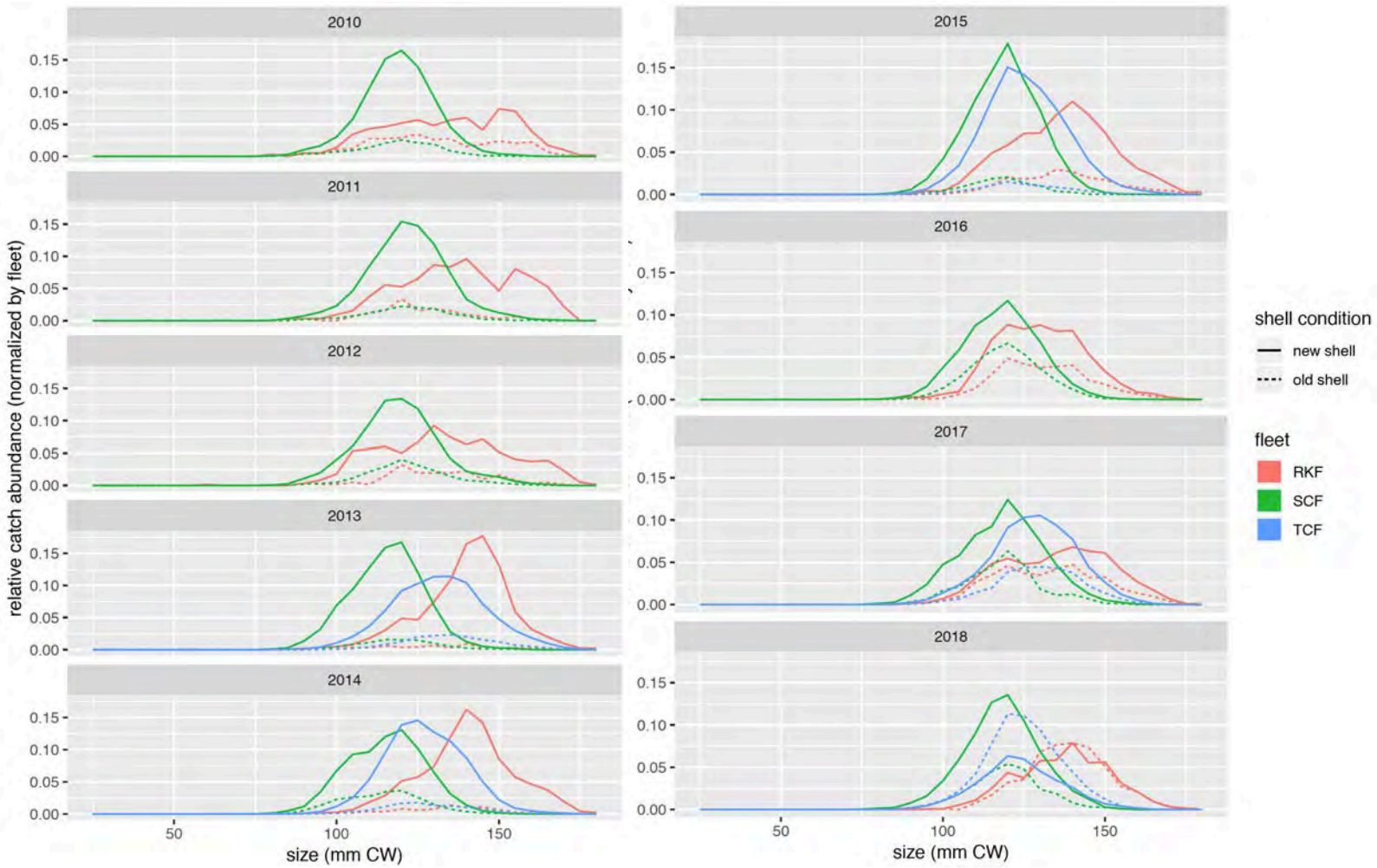


Figure 8. Total catch (retained + discards) size compositions for males, normalized by fleet, during 2010/11-2018/19 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). The directed fishery was closed in 2010/11-2012/13 and 206/17, and was open only in the western area in 2017/18 and 2018/19.

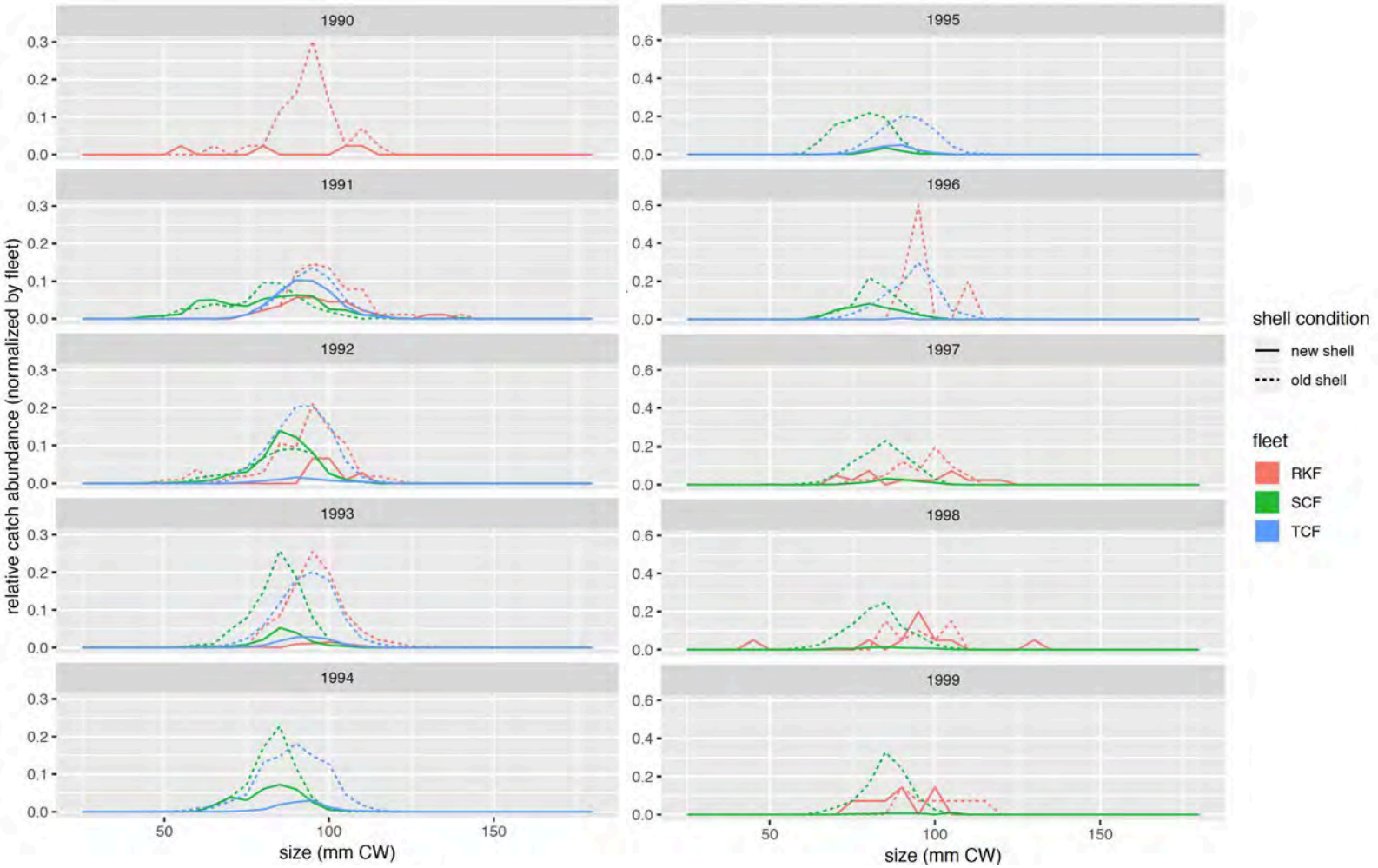


Figure 9. Bycatch size compositions for females, normalized by fleet, during 1990/91-1999/2000 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

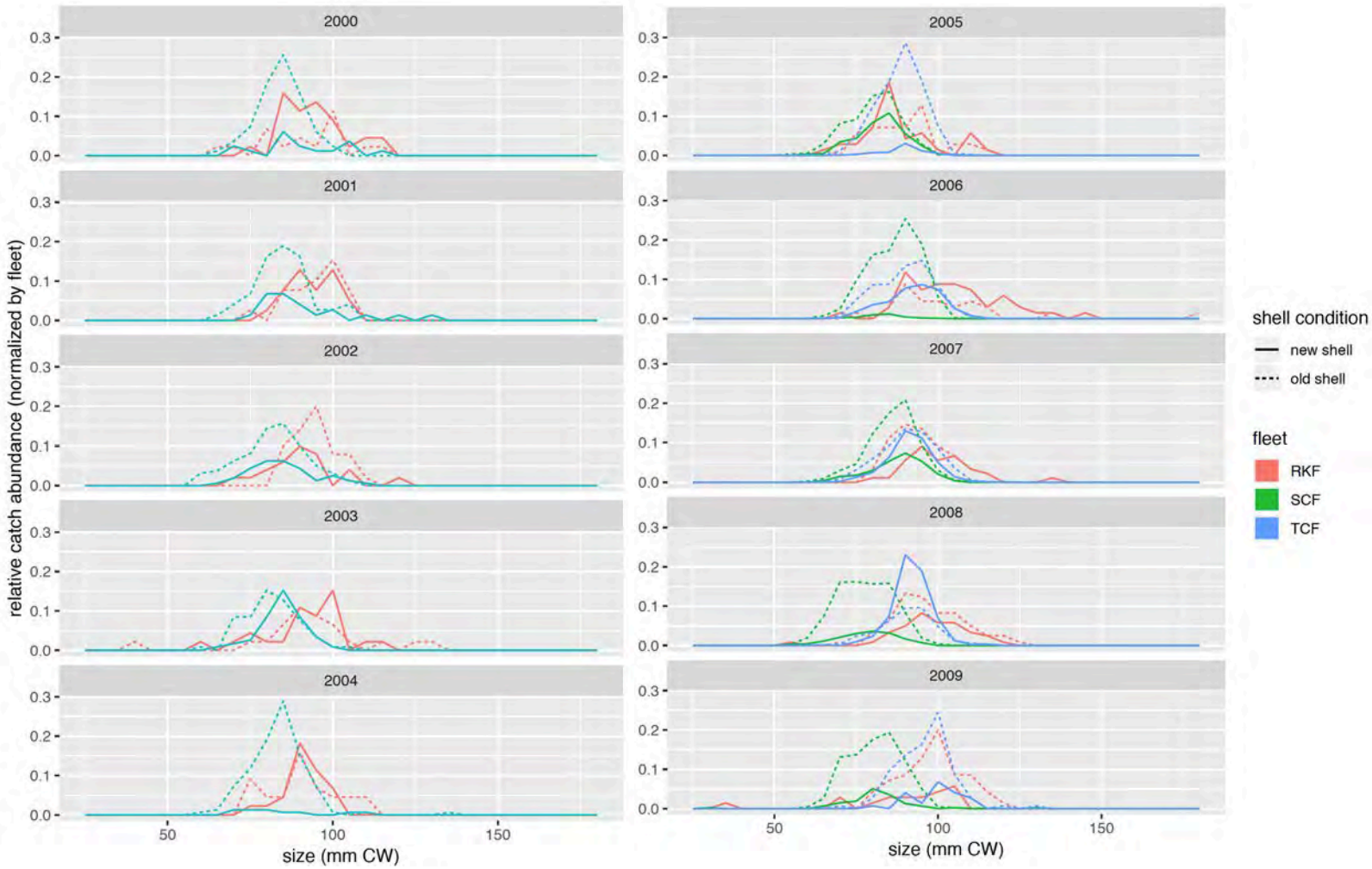


Figure 10. Bycatch size compositions for females, normalized by fleet, during 2000/01-2009/10 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

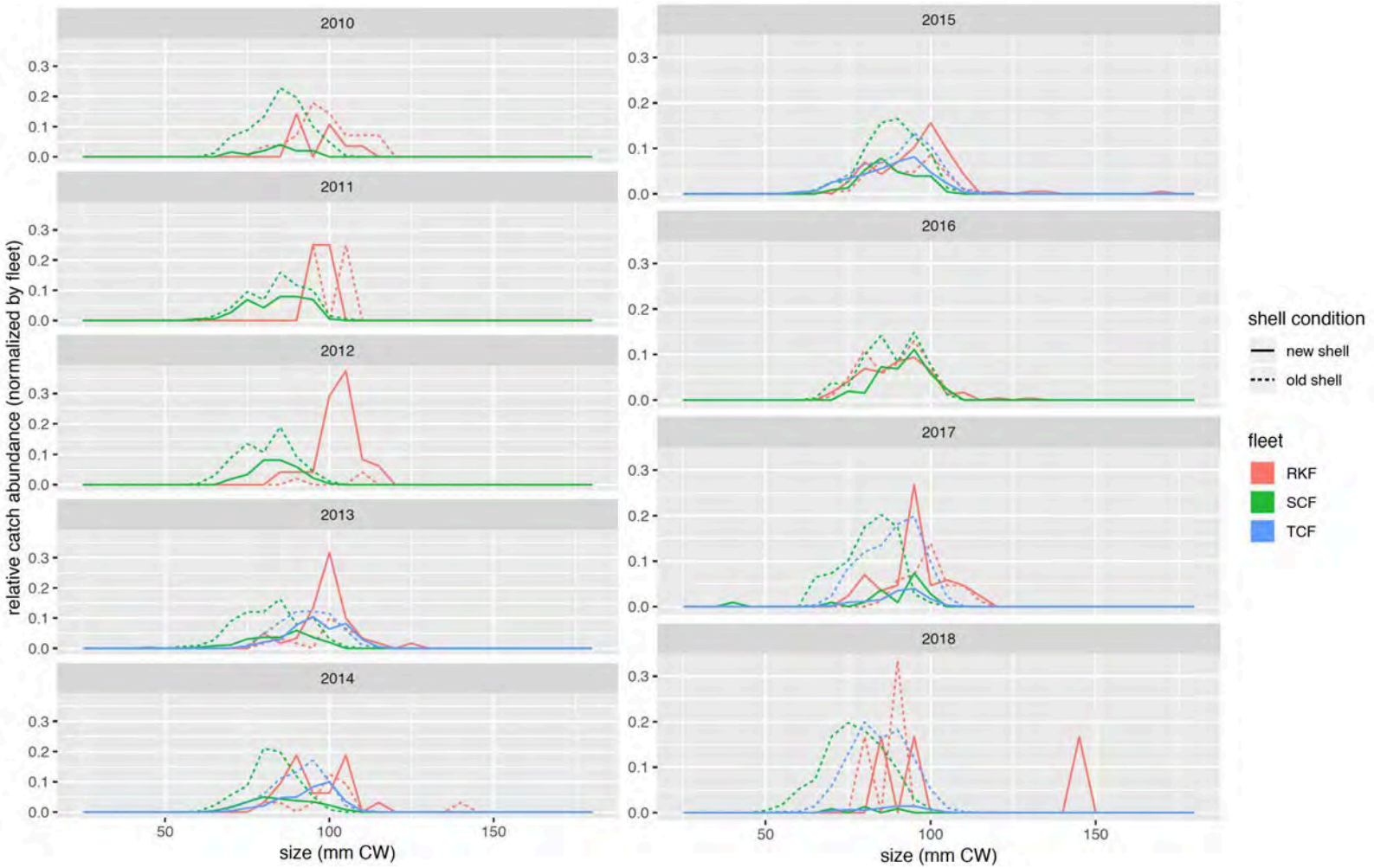


Figure 11. Bycatch size compositions for females, normalized by fleet, during 2010/11-2018/19 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

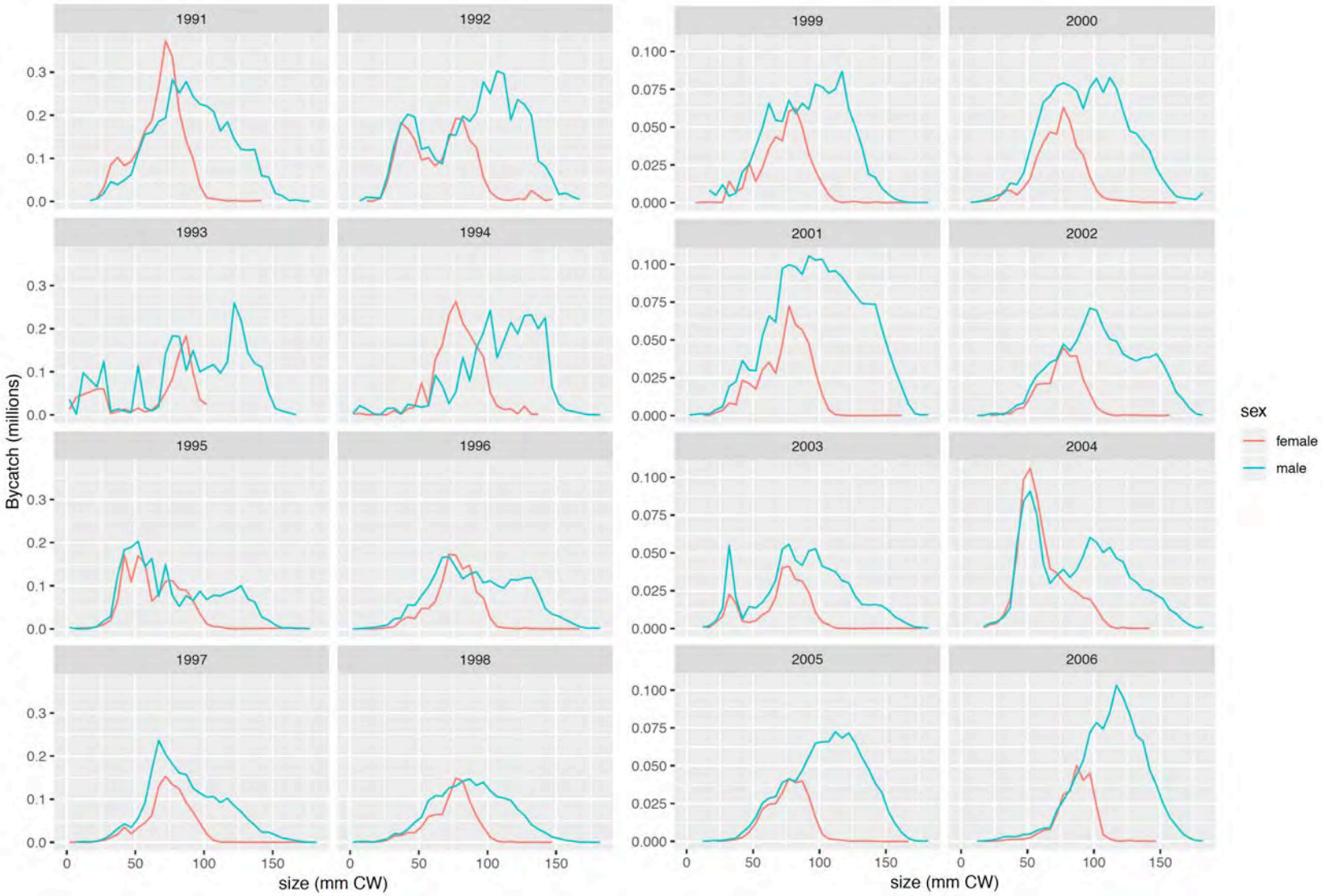


Figure 12. Annual bycatch size compositions in the groundfish fisheries by sex, expanded to total bycatch, during 1991/92-2006/07. Red lines: females; green lines: males.

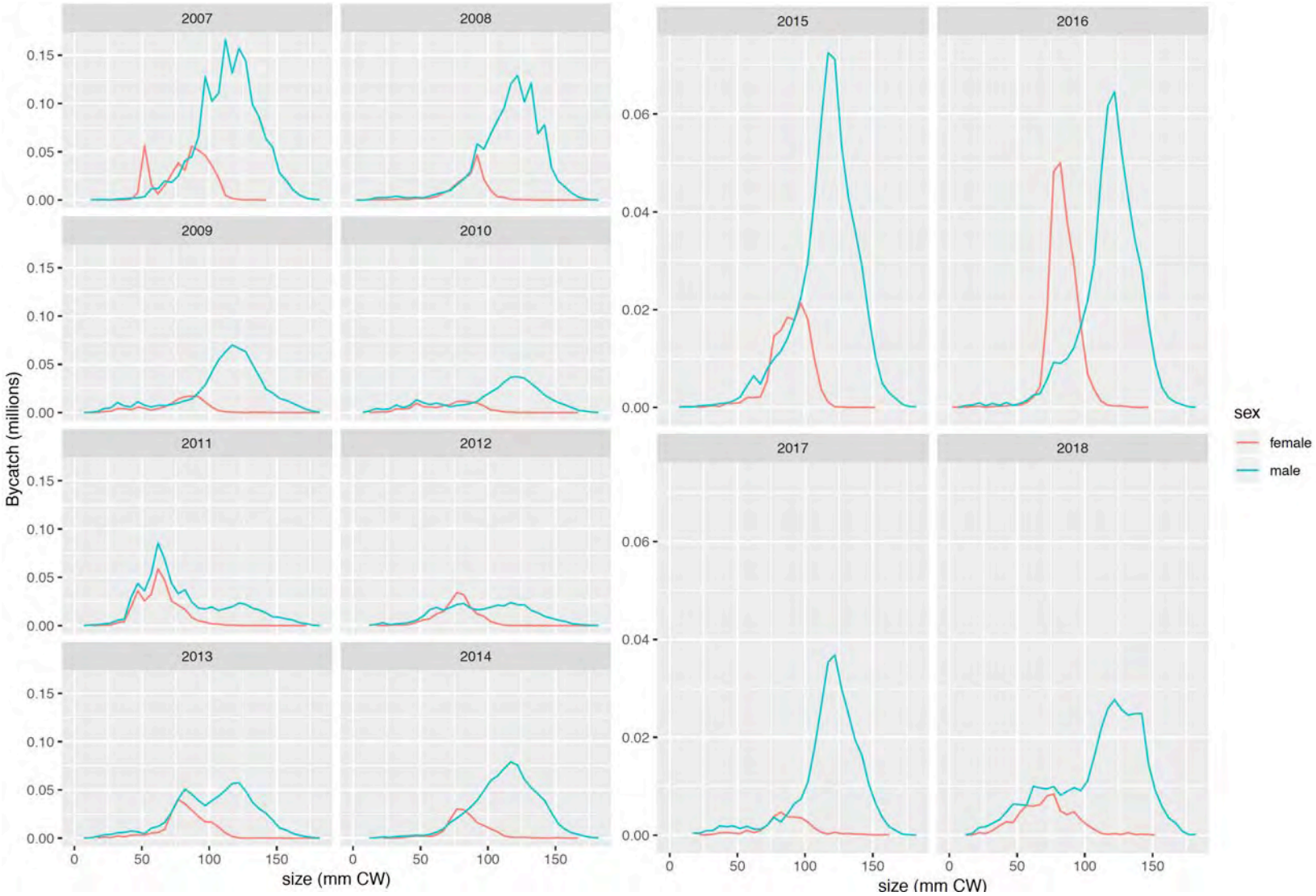


Figure 13. Annual bycatch size compositions in the groundfish fisheries by sex, expanded to total bycatch, during 2007/08-2018/19. Red lines: females; green lines: males.

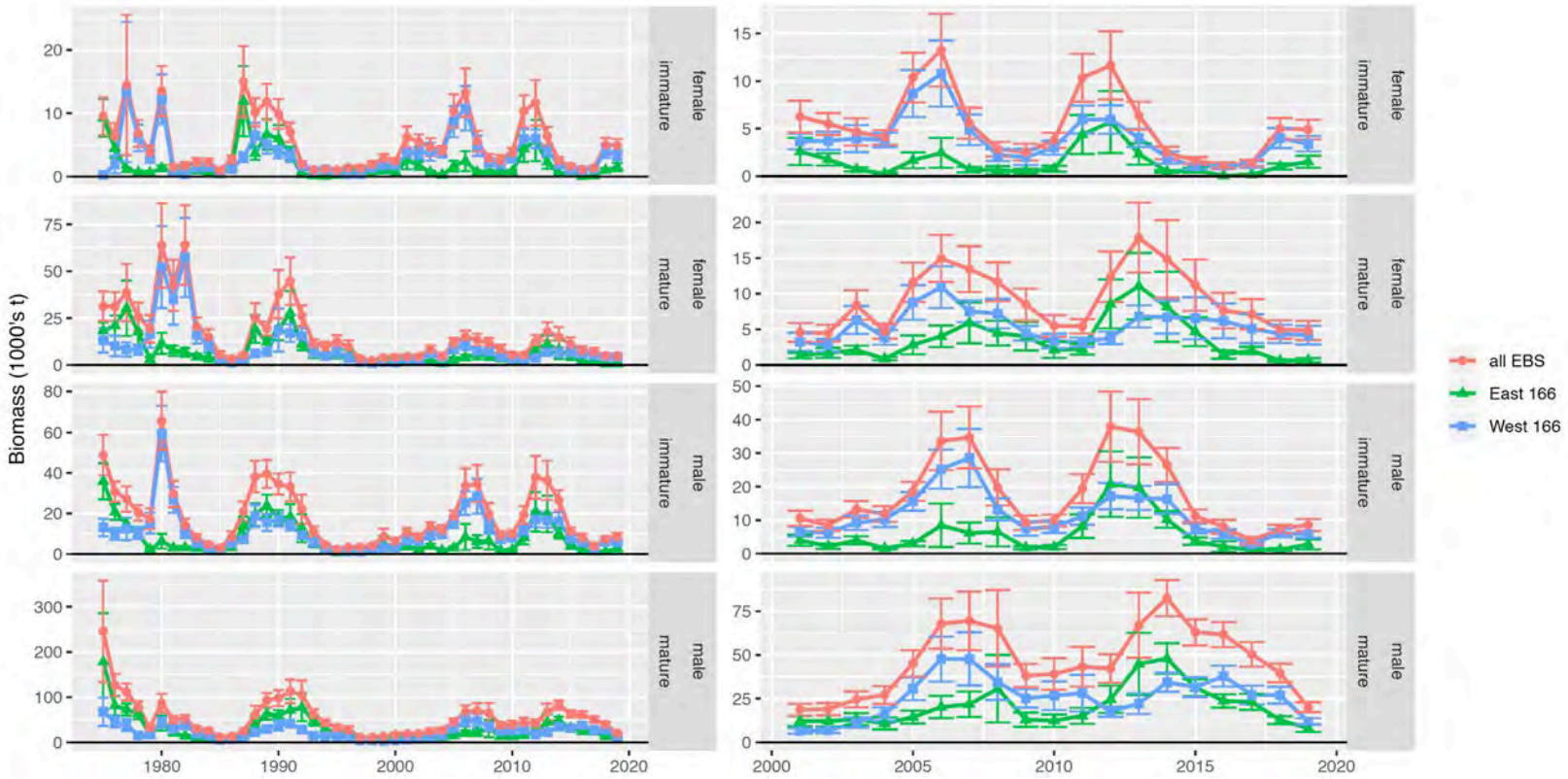


Figure 14. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey, by sex, maturity state, and management area. Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

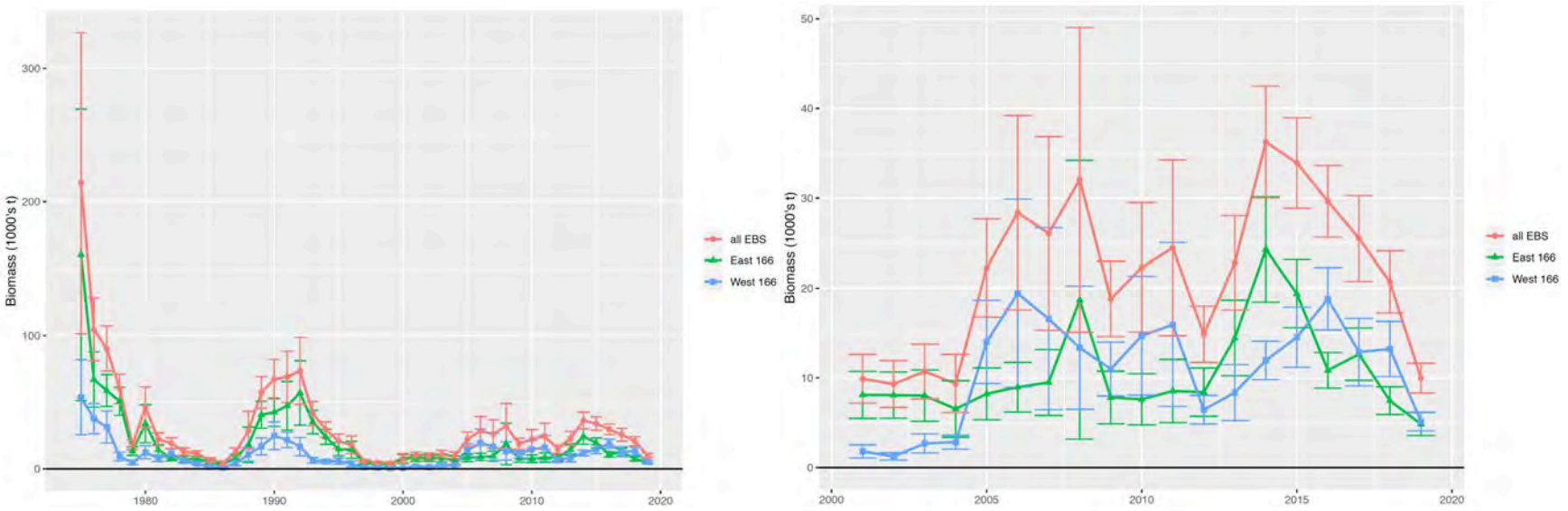


Figure 15. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey for preferred-size (>125 mm CW) legal males . Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

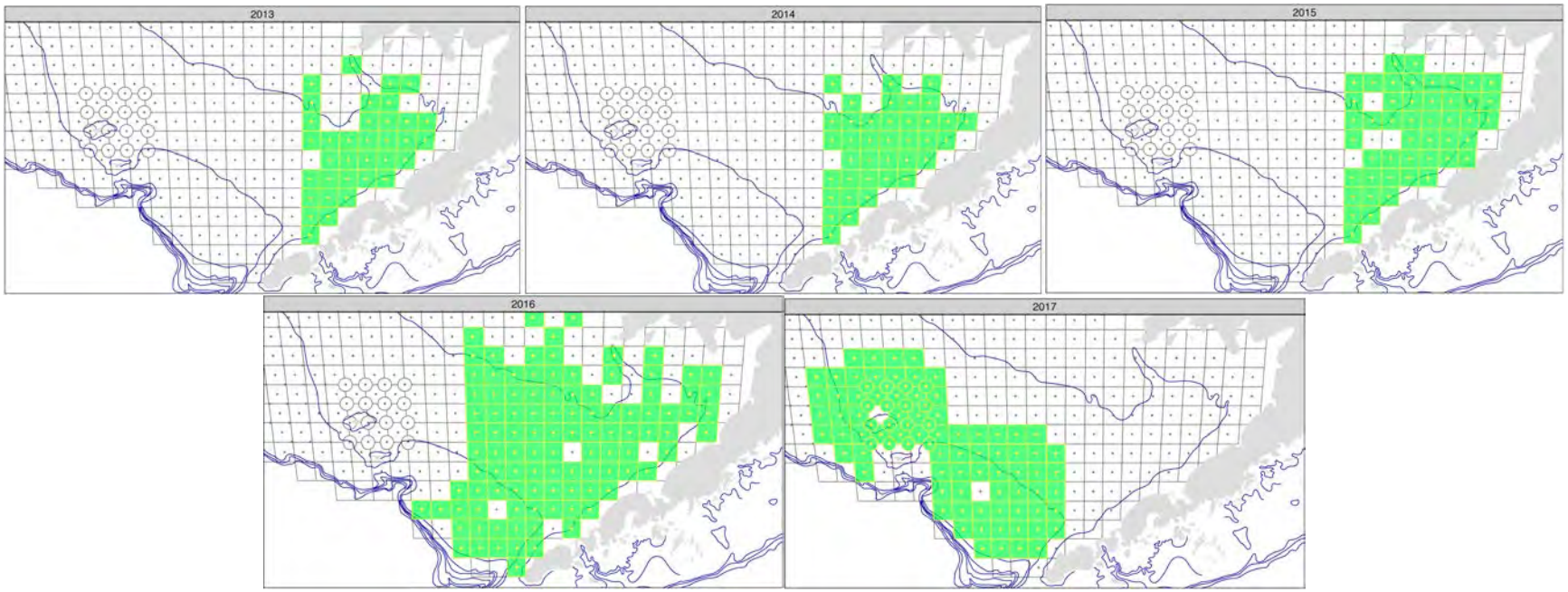


Figure 16. Spatial footprints (stations occupied in green) during the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. Squares and circles represent stations in the standard NMFS EBS bottom trawl survey (which extends beyond the area shown in the maps).

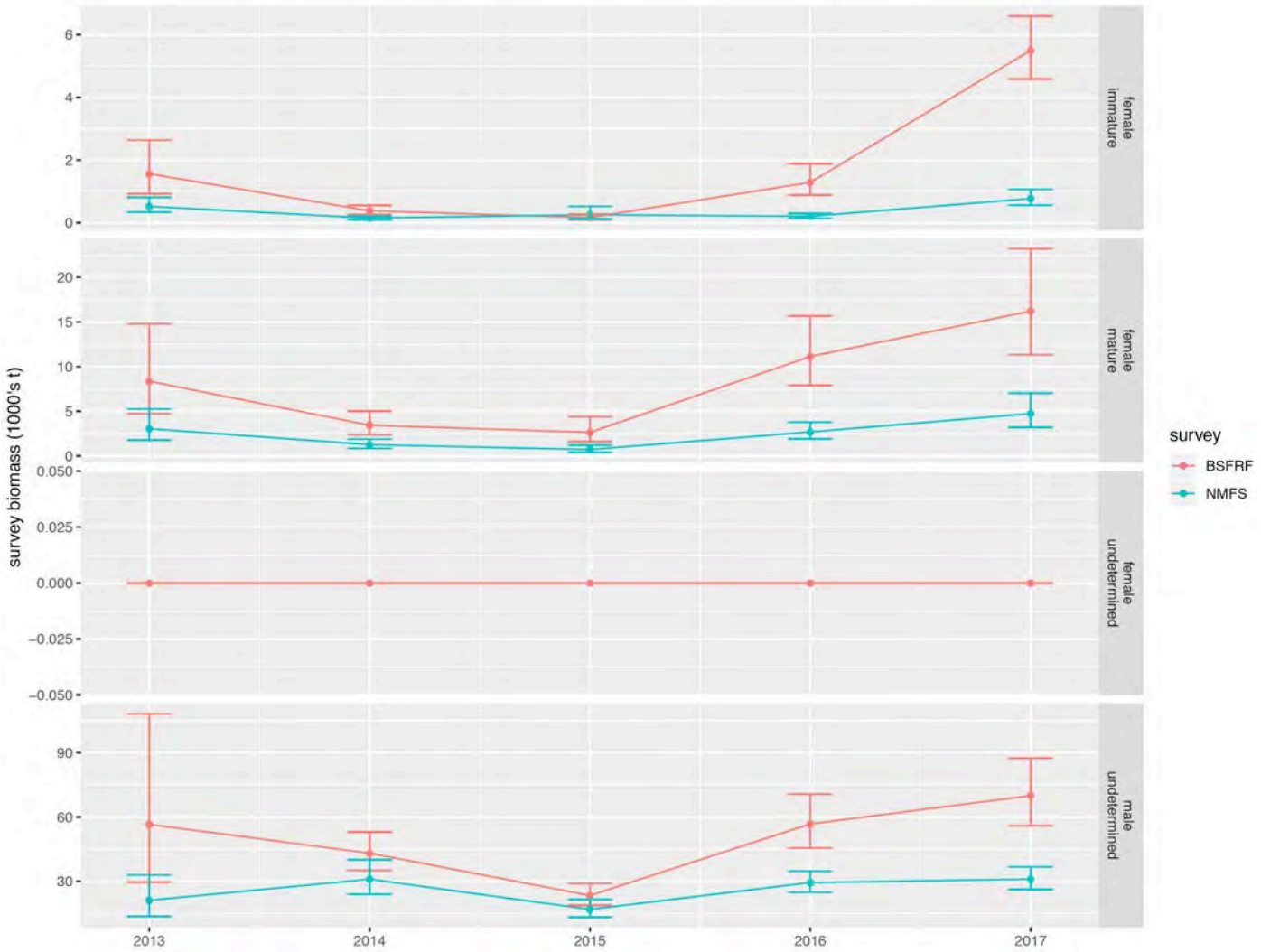


Figure 17. Annual estimates of area-swept biomass from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. The SBS studies had different spatial footprints each year, so annual changes in biomass do not necessarily reflect underlying population trends. Red lines: BSFRF; green lines: NMFS.

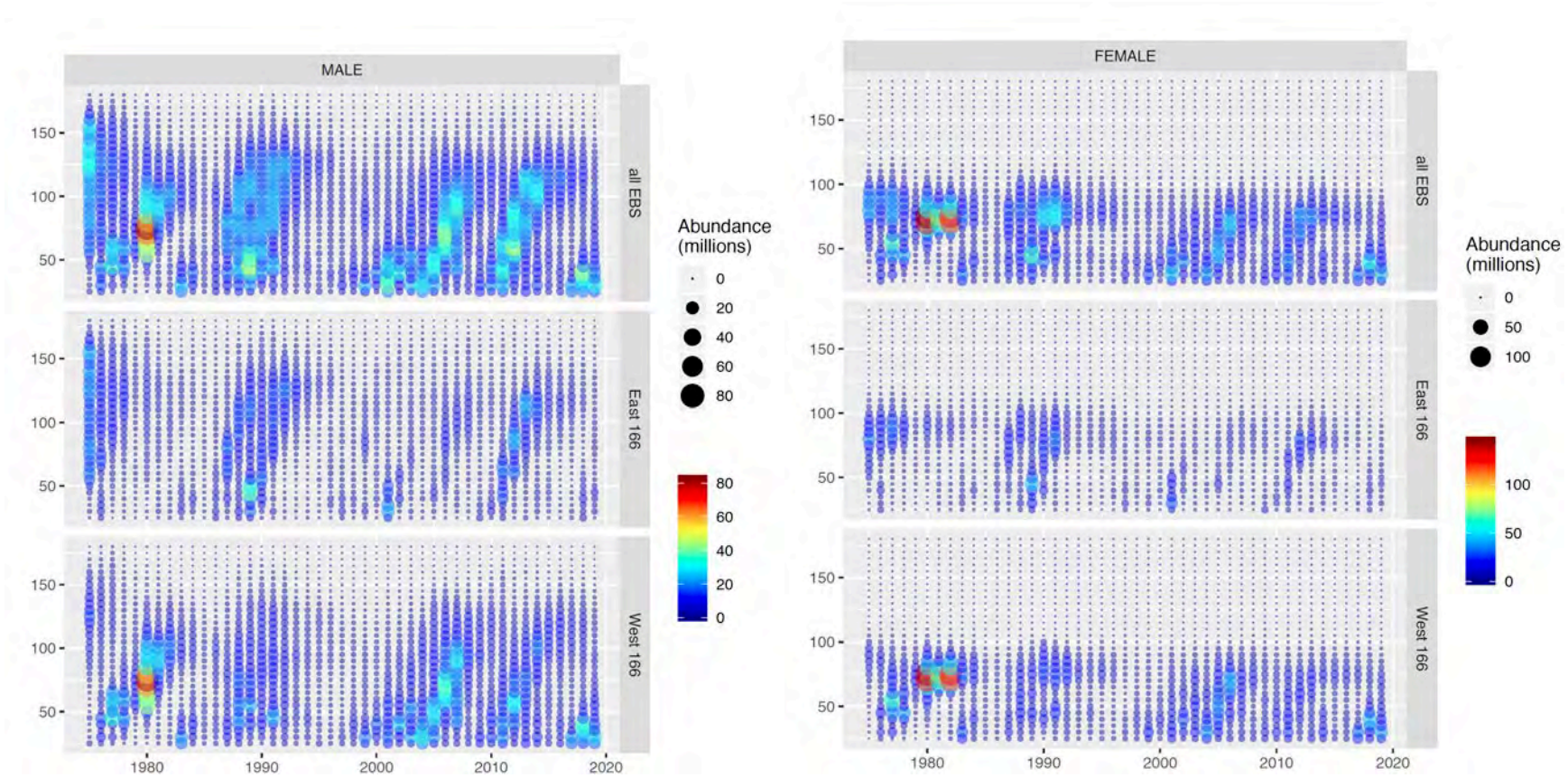


Figure 18. Size compositions from the NMFS EBS bottom trawl survey for 1975-2019.

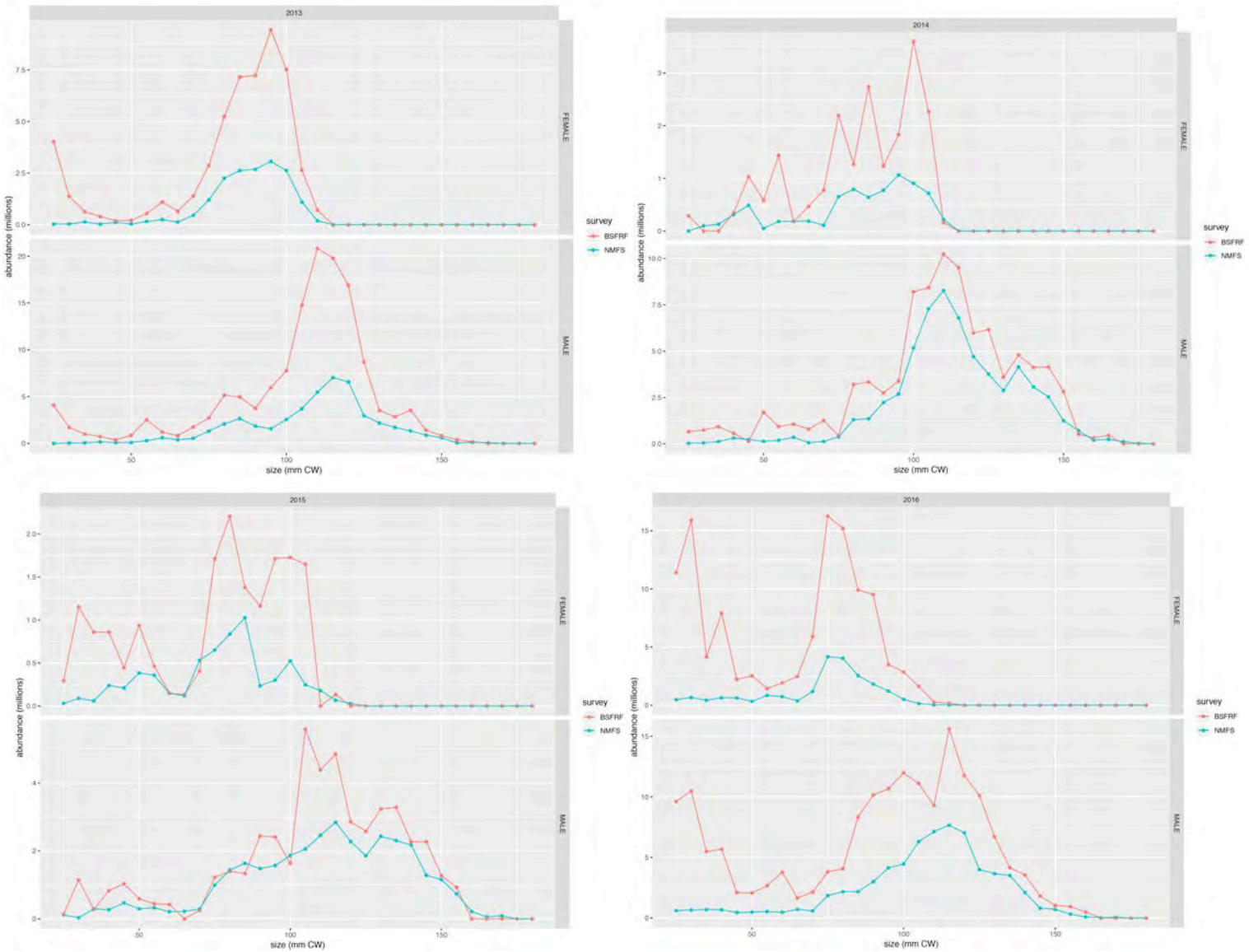


Figure 19. Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2015. Red lines: BSFRF; green lines: NMFS.

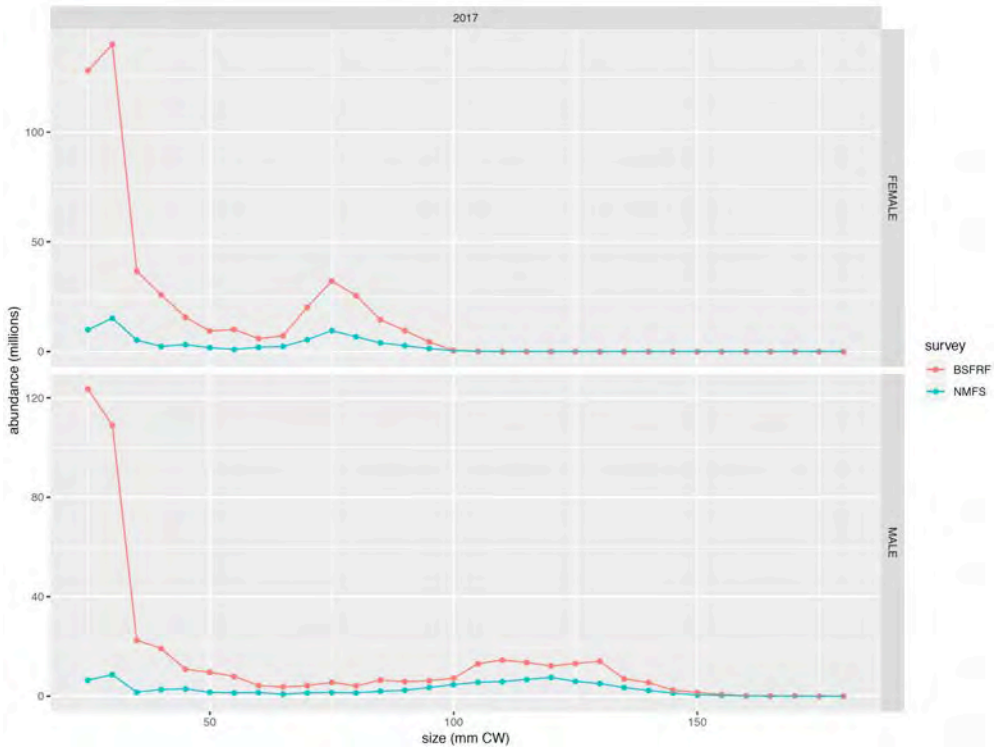


Figure 19 (cont.). Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2017. Red lines: BSFRF; green lines: NMFS

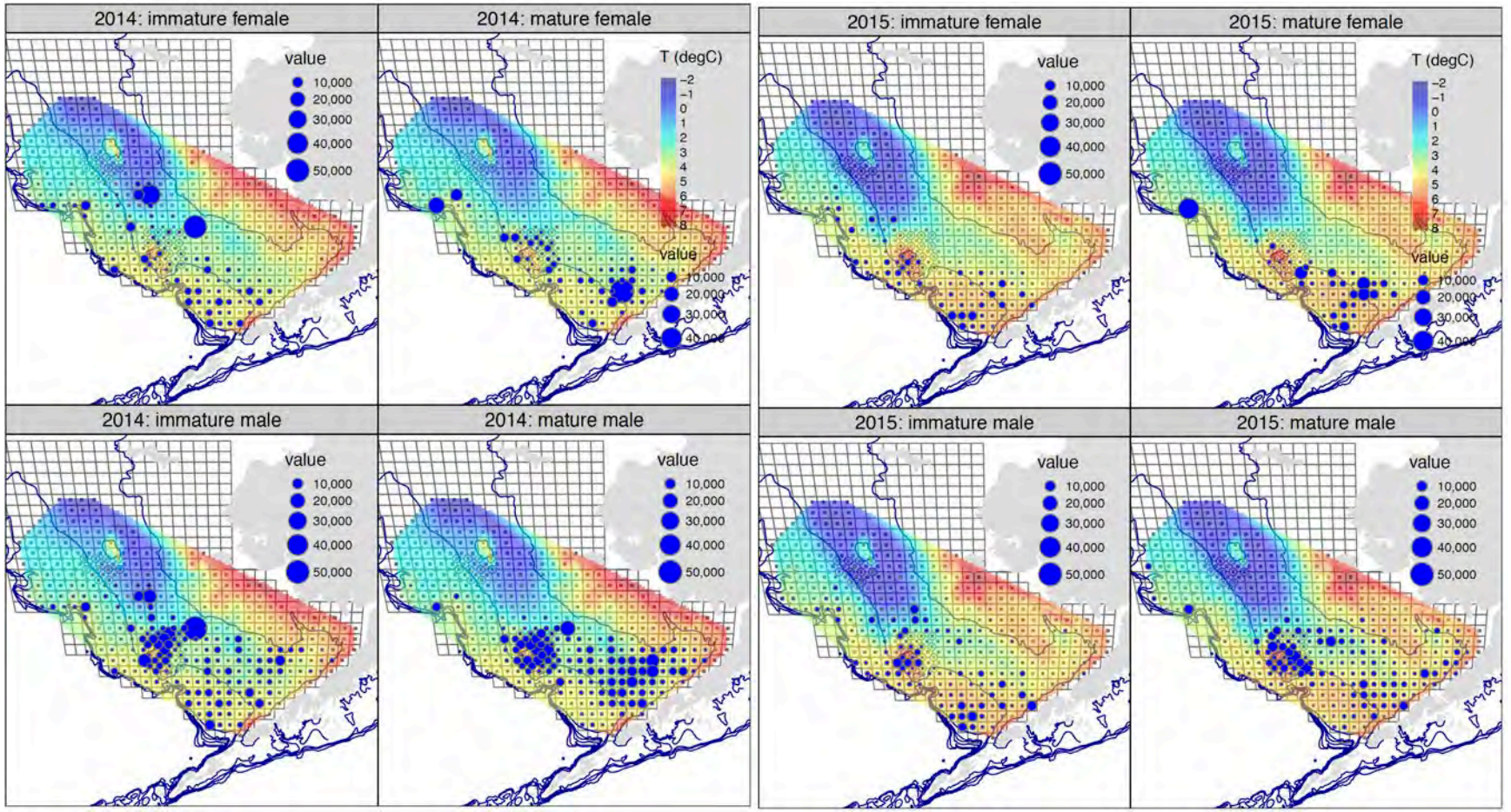


Figure 20. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2014 and 2015. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

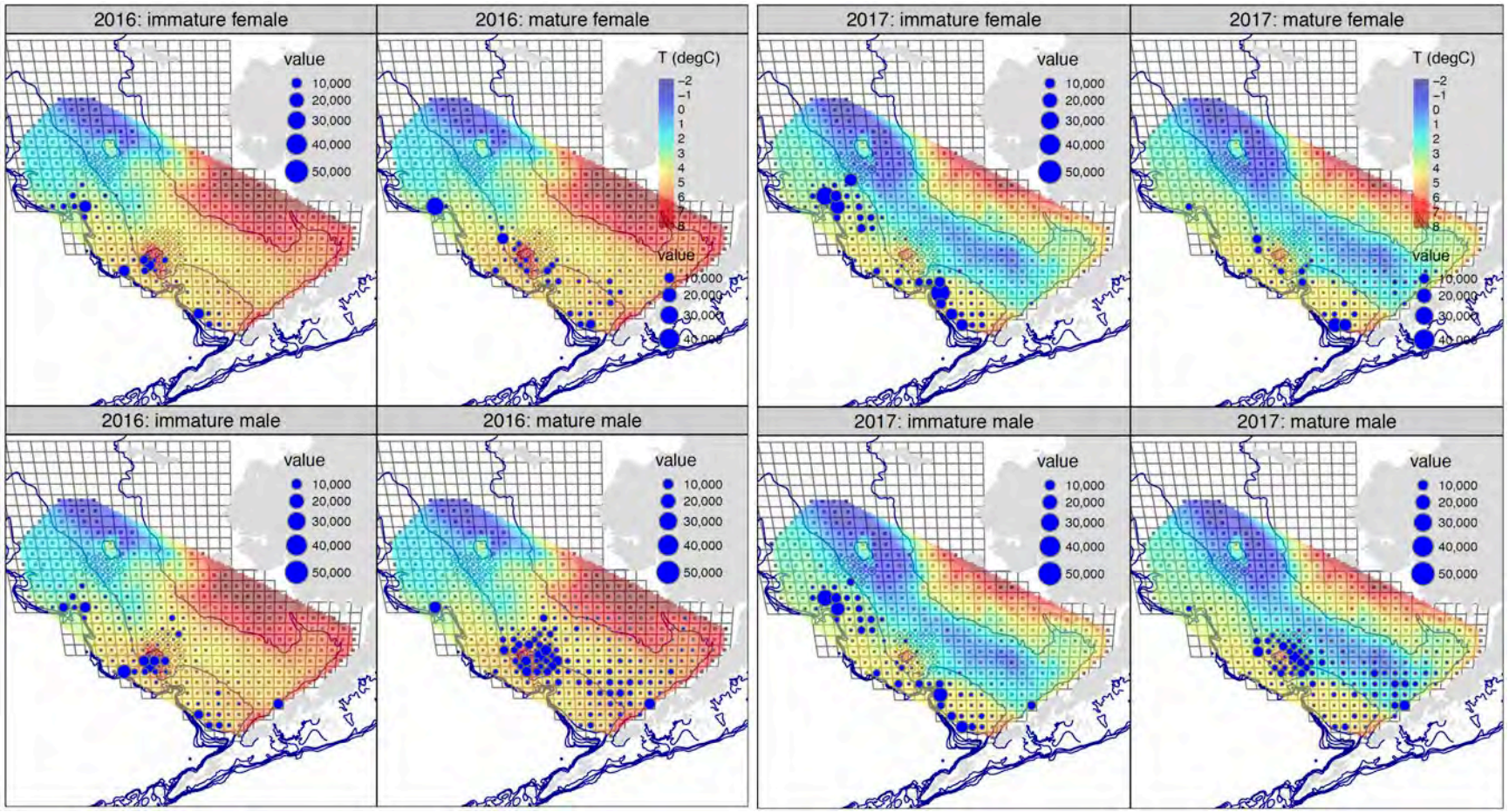


Figure 21. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2016 and 2017. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

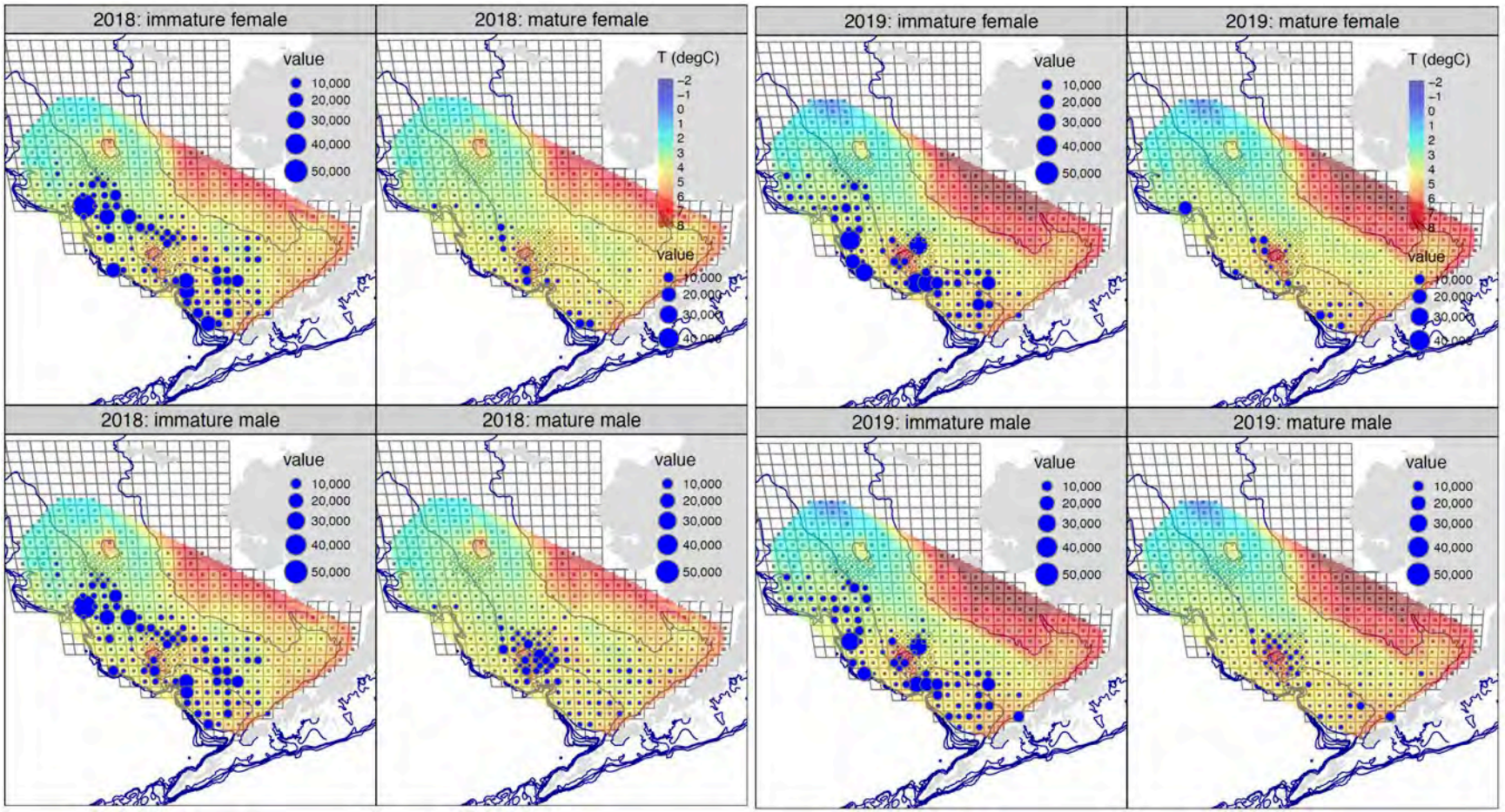


Figure 22. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2018 and 2019. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

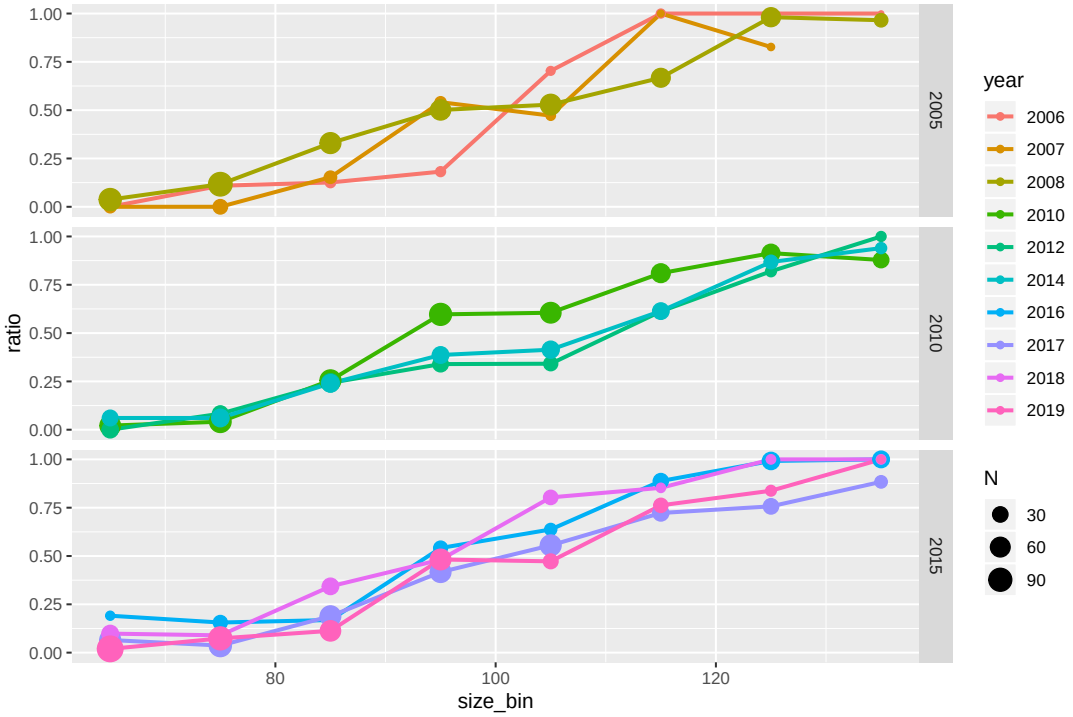


Figure 23. Male maturity ogives (the fraction of new shell mature males, relative to all new shell males) as determined from chela height:carapace width ratios from the NMFS EBS bottom trawl survey for years when chela heights were collected with 0.1 mm precision..

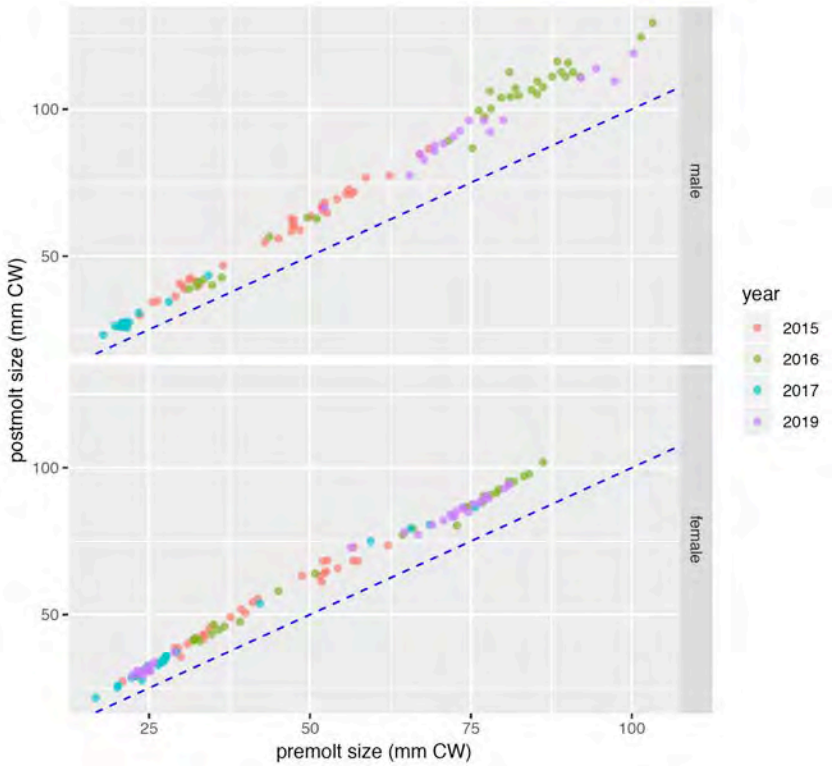


Figure 24. Molt increment data collected collaboratively by NMFS, BSFRF, and ADFG.

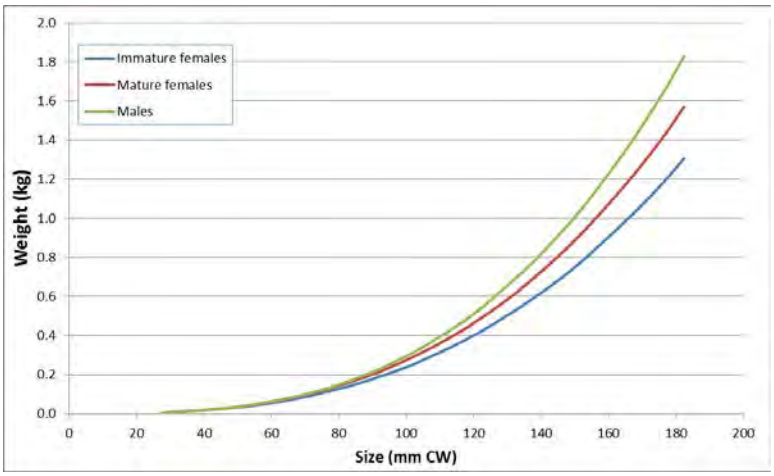


Figure 25. Size-weight relationships developed from NMFS EBS summer trawl survey data.

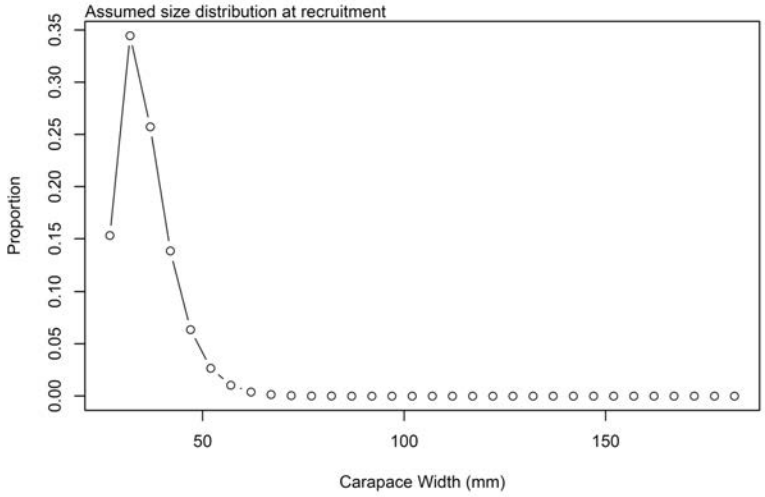


Figure 26. Assumed size distribution for recruits entering the population.

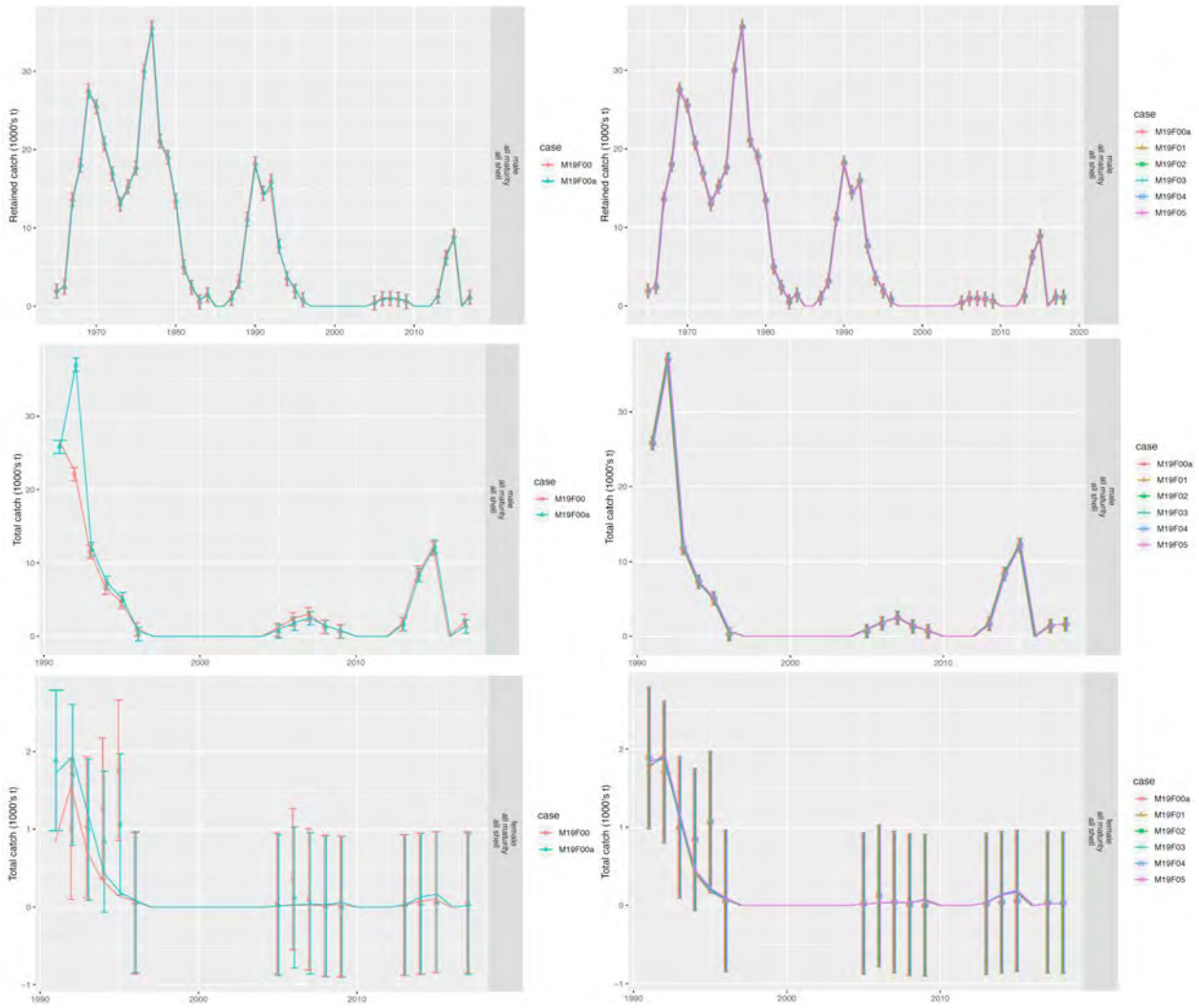


Figure 27. Fits to retained and total catch biomass in the directed fishery from all model scenarios.

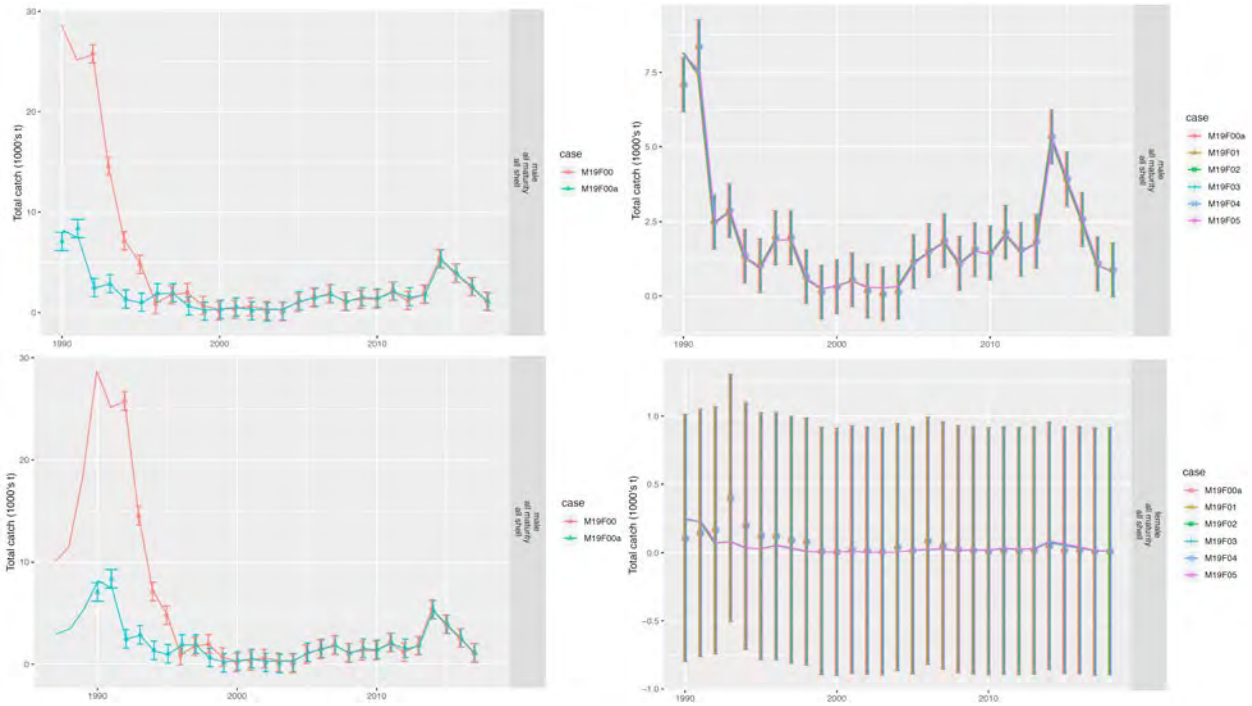


Figure 28. Fits to total catch biomass in the snow crab fishery from all scenarios.

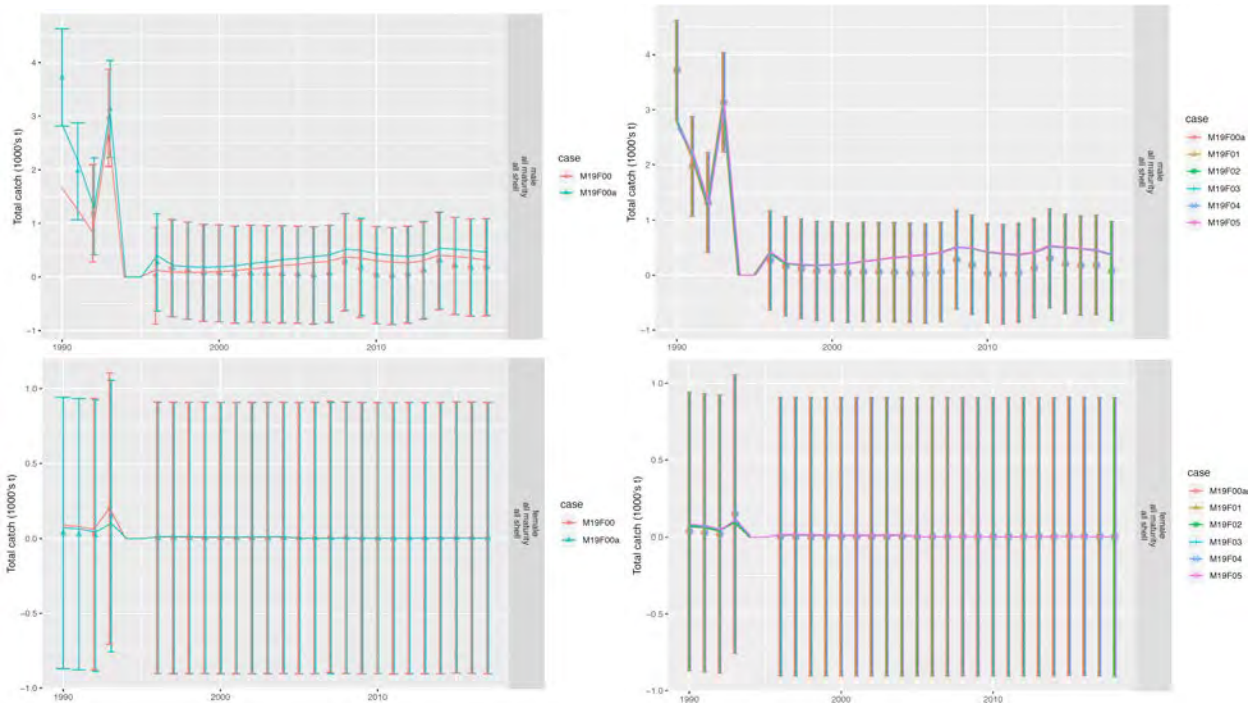


Figure 29. Fits to total catch biomass in the BBRKC fishery from all scenarios.

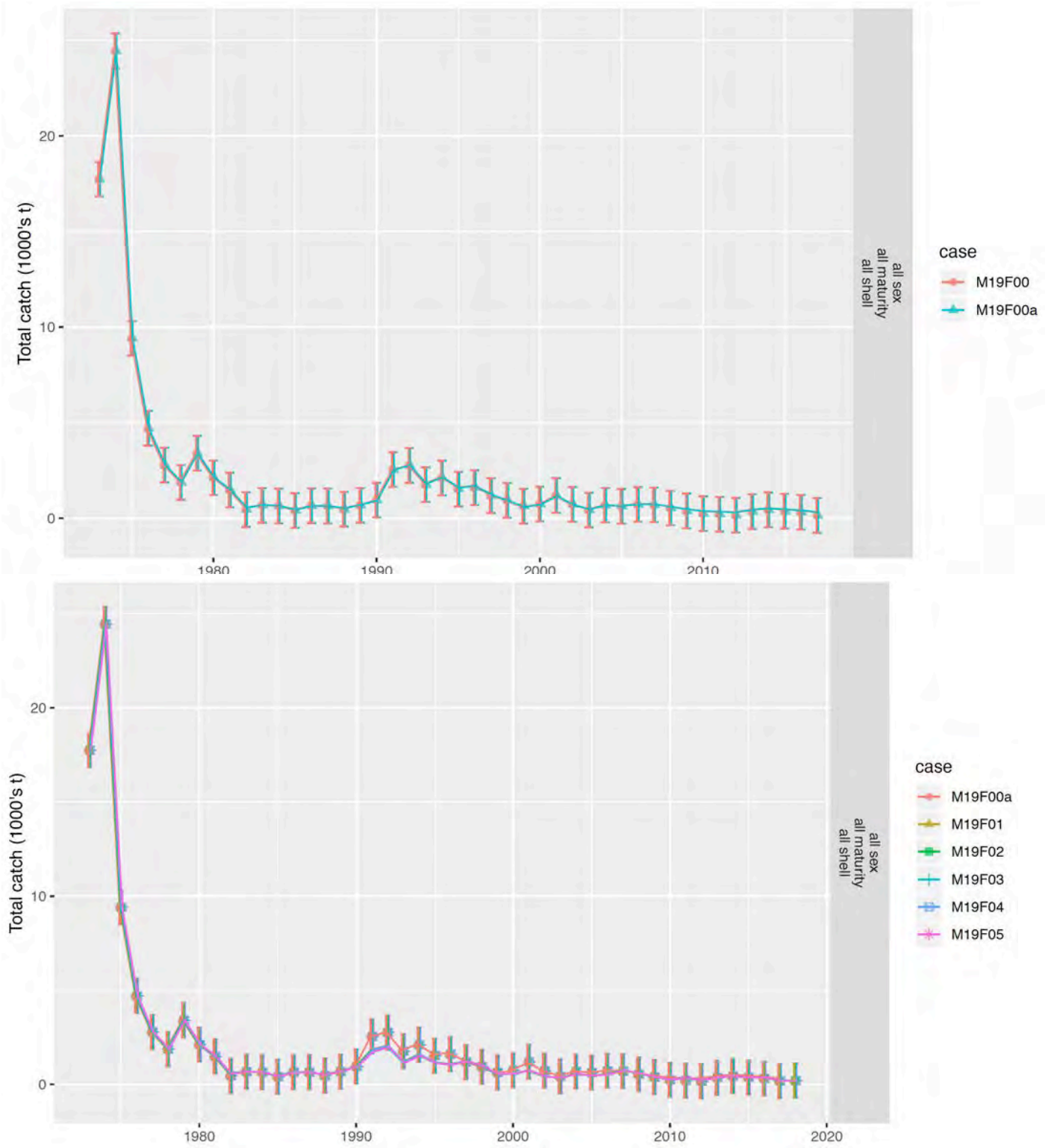


Figure 30. Fits to total catch biomass in the groundfish fisheries for all scenarios.

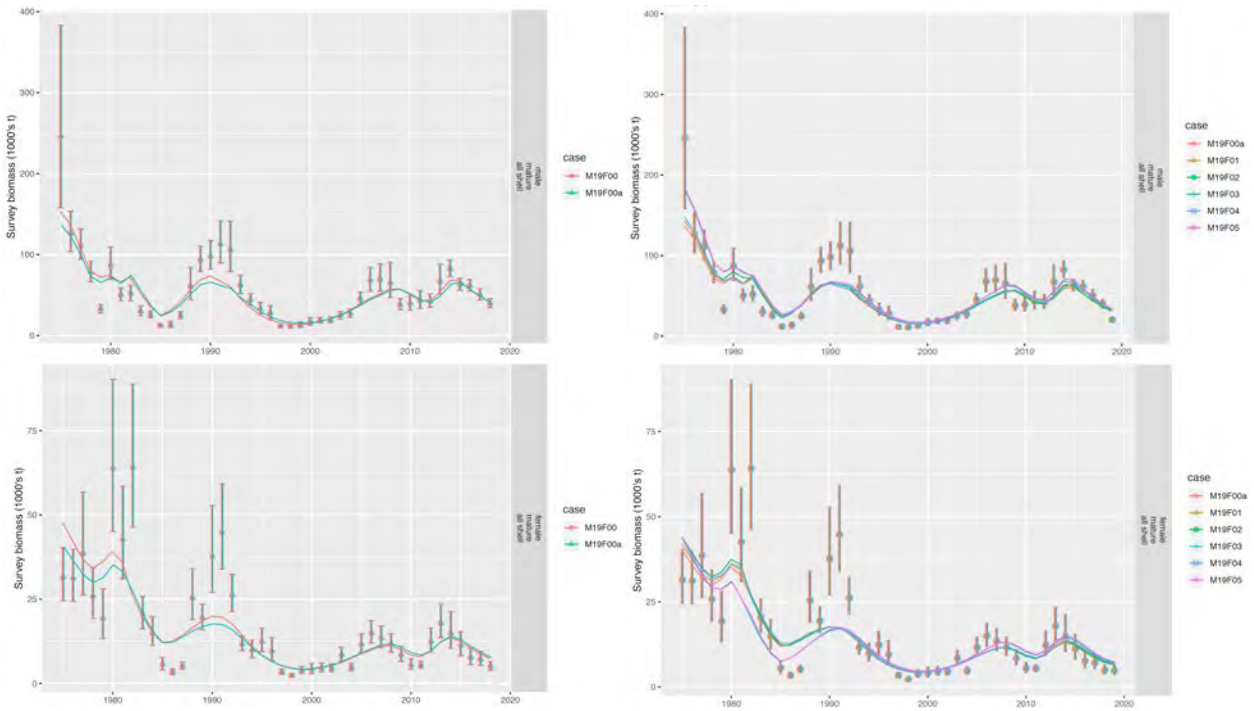


Figure 31. Fits to mature biomass from the NMFS "0" EBS bottom trawl survey data for all. Note that scenarios M19F03 and M19F05 do not include the mature male component in the likelihood (they fit total male biomass) and fit both mature and immature biomass for females.

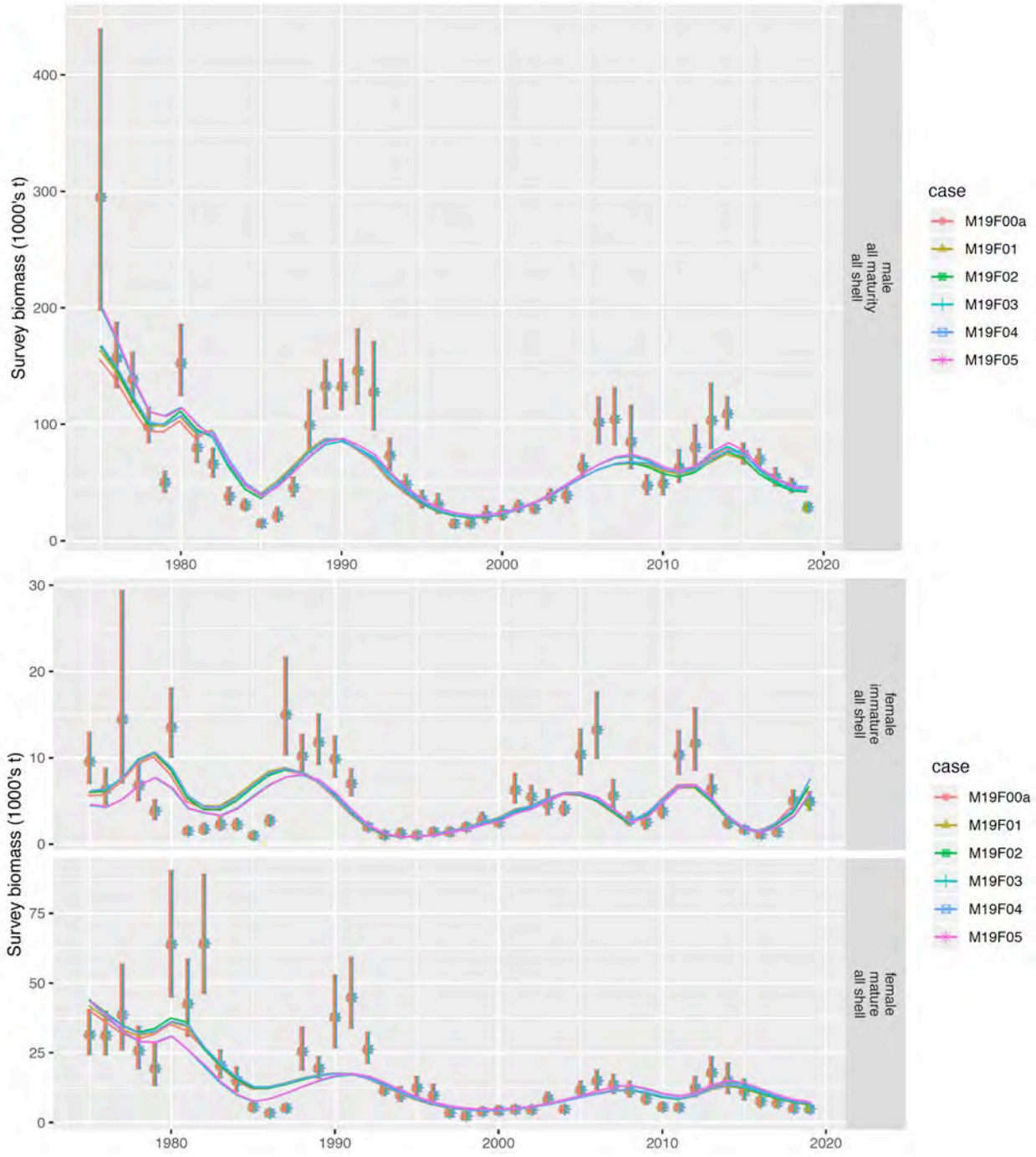


Figure 32. Fits to mature biomass from the NMFS "M" and NMFS "F" EBS bottom trawl survey data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05. Note that only scenarios M19F03 and M19F05 include these data components in the model objective function.

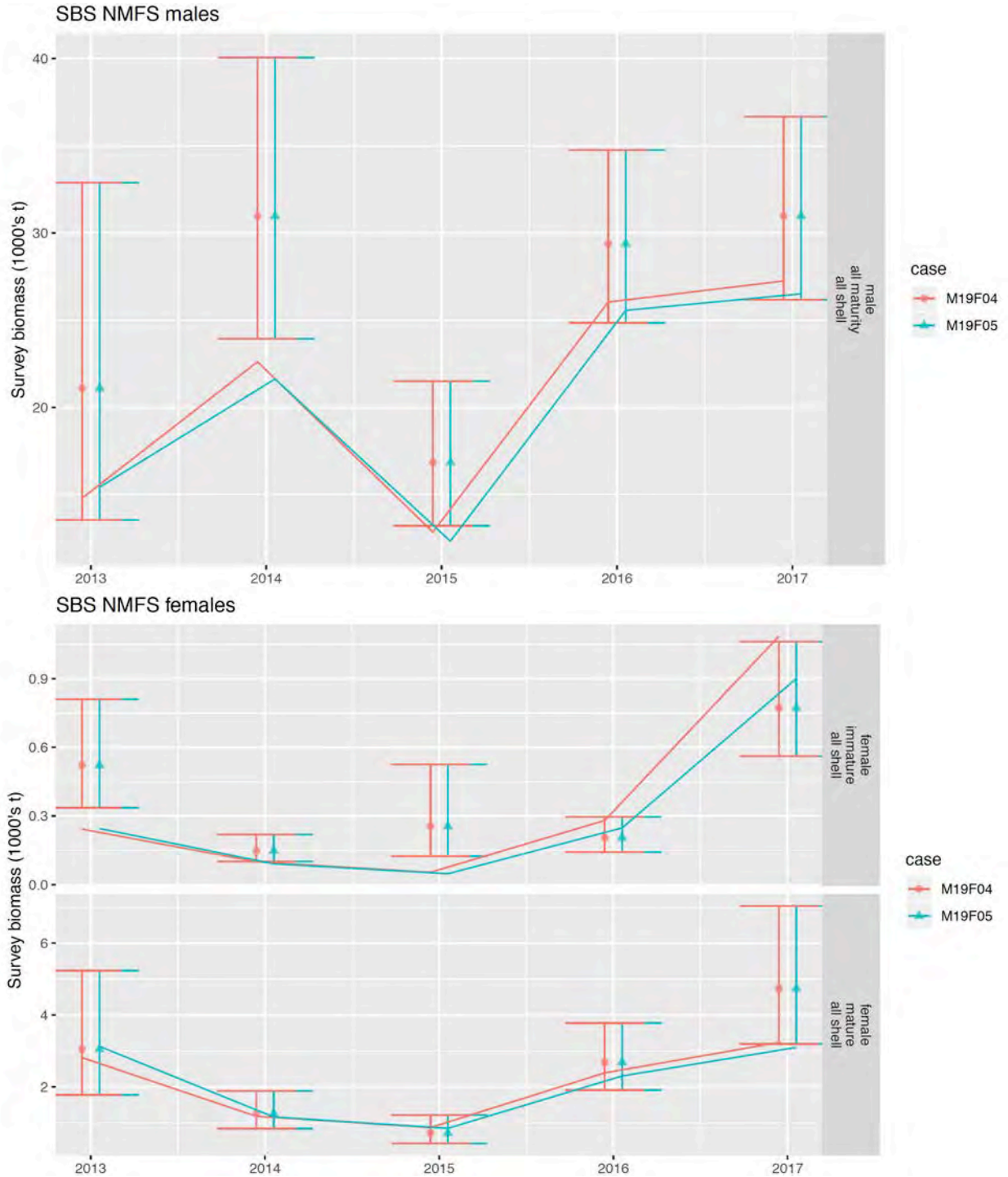


Figure 33. Fits to survey biomass from the NMFS SBS bottom trawl survey data for scenarios M19F04 and M19F05.

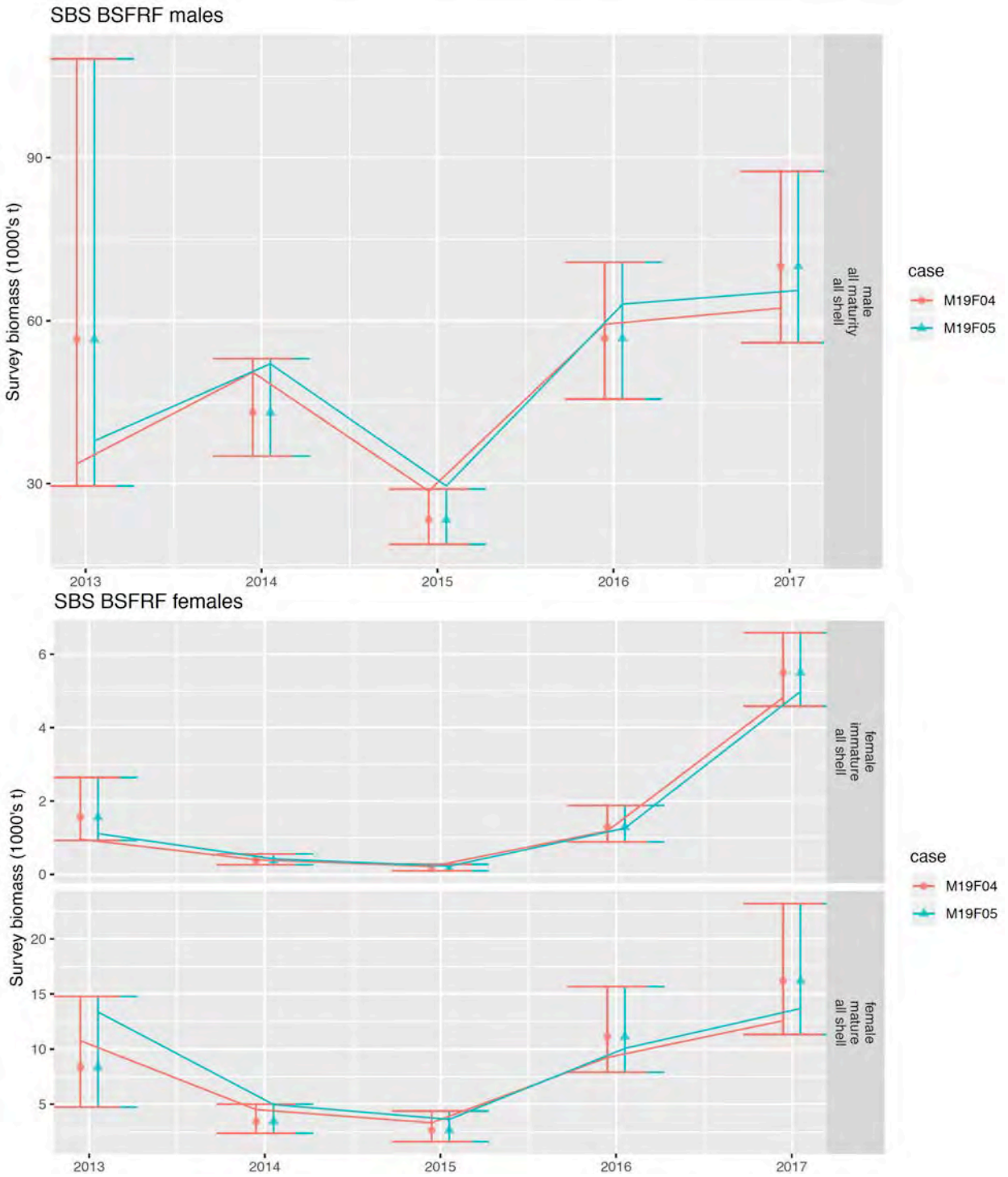


Figure 34. Fits to survey biomass from the BSFRF SBS bottom trawl survey data for scenarios M19F04 and M19F05.

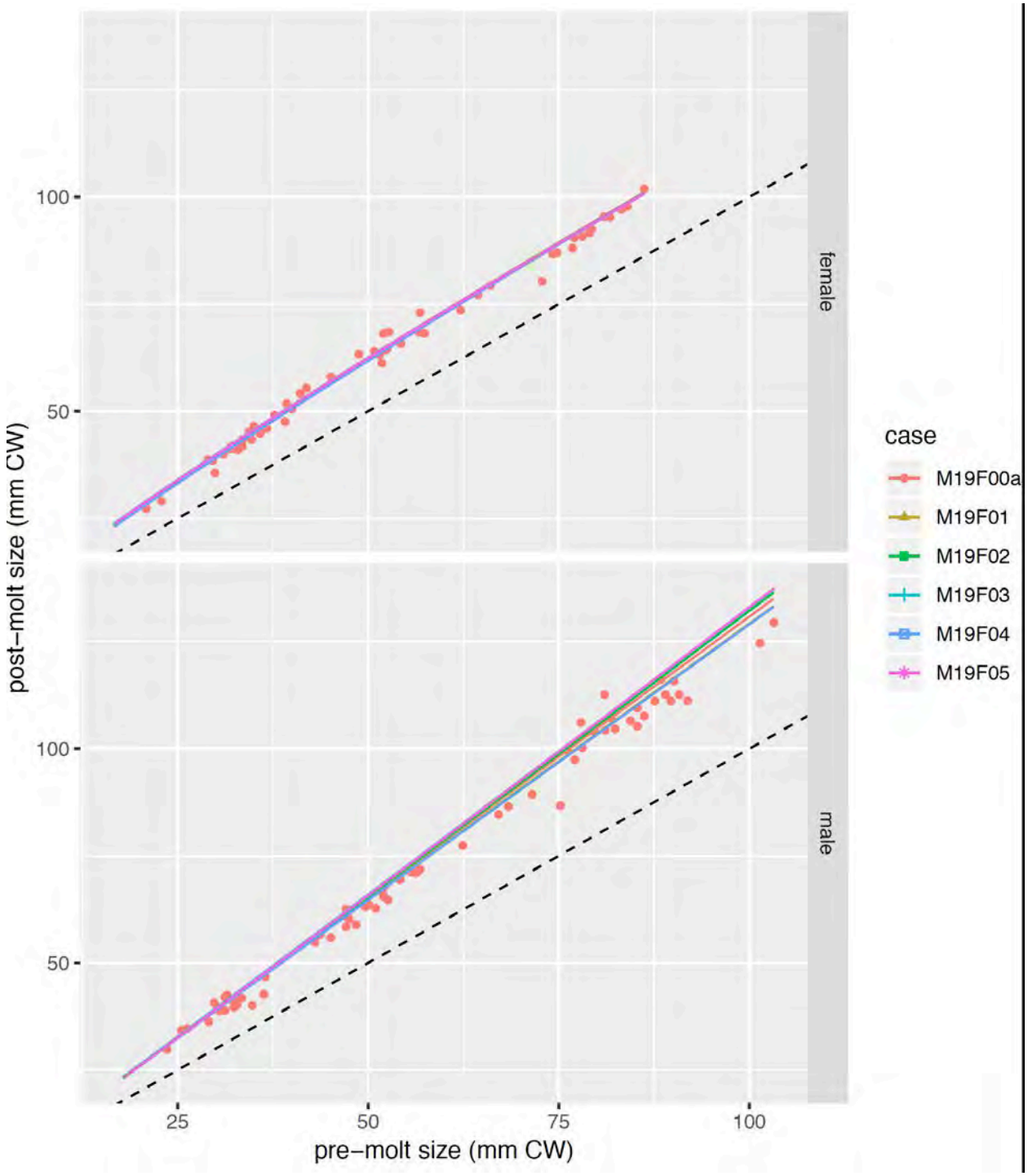


Figure 35. Fits to molt increment data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05.

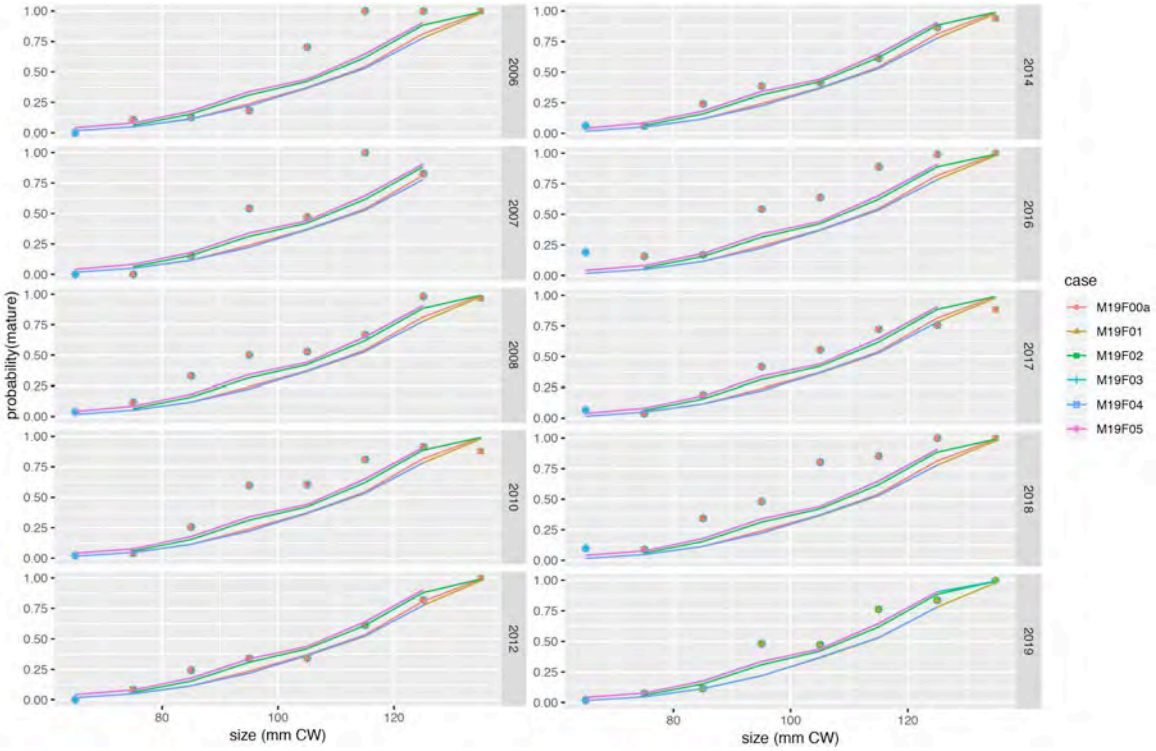


Figure 36. Fits to male maturity ogive data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05. Note that only scenarios M1902, M19F03, and M19F05 include the data in the likelihood.

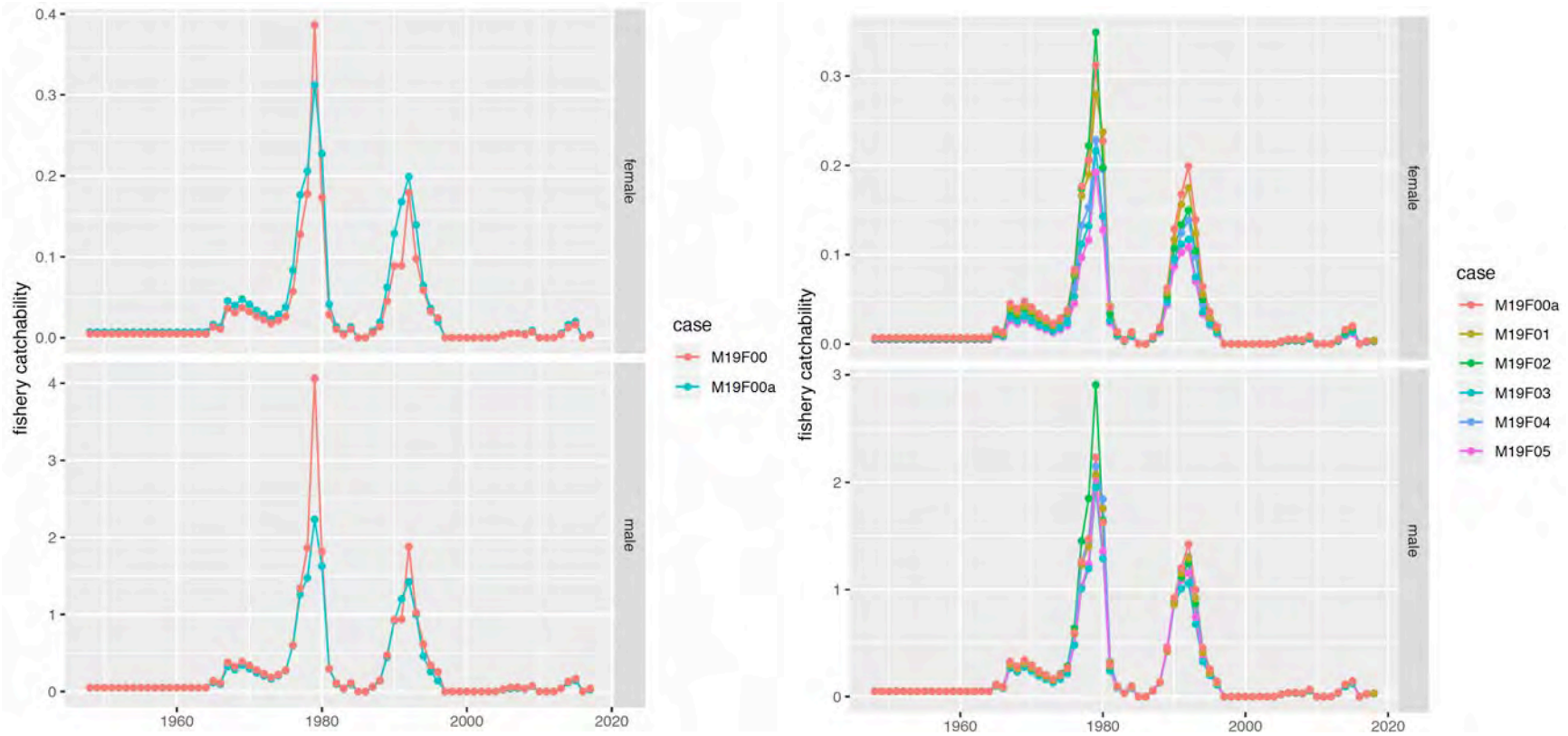


Figure 37. Directed fishery catchability (capture rates) from all model scenarios.

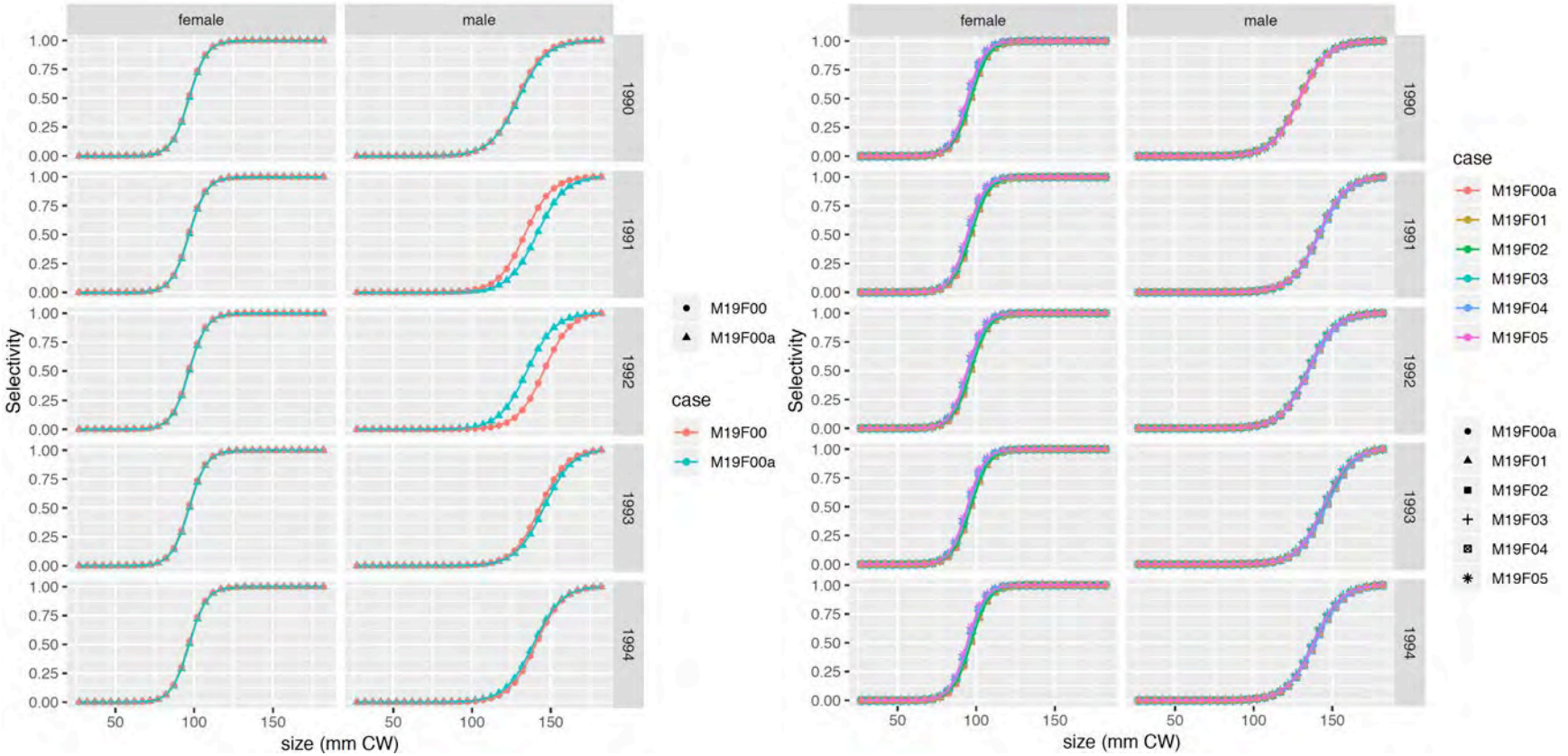


Figure 38. Directed fishery selectivity curves from all scenarios for the pre-1991 time period and 1991-1994. The 50%-selected parameter varies annually for 1991+.

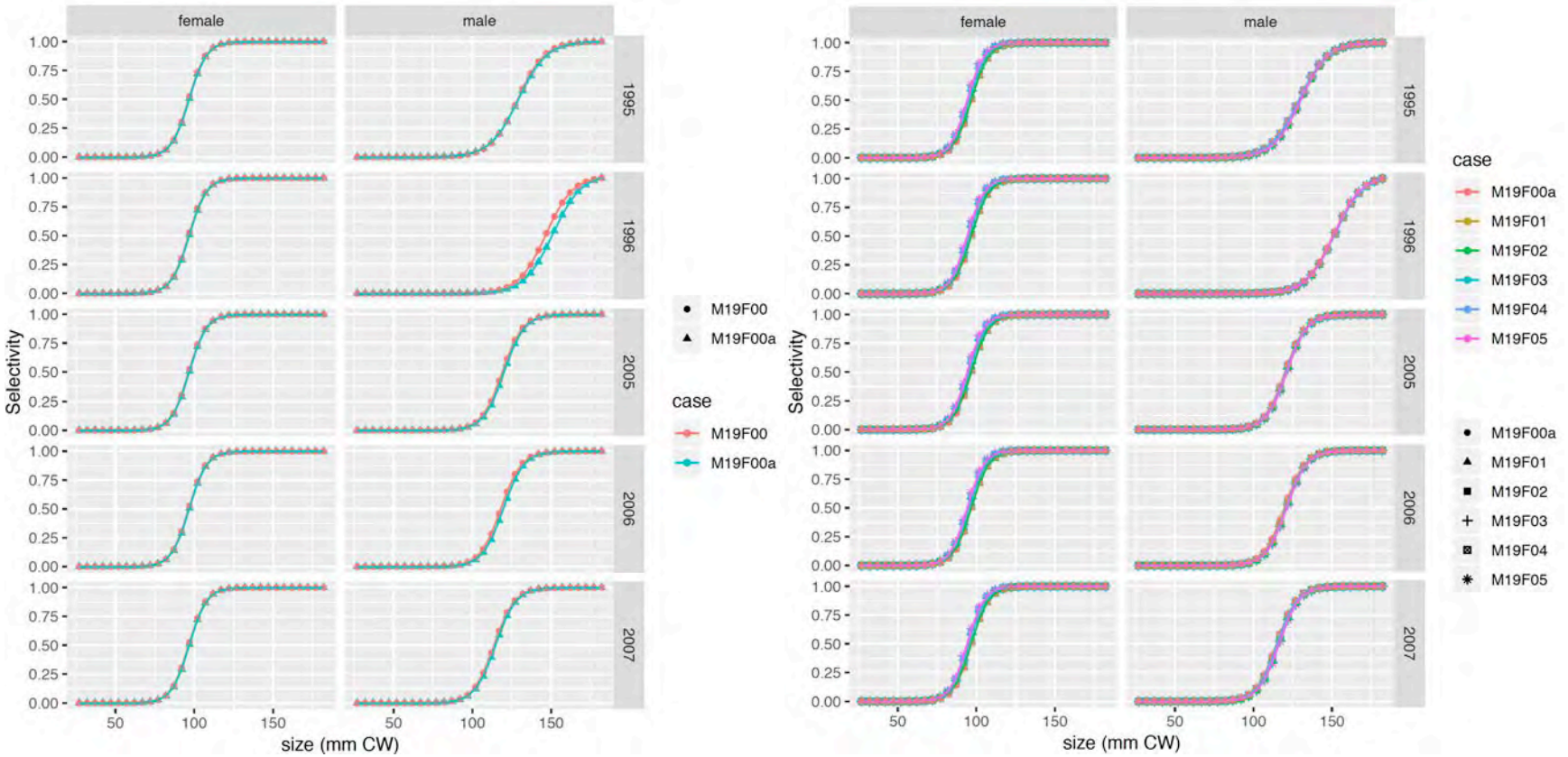


Figure 39. Directed fishery selectivity curves from all scenarios for 1995-1996 and 2005-2007. The 50%-selected parameter varies annually for 1991+.

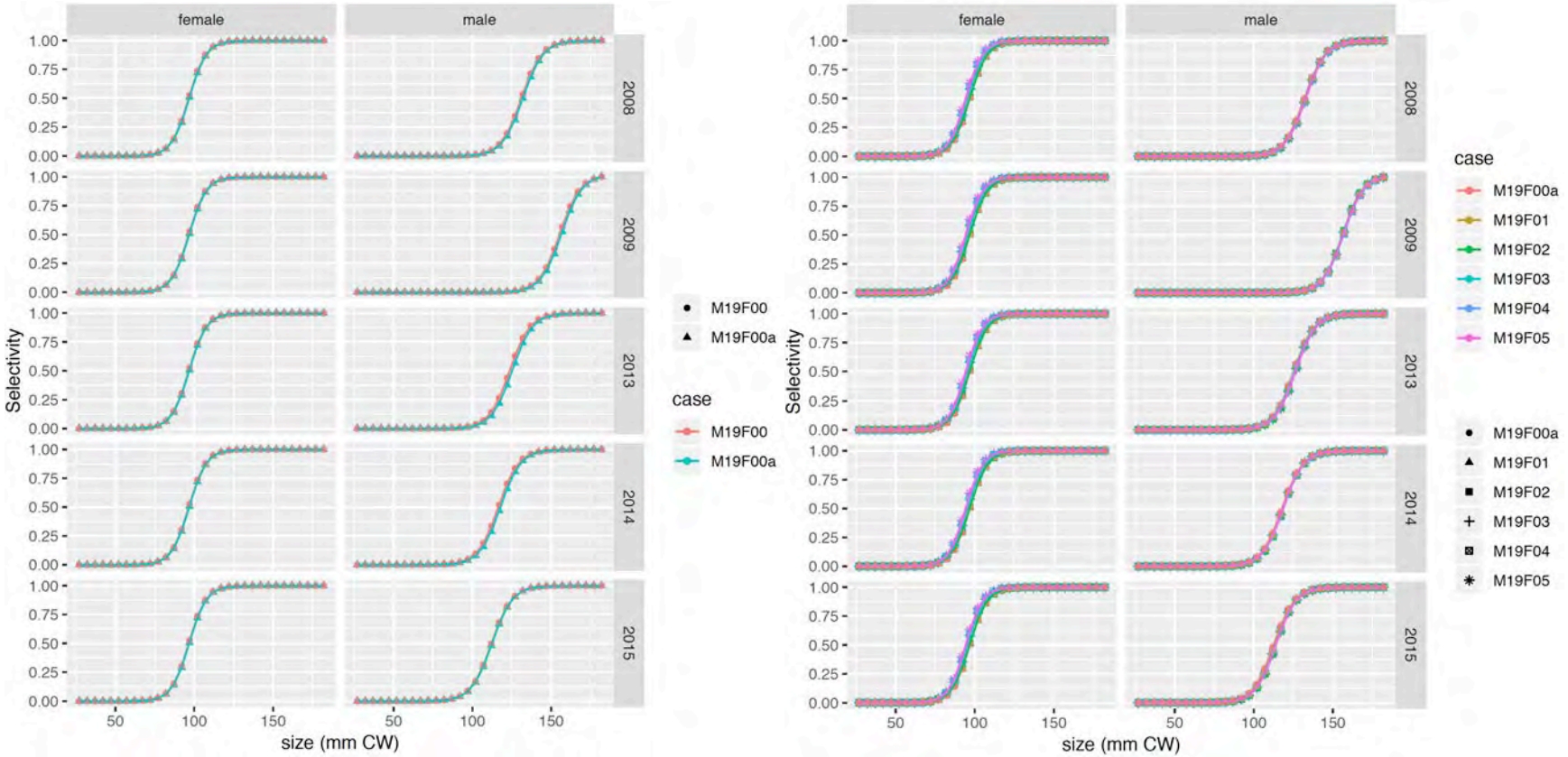


Figure 40. Directed fishery selectivity curves from all scenarios for 2008-2009 and 2013-2015. The 50%-selected parameter varies annually for 1991+.

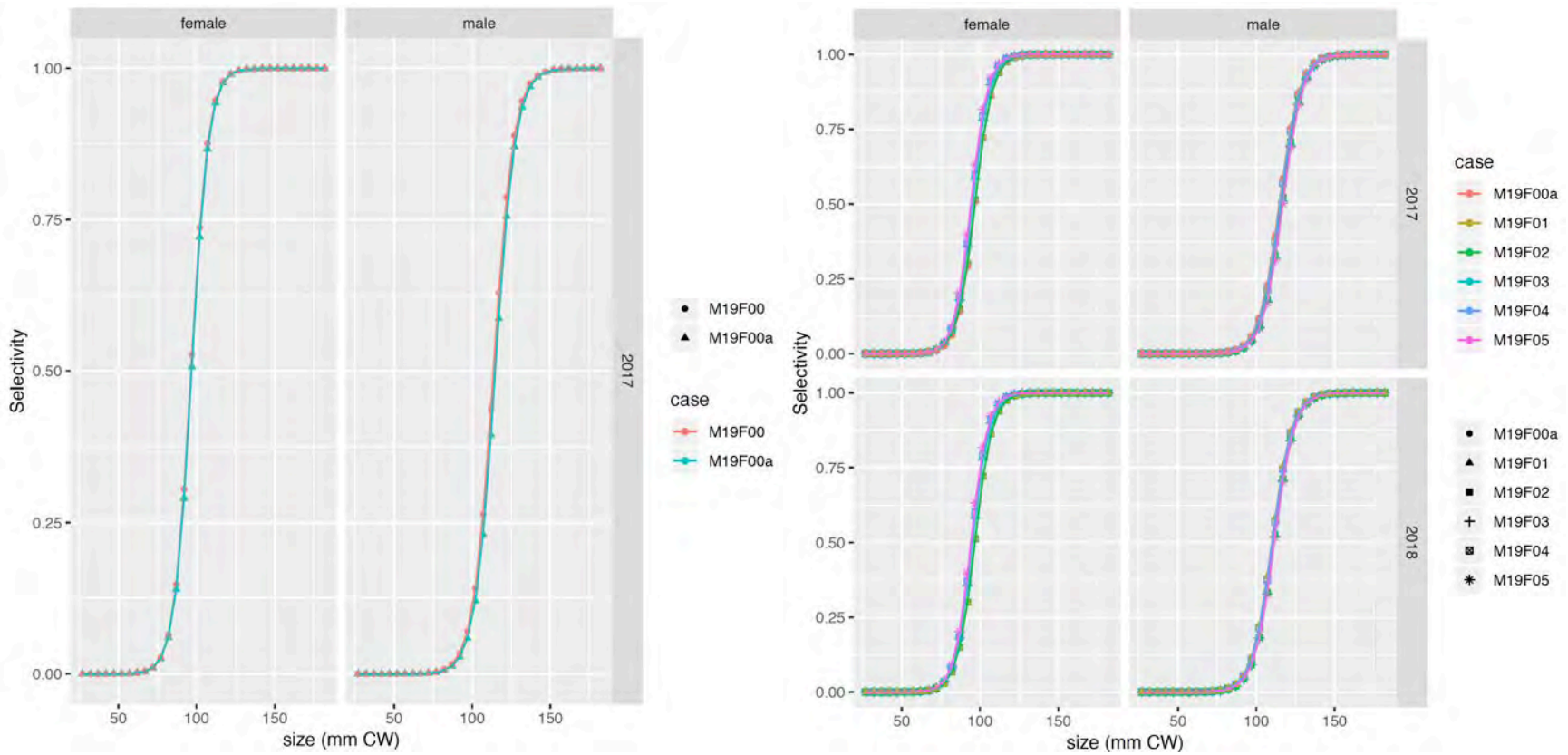


Figure 41. Directed fishery selectivity curves from all scenarios for 2008-2009 and 2013-2015. The 50%-selected parameter varies annually for 1991+.

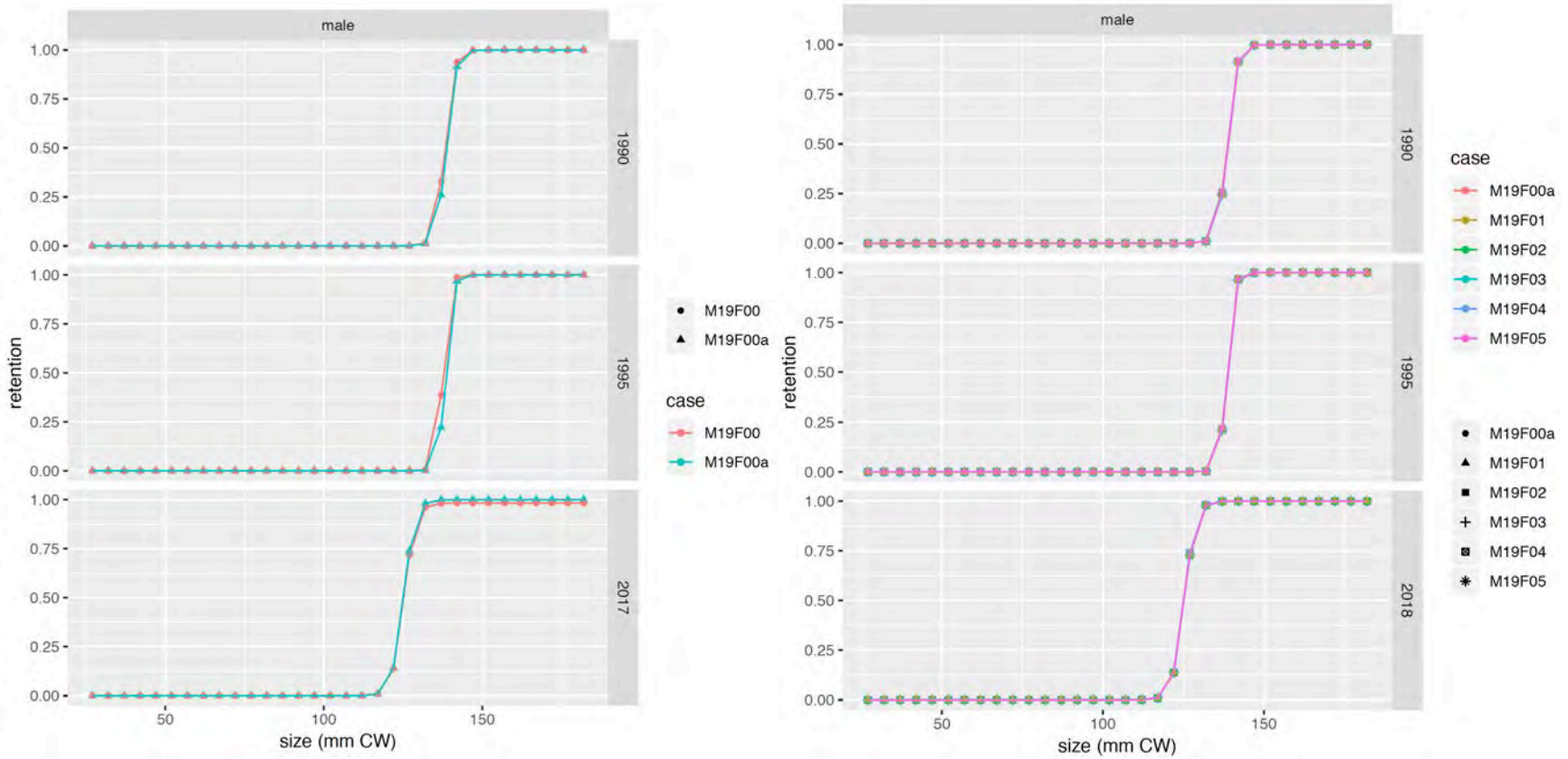


Figure 42. Directed fishery retention curves from all scenarios for the pre-1991, 1991-1996, and post-2004 time periods

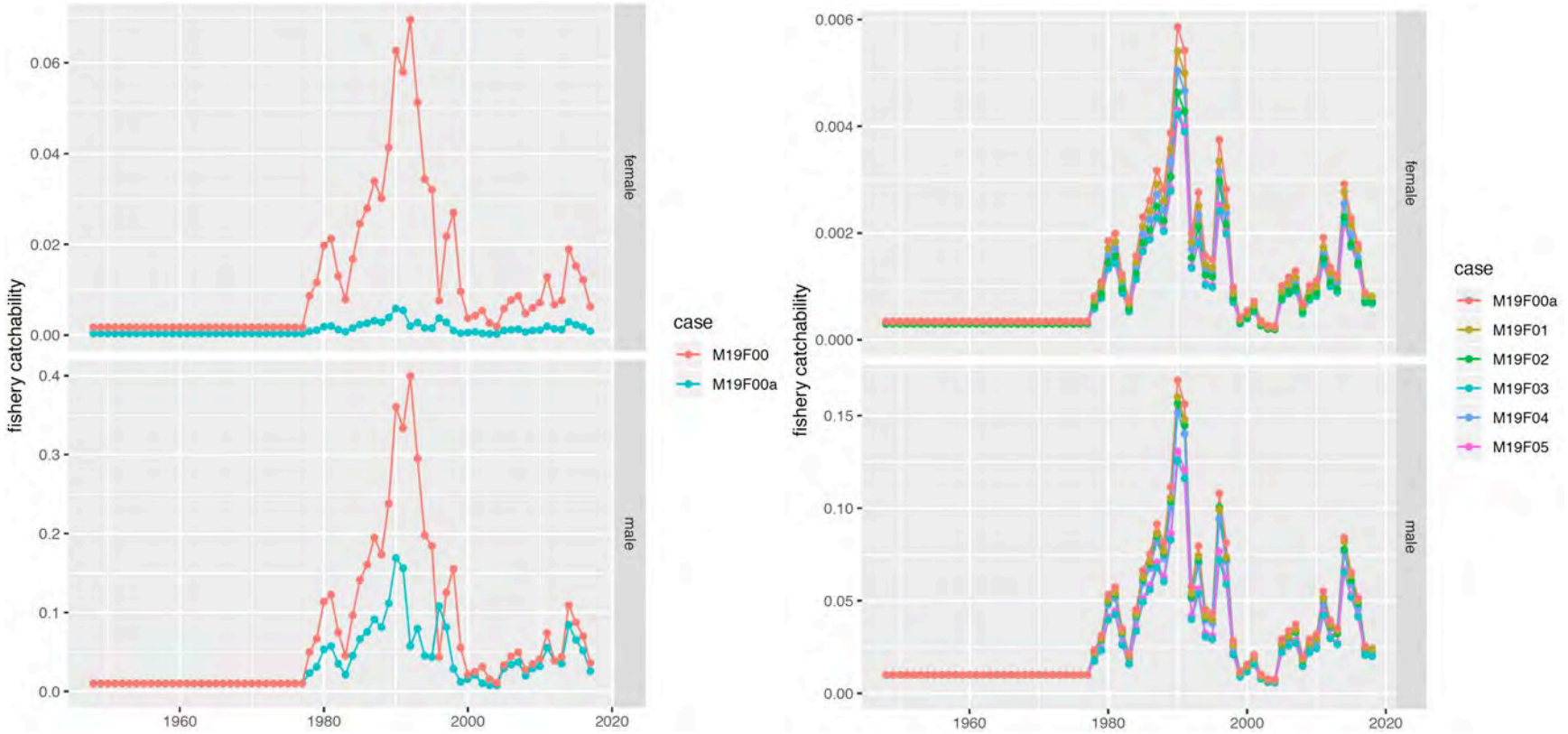


Figure 43. Snow crab fishery catchability (capture rates) from all scenarios.

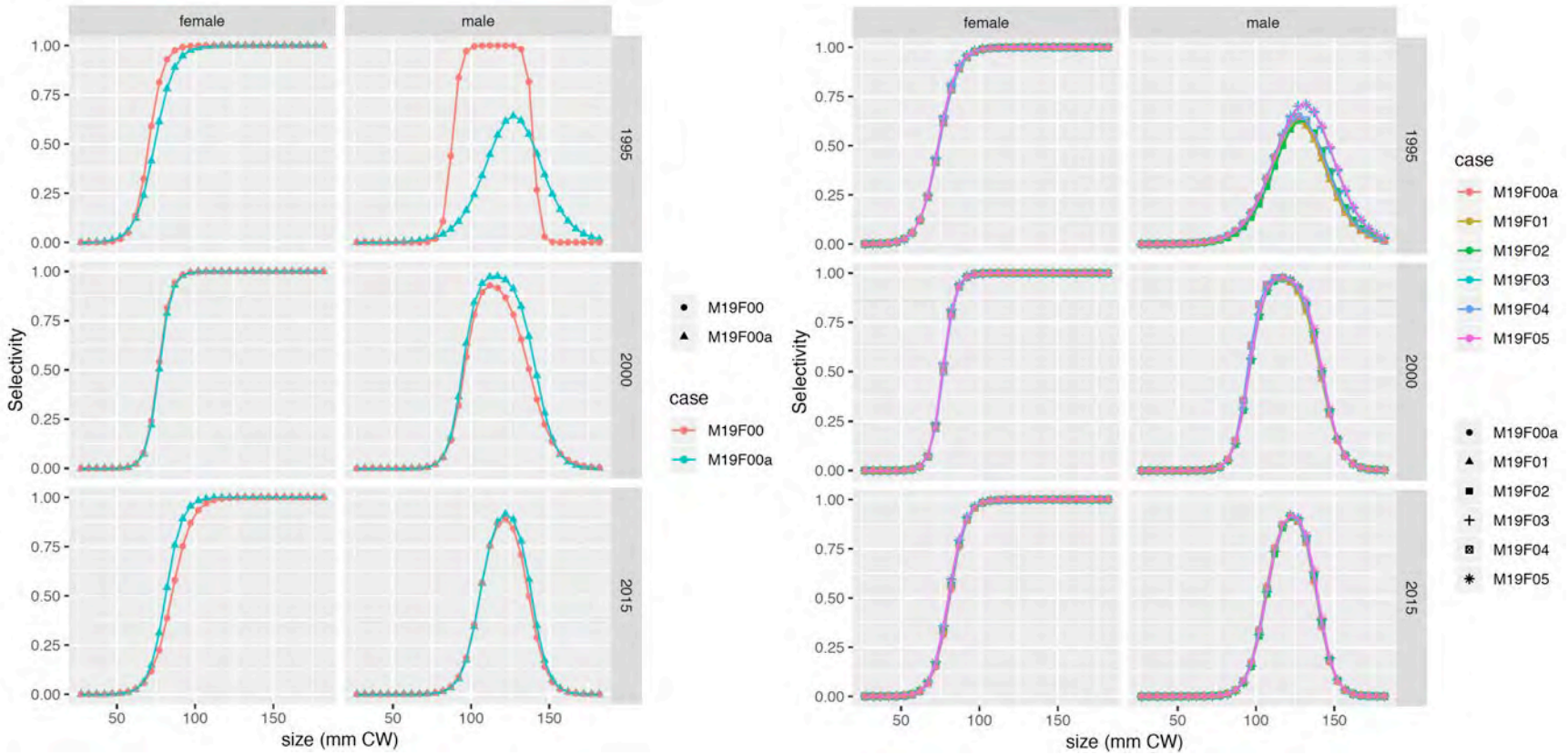


Figure 44. Snow crab fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

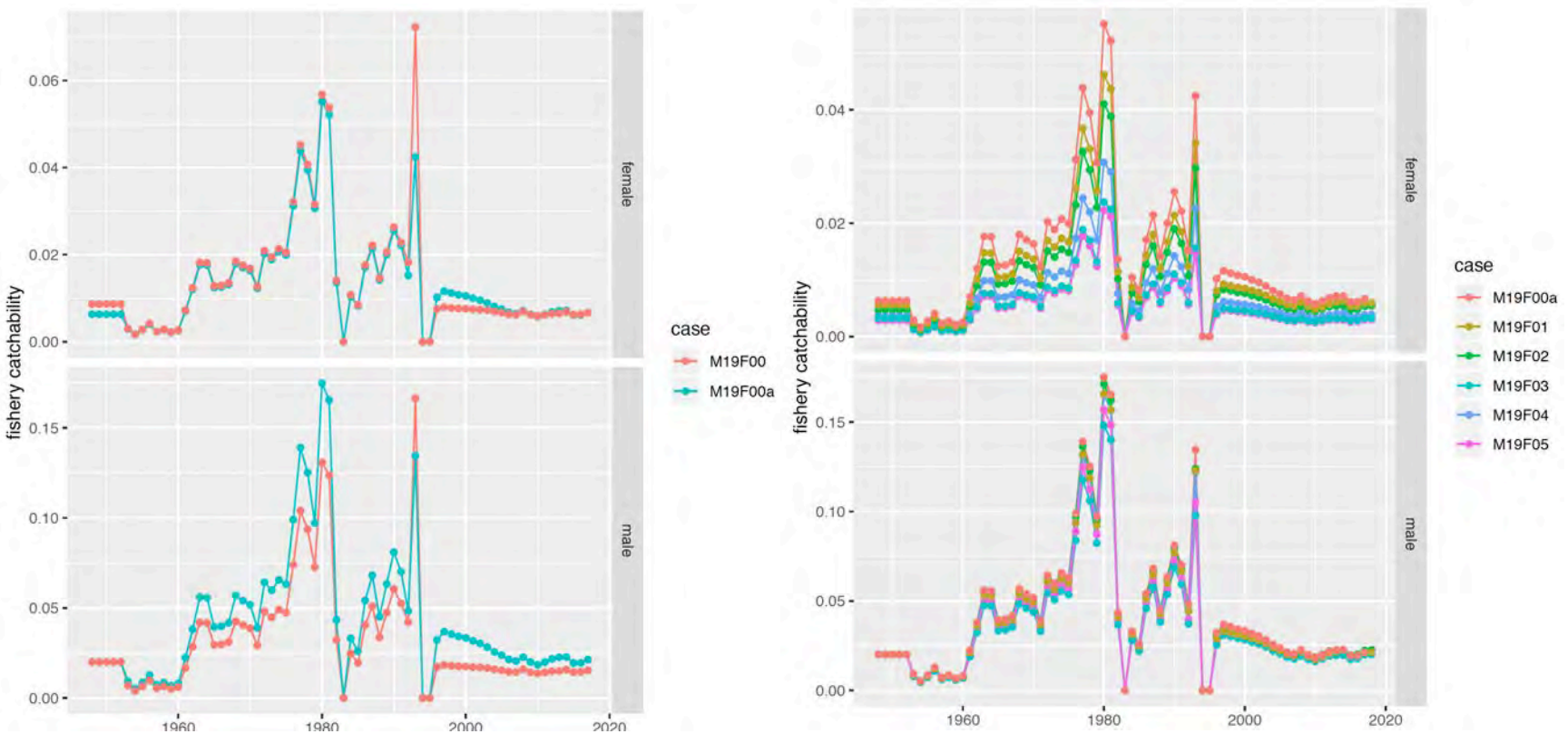


Figure 45. BBRKC fishery catchability (capture rates) from all scenarios.

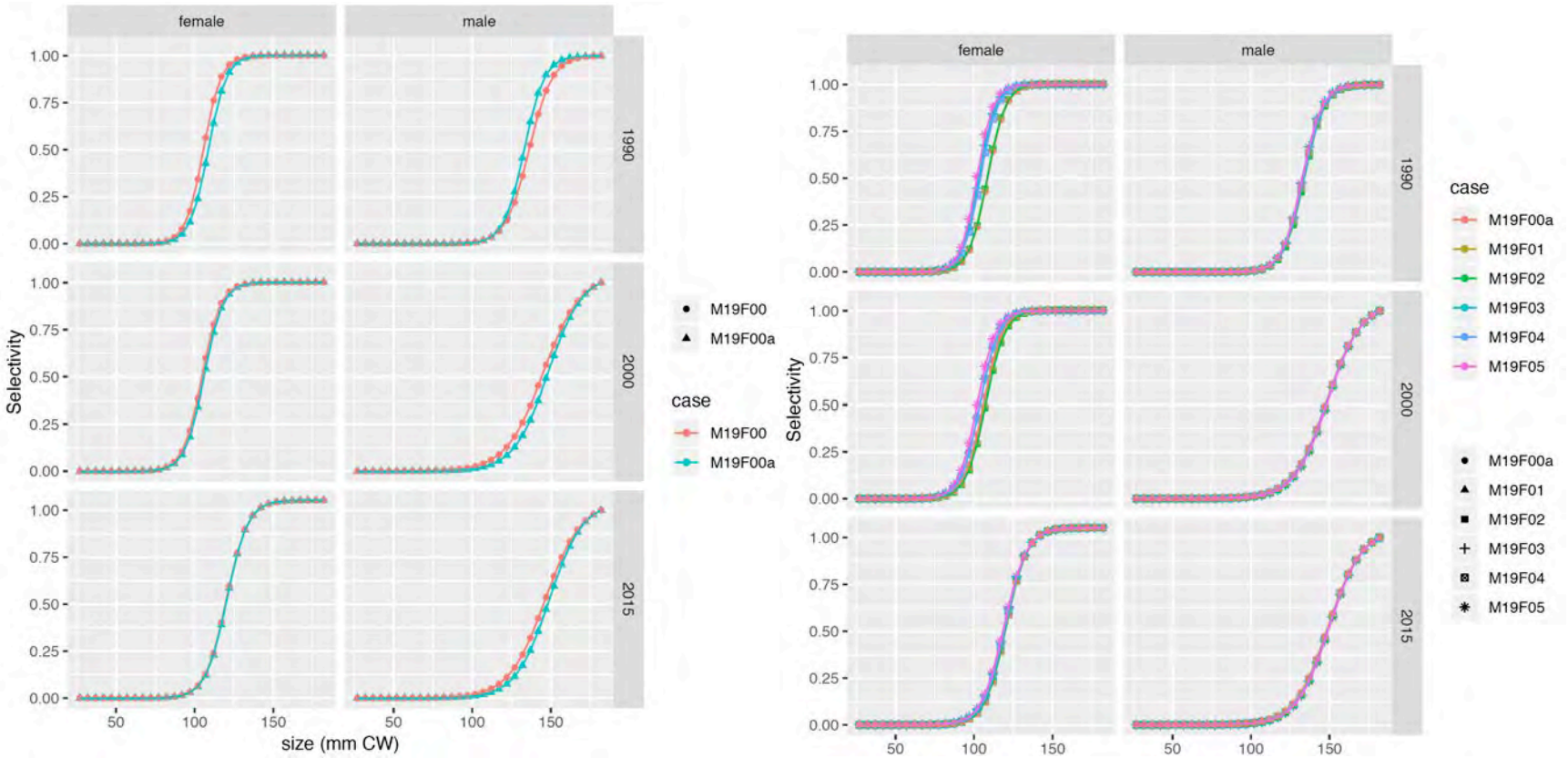


Figure 46. BBRKC fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

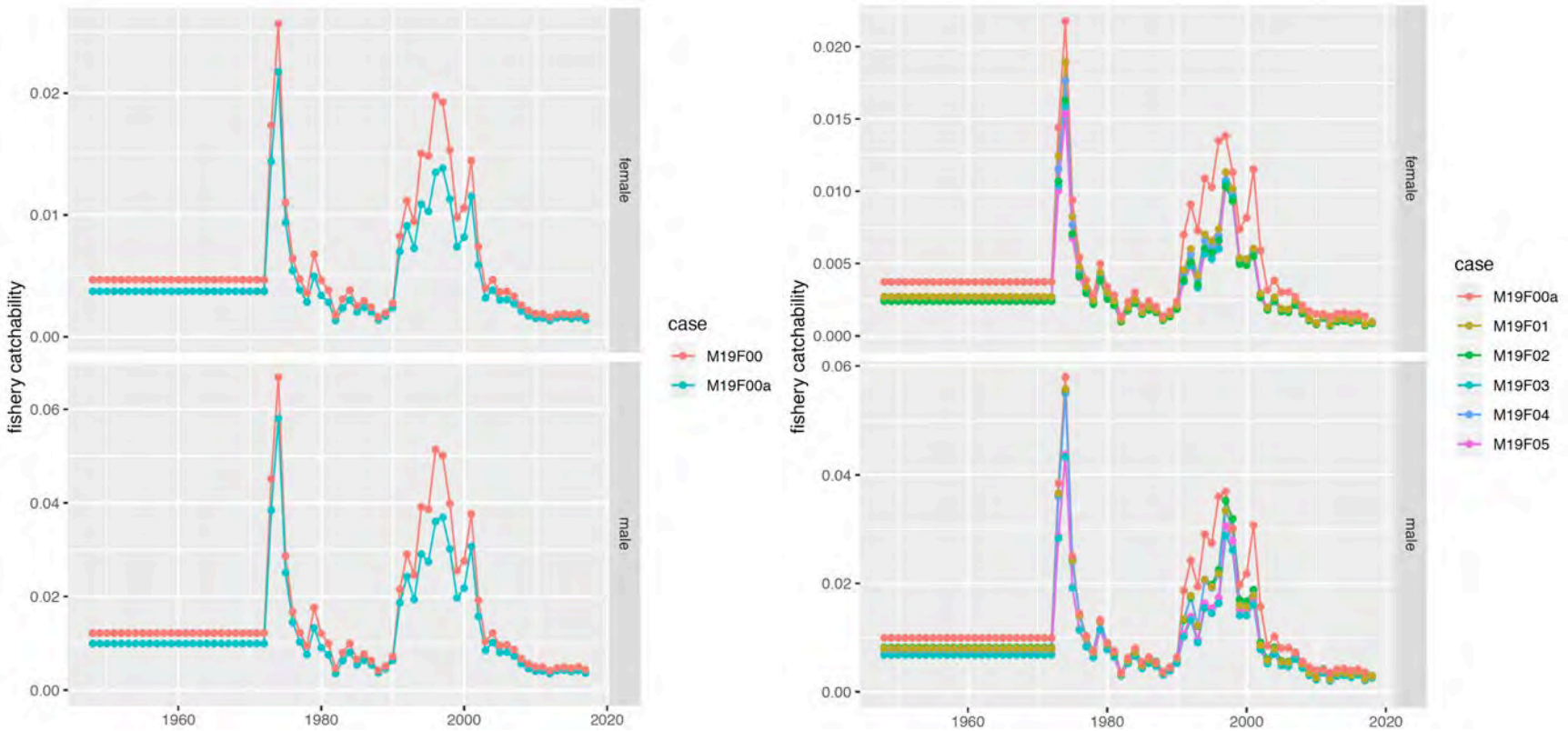


Figure 47. Catchability (capture rates) in the groundfish fisheries from all scenarios.

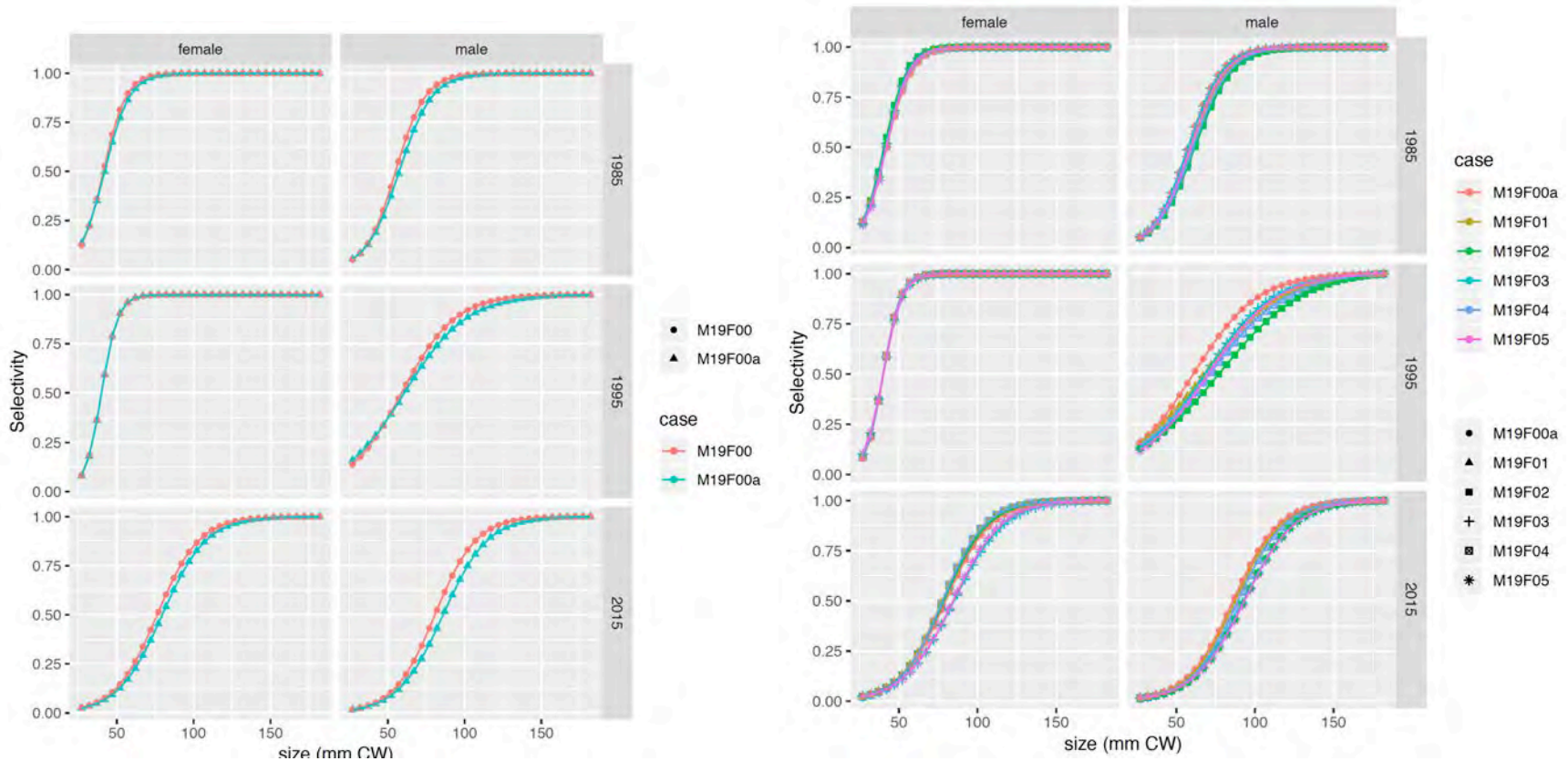


Figure 48. Groundfish fisheries selectivity curves from all scenarios estimated for 3 time periods: pre-1987, 1987-1996, 1997+.

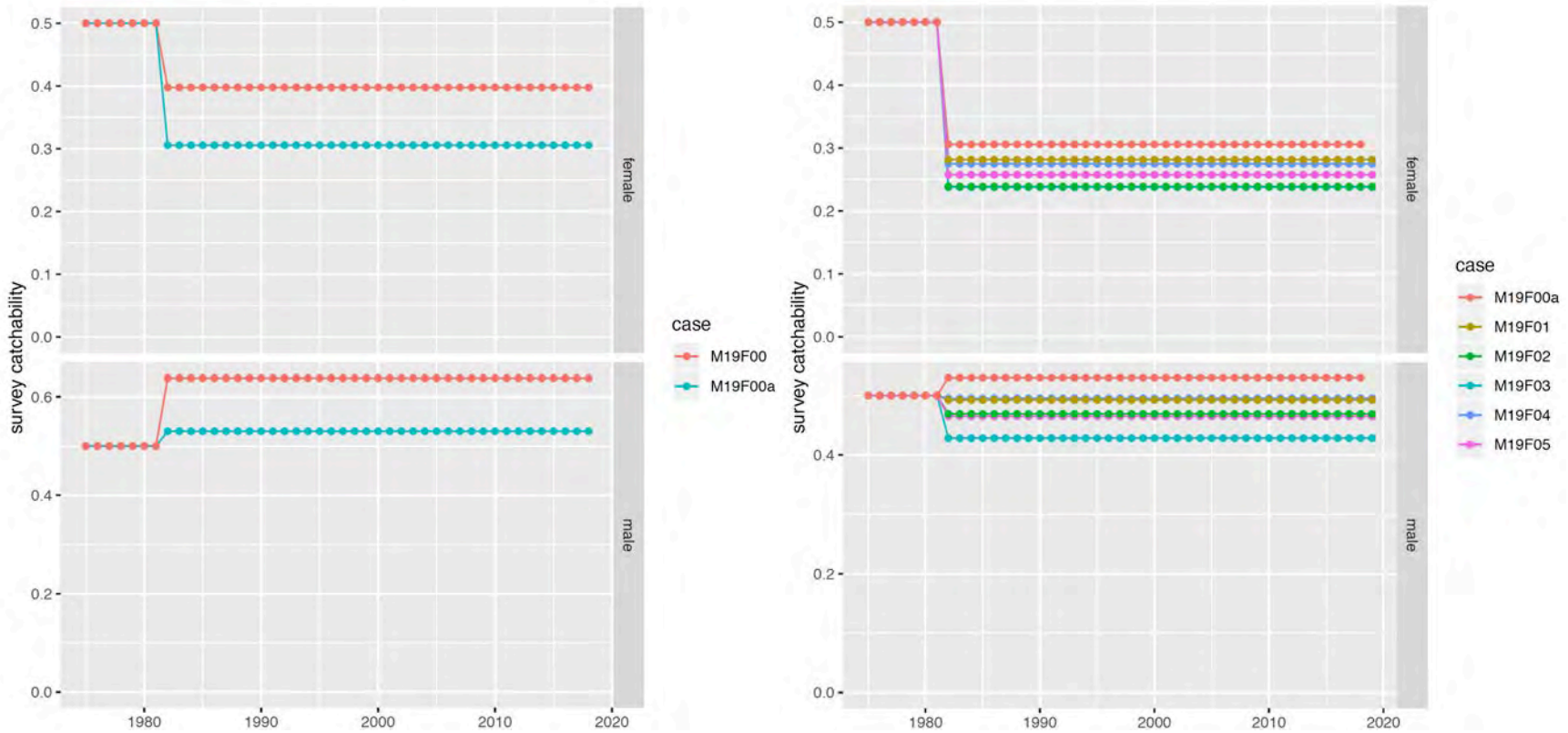


Figure 49. NMFS "0" survey catchabilities for all scenarios for the 1975-1981 and 1982+ time periods.

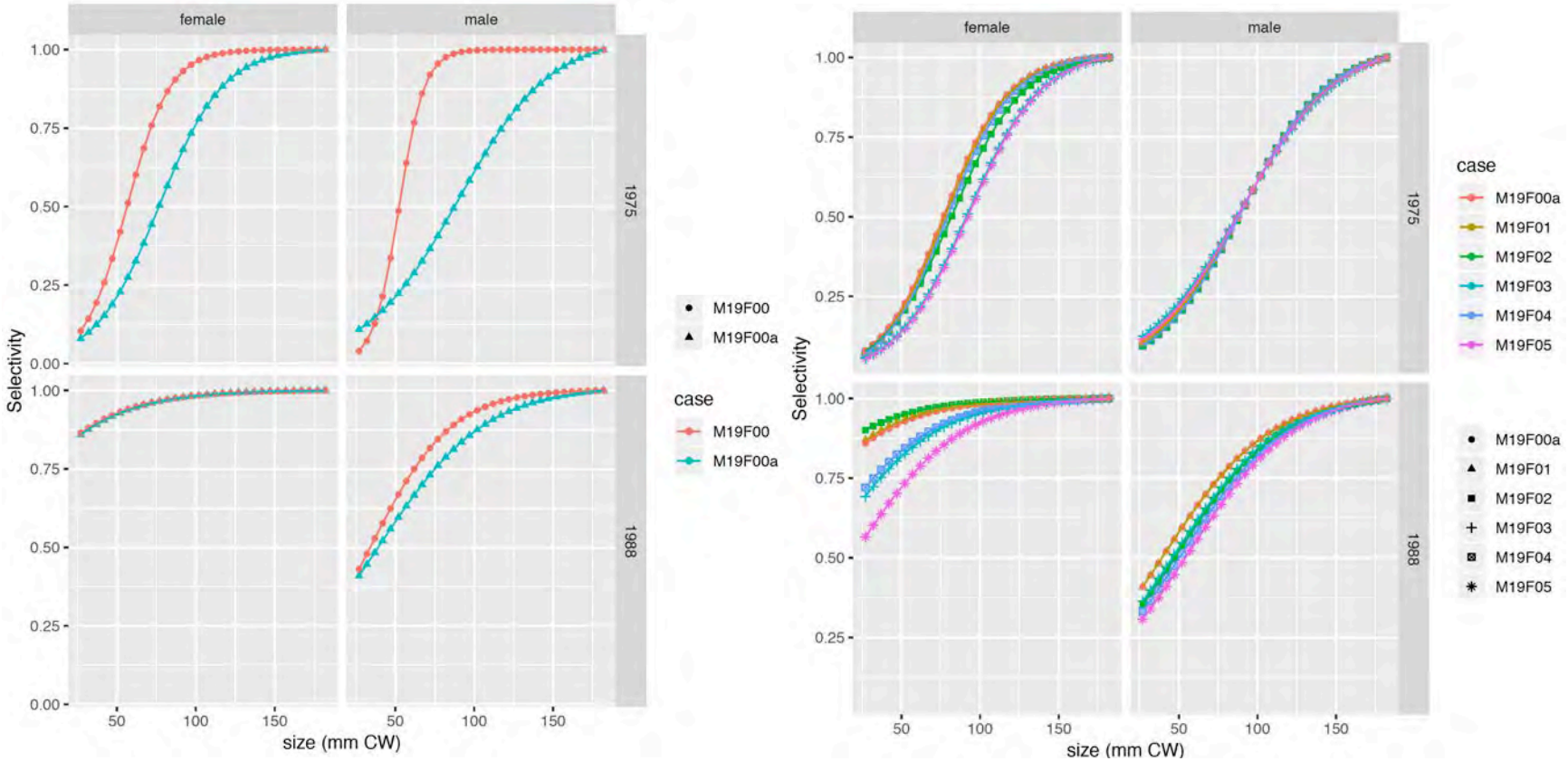


Figure 50. NMFS "0" survey selectivity functions for all scenarios for the 1975-1981 and 1982+ time periods.

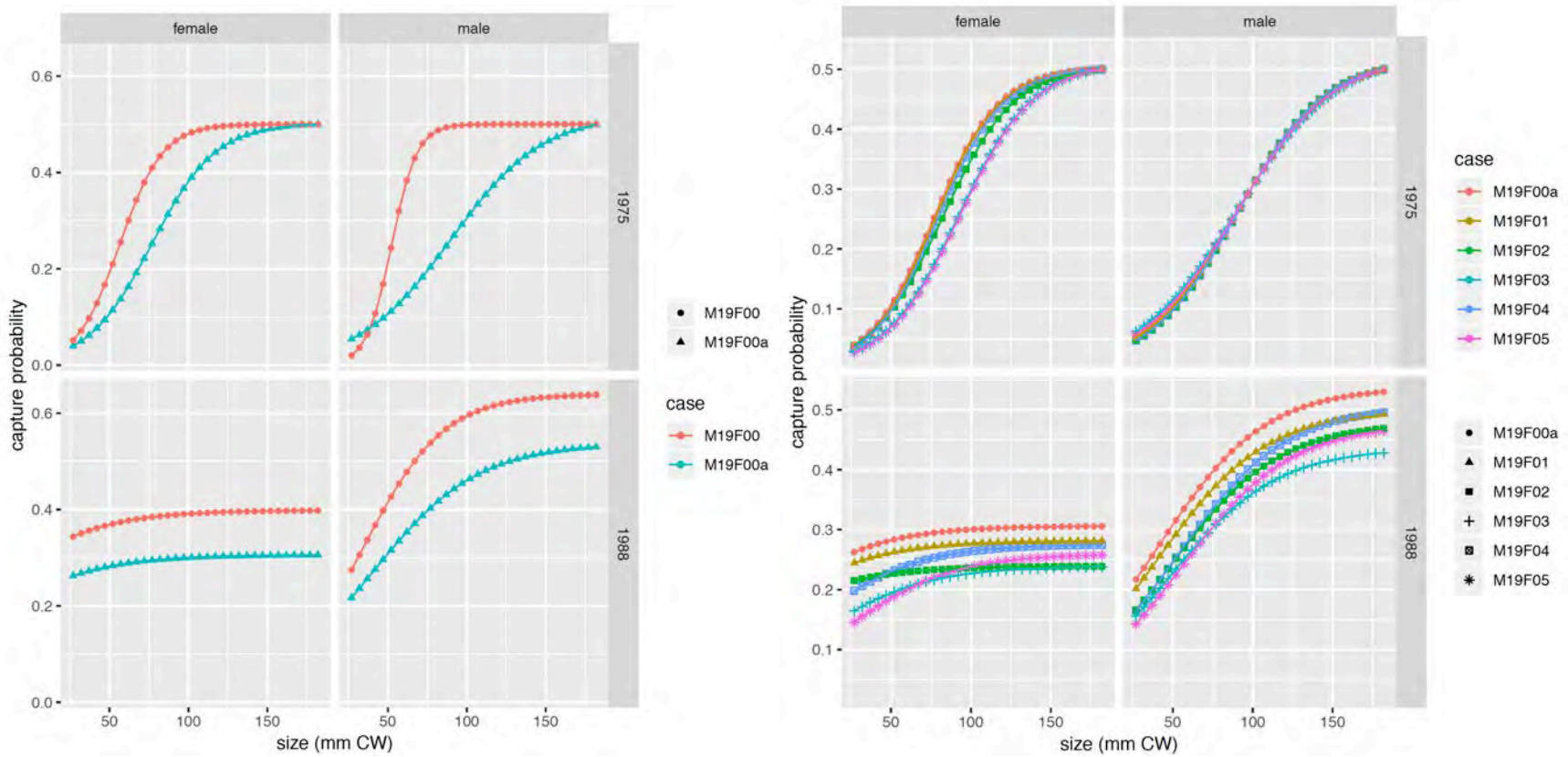


Figure 51. NMFS "0" survey capture probabilities (i.e., catchability *x* selectivity) for all scenarios for the 1975-1981 and 1982+ time periods.

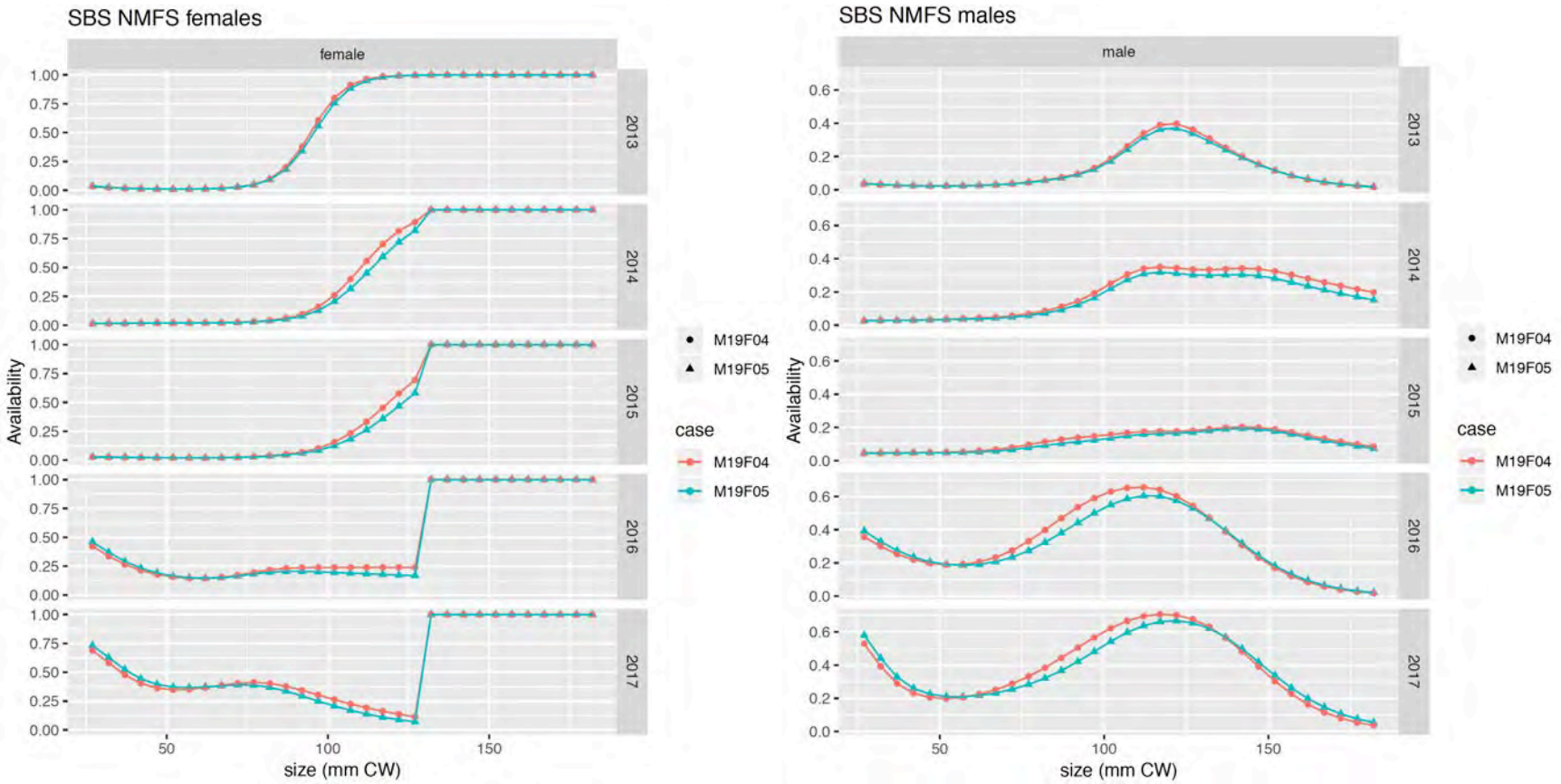


Figure 52. Survey availabilities from scenarios M19F04 and M19F05 for the 2013-2017 SBS studies.

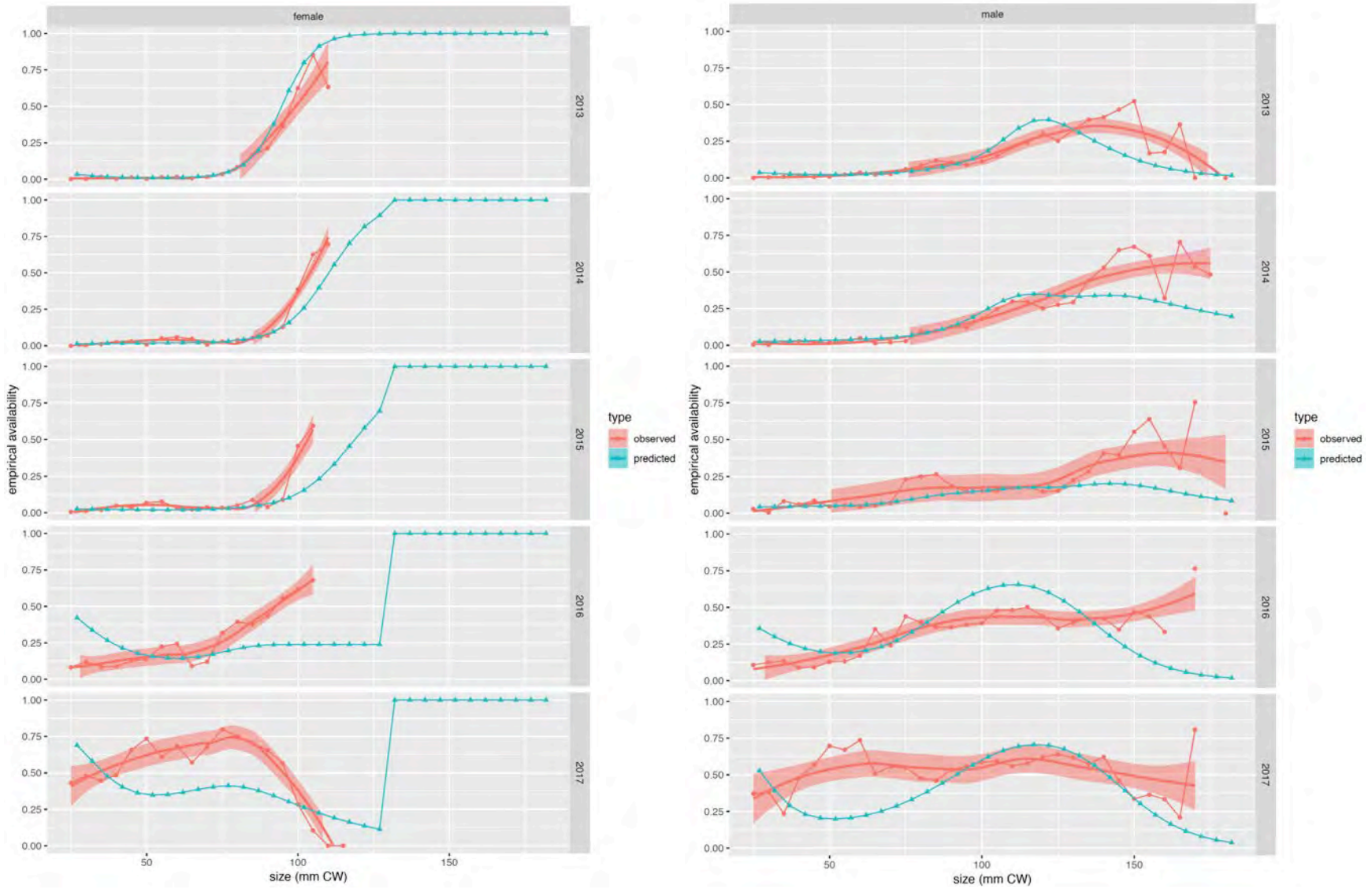


Figure 53. Comparison of empirical "observed" and predicted availability in the 2013-2017 SBS studies from scenario M19F04. The "observed" availability is the ratio of abundance in the NMFS SBS survey to that in the full NMFS survey by size bin. Observed: red points, lines. Red fills are from loess smoothing of the observed availability. Predicted: green points, lines.

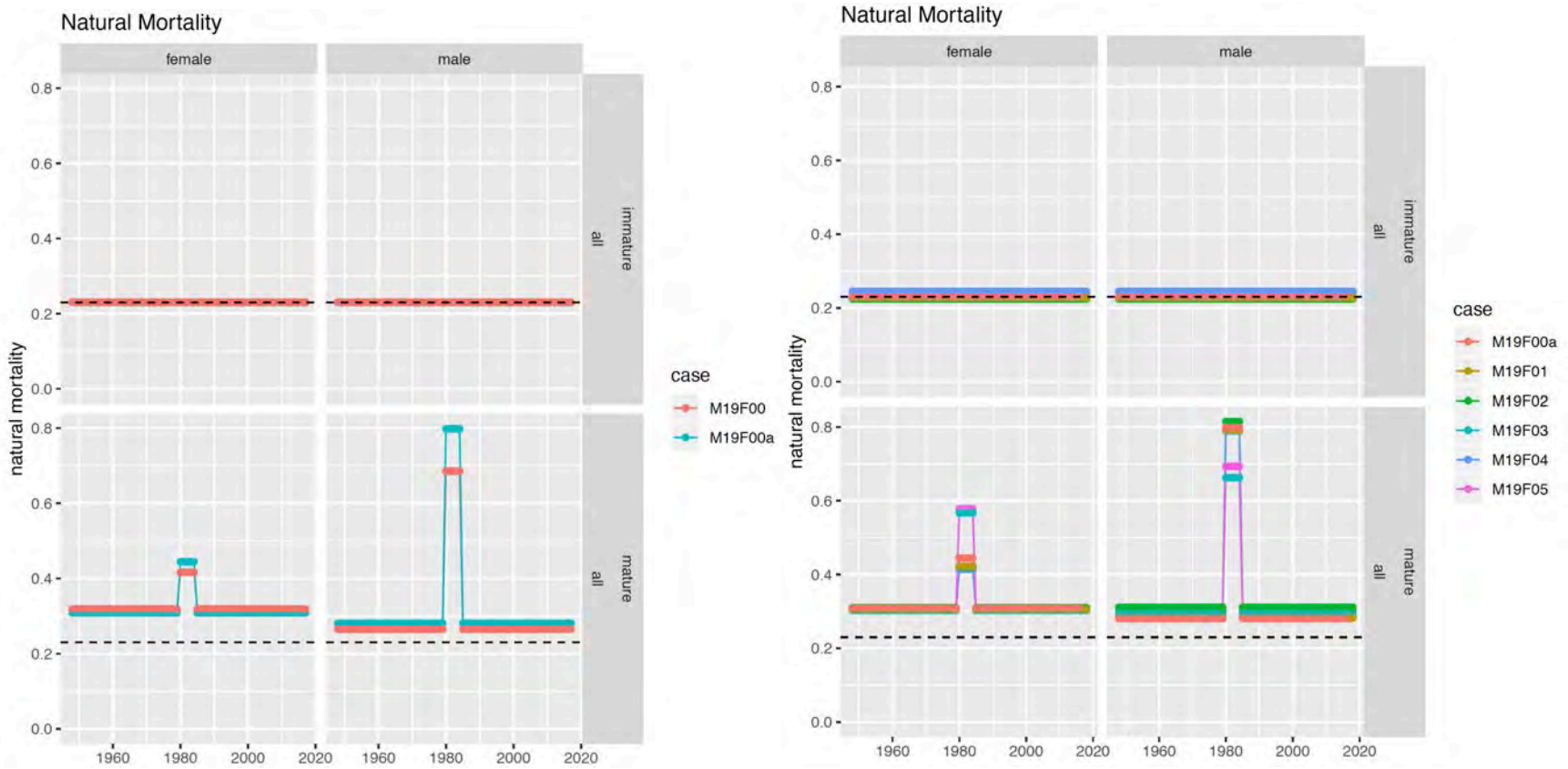


Figure 54. Estimates of natural mortality from all scenarios.

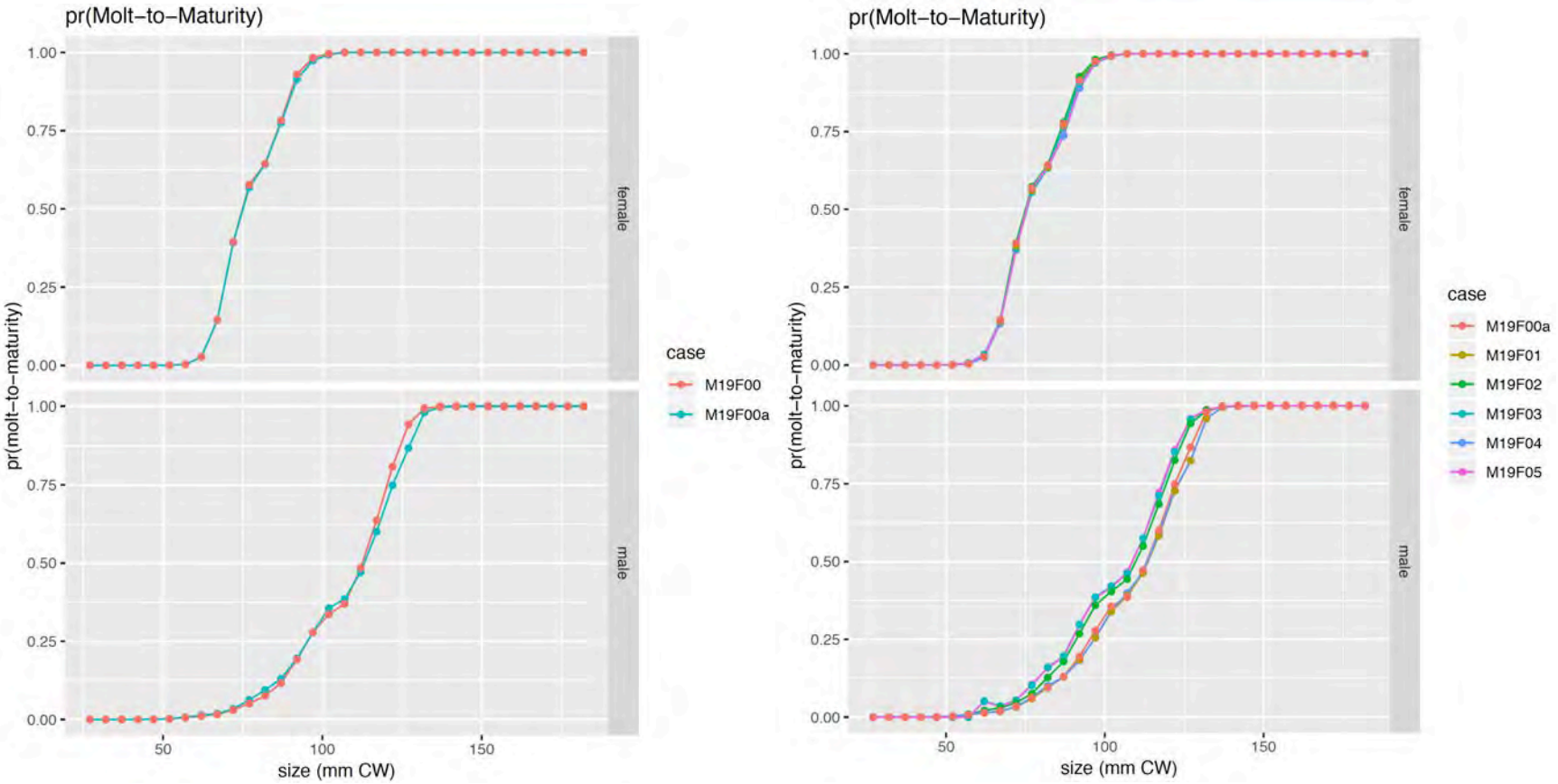


Figure 55. Estimates of the probability of terminal molt from all scenarios.

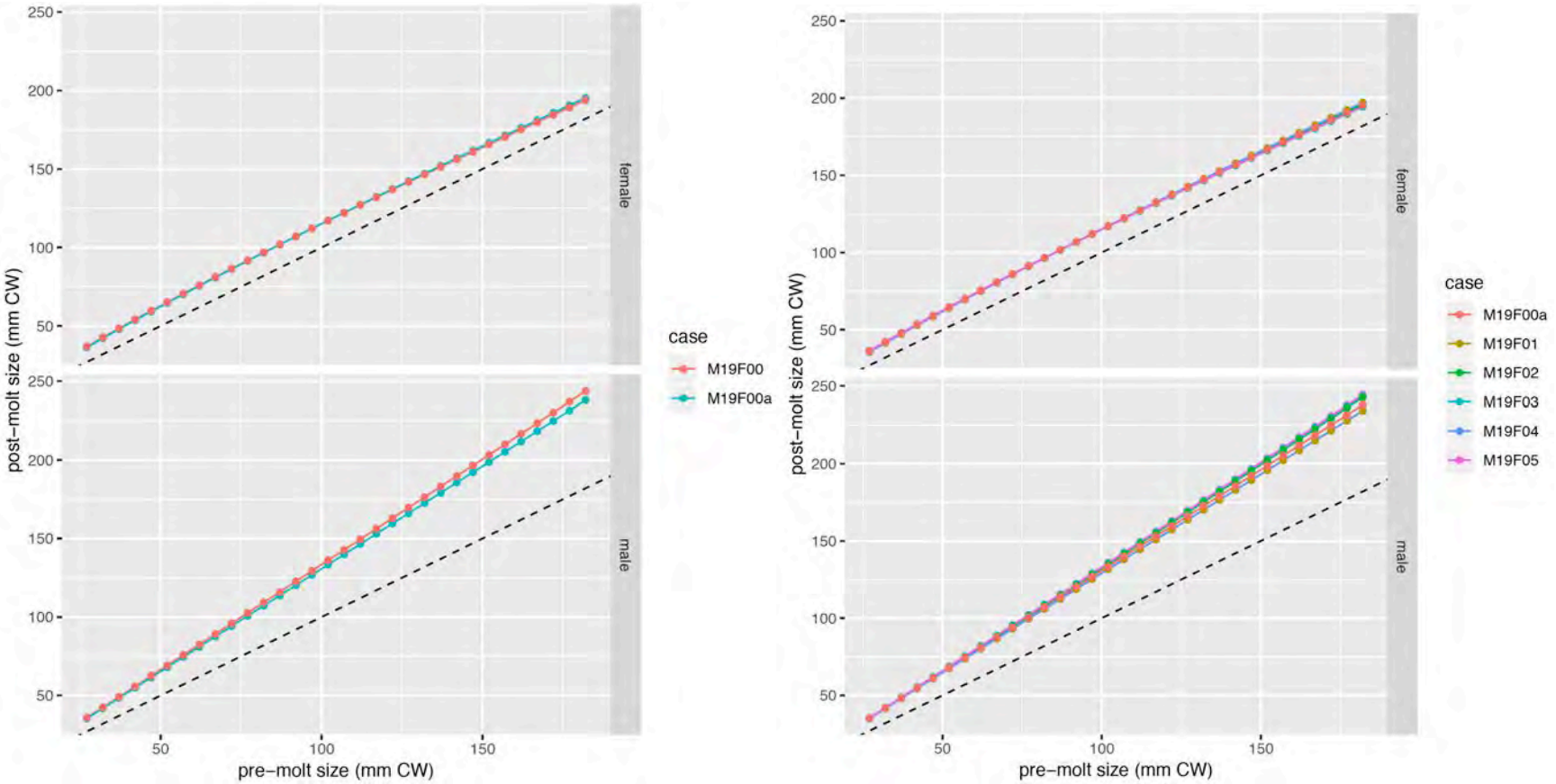


Figure 56. Estimates of mean growth from all scenarios. Dashed line is 1:1.

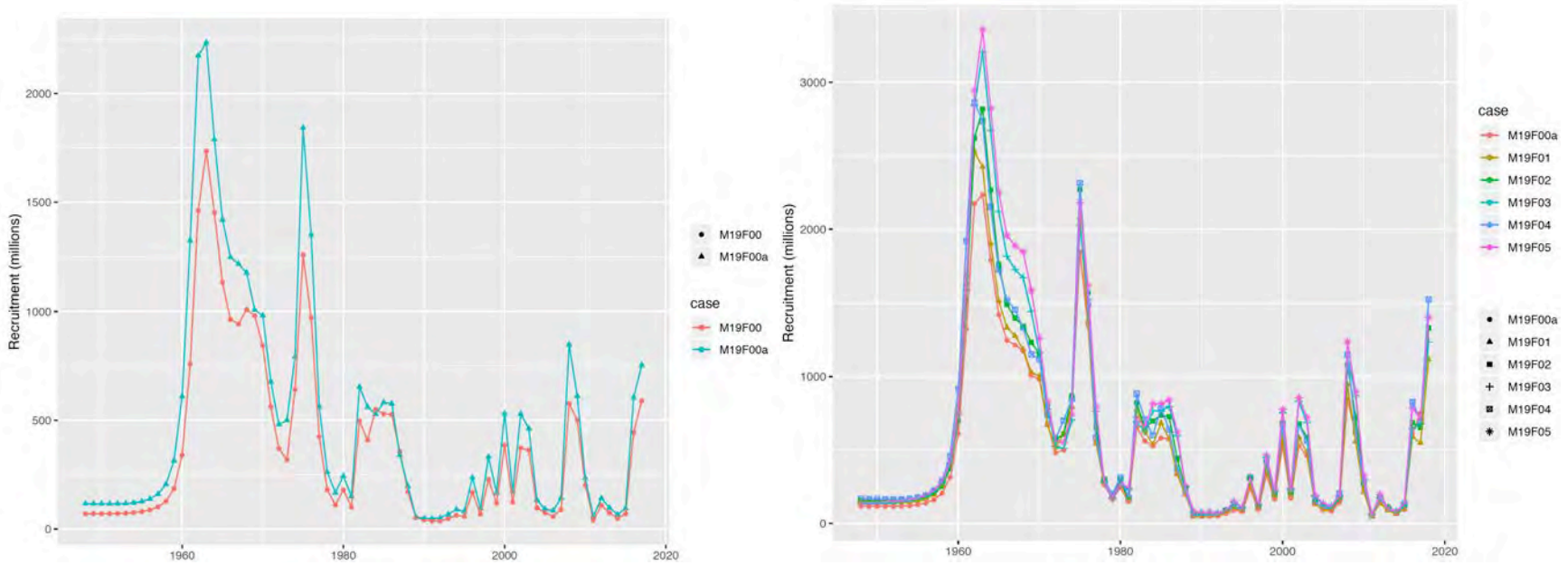


Figure 57. Estimated recruitment time series from all scenarios.

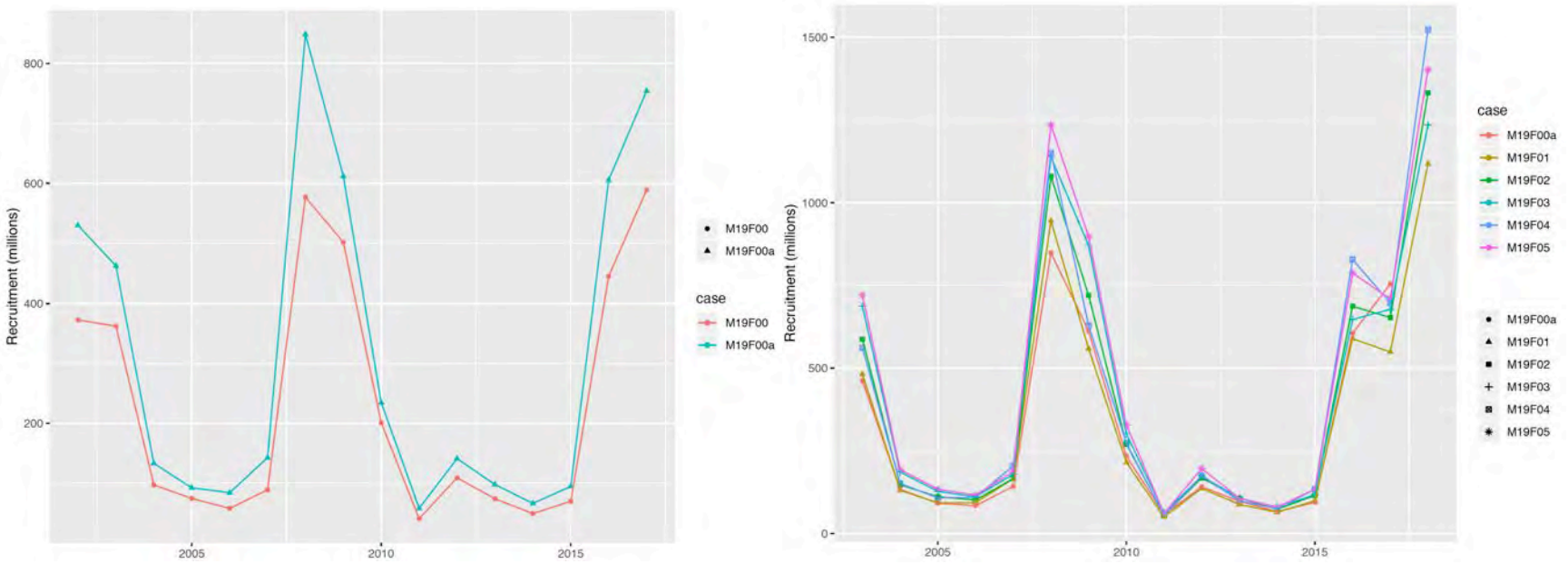


Figure 58. Estimated recent recruitment time series from all scenarios.

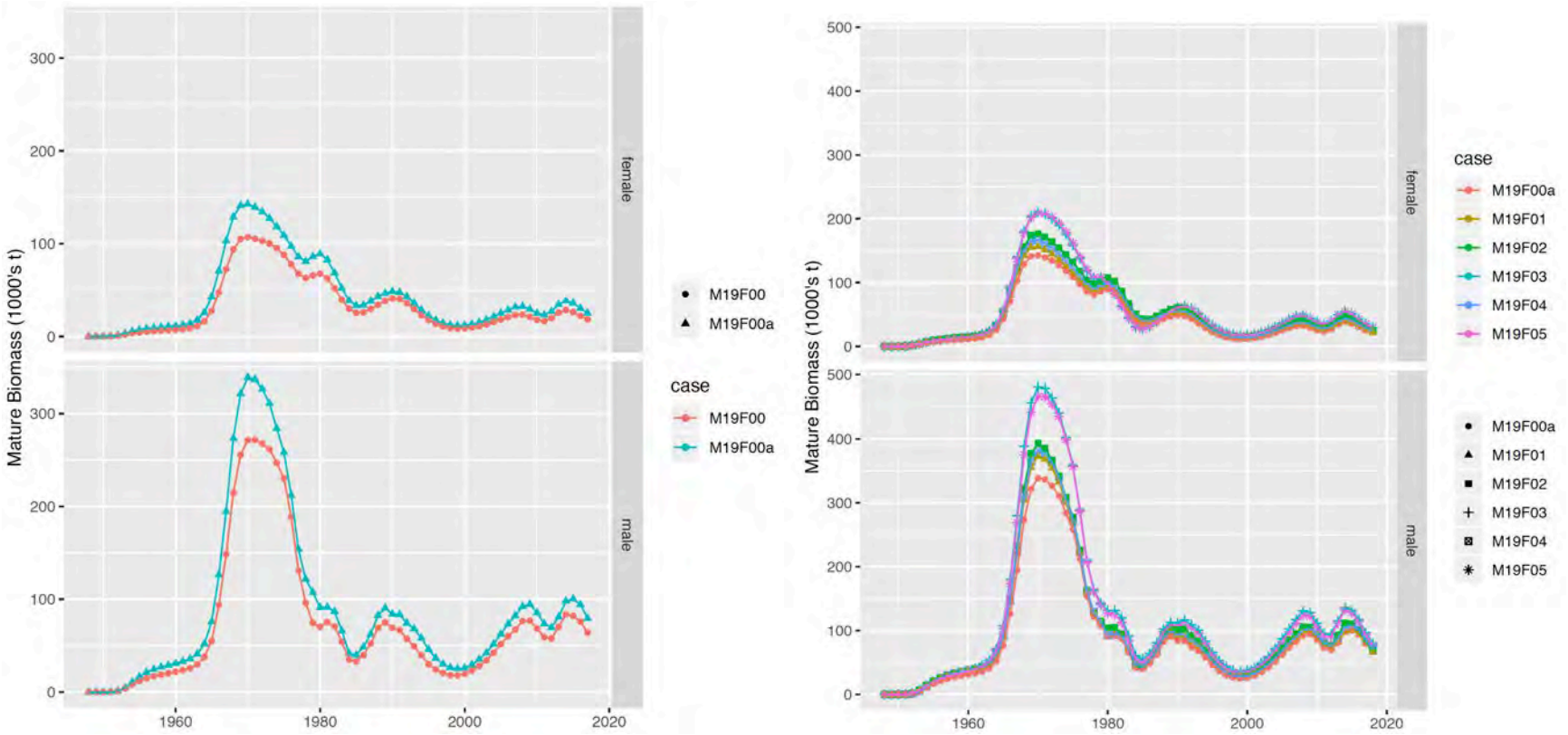


Figure 59. Estimated (Feb. 15) mature biomass time series from all scenarios.

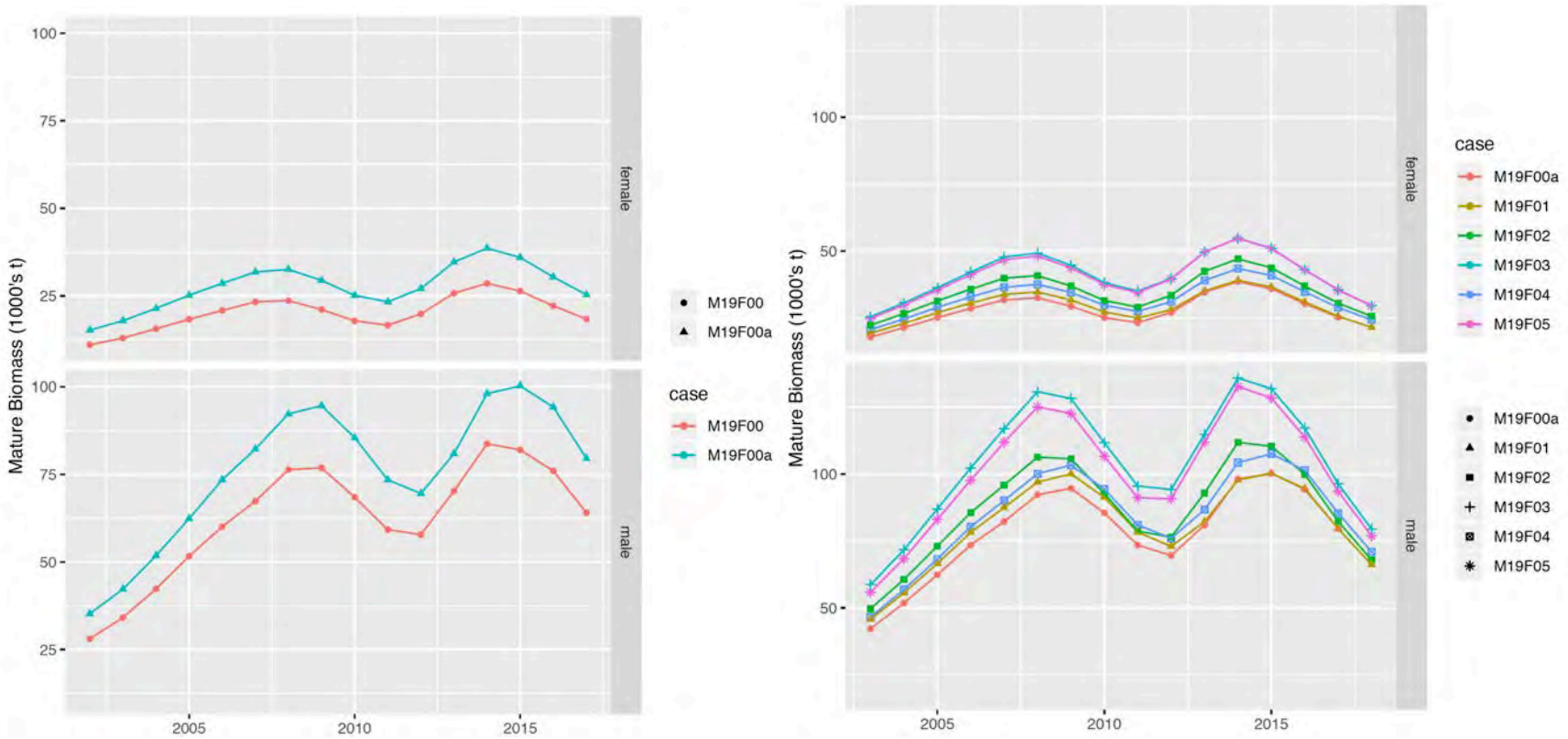


Figure 60. Estimated recent (Feb. 15) mature biomass time series from all scenarios.

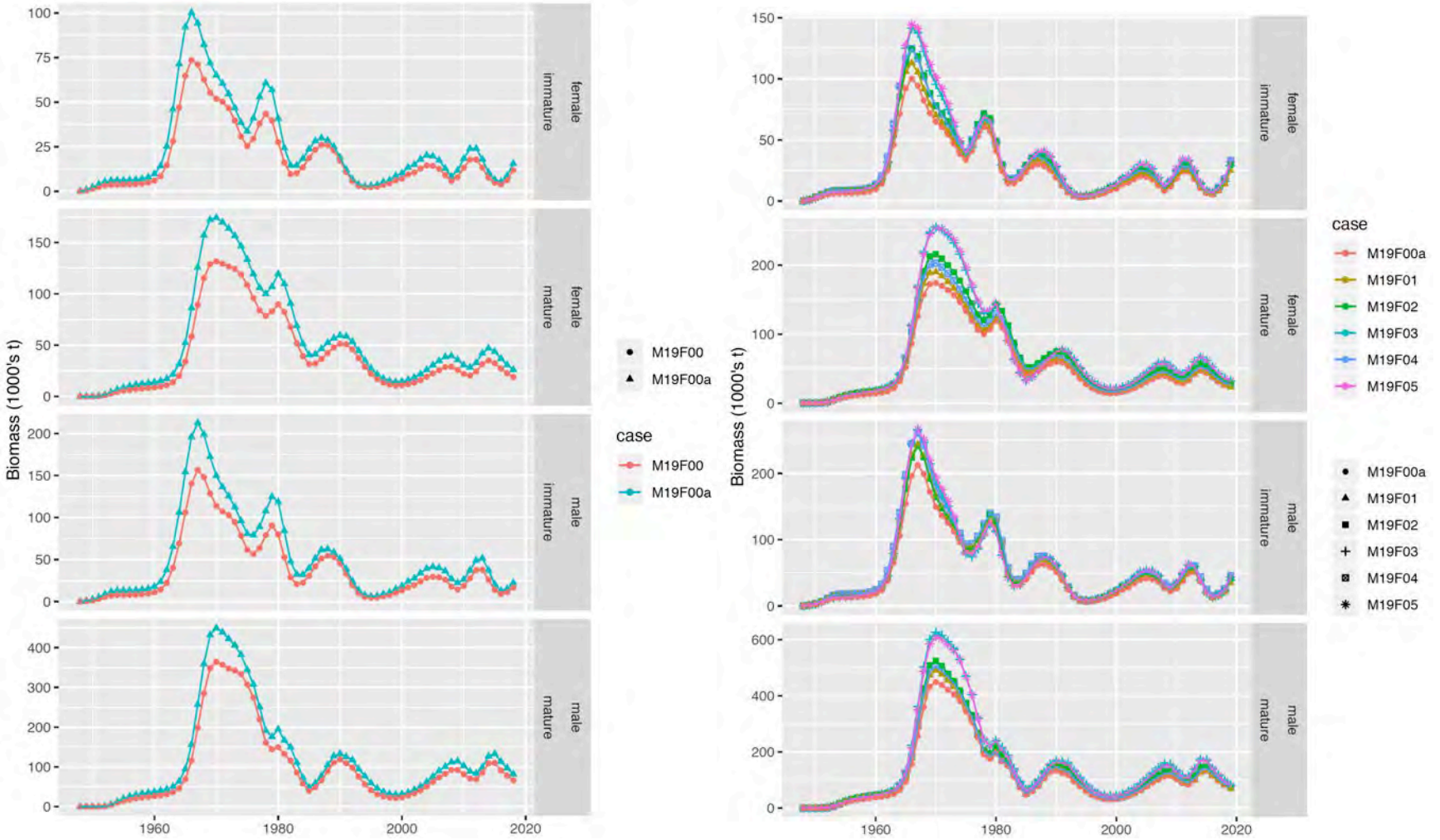


Figure 61. Estimated (July 1) biomass time series by population category for all scenarios.

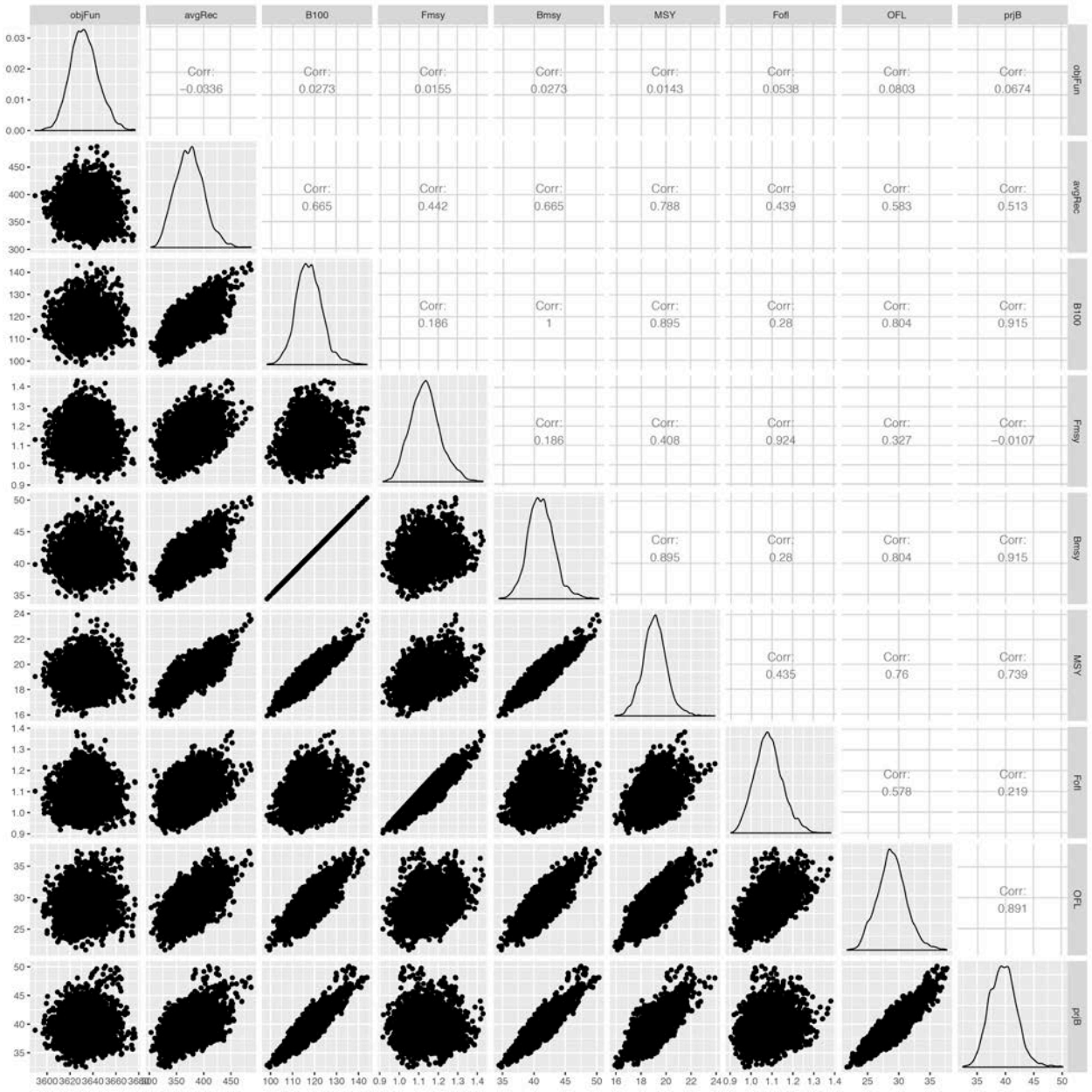


Figure 62. MCMC results from scenario M19F03, the author's preferred model, for OFL-related quantities.

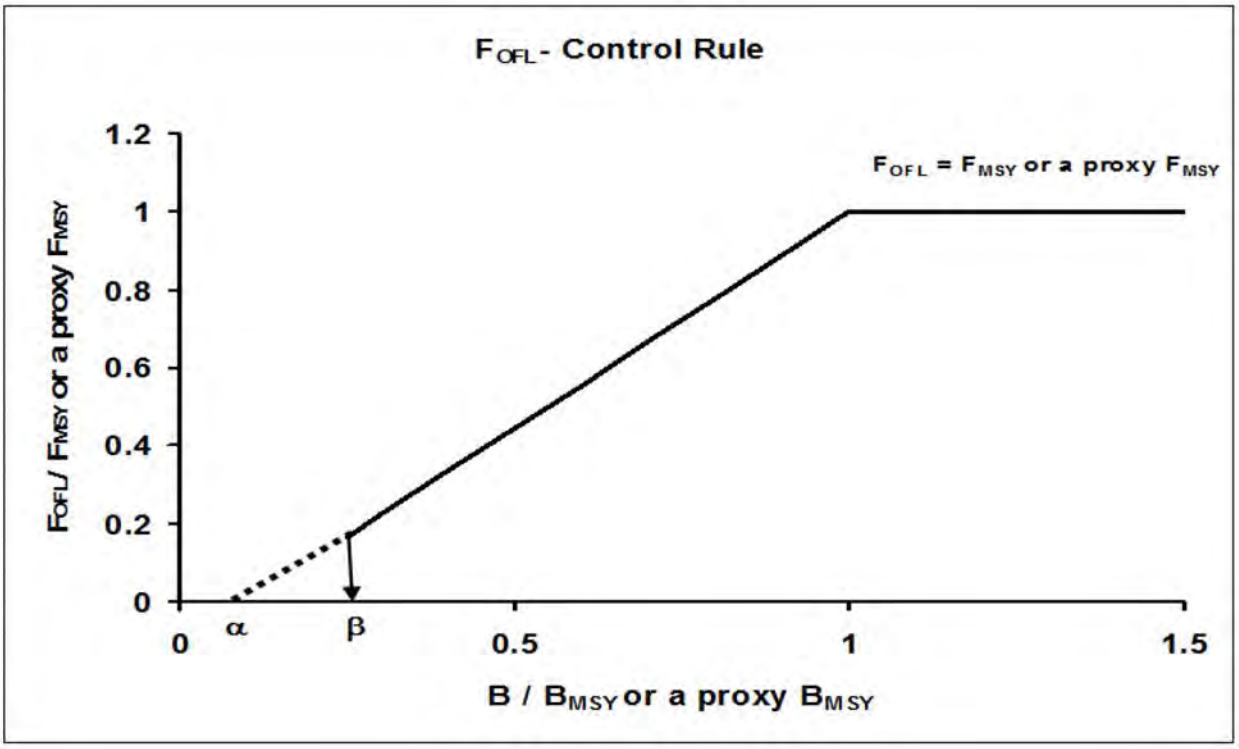


Figure 63. The F_{OFL} harvest control rule.

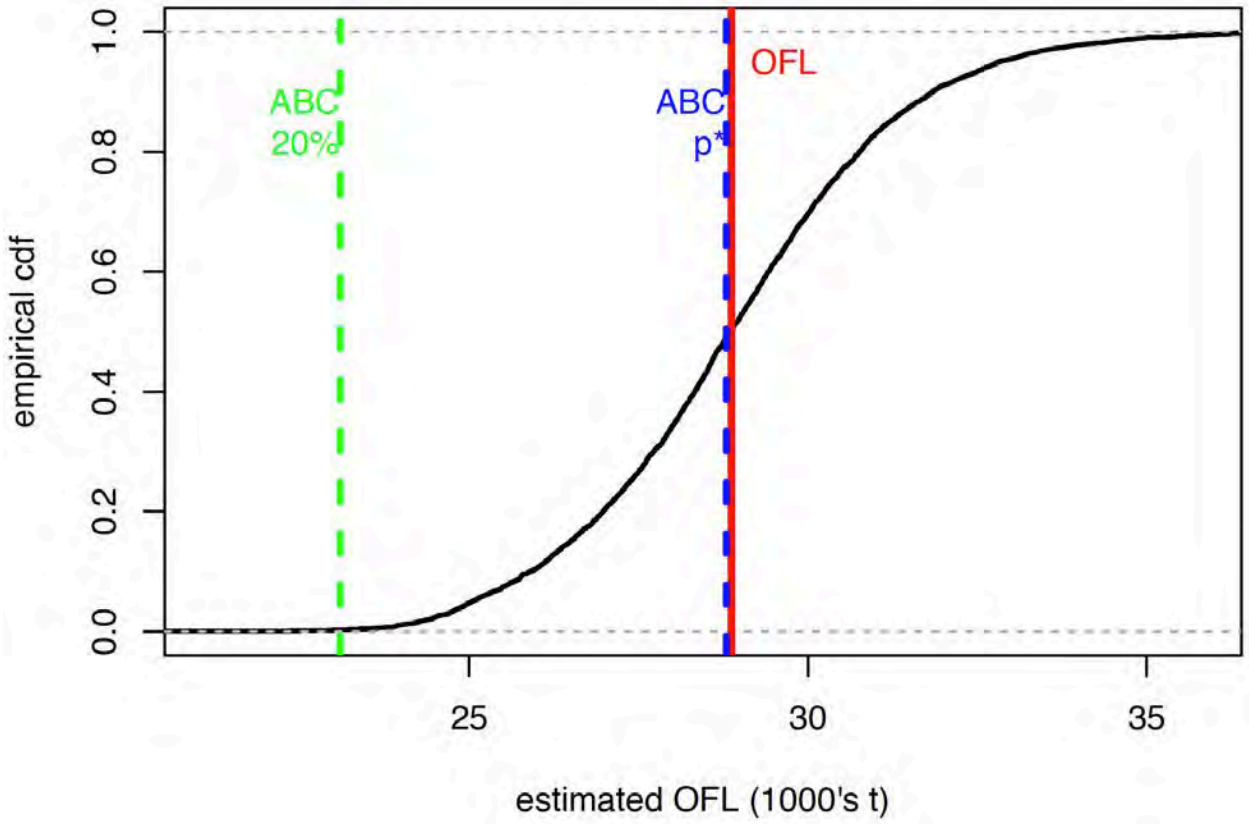


Figure 64. The OFL and ABC from the author's preferred model, scenario M19F03.

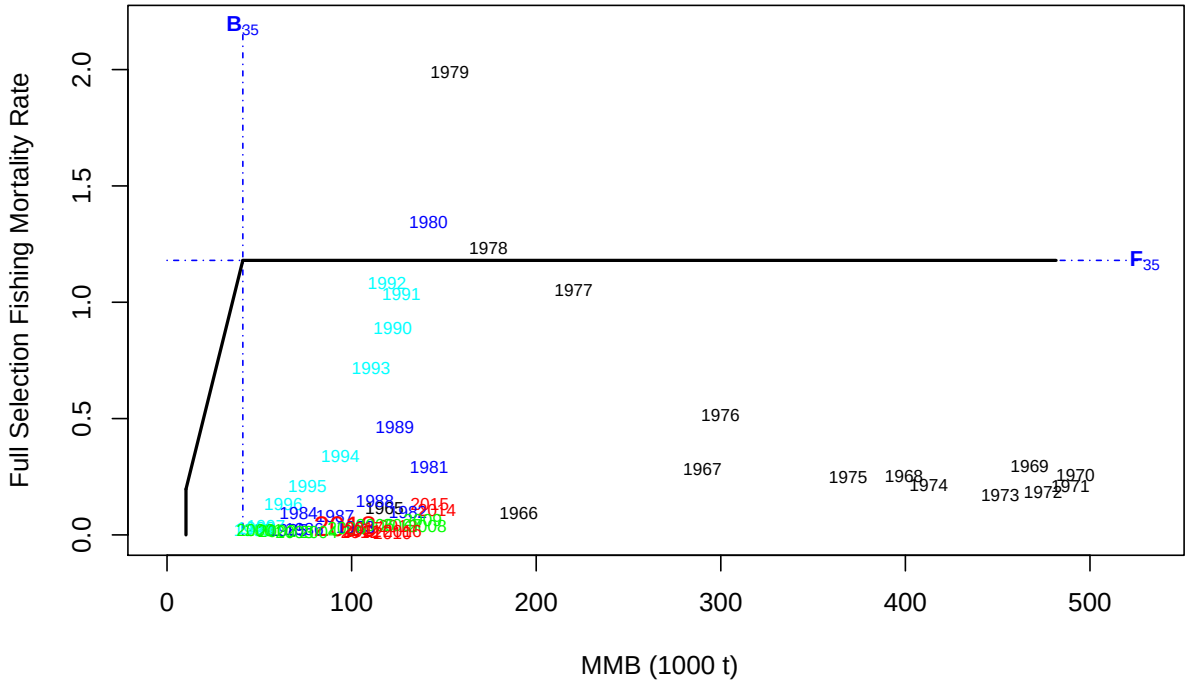


Figure 65. Quad plot for the author's preferred model, scenario M19F03.

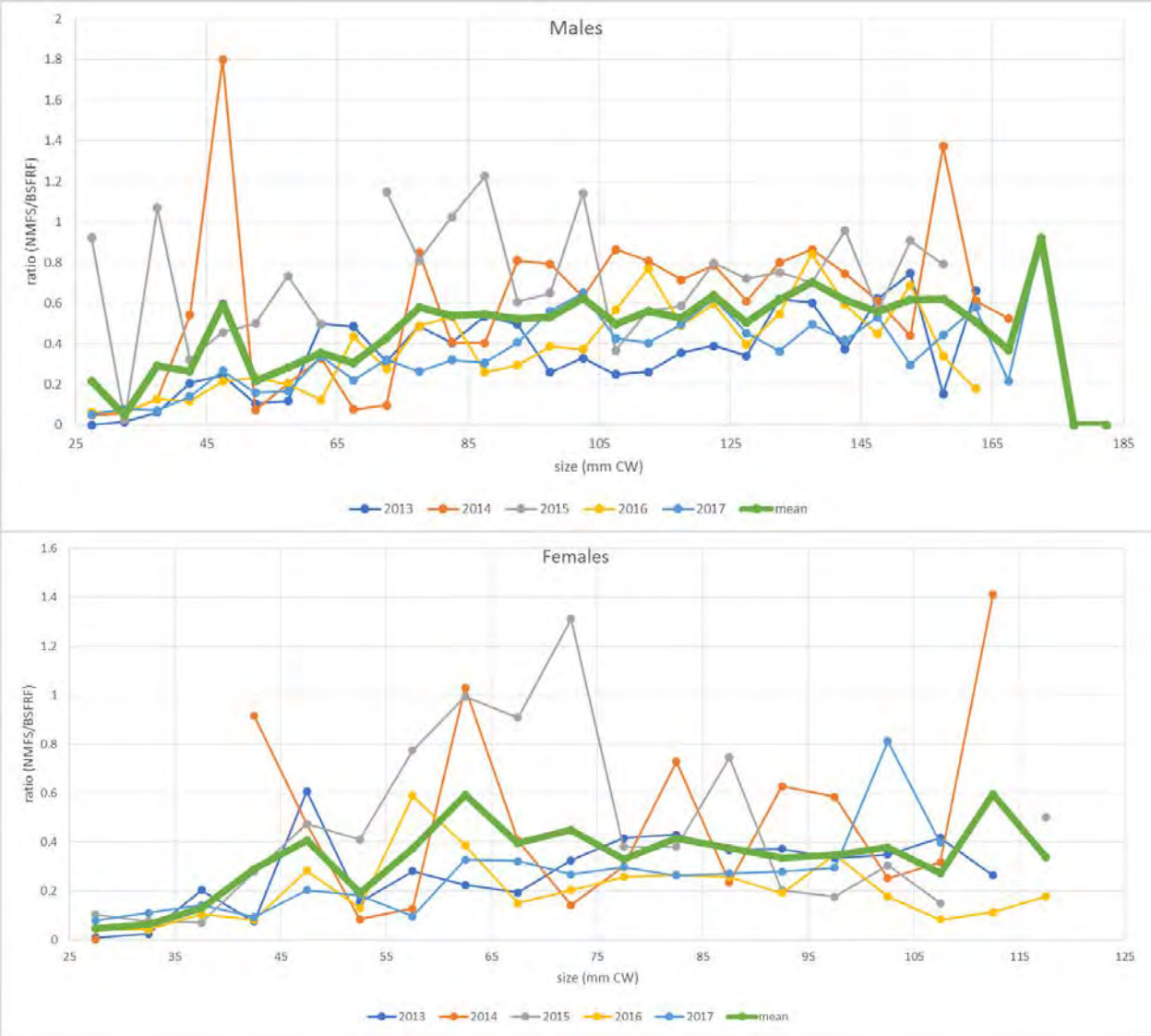


Figure 66. The ratio of estimated abundance by size from the NMFS and BSFRF side-by-side catchability studies. The heavy green line is the size-specific mean over the 5 years. These represent simple empirical estimates of the size-specific catchability of the NMFS survey gear relative to the BSFRF gear. If the BSFRF survey gear is assumed to capture all crab within the area swept, these curves represent empirical estimates of the size-specific NMFS survey gear catchability (i.e., fully selected catchability [q] *x* selectivity).

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

September, 2019

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 2019 assessment model code is available at "201909CPTdoRetro"). 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".

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.

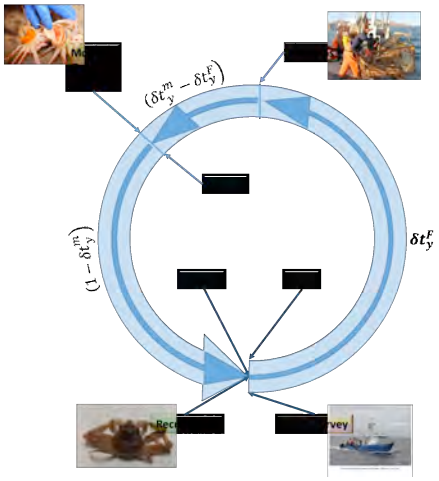


Fig. 1. Timing of annual events in TCSAM02 when fisheries occur before molting/growth/mating.

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).

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:

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

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:

$$n^2_{y,x,m,s,z} = e^{-F^T_{y,x,m,s,z}} \cdot n^1_{y,x,m,s,z} \qquad \text{A1.2}$$

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 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:

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

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 $\delta t^m_y < \delta t^F_y$

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:

$\Theta_{t,x,z,z'} = c_{t,x,z'} \cdot \int_{z-bin/2}^{+bin/2} \Gamma\left(\frac{z''-\bar{z}_{t,x,z'}}{\beta_{t,x}}\right) dz''$	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:

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

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

$R_{y,x,z} = \dot{R}_y \cdot \ddot{R}_{y,x} \cdot \ddot{\ddot{R}}_{y,z}$	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 $\ddot{\ddot{R}}_{y,z}$ 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

$\ddot{R}_{y,x} = \begin{cases} \dfrac{1}{1 + e^{pLgtRx_t}} & x = MALE \\ 1 - \ddot{R}_{y,MALE} & x = FEMALE \end{cases} \quad y \in t$	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*, $\ddot{\ddot{R}}_{t,z}$, is assumed to be a gamma distribution and is parameterized as

$\ddot{\ddot{R}}_{t,z} = c^{-1} \cdot \Delta_z^{\frac{\alpha_t}{\beta_t} - 1} \cdot e^{-\frac{\Delta_z}{\beta_t}}$	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 $1 = \sum_z \ddot{\ddot{R}}_{t,z}$	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

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

$\rho_{f,y,x,m,s,z} = \frac{1}{1 + e^{\rho_{f,t,x,m,s}}} \cdot R_{f,y,x,m,s,z}$	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

$c_{f,y,x,m,s,z} = \frac{\phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	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

$r_{f,y,x,m,s,z} = \frac{\rho_{f,y,x,m,s,z} \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	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

$\phi_{f,y,x,m,s,z} = \bar{\phi}_{f,y,x,m,s} \cdot S_{f,y,x,m,s,z}$	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:

$\phi_{f,y,x,m,s} = \exp\left(lnC_{f,t,x,m,s} + pDevsC_{f,y,x,m,s}\right)$	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 $lnC_{f,t,x,m,s}$. The latter is expressed in terms of model parameters as

$lnC_{f,t,x,m,s} = pLnC_{f,t,x,m,s} + \sum_{i=1}^{4} \delta C^{i}_{f,t,x,m,s}$	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

$v,y,x,m,s,z = \bar{q}_{v,y,x,m,s,z} \cdot n_{y,x,m,s,z}$	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*:

$q_{v,y,x,m,s,z} = \bar{q}_{v,t,x,m,s} \cdot S_{v,t,x,m,s,z} \cdot A_{v,t,x,m,s,z}$	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, $\mathcal{O}$, 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:

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

where $\wp_p$ represents the *p*th prior probability function, $\mathcal{L}_l$ represents the *l*th 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:

$\ln(\mathcal{L}) = -\sum_{y} n_{y,c} \cdot \sum_{z} \{p^{obs}_{y,c,z} \cdot \ln(p^{mod}_{y,c,z} + \delta) - p^{obs}_{y,c,z} \cdot \ln(p^{obs}_{y,c,z} + \delta)\}$	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

$\ln(\mathcal{L}^{N})_{c} = -\frac{1}{2}\sum_{y}\left\{\frac{\left[a_{y,c}^{obs} - a_{y,c}^{mod}\right]^2}{\sigma_{y,c}^2}\right\}$	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

$\ln(\mathcal{L}^{LN})_{c} = -\frac{1}{2}\sum_{y}\left\{\frac{\left[ln\left(a_{y,c}^{obs}+\delta\right) - ln\left(a_{y,c}^{mod}+\delta\right)\right]^2}{\sigma_{y,c}^2}\right\}$	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

$\ln(\mathcal{L}^{N2})_{x} = -\frac{1}{2}\sum_{y}\left[a_{y,x}^{obs} - a_{y,x}^{mod}\right]^2$	"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:

$L_d = -\sum_{i\in d} ln\left\{\Gamma\left(\frac{\tilde{z}_i - \bar{z}_{y_i,x_i,z_i}}{\beta_{y_i,x_i}}\right)\right\}$	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:

$L_m = -\sum_{y,z} n_{y,z} \cdot \{p_{y,z}^{obs} \cdot \ln(p_{y,z}^{mod} + \delta) + (1 - p_{y,z}^{obs}) \cdot \ln(1 - p_{y,z}^{mod} + \delta)\}$	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 by	Size Conpositions 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		none	exponential pdf
gamma	r, μ^-	none	gamma pdf
invchisquare	υ^-	none	inverse χ^{2^-}pdf

invgamma	r, μ^-	none	inverse gamma pdf
invgaussian	$\mu,^-$	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**	a_{x,m^-}	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

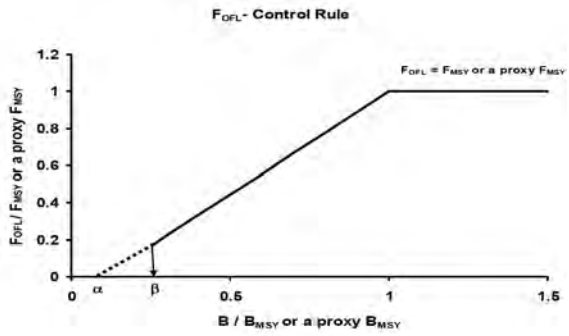


Fig. 2. The F_{OFL} harvest control rule.

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)
I – 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.

References

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Methot, R.D. and C.R. Wetzel. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142: 86-99.

NPFMC. 2016. Introduction. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2016 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 1-40.

Rugolo, L.J. and B.J. Turnock. 2011. Length-Based Stock Assessment Model of eastern Bering Sea Tanner Crab. Report to Subgroup of NPFMC Crab Plan Team. 61p.

Rugolo, L.J. and B.J. Turnock. 2012a. Length-Based Stock Assessment Model of eastern Bering Sea Tanner Crab. Report to Subgroup of NPFMC Crab Plan Team. 69p.

Rugolo L,J. and B.J. Turnock. 2012b. 2012 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2012 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 267-416.

Stockhausen, W.T., B.J. Turnock and L. Rugolo. 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2013 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-449.

Stockhausen, W.T. 2014. 2014 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2014 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 324-545.

Stockhausen, W.T. 2015. 2015 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2015 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 293-440.

Stockhausen, W.T. 2016. 2016 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2016 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 251-446.

Model Comparisons: Fits to Size Composition Data – M19F00a vs M19F01 vs M19F02 vs M19F03 vs M19F04 vs M19F05

William Stockhausen

07 September, 2019

Contents

Model fits to size compositions, by year **1**

Survey size compositions **2**

Fishery retained catch size compositions **43**

Fishery total catch size compositions **47**

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, immature, all shell survey size comps for NMFS 0. Page 1 of 5.

Figure 2: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 2 of 5.

Figure 3: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 3 of 5.

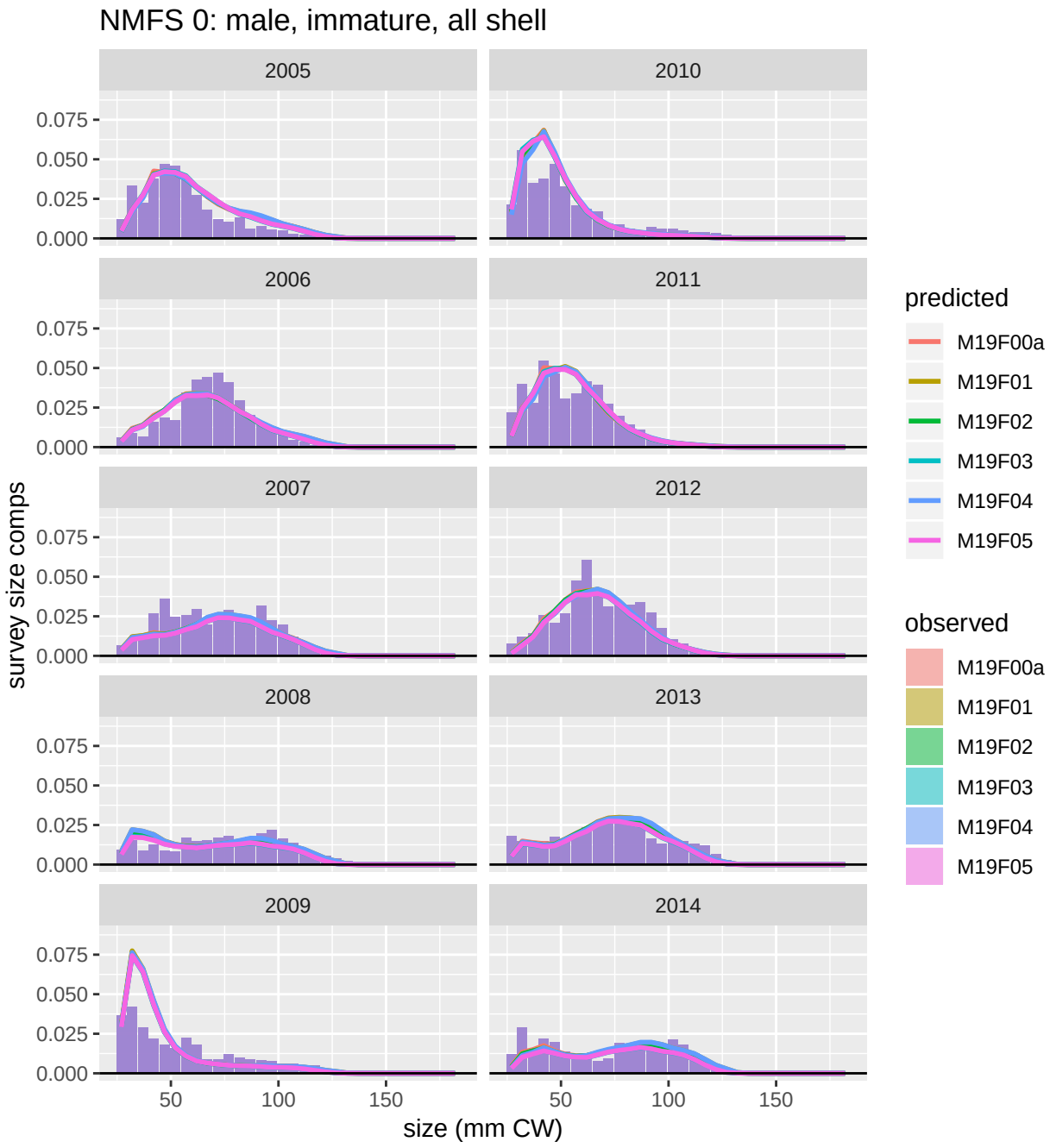


Figure 4: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 4 of 5.

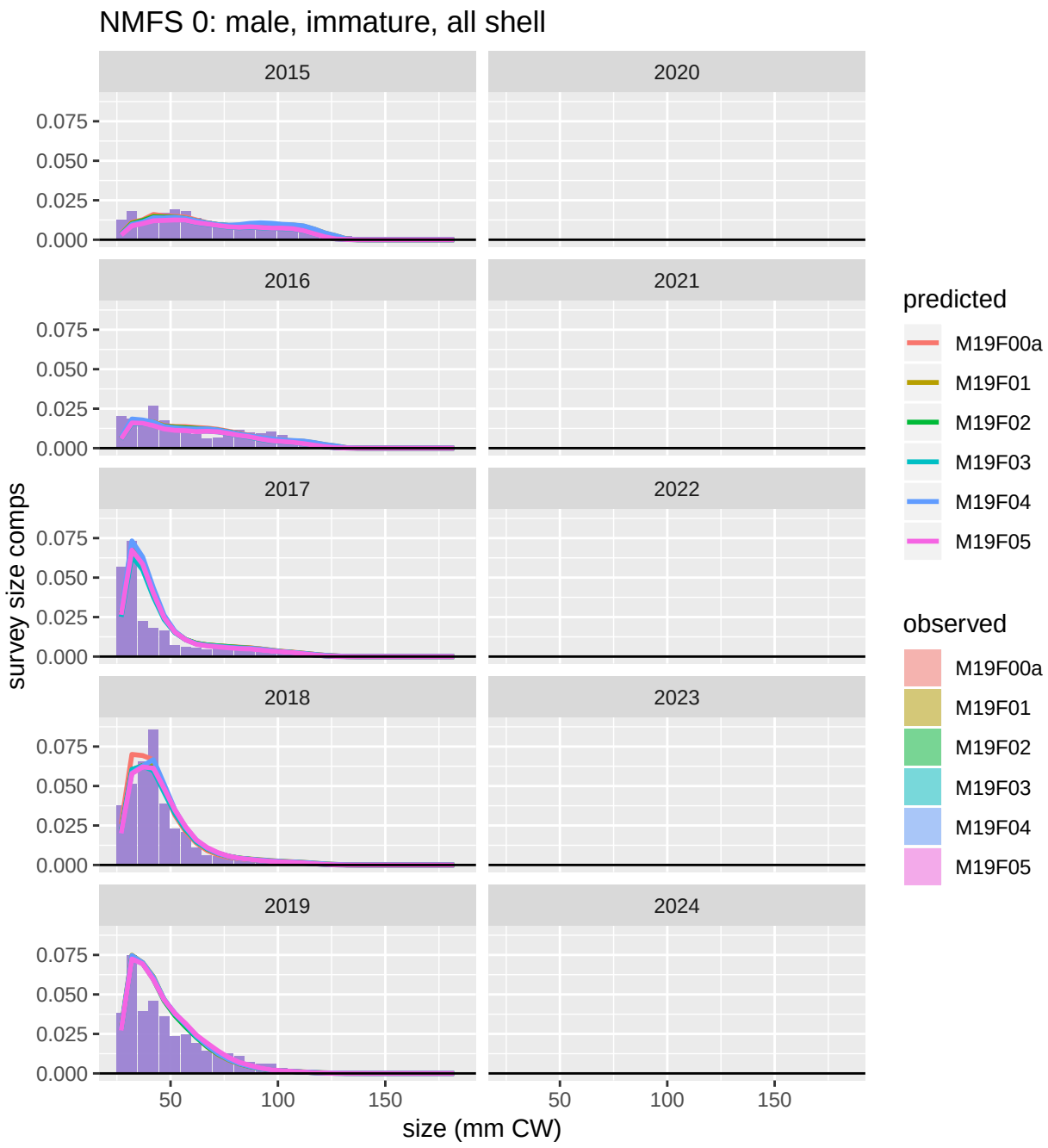


Figure 5: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 5 of 5.

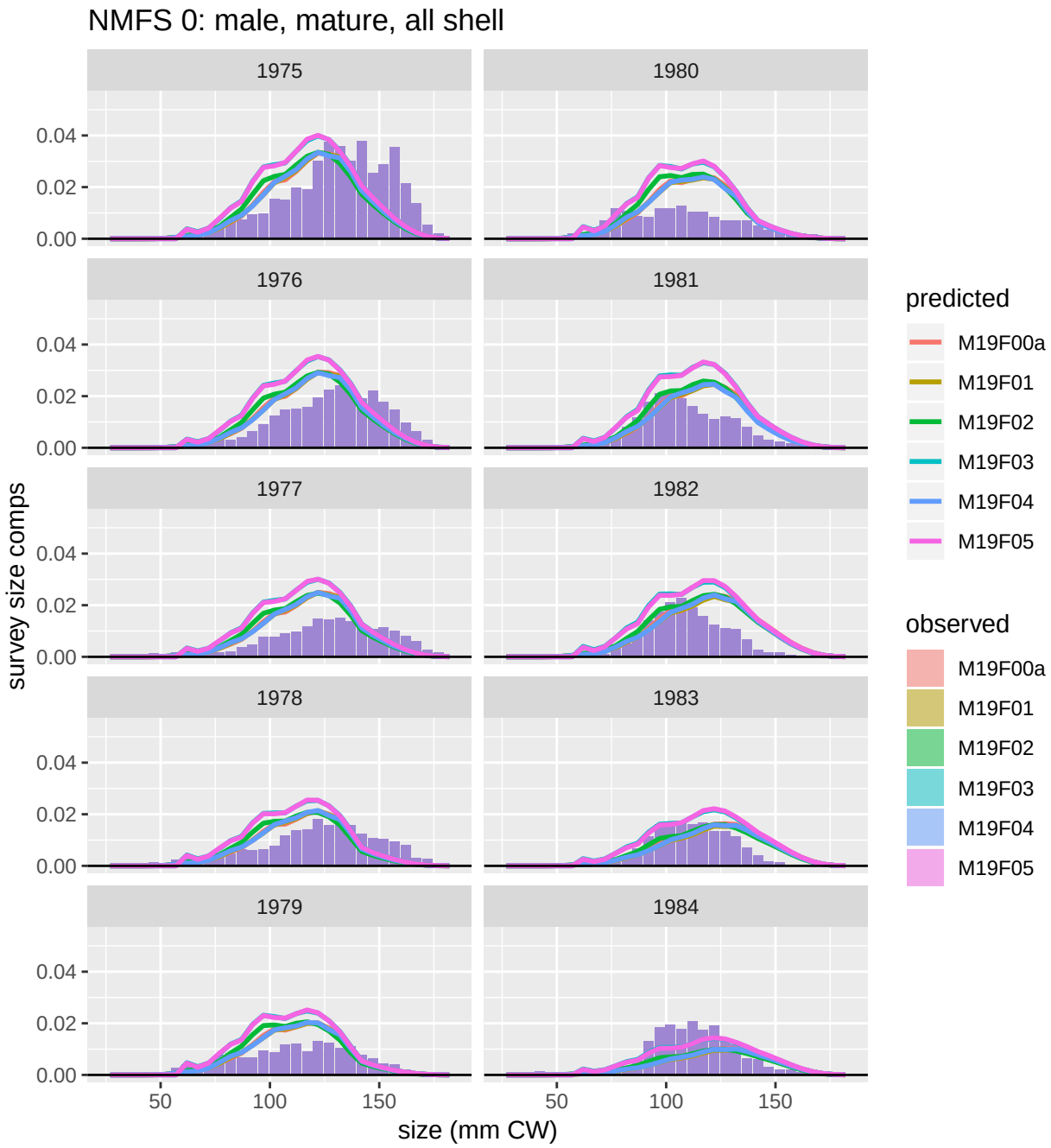


Figure 6: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 1 of 5.

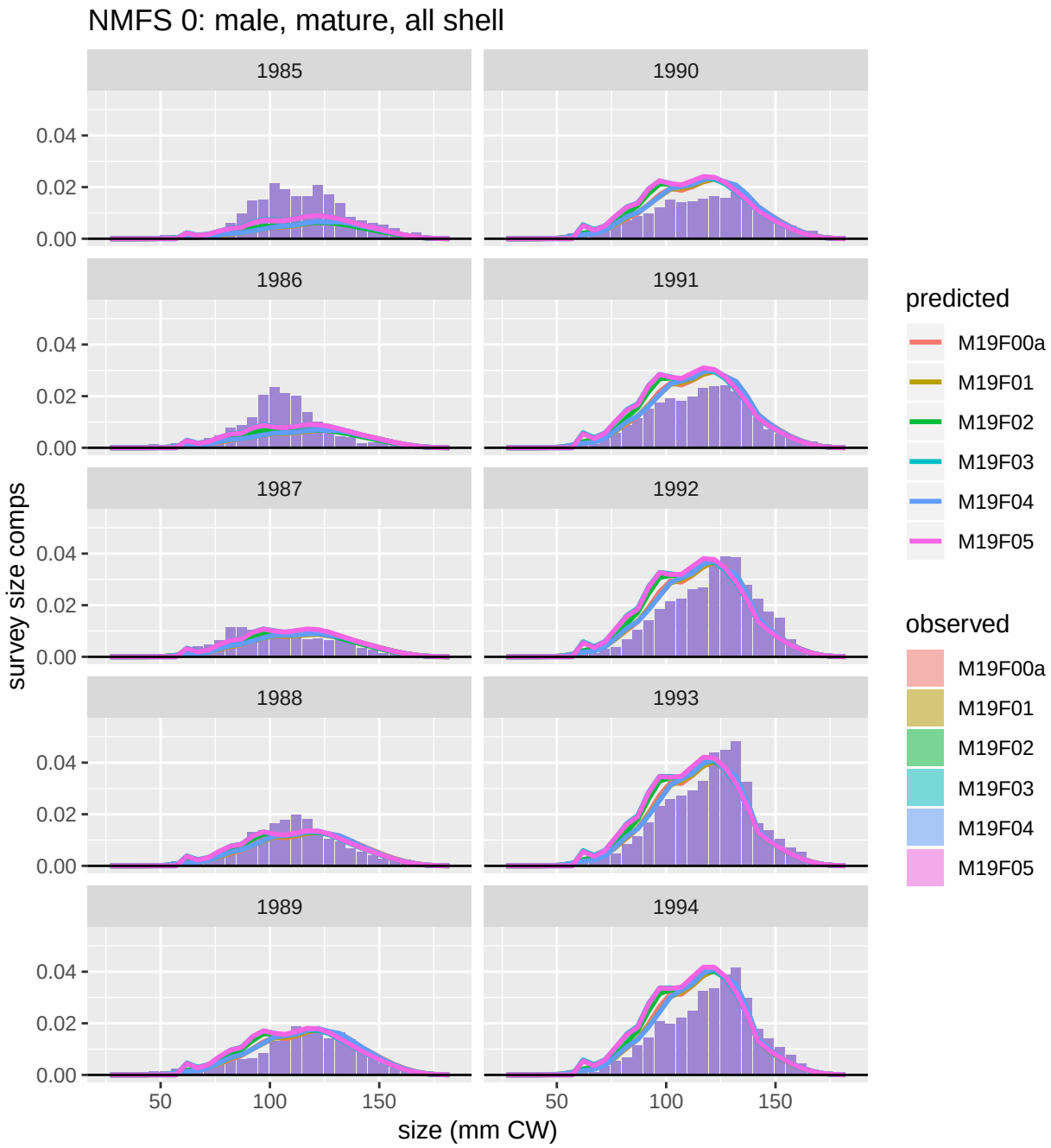


Figure 7: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 2 of 5.

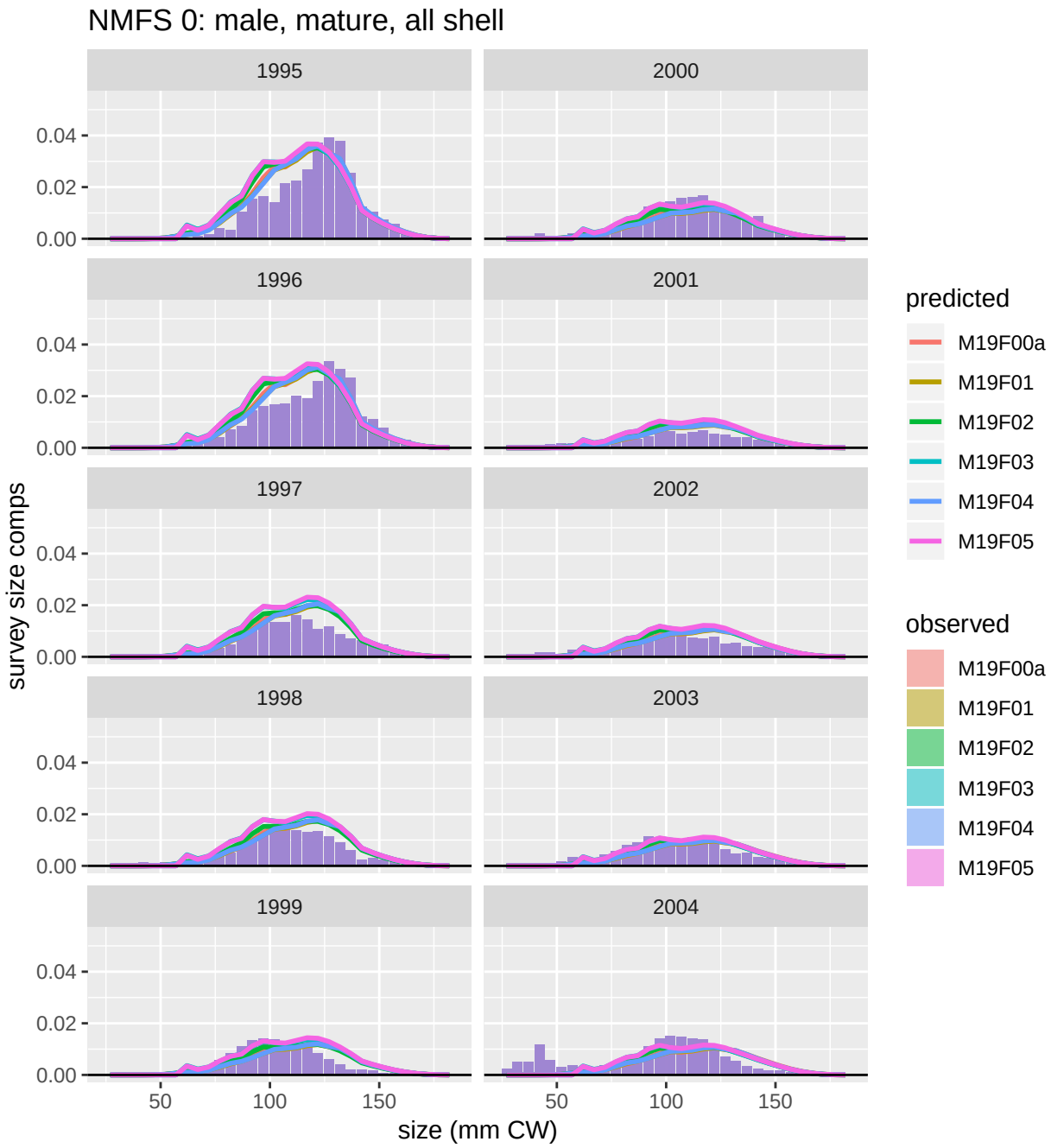


Figure 8: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 3 of 5.

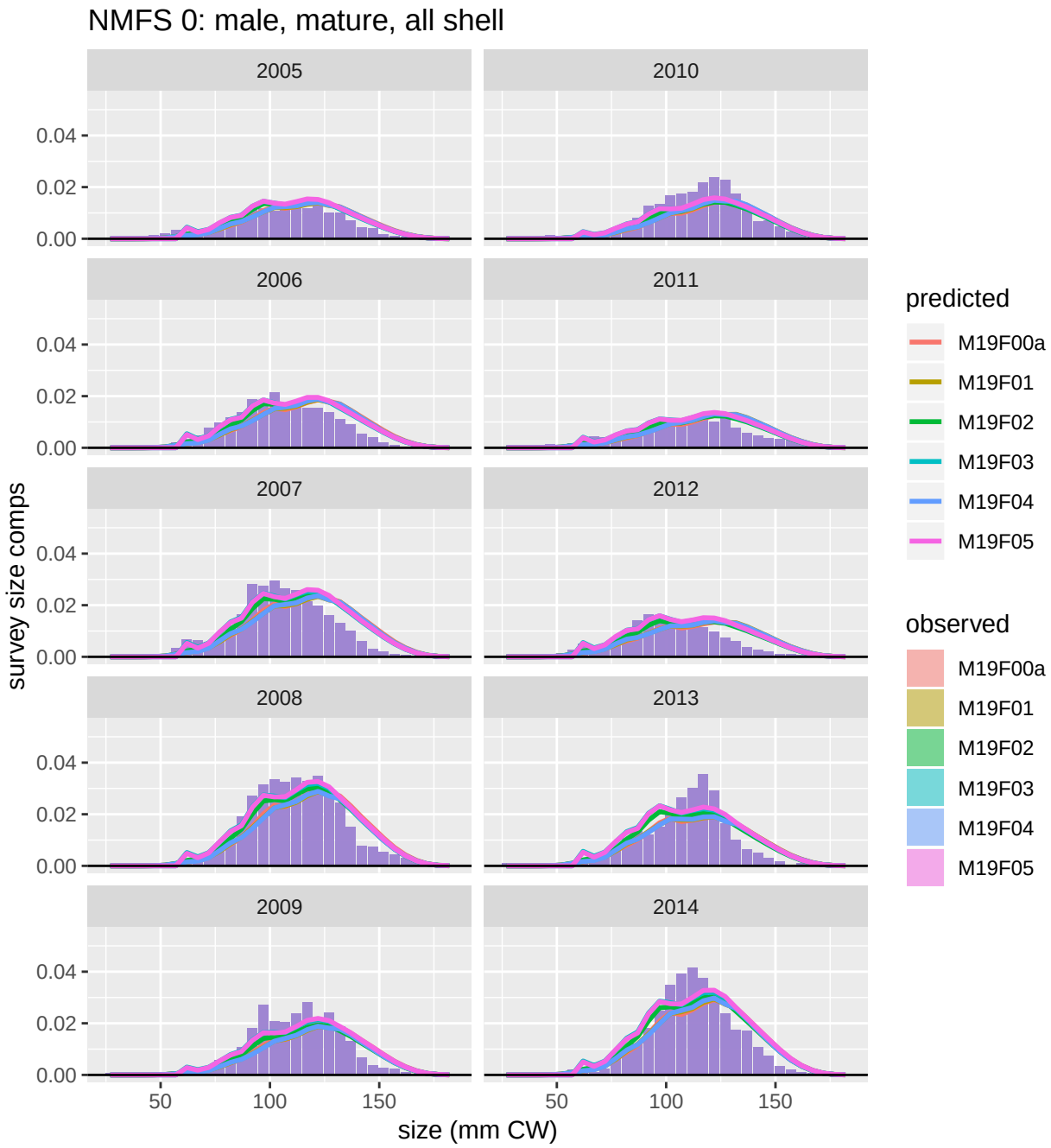


Figure 9: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 4 of 5.

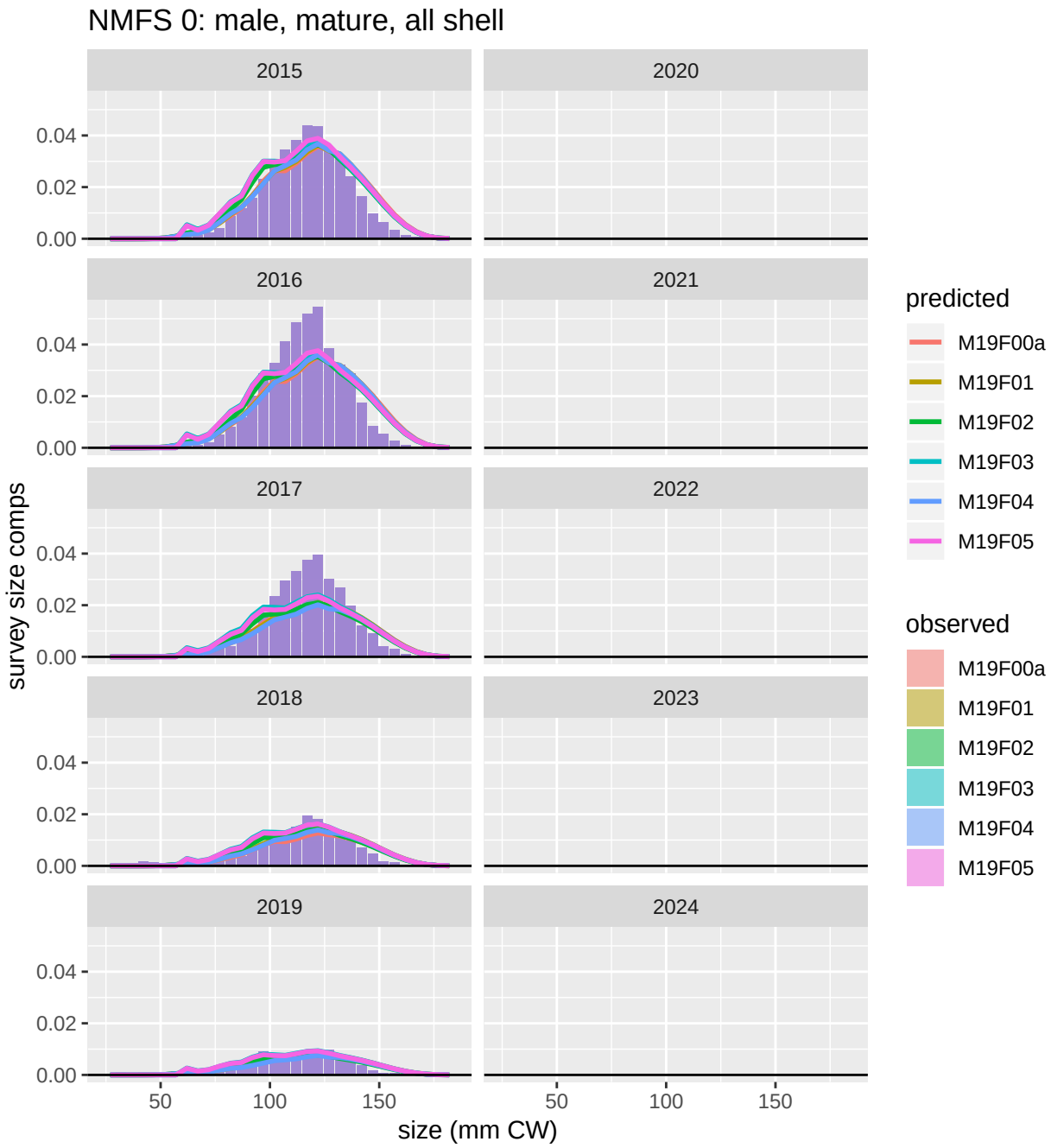


Figure 10: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 5 of 5.

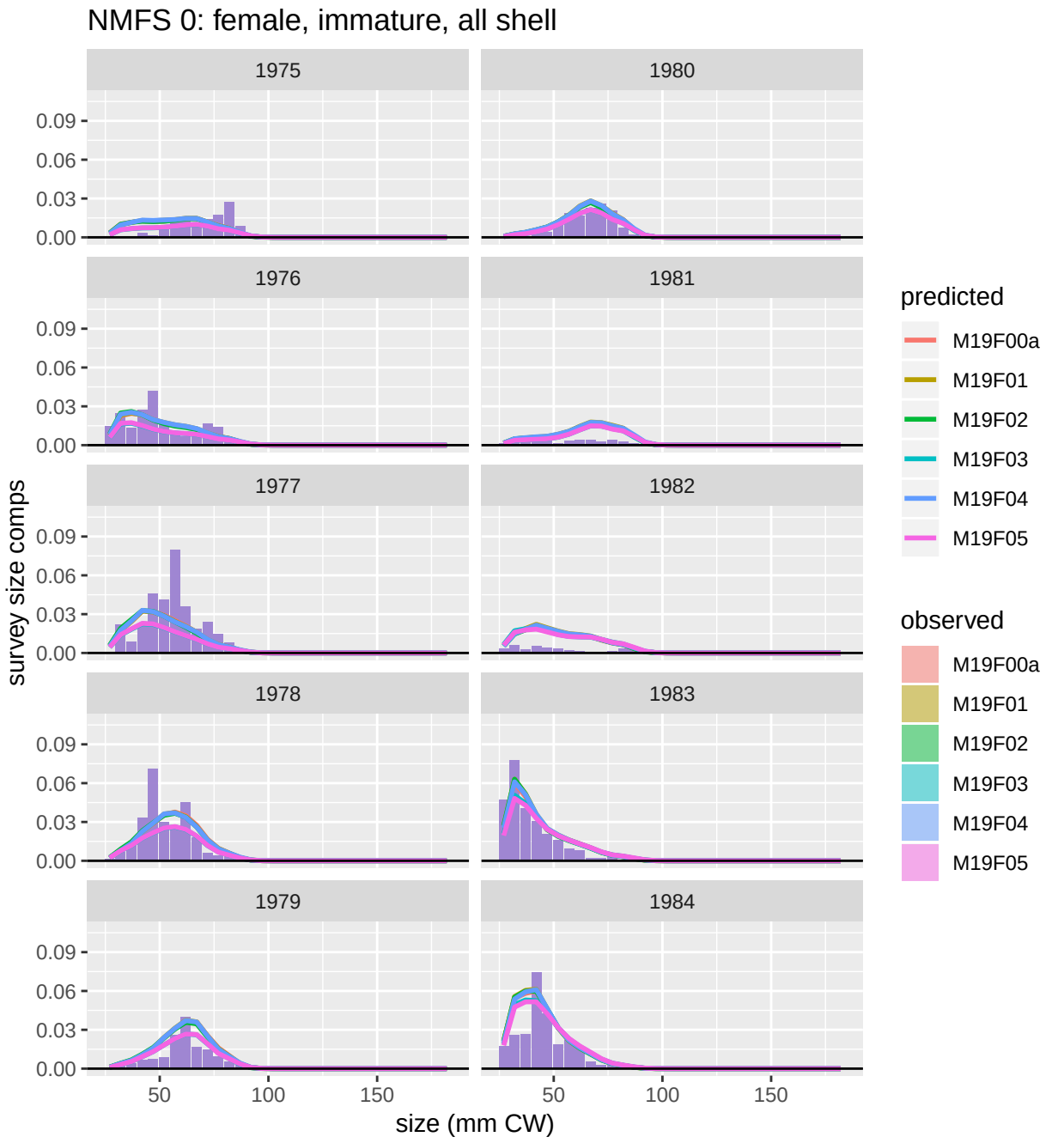


Figure 11: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 1 of 5.

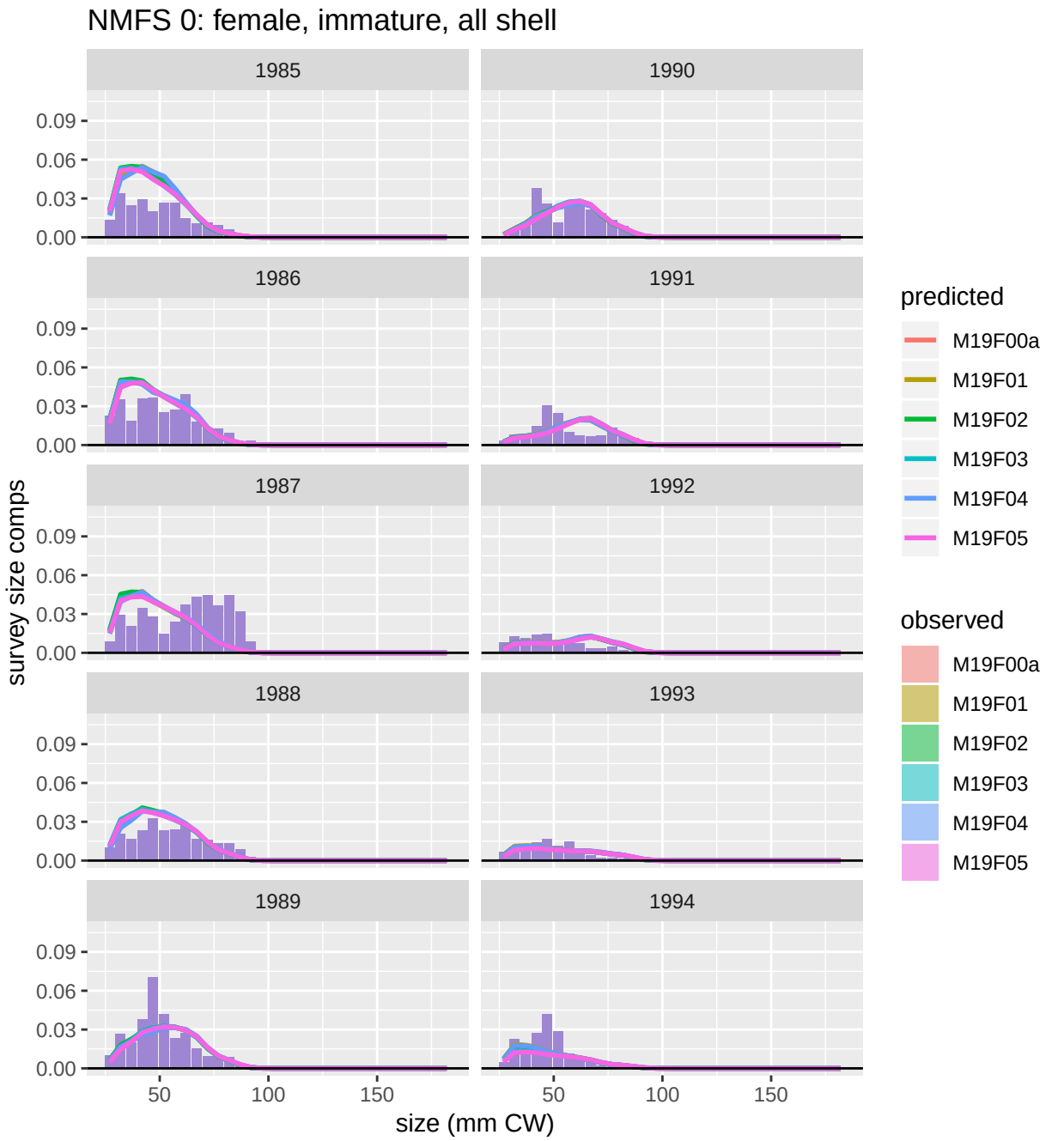


Figure 12: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 2 of 5.

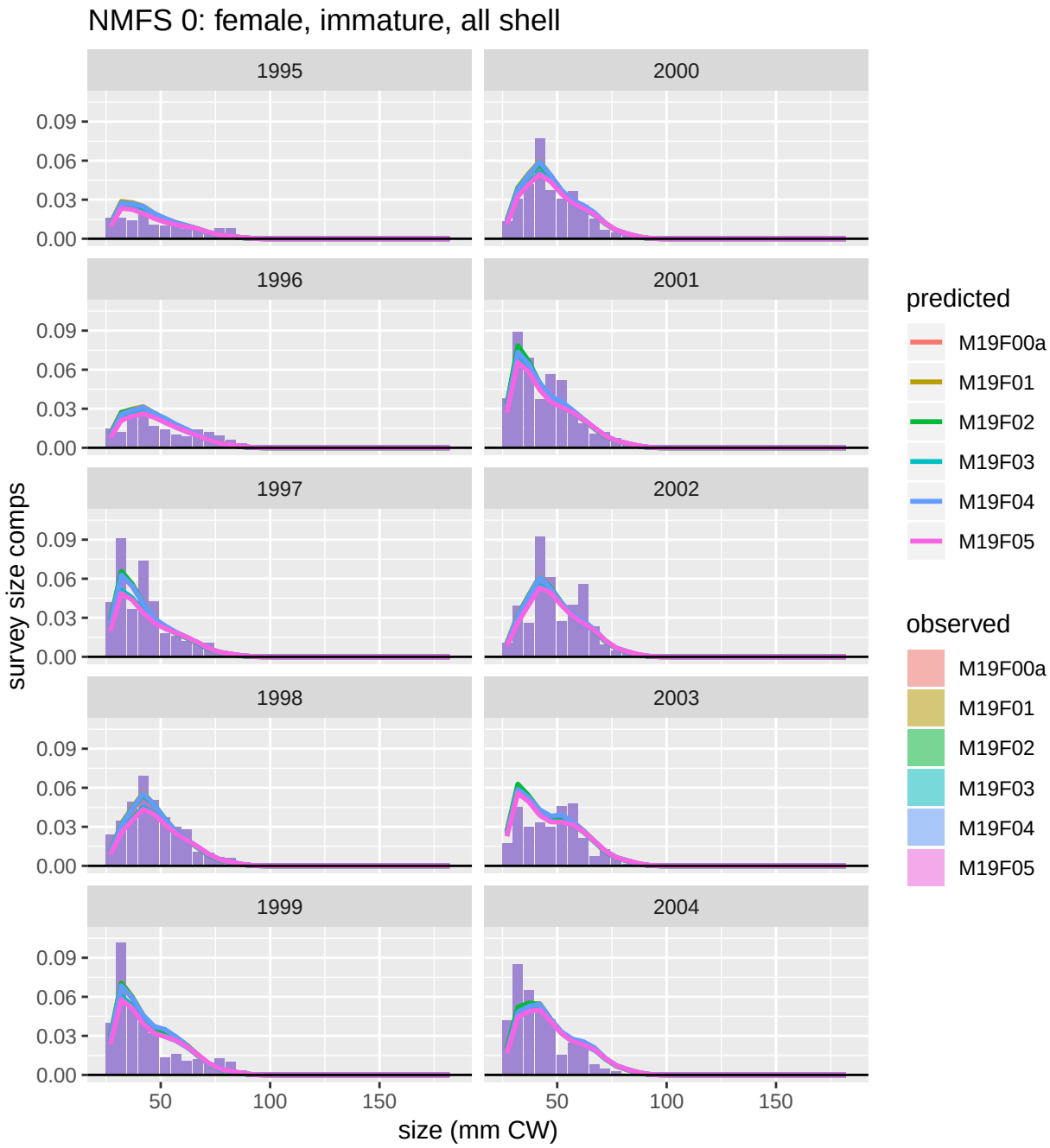


Figure 13: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 3 of 5.

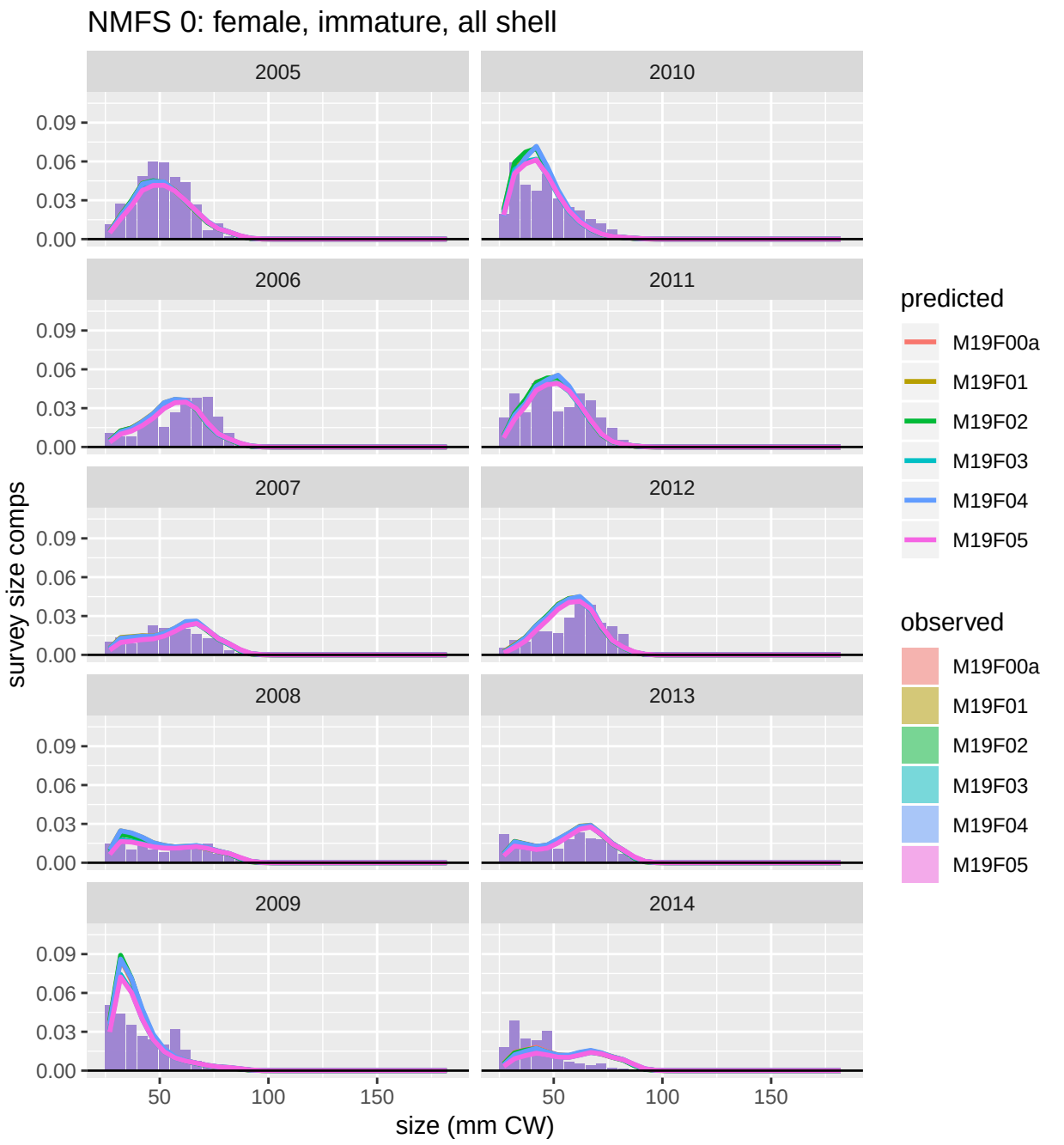


Figure 14: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 4 of 5.

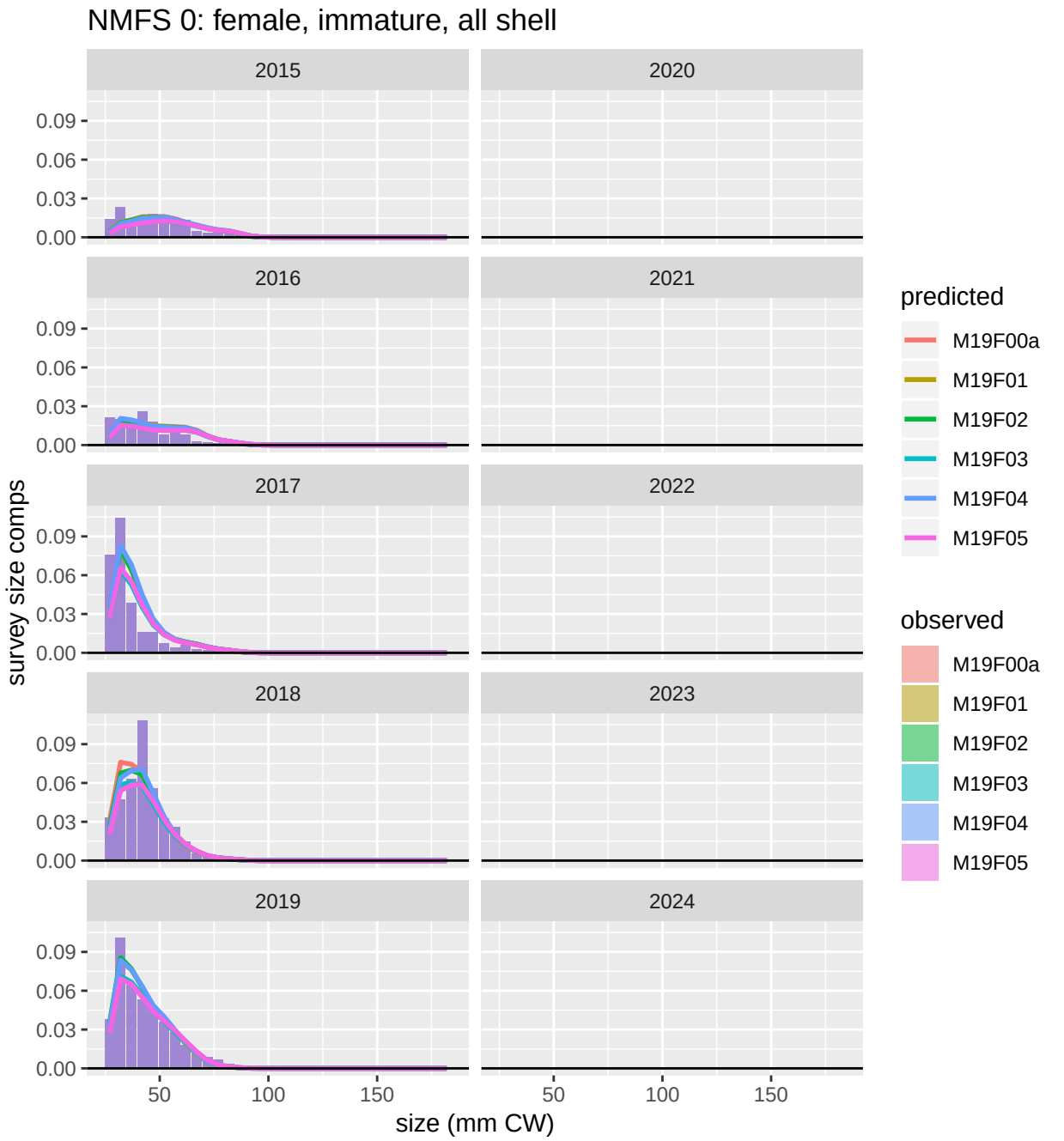


Figure 15: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 5 of 5.

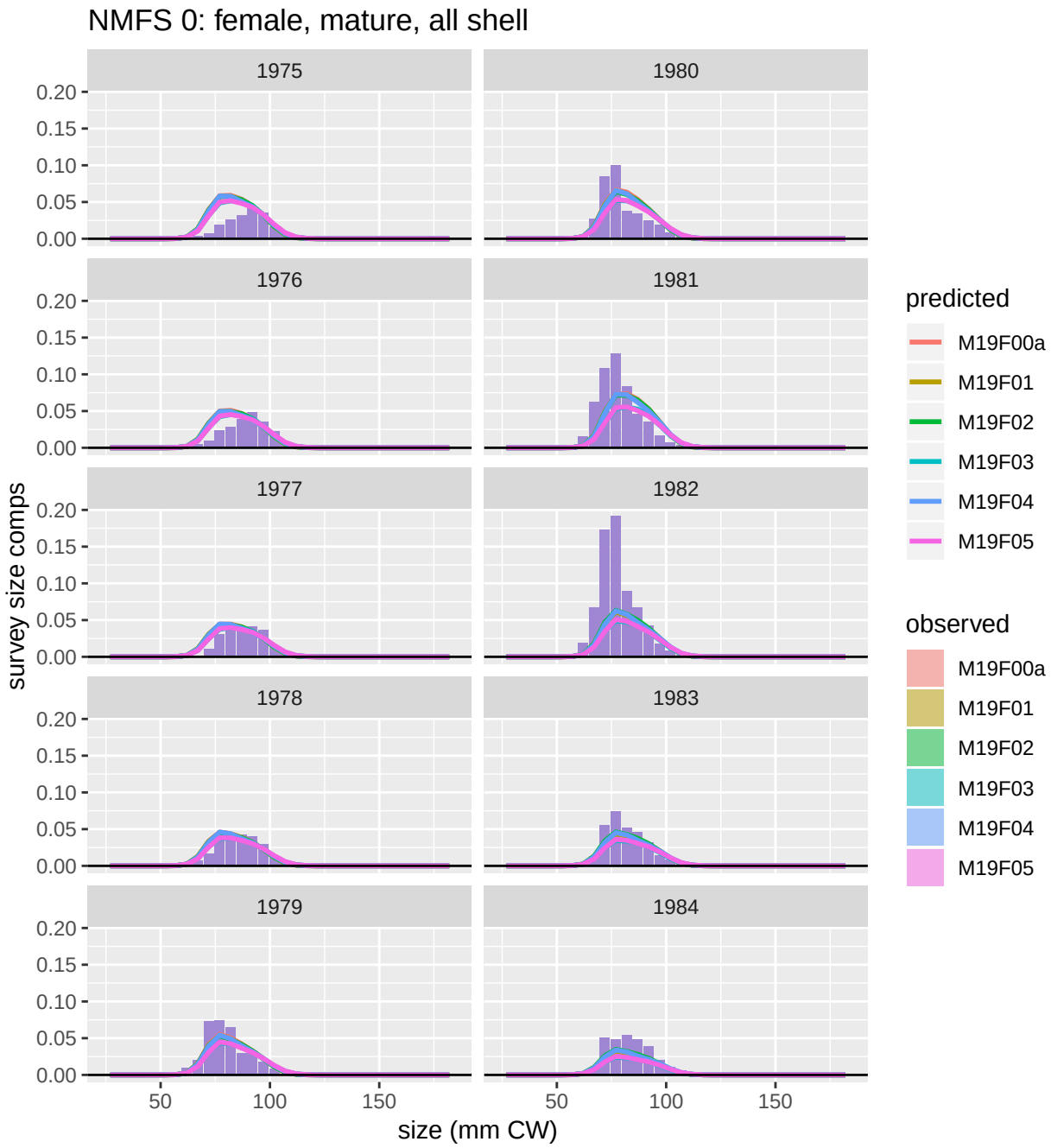


Figure 16: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 1 of 5.

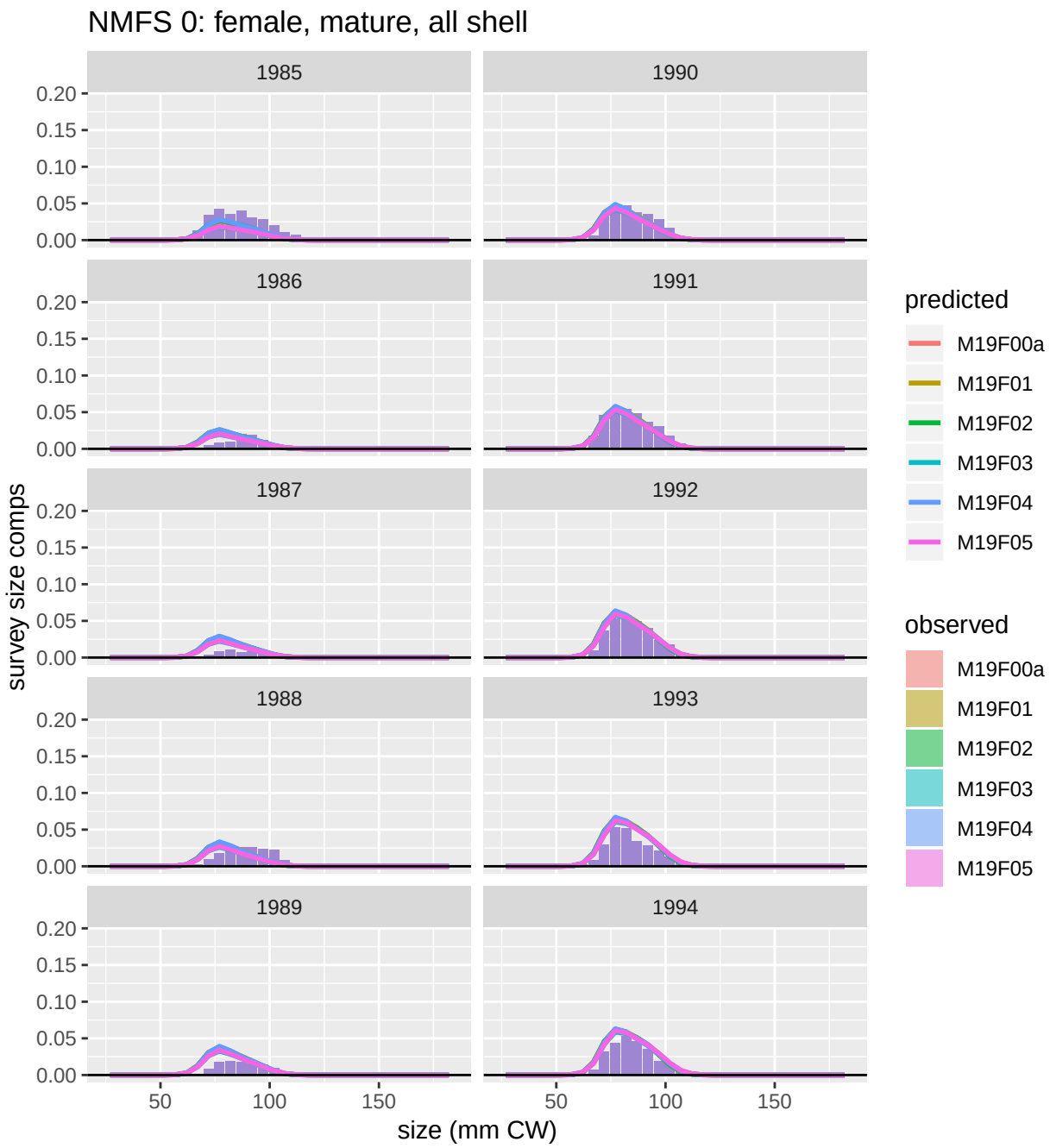


Figure 17: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 2 of 5.

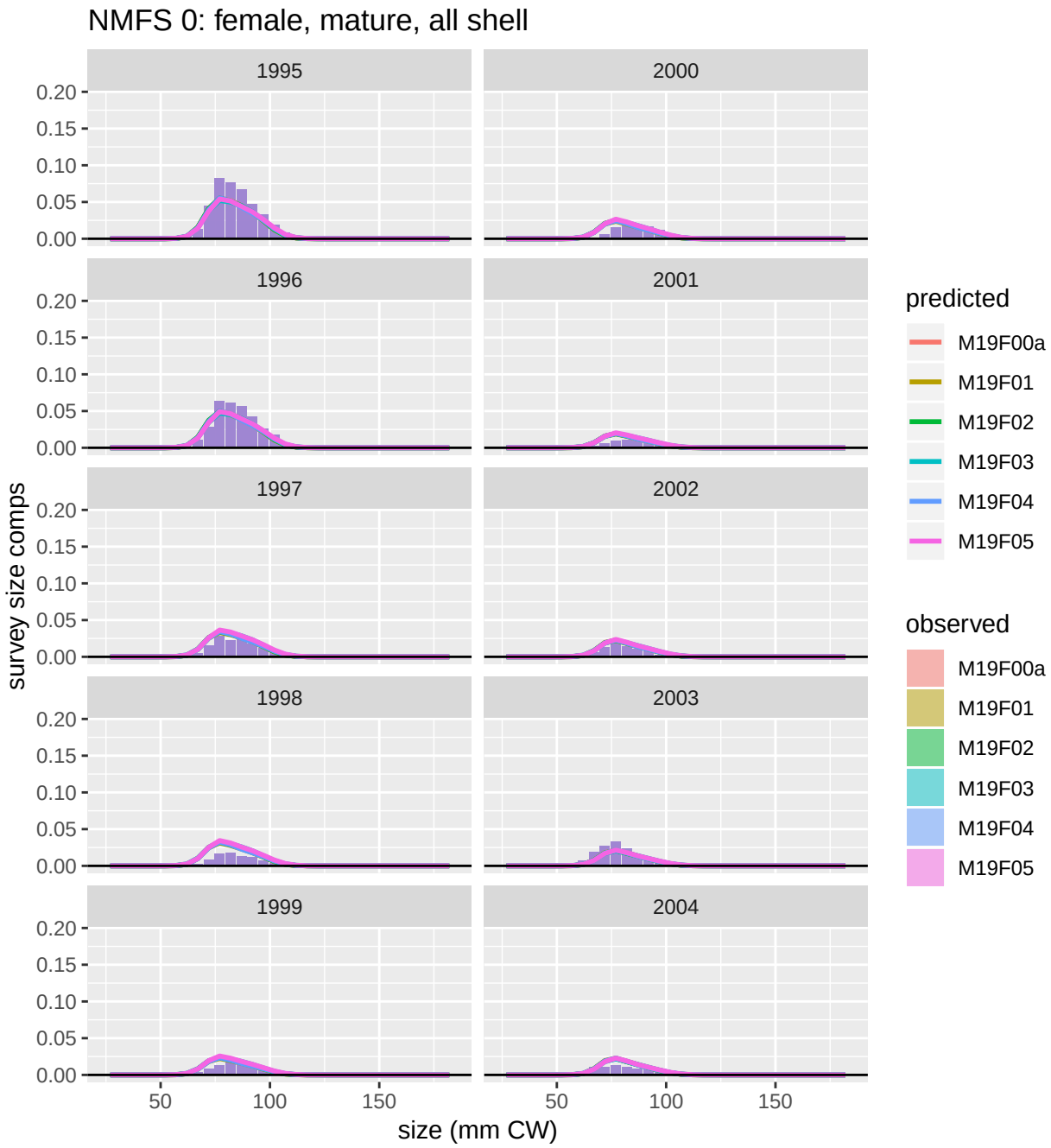


Figure 18: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 3 of 5.

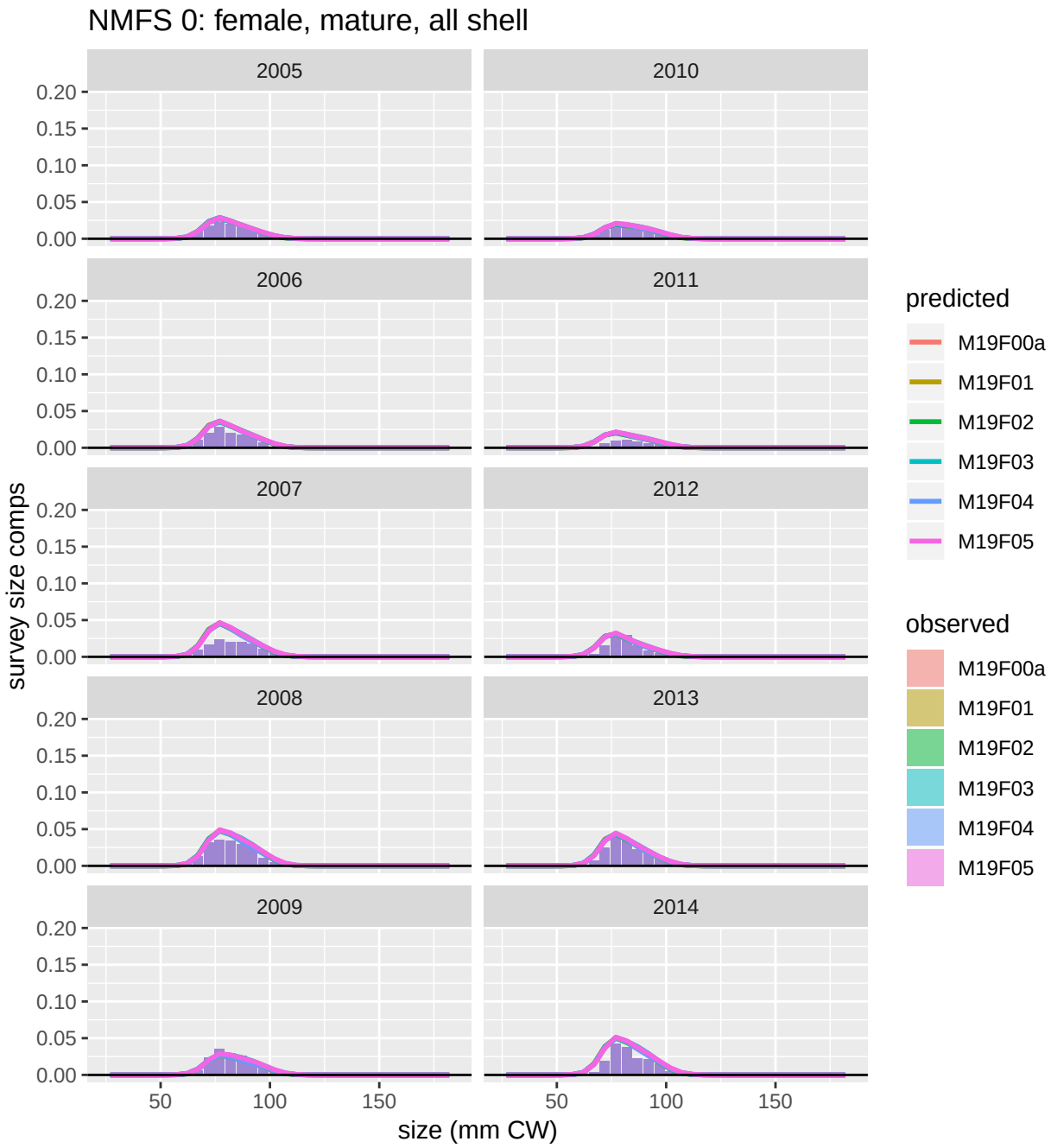


Figure 19: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 4 of 5.

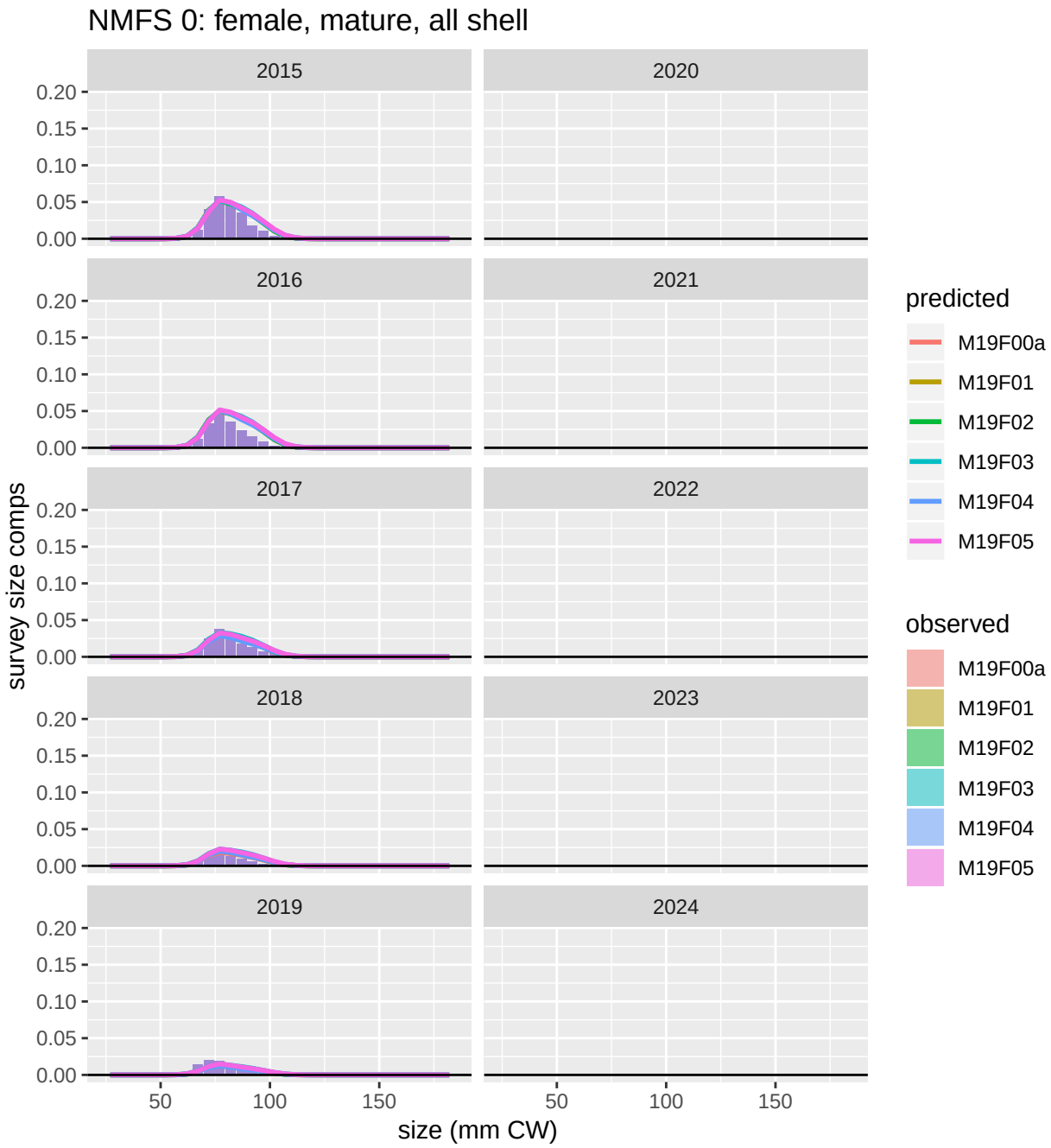


Figure 20: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 5 of 5.

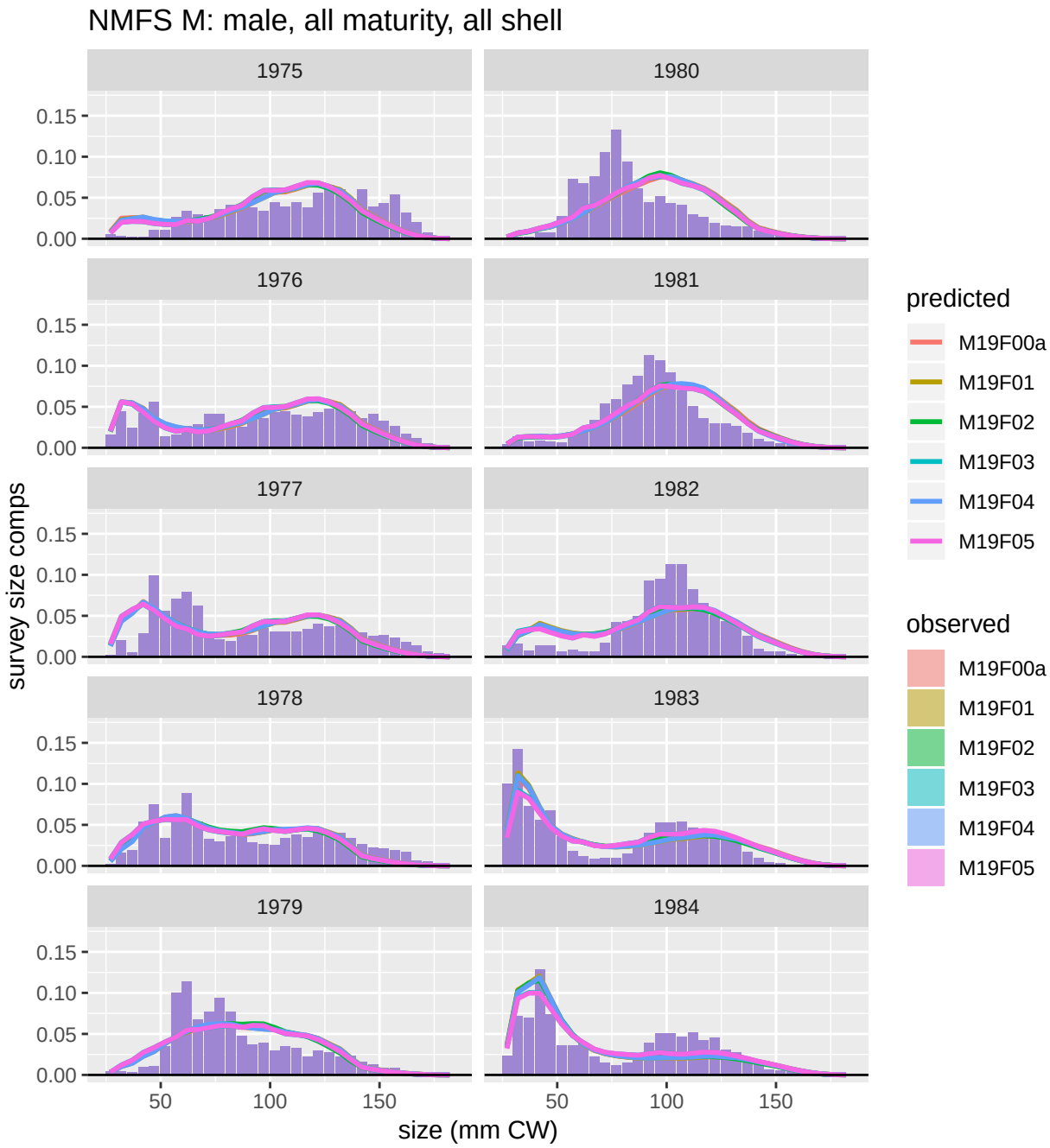


Figure 21: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 1 of 5.

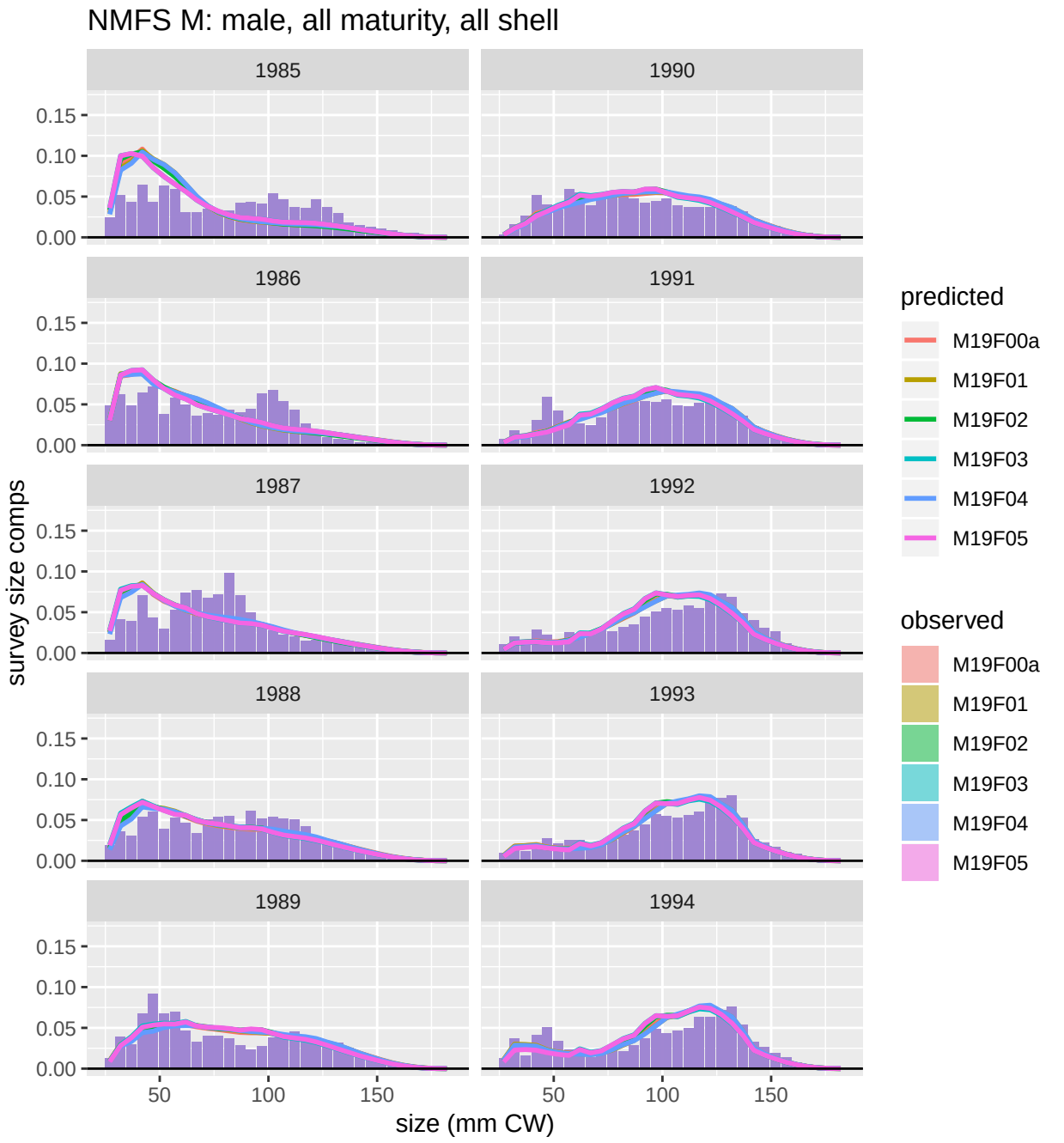


Figure 22: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 2 of 5.

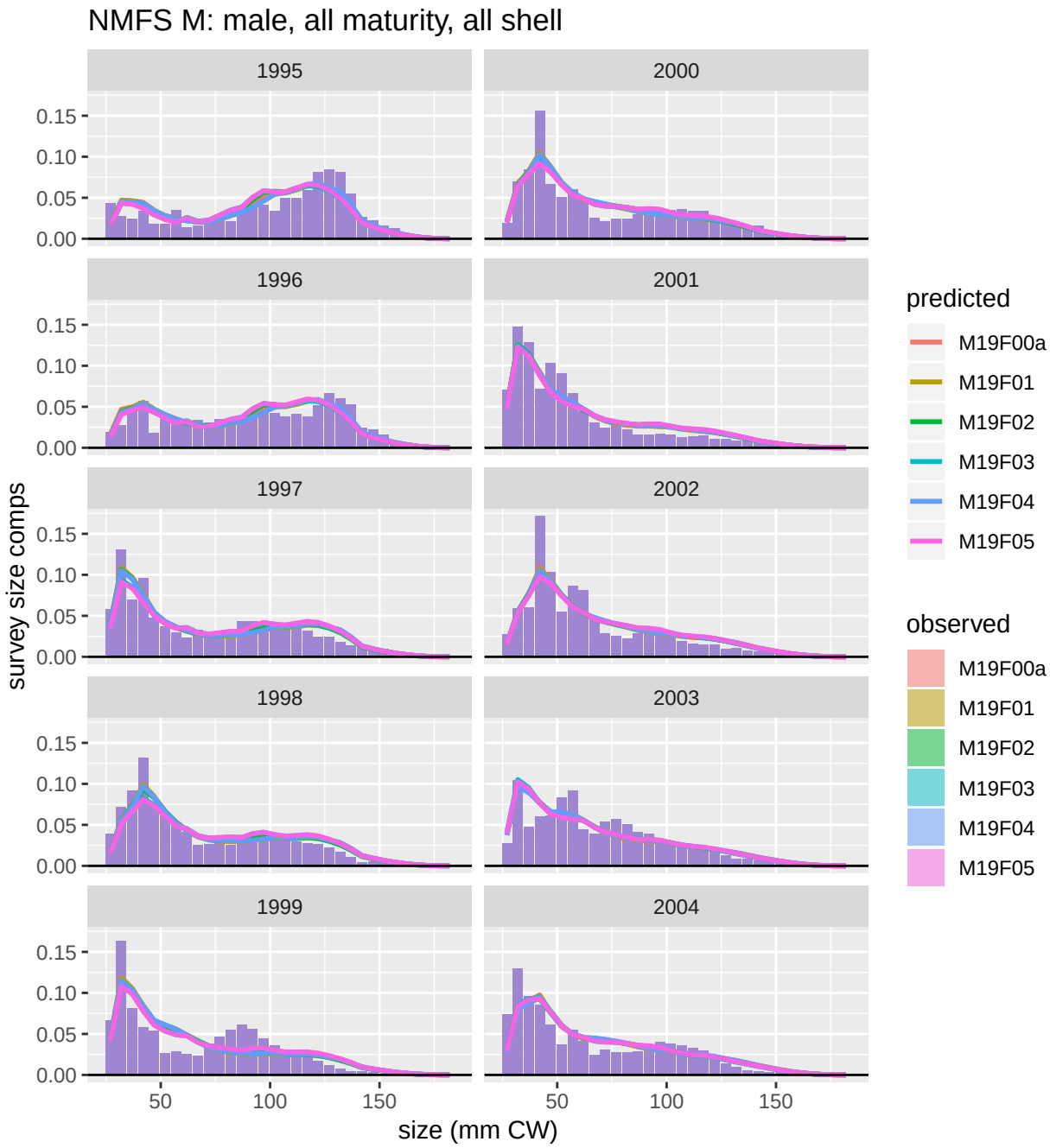


Figure 23: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 3 of 5.

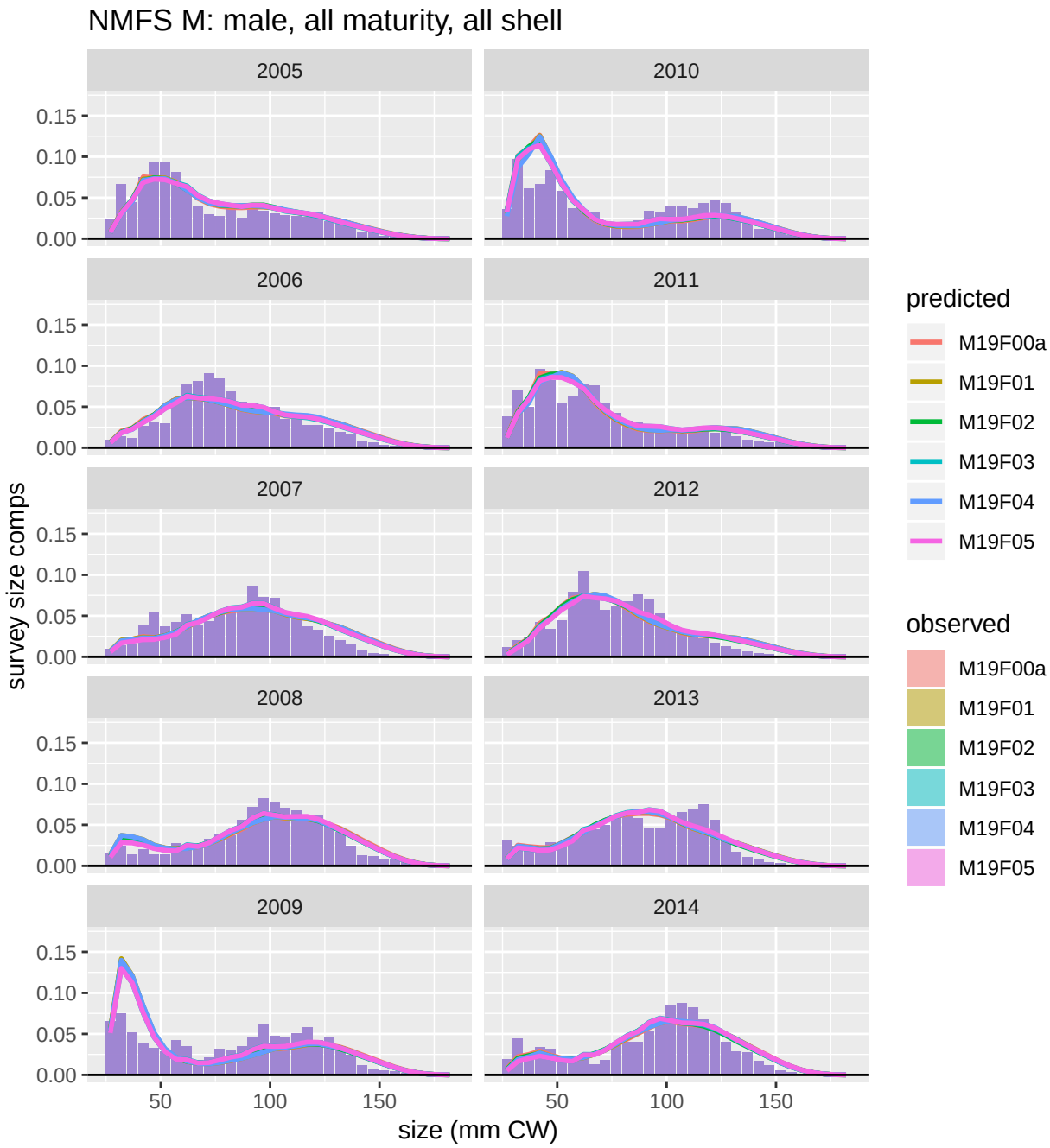


Figure 24: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 4 of 5.

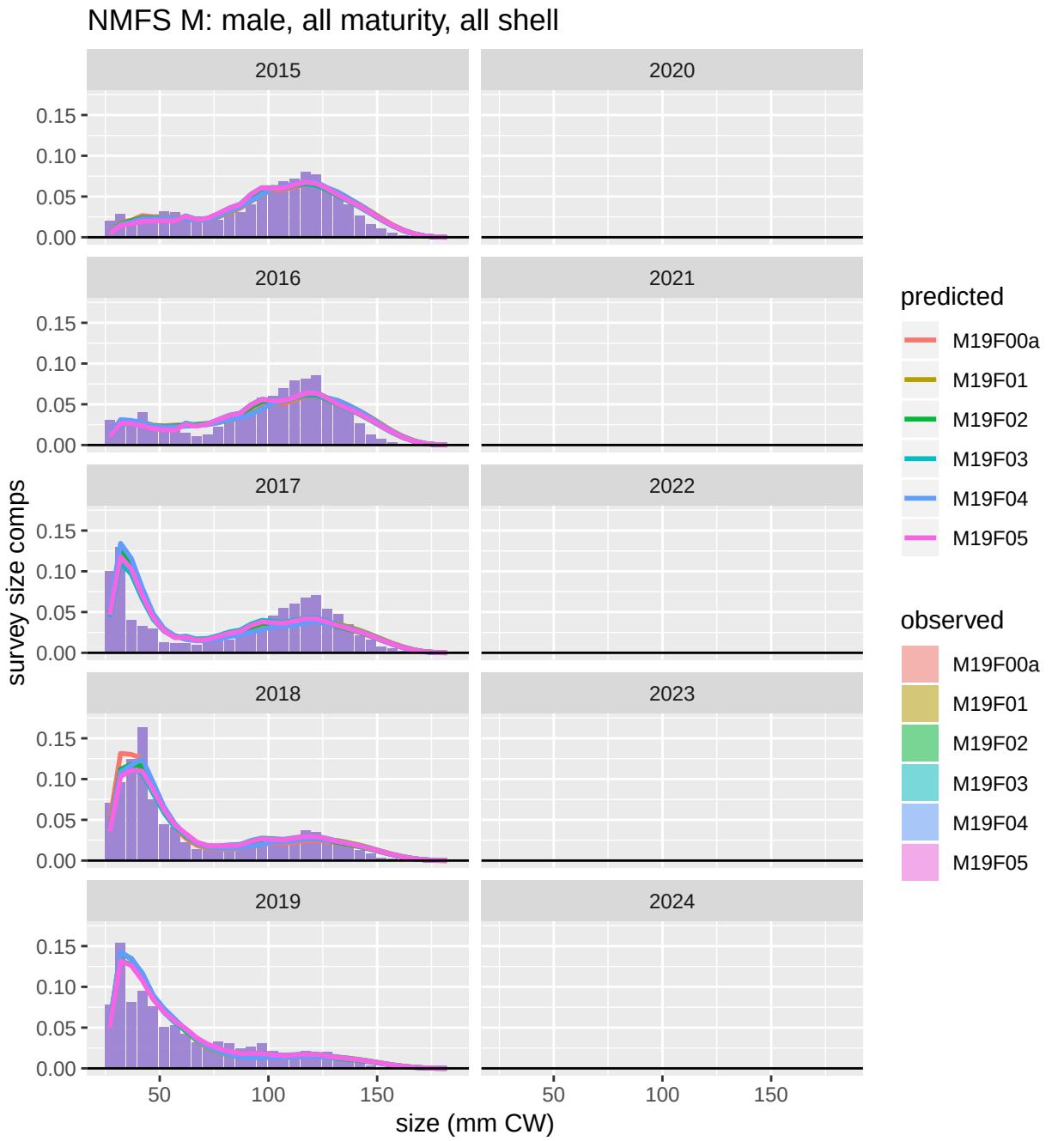


Figure 25: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 5 of 5.

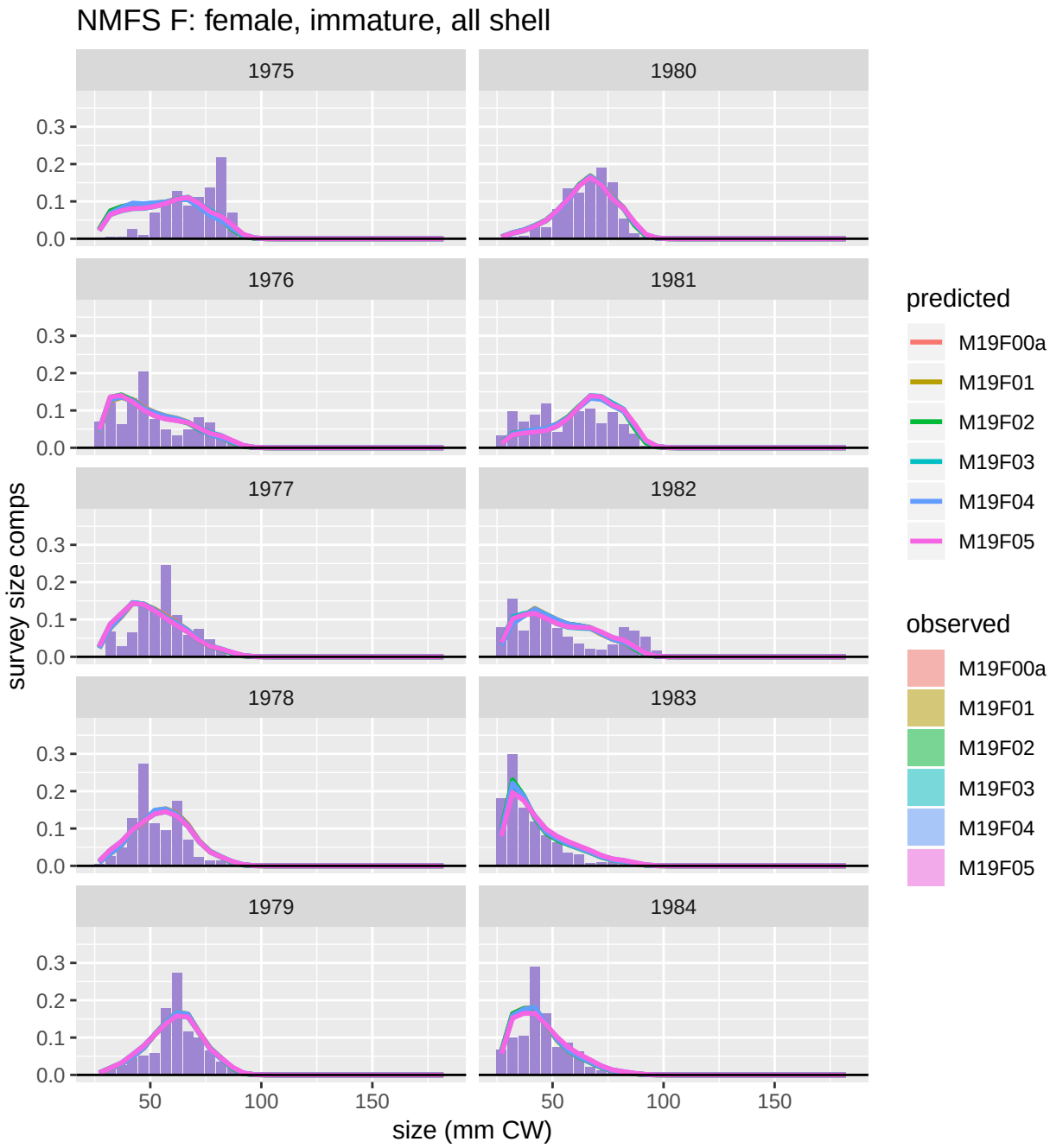


Figure 26: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 1 of 5.

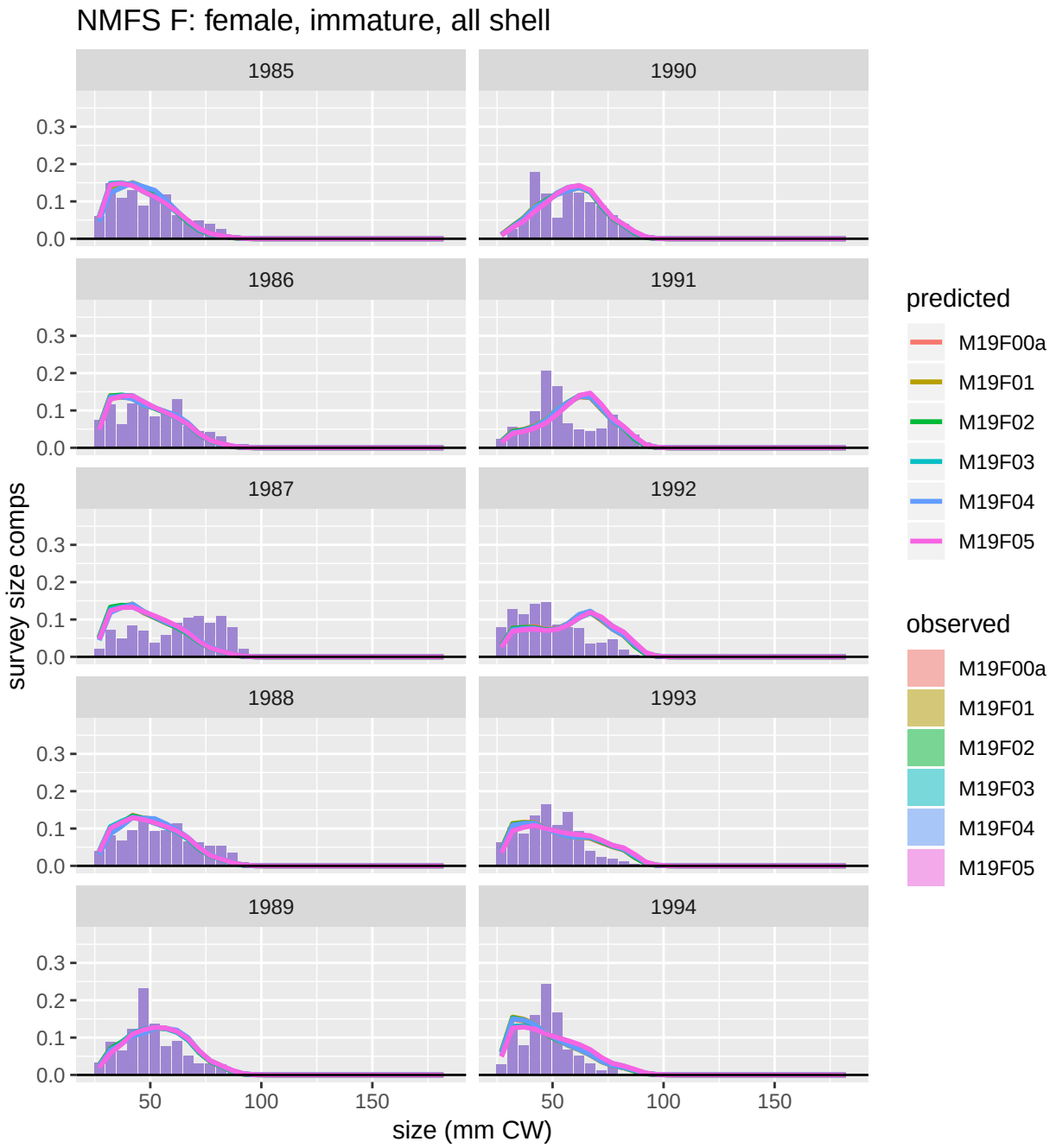


Figure 27: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 2 of 5.

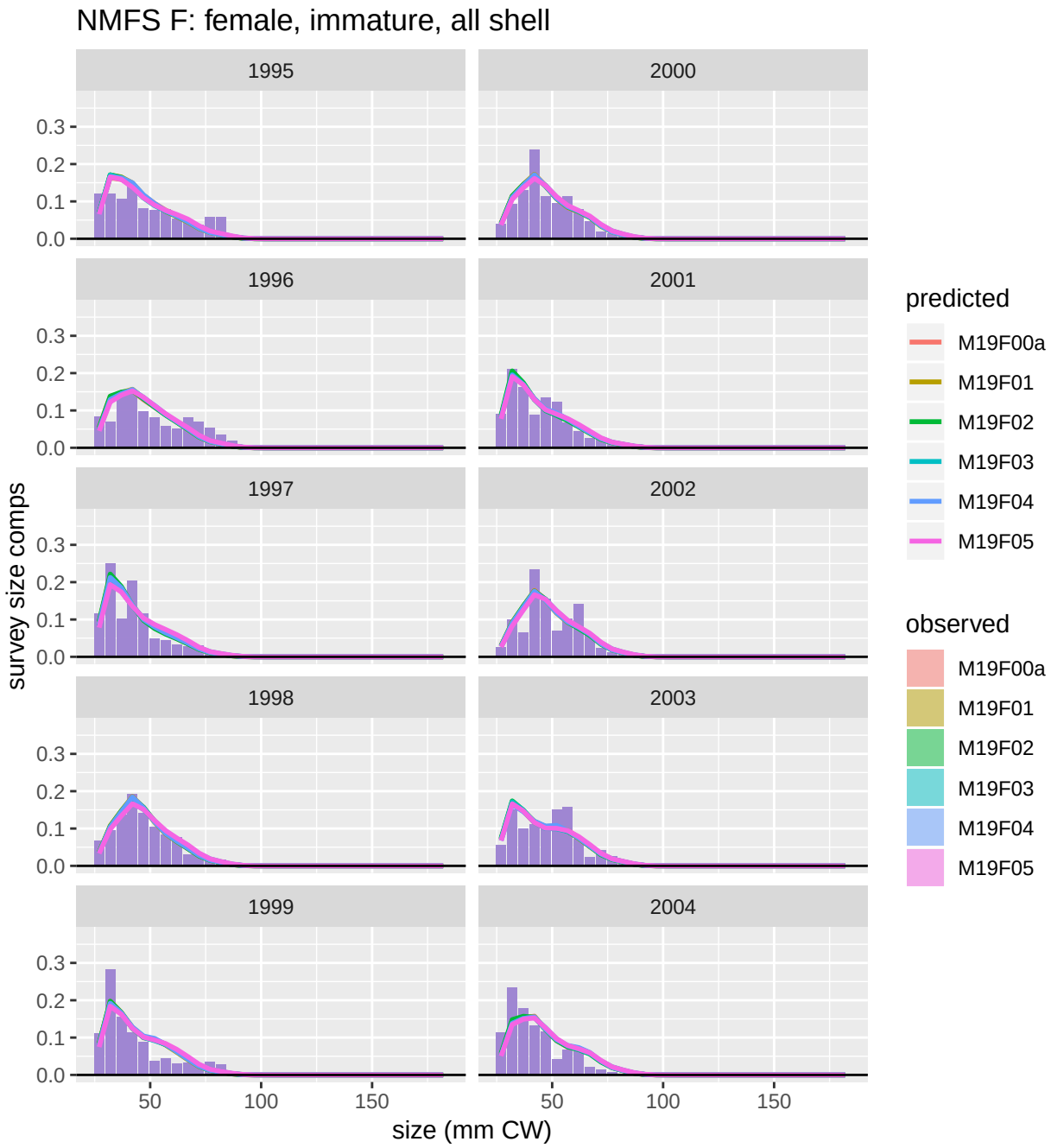


Figure 28: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 3 of 5.

Figure 29: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 4 of 5.

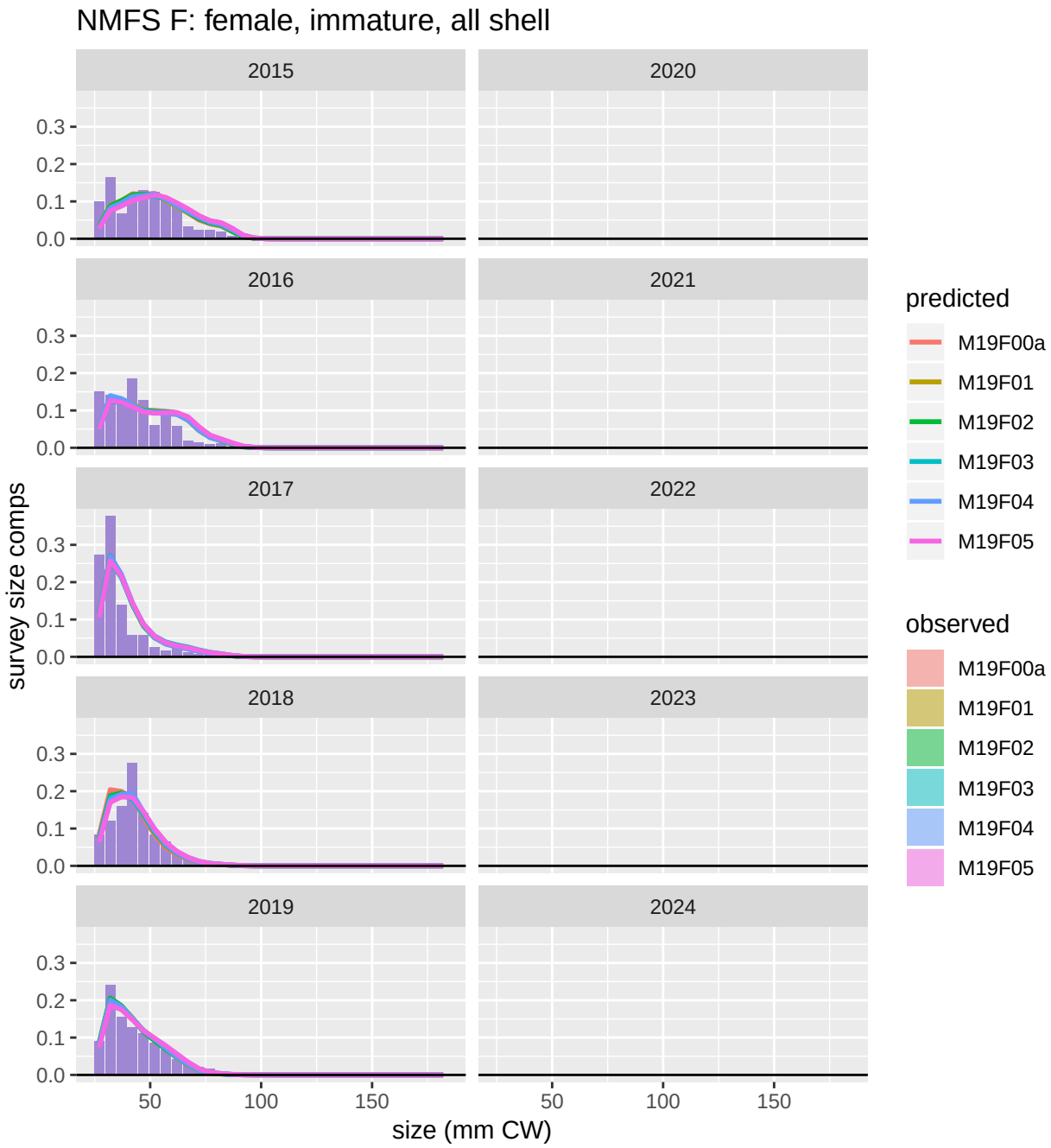


Figure 30: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 5 of 5.

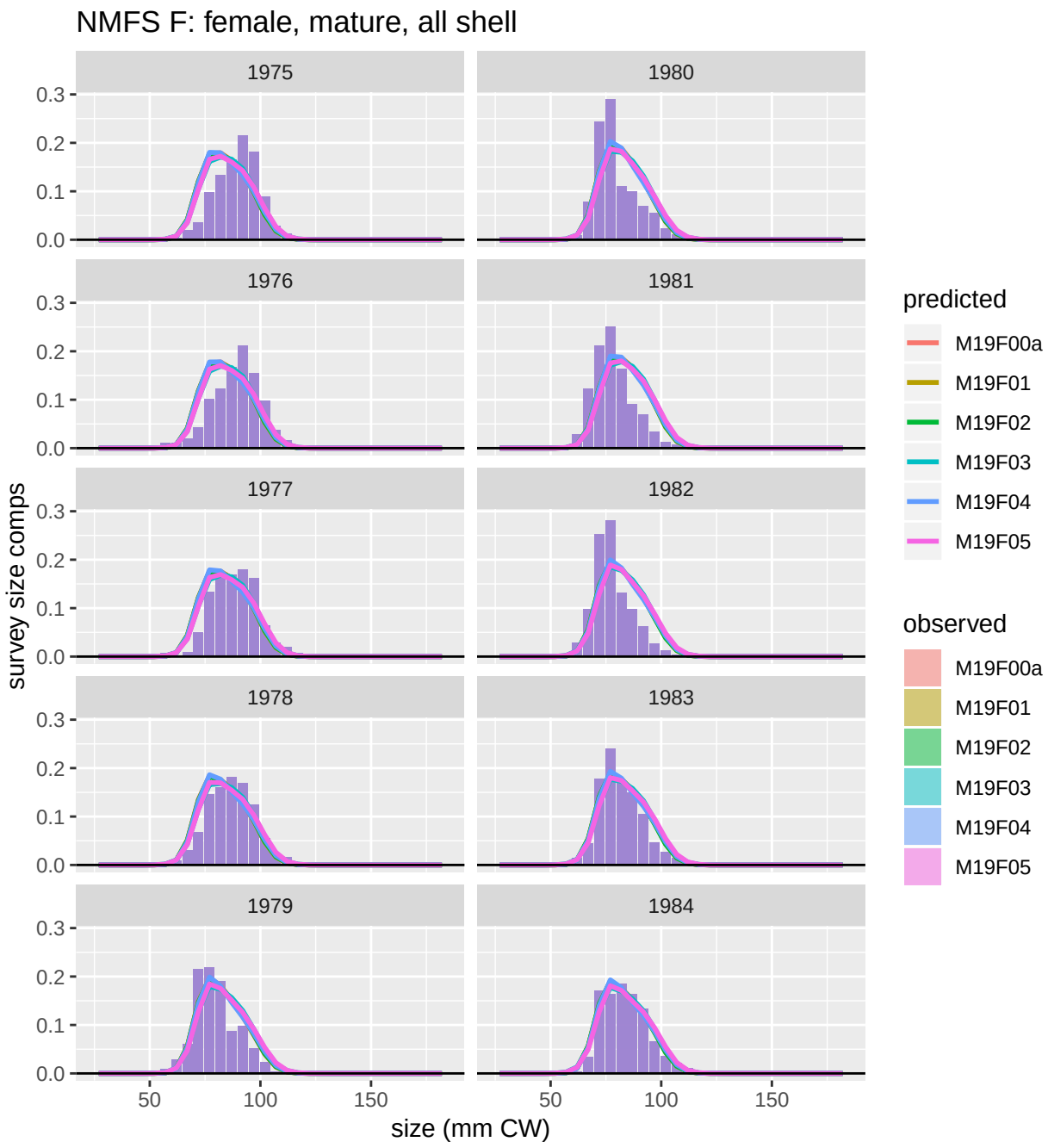


Figure 31: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 1 of 5.

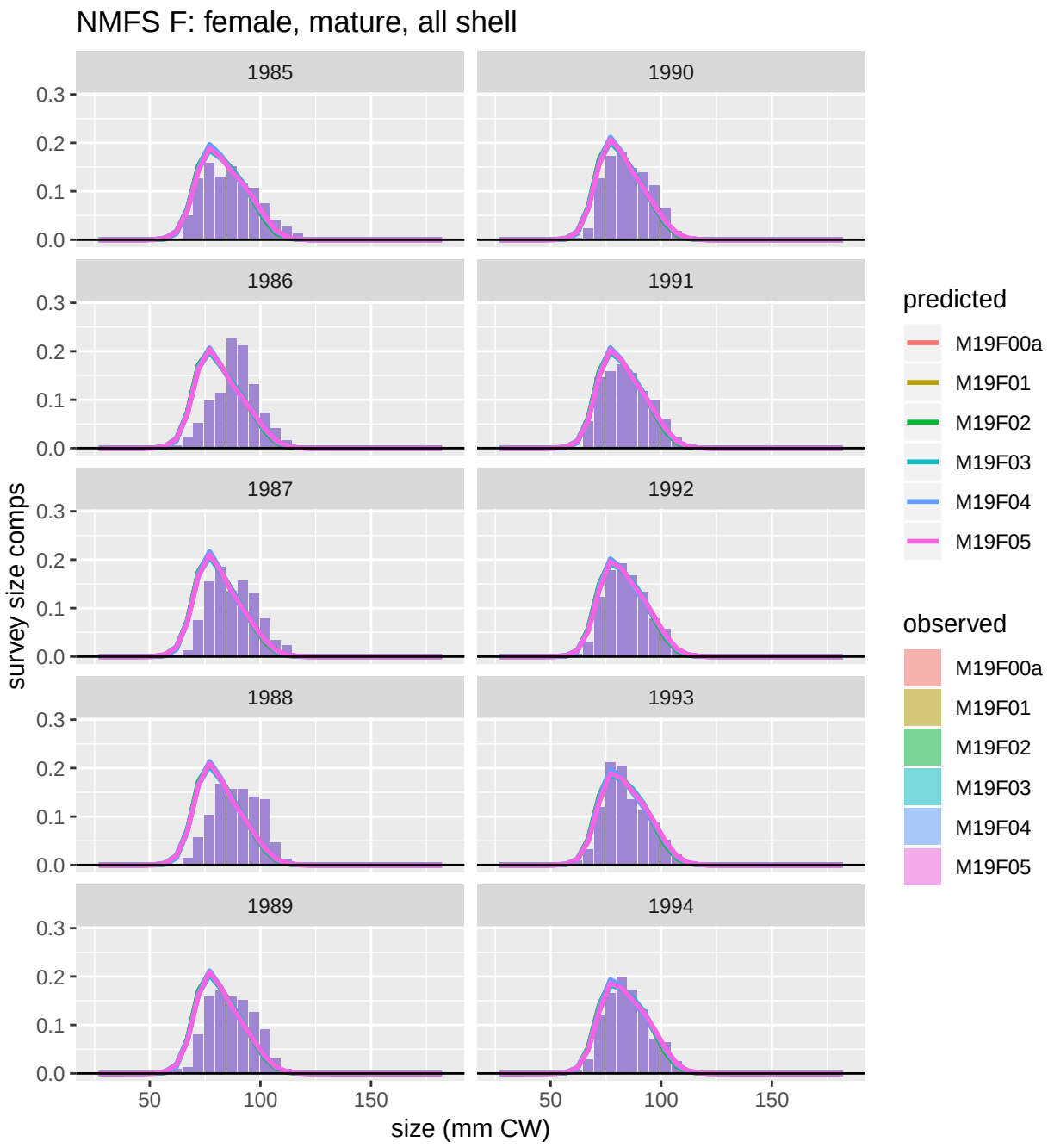


Figure 32: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 2 of 5.

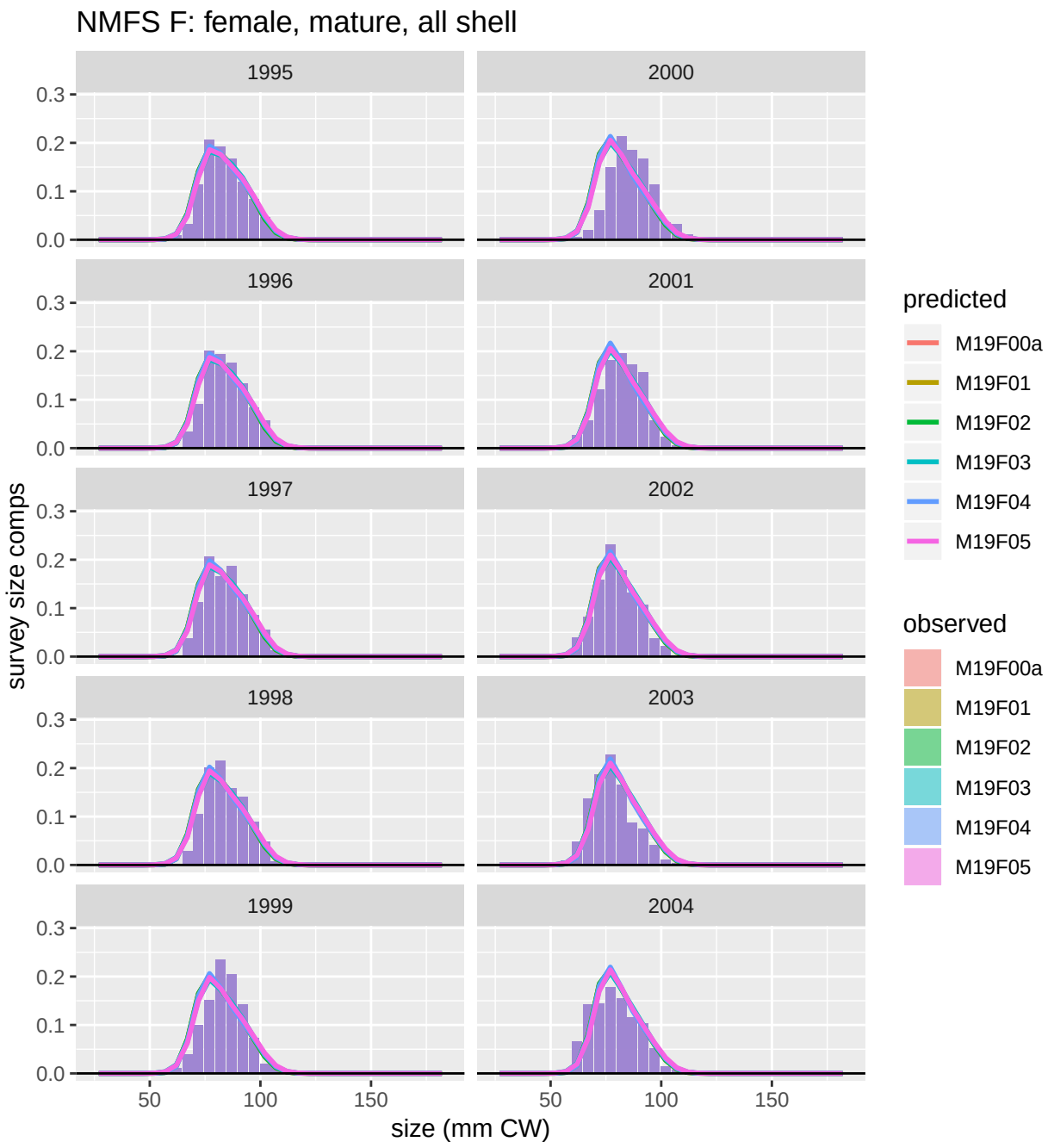


Figure 33: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 3 of 5.

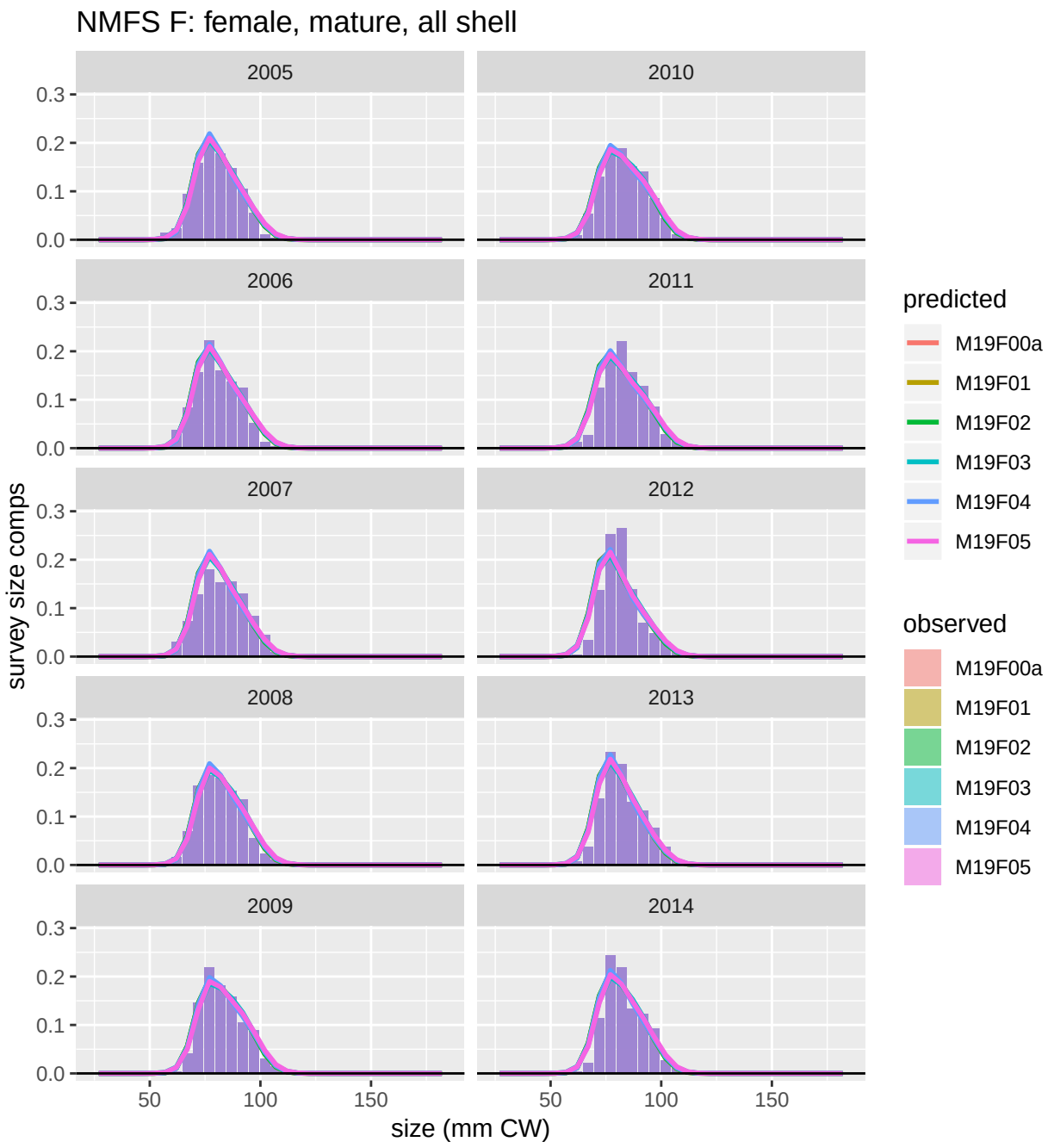


Figure 34: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 4 of 5.

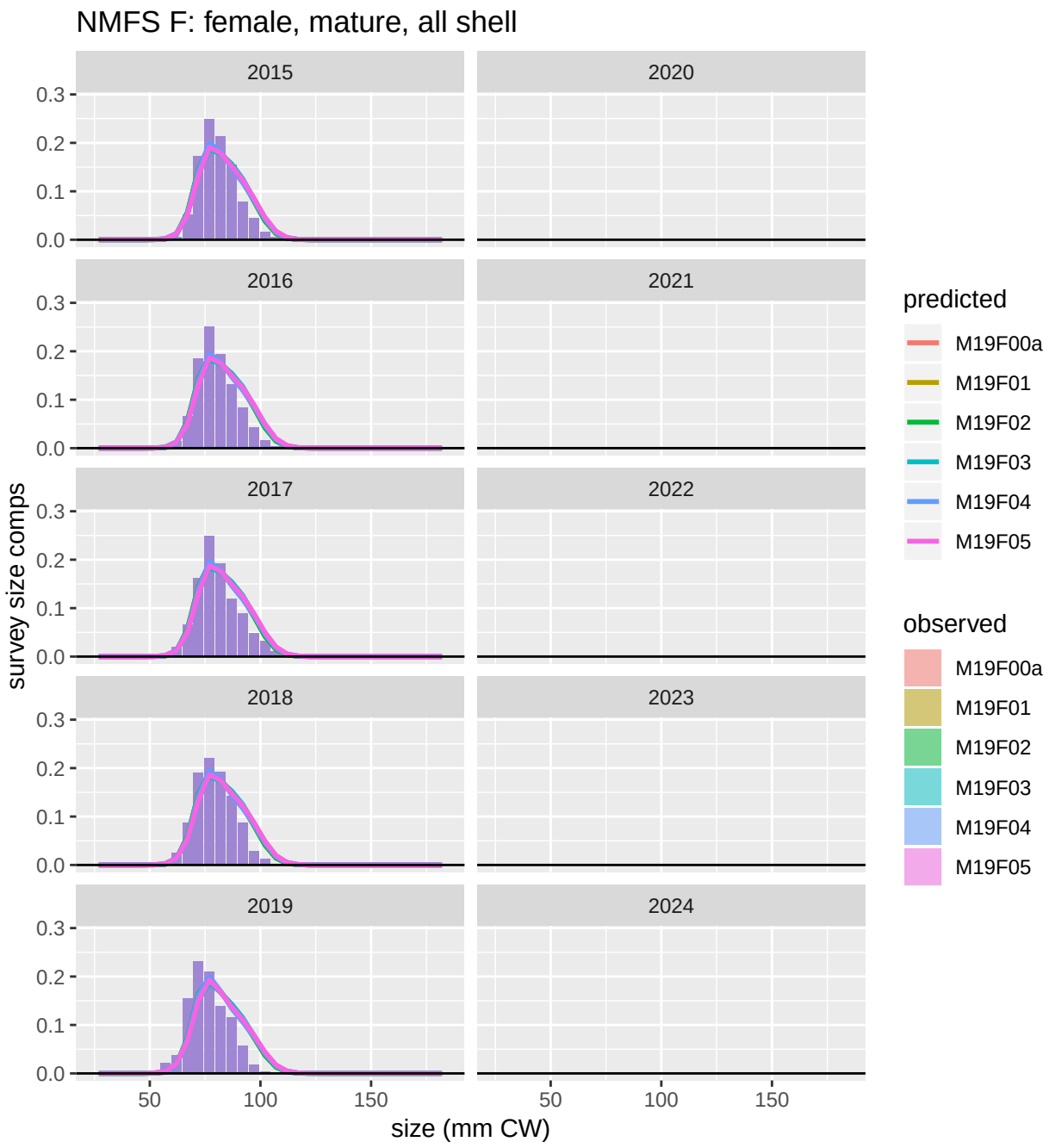


Figure 35: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 5 of 5.

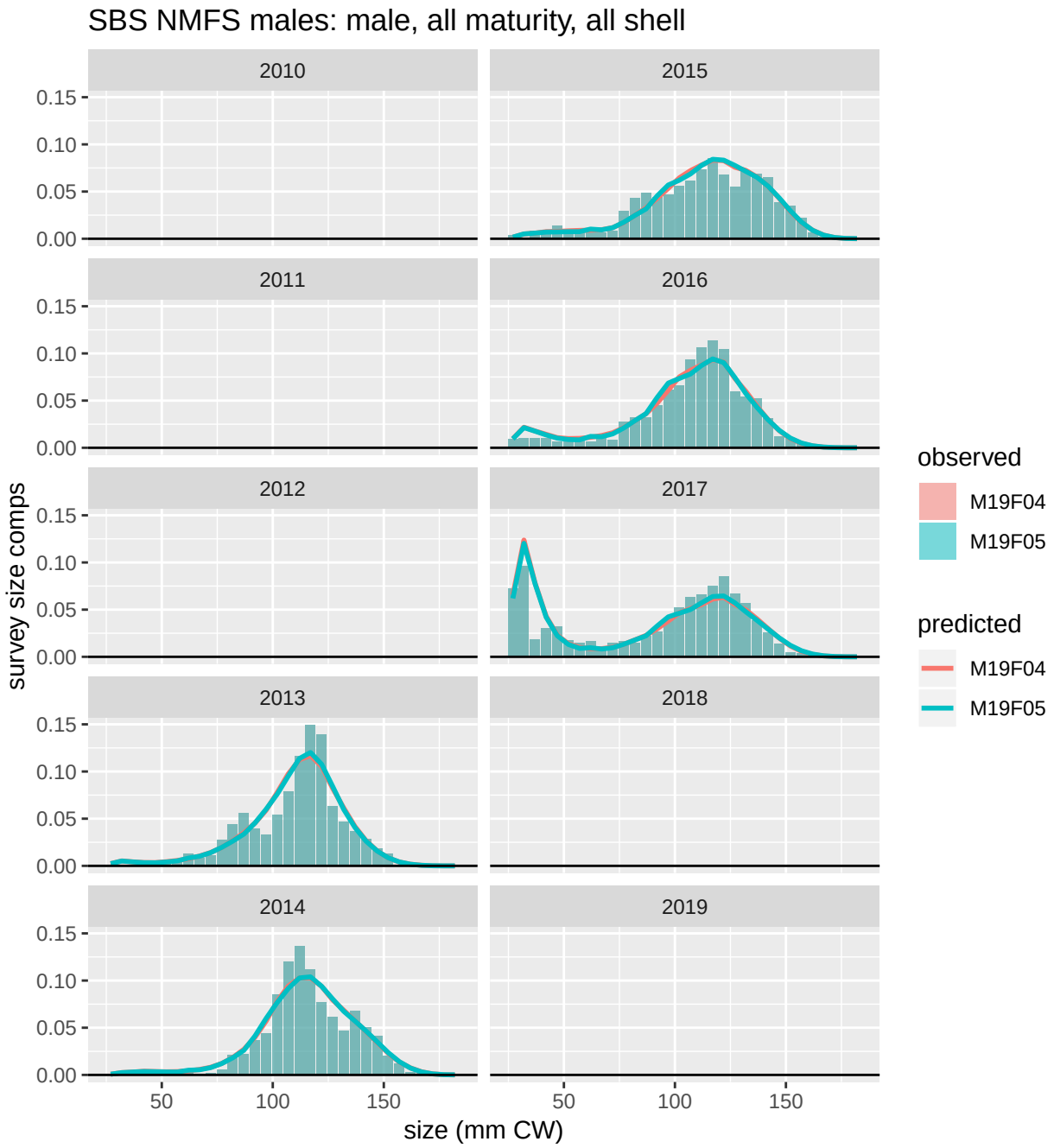


Figure 36: Comparison of observed and predicted male, all maturity, all shell survey size comps for SBS NMFS males. Page 1 of 1.

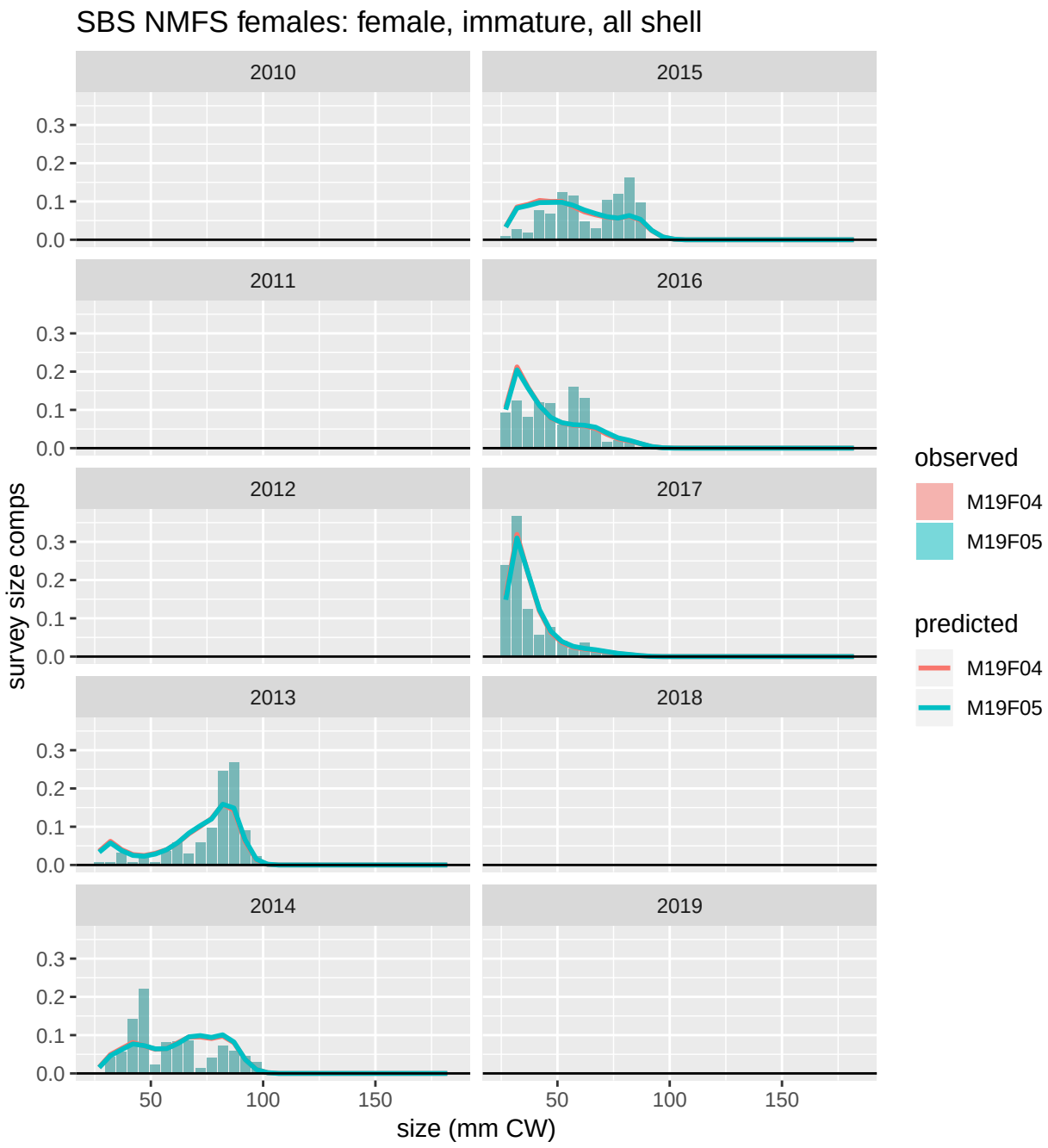


Figure 37: Comparison of observed and predicted female, immature, all shell survey size comps for SBS NMFS females. Page 1 of 1.

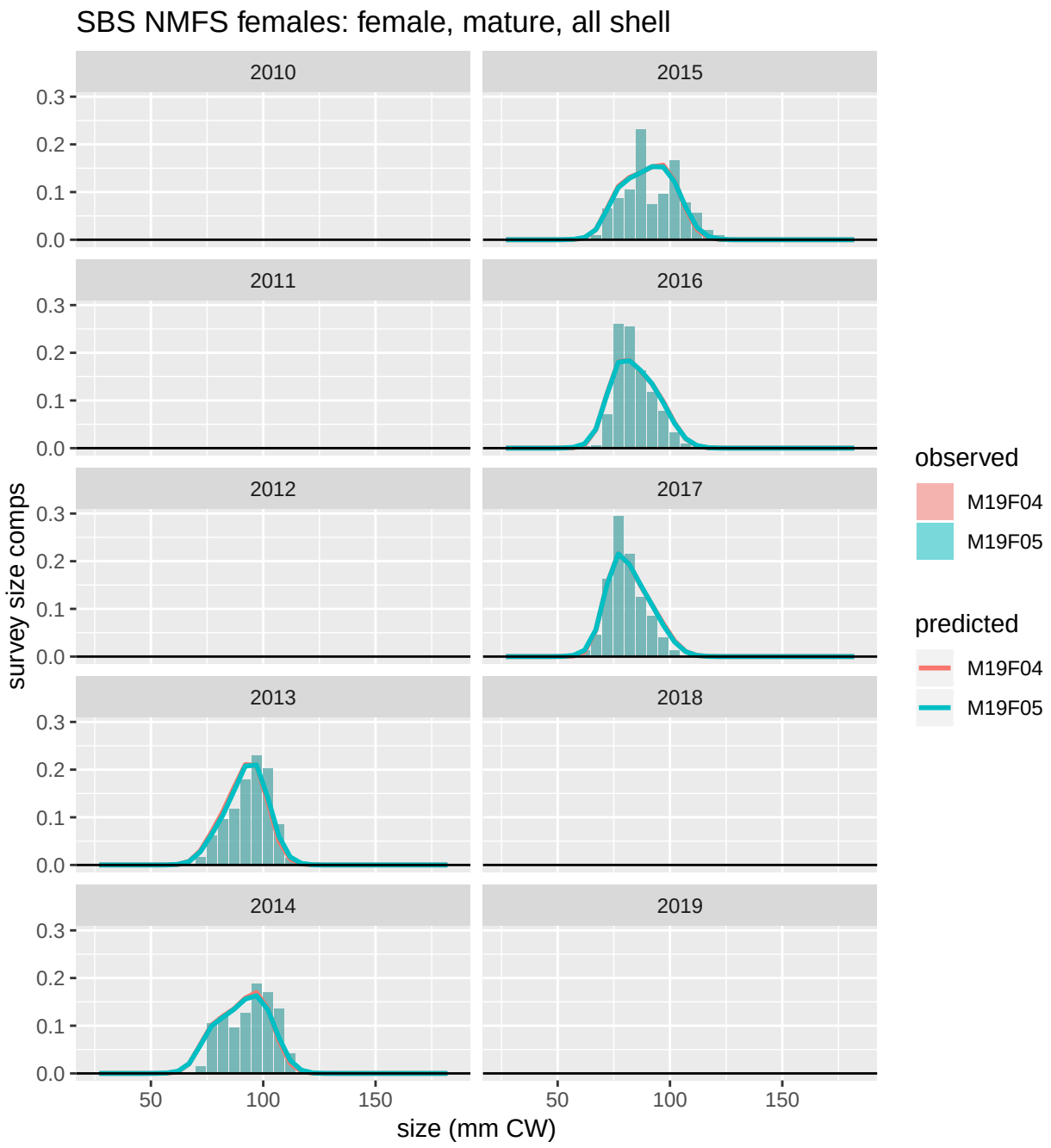


Figure 38: Comparison of observed and predicted female, mature, all shell survey size comps for SBS NMFS females. Page 1 of 1.

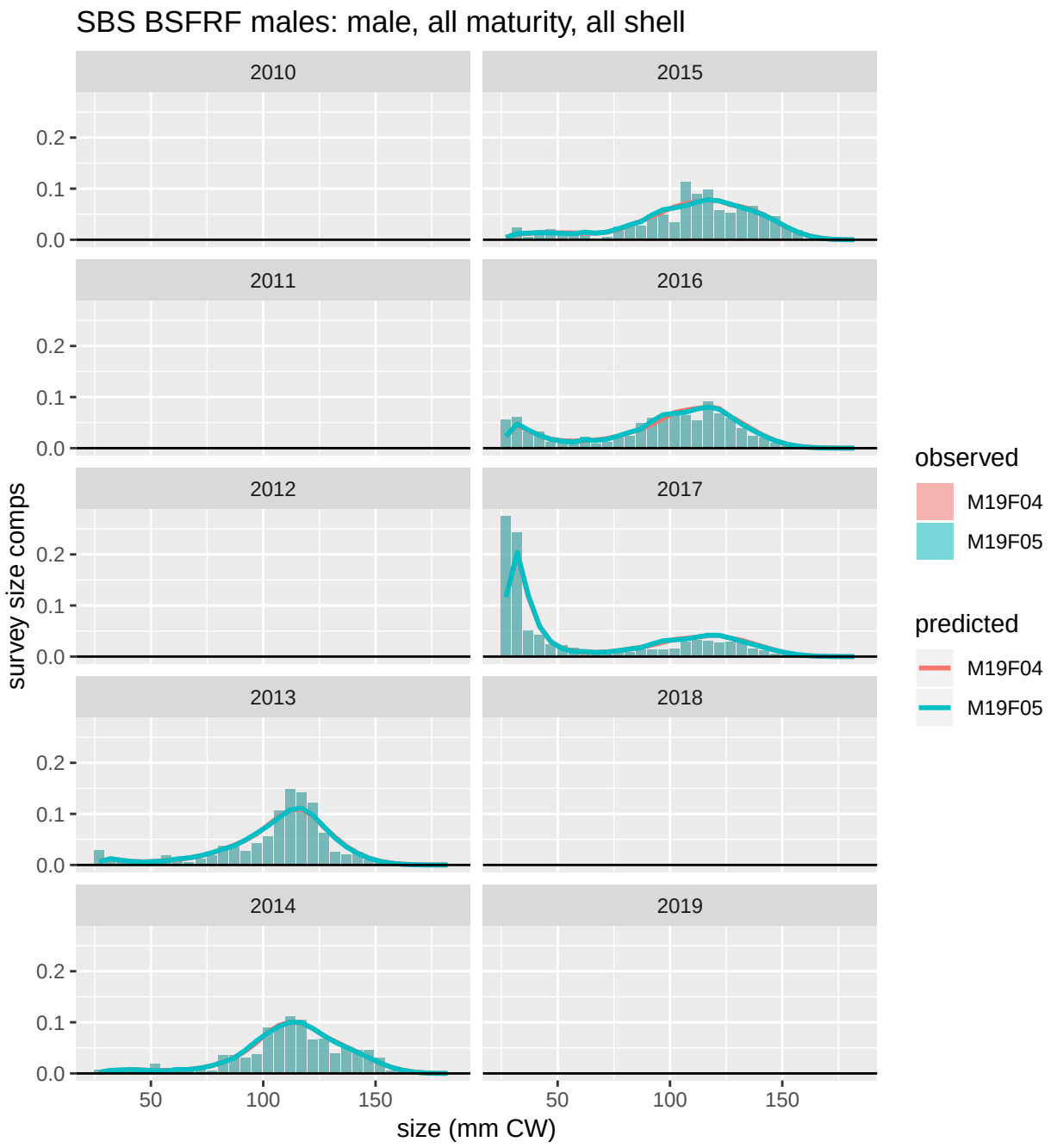


Figure 39: Comparison of observed and predicted male, all maturity, all shell survey size comps for SBS BSFRF males. Page 1 of 1.

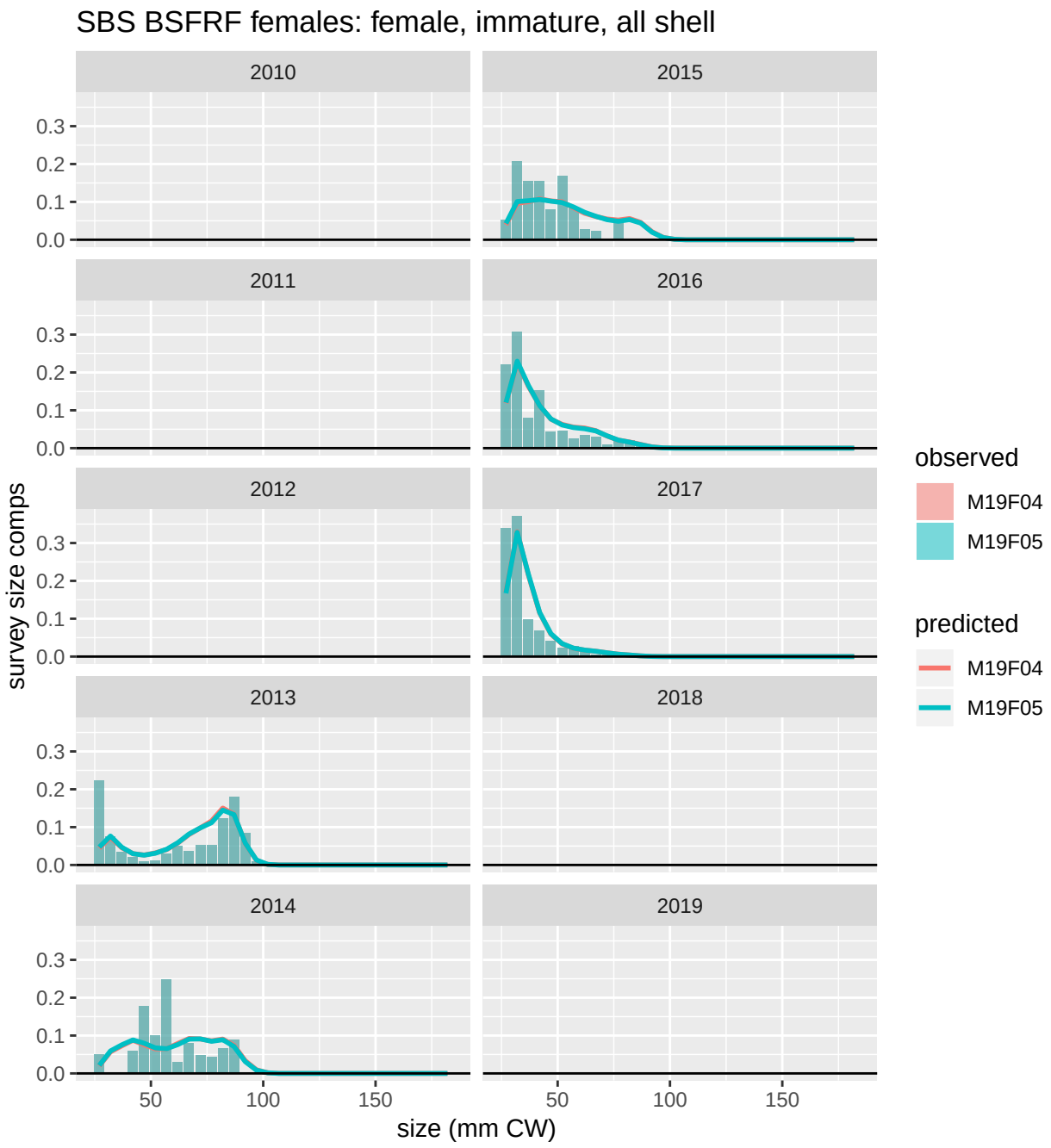


Figure 40: Comparison of observed and predicted female, immature, all shell survey size comps for SBS BSFRF females. Page 1 of 1.

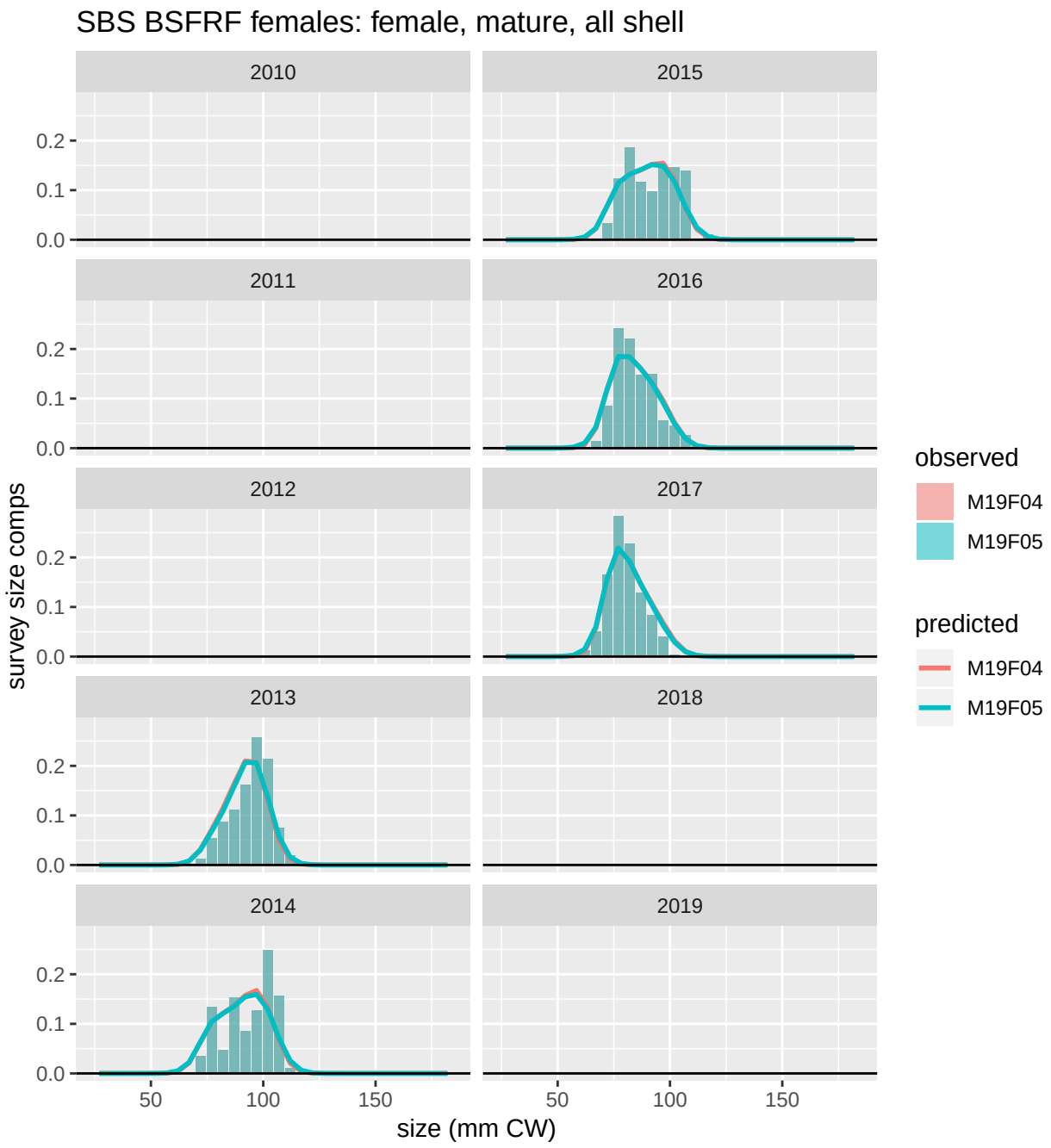


Figure 41: Comparison of observed and predicted female, mature, all shell survey size comps for SBS BSFRF females. Page 1 of 1.

Fishery retained catch size compositions

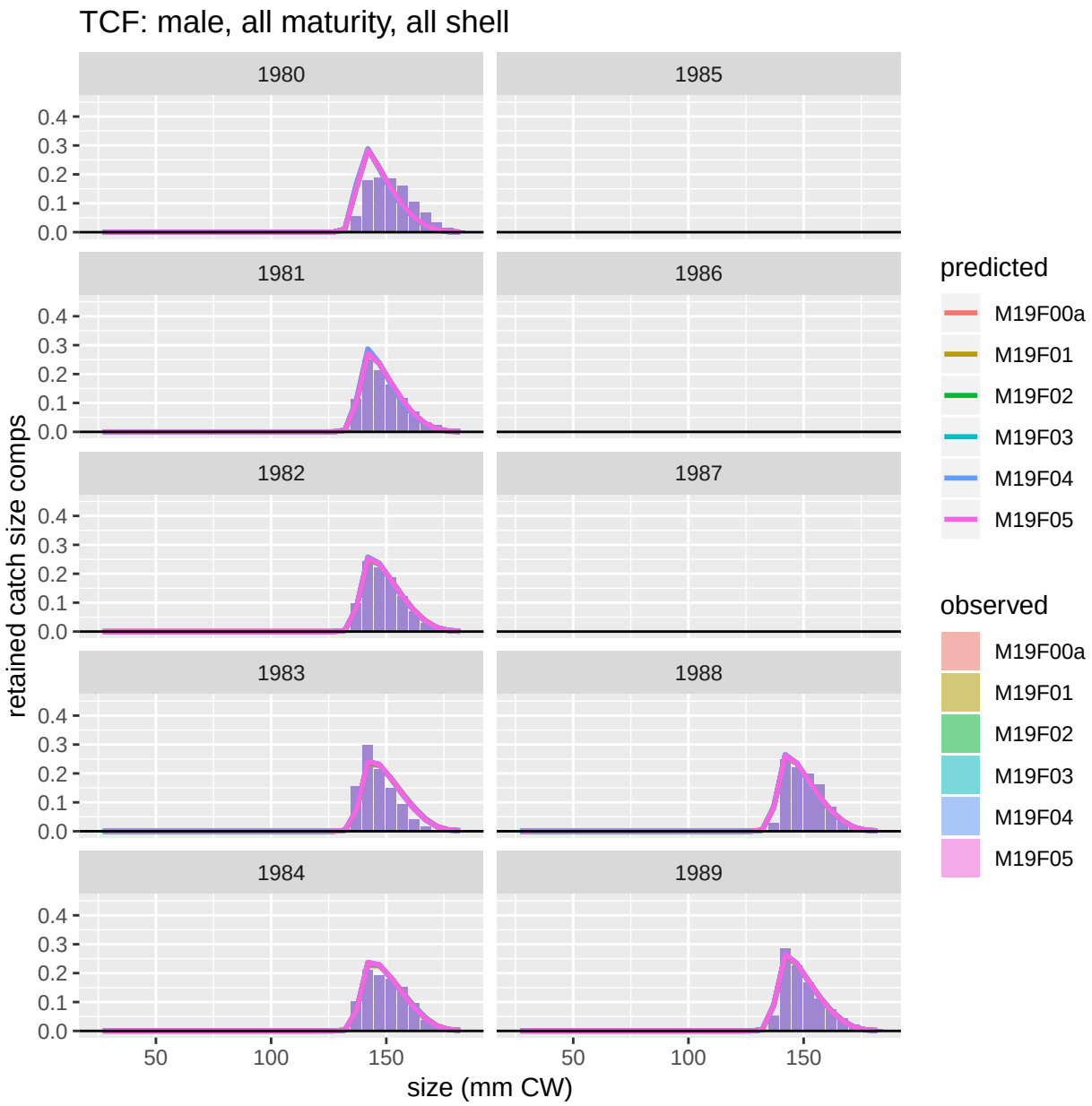


Figure 42: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 1 of 4.

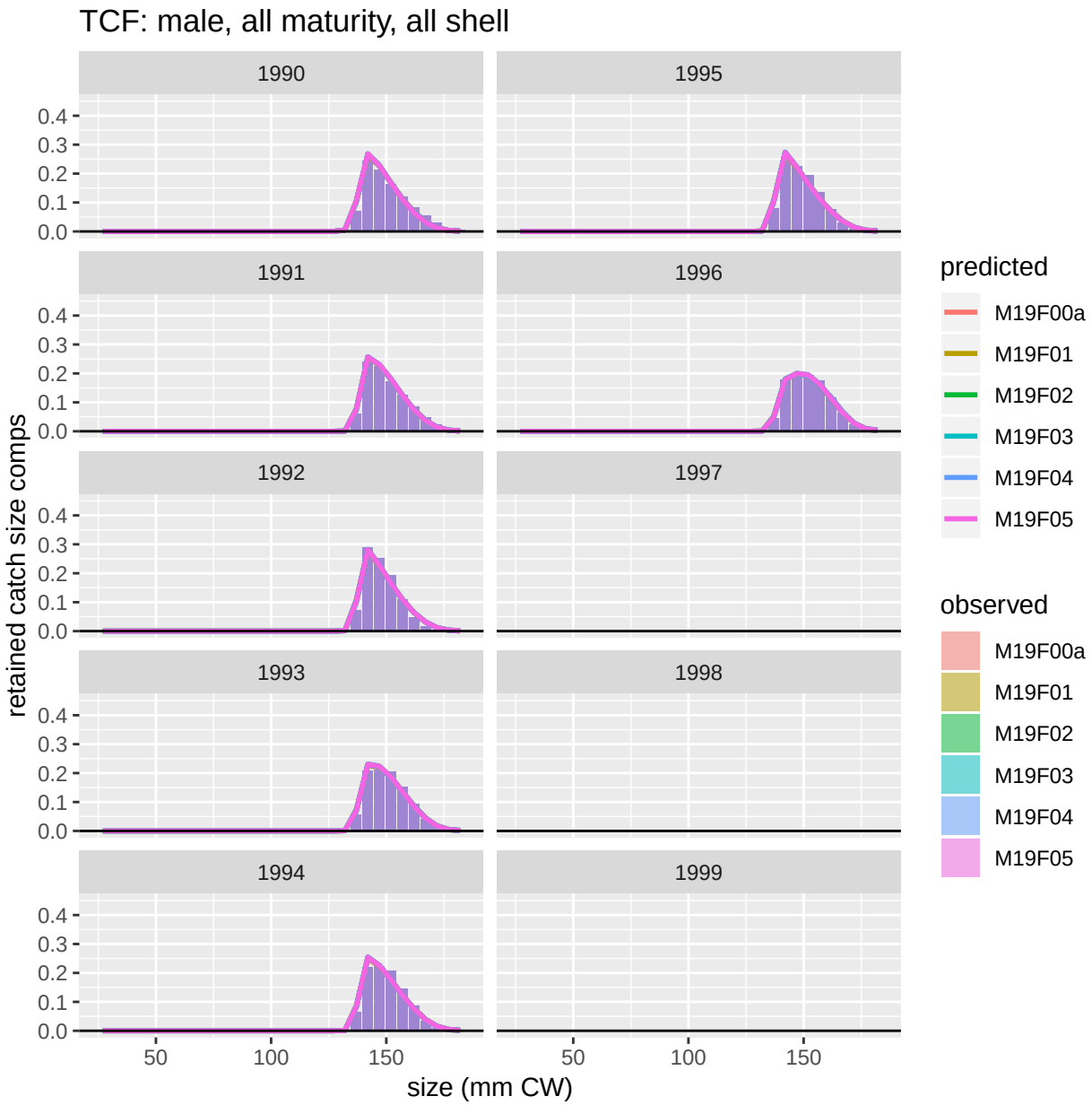


Figure 43: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 2 of 4.

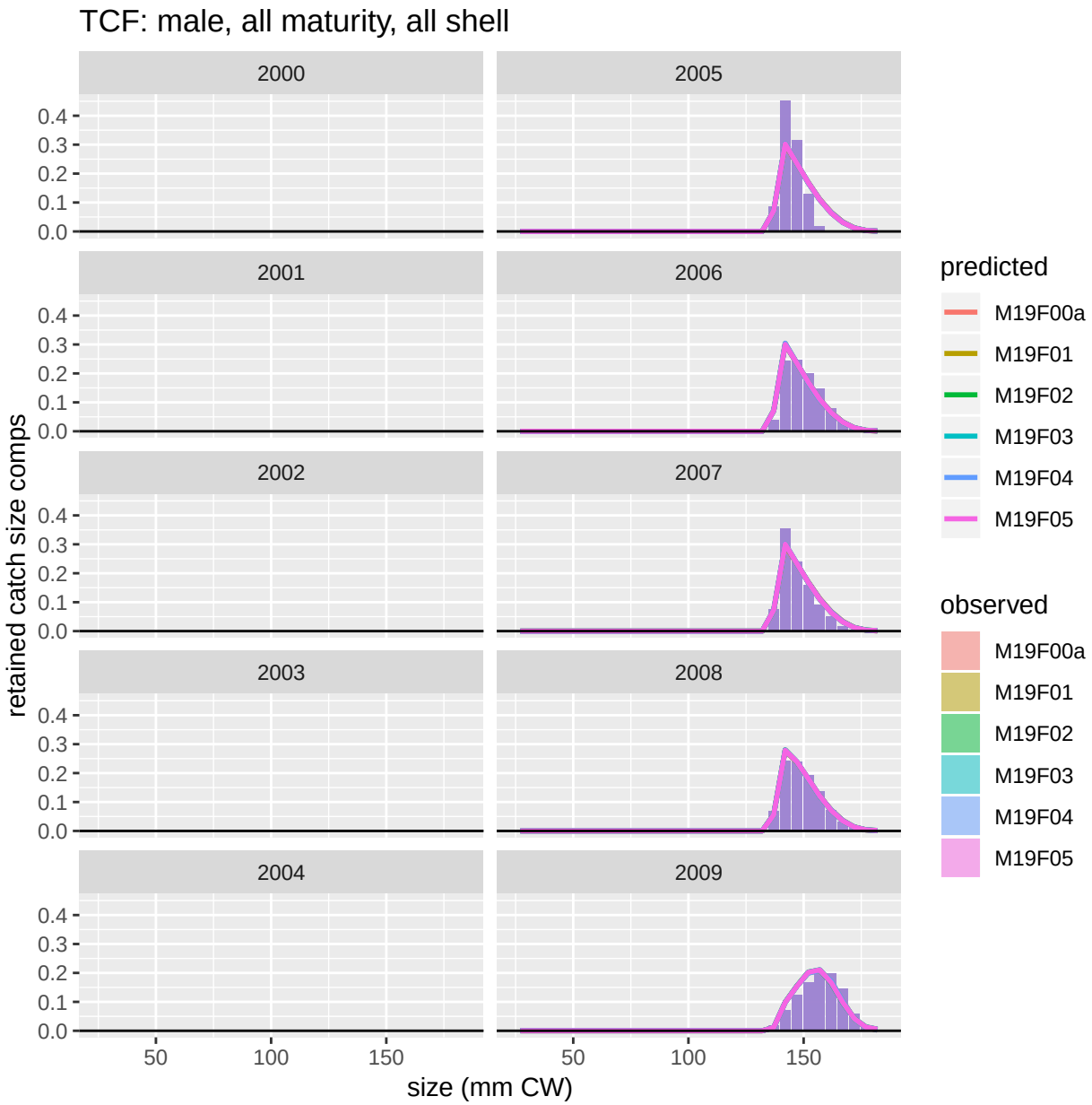


Figure 44: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 3 of 4.

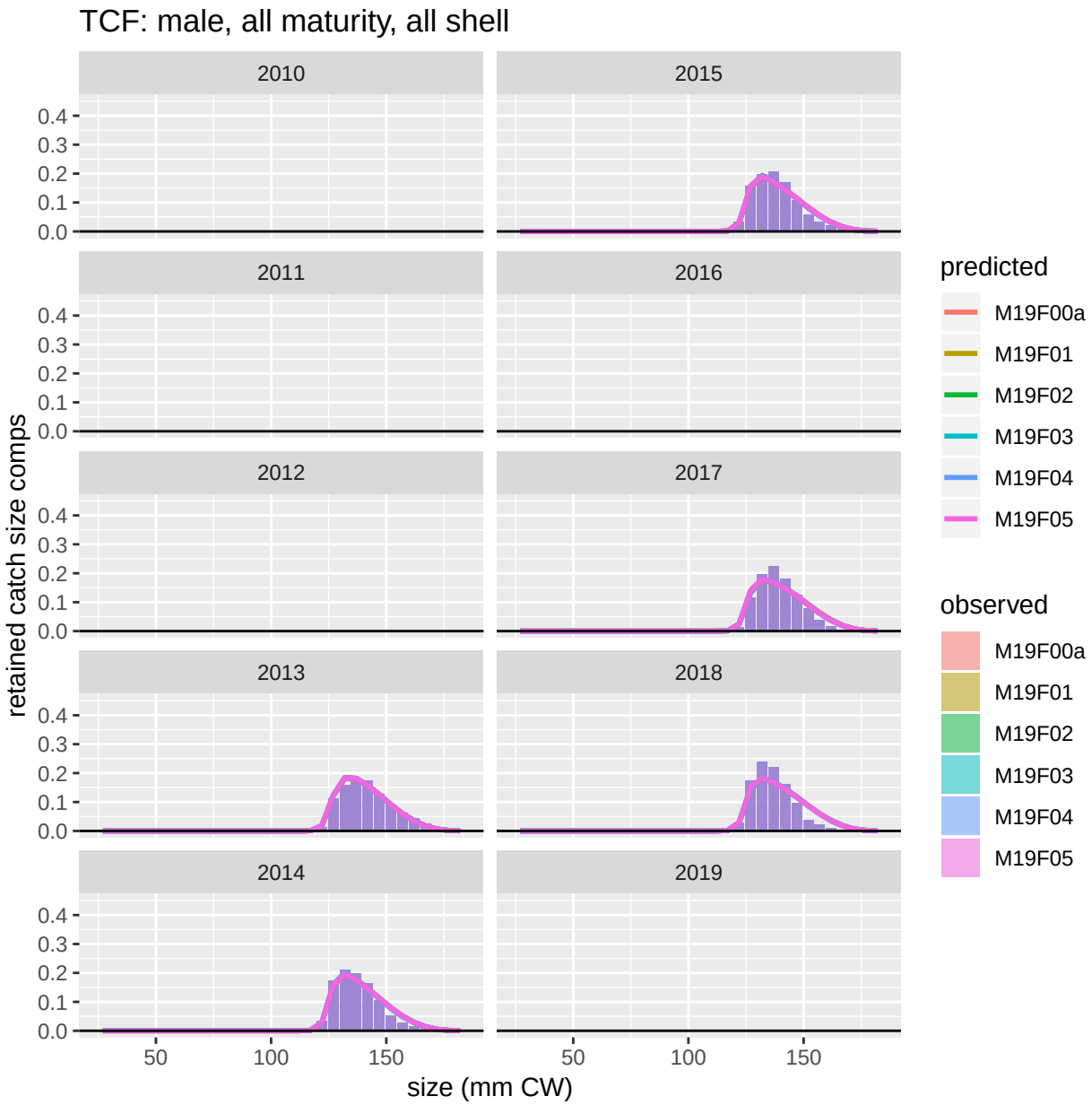


Figure 45: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 4 of 4.

Fishery total catch size compositions

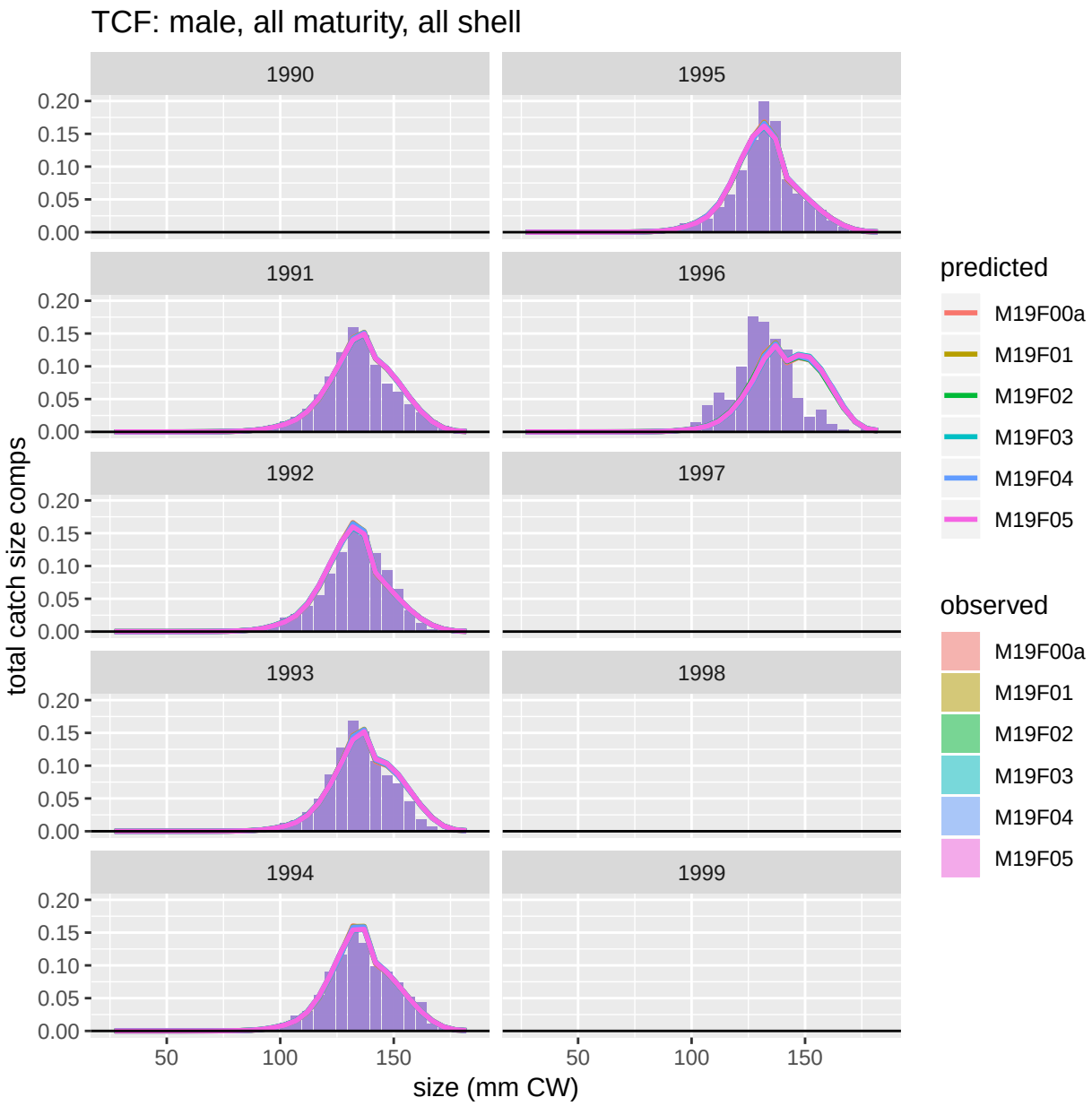


Figure 46: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

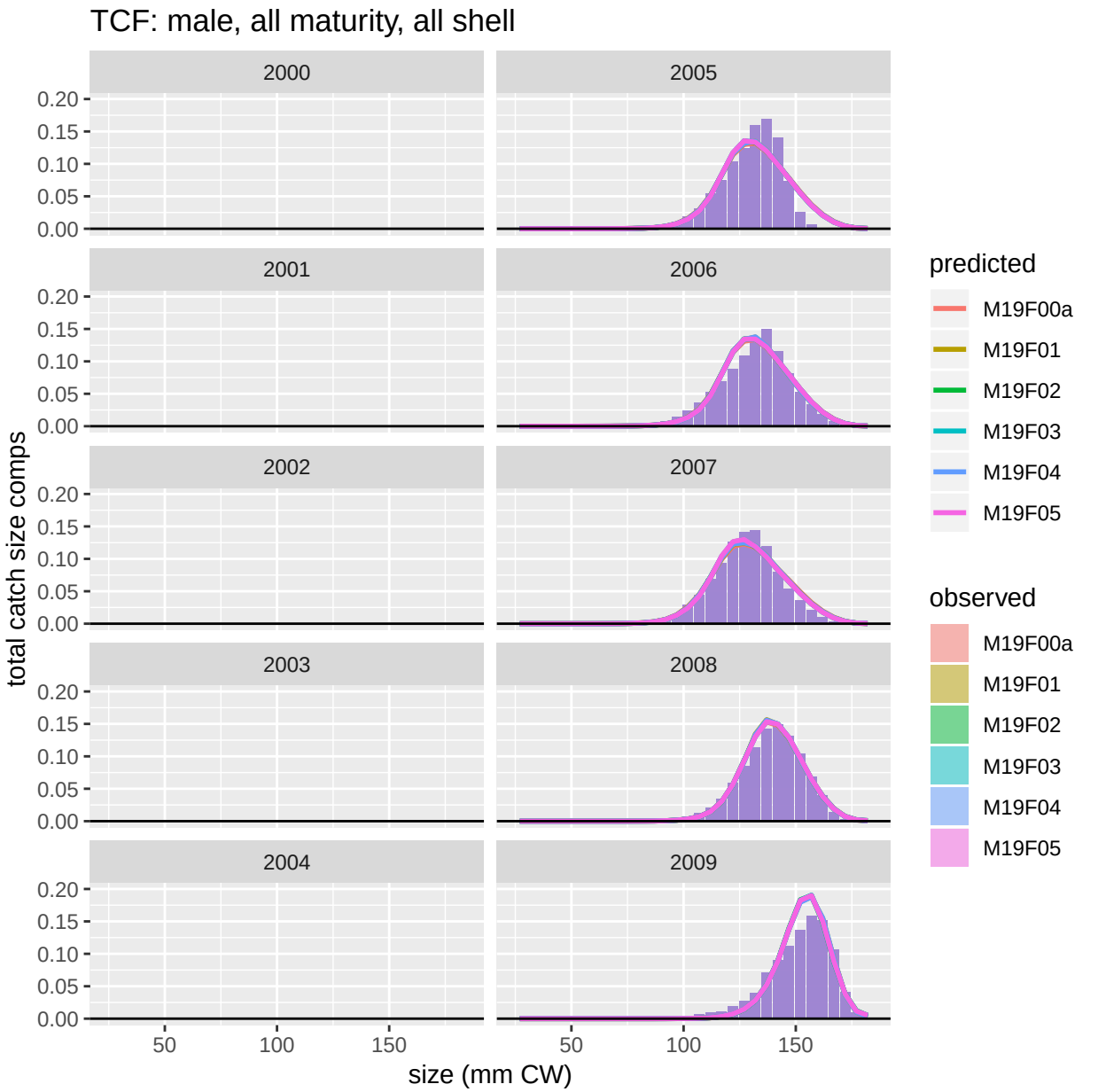


Figure 47: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

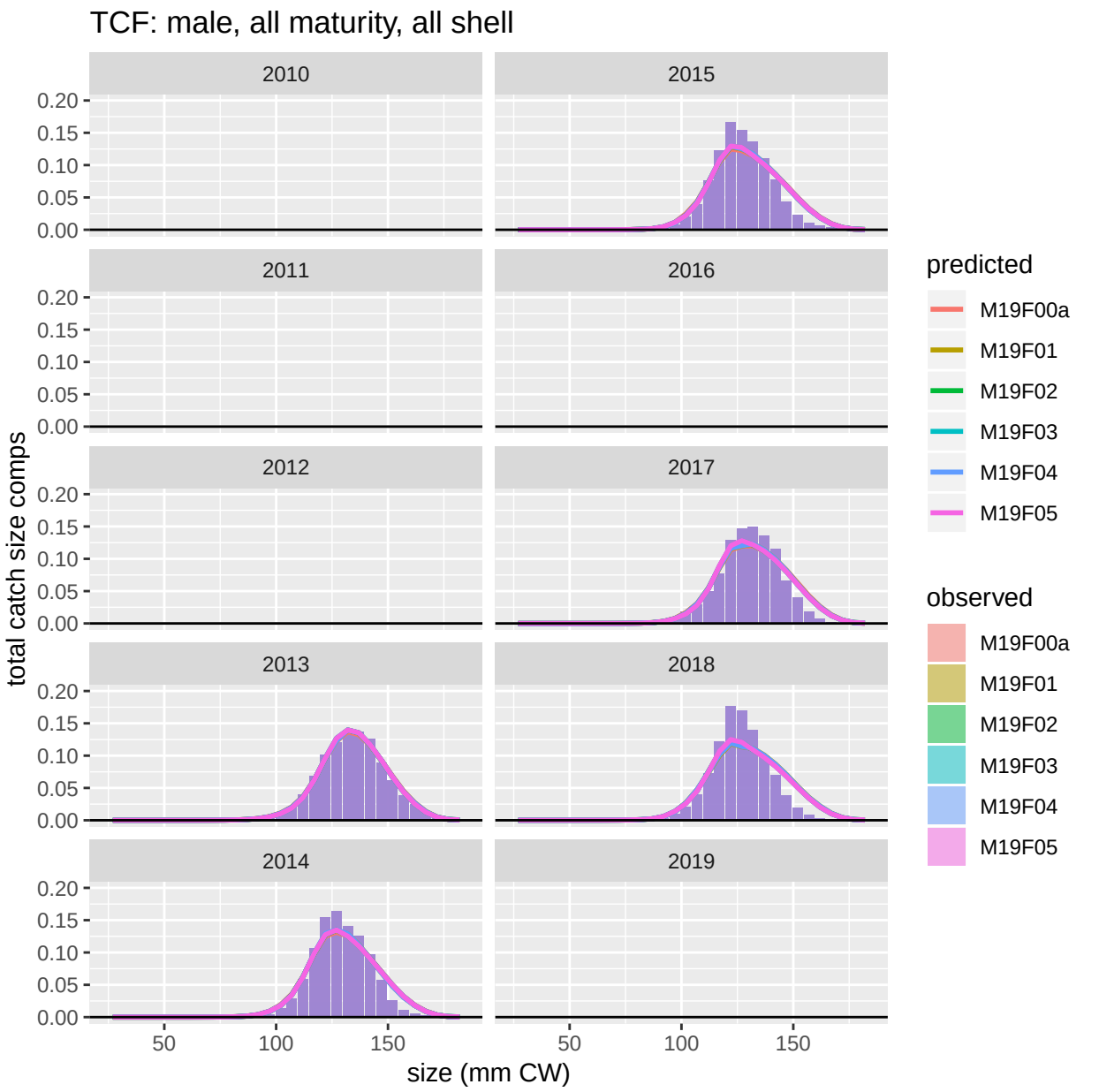


Figure 48: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

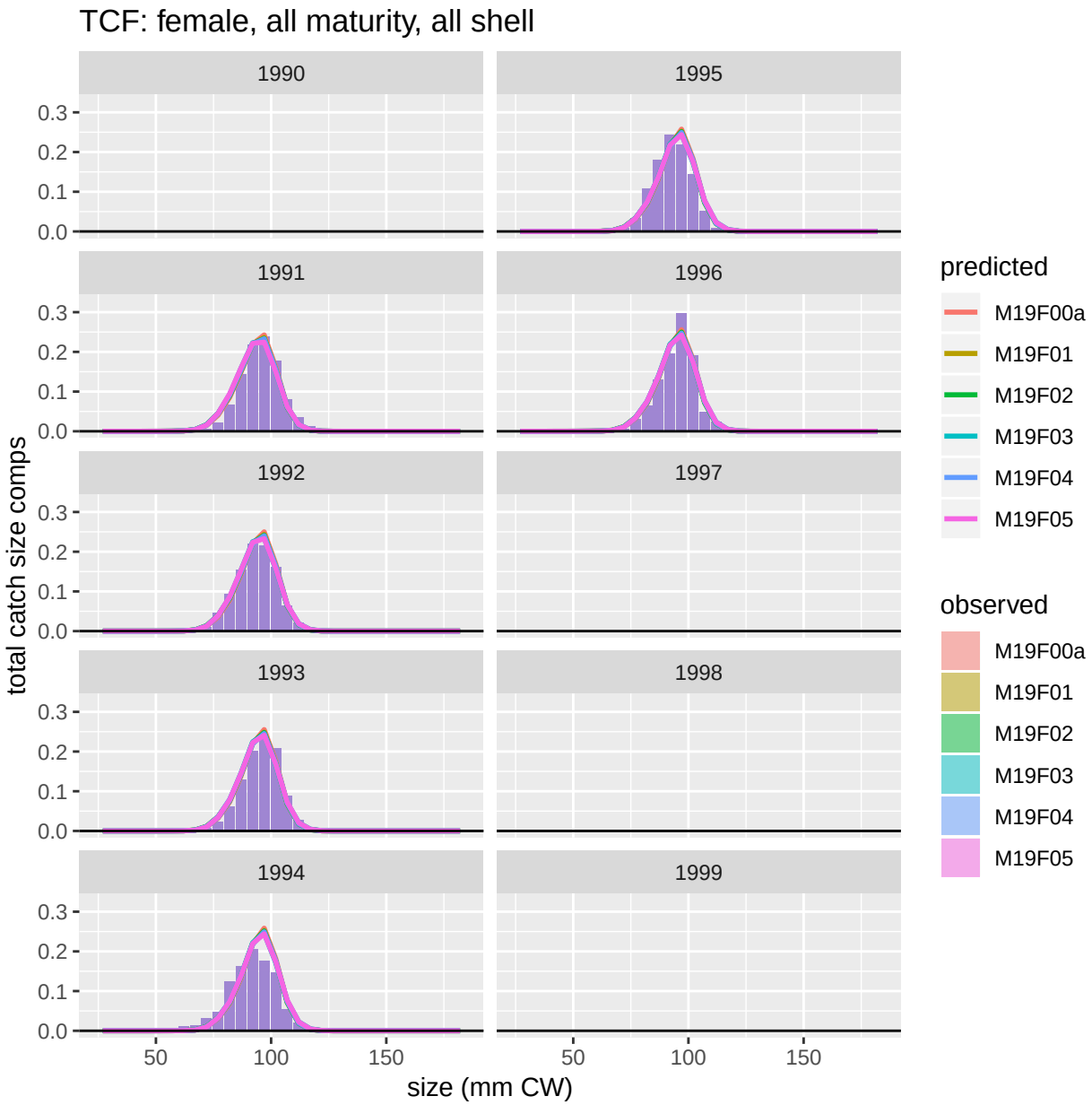


Figure 49: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

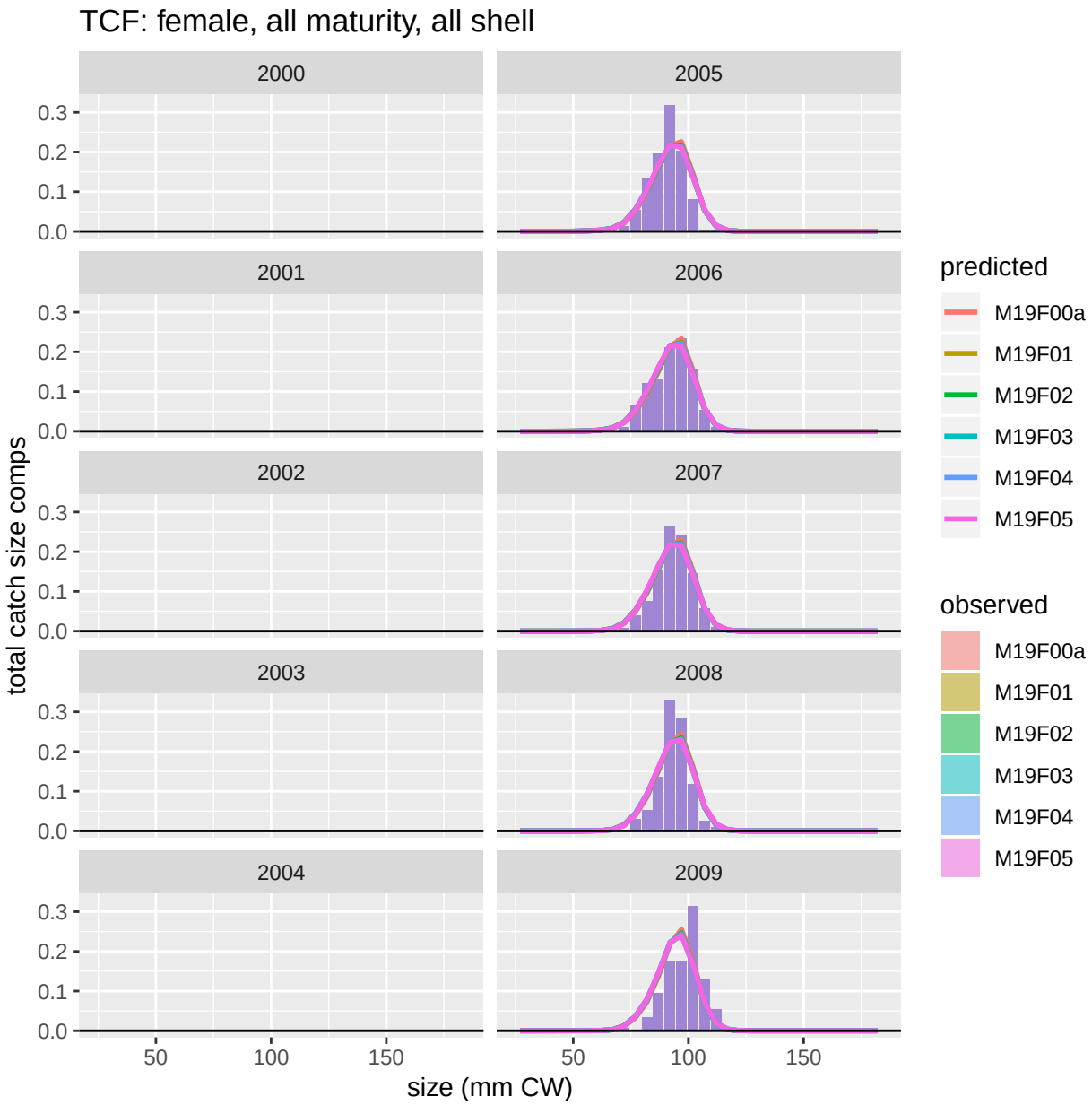


Figure 50: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

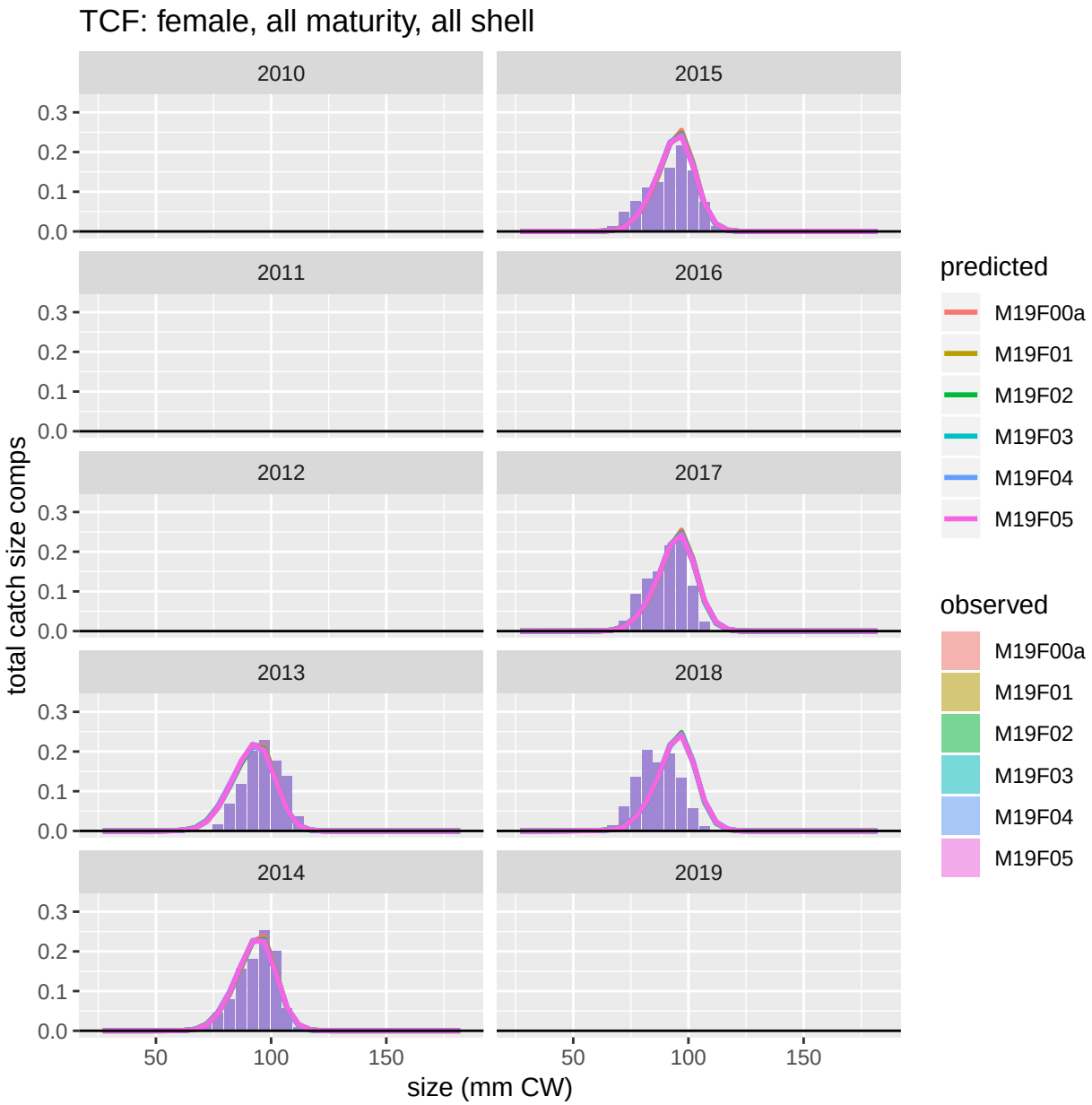


Figure 51: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

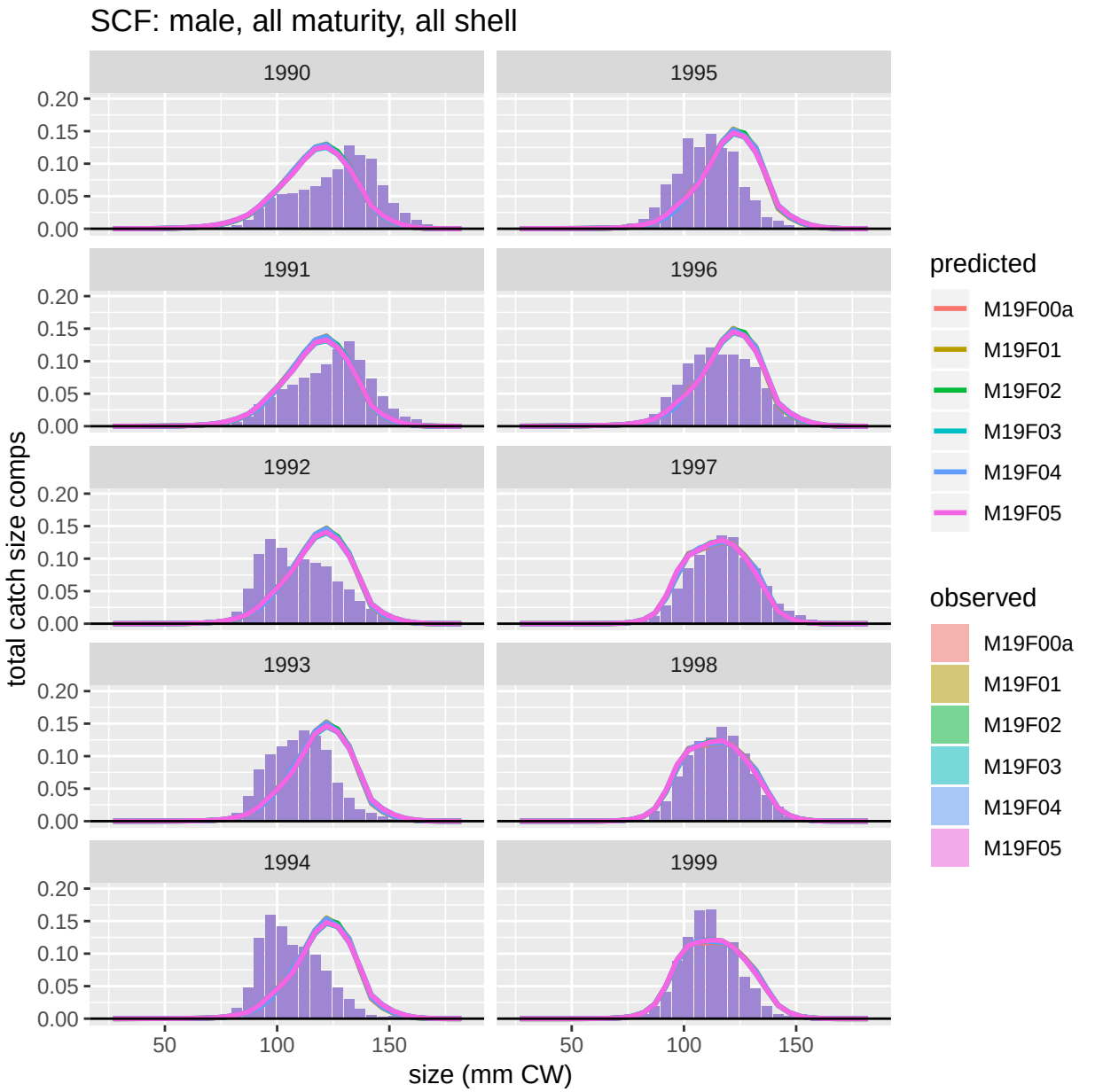


Figure 52: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

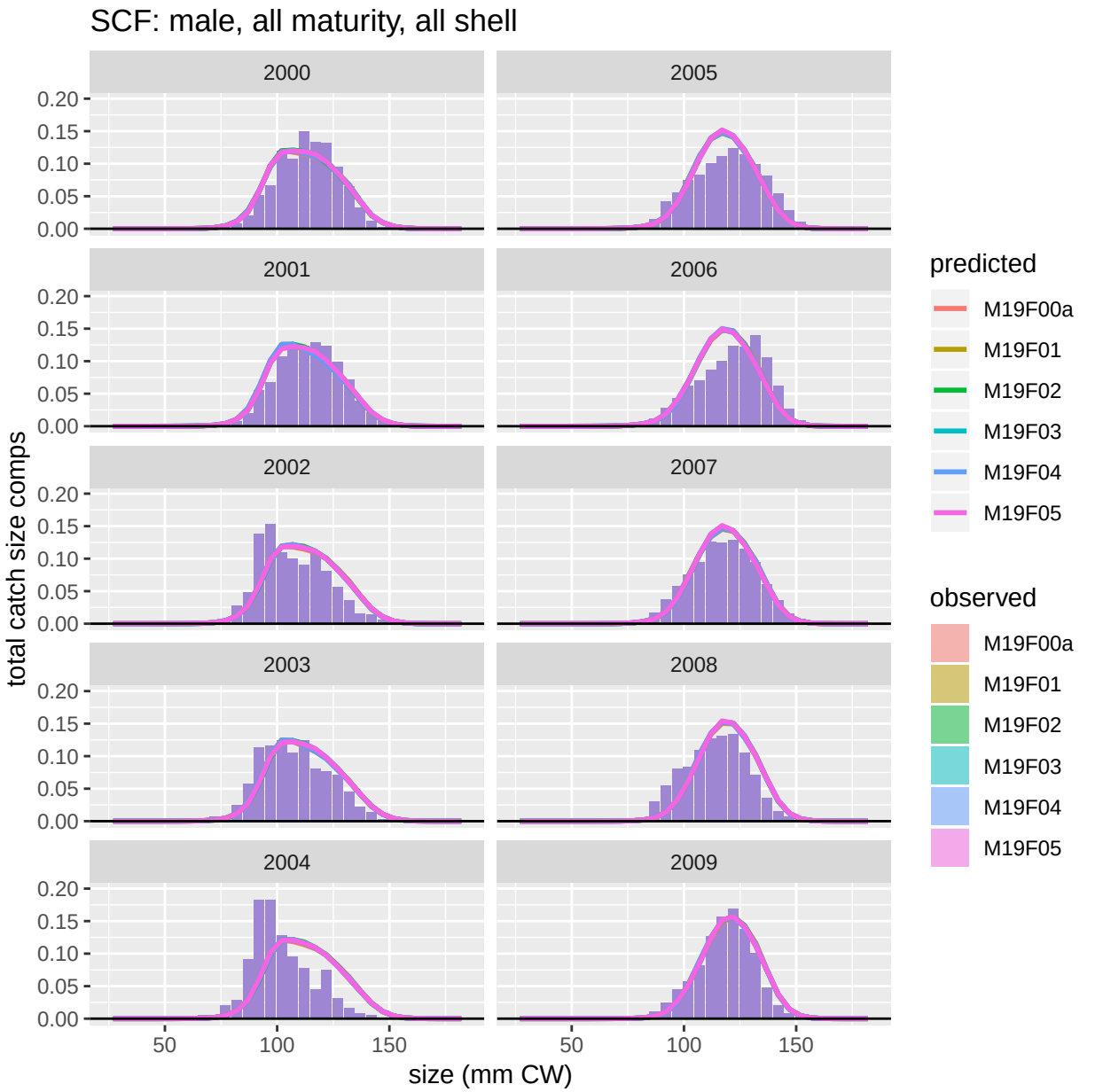


Figure 53: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

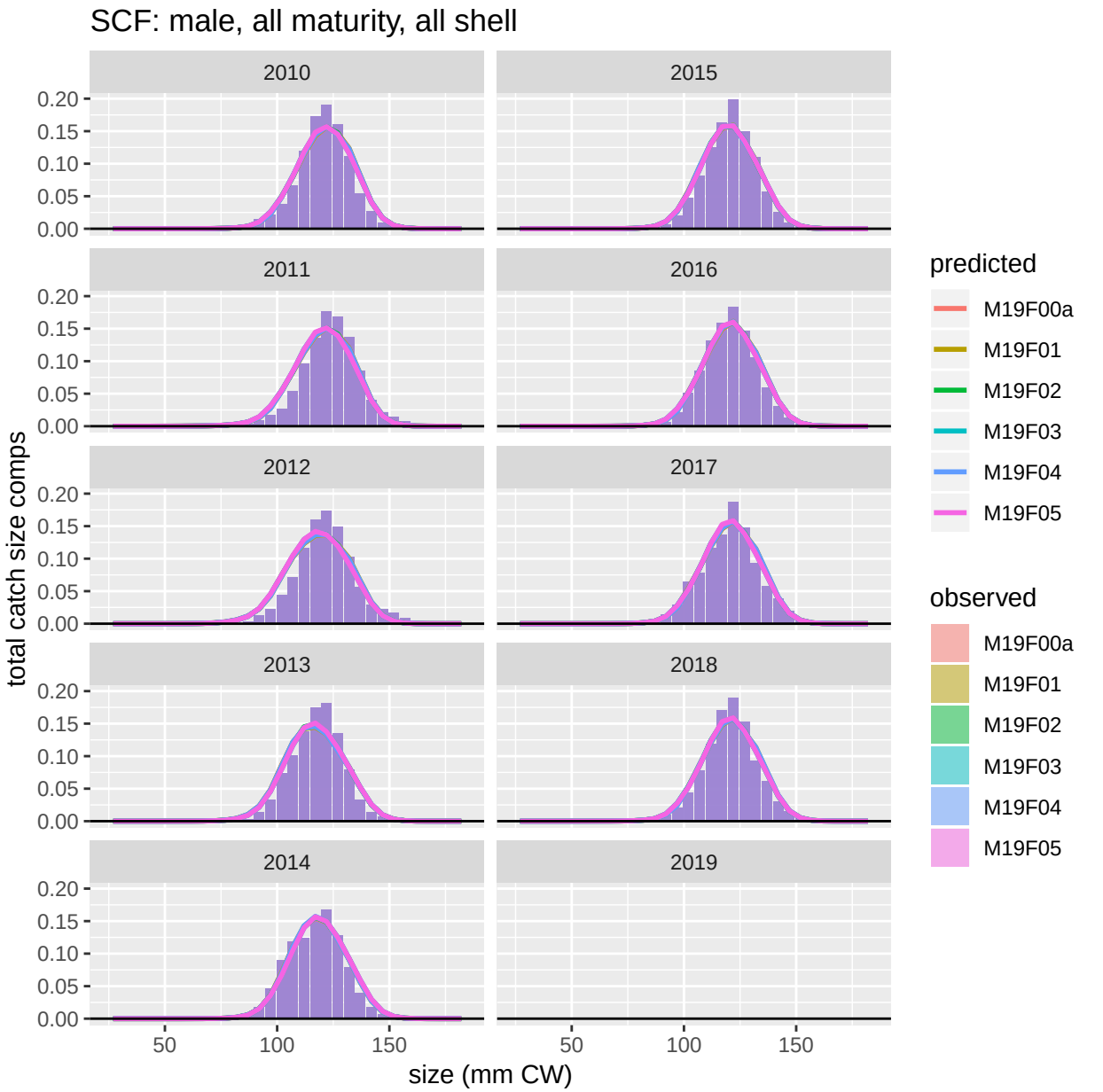


Figure 54: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

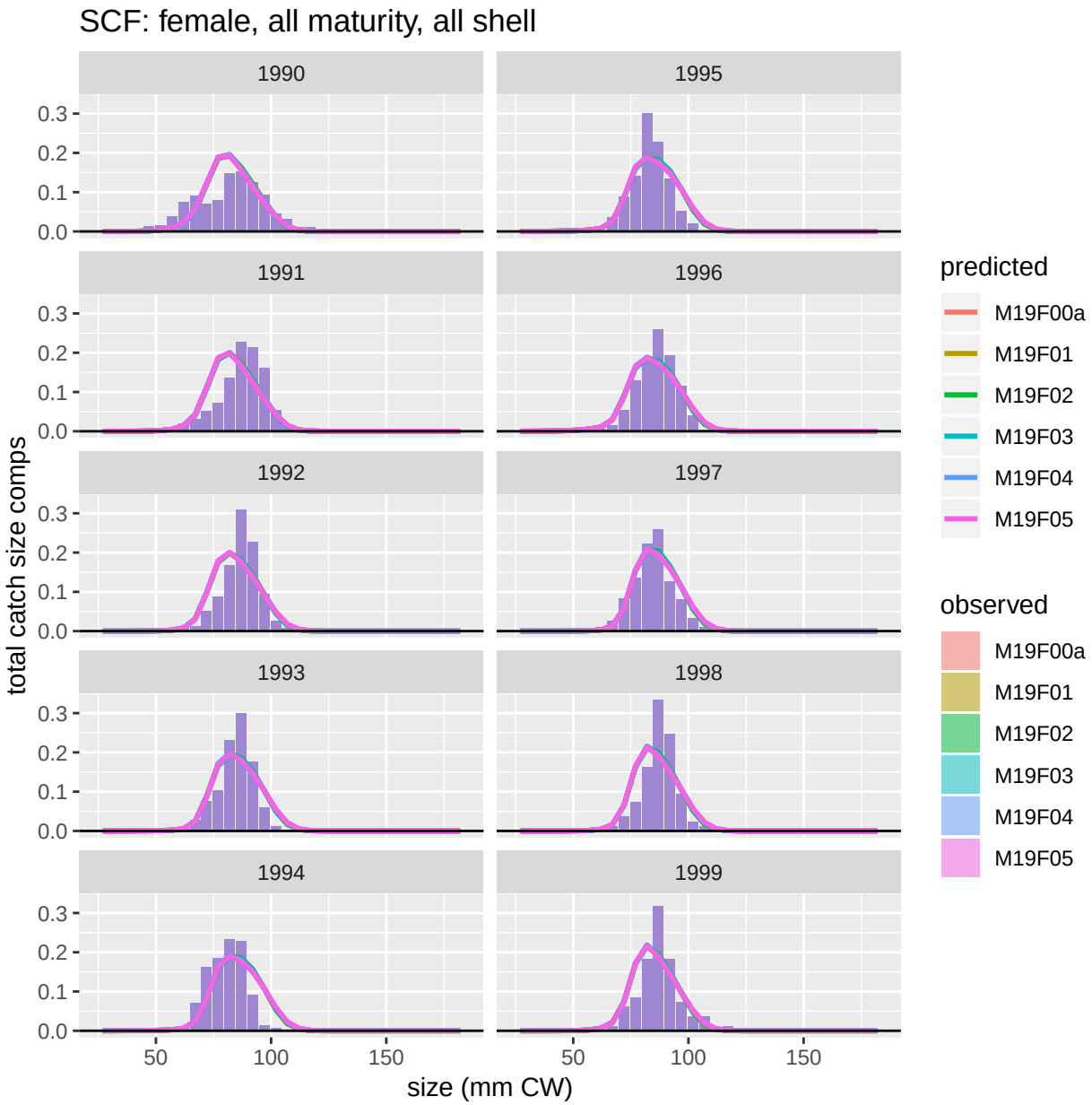


Figure 55: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

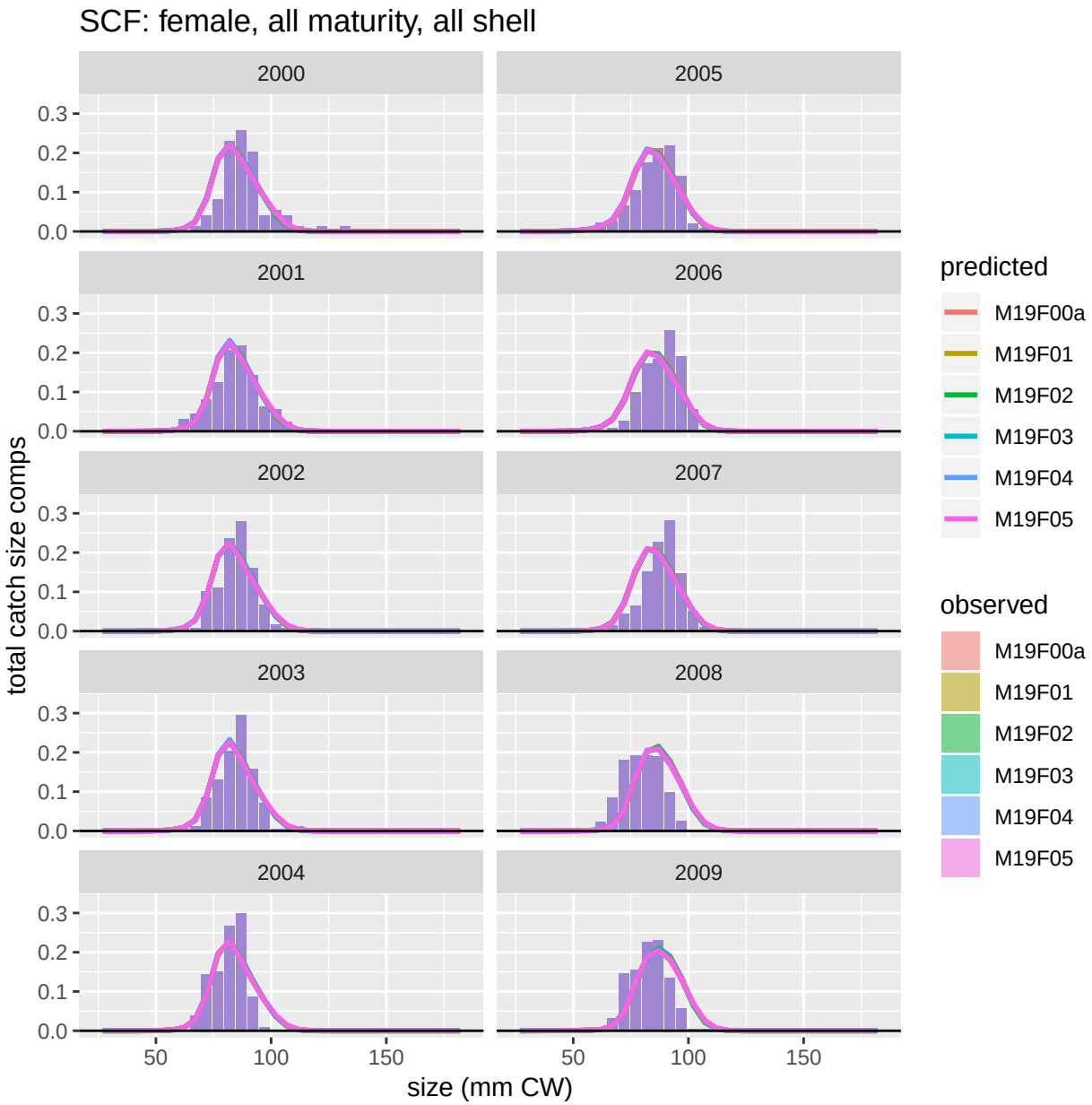


Figure 56: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

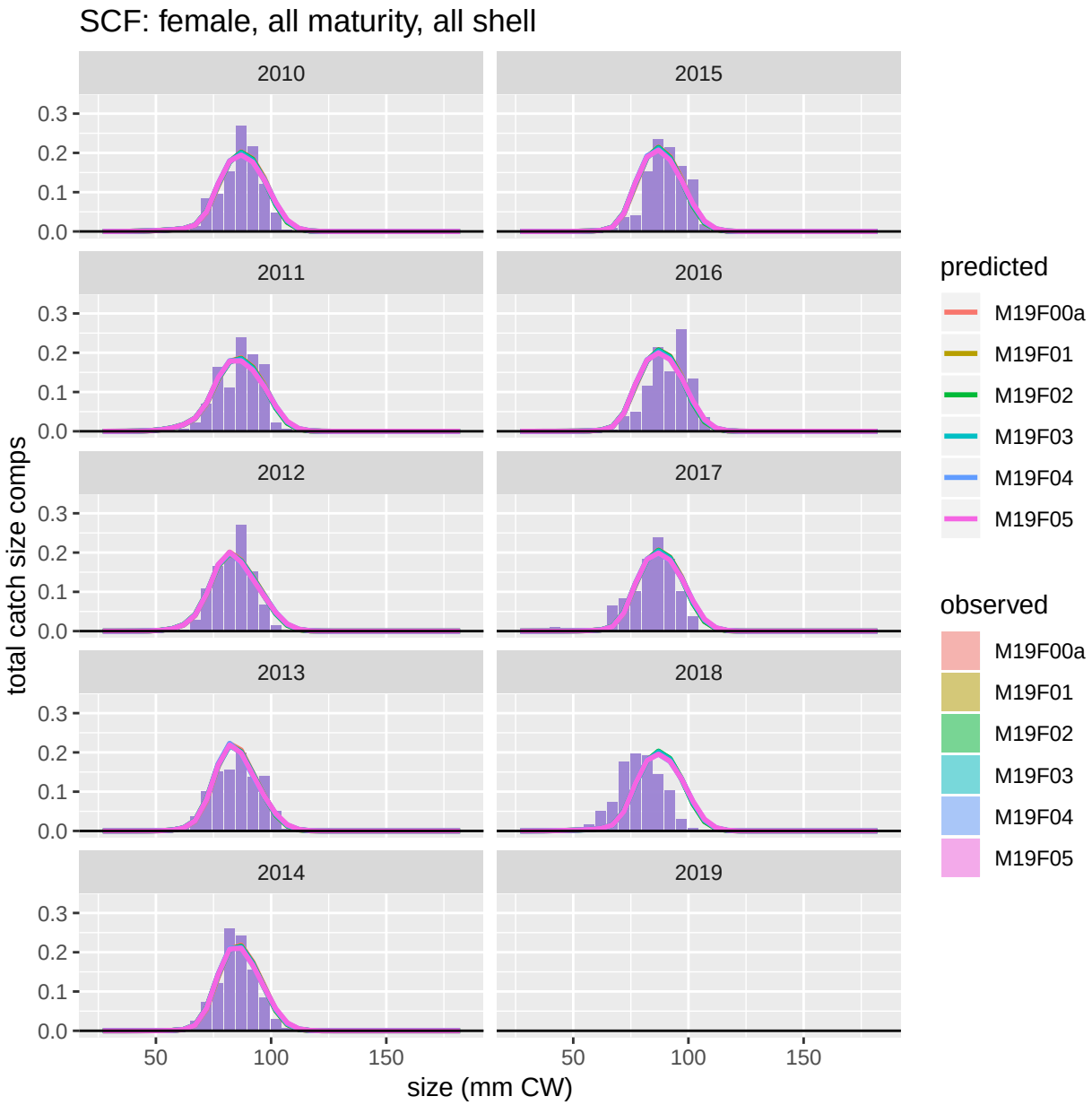


Figure 57: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

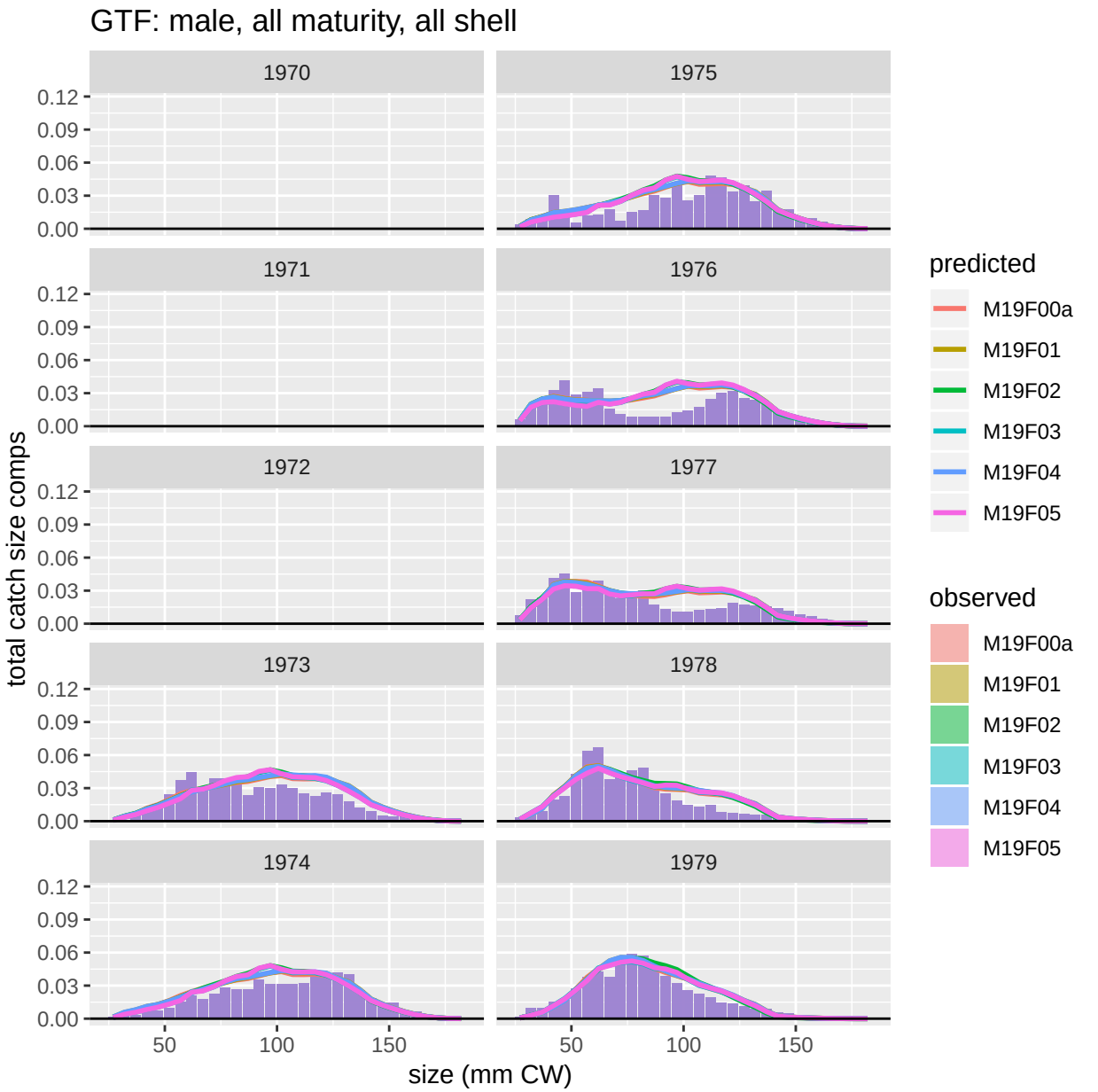


Figure 58: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 1 of 5.

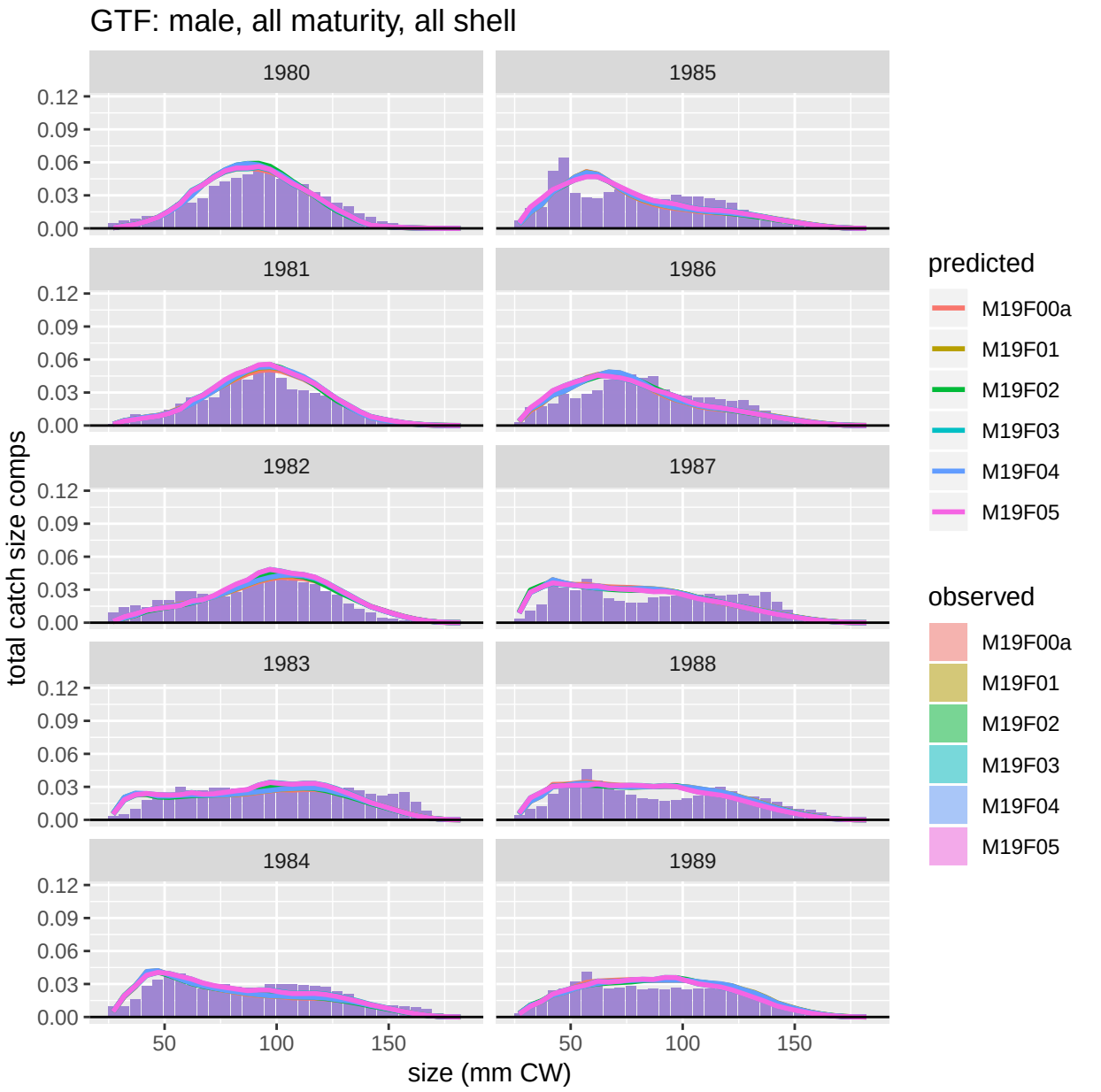


Figure 59: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 2 of 5.

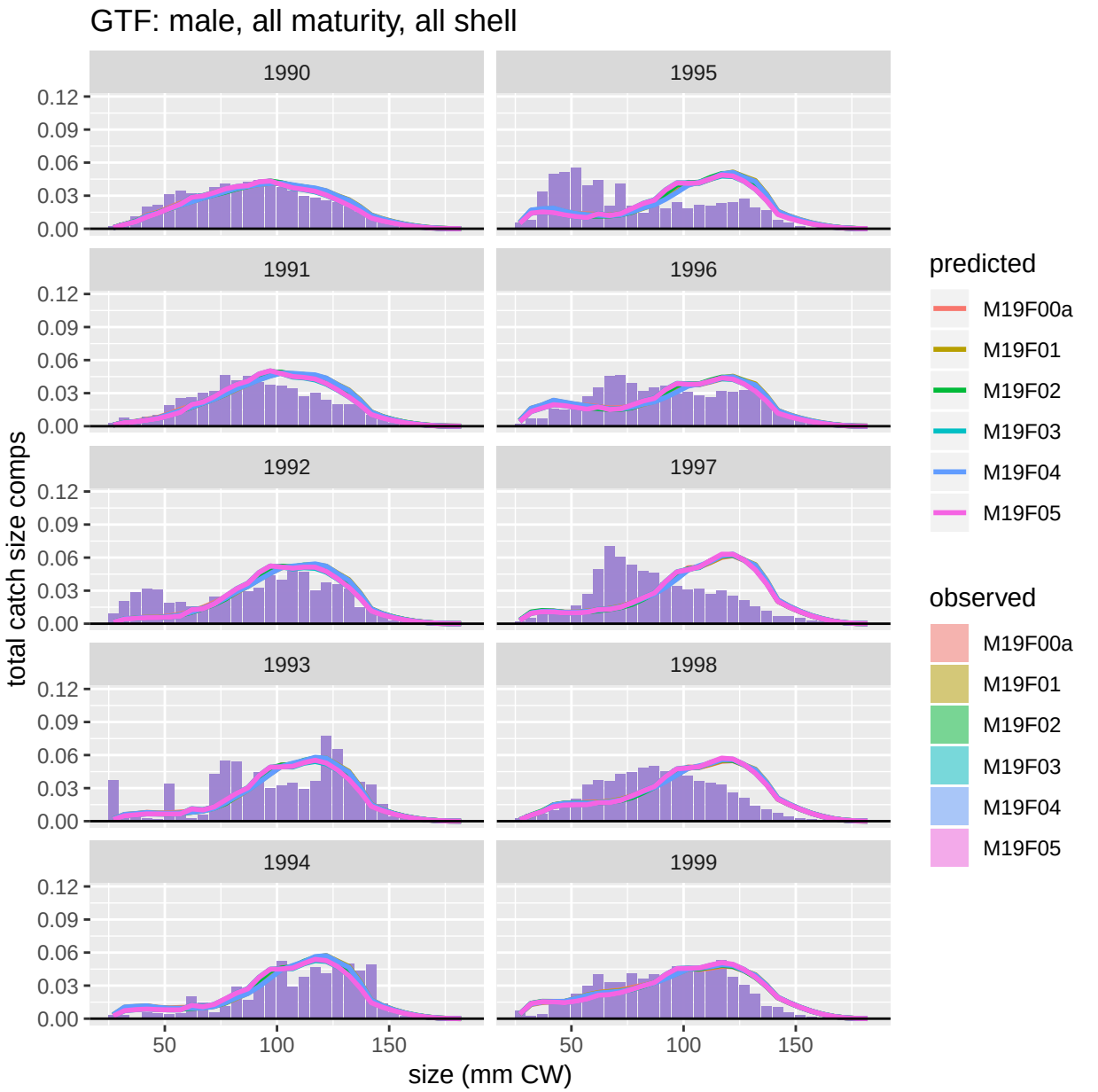


Figure 60: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 3 of 5.

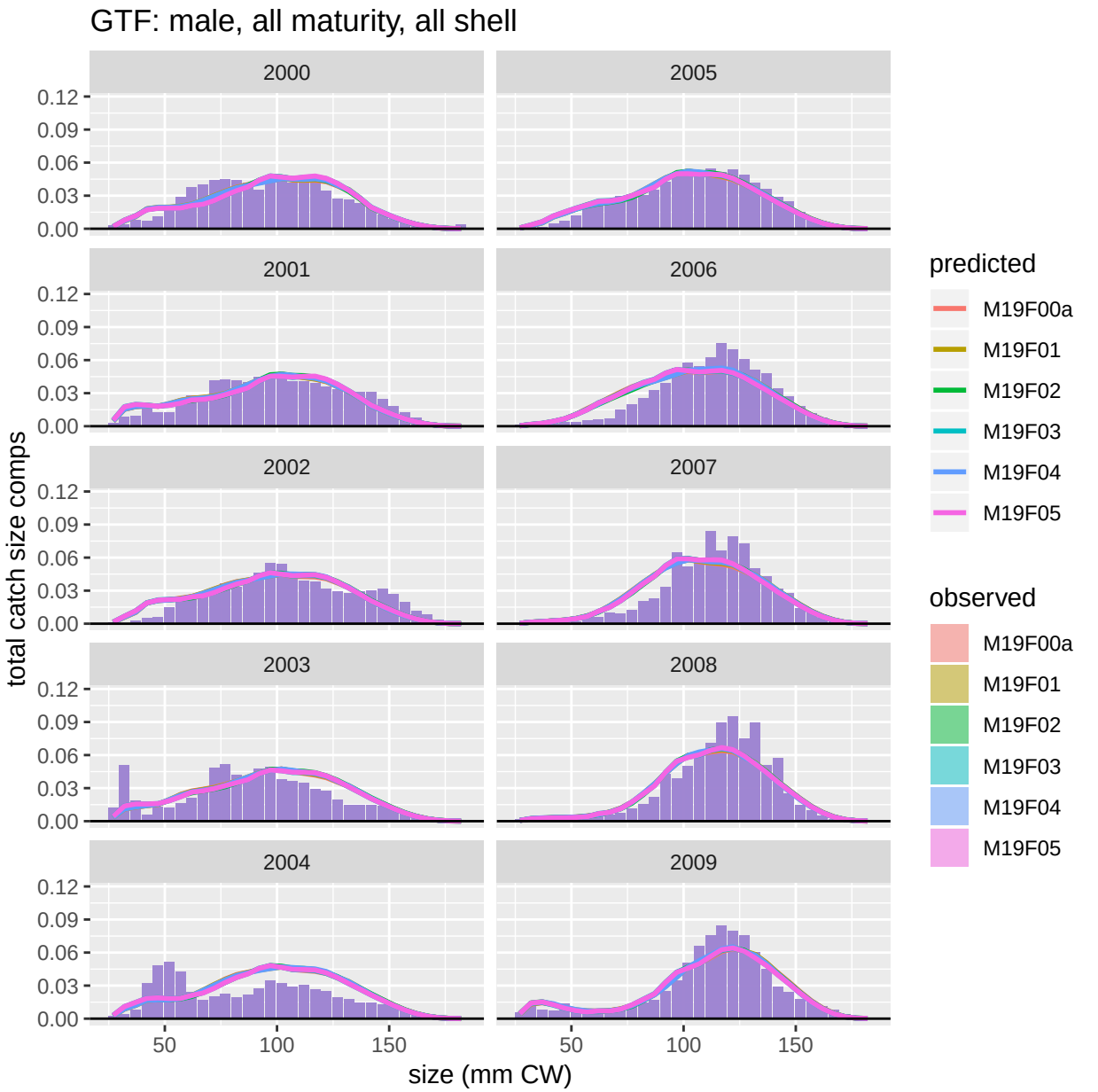


Figure 61: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 4 of 5.

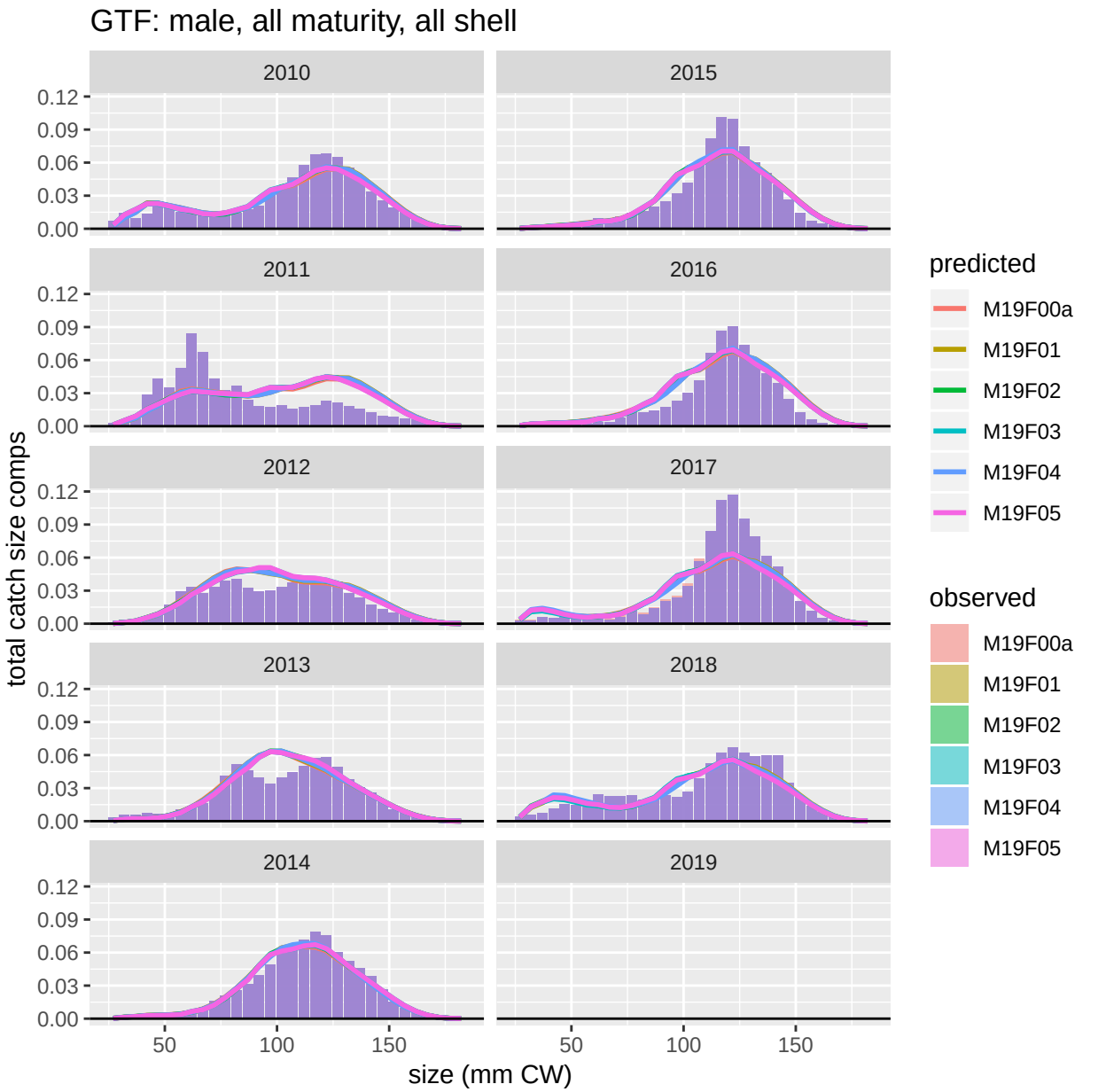


Figure 62: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 5 of 5.

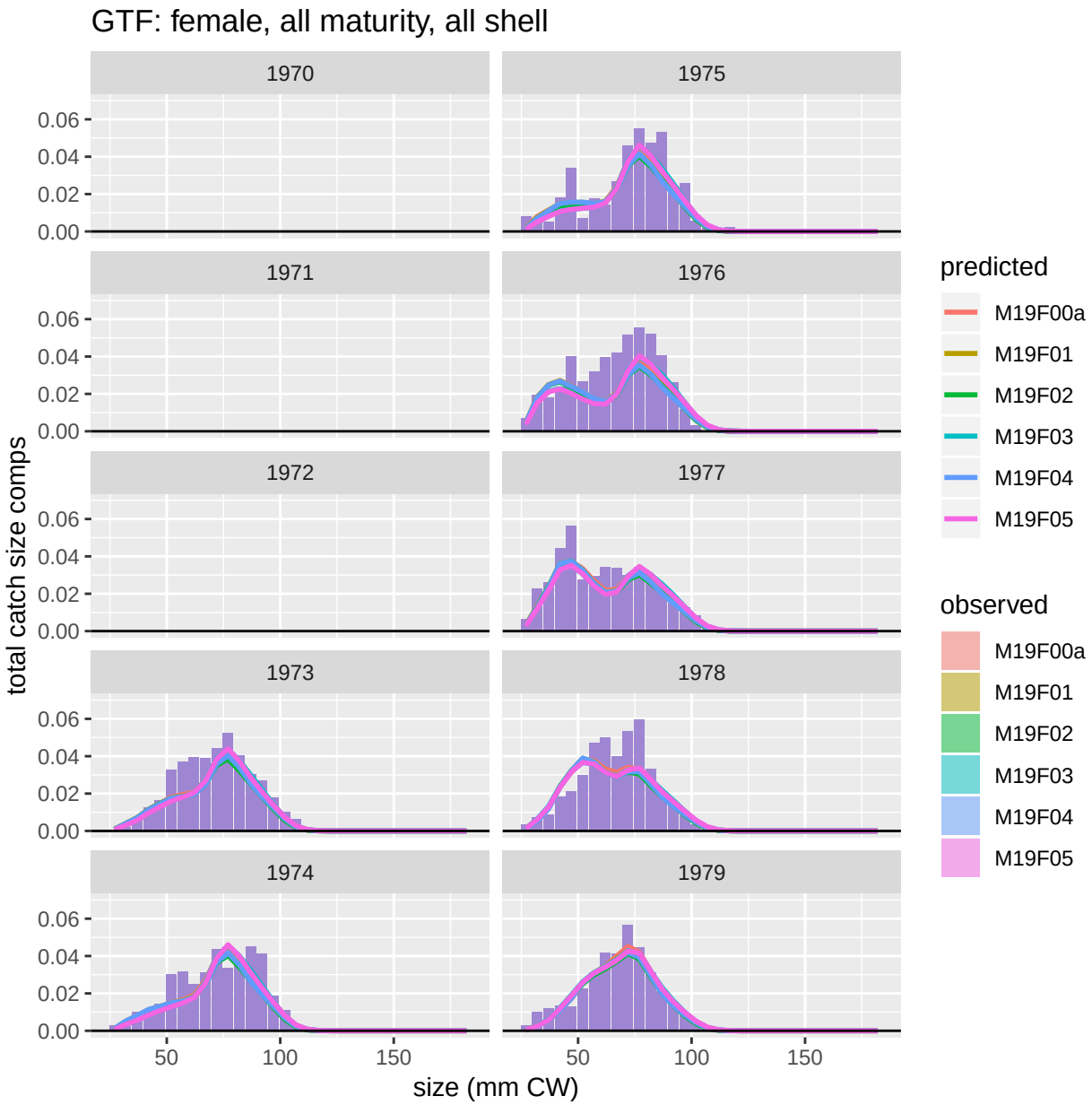


Figure 63: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 1 of 5.

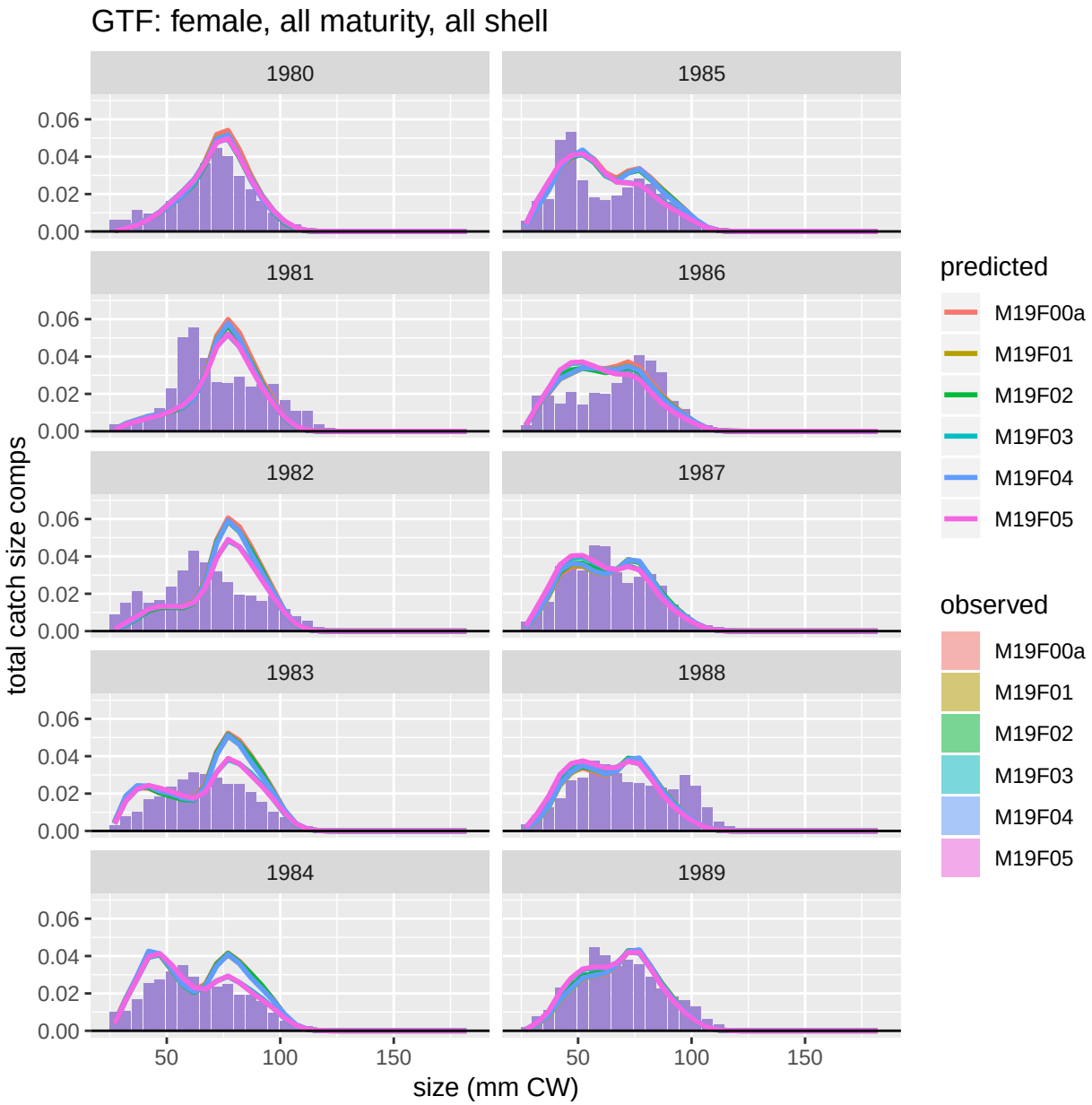


Figure 64: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 2 of 5.

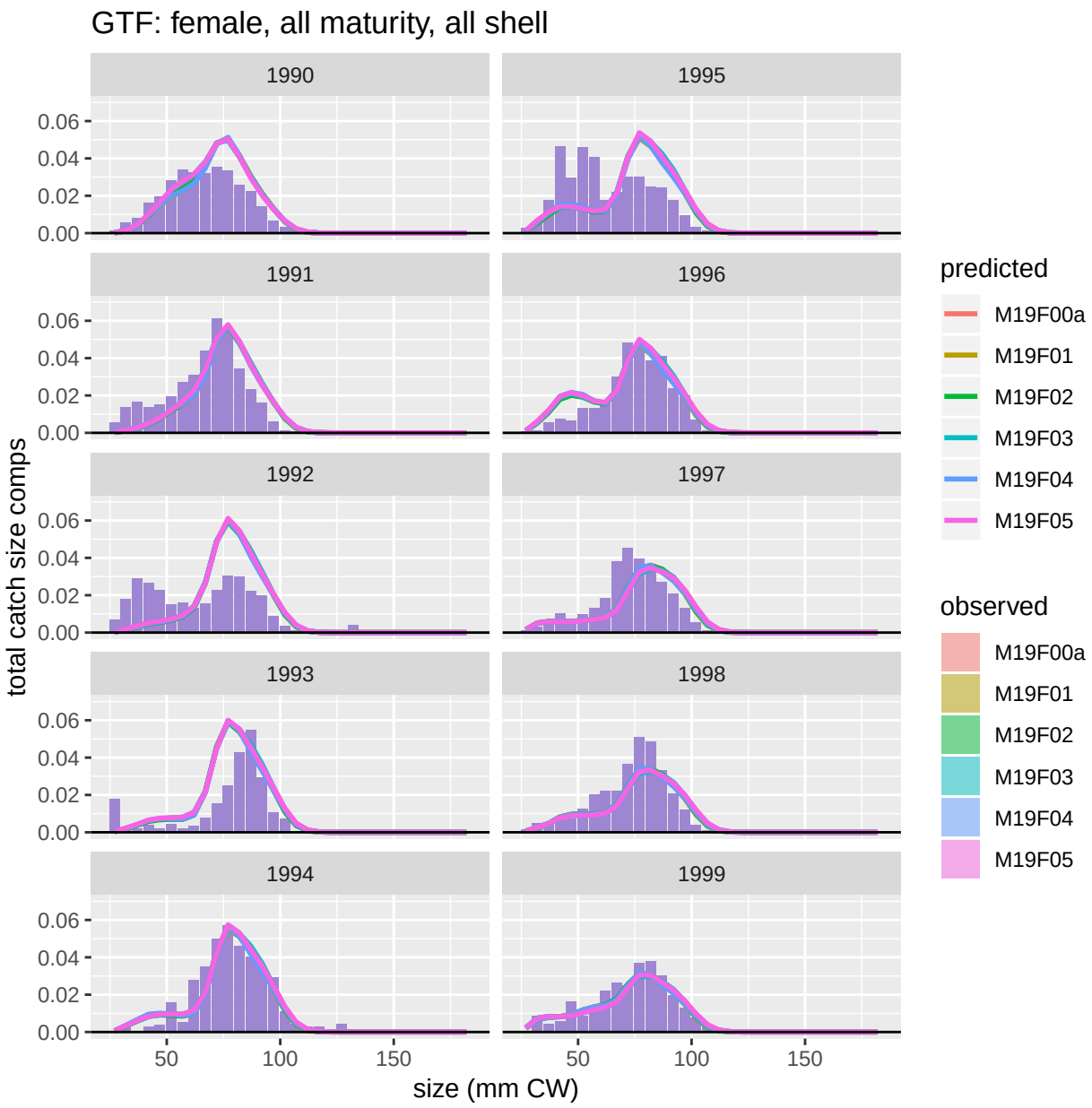


Figure 65: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 3 of 5.

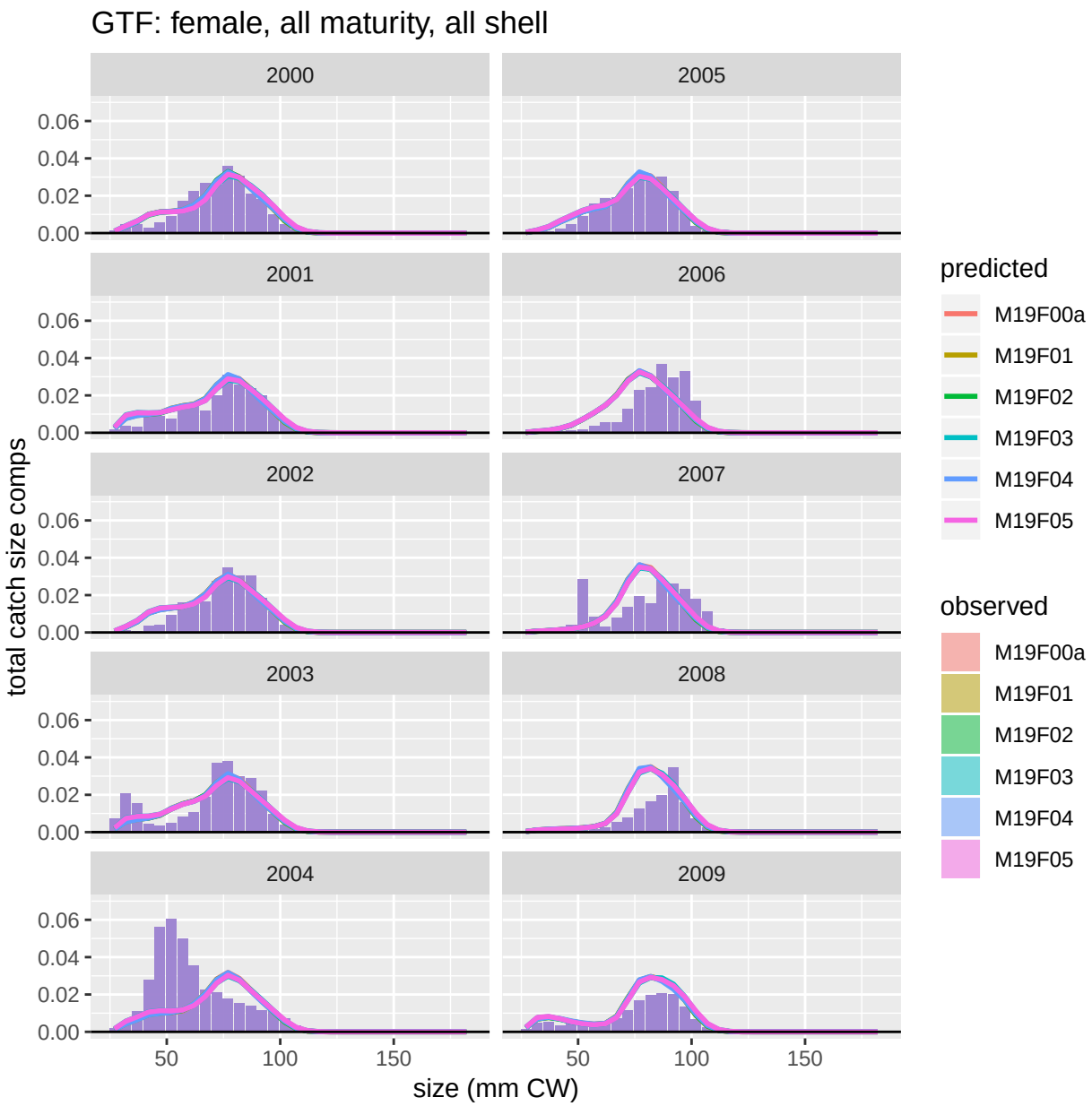


Figure 66: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 4 of 5.

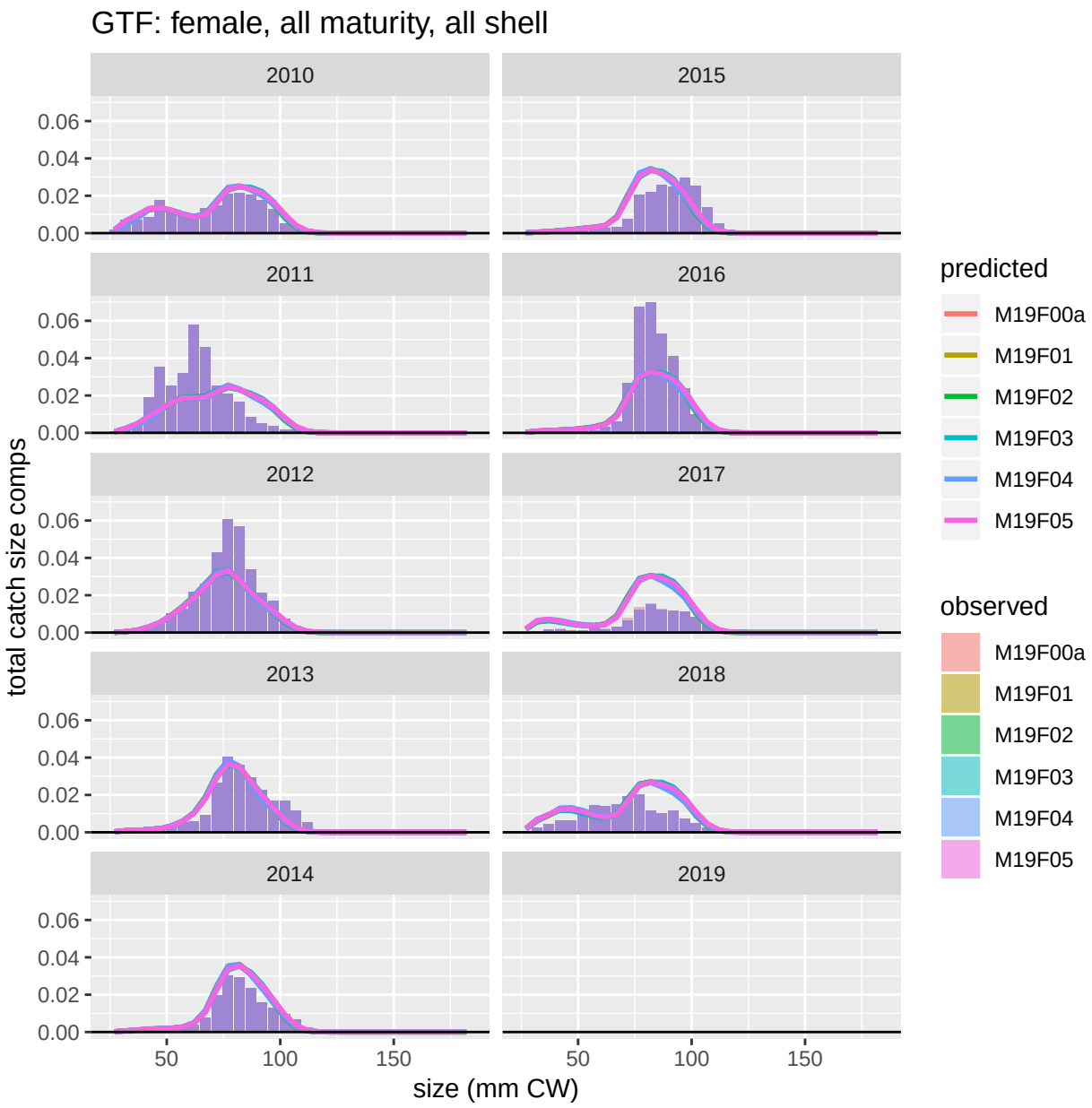


Figure 67: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 5 of 5.

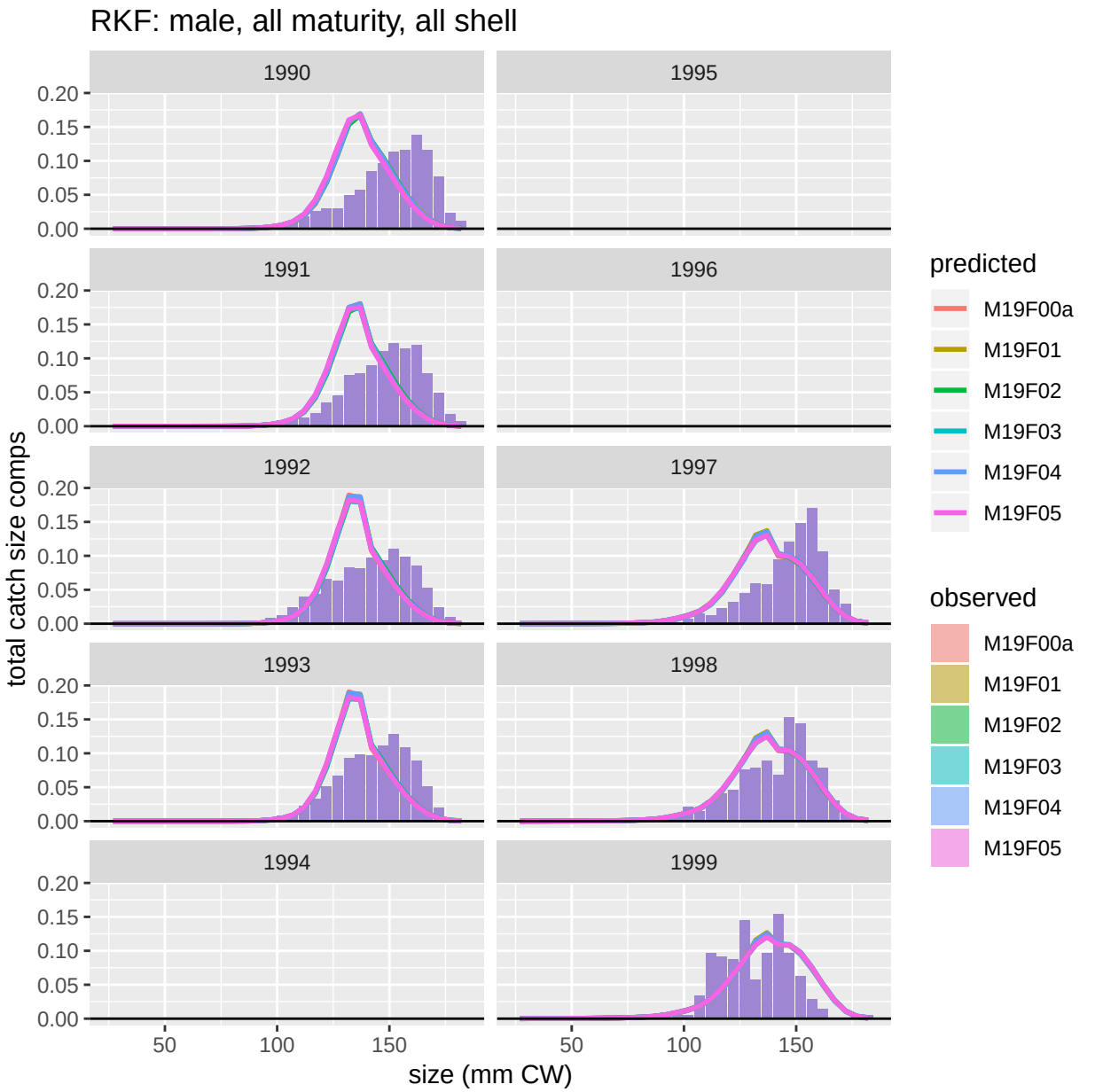


Figure 68: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

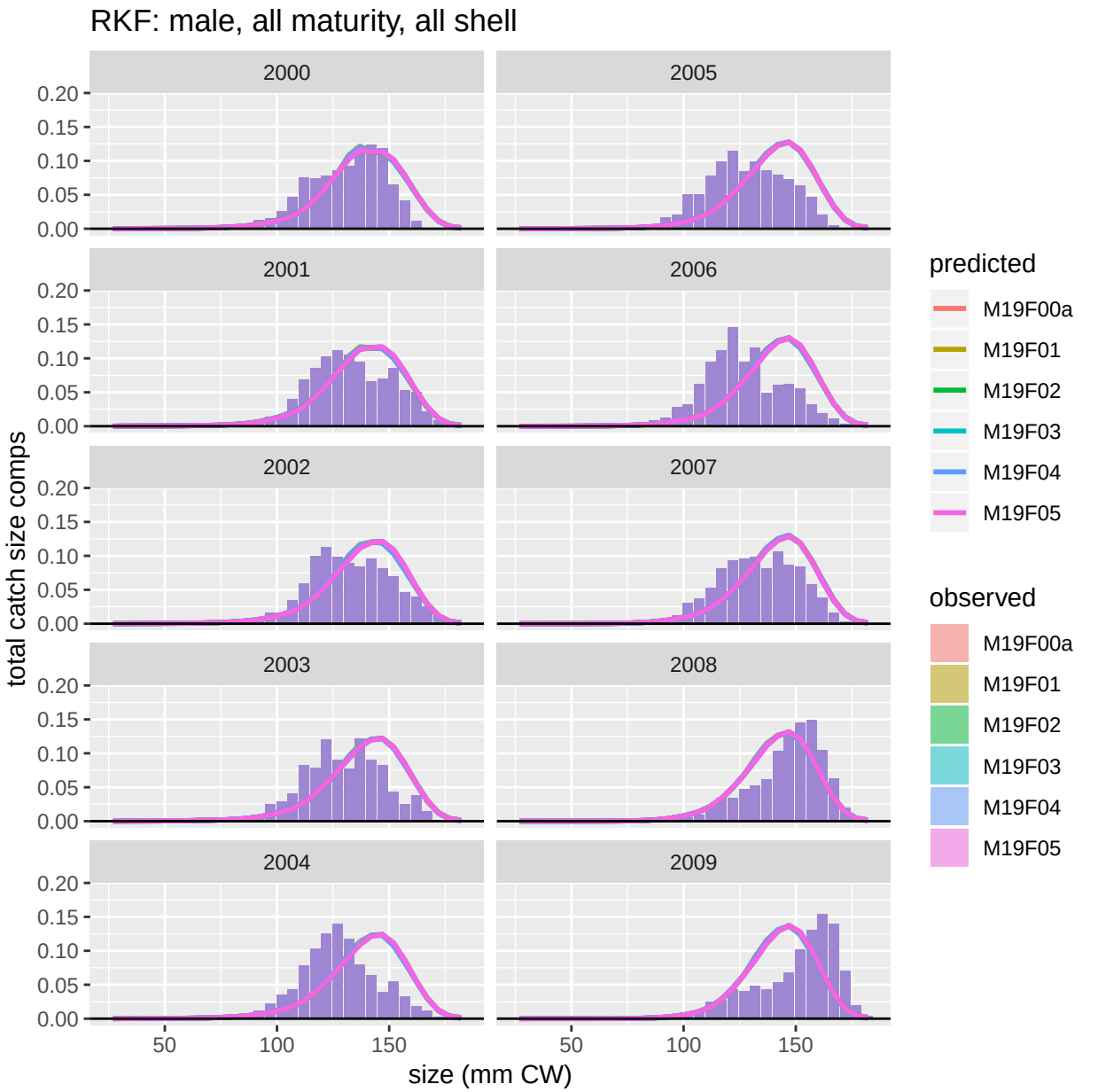


Figure 69: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

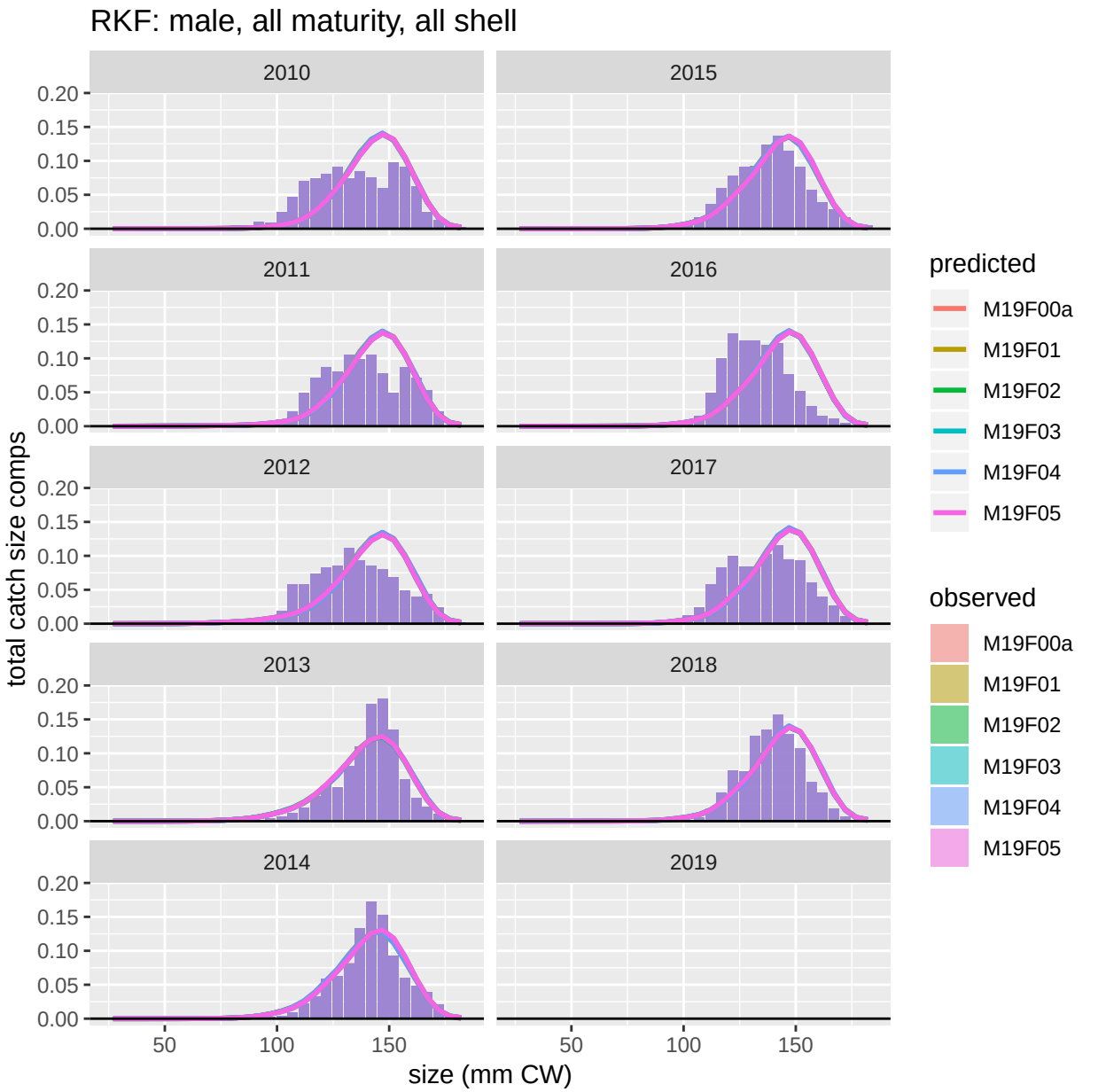


Figure 70: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

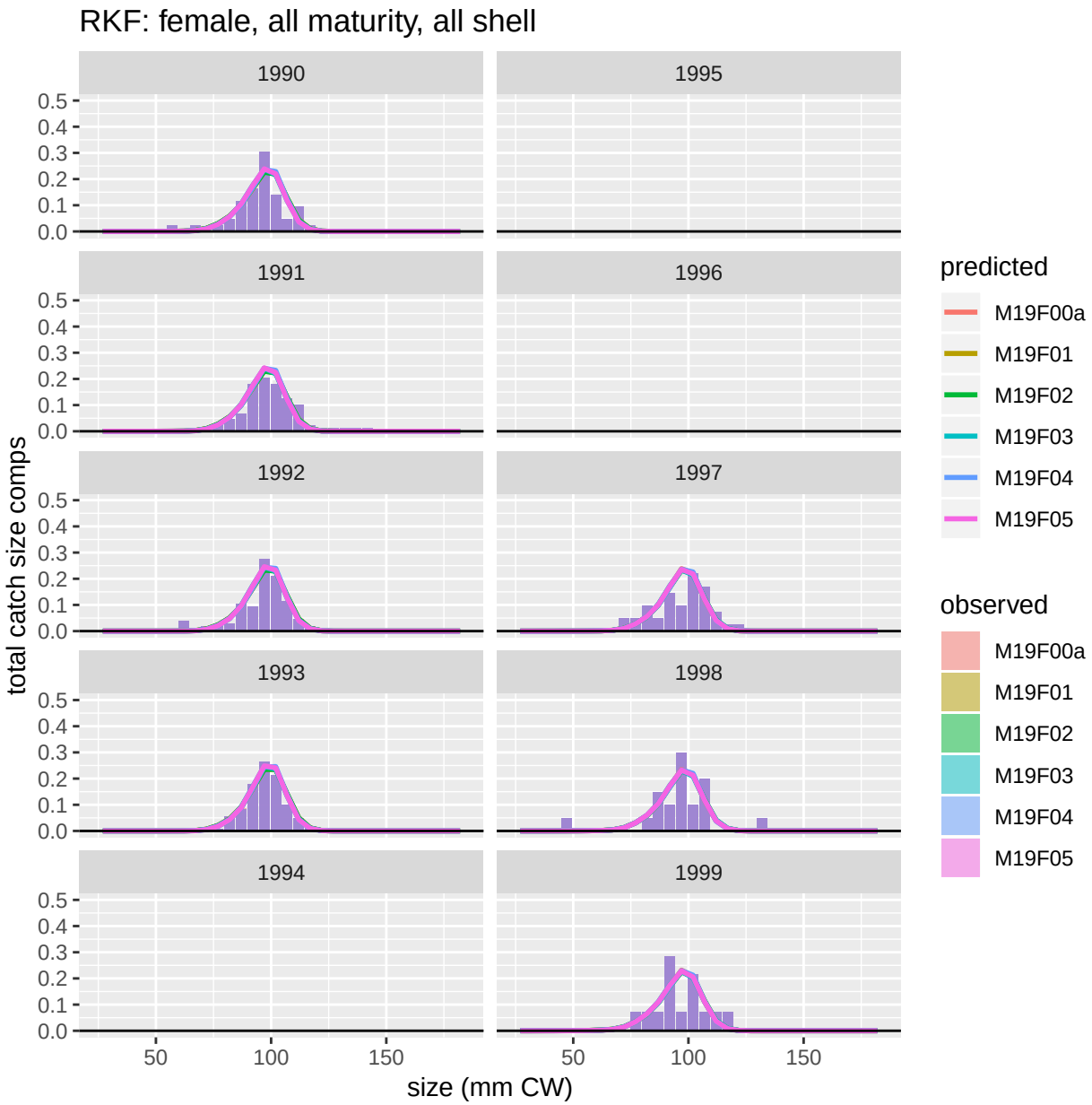


Figure 71: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

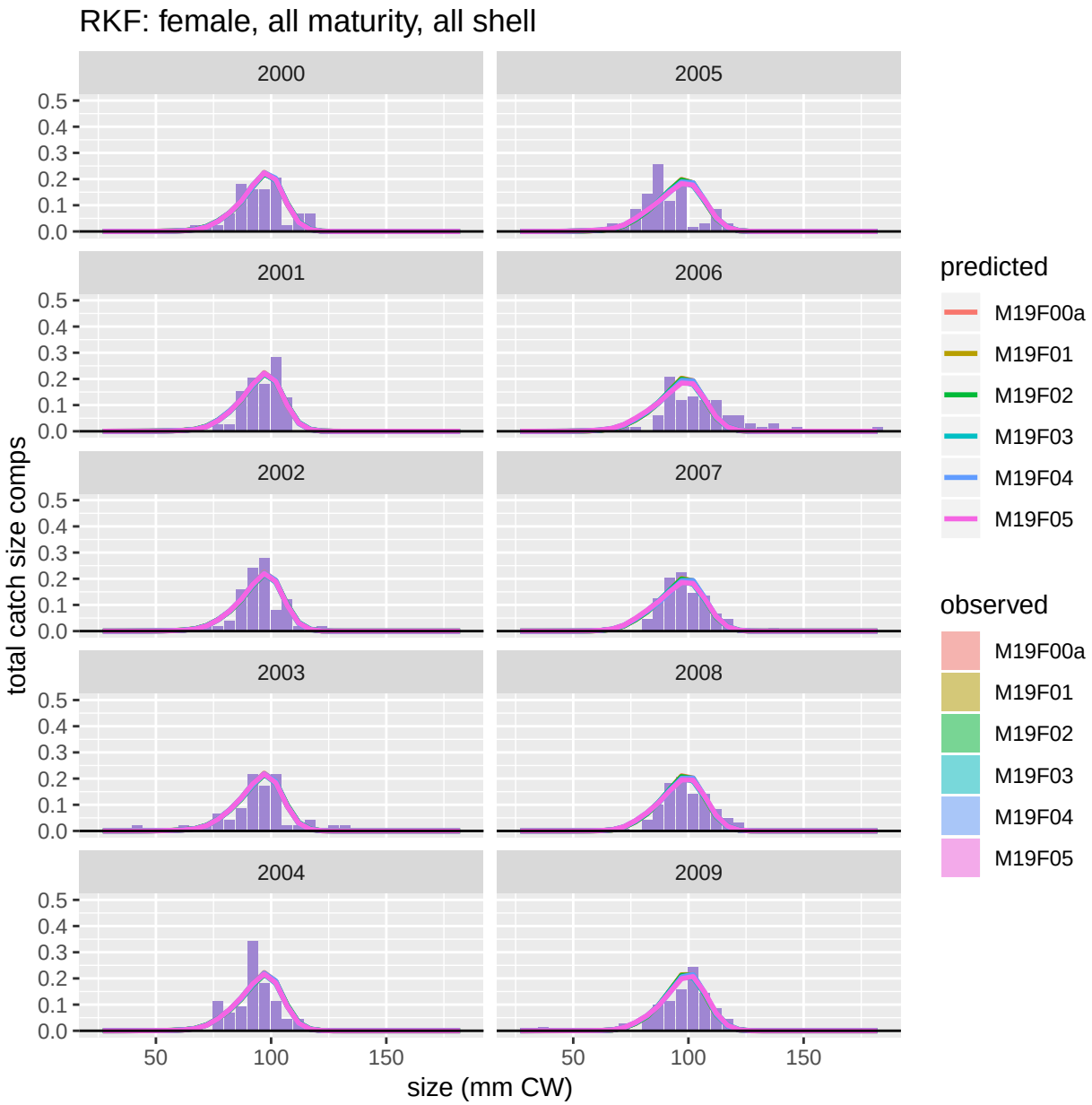


Figure 72: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

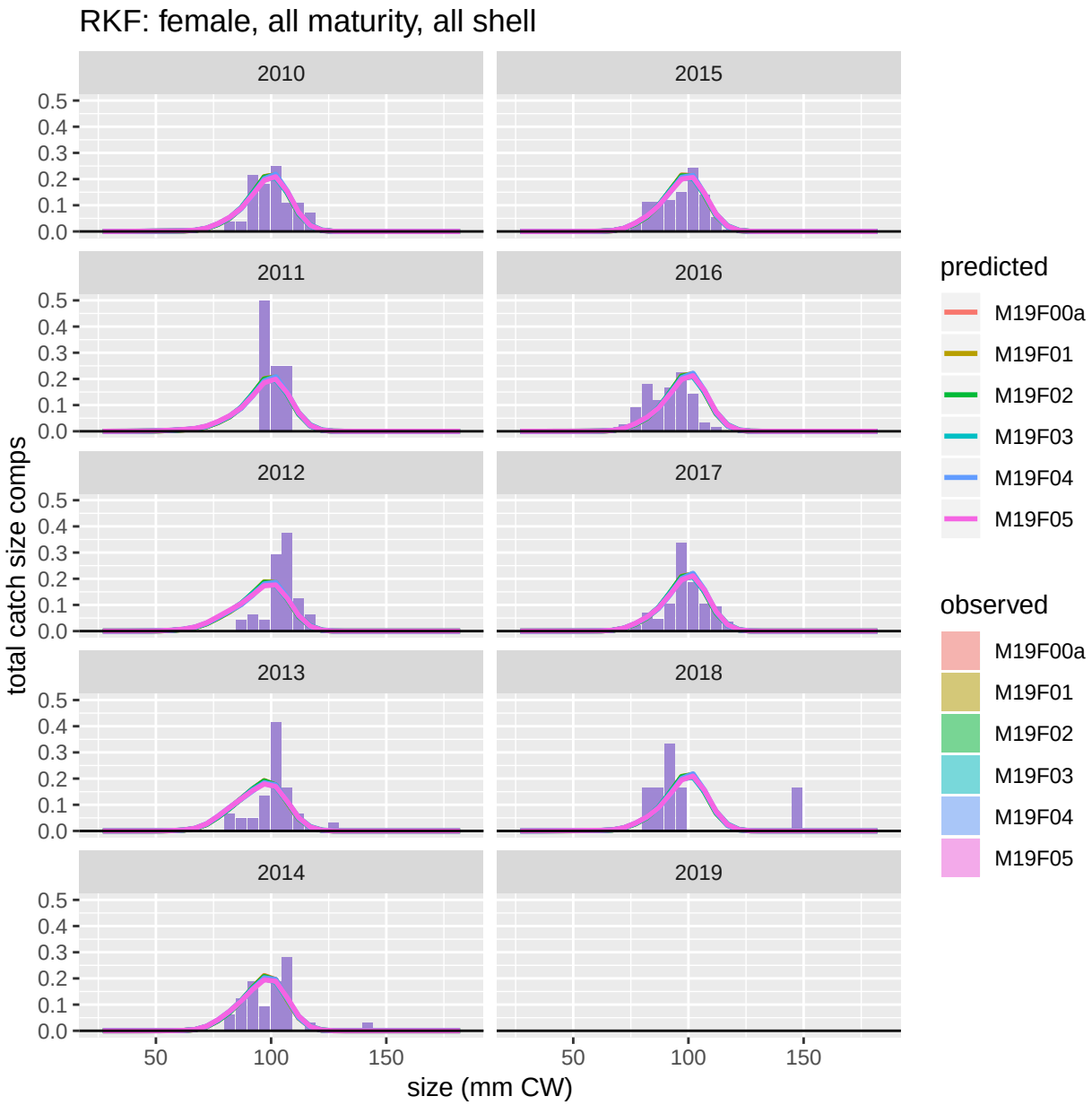


Figure 73: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

Model Comparisons: Fits to Fisheries Size Composition Data – M19F00a vs M19F01 vs M19F02 vs M19F03 vs M19F04 vs M19F05

William Stockhausen

07 September, 2019

Contents

Introduction **1**

Retained catch mean size compositions **2**

Total catch mean size compositions **3**

Fishery retained catch size composition residuals **8**

Effective Ns for retained catch size compositions **14**

Total catch size composition residuals **15**

Effective Ns for total catch size compositions **63**

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

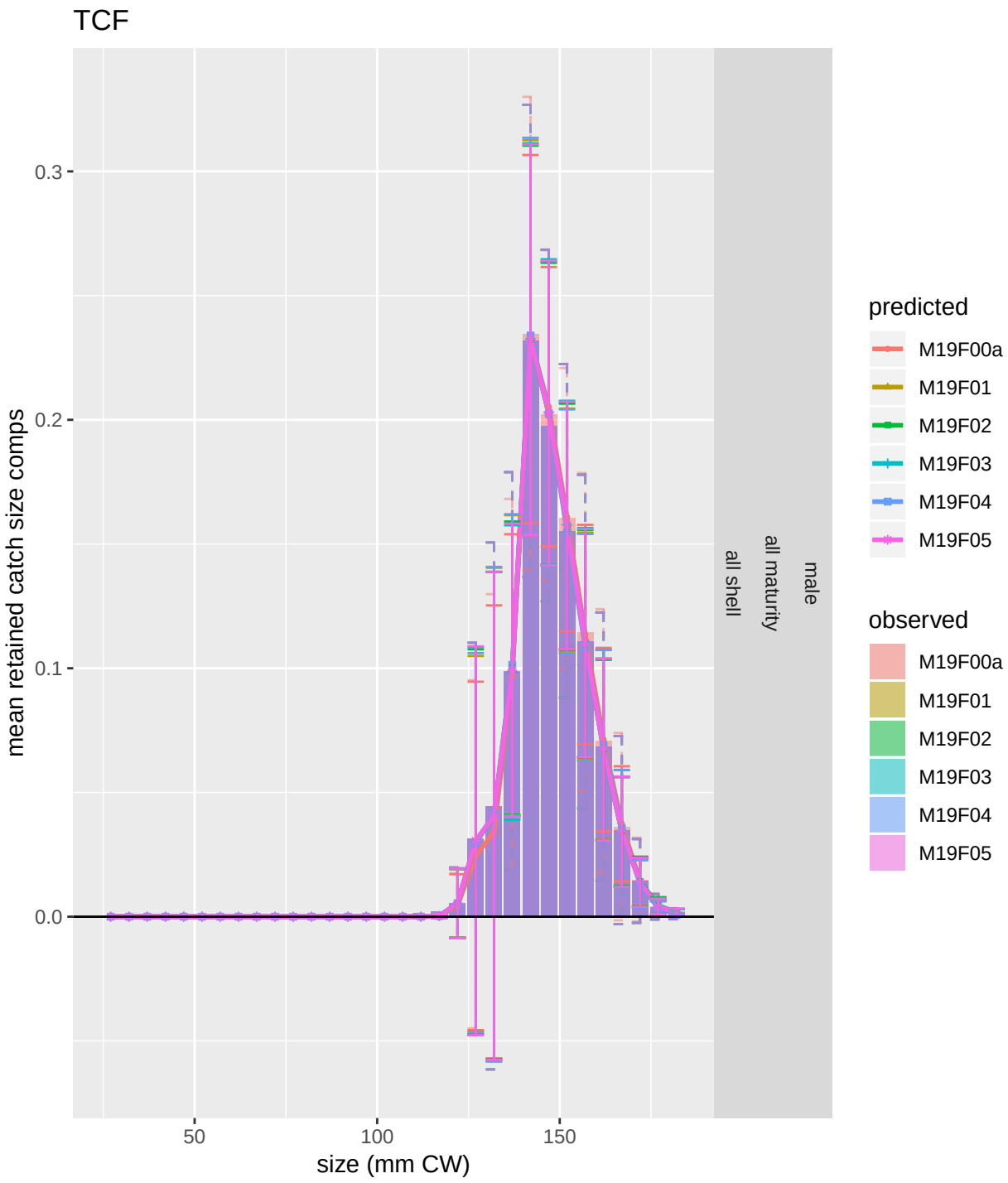


Figure 1: Comparison of observed and predicted mean retained catch size comps for TCF.

Total catch mean size compositions

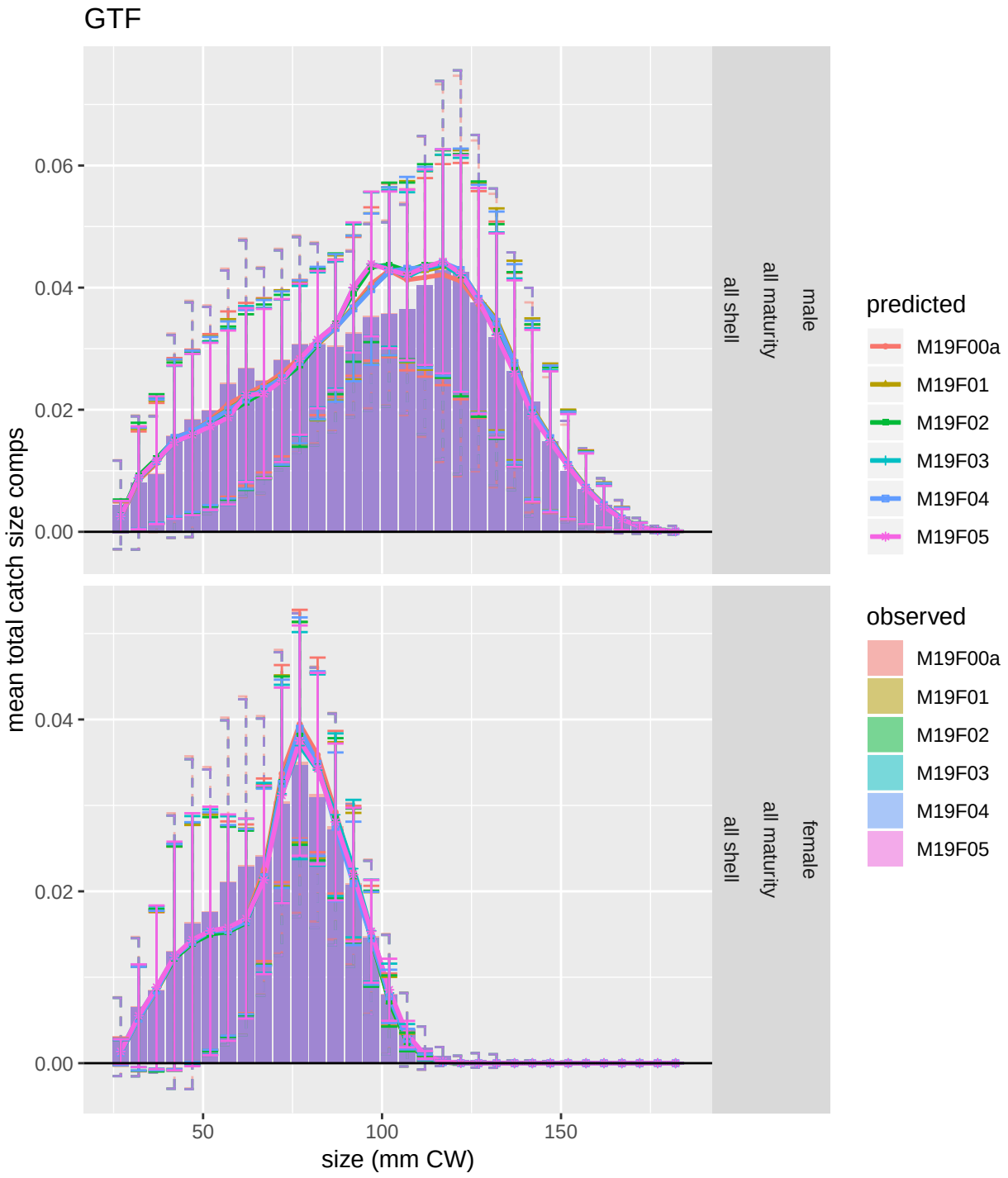


Figure 2: Comparison of observed and predicted mean total catch size comps for GTF.

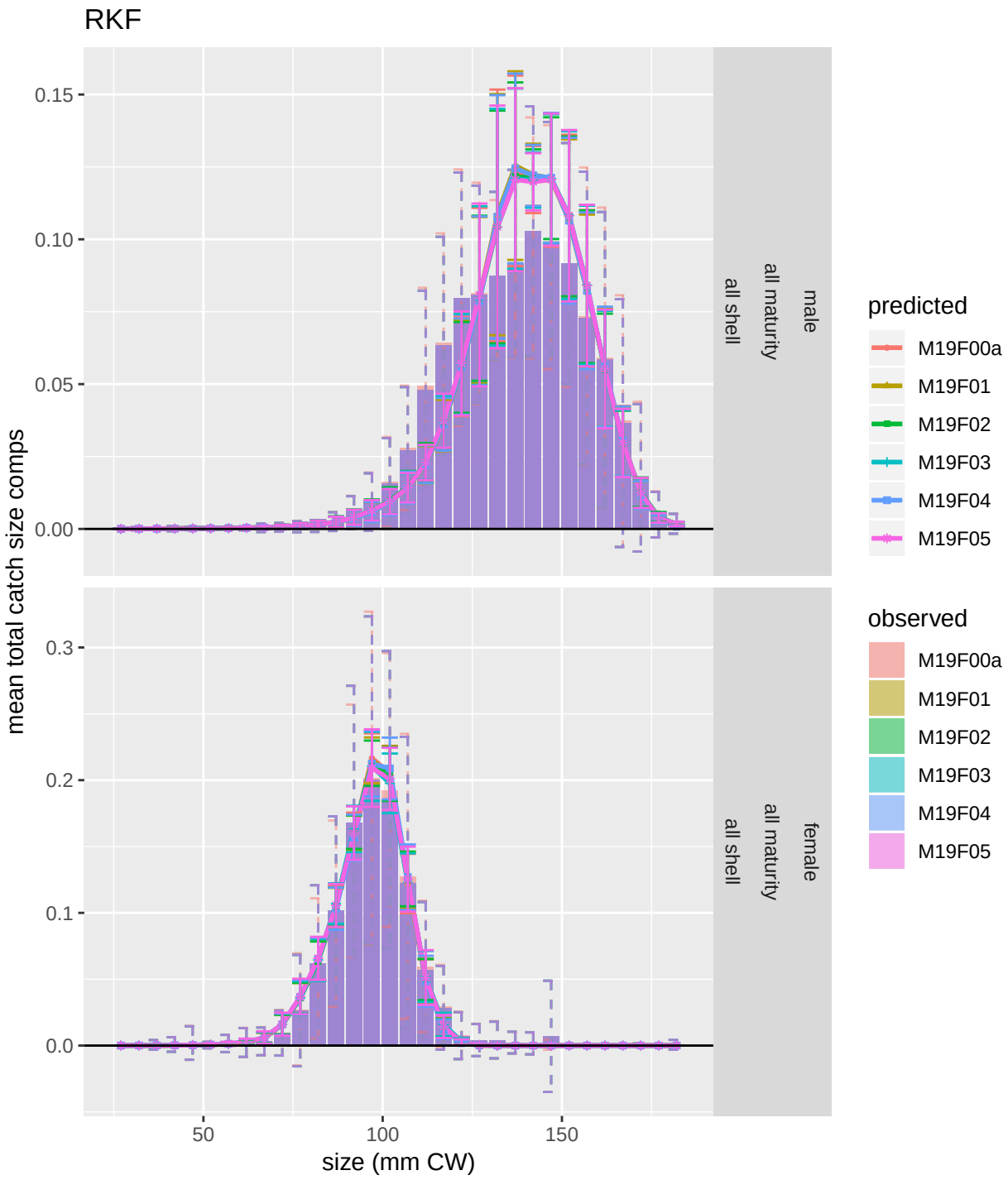


Figure 3: Comparison of observed and predicted mean total catch size comps for RKF.

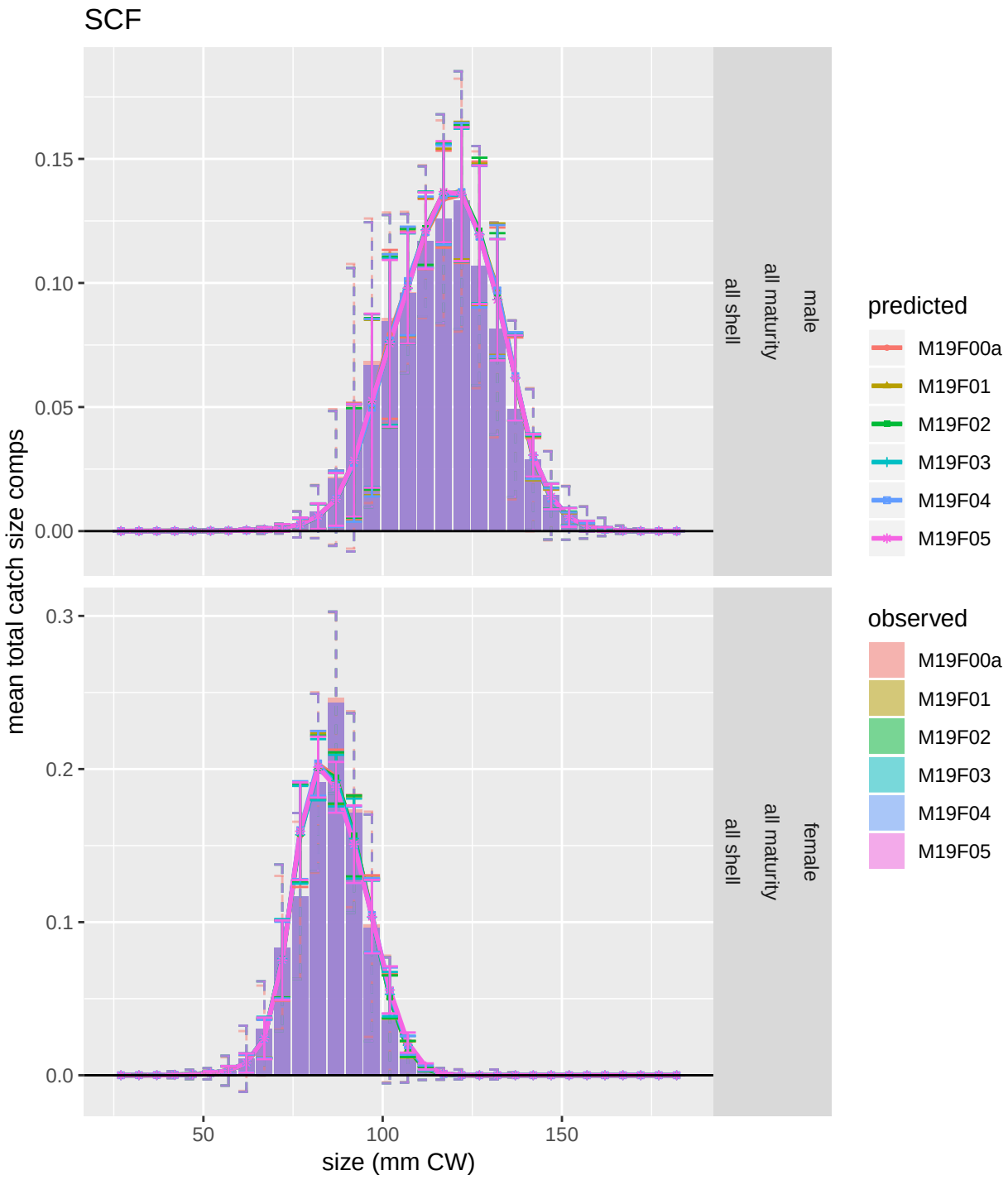


Figure 4: Comparison of observed and predicted mean total catch size comps for SCF.

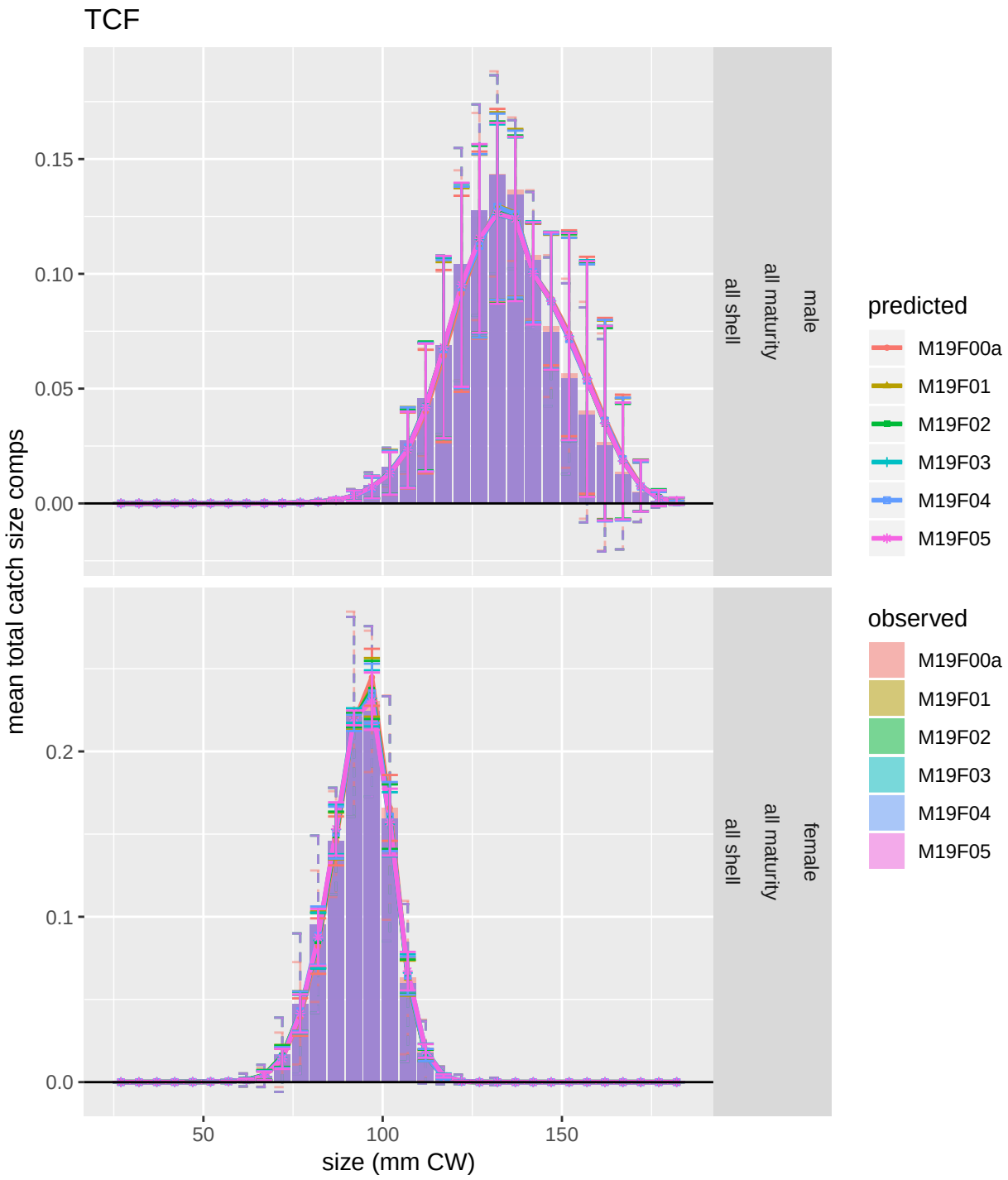


Figure 5: Comparison of observed and predicted mean total catch size comps for TCF.

Fishery retained catch size composition residuals

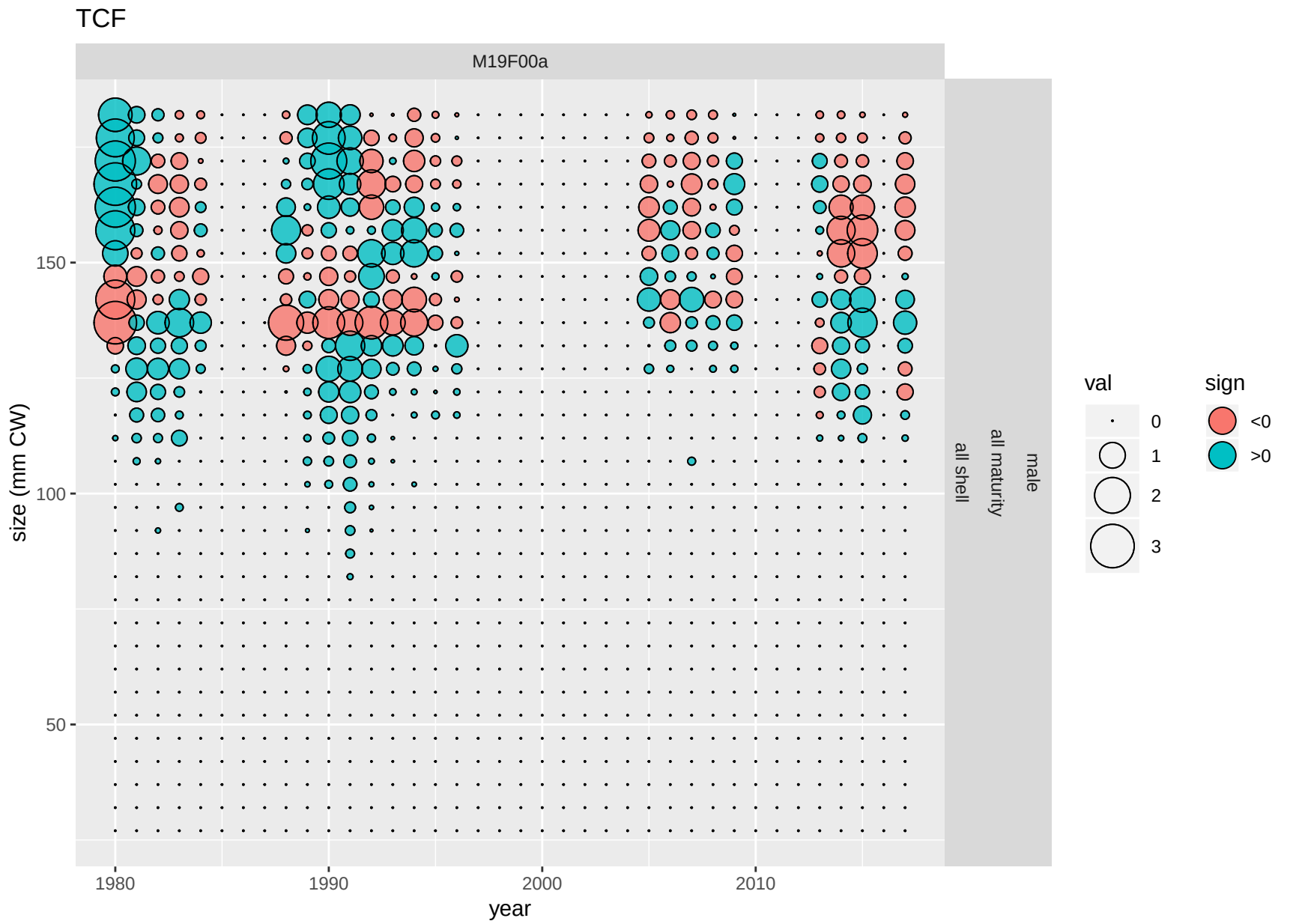


Figure 6: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F00a.

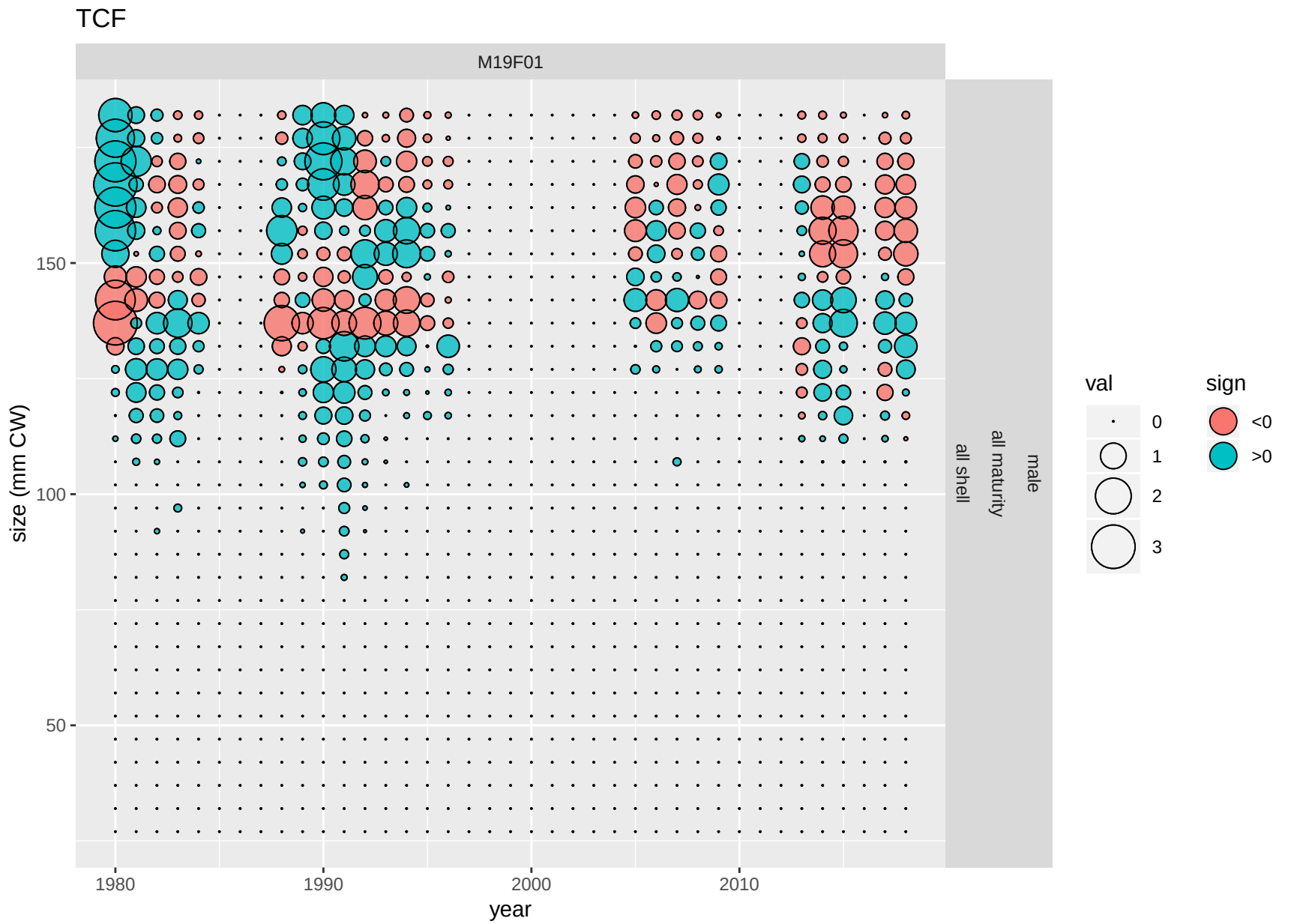


Figure 7: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F01.

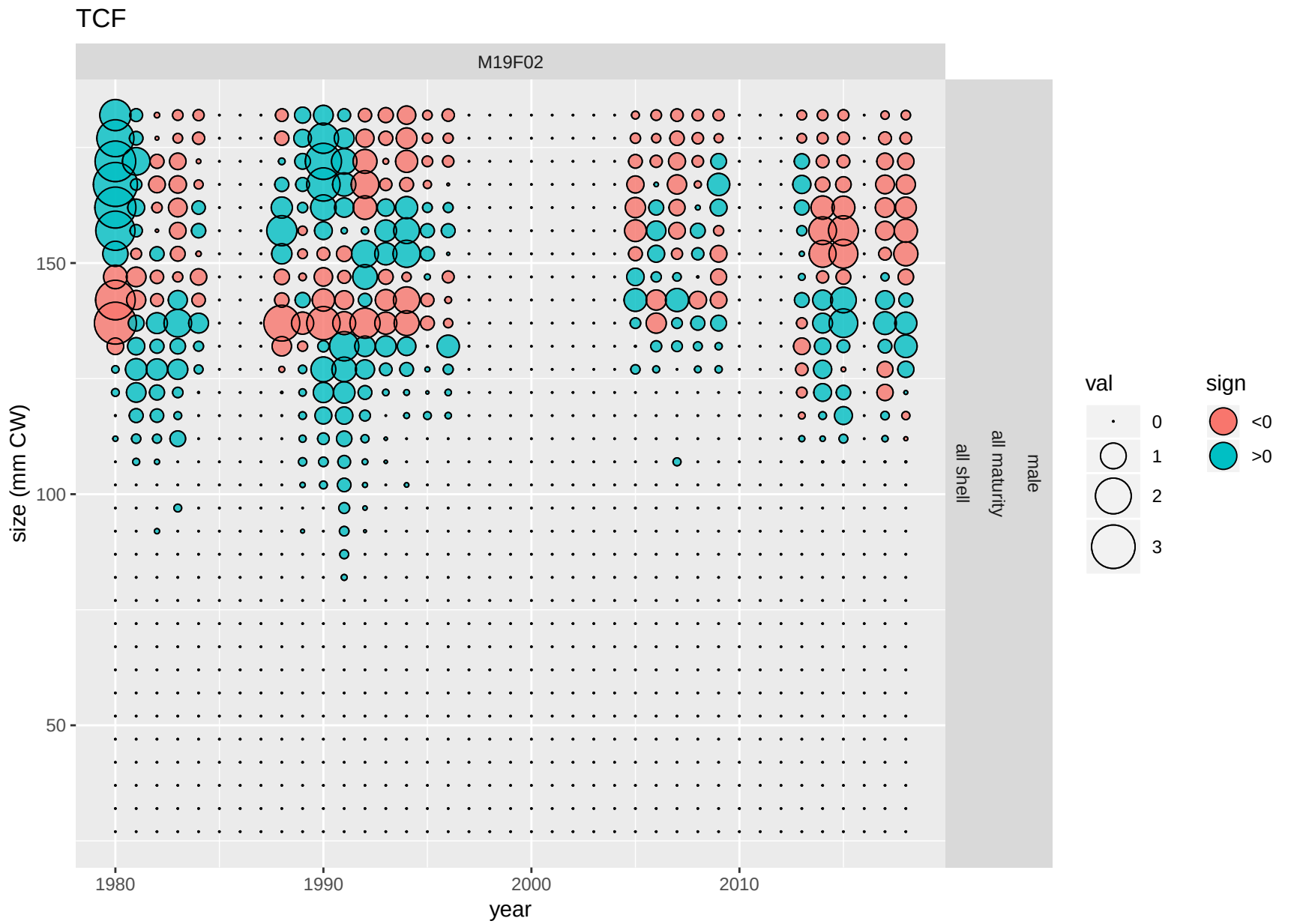


Figure 8: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F02.

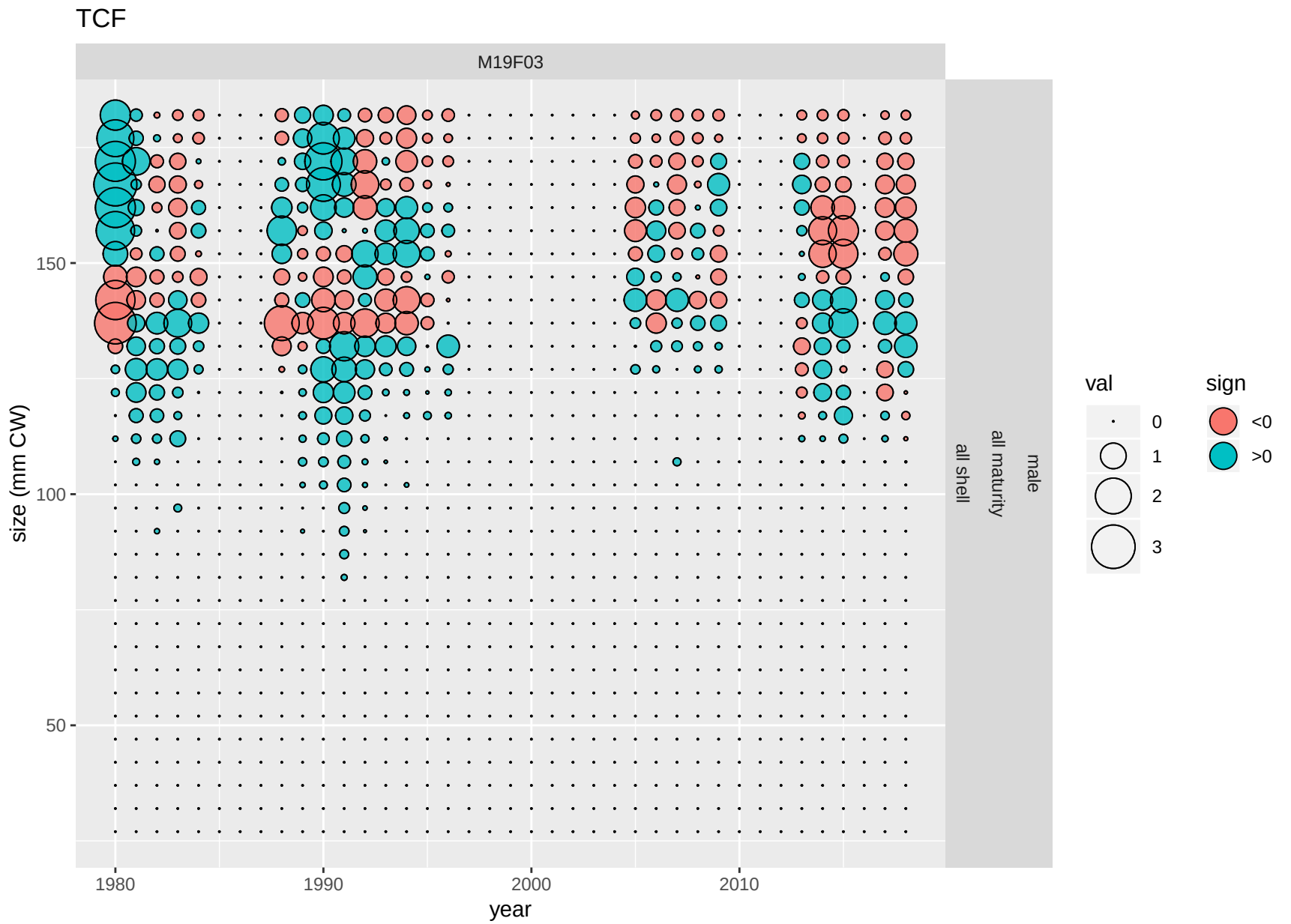


Figure 9: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F03.

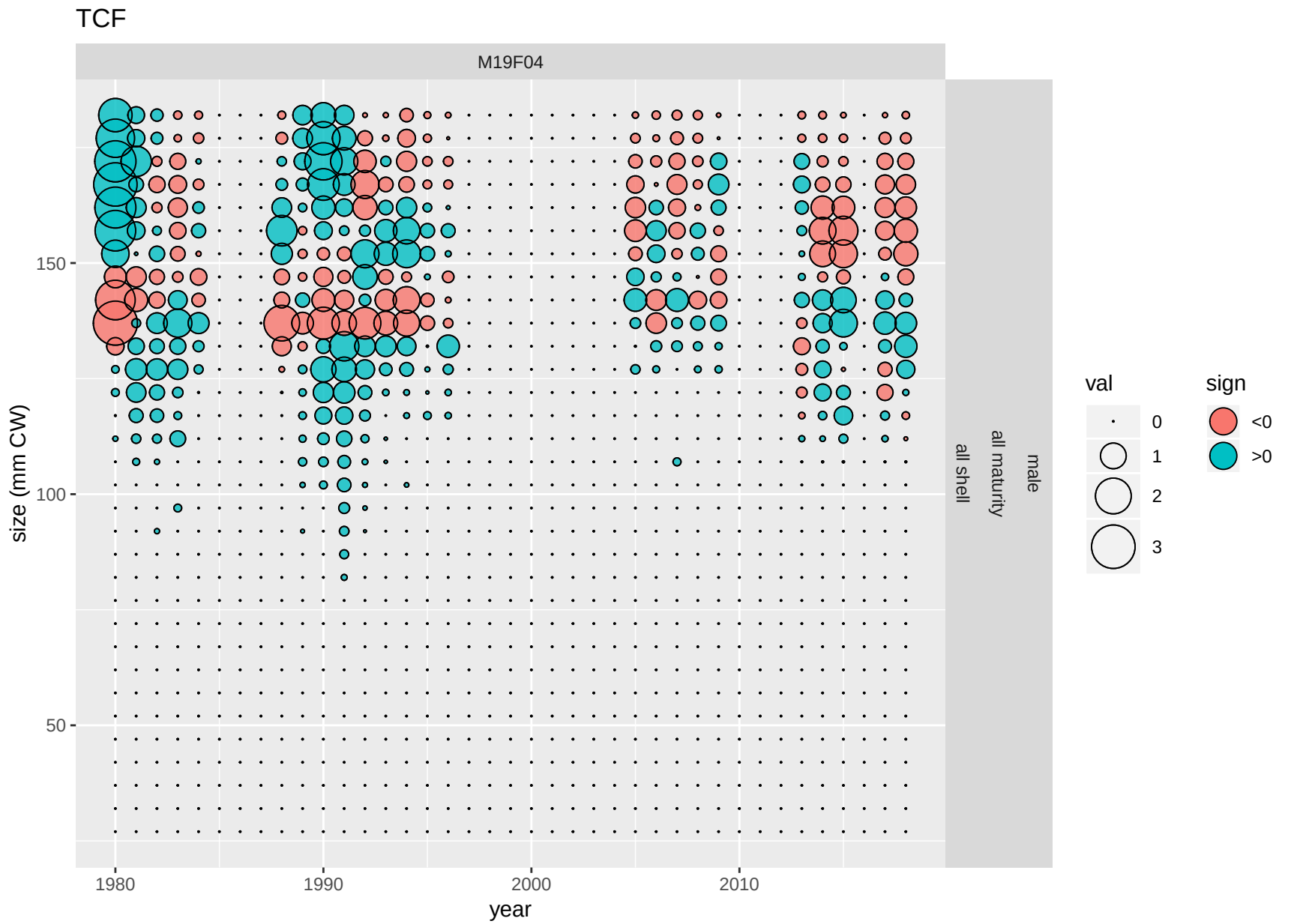


Figure 10: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F04.

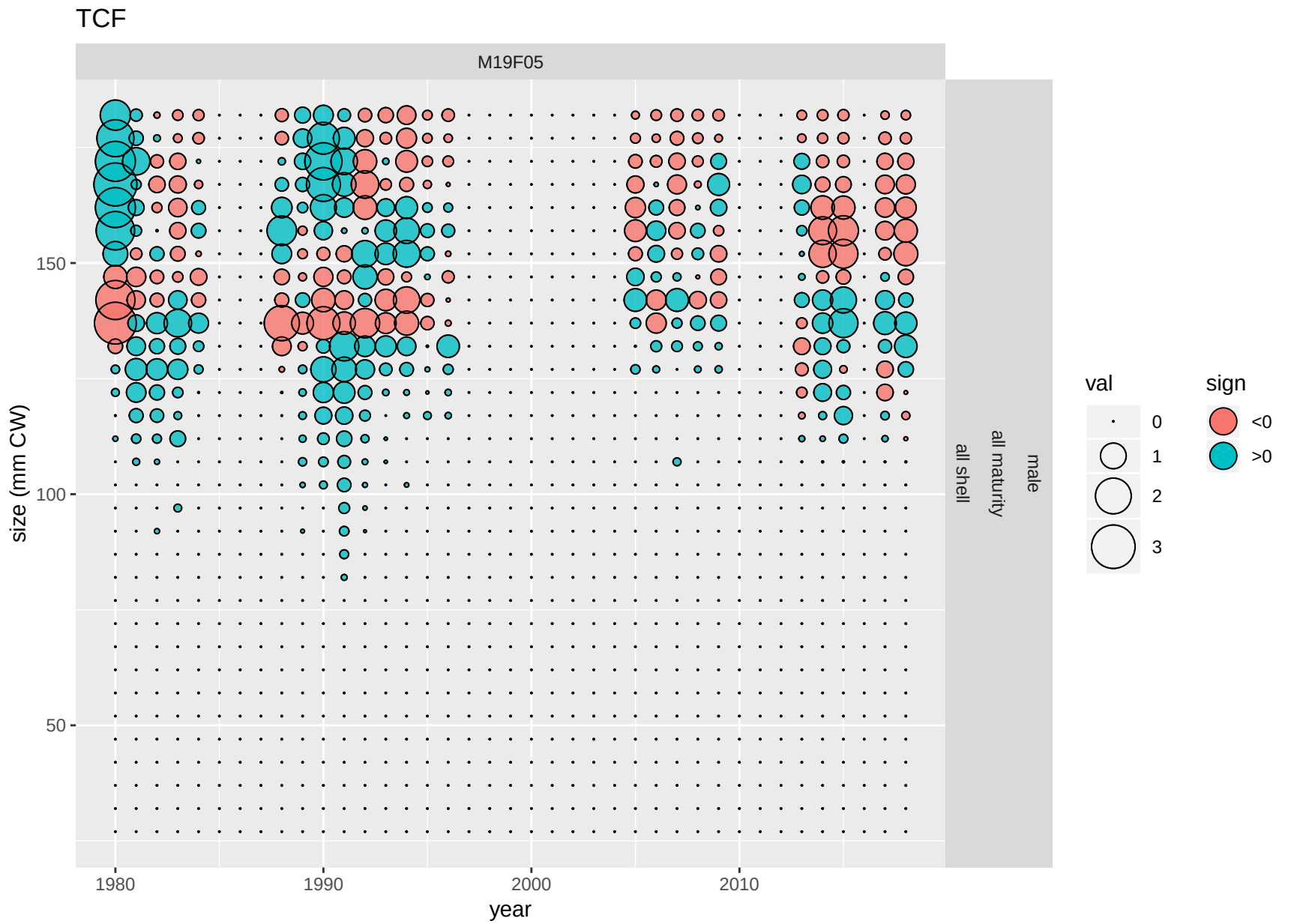


Figure 11: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F05.

Effective Ns for retained catch size compositions

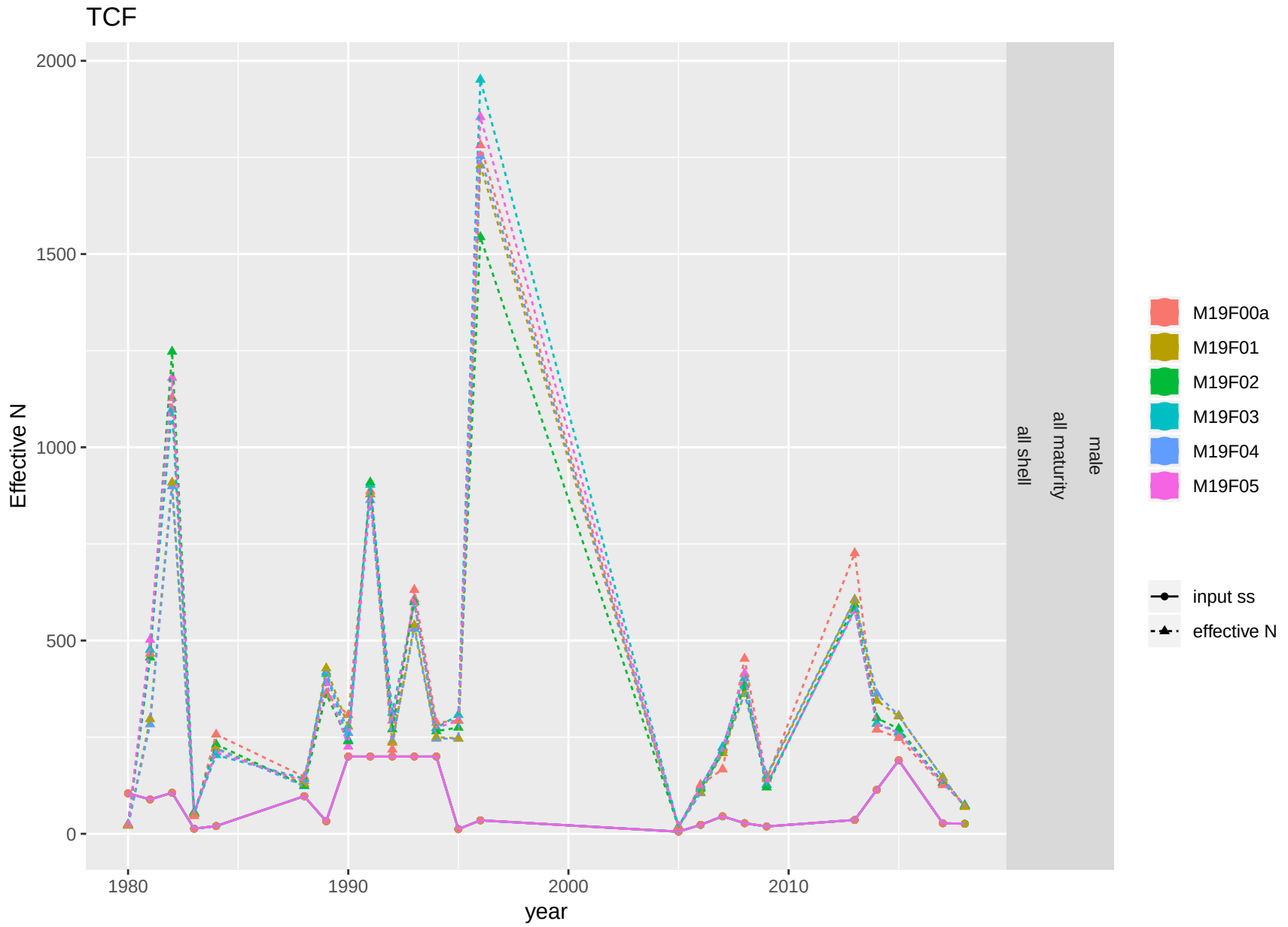


Figure 12: Input and effective sample sizes from retained catch size compositions from the TCF fishery.

Total catch size composition residuals

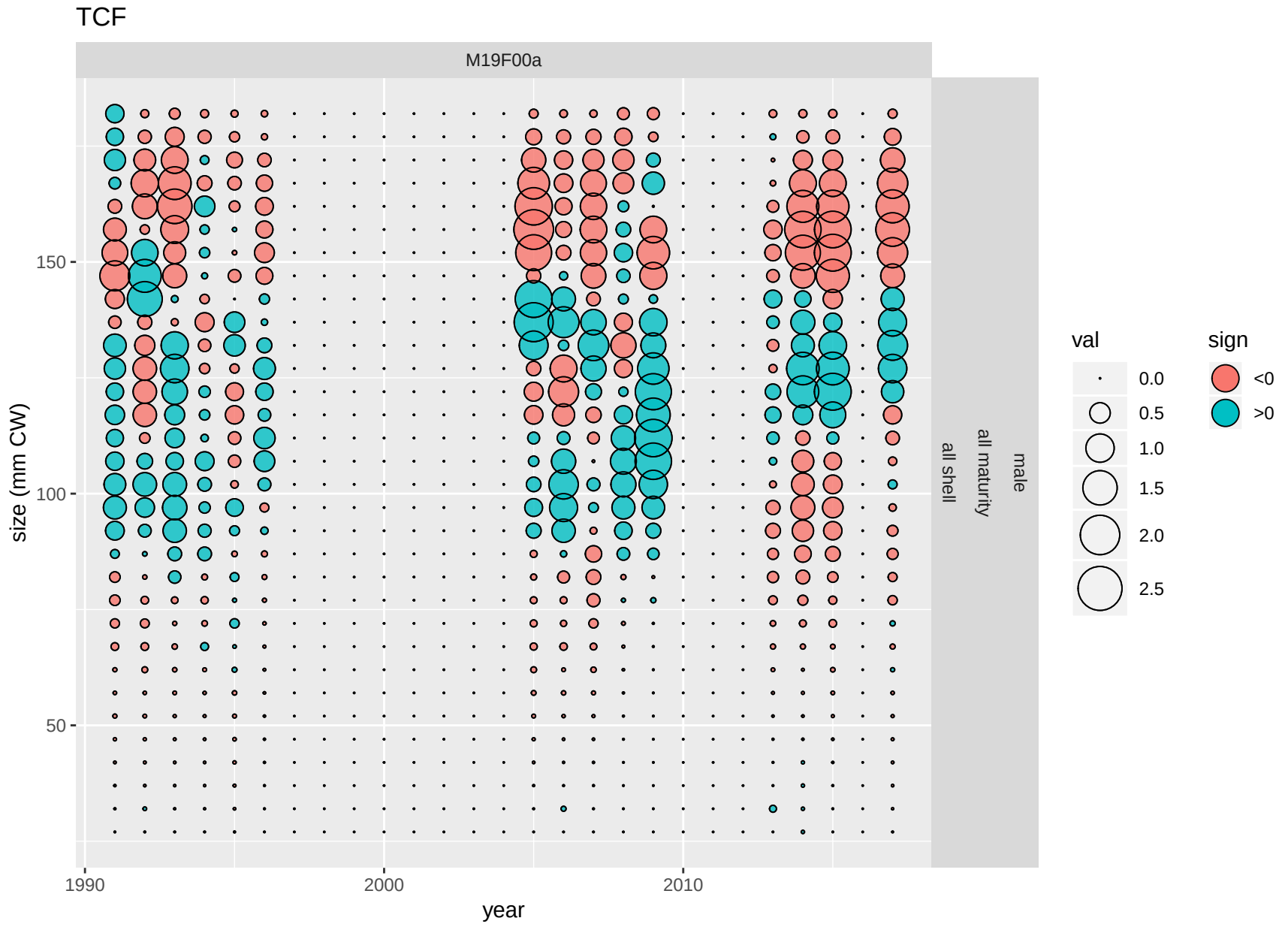


Figure 13: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F00a.

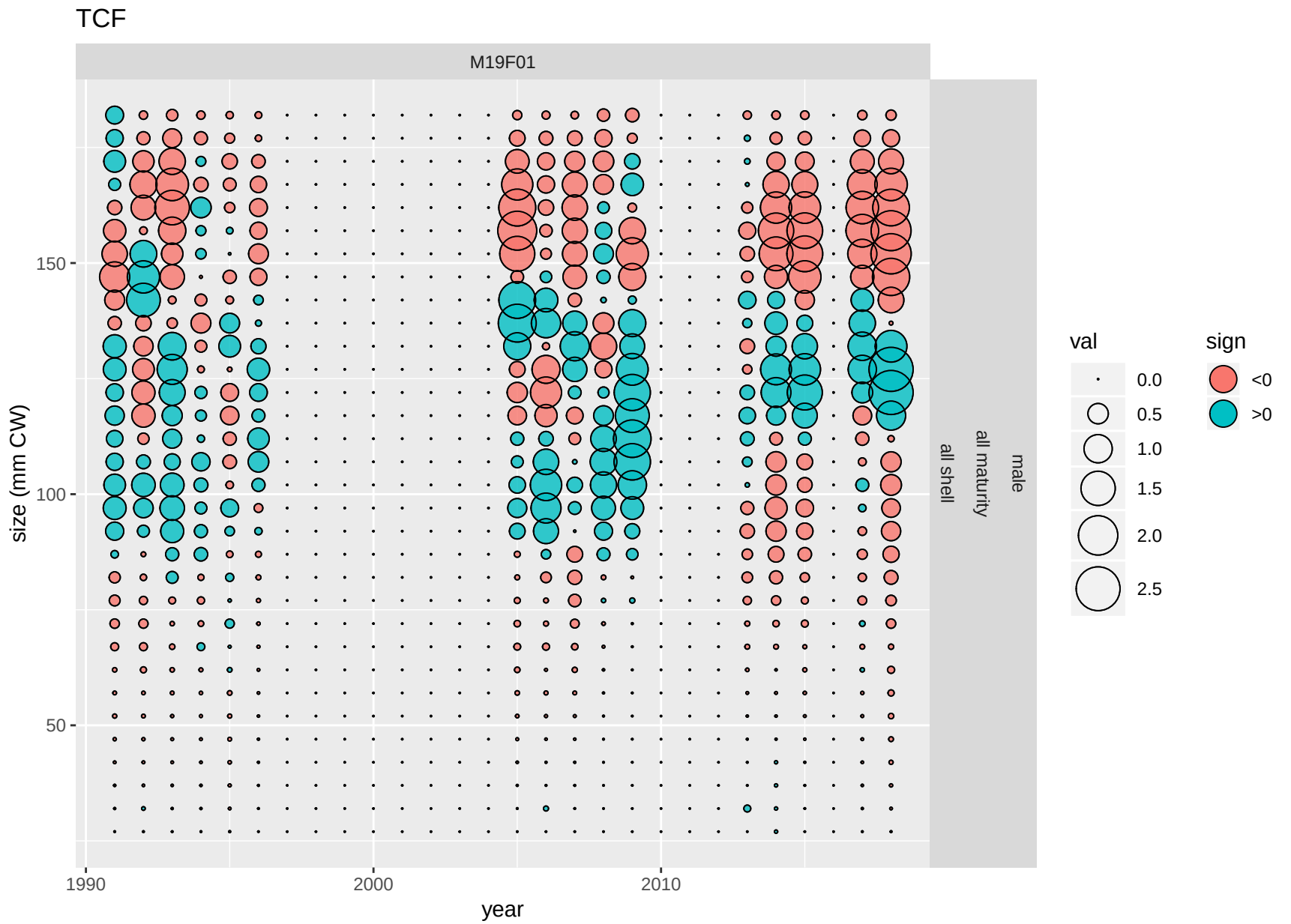


Figure 14: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F01.

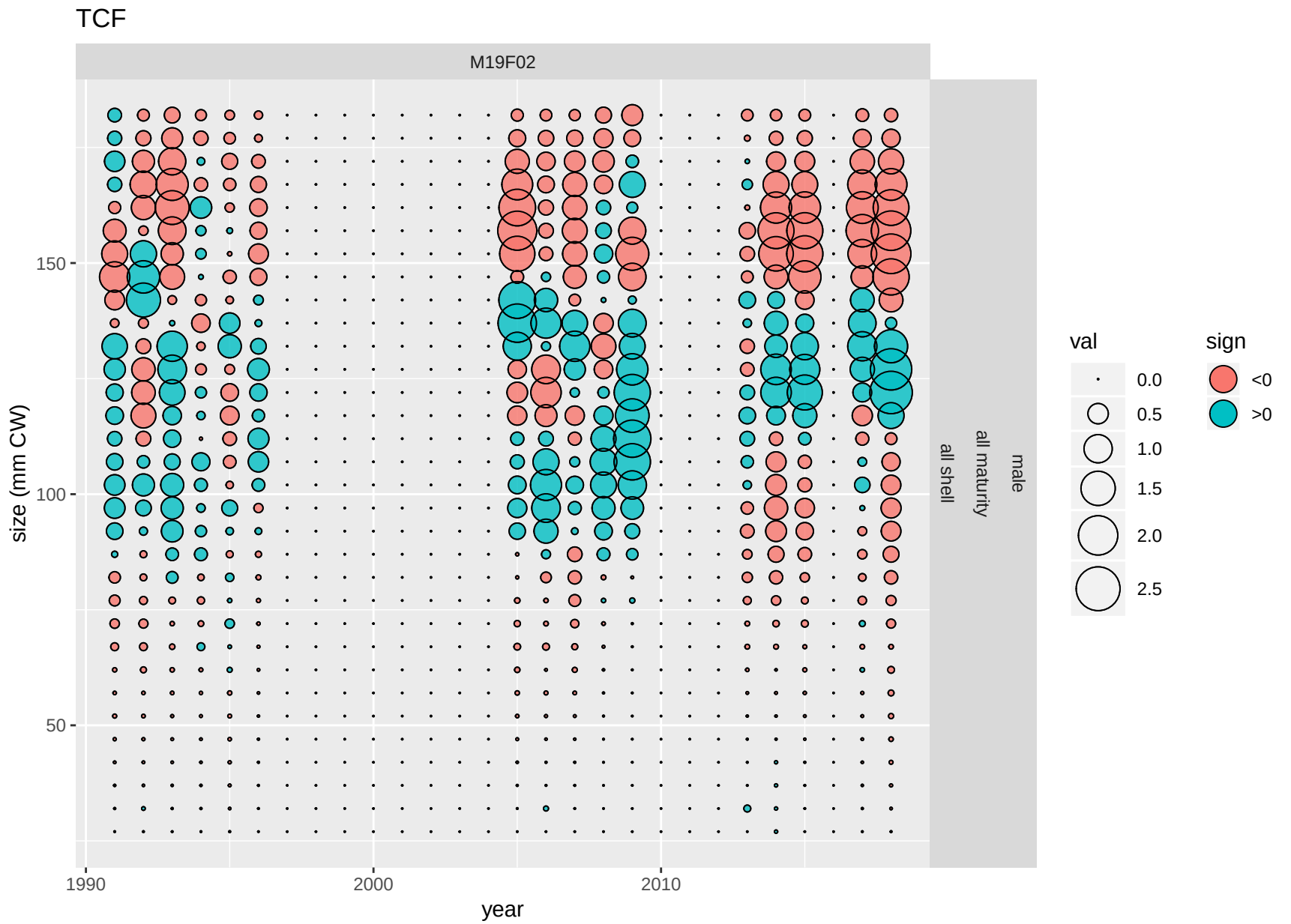


Figure 15: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F02.

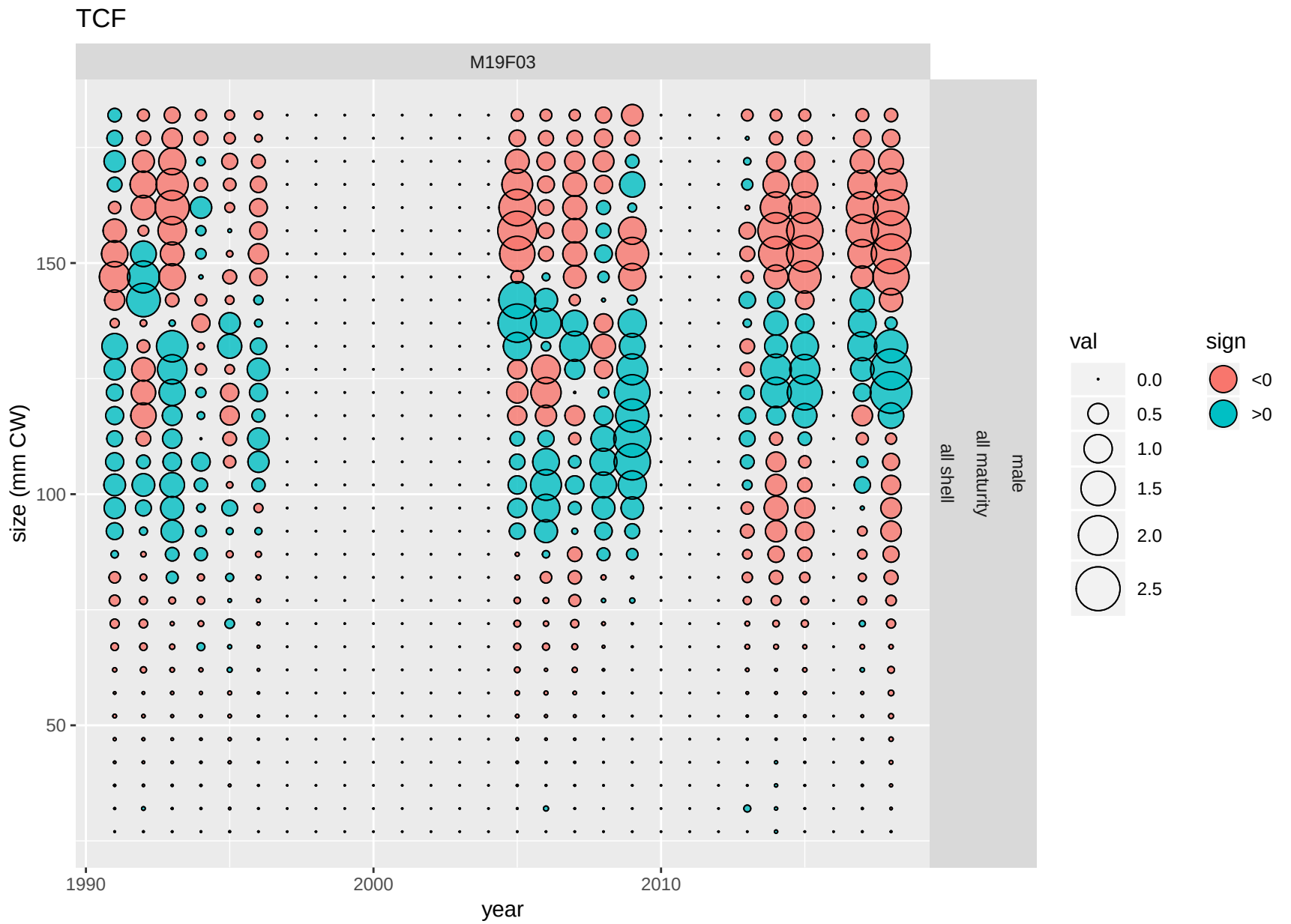


Figure 16: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F03.

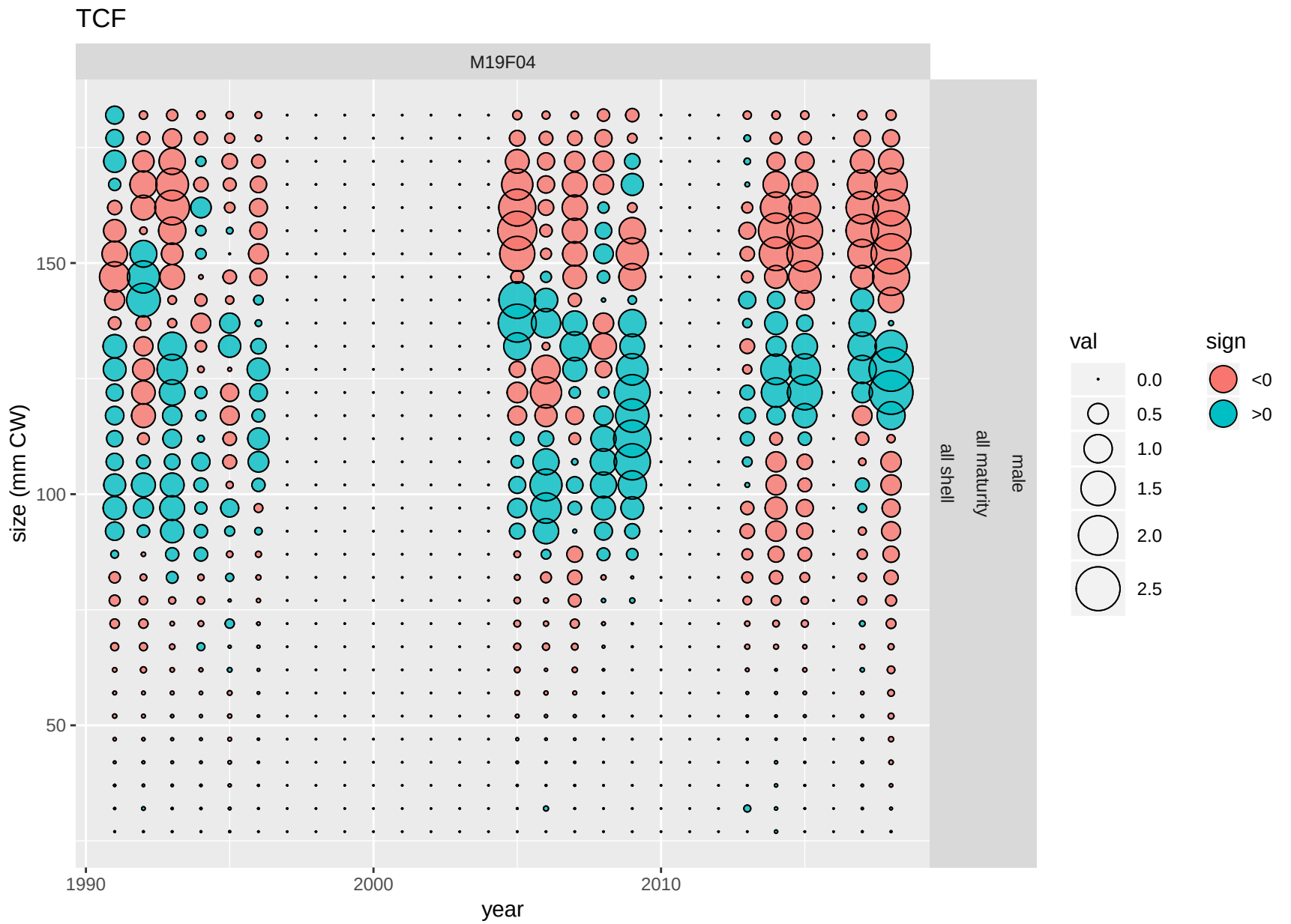


Figure 17: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F04.

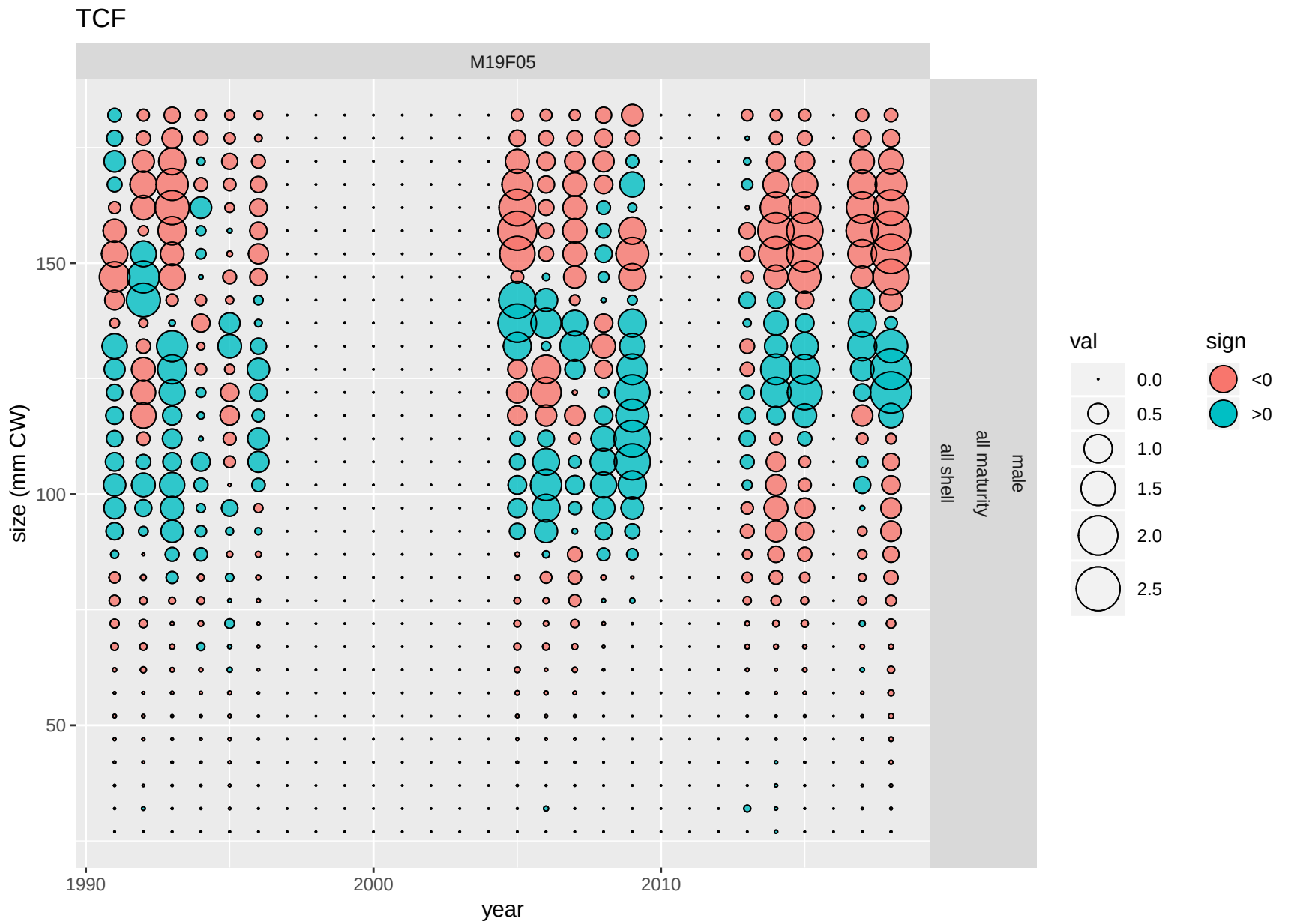


Figure 18: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F05.

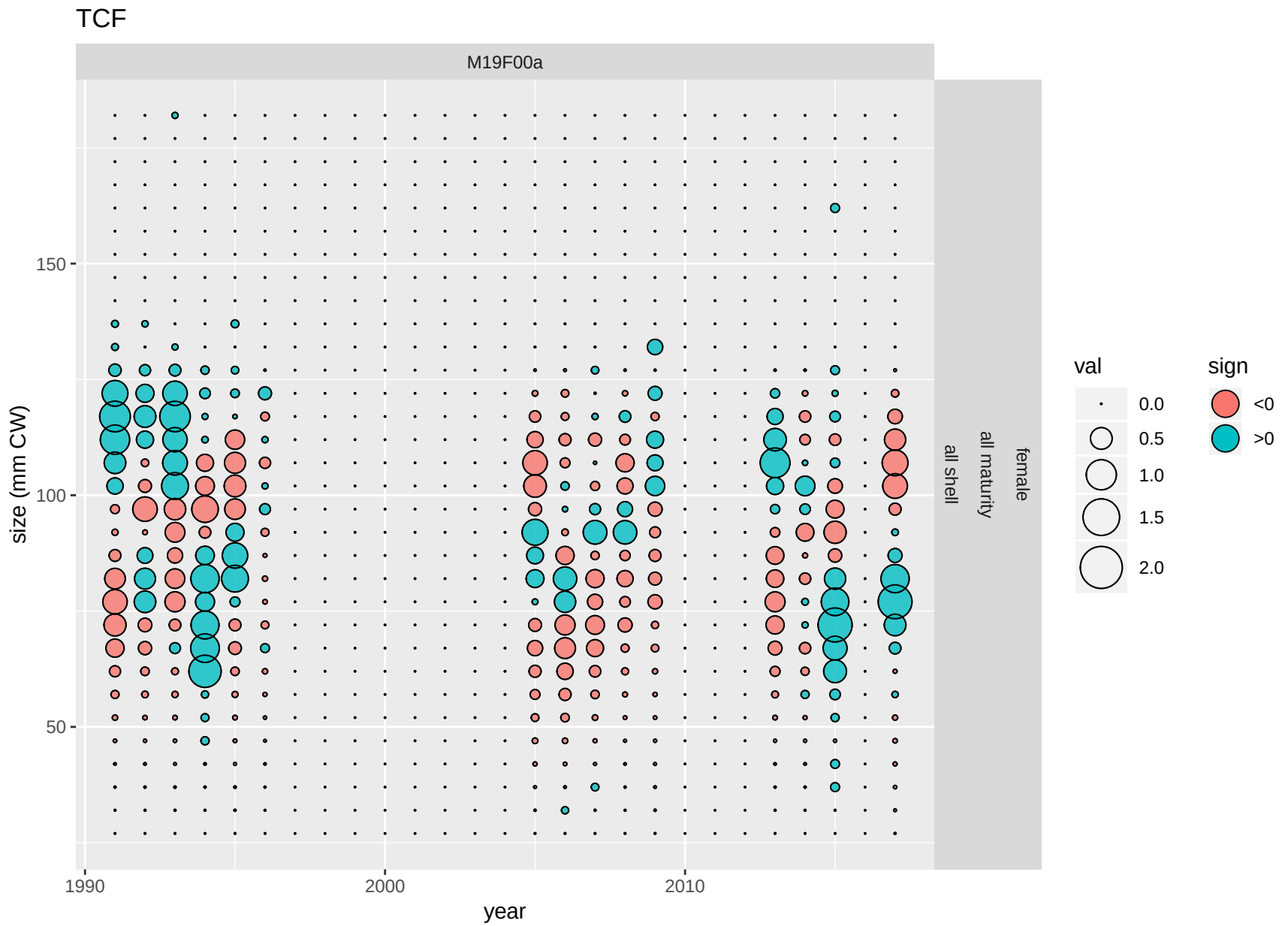


Figure 19: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F00a.

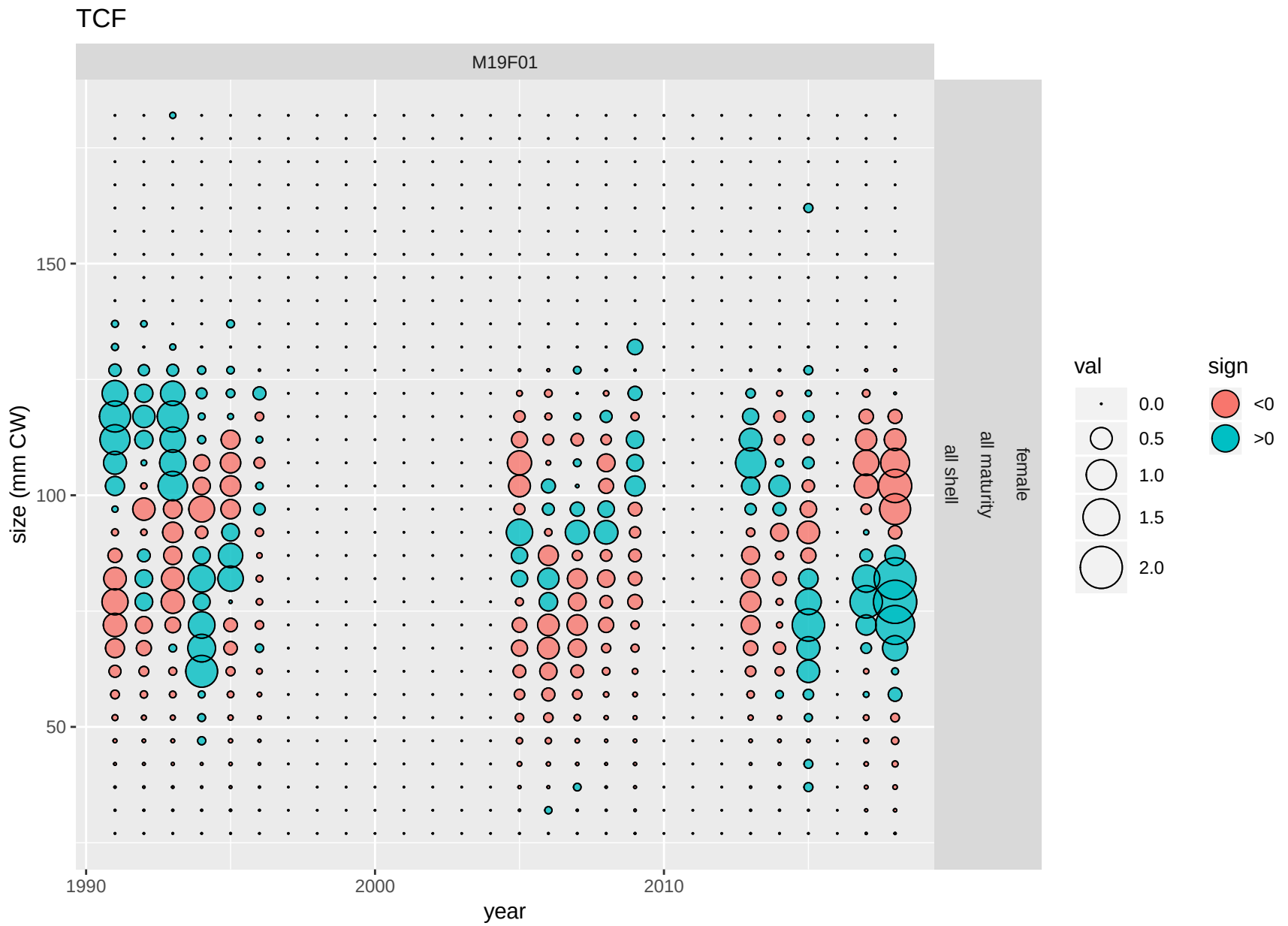


Figure 20: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F01.

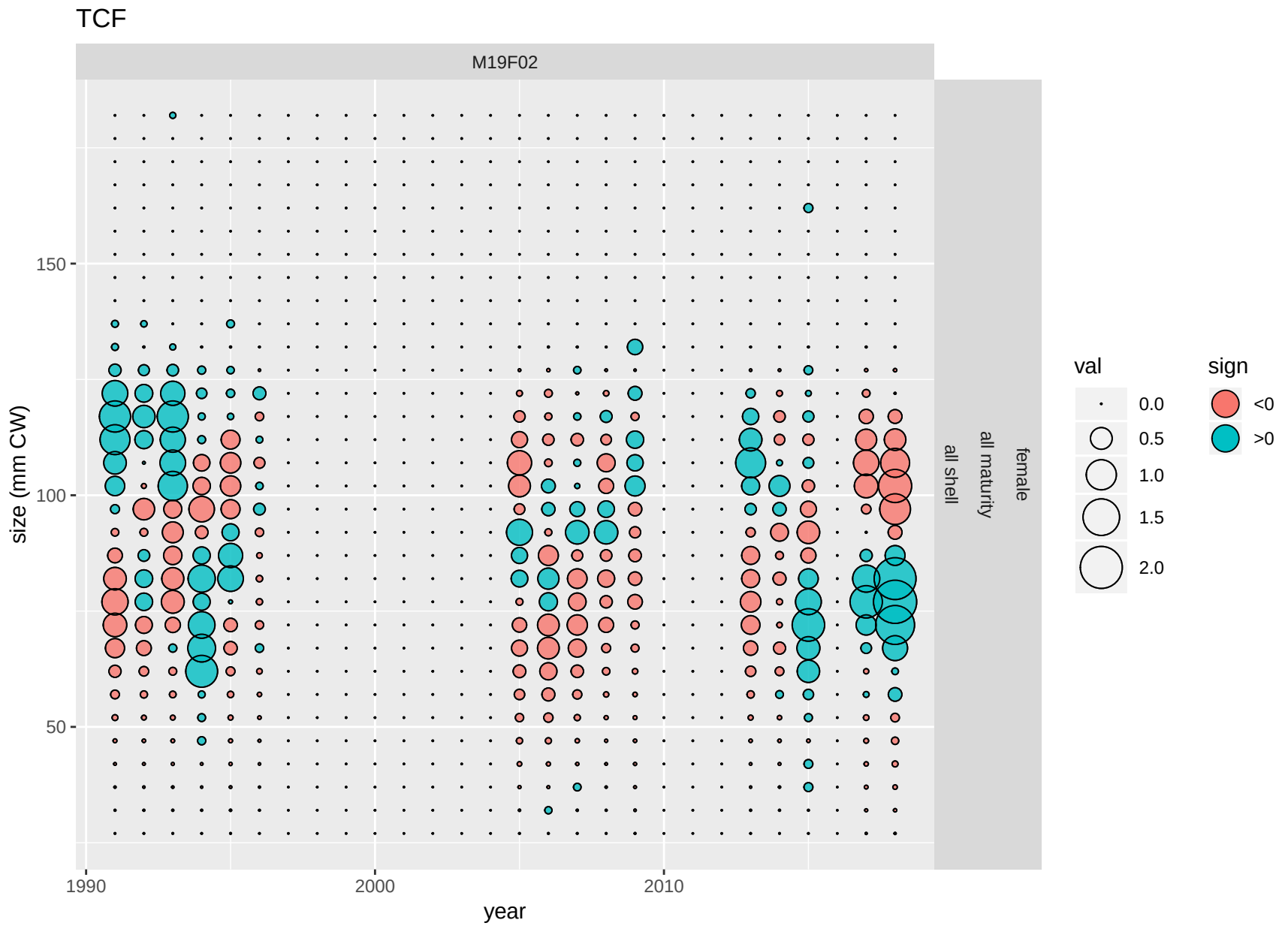


Figure 21: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F02.

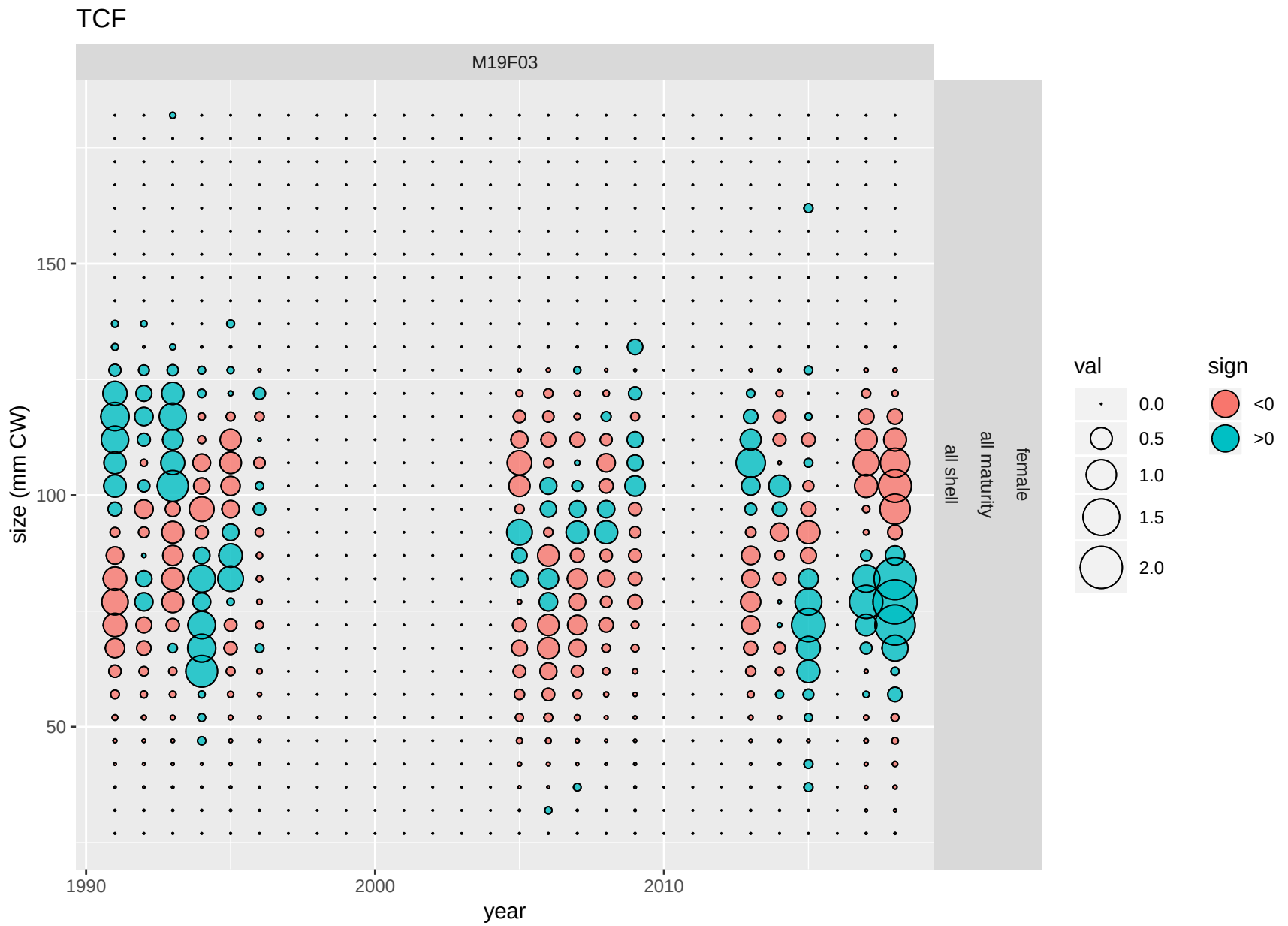


Figure 22: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F03.

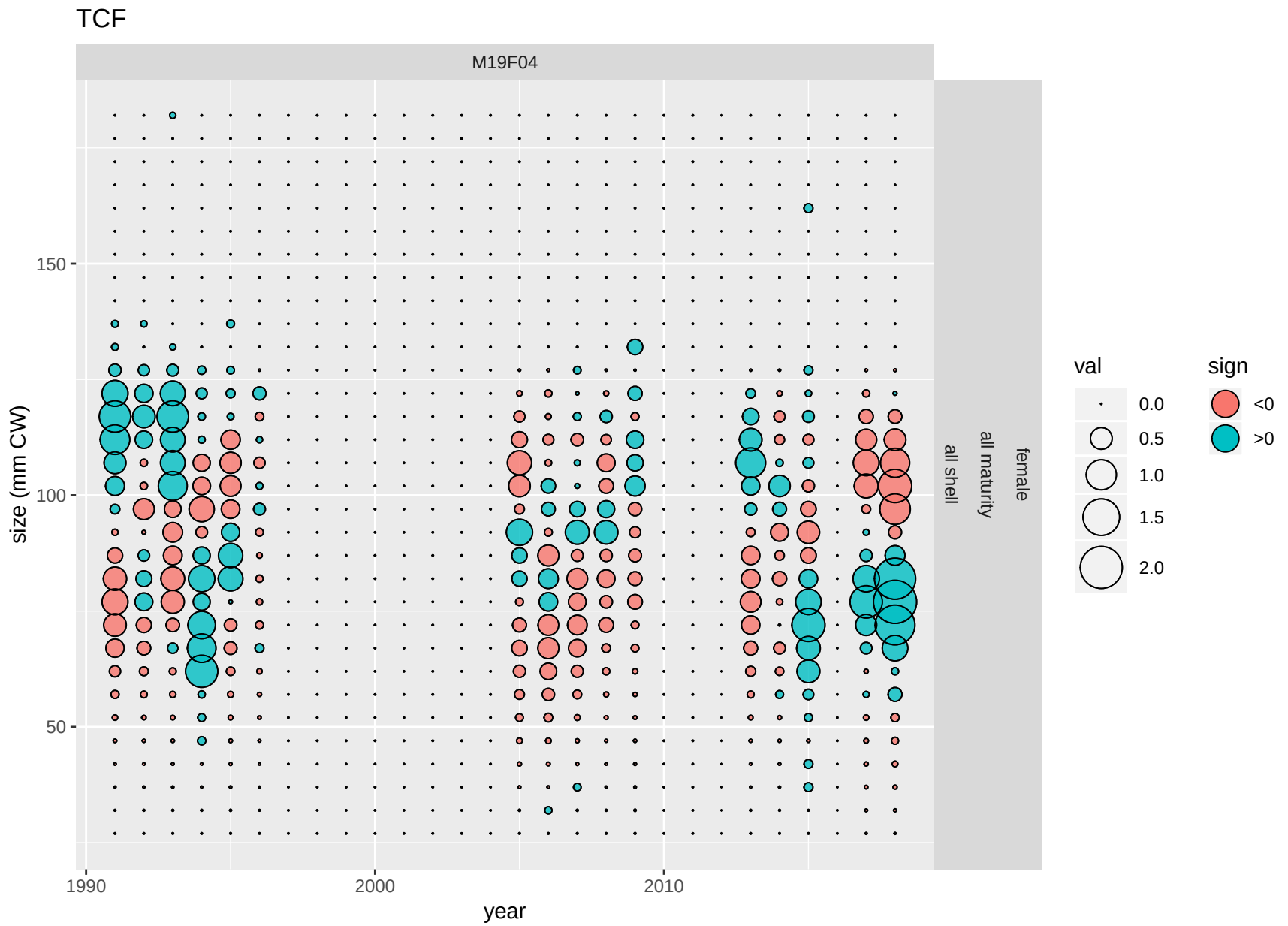


Figure 23: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F04.

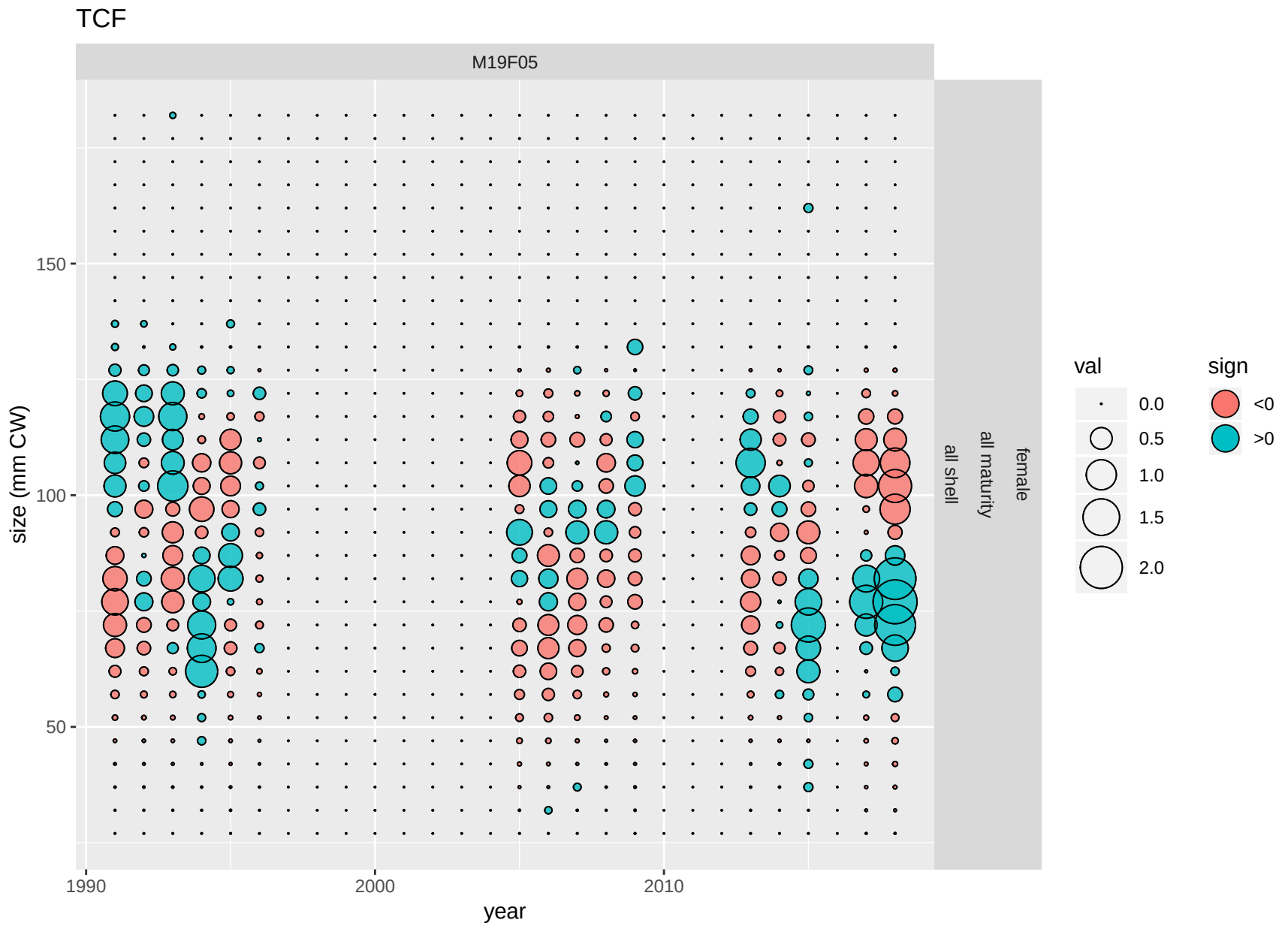


Figure 24: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F05.

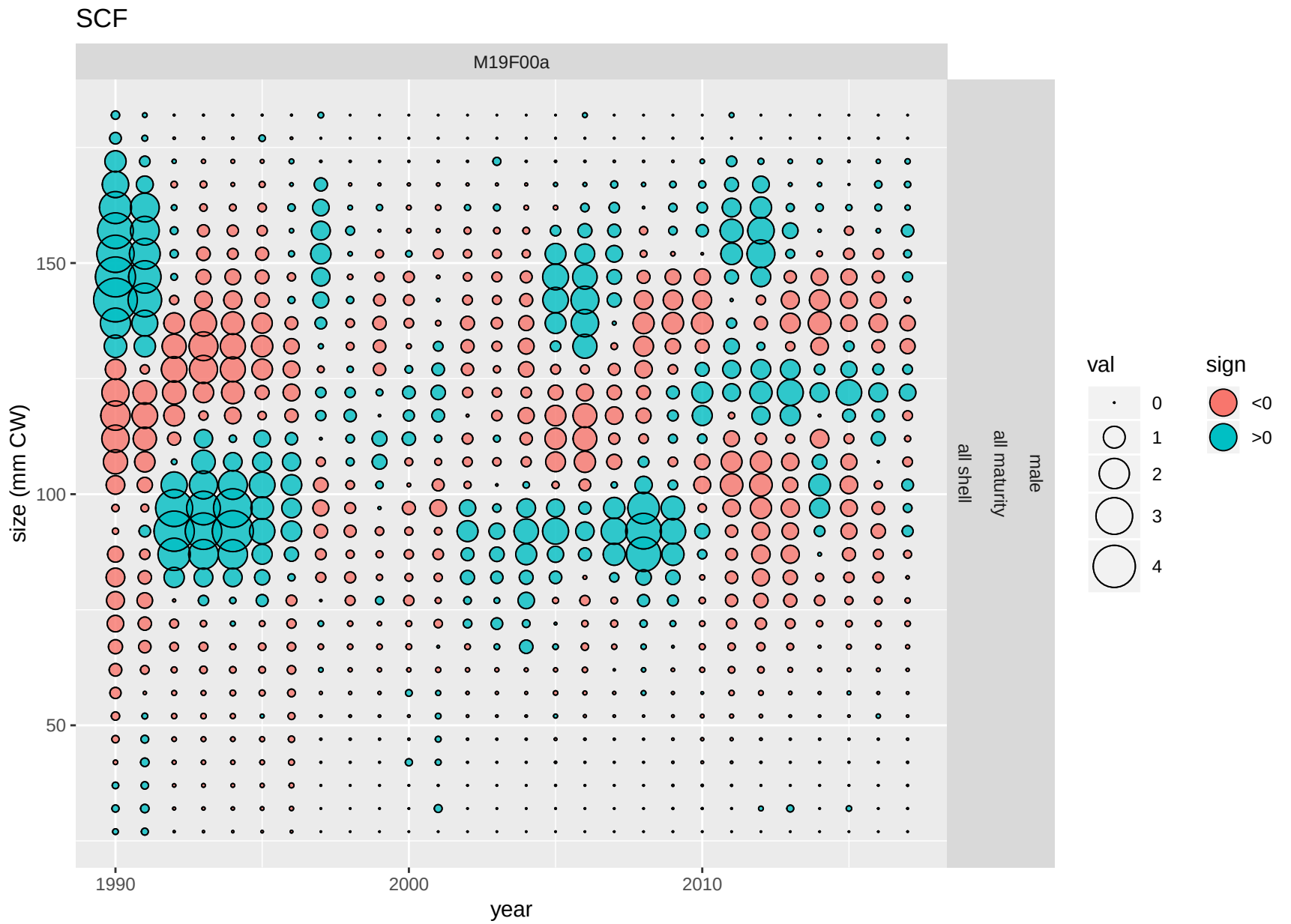


Figure 25: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F00a.

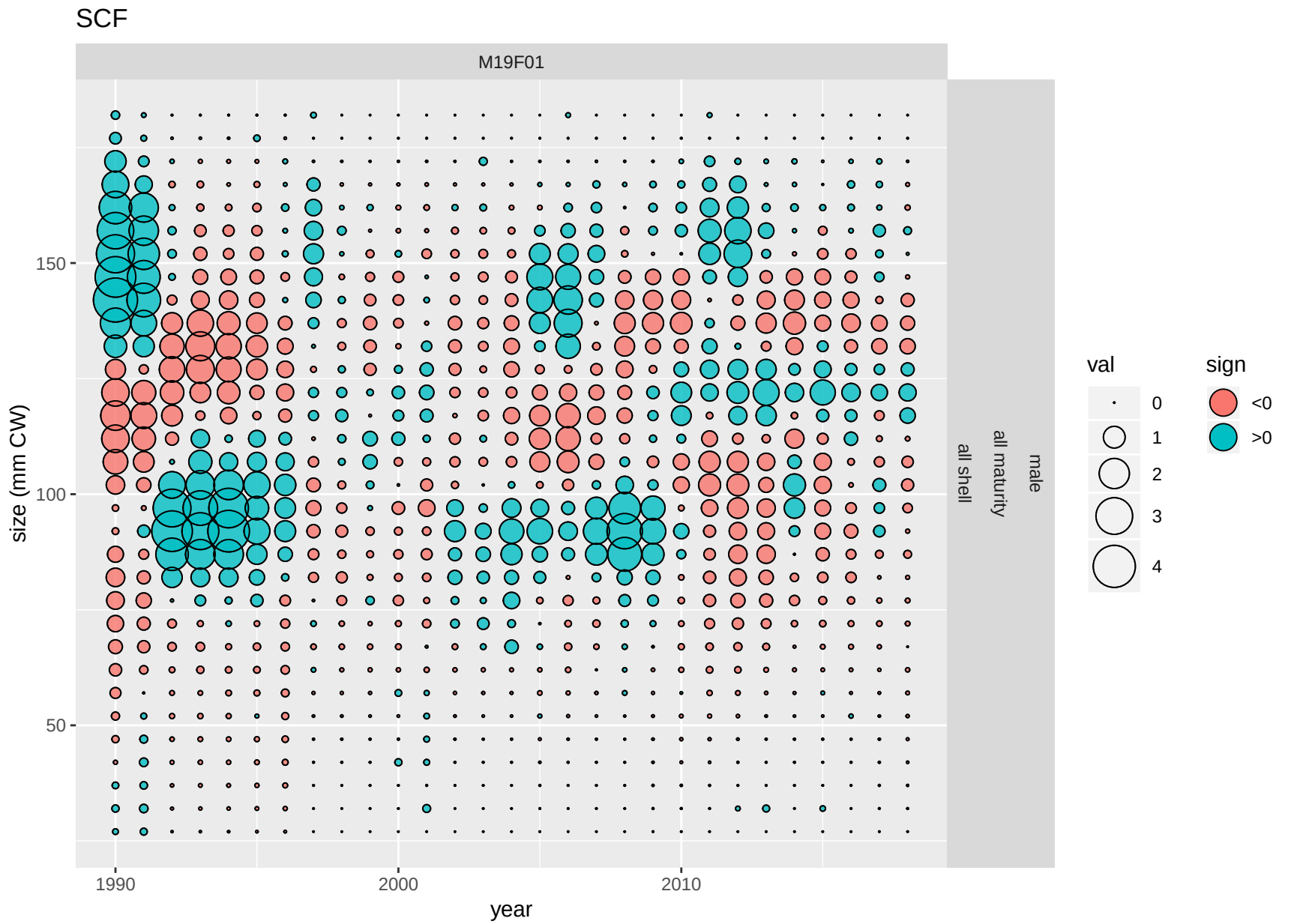


Figure 26: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F01.

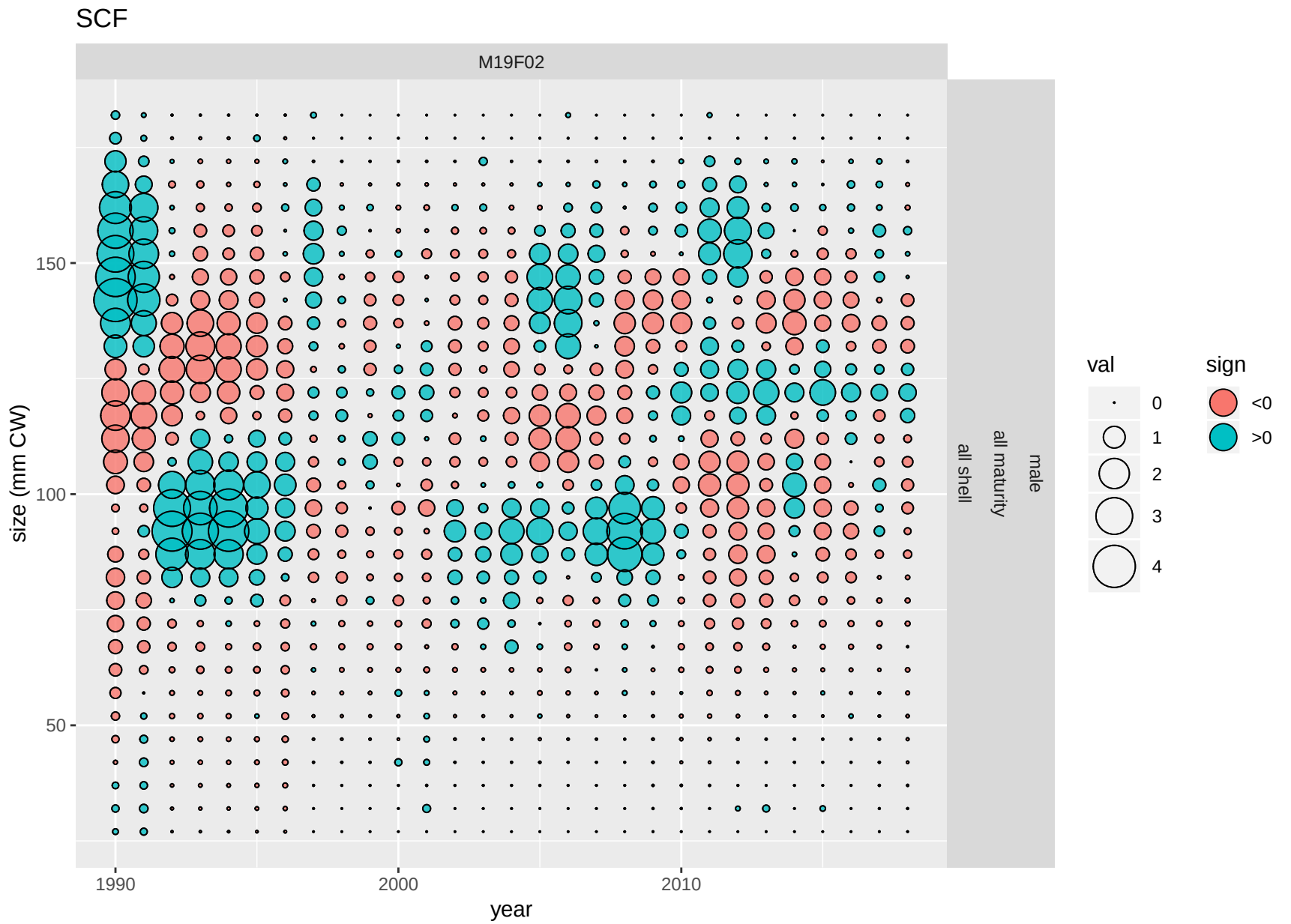


Figure 27: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F02.

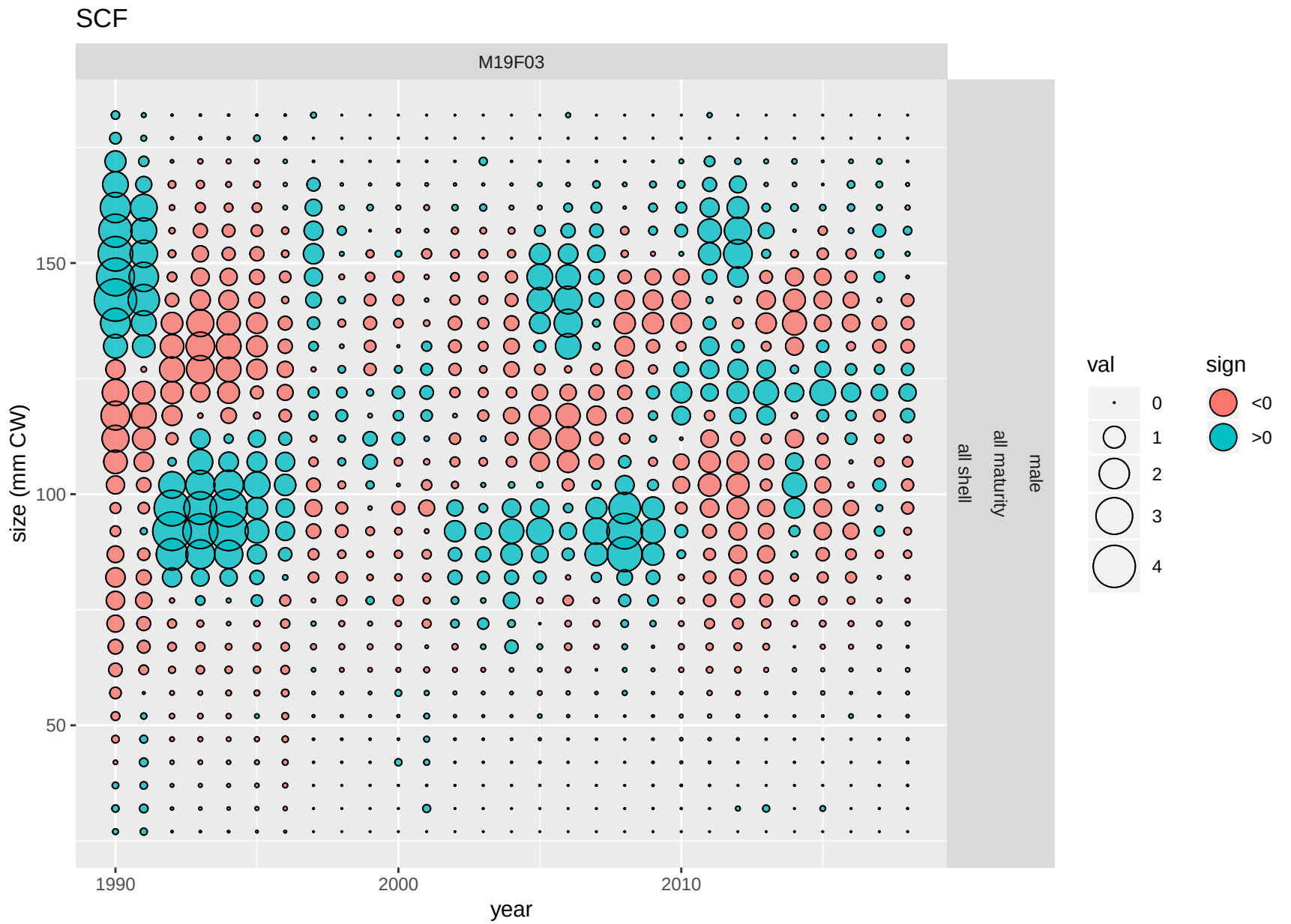


Figure 28: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F03.

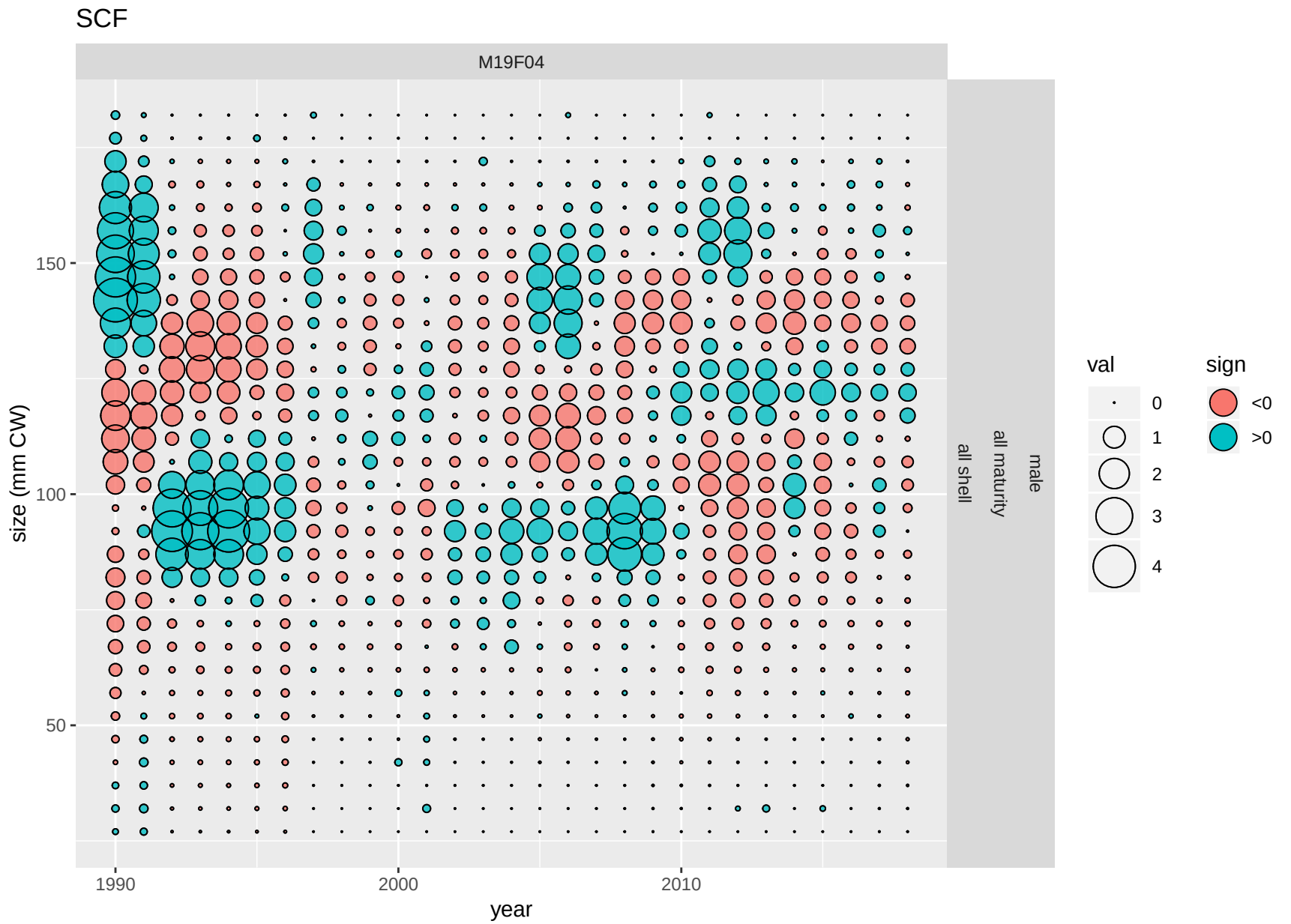


Figure 29: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F04.

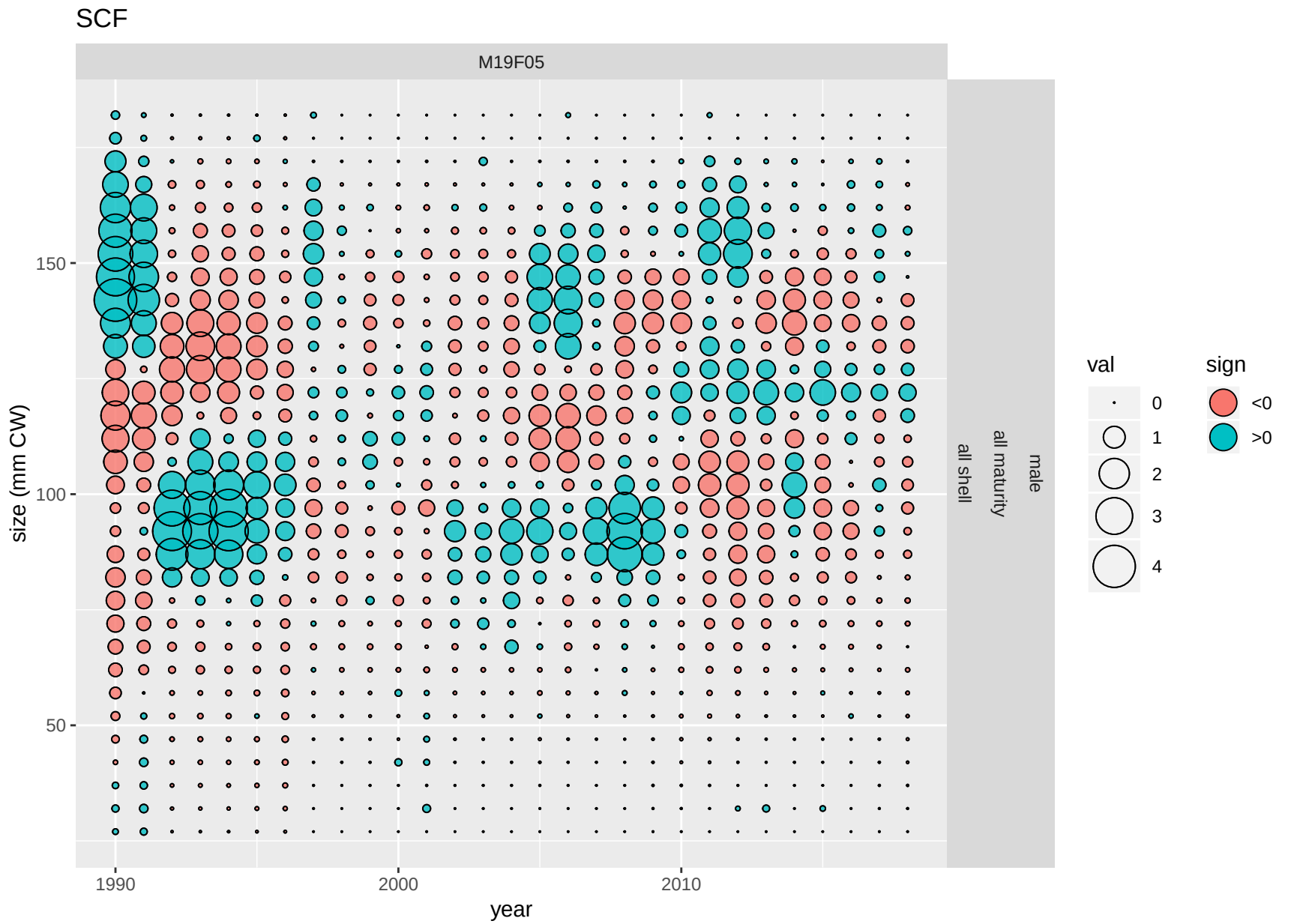


Figure 30: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F05.

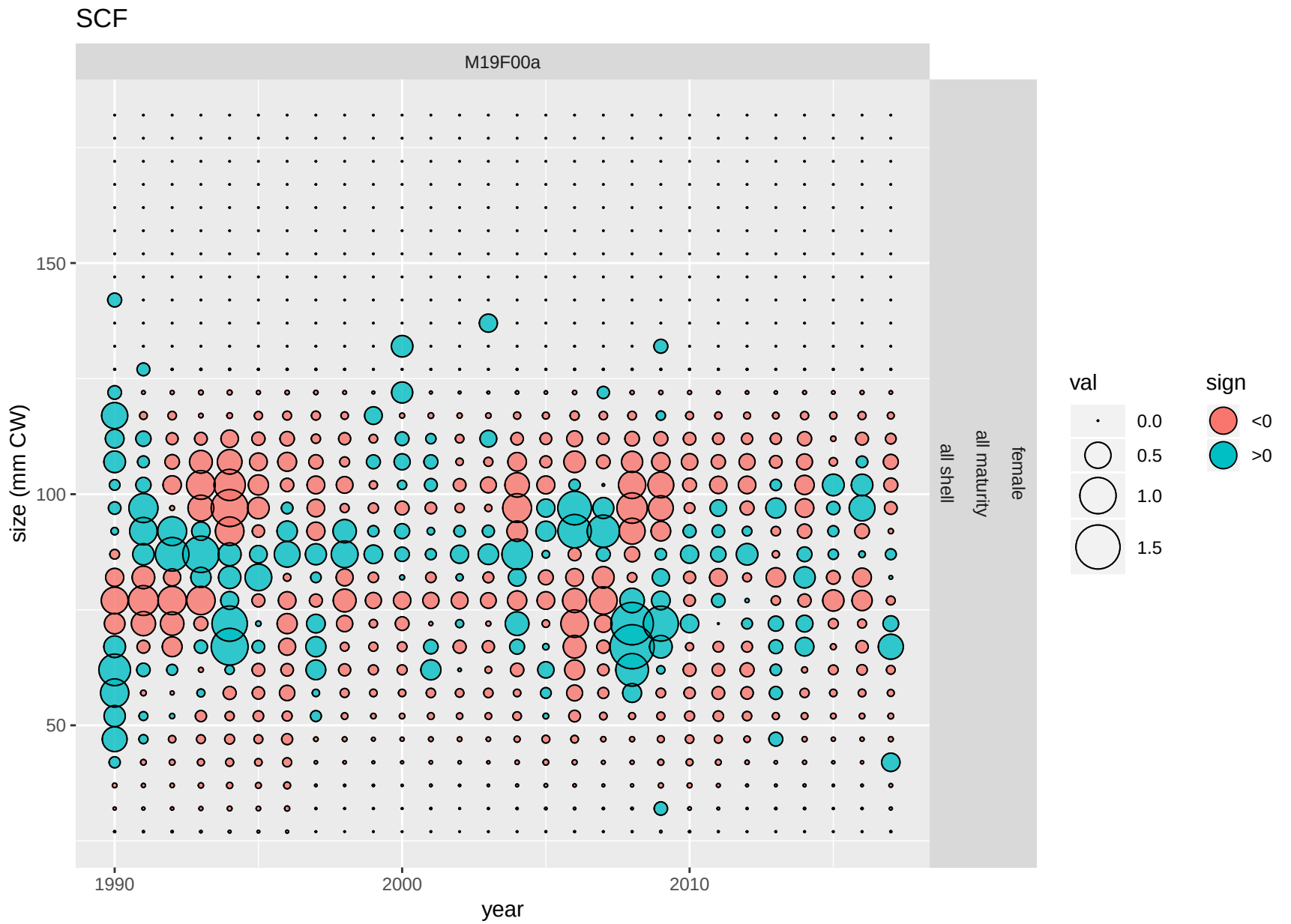


Figure 31: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F00a.

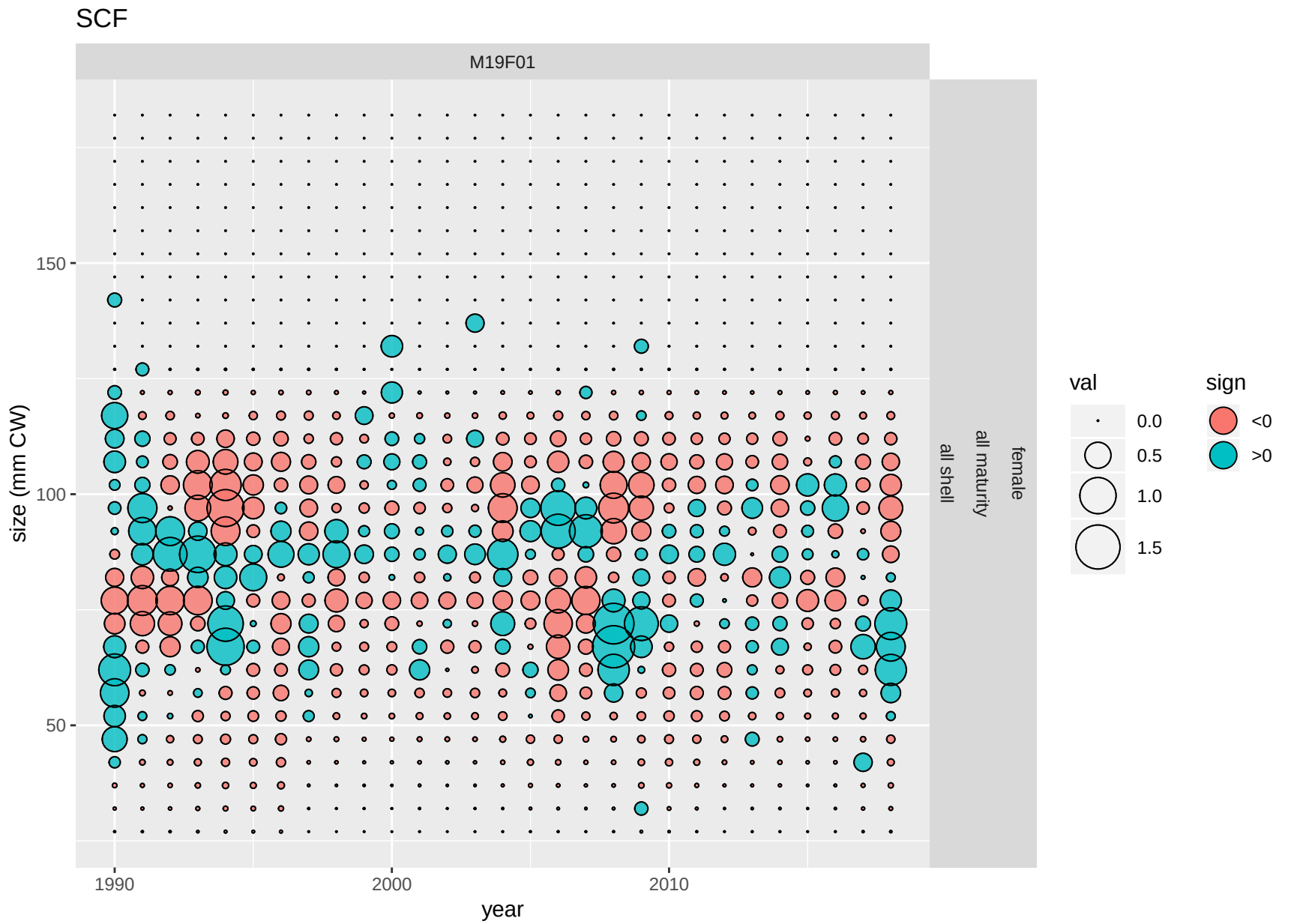


Figure 32: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F01.

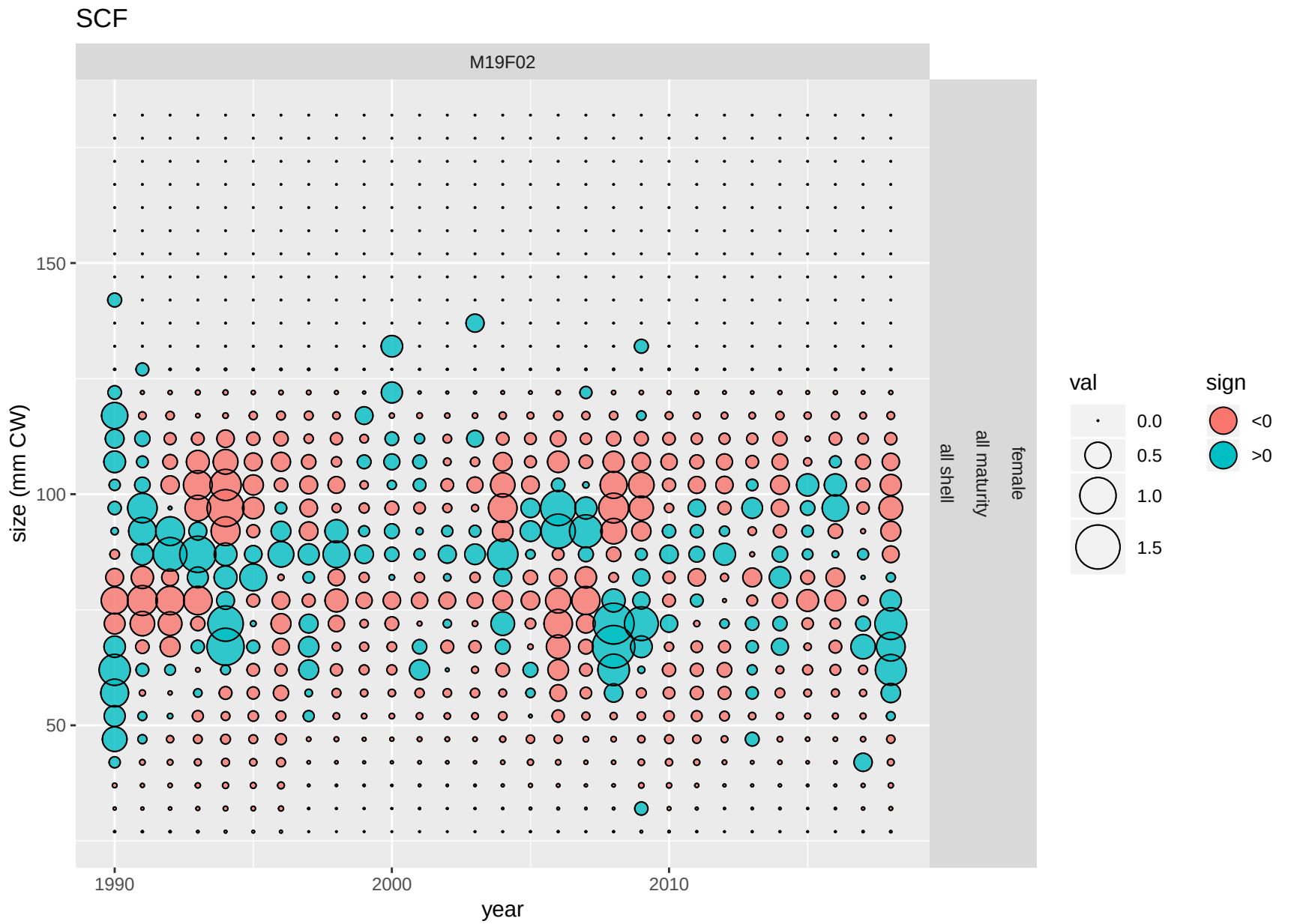


Figure 33: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F02.

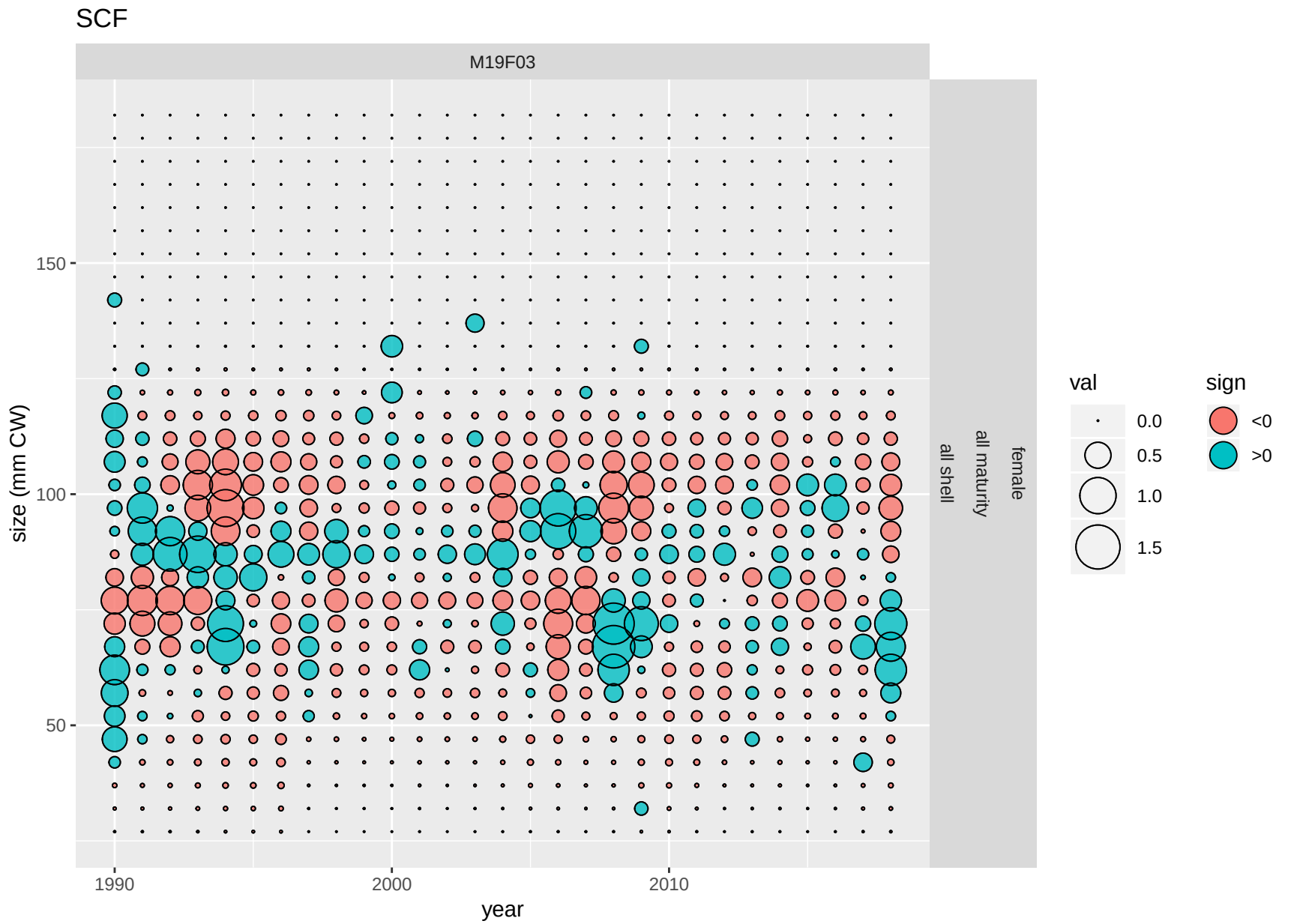


Figure 34: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F03.

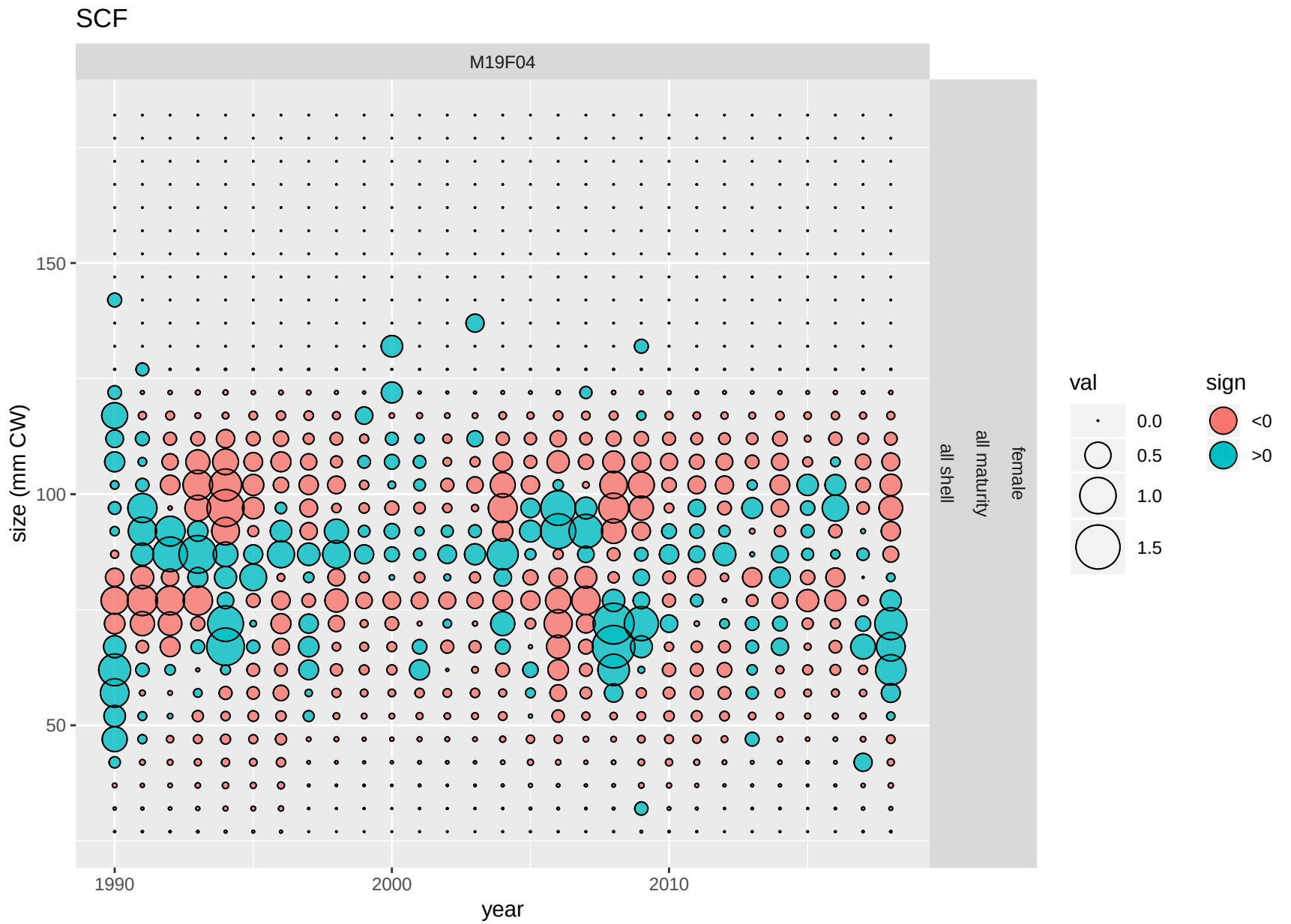


Figure 35: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F04.

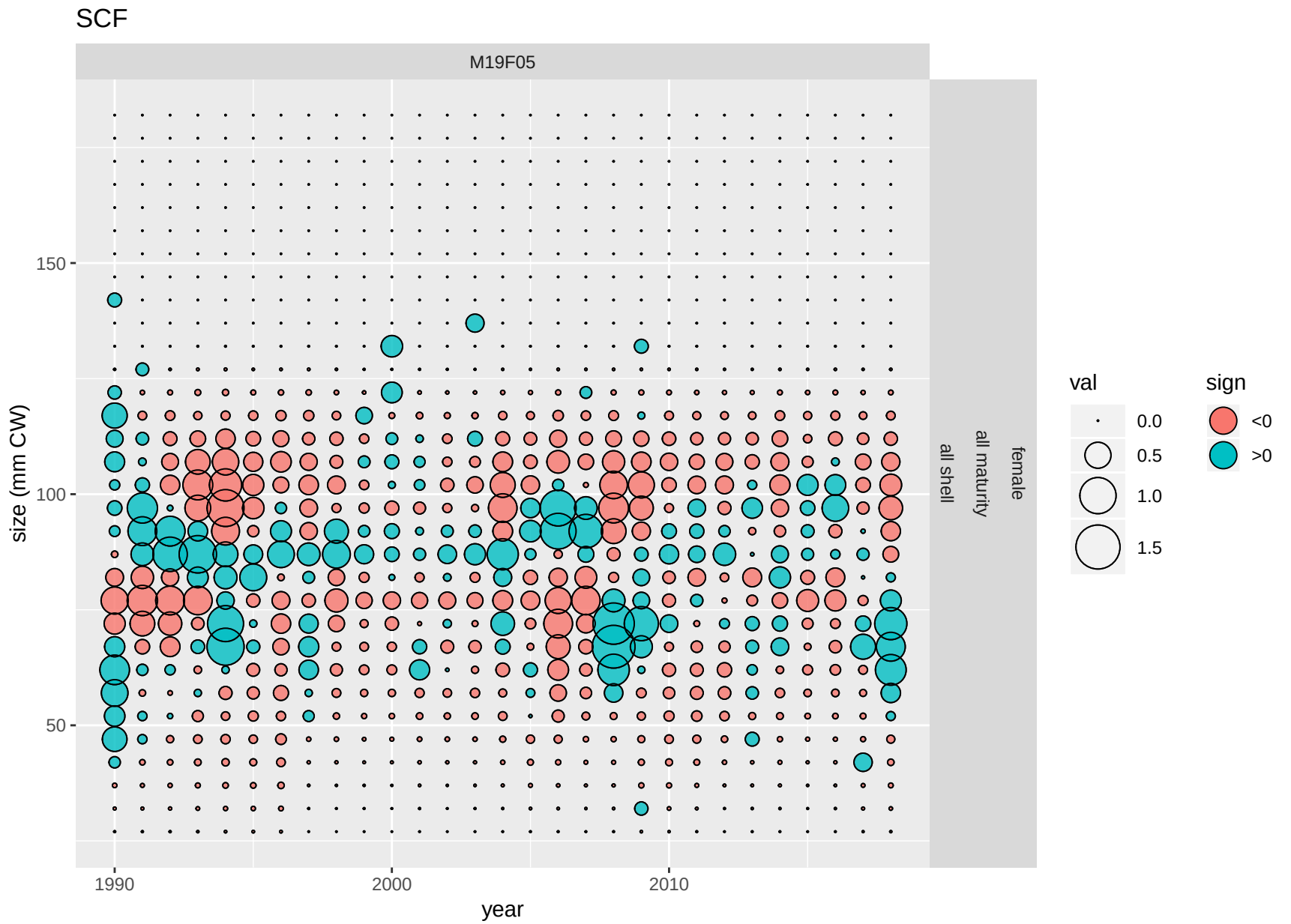


Figure 36: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F05.

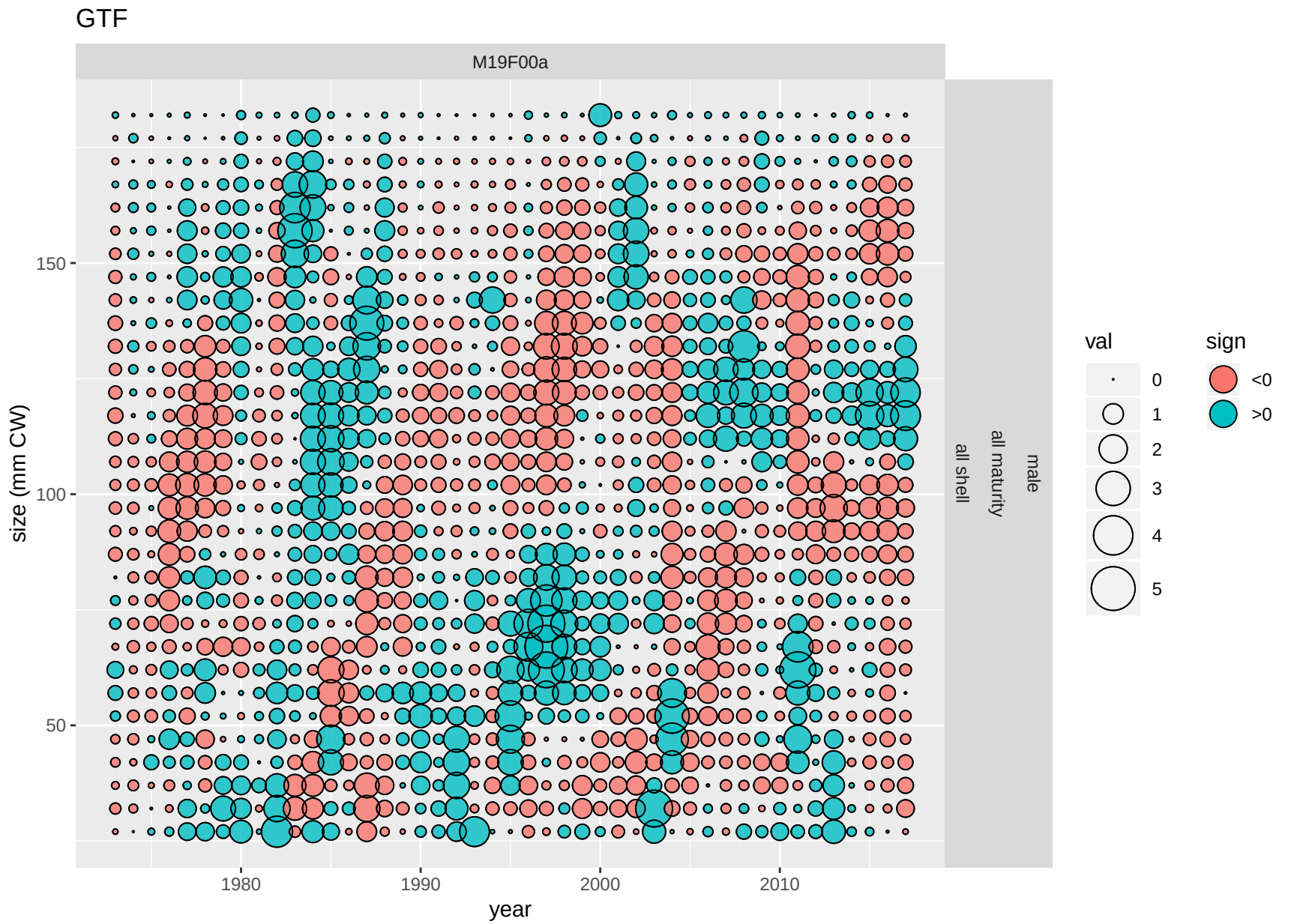


Figure 37: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F00a.

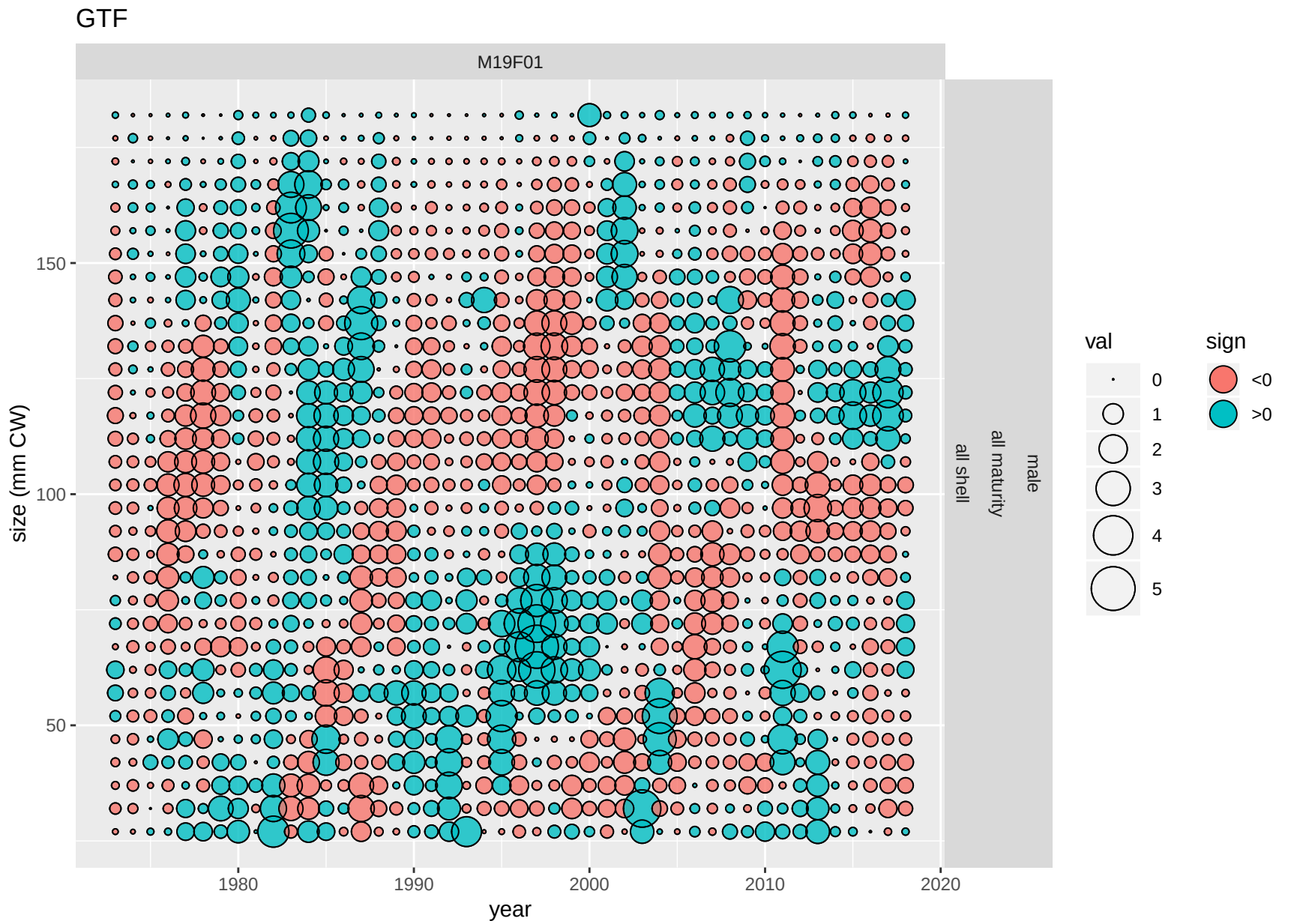


Figure 38: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F01.

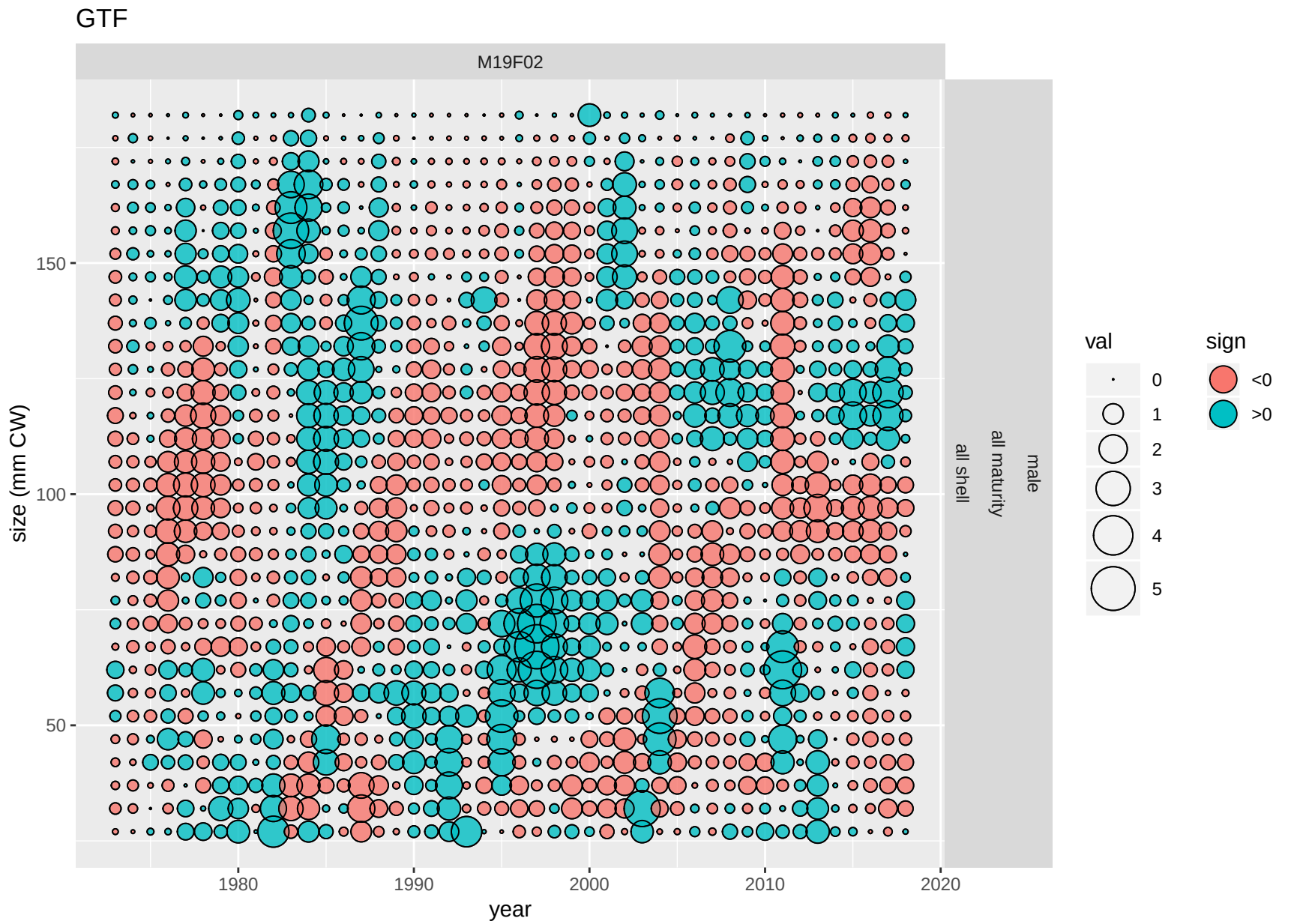


Figure 39: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F02.

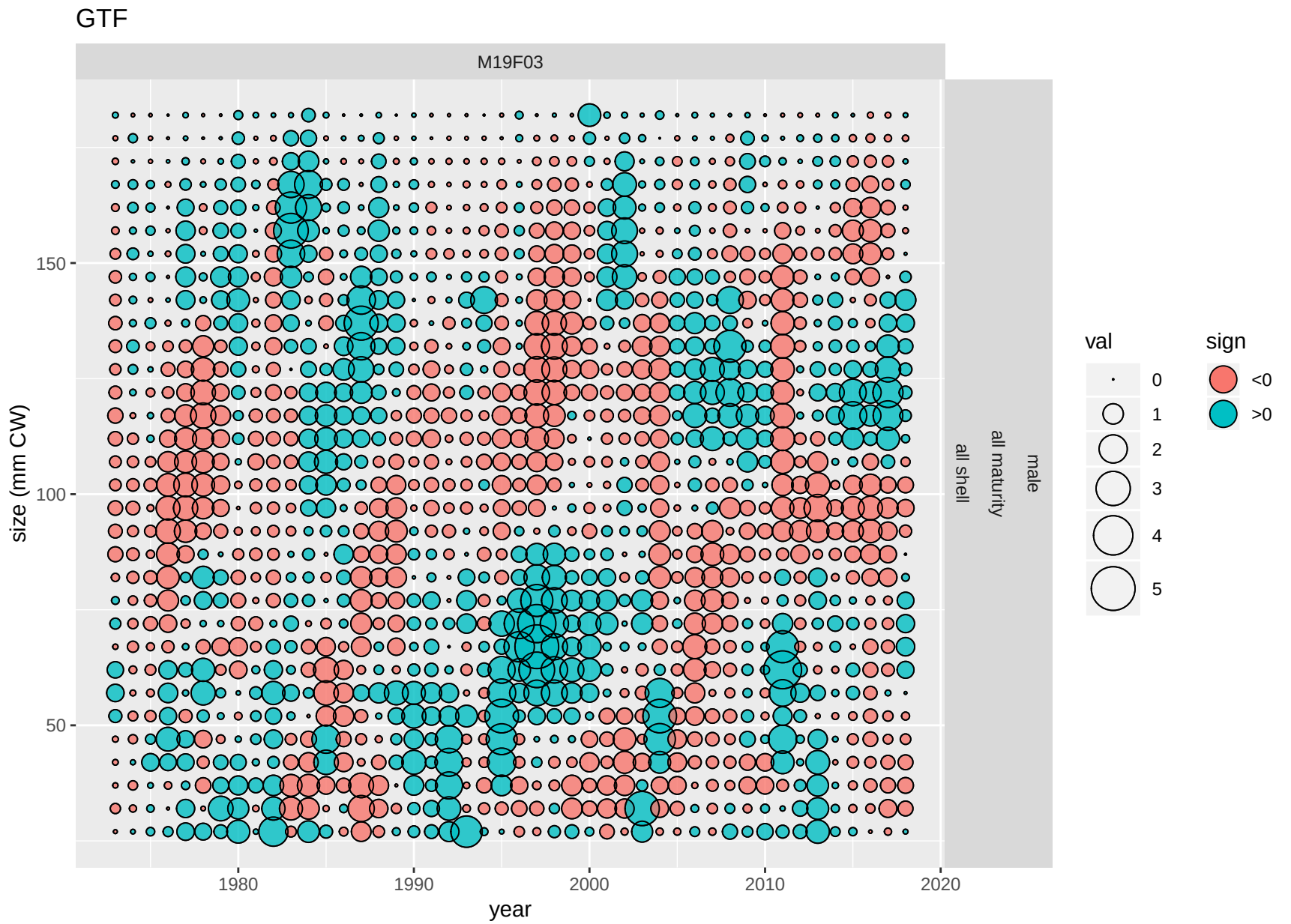


Figure 40: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F03.

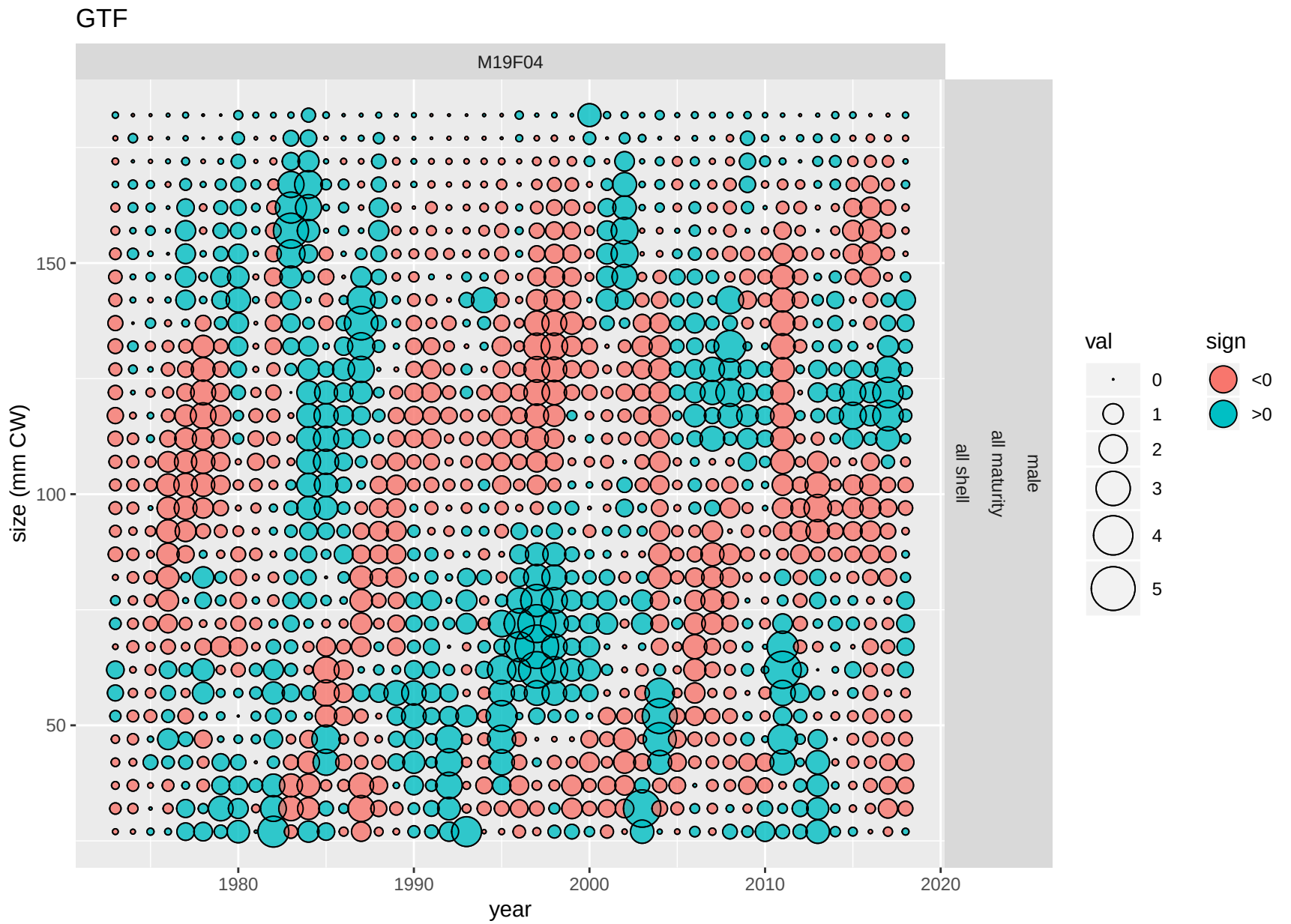


Figure 41: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F04.

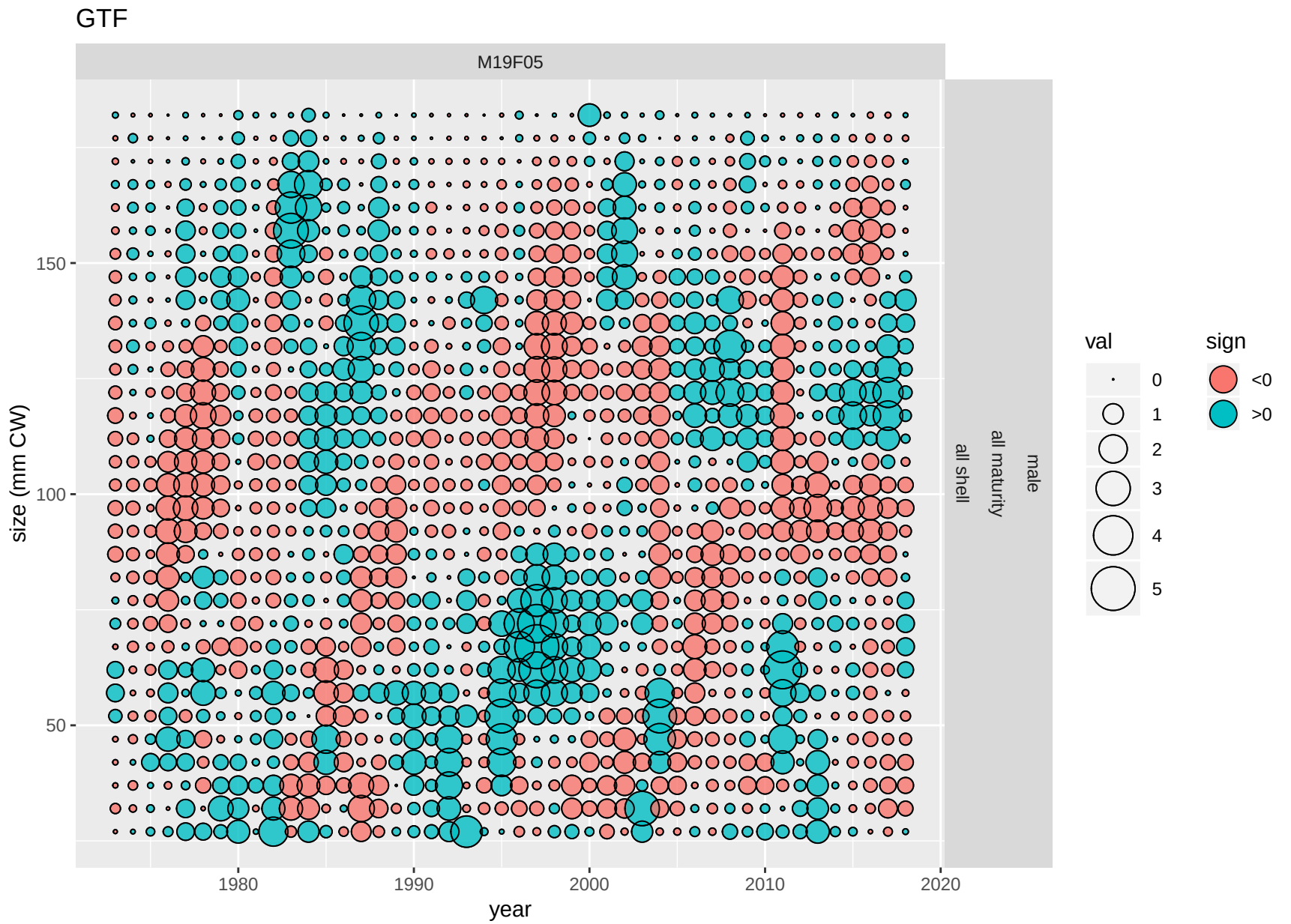


Figure 42: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F05.

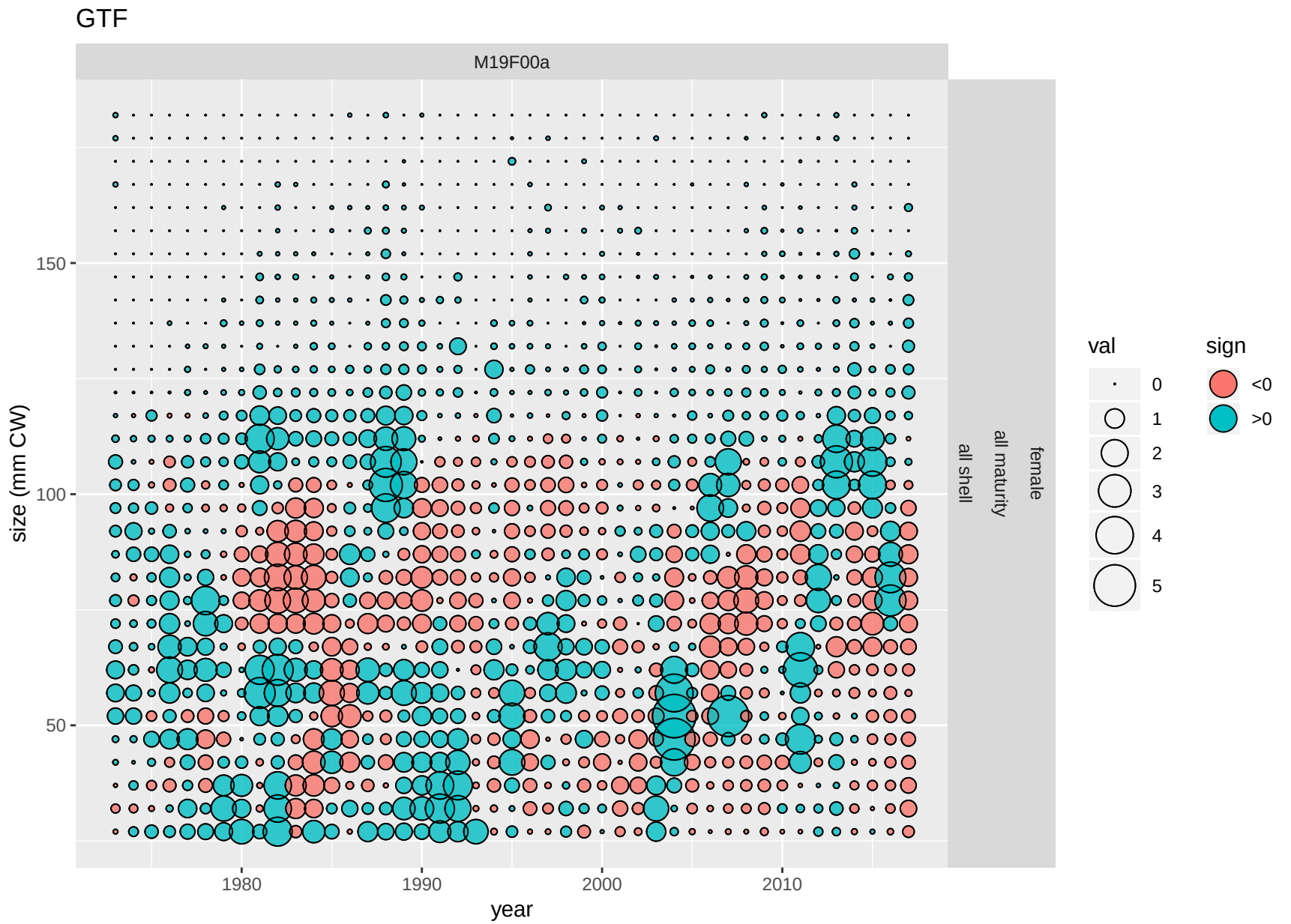


Figure 43: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F00a.

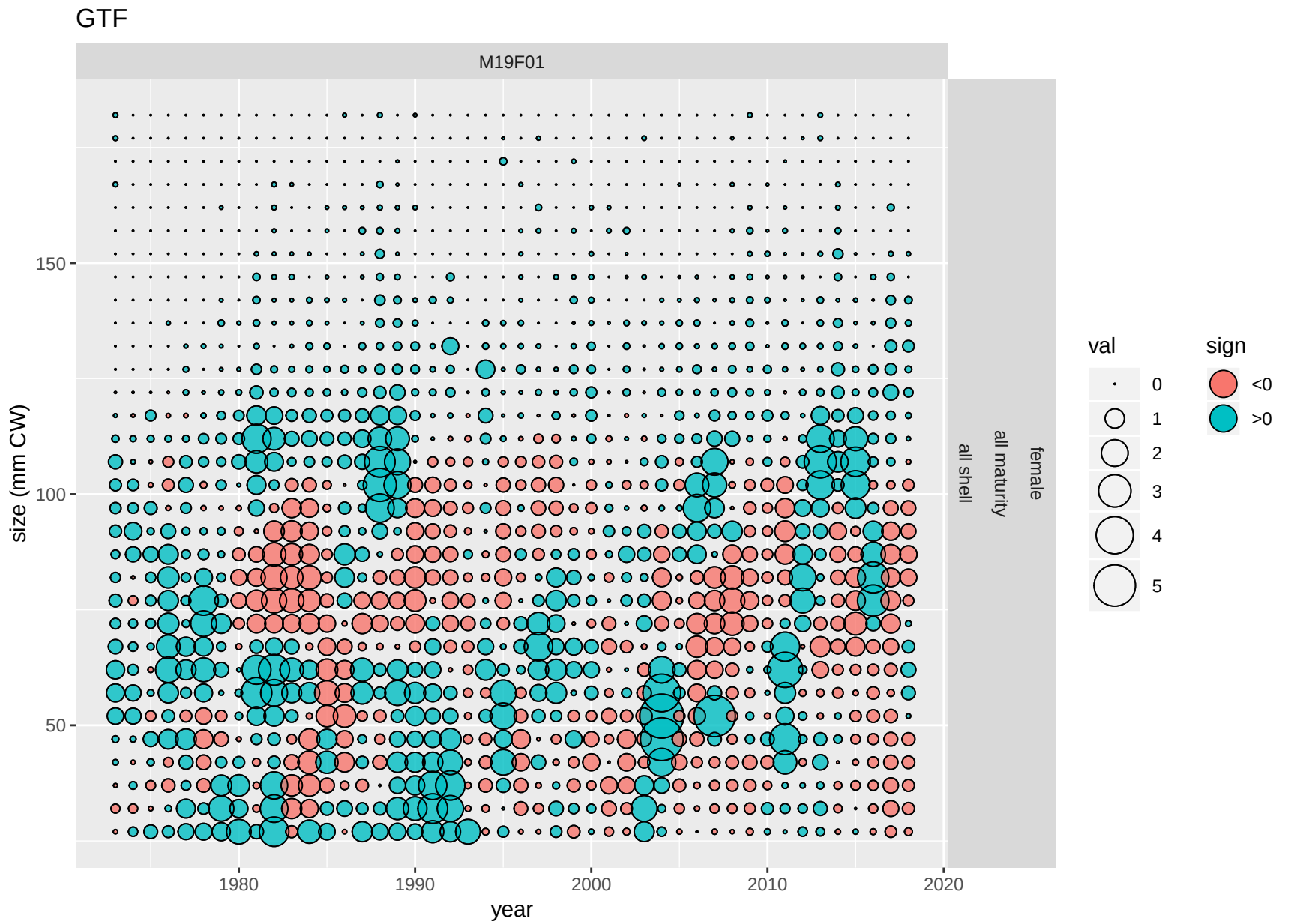


Figure 44: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F01.

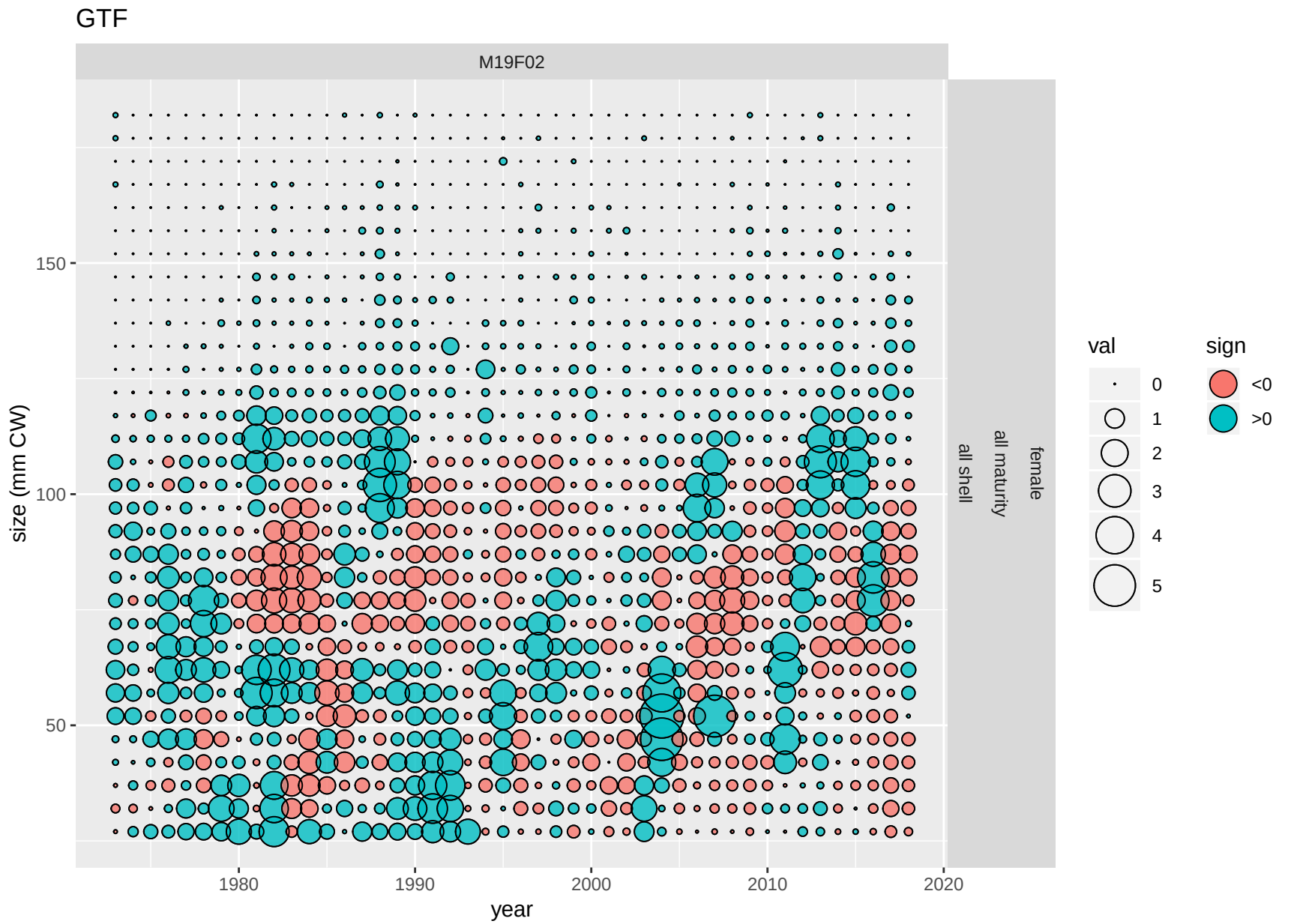


Figure 45: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F02.

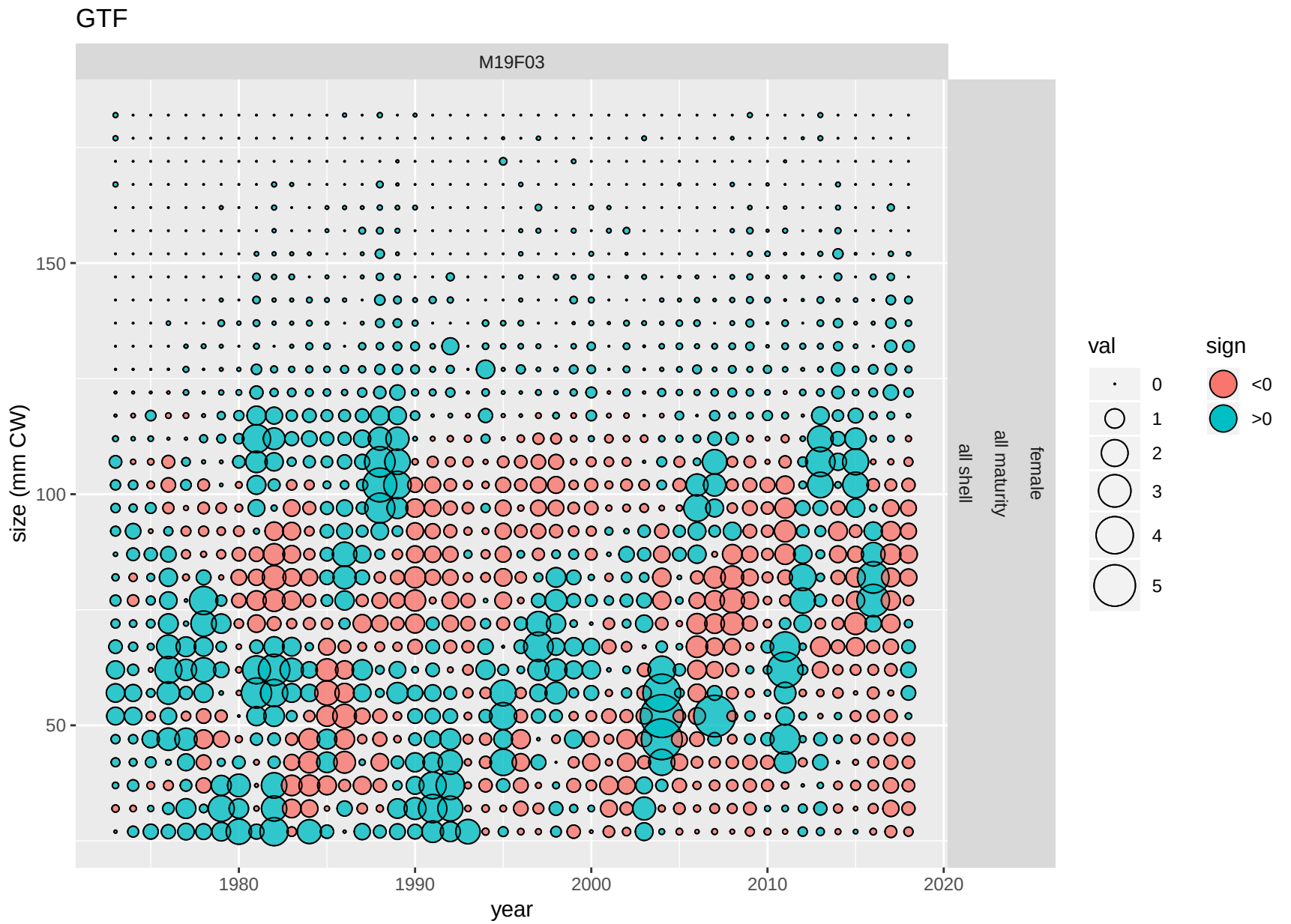


Figure 46: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F03.

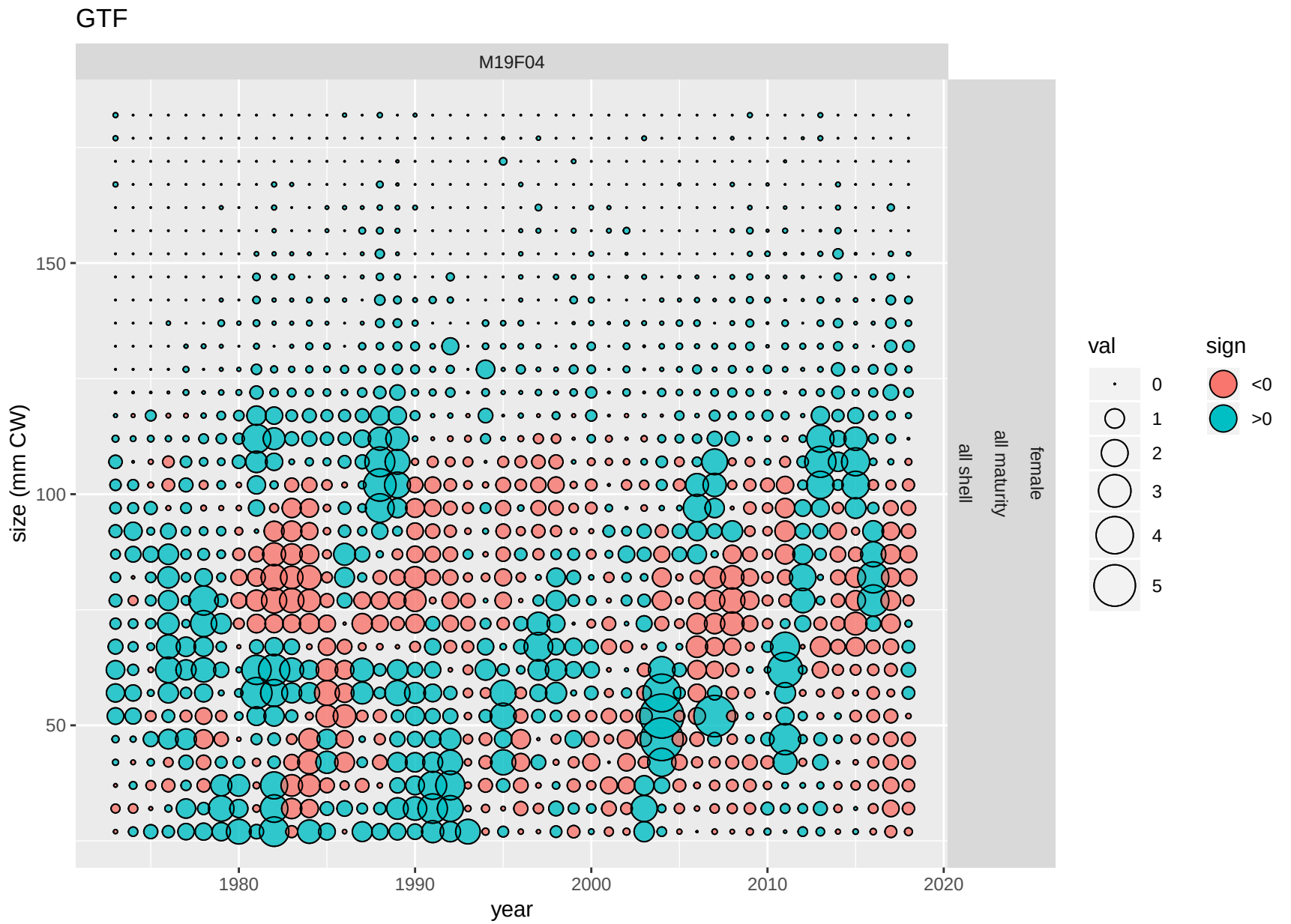


Figure 47: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F04.

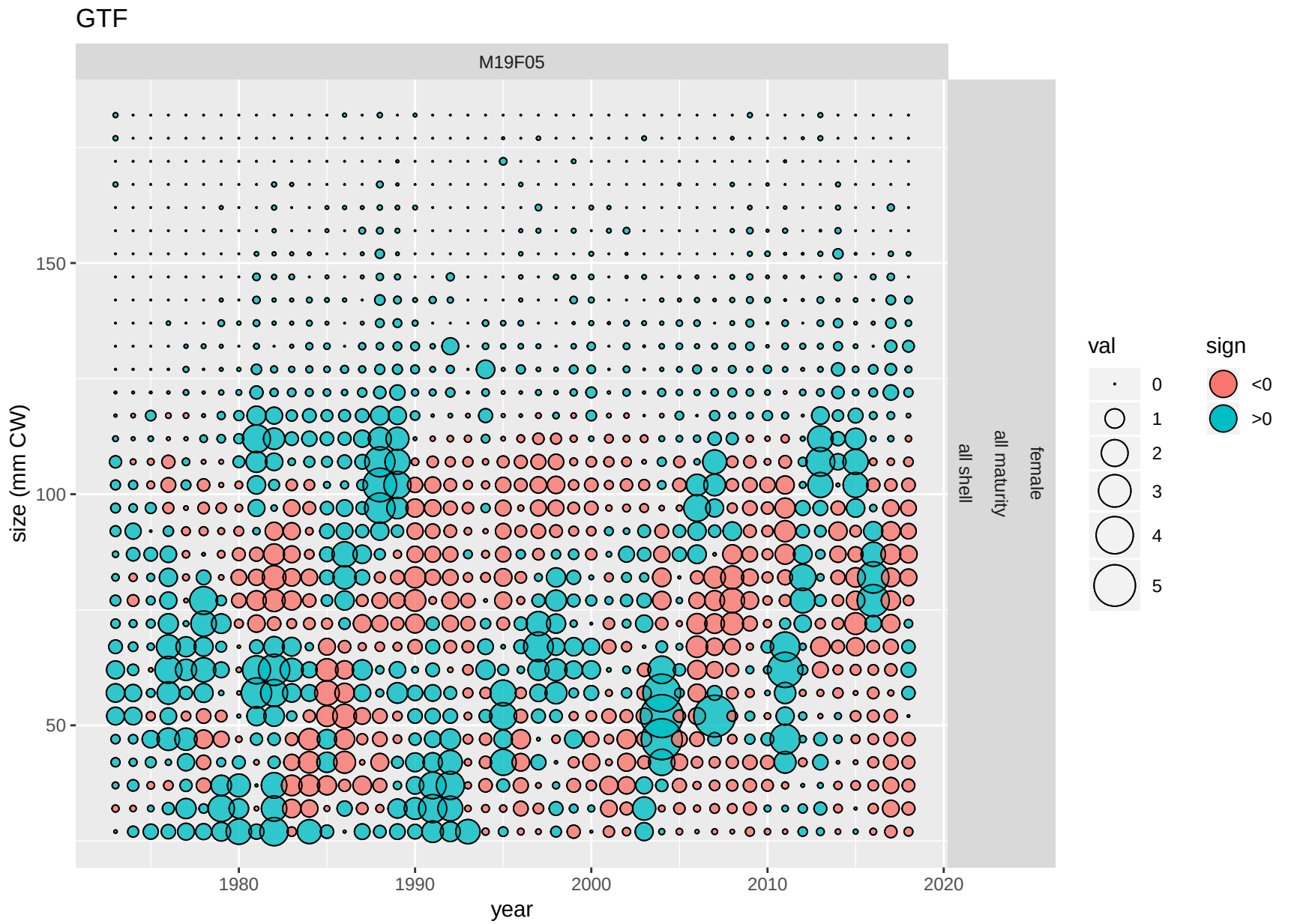


Figure 48: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F05.

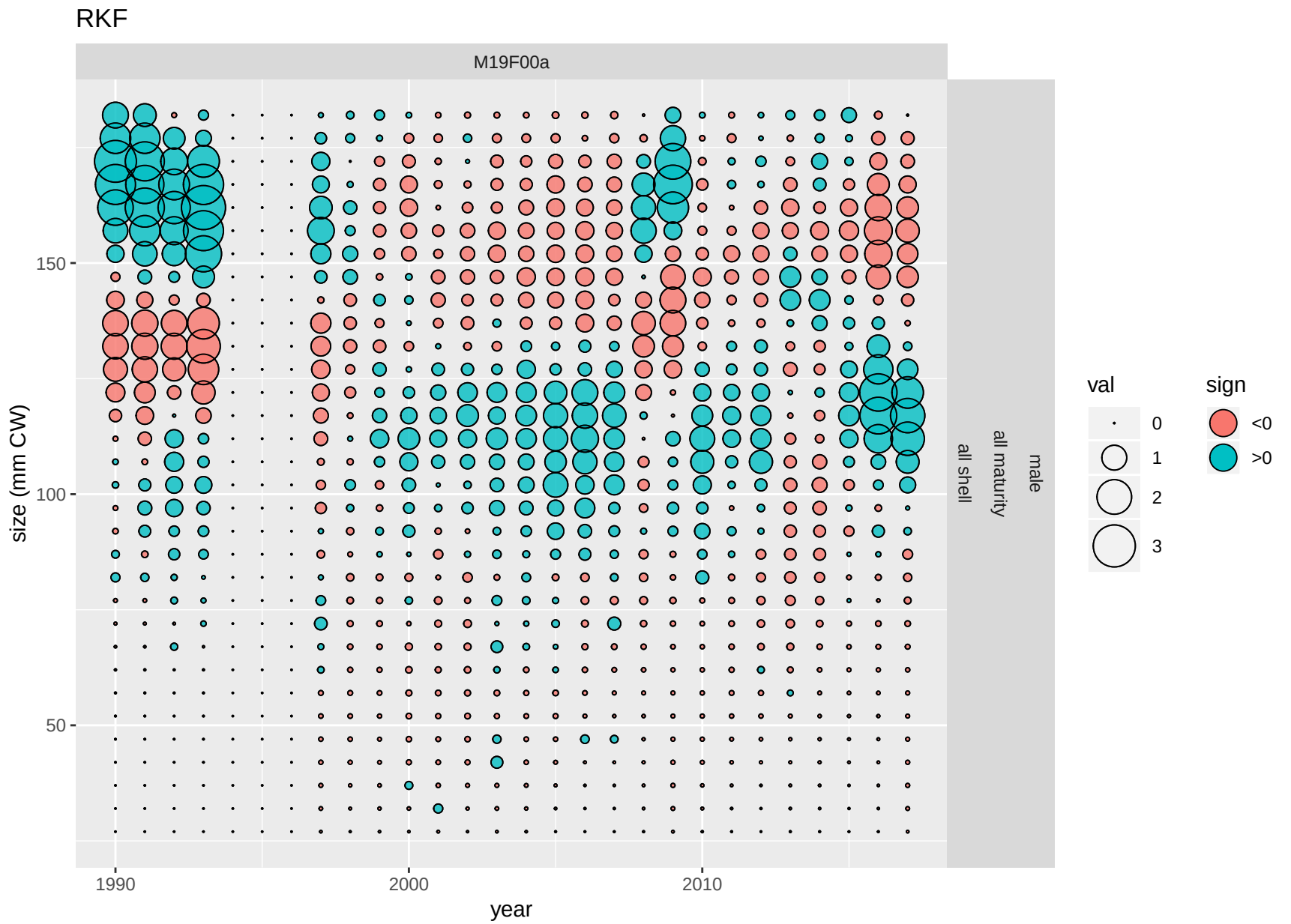


Figure 49: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F00a.

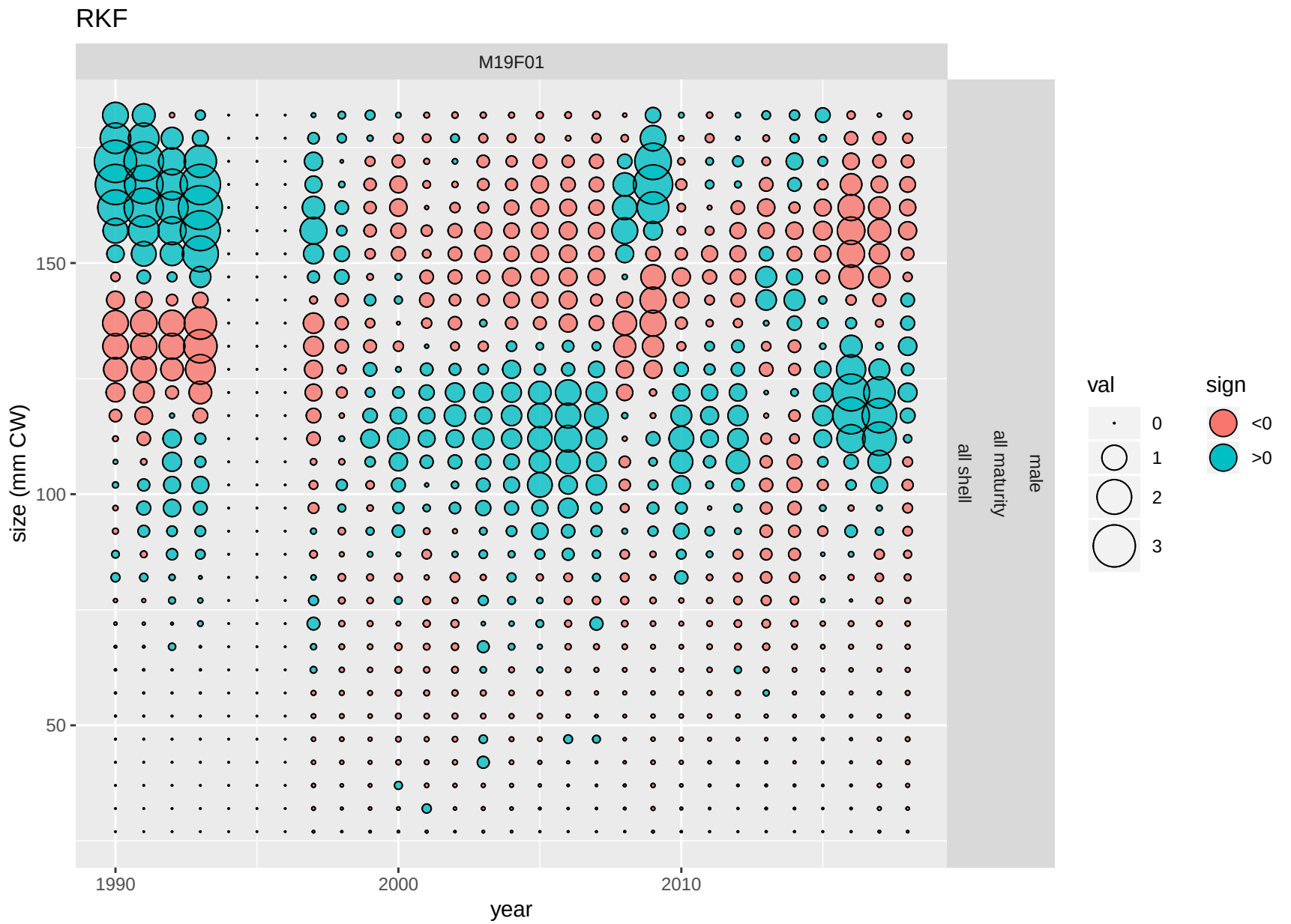


Figure 50: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F01.

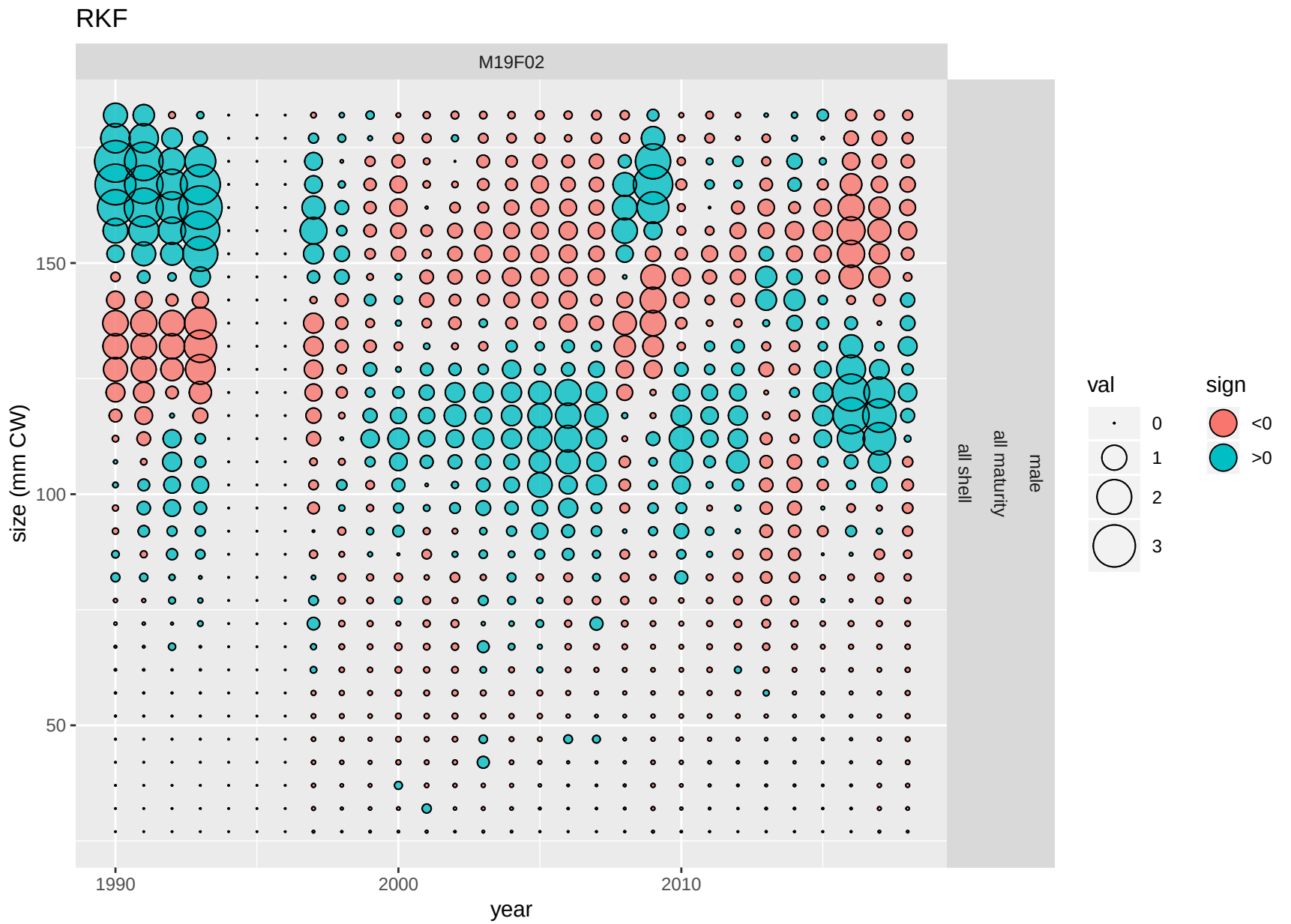


Figure 51: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F02.

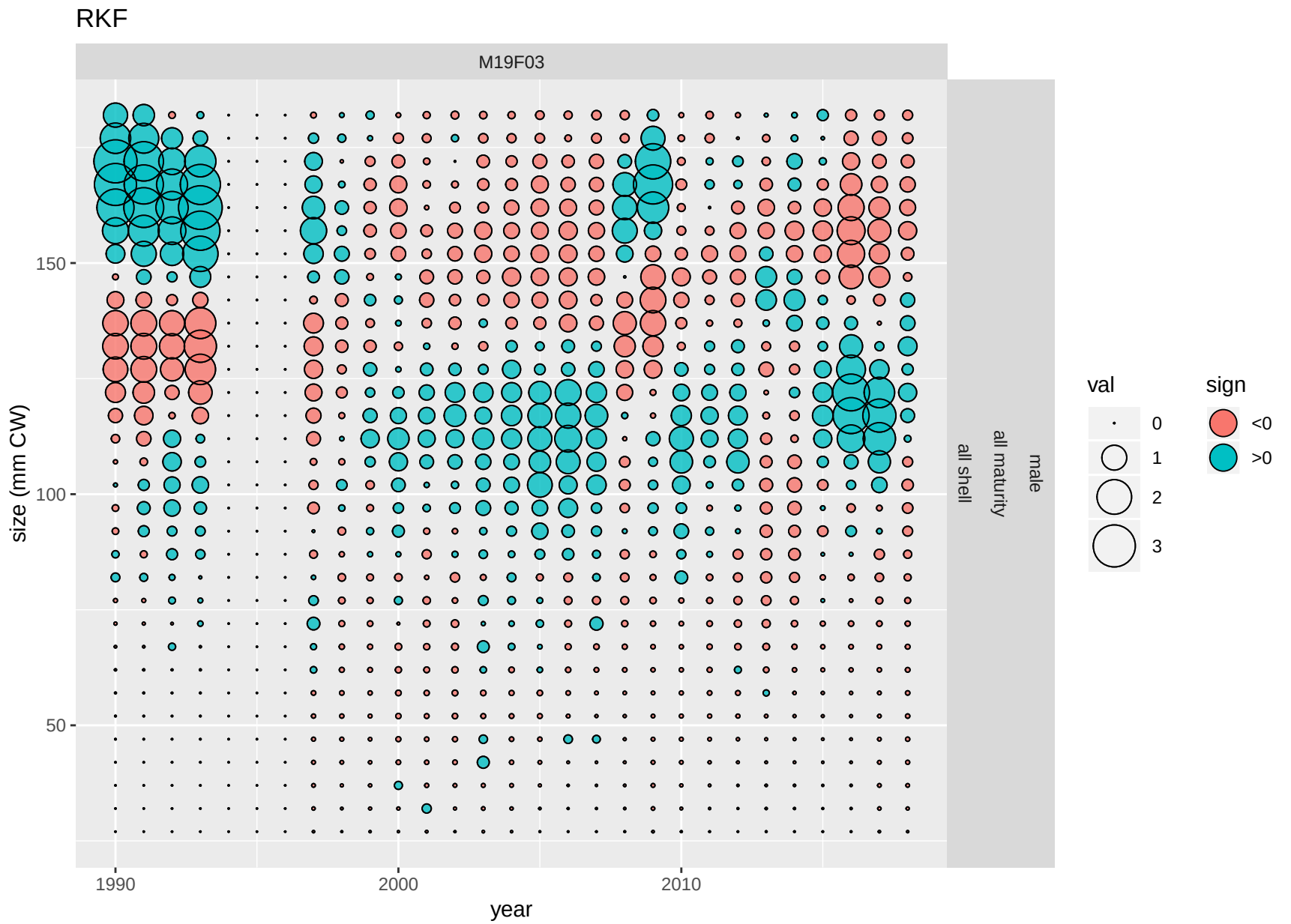


Figure 52: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F03.

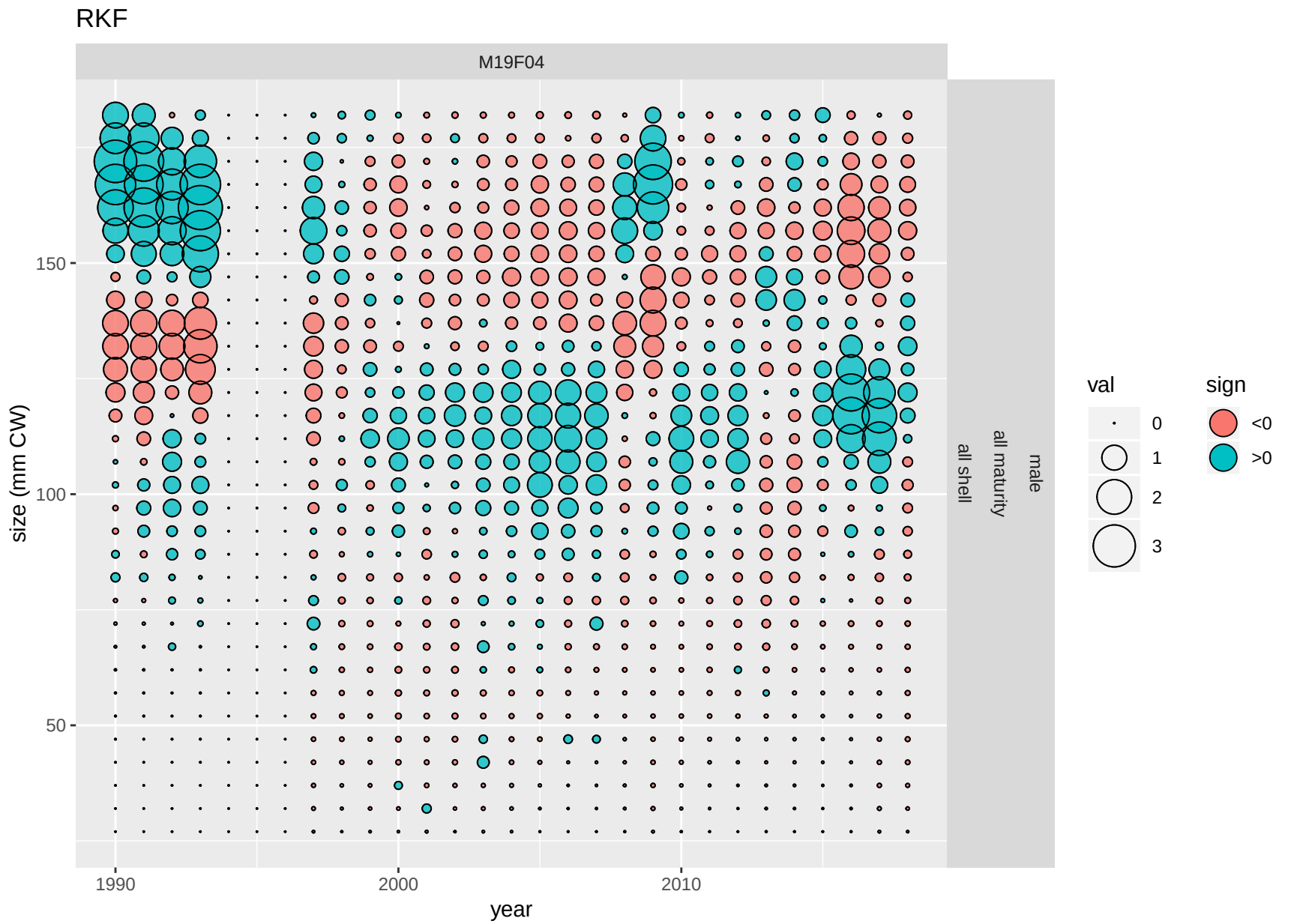


Figure 53: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F04.

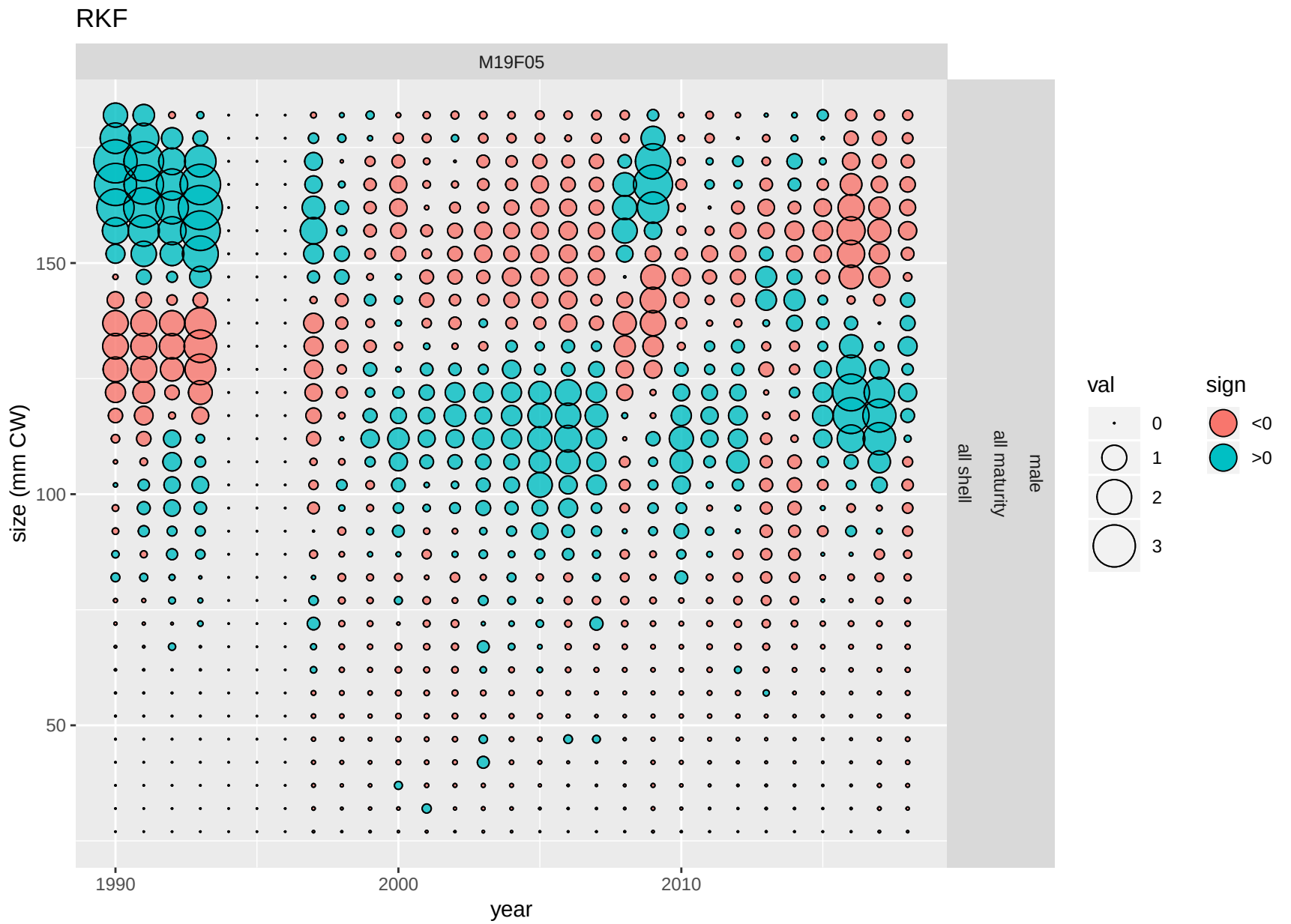


Figure 54: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F05.

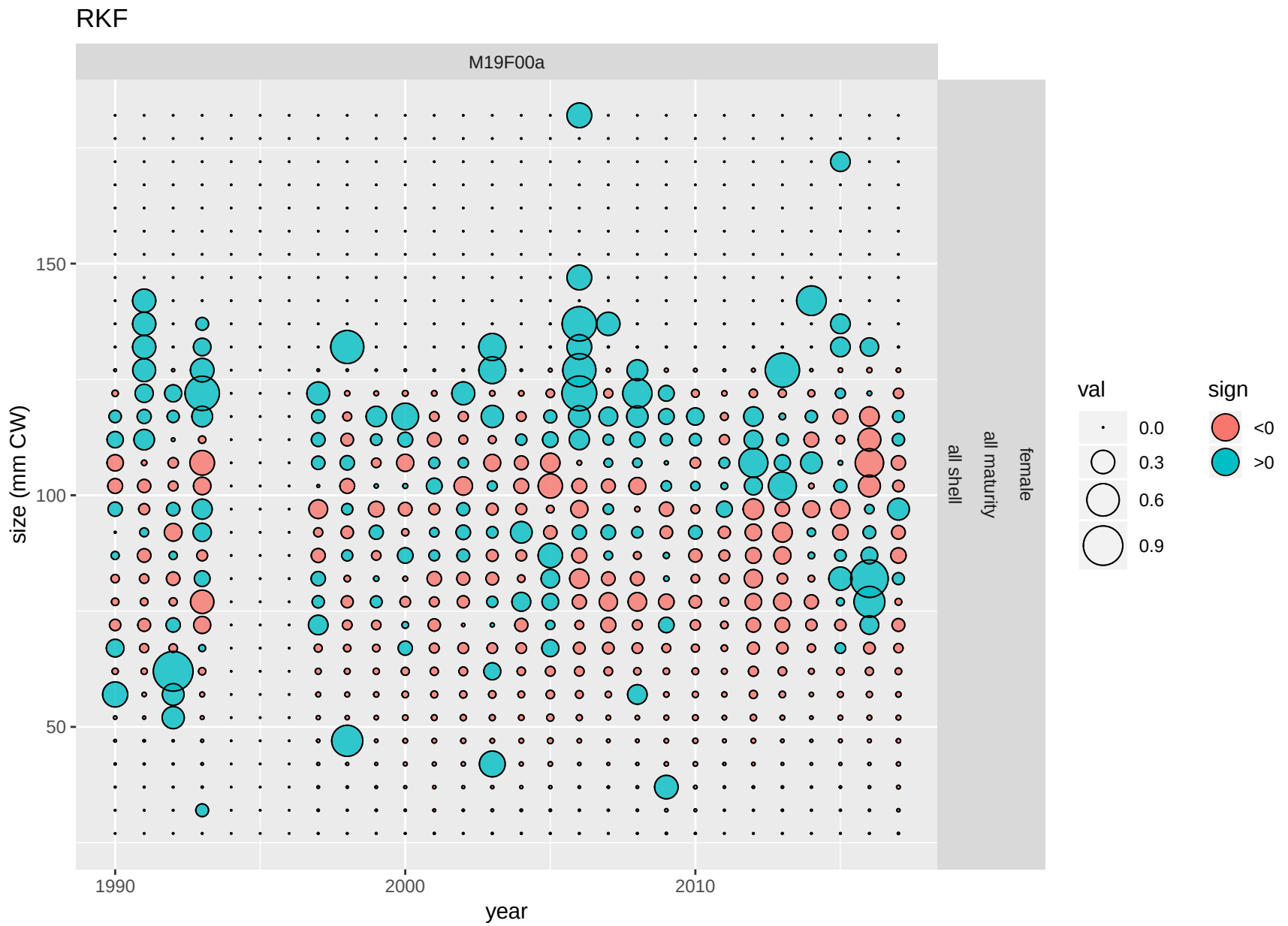


Figure 55: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F00a.

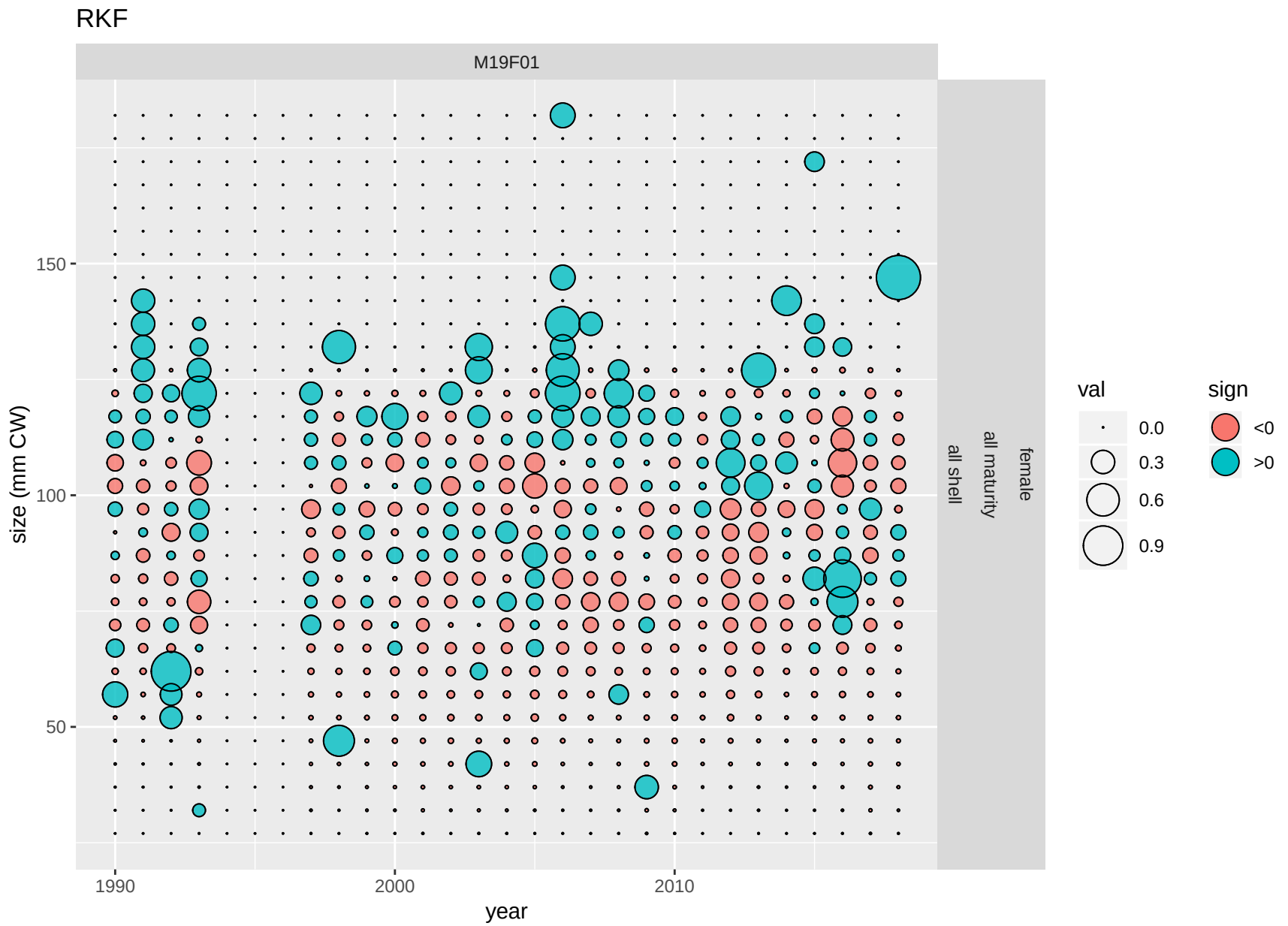


Figure 56: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F01.

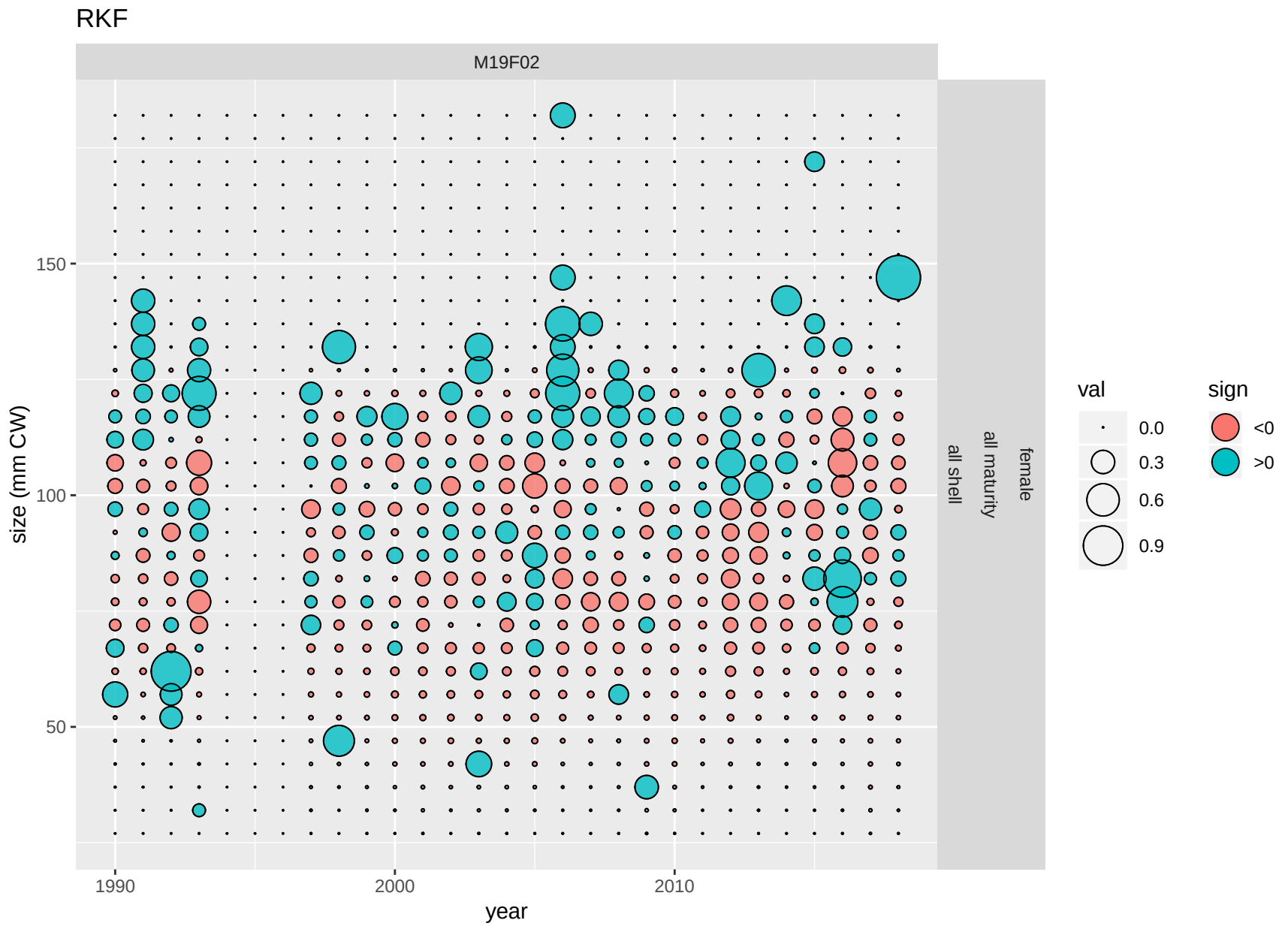


Figure 57: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F02.

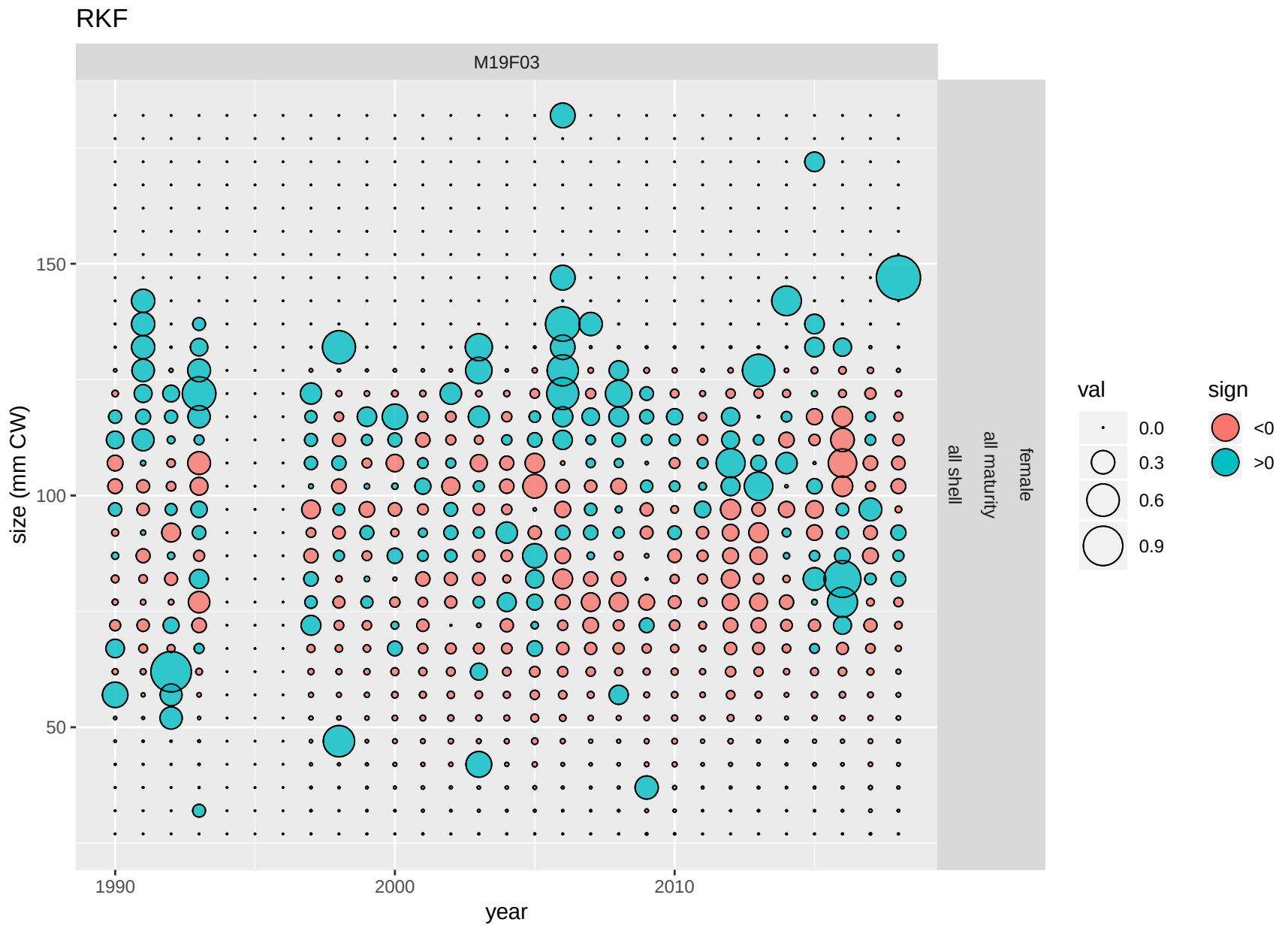


Figure 58: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F03.

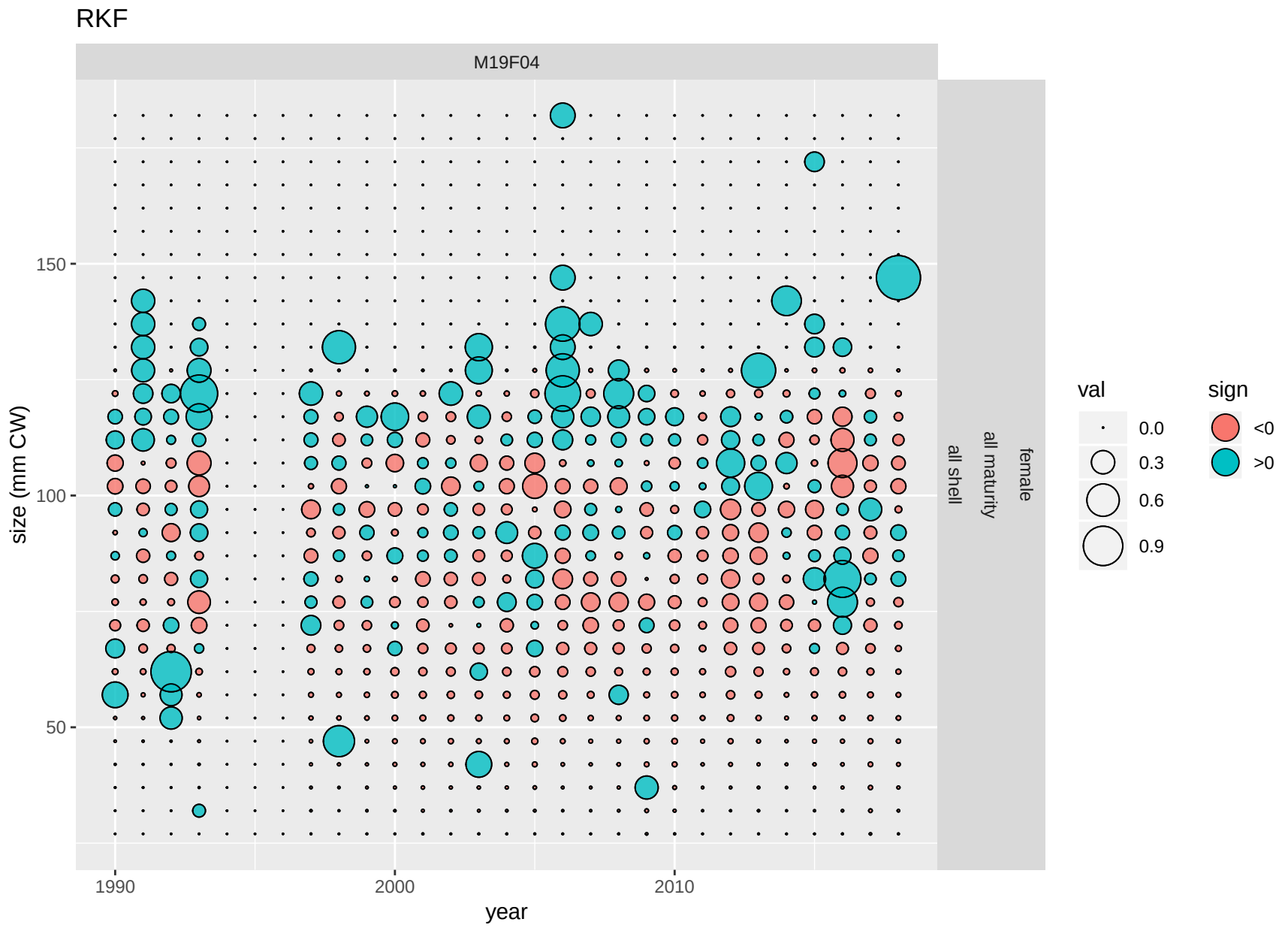


Figure 59: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F04.

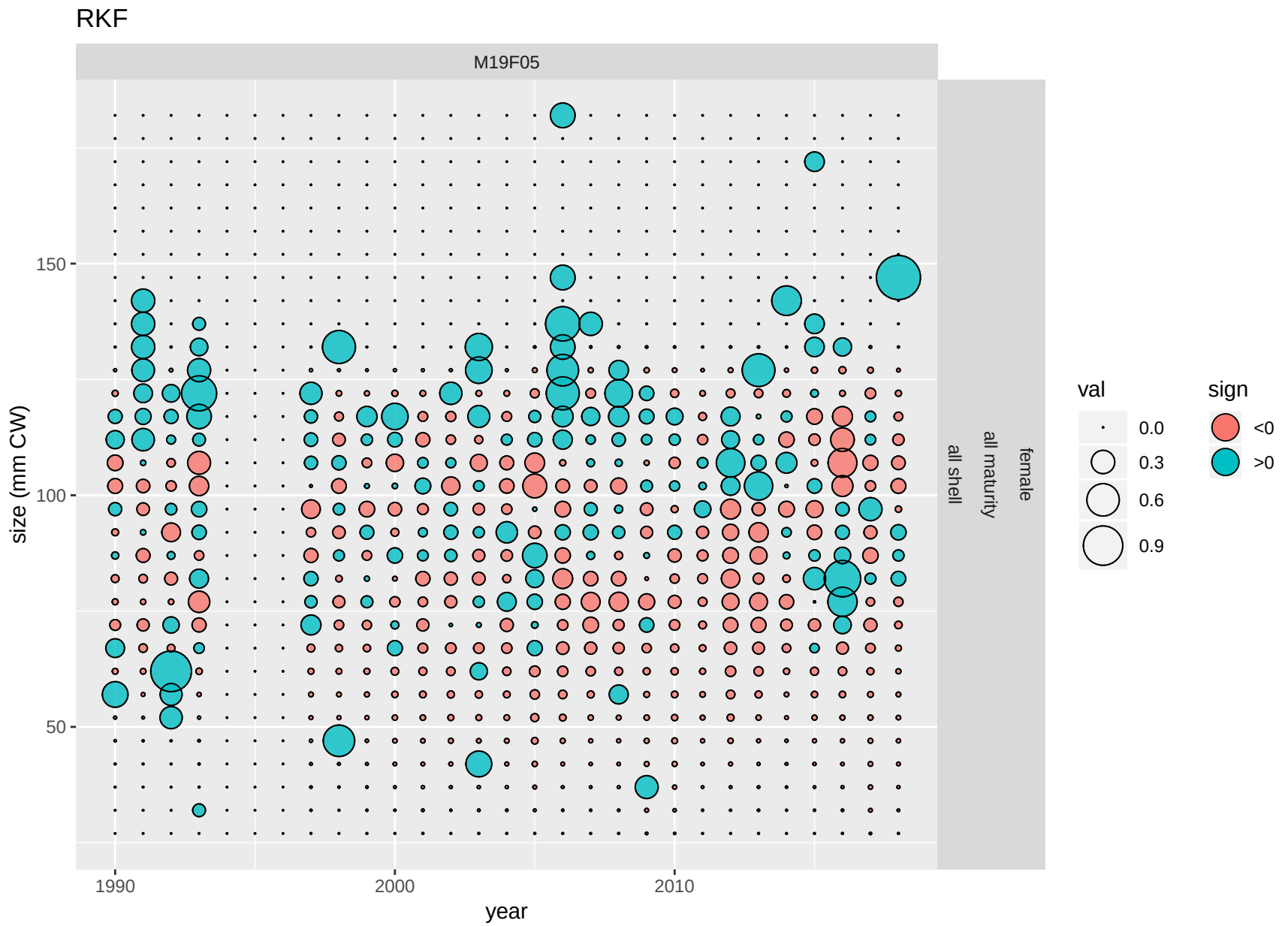


Figure 60: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F05.

Effective Ns for total catch size compositions

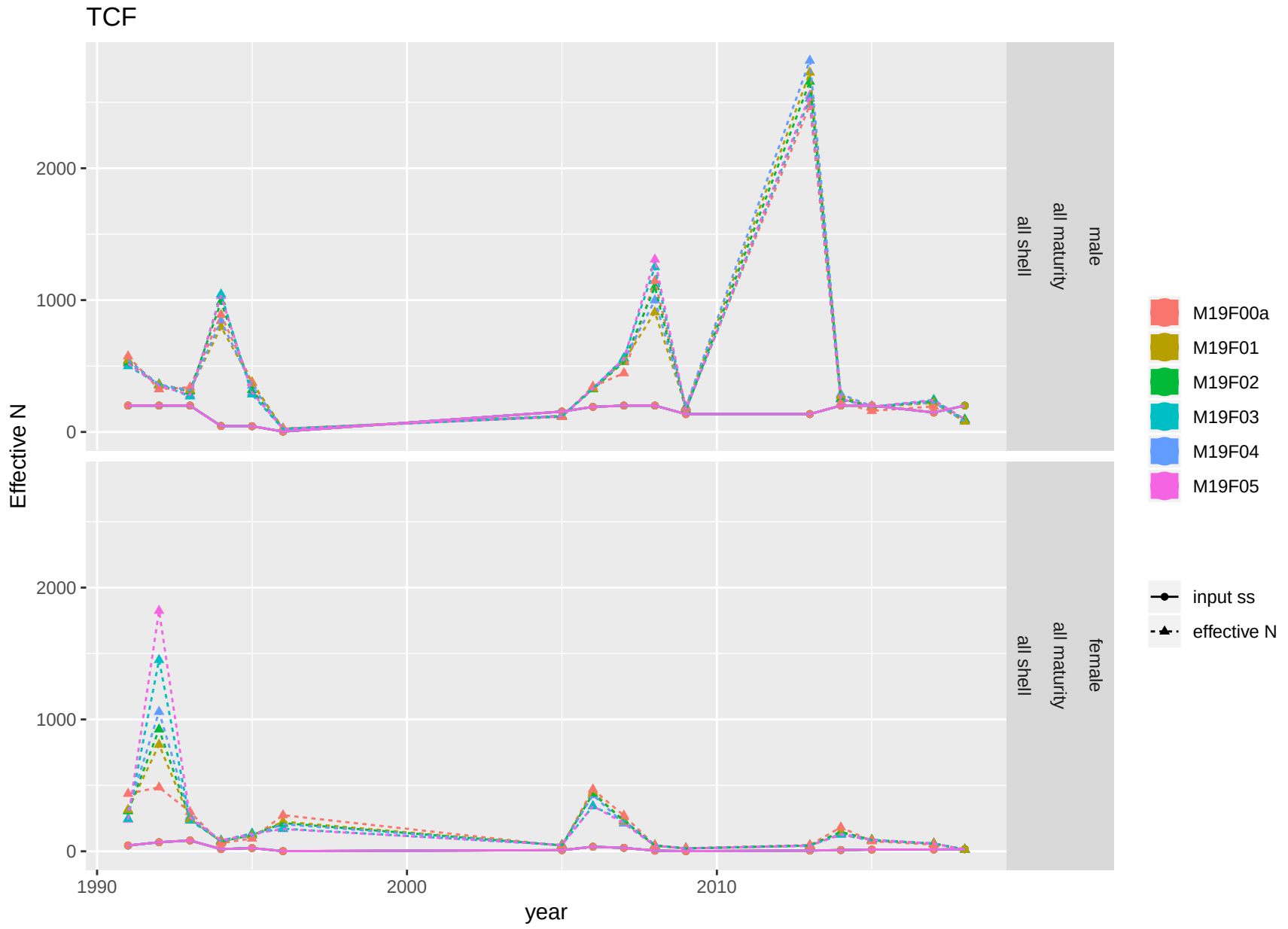


Figure 61: Input and effective sample sizes from total catch size compositions from the TCF fishery.

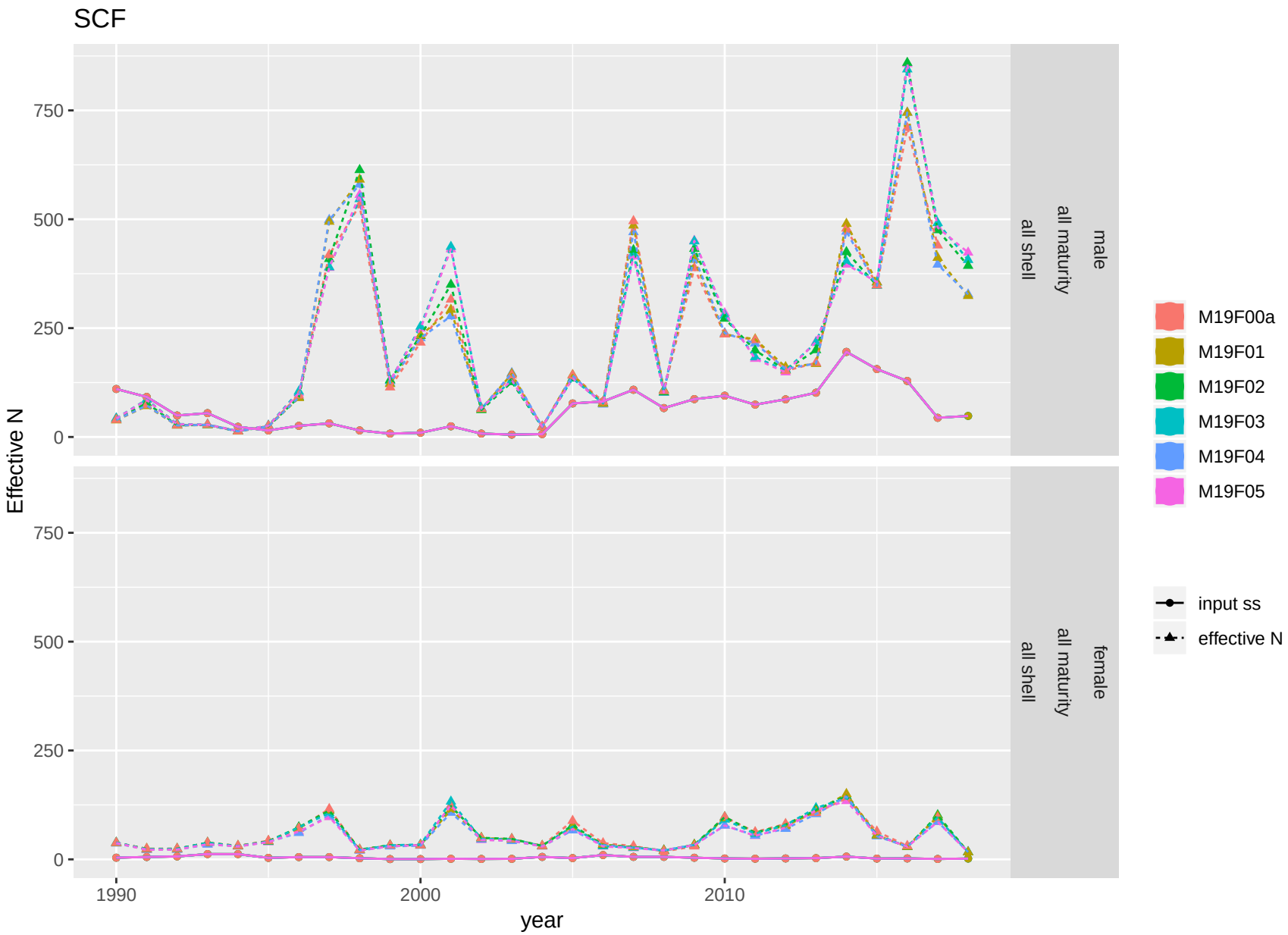


Figure 62: Input and effective sample sizes from total catch size compositions from the SCF fishery.

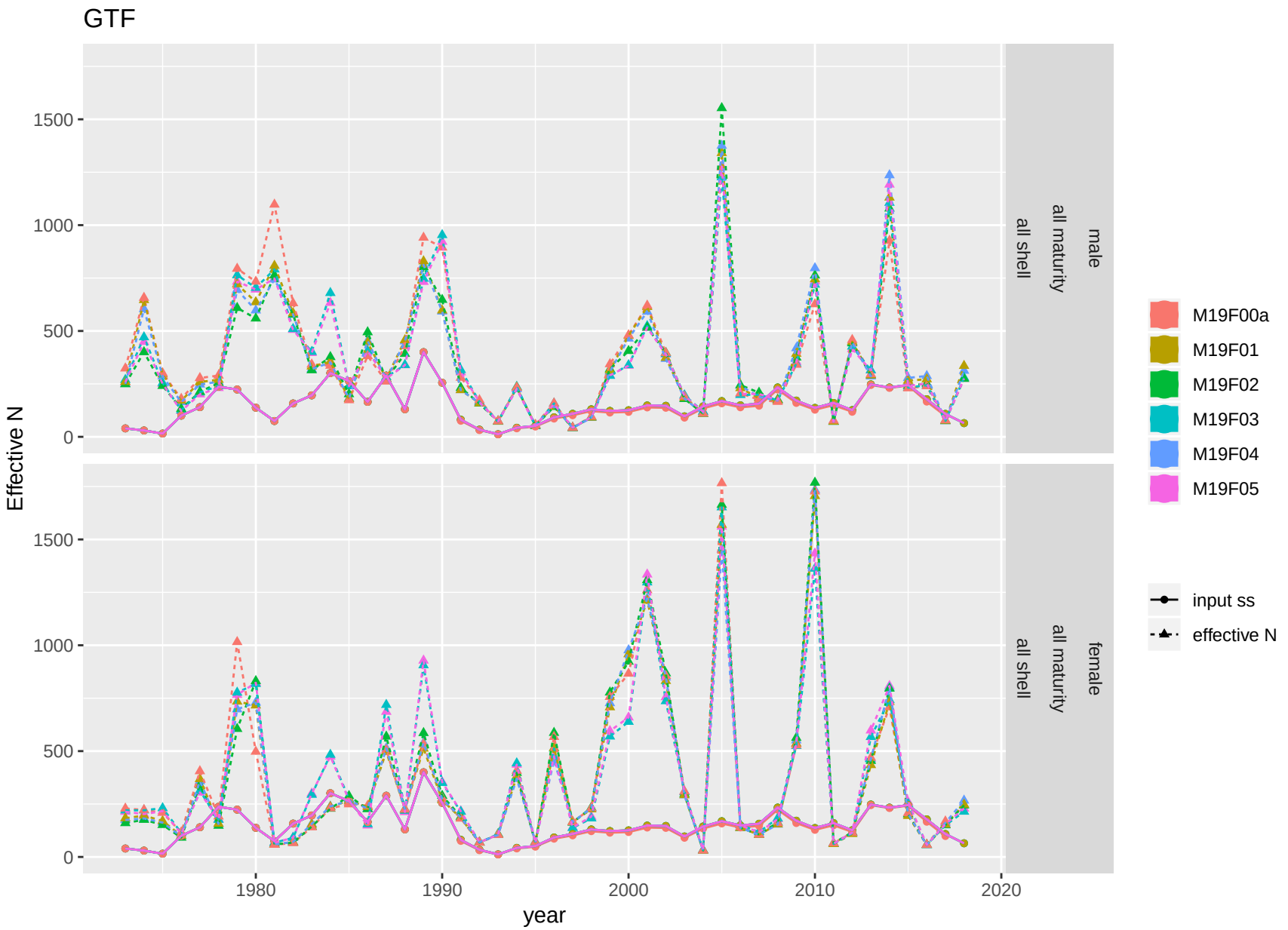


Figure 63: Input and effective sample sizes from total catch size compositions from the GTF fishery.

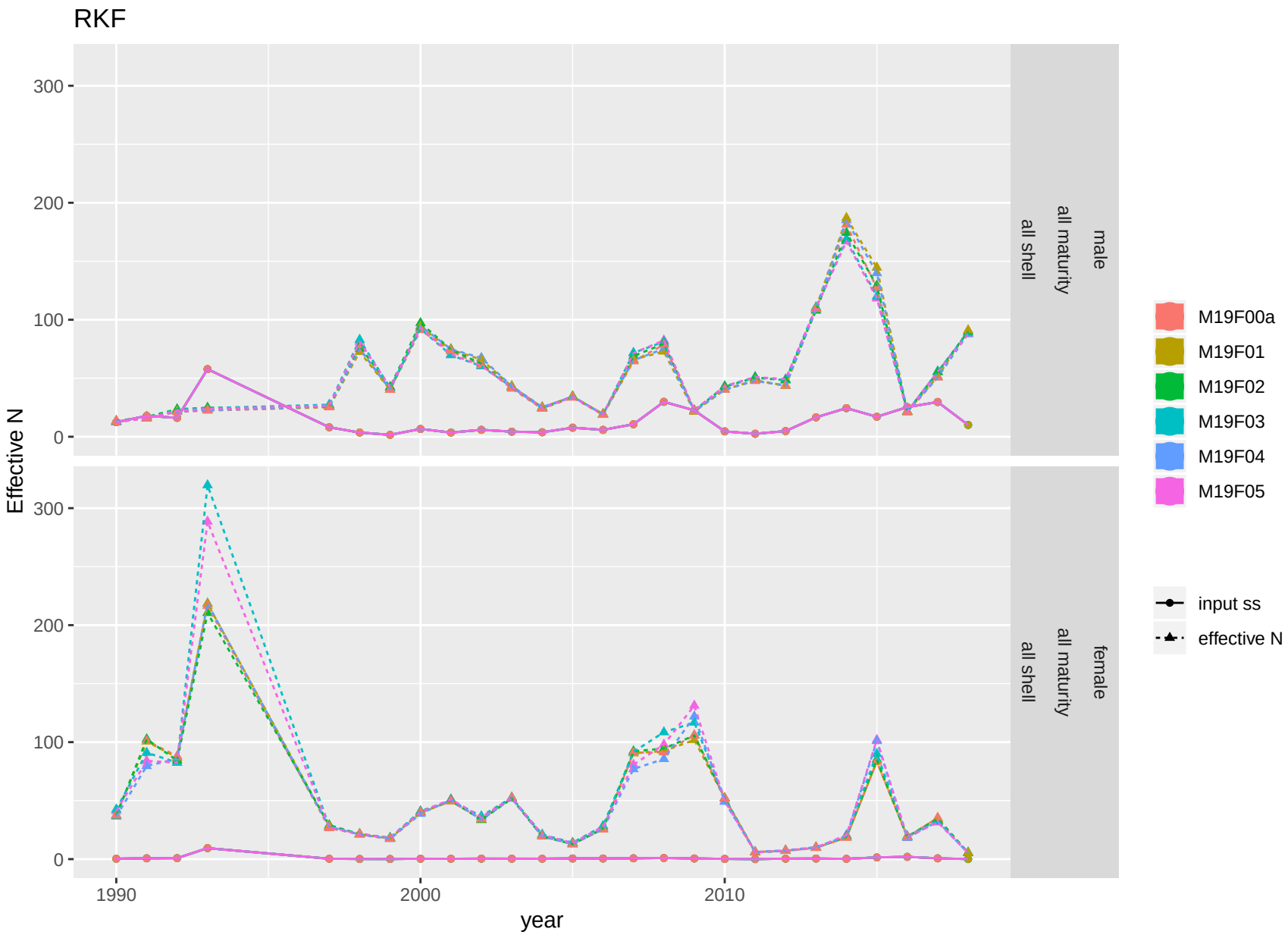


Figure 64: Input and effective sample sizes from total catch size compositions from the RKF fishery.

Model Comparisons: Fits to Surveys Size Composition Data – M19F00a vs M19F01 vs M19F02 vs M19F03 vs M19F04 vs M19F05

William Stockhausen

07 September, 2019

Contents

Introduction **1**

Mean survey size compositions **2**

Residuals to survey size composition data **10**

Effective sample sizes for survey size compositions **42**

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

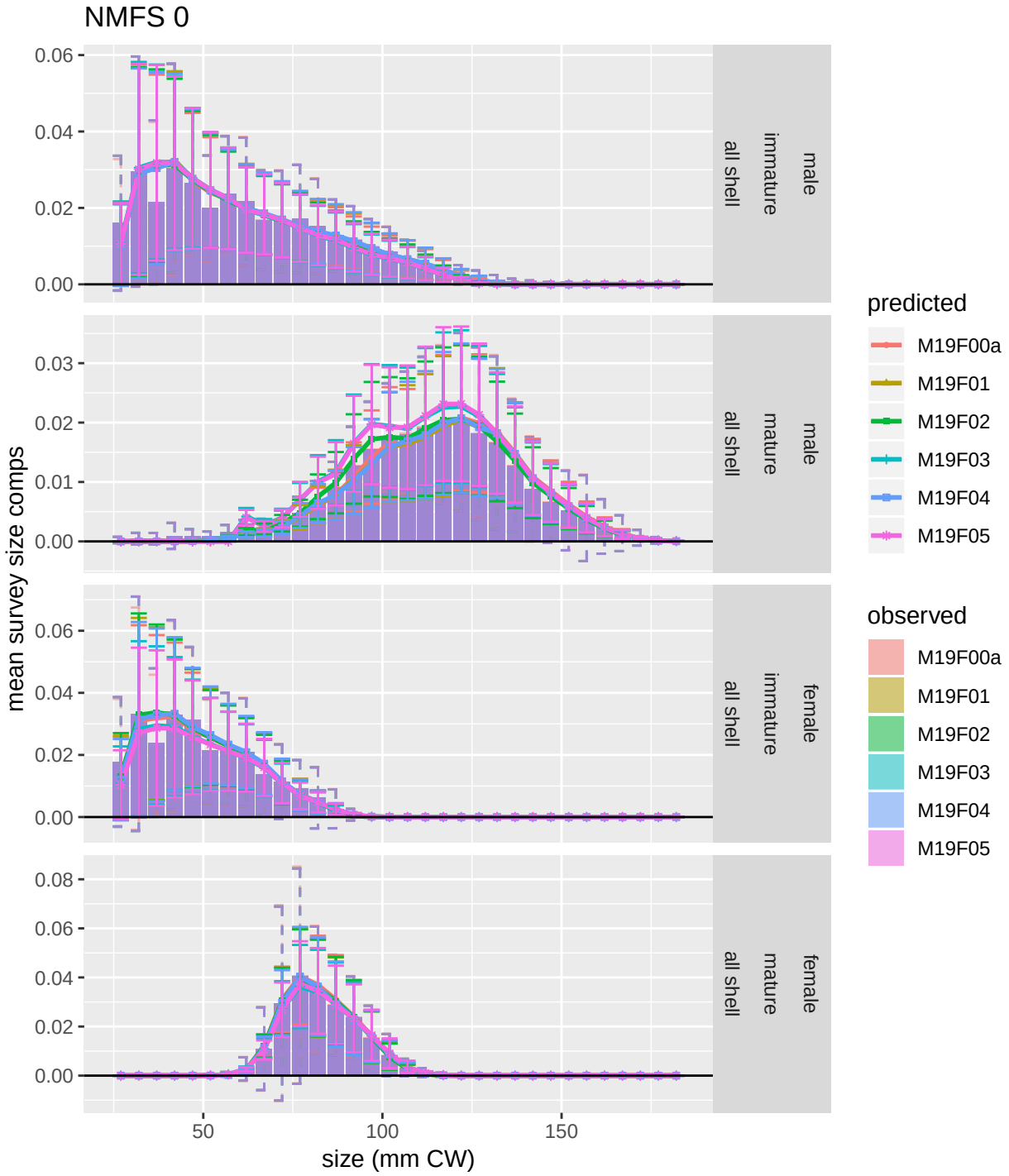


Figure 1: Comparison of observed and predicted mean survey size comps for NMFS 0.

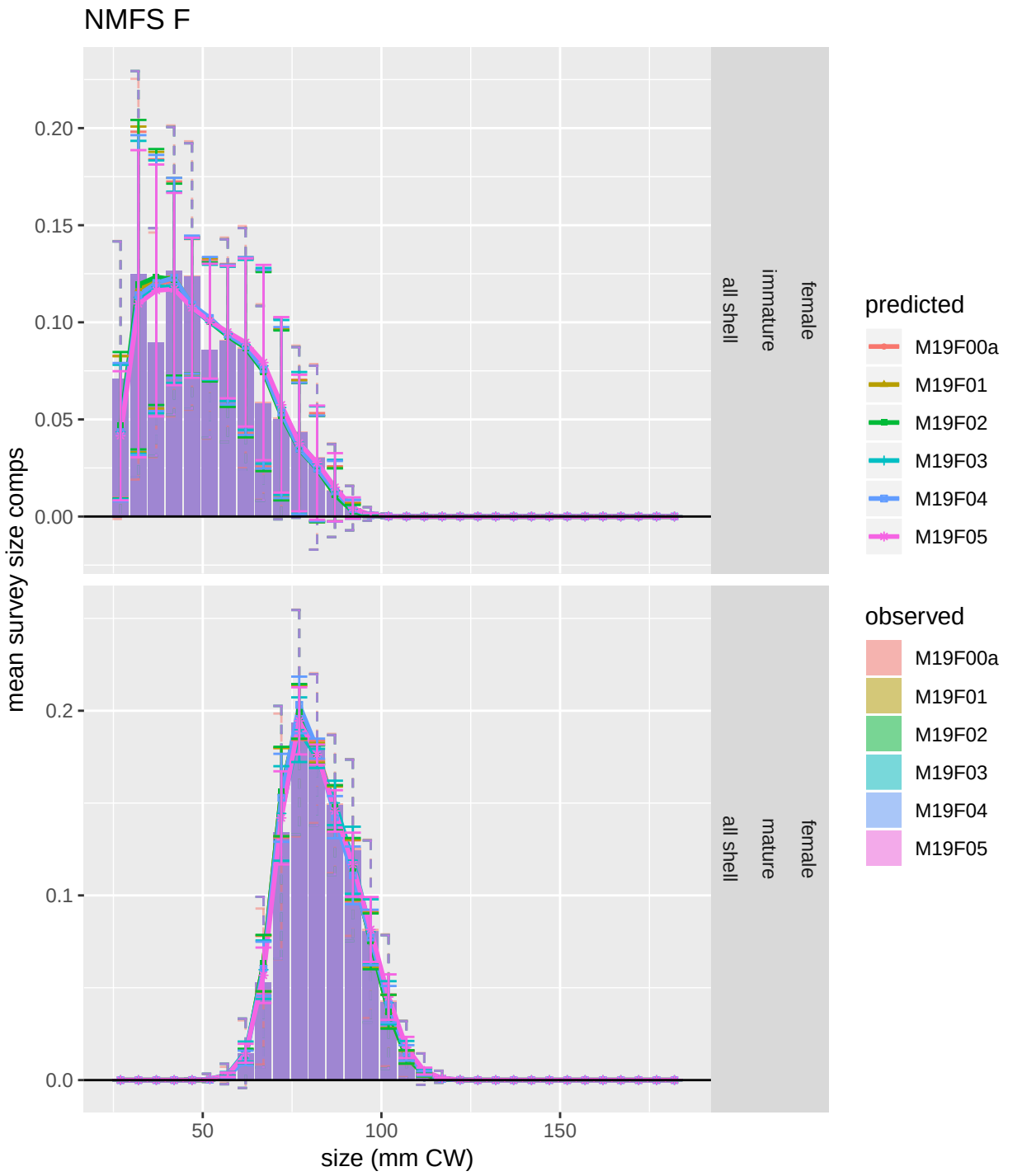


Figure 2: Comparison of observed and predicted mean survey size comps for NMFS F.

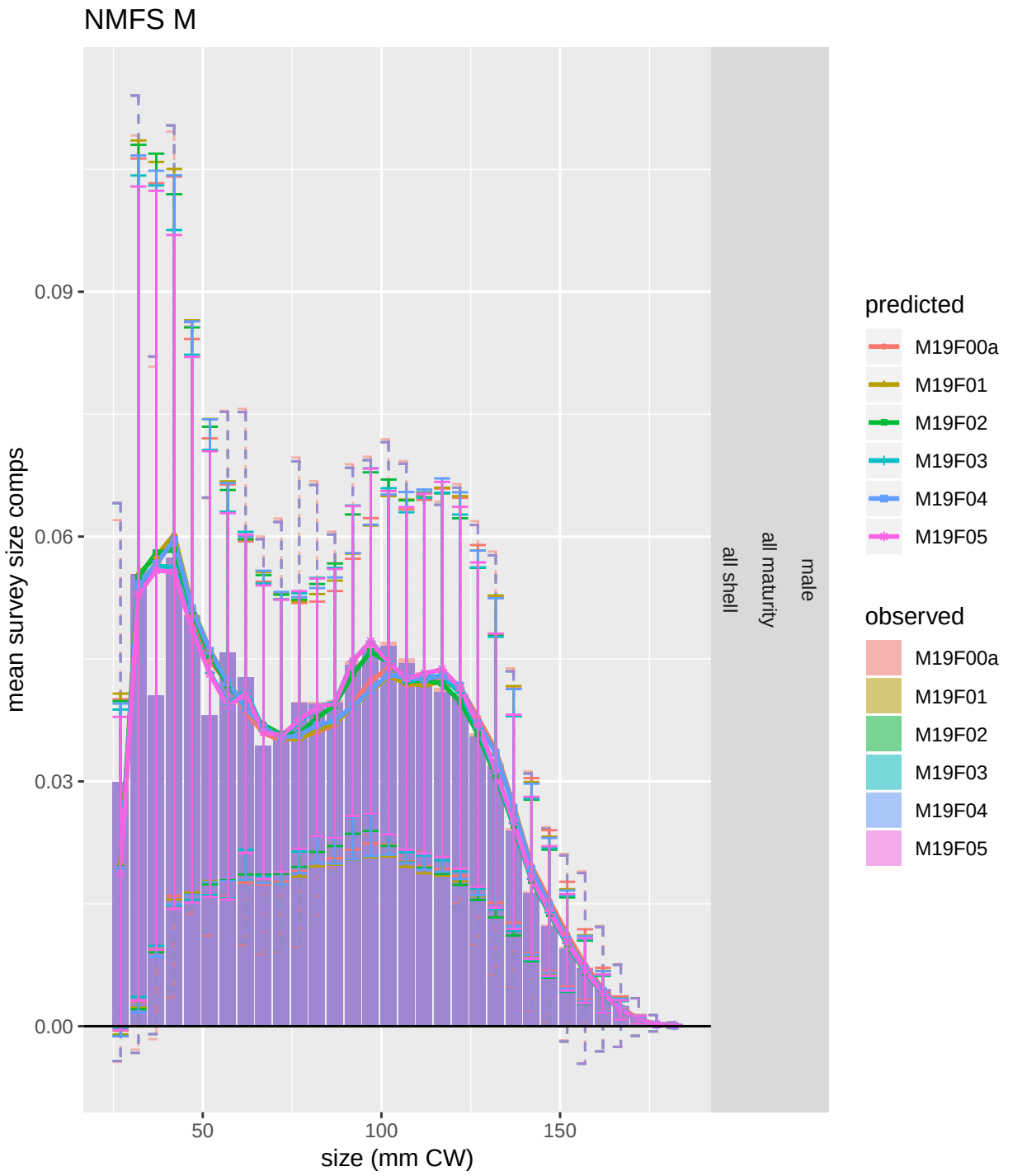


Figure 3: Comparison of observed and predicted mean survey size comps for NMFS M.

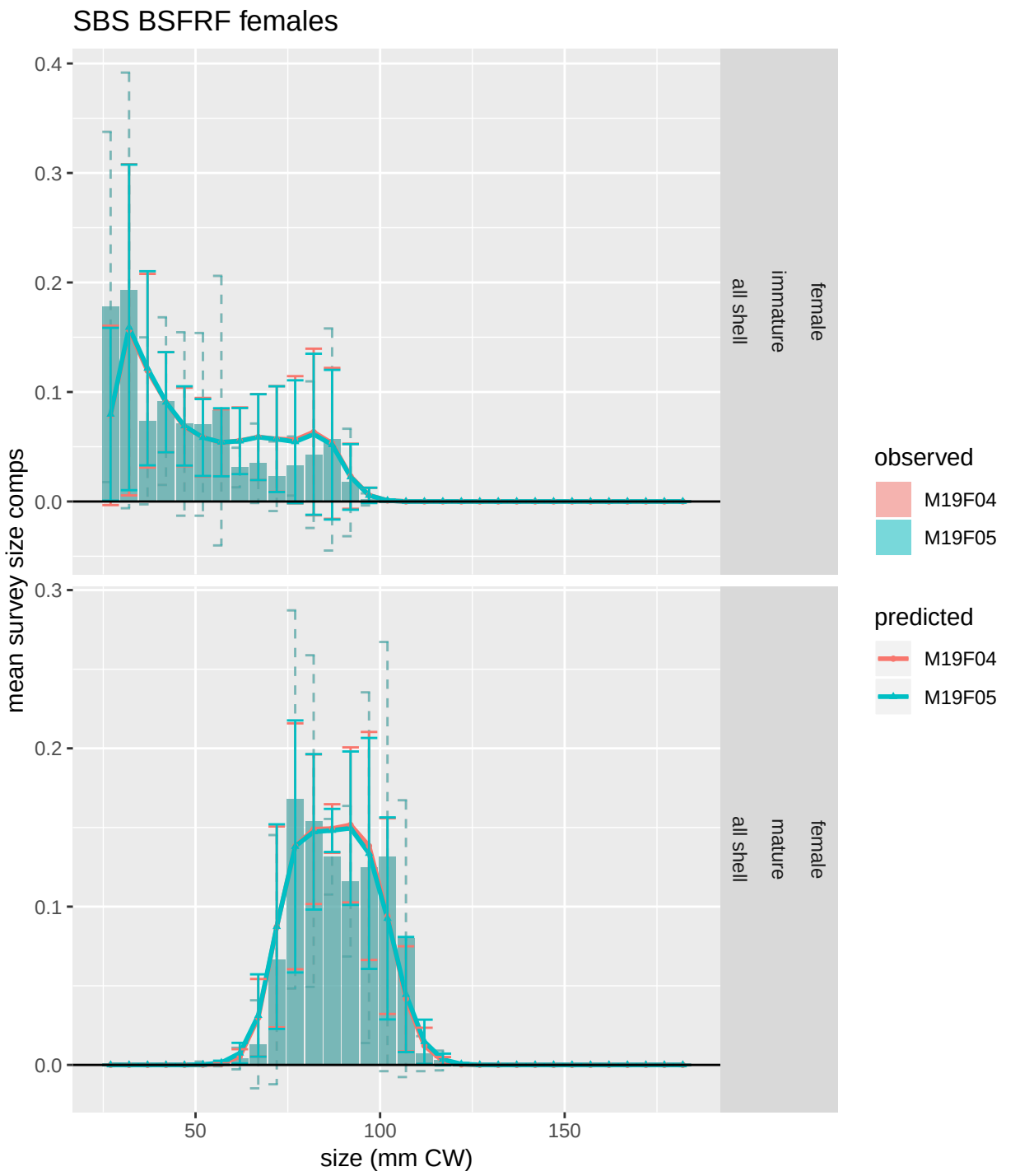


Figure 4: Comparison of observed and predicted mean survey size comps for SBS BSFRF females.

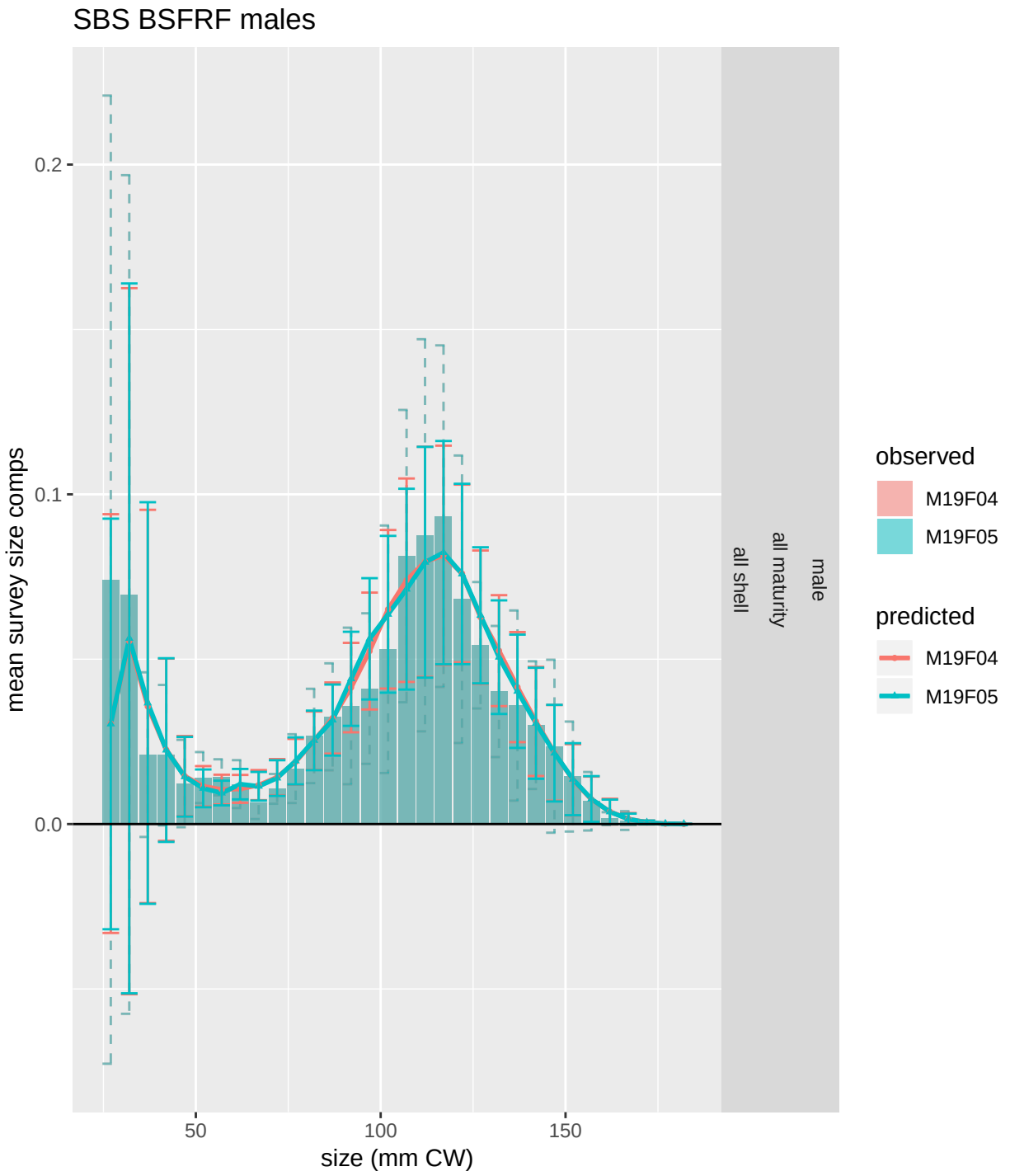


Figure 5: Comparison of observed and predicted mean survey size comps for SBS BSFRF males.

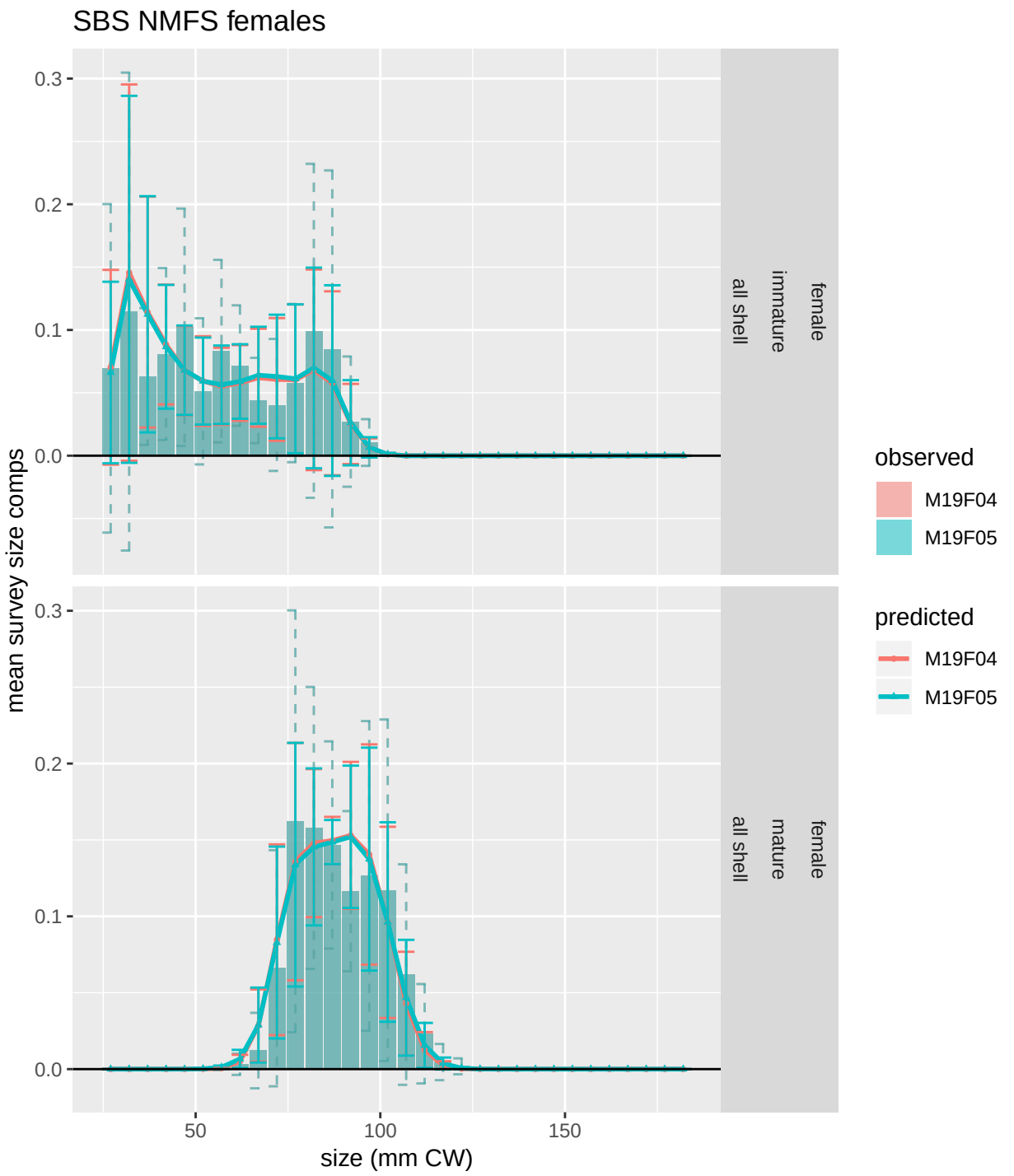


Figure 6: Comparison of observed and predicted mean survey size comps for SBS NMFS females.

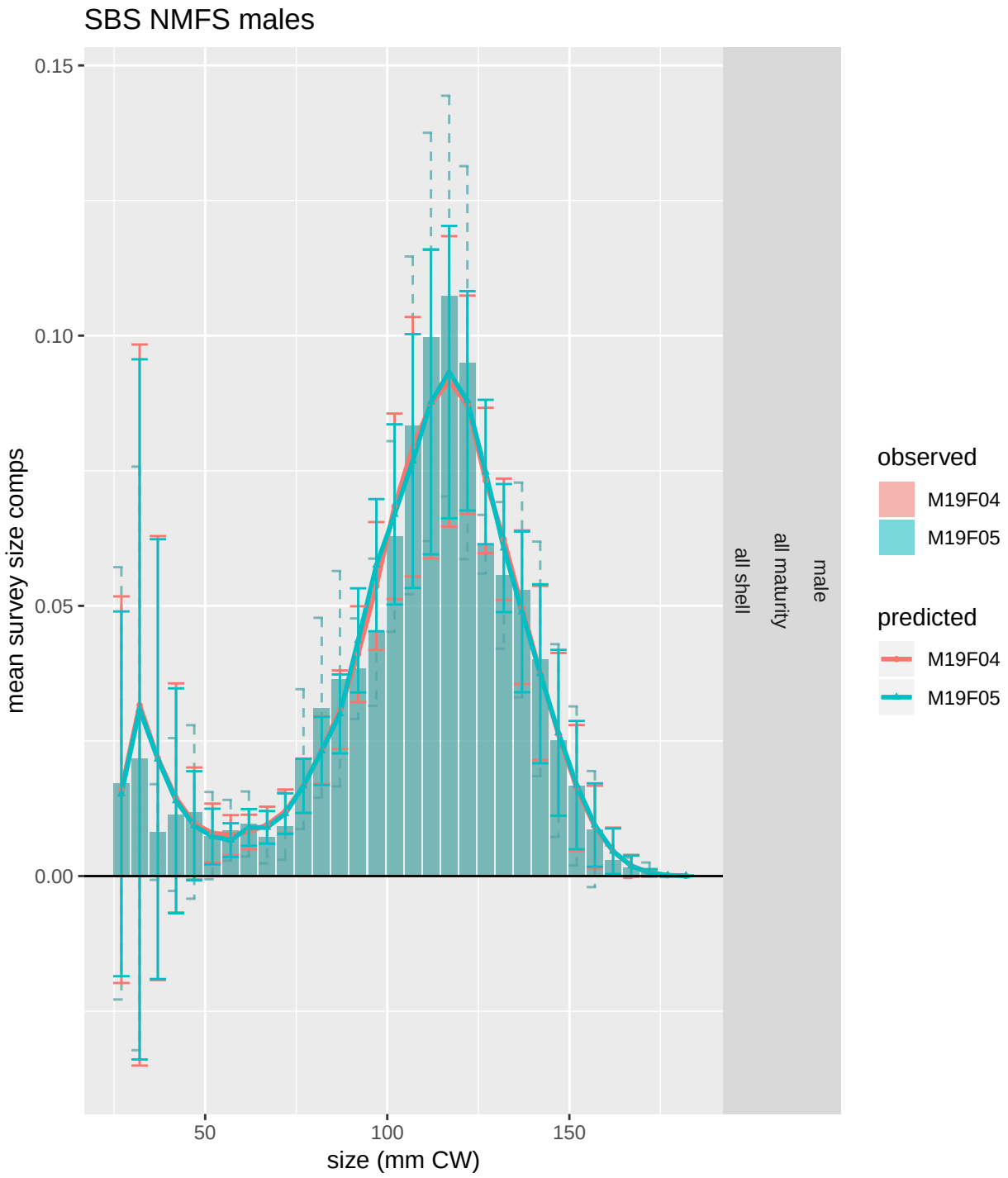


Figure 7: Comparison of observed and predicted mean survey size comps for SBS NMFS males.

Residuals to survey size composition data

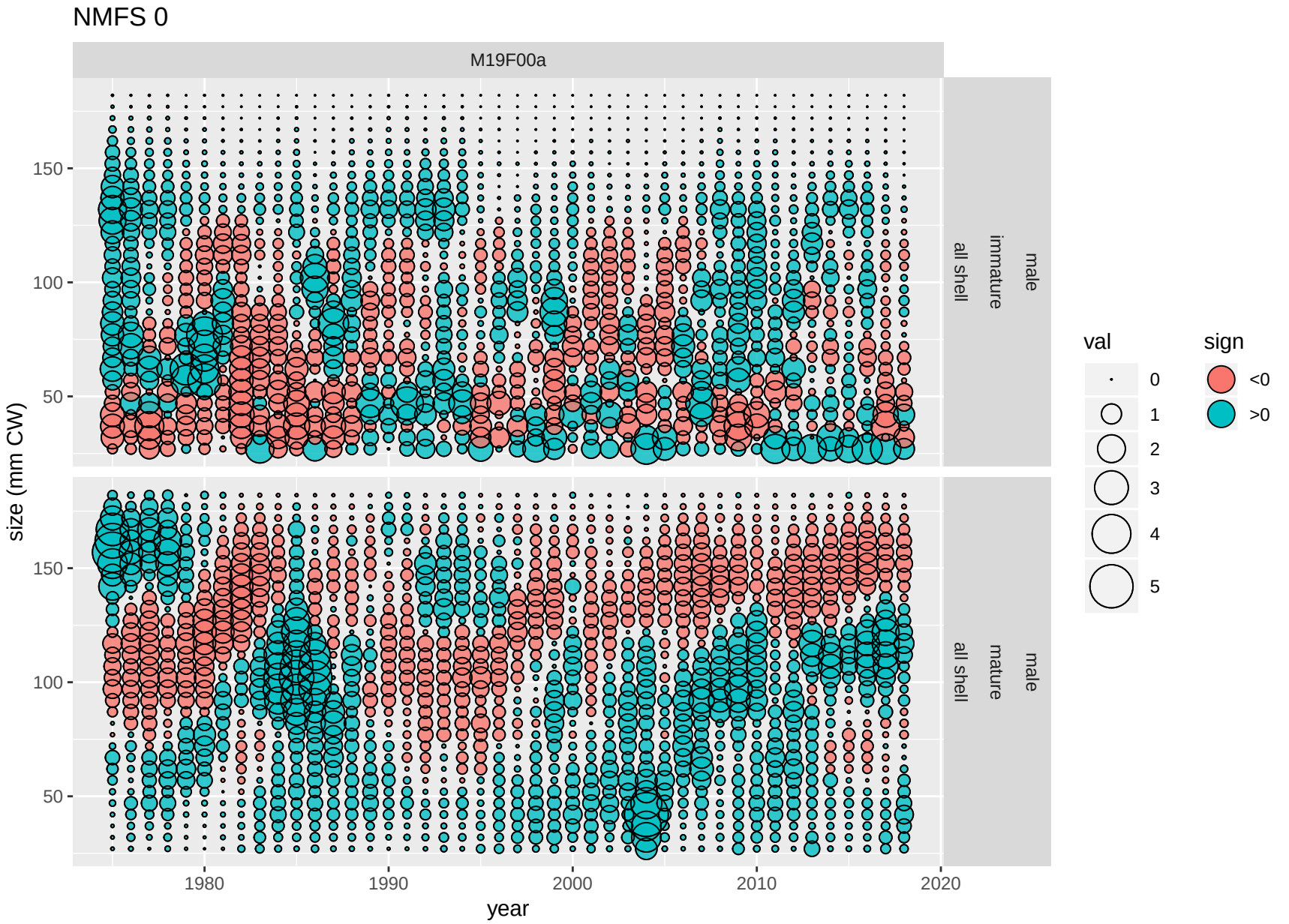


Figure 8: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F00a.

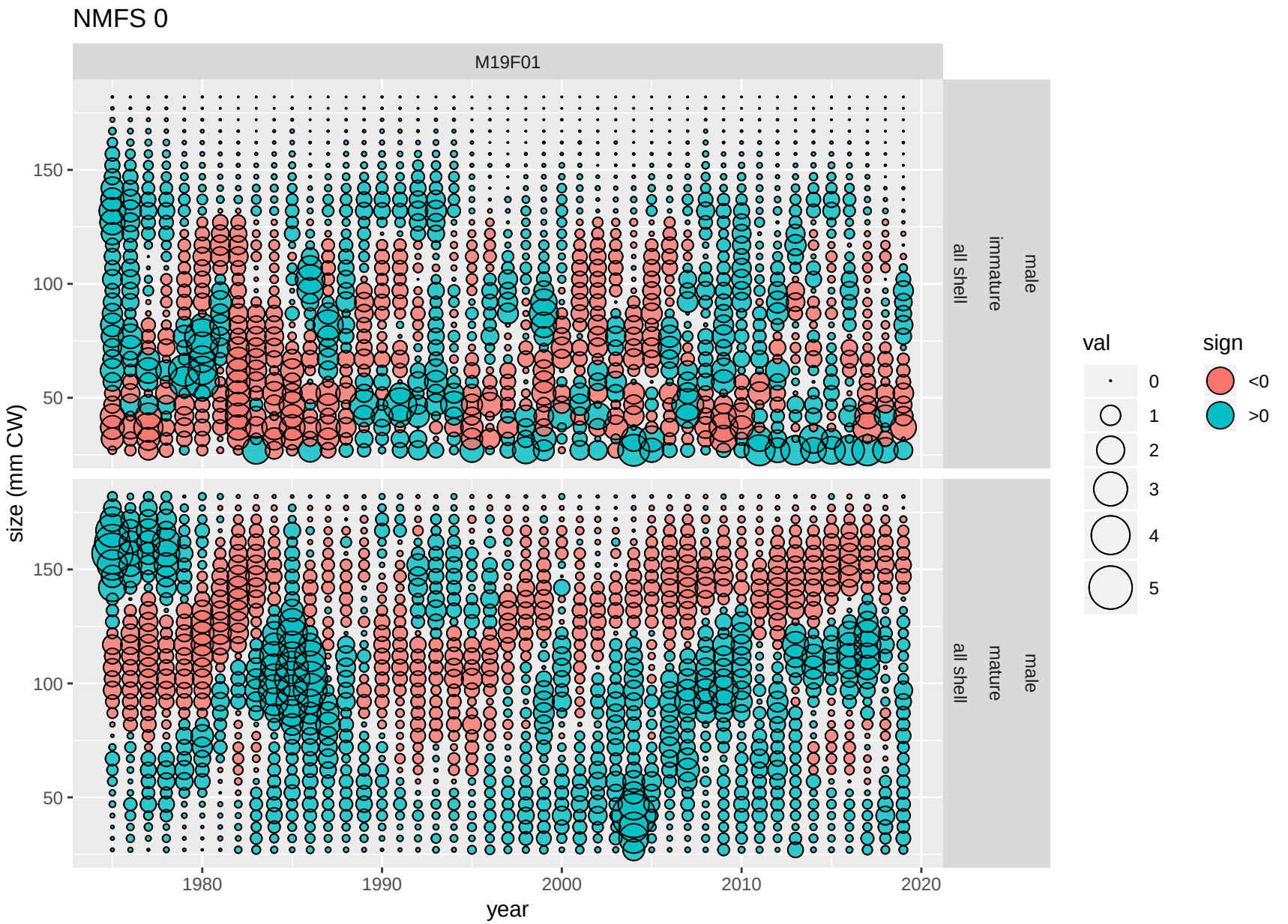


Figure 9: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F01.

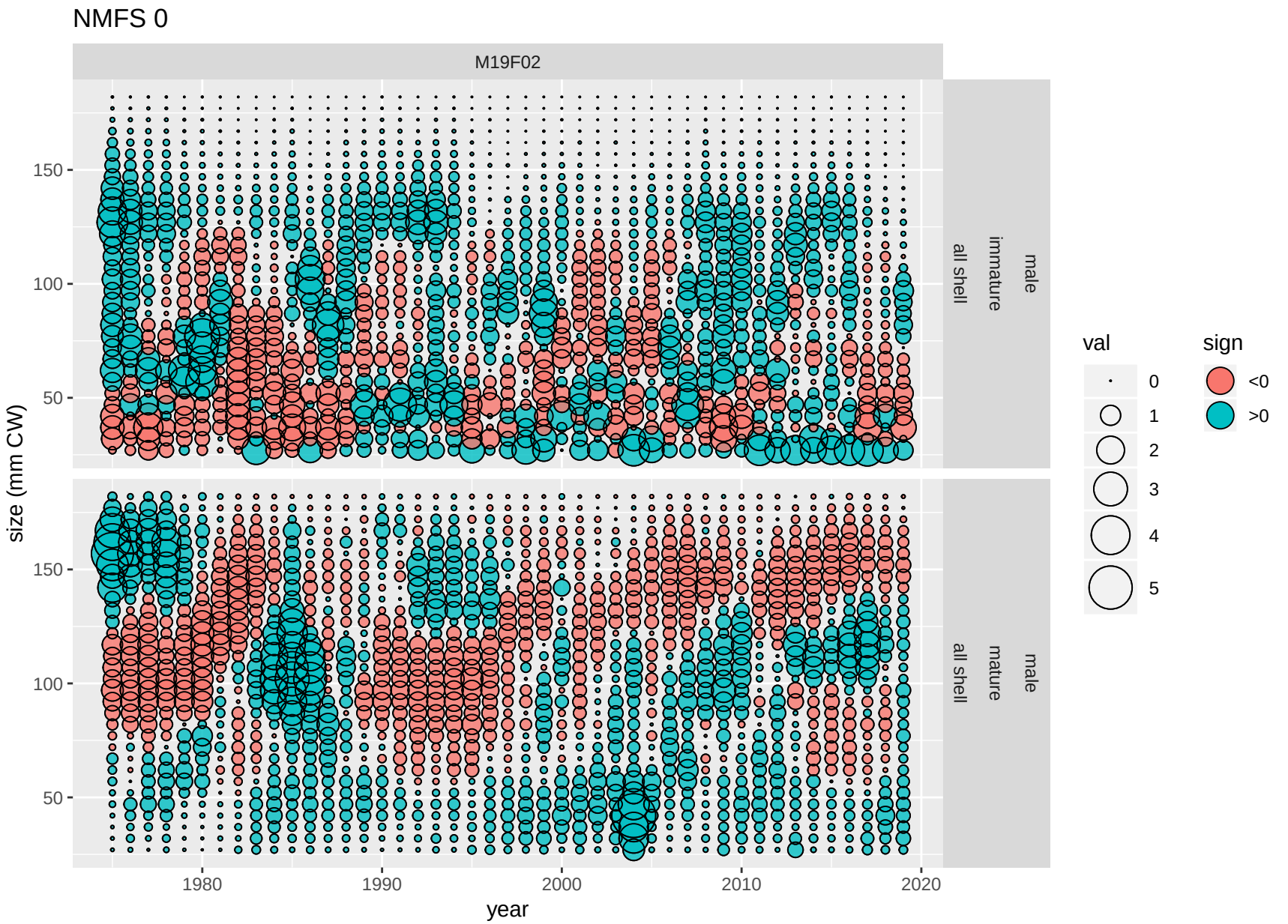


Figure 10: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F02.

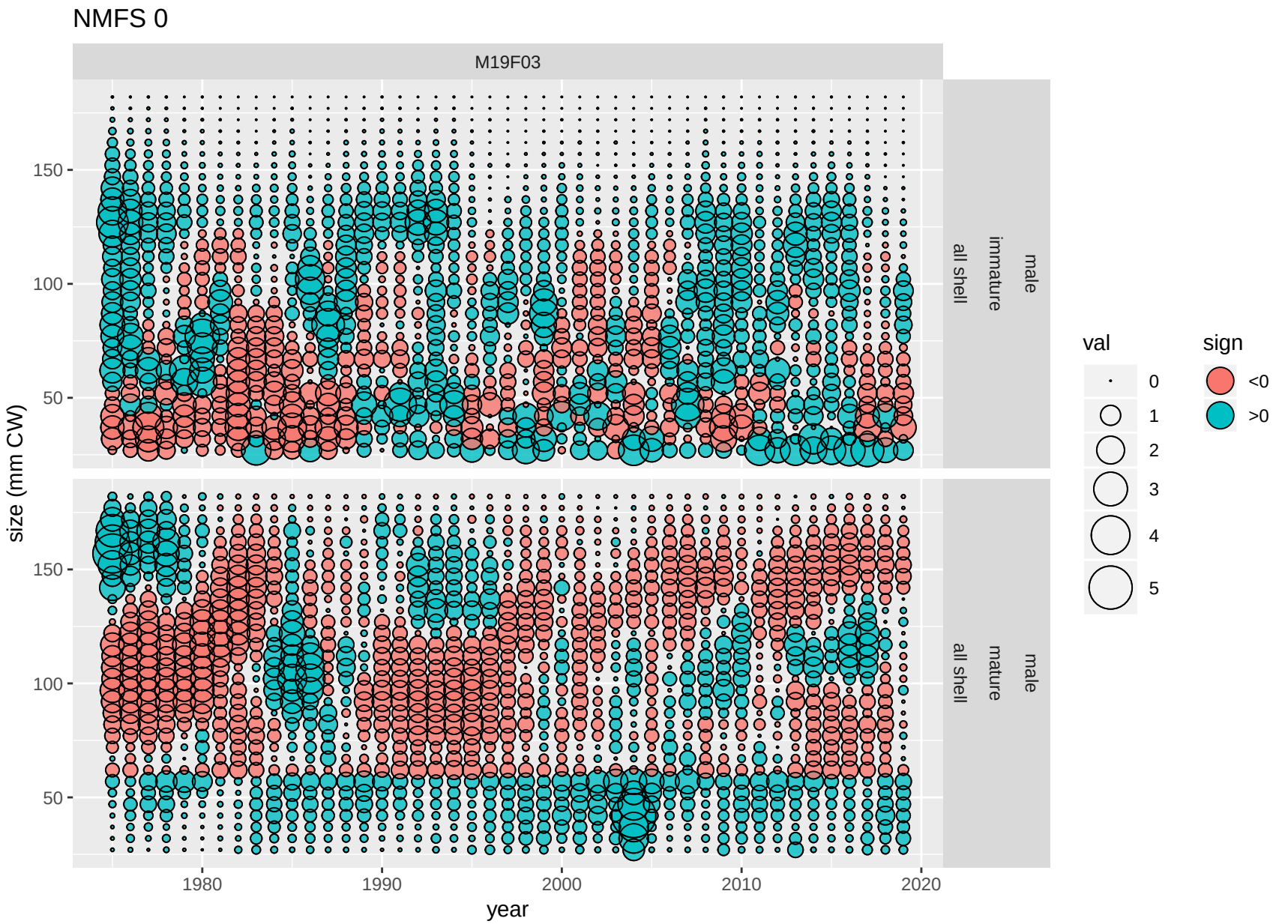


Figure 11: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F03.

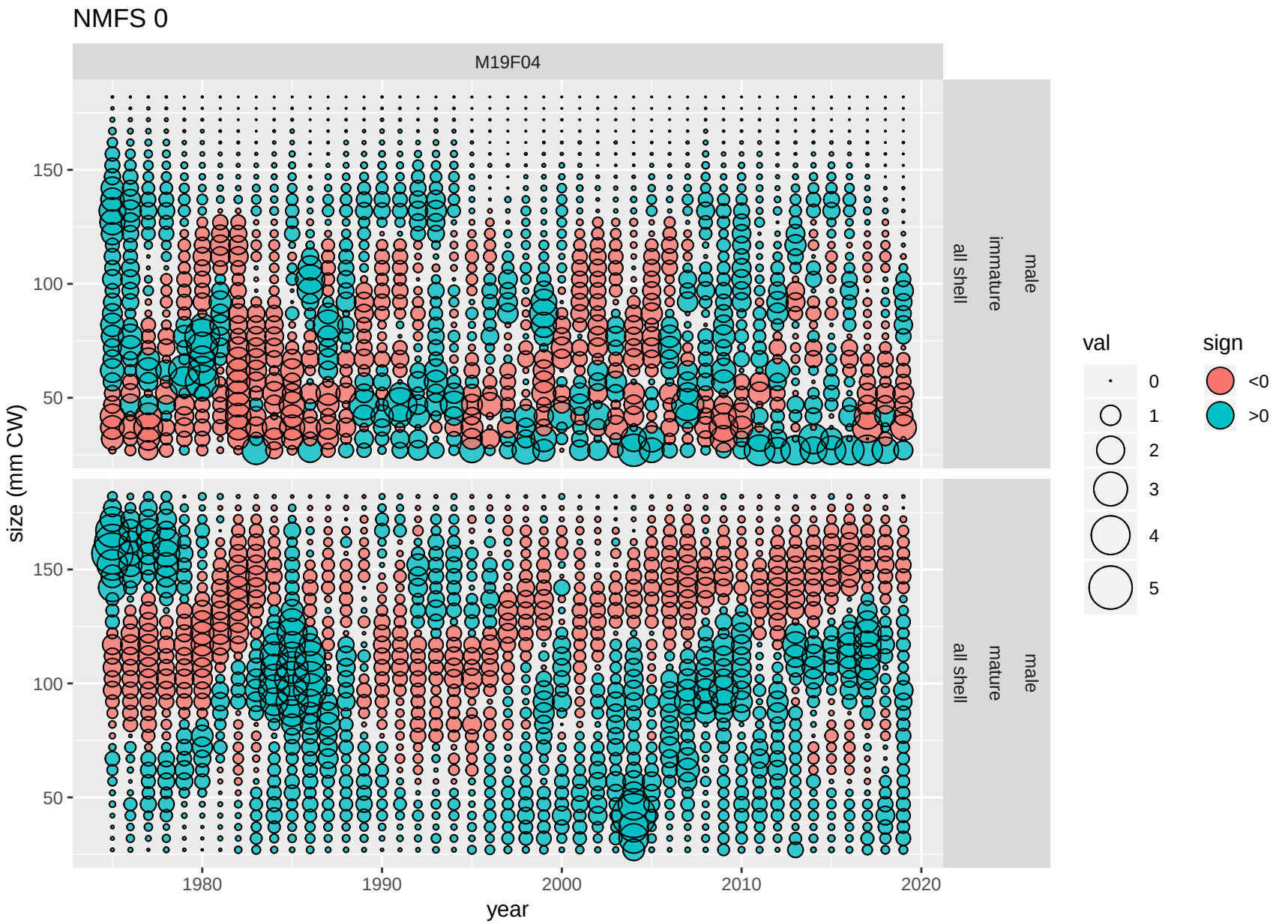


Figure 12: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F04.

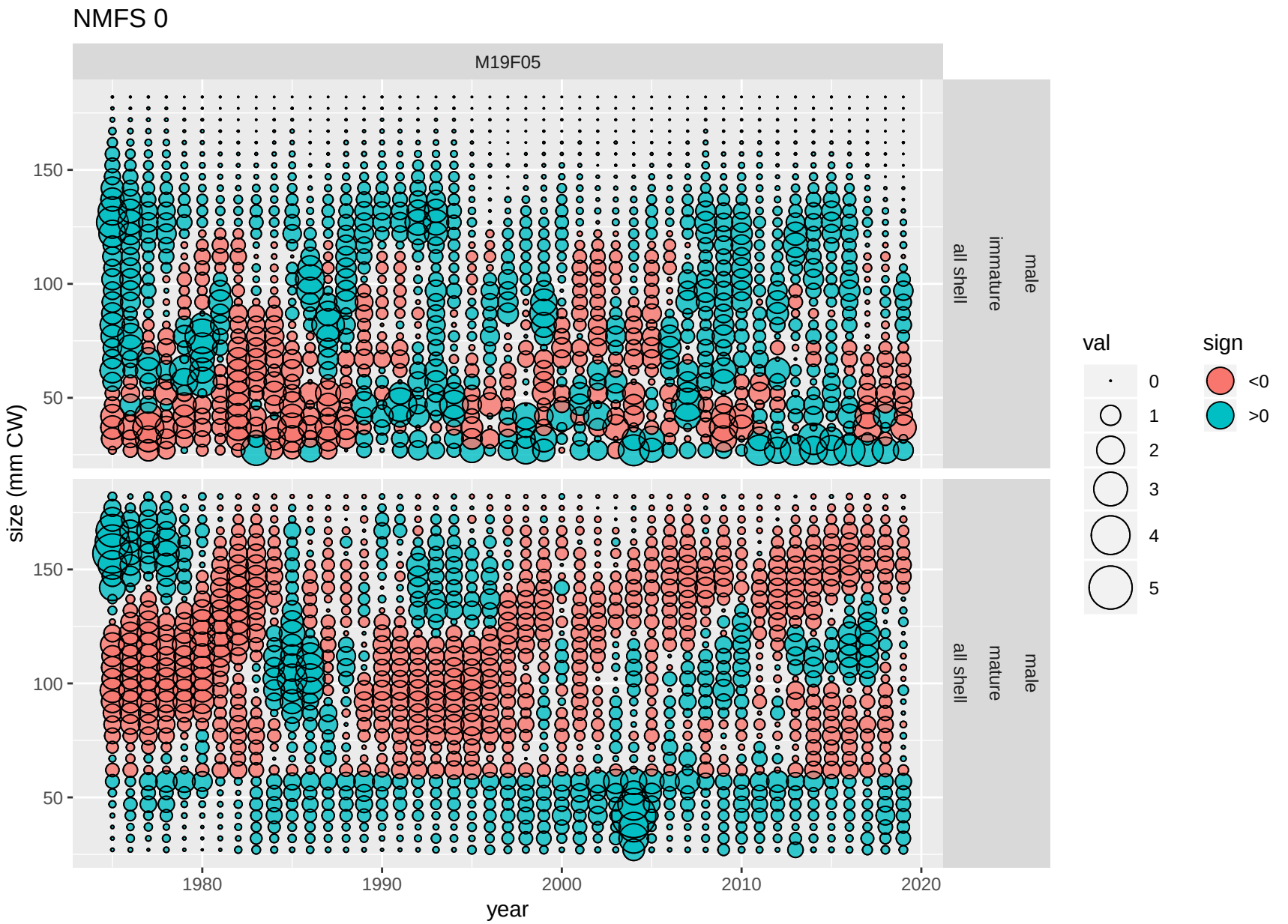


Figure 13: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F05.

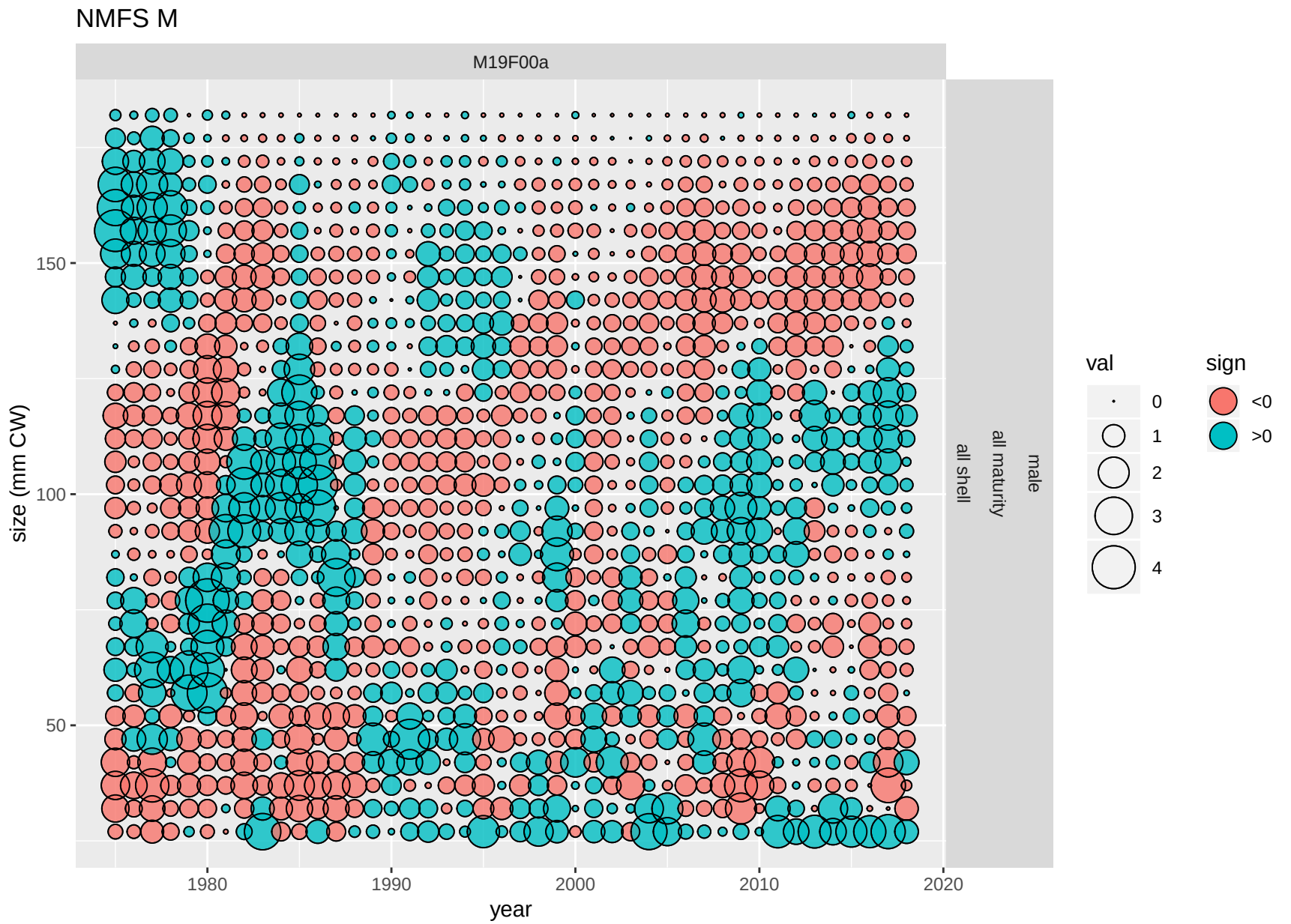


Figure 14: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F00a.

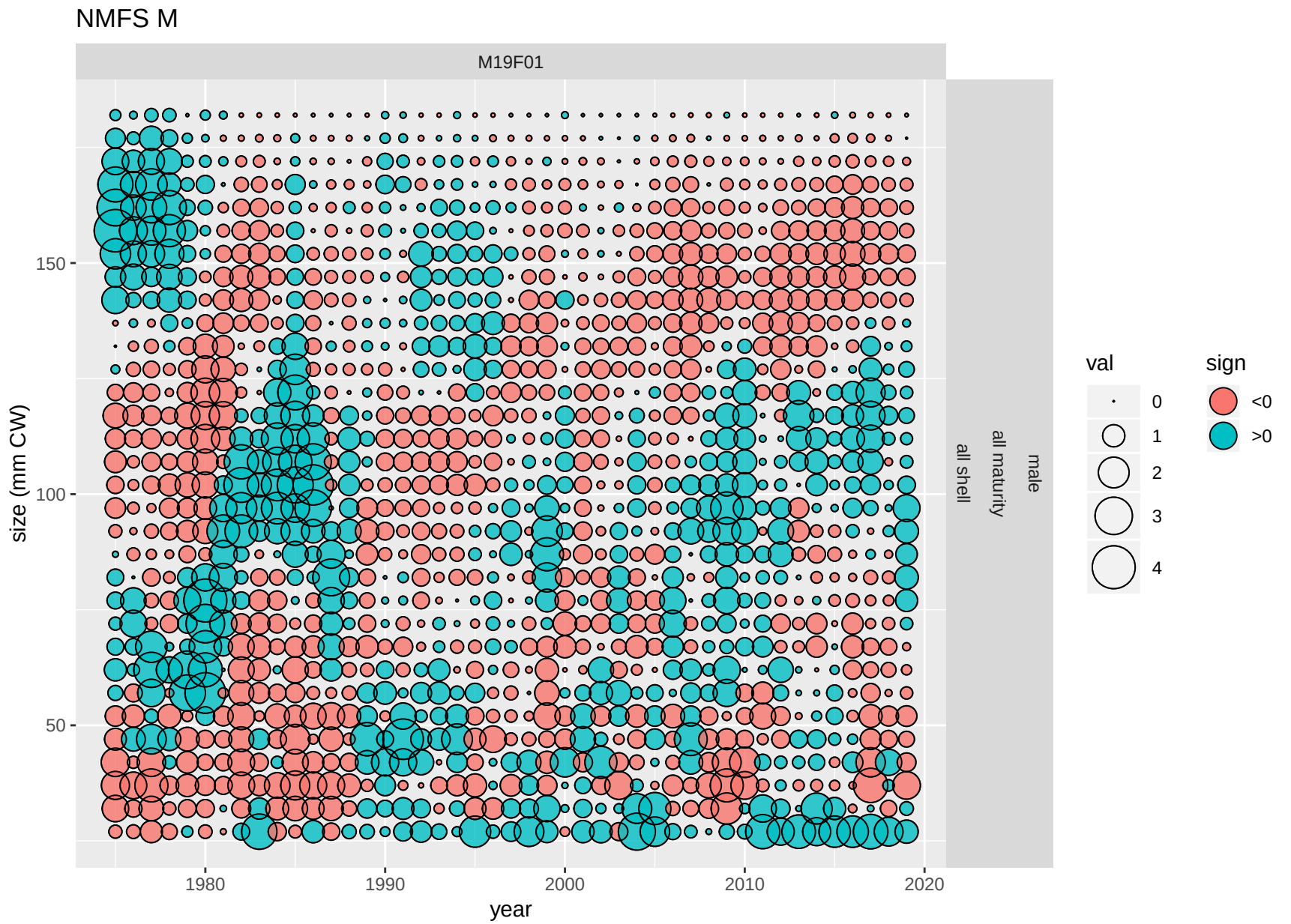


Figure 15: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F01.

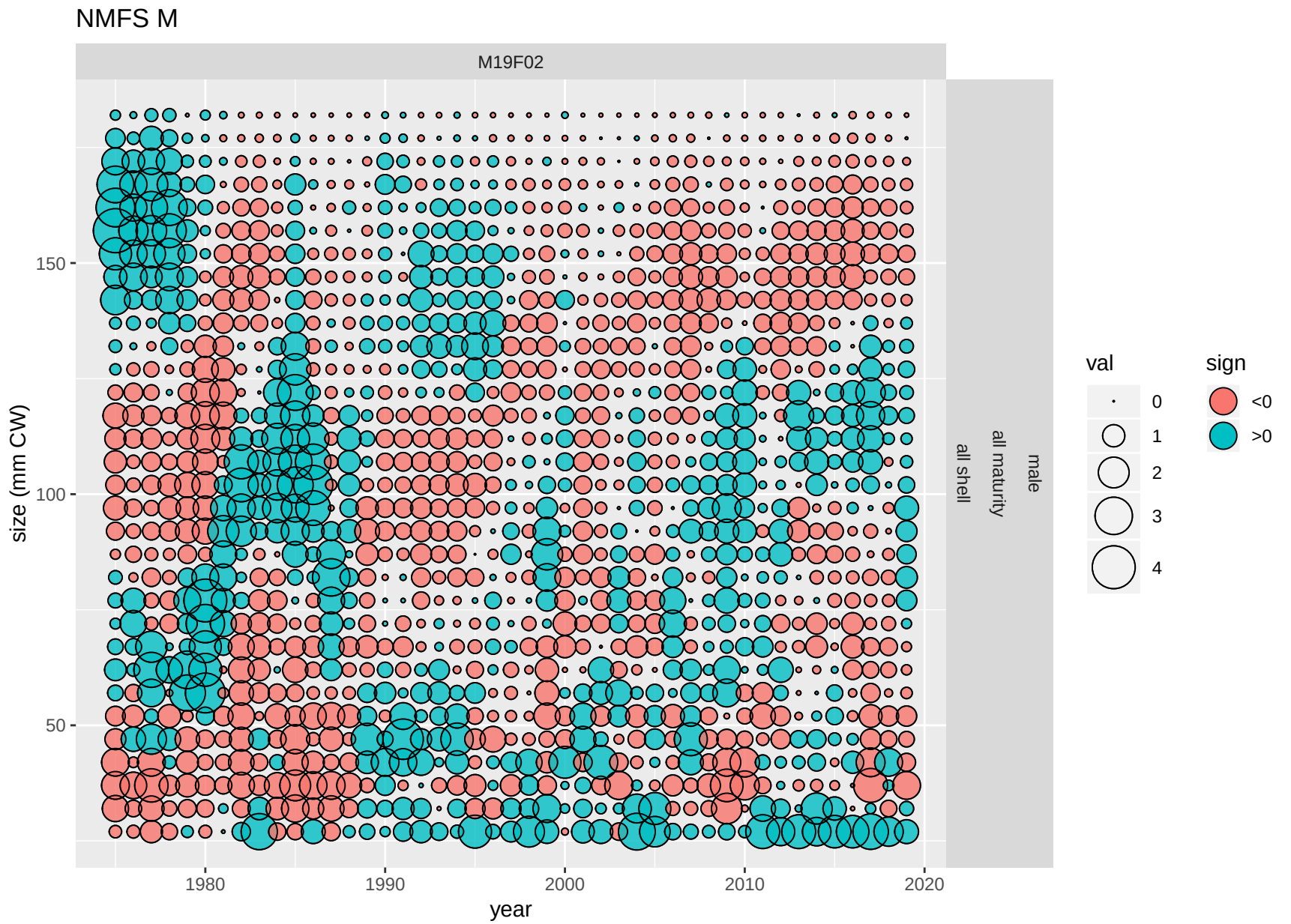


Figure 16: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F02.

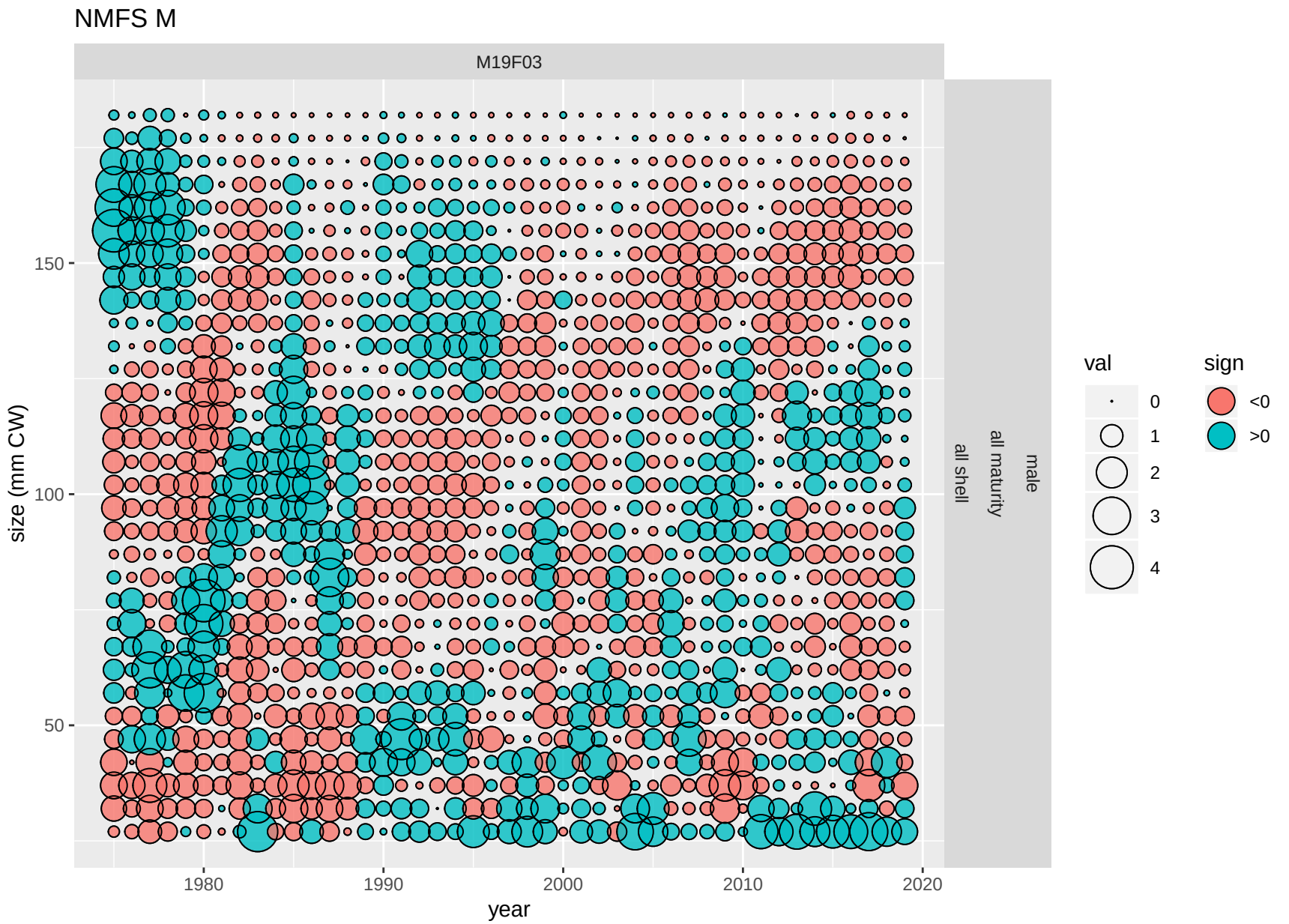


Figure 17: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F03.

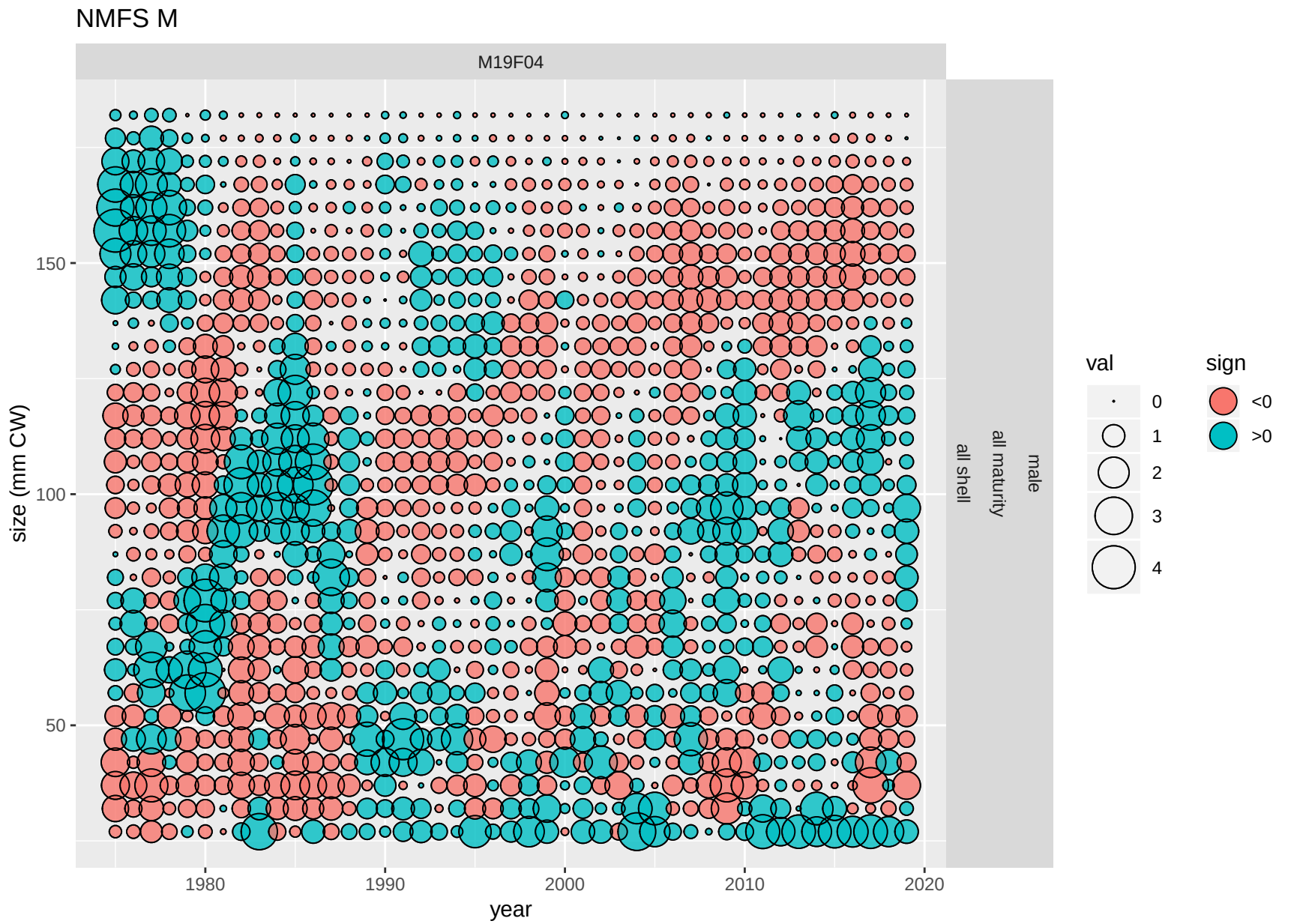


Figure 18: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F04.

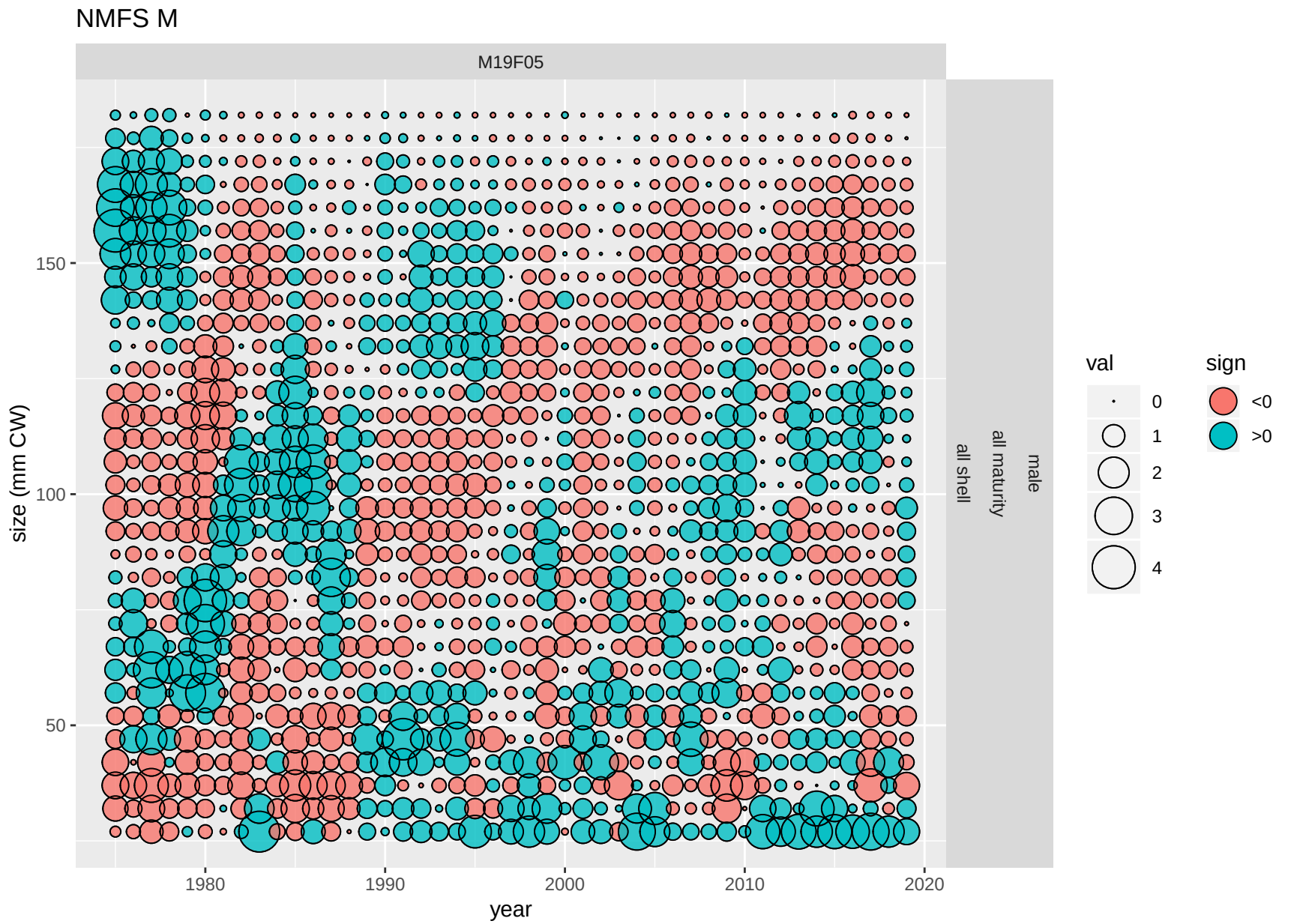


Figure 19: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F05.

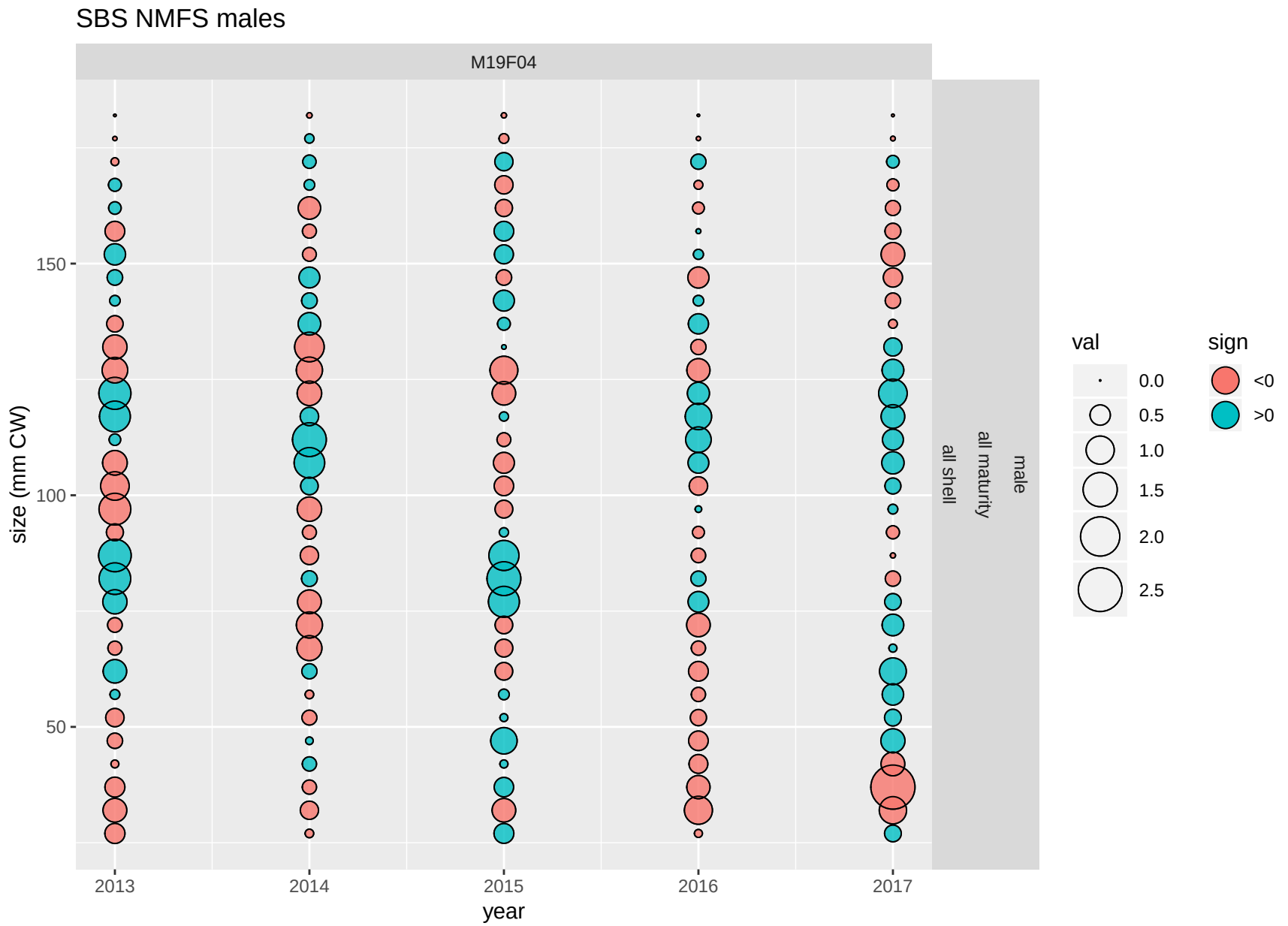


Figure 20: Pearson's residuals for male proportions-at-size from the SBS NMFS males for scenario M19F04.

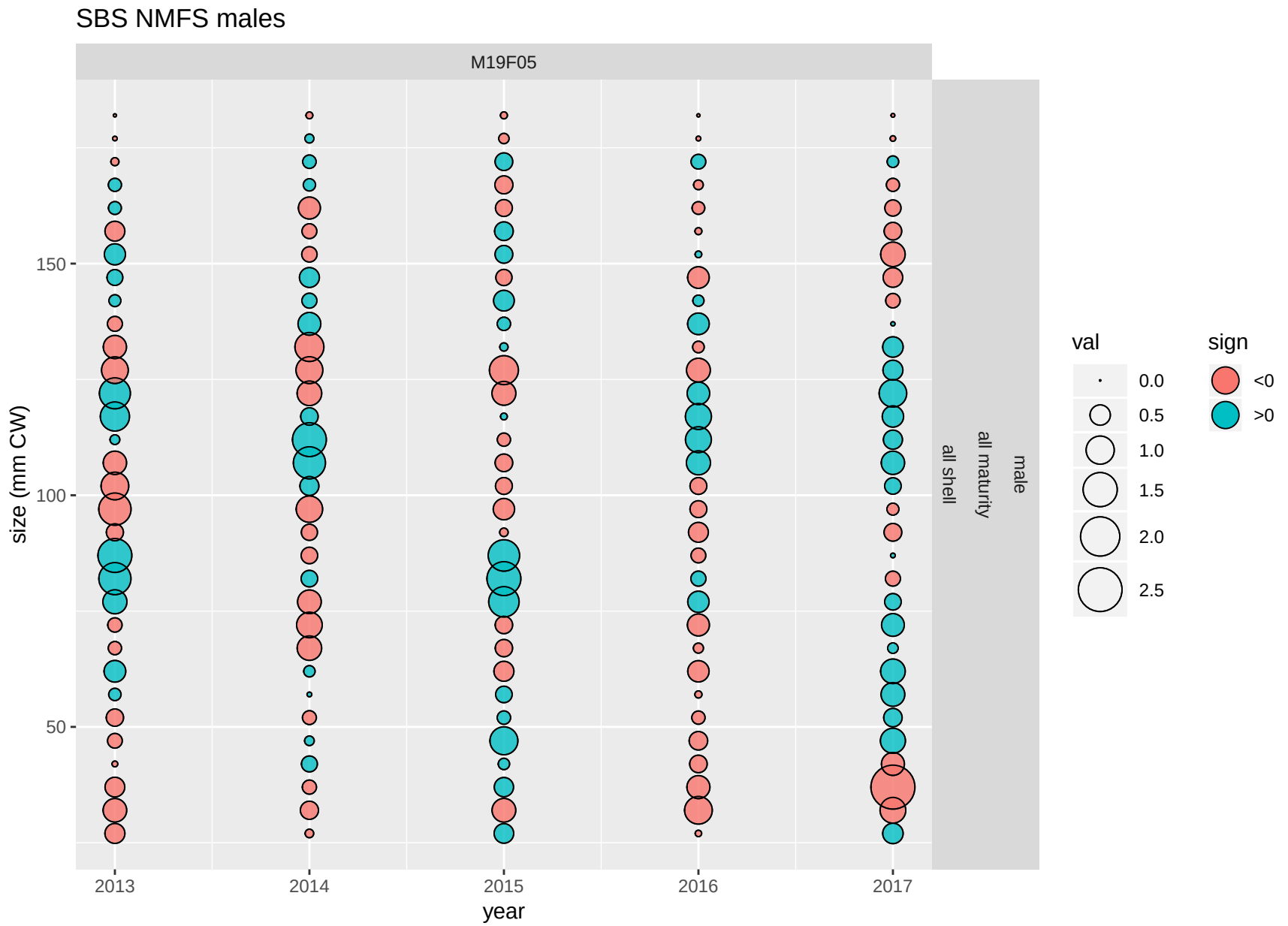


Figure 21: Pearson's residuals for male proportions-at-size from the SBS NMFS males for scenario M19F05.

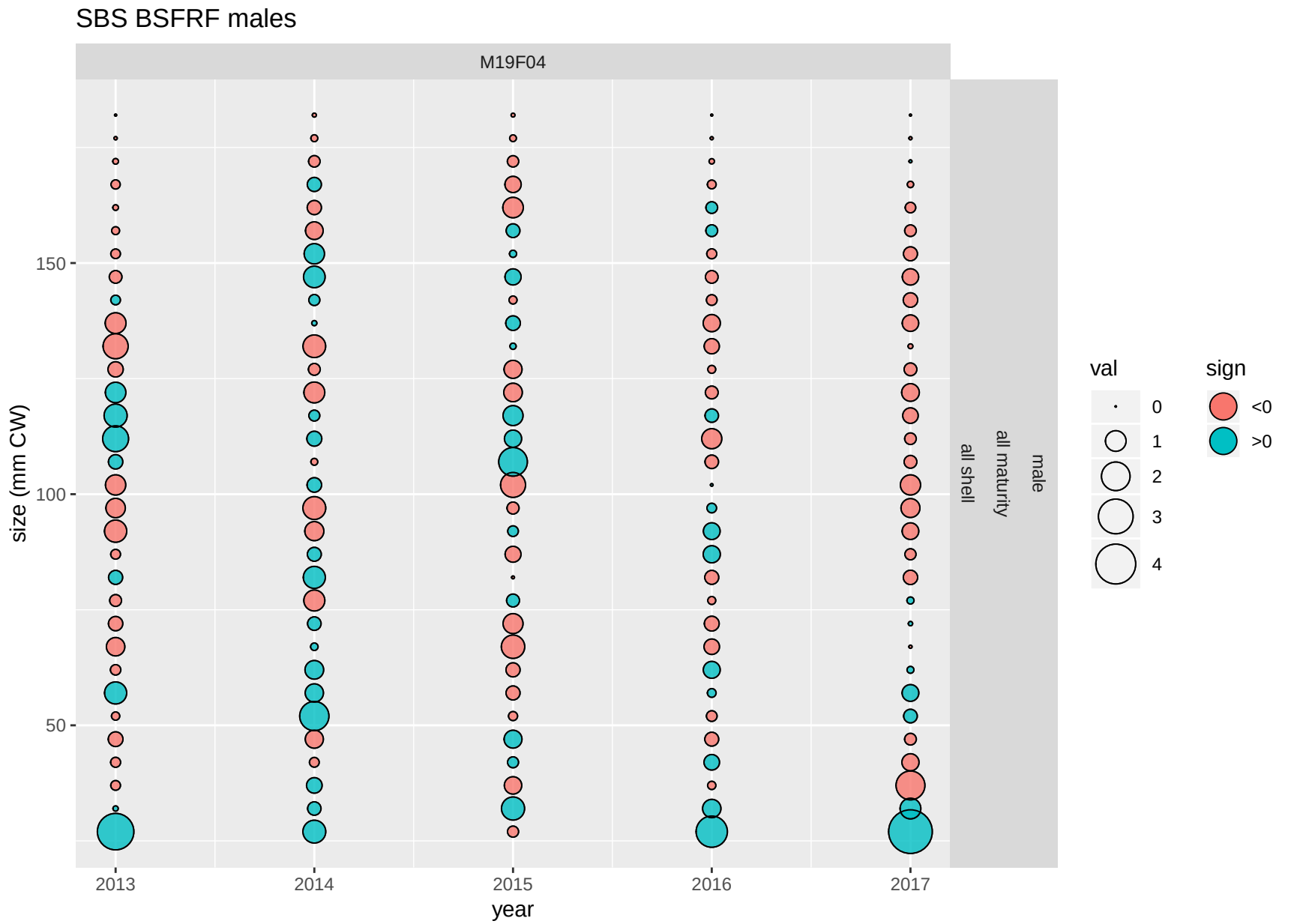


Figure 22: Pearson's residuals for male proportions-at-size from the SBS BSFRF males for scenario M19F04.

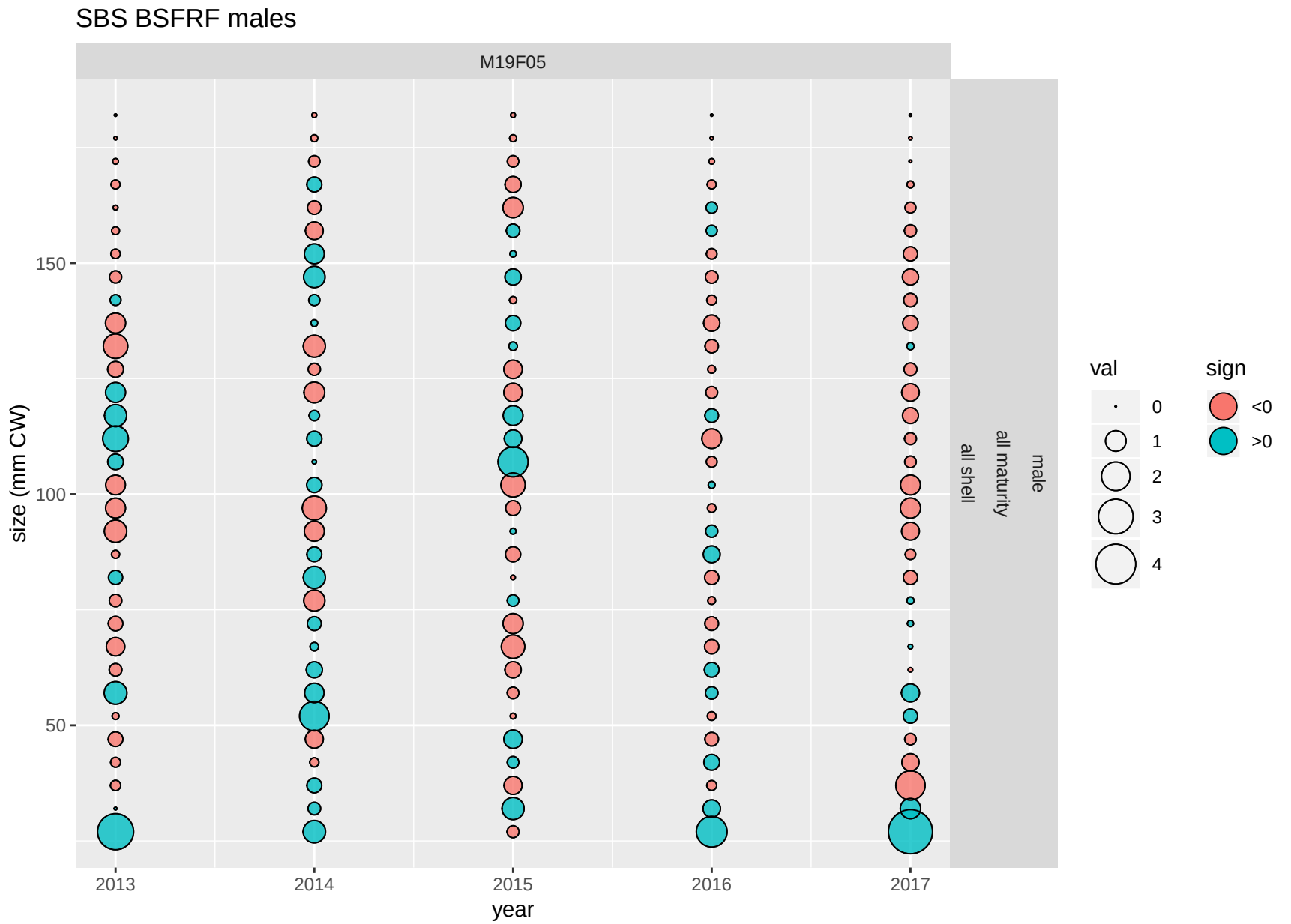


Figure 23: Pearson's residuals for male proportions-at-size from the SBS BSFRF males for scenario M19F05.

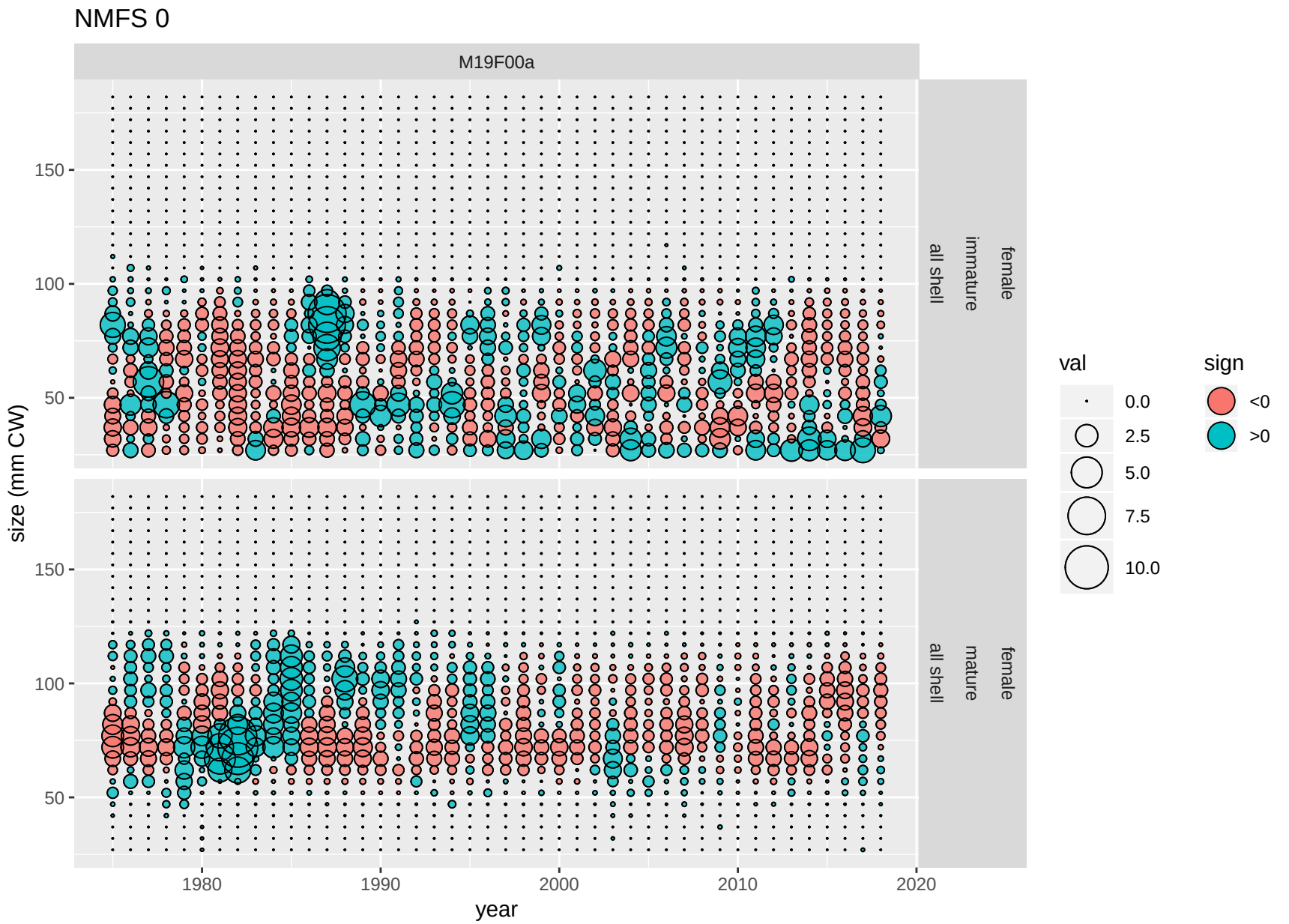


Figure 24: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F00a.

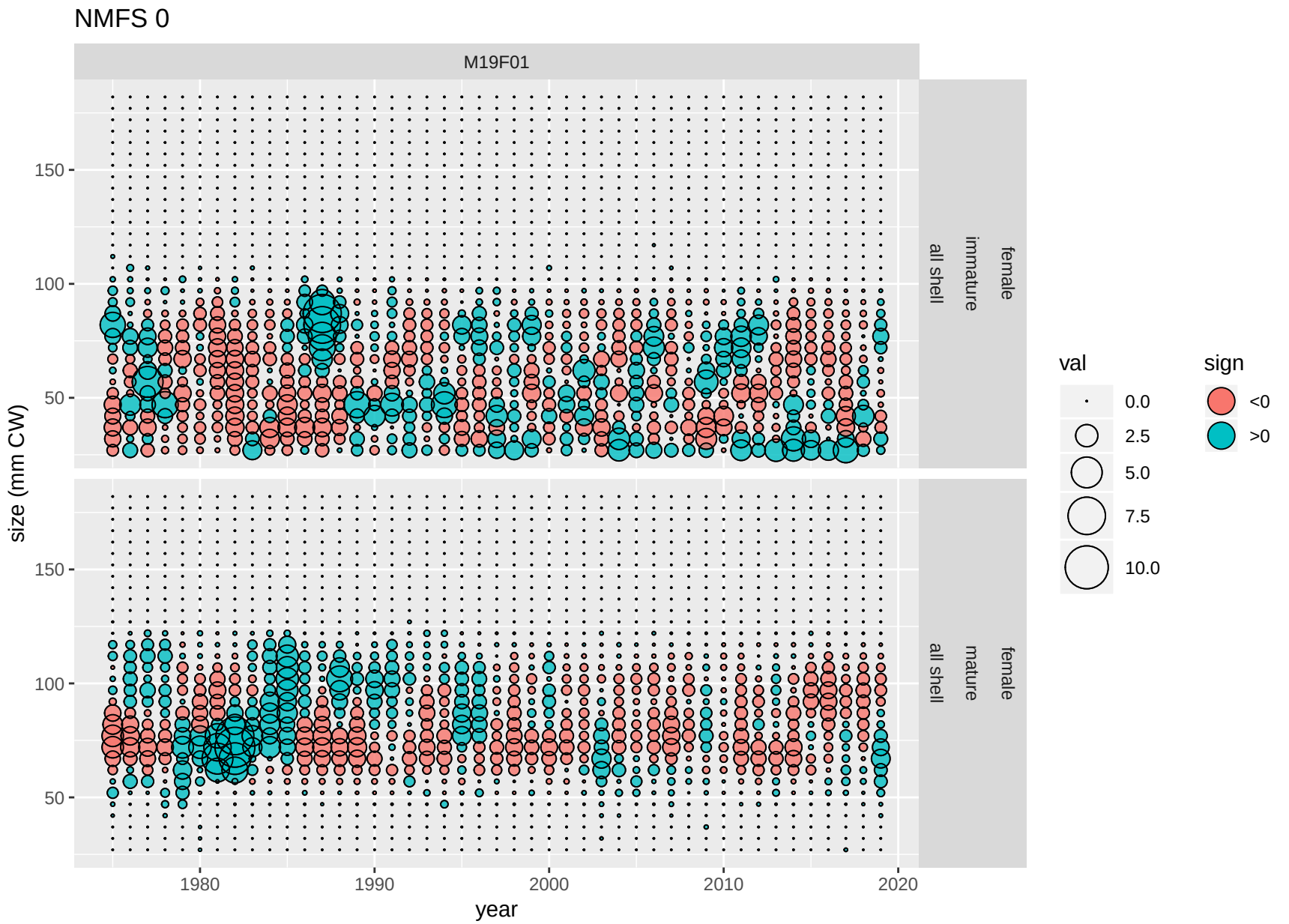


Figure 25: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F01.

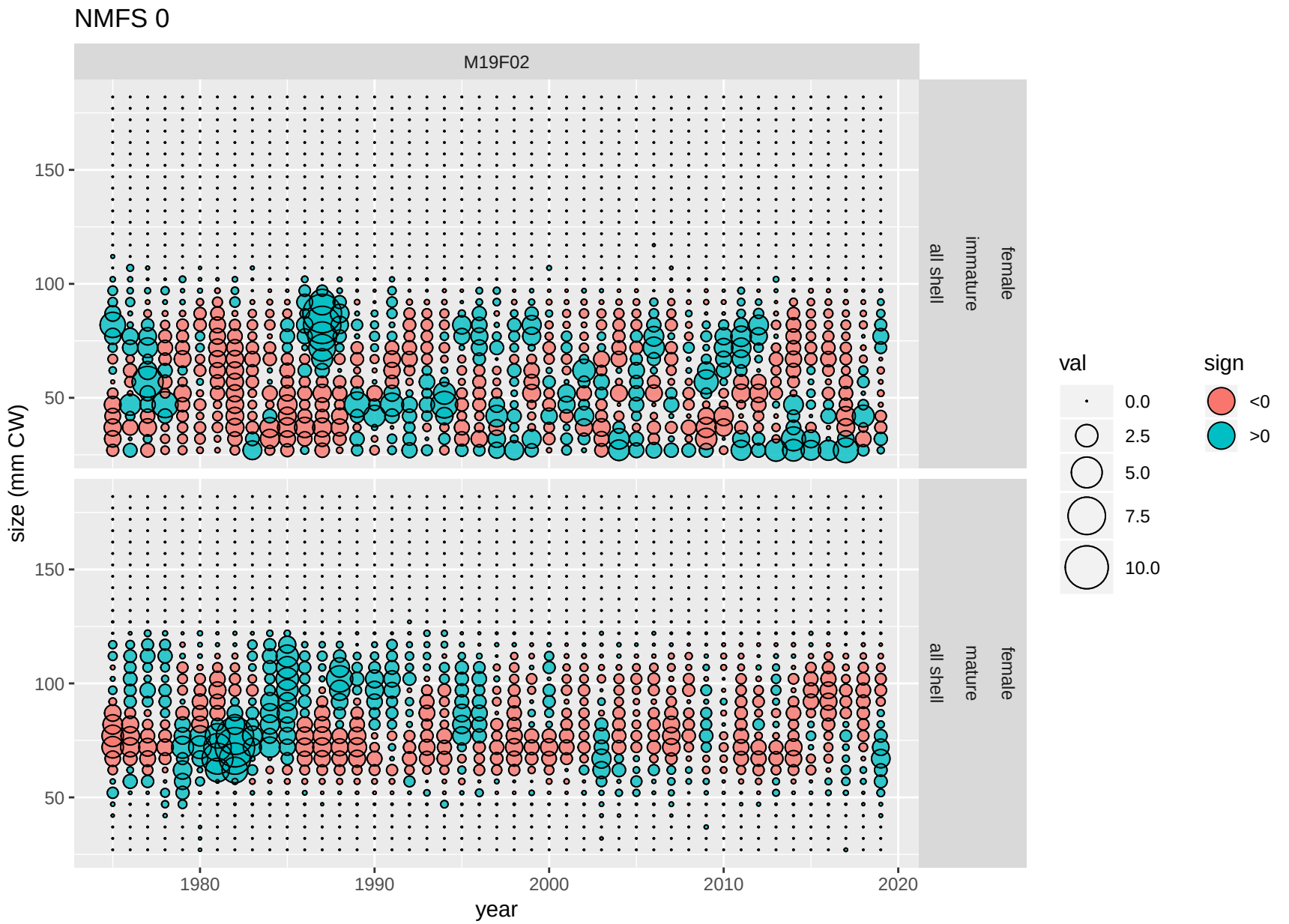


Figure 26: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F02.

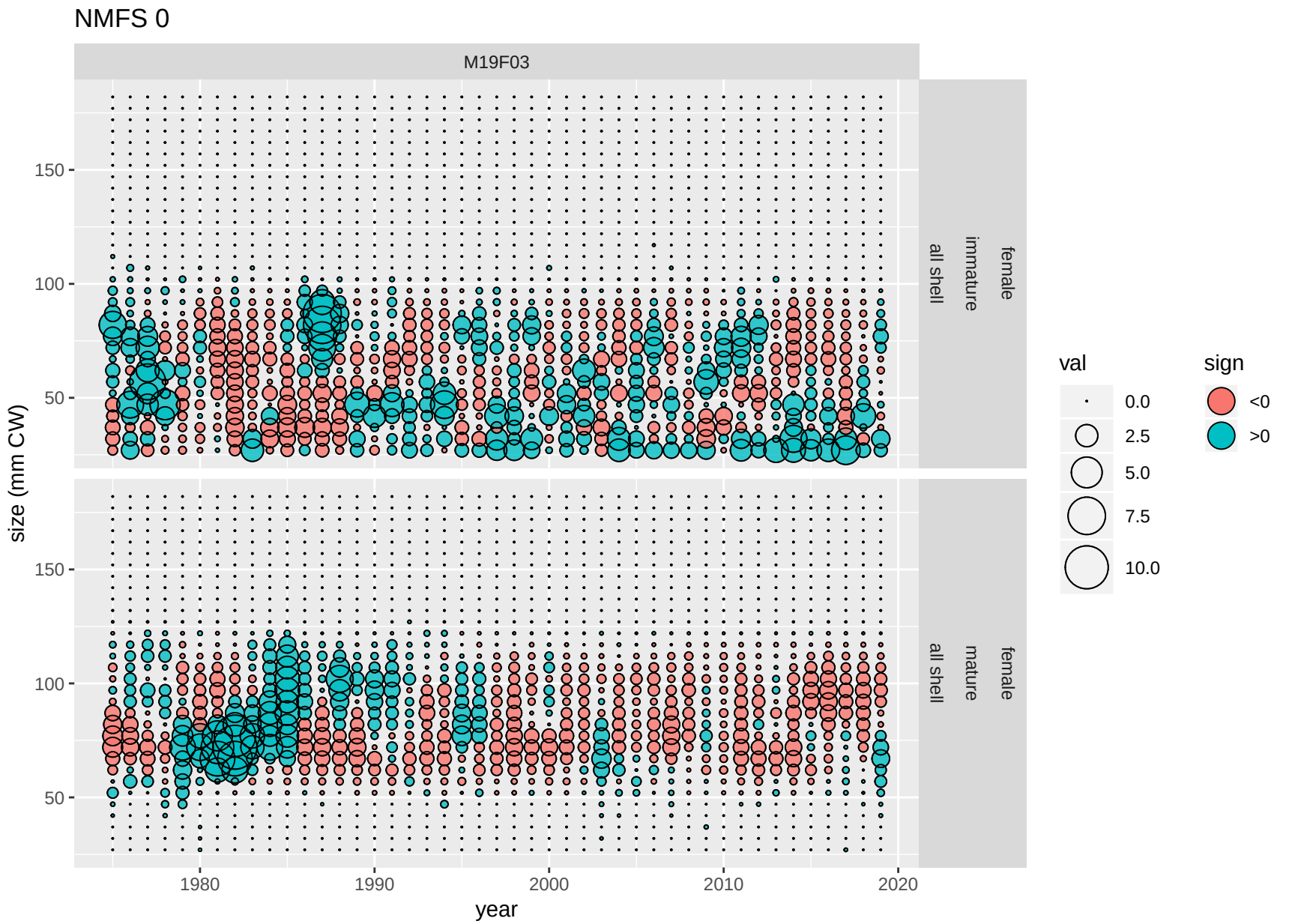


Figure 27: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F03.

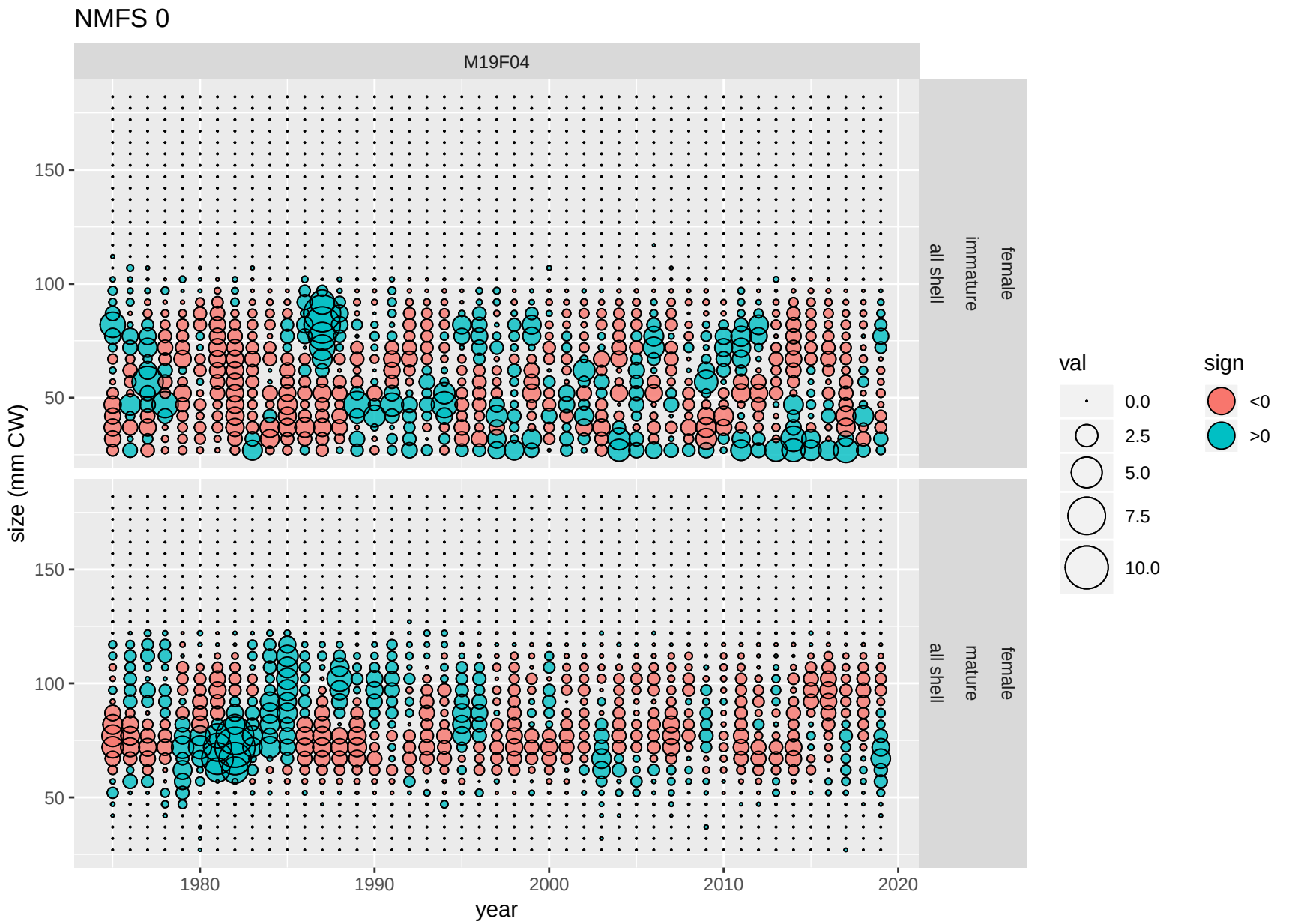


Figure 28: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F04.

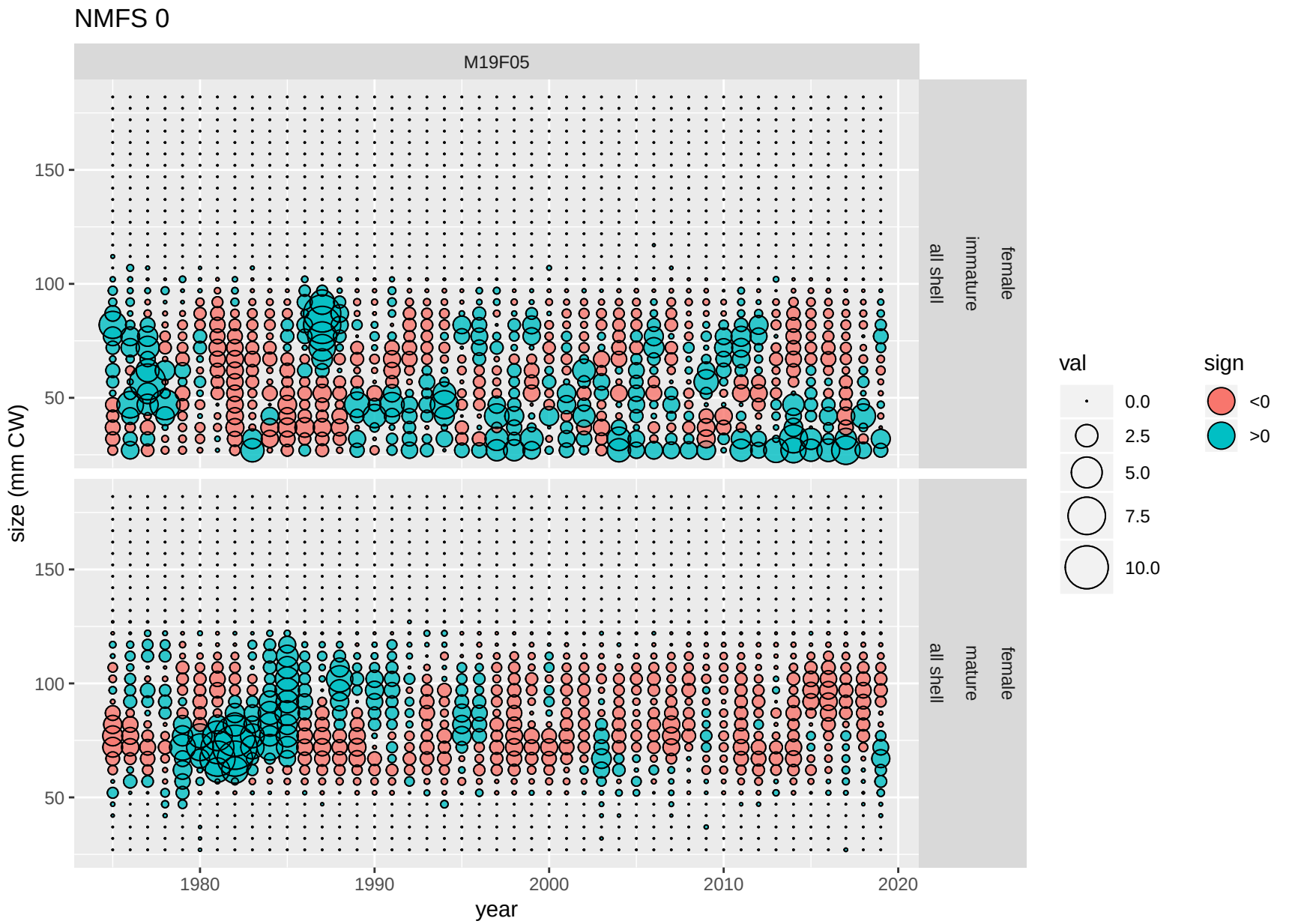


Figure 29: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F05.

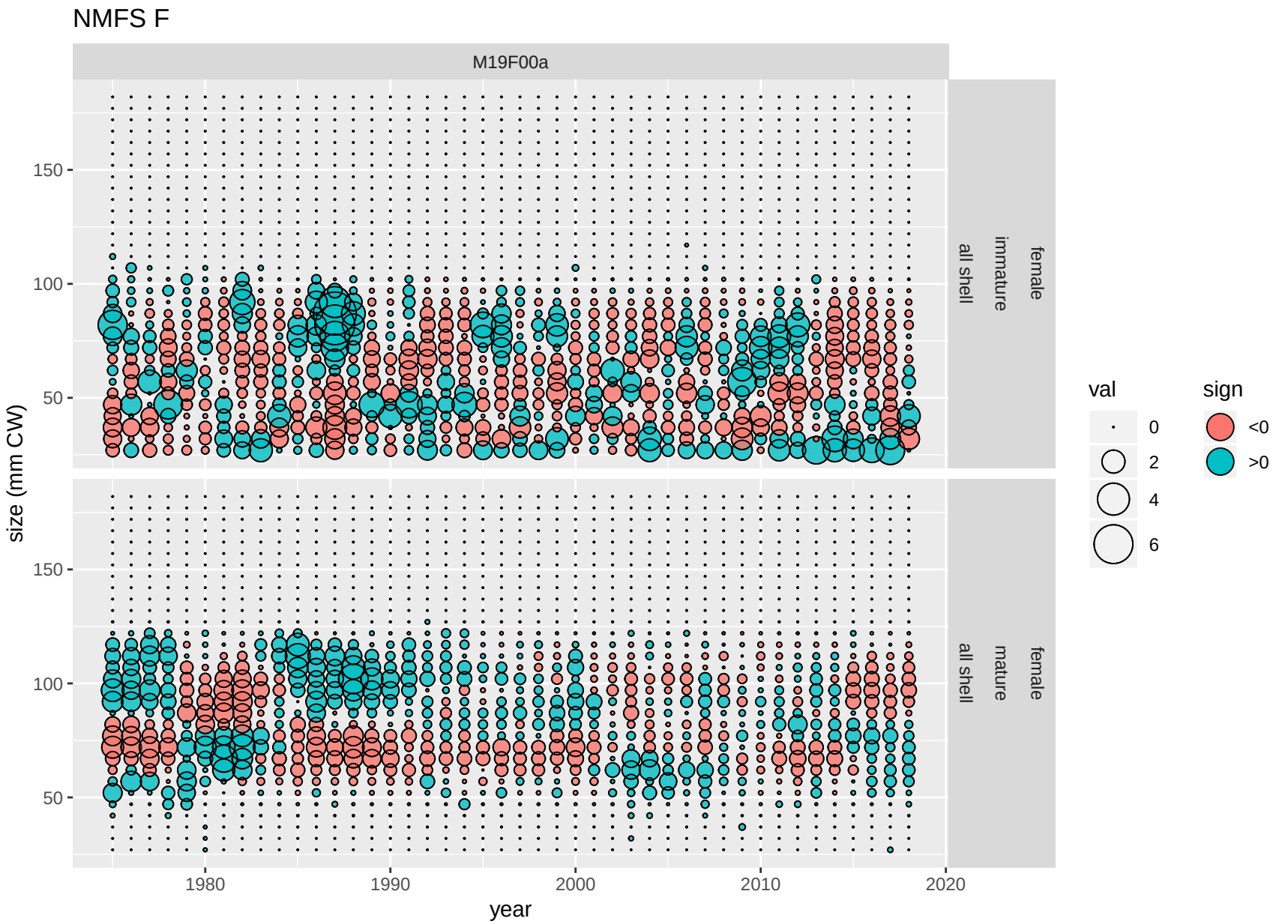


Figure 30: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F00a.

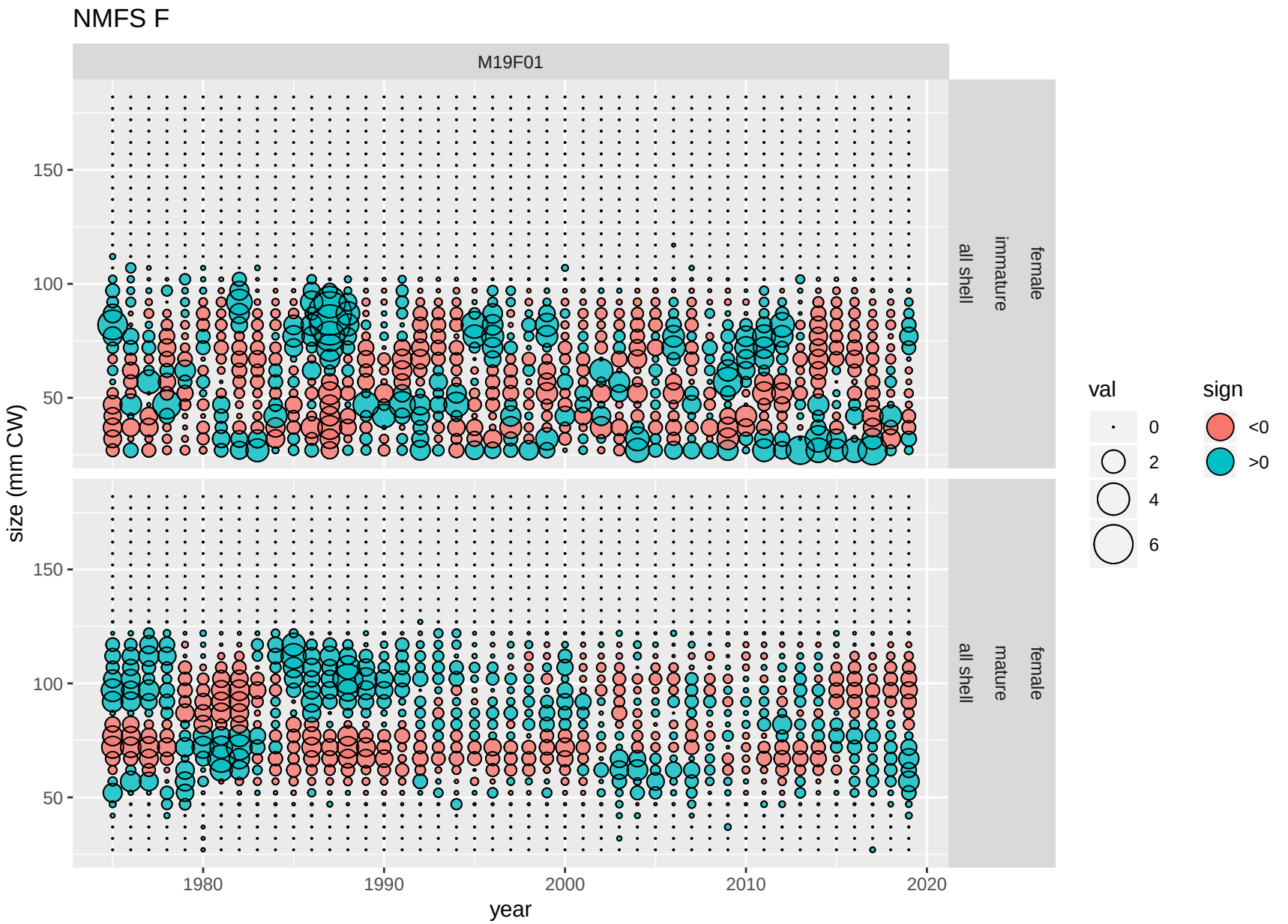


Figure 31: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F01.

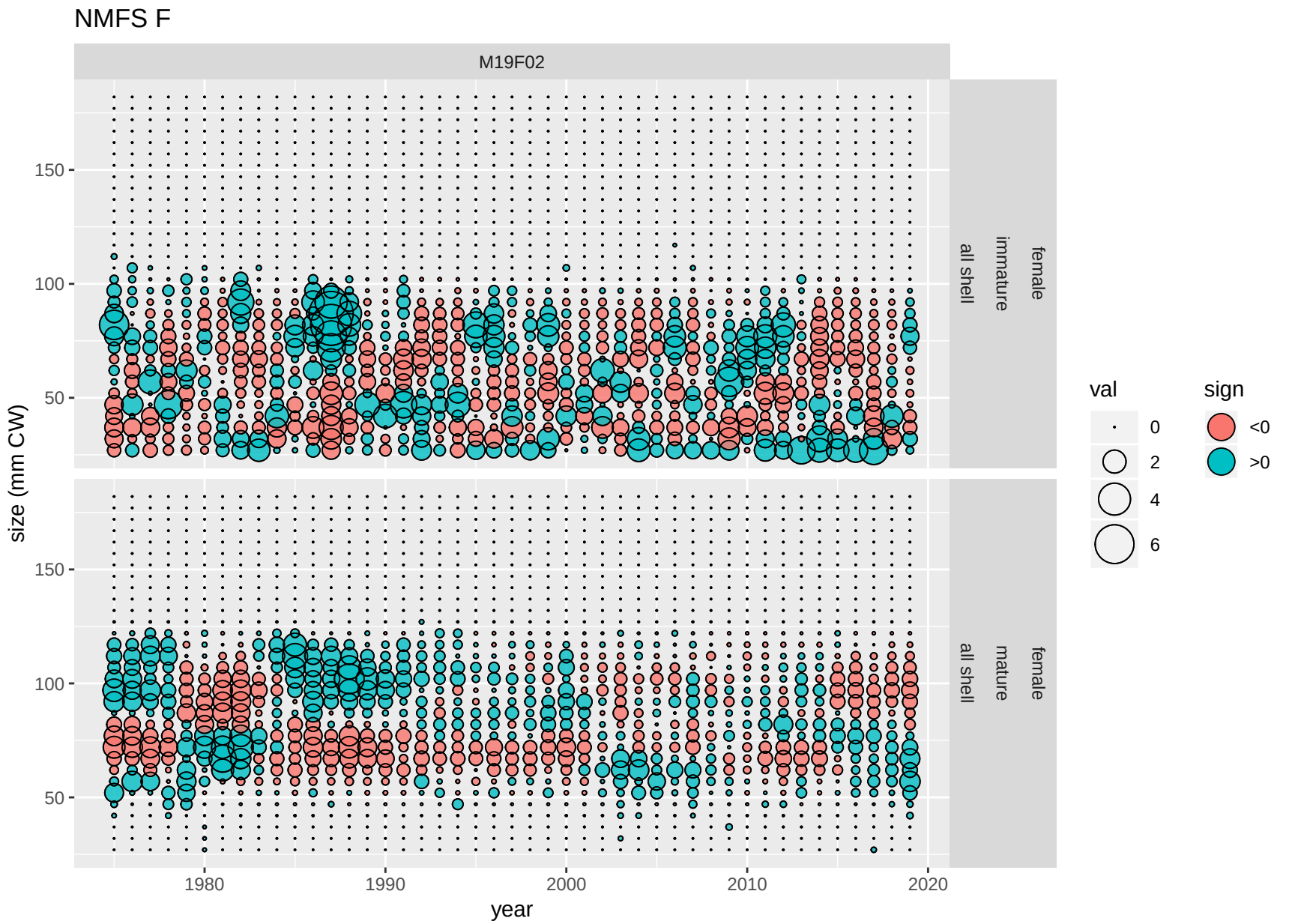


Figure 32: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F02.

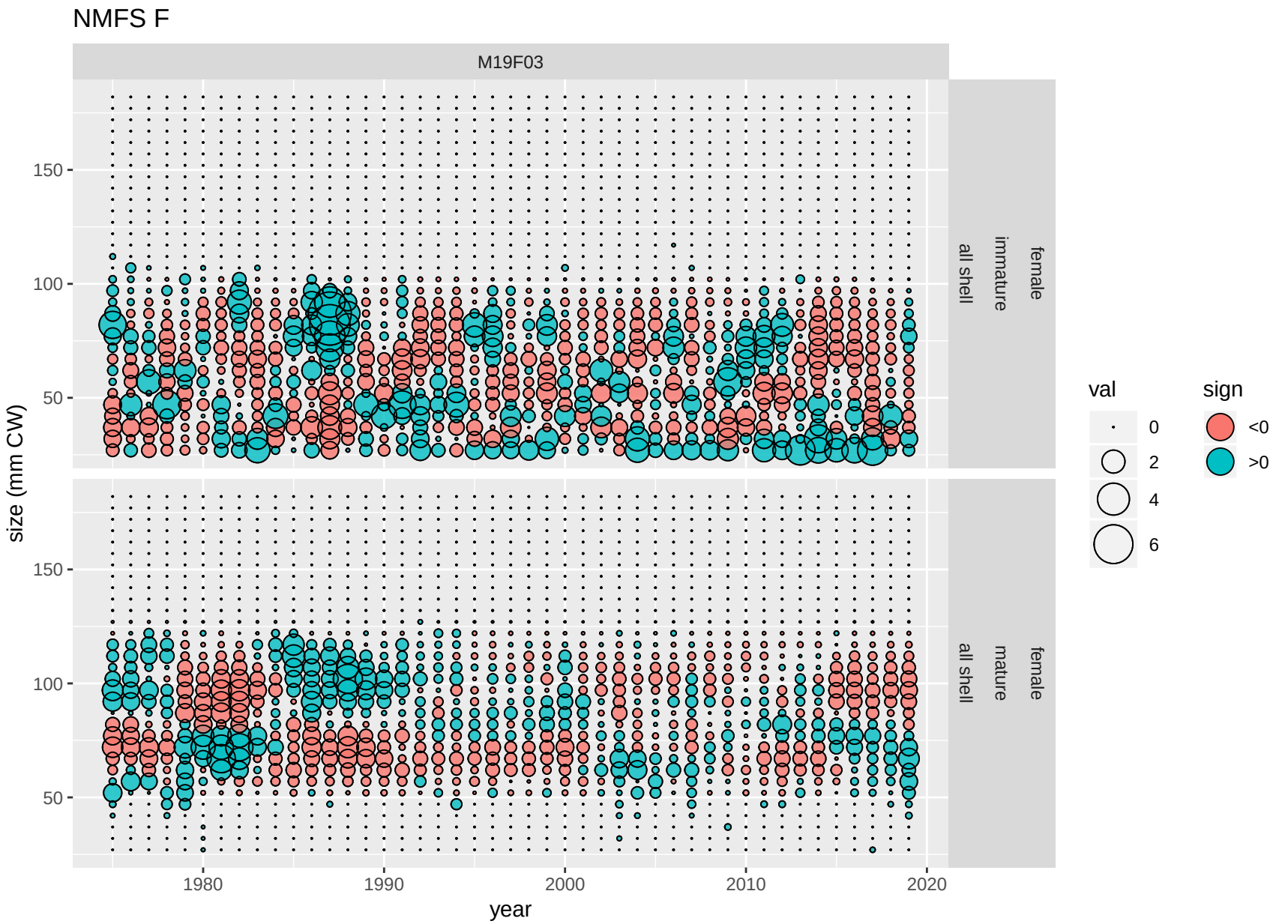


Figure 33: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F03.

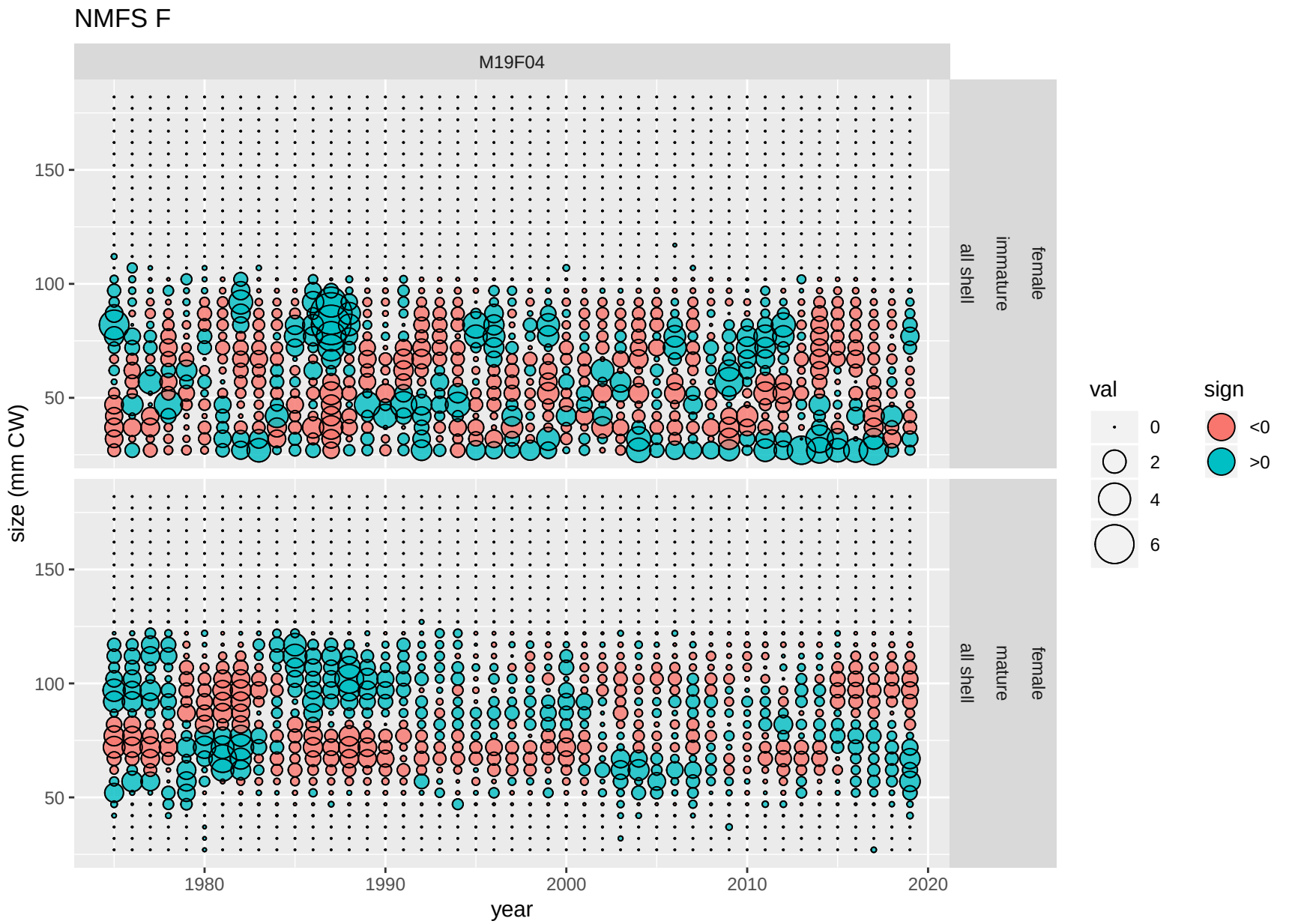


Figure 34: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F04.

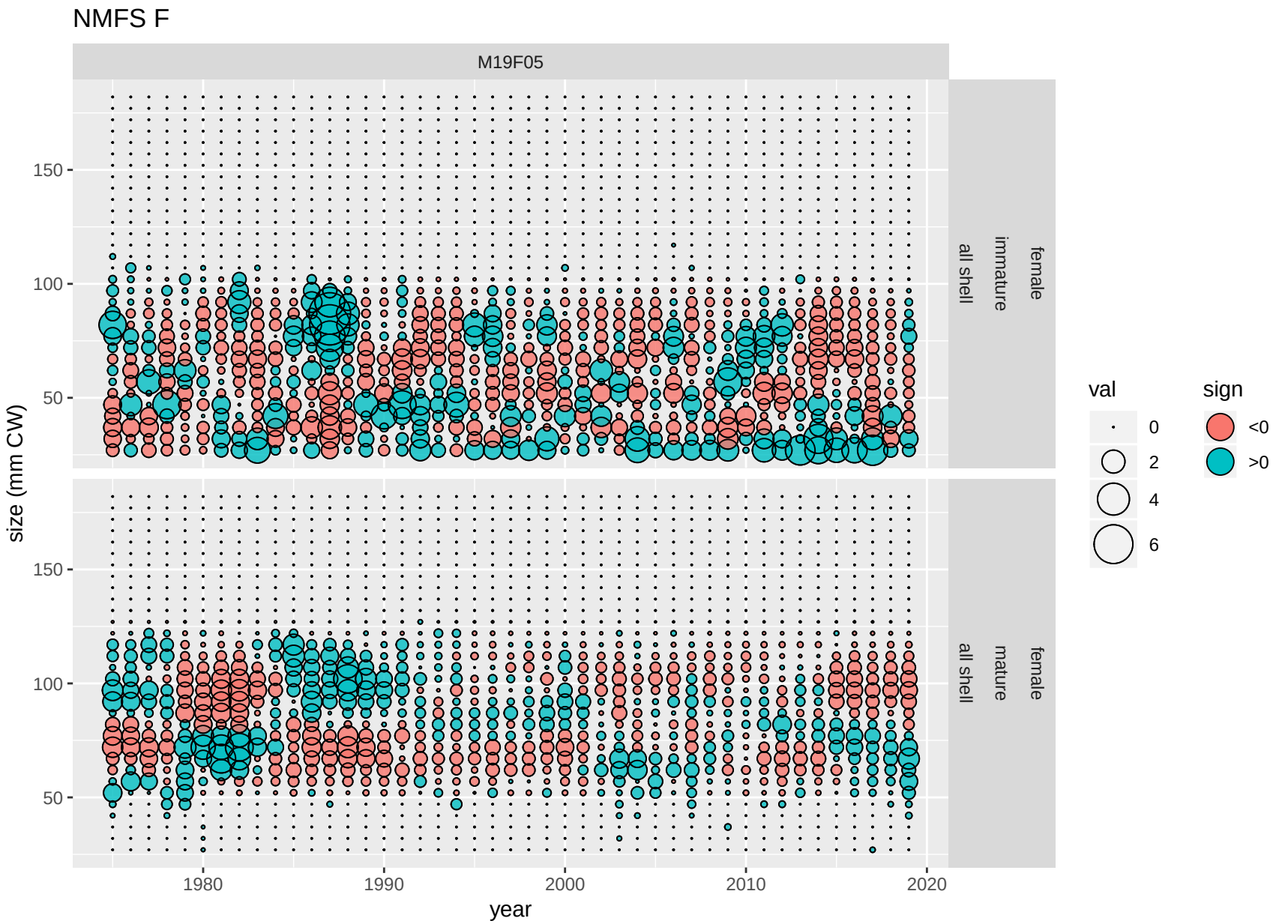


Figure 35: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F05.

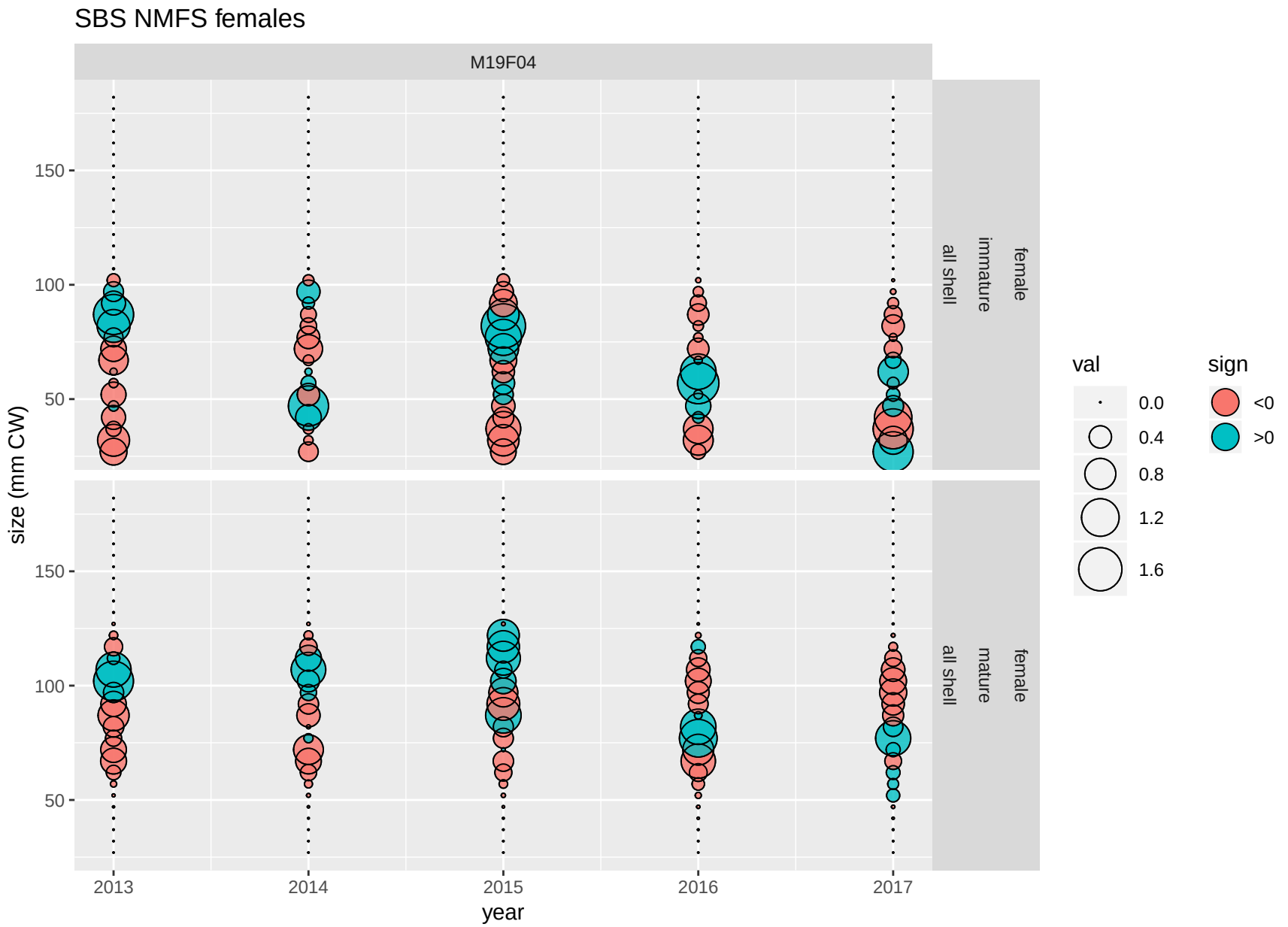


Figure 36: Pearson's residuals for female proportions-at-size from the SBS NMFS females for scenario M19F04.

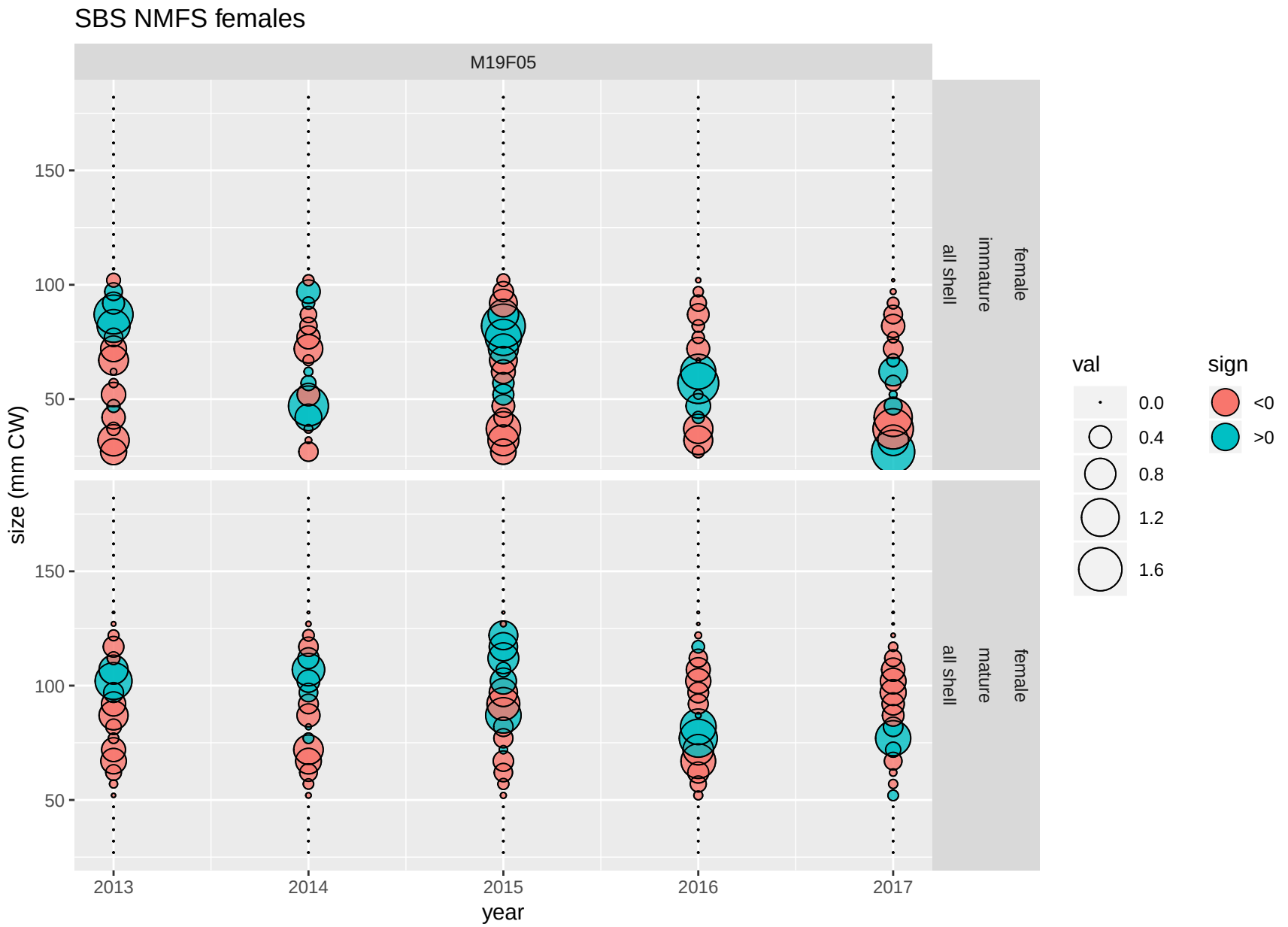


Figure 37: Pearson's residuals for female proportions-at-size from the SBS NMFS females for scenario M19F05.

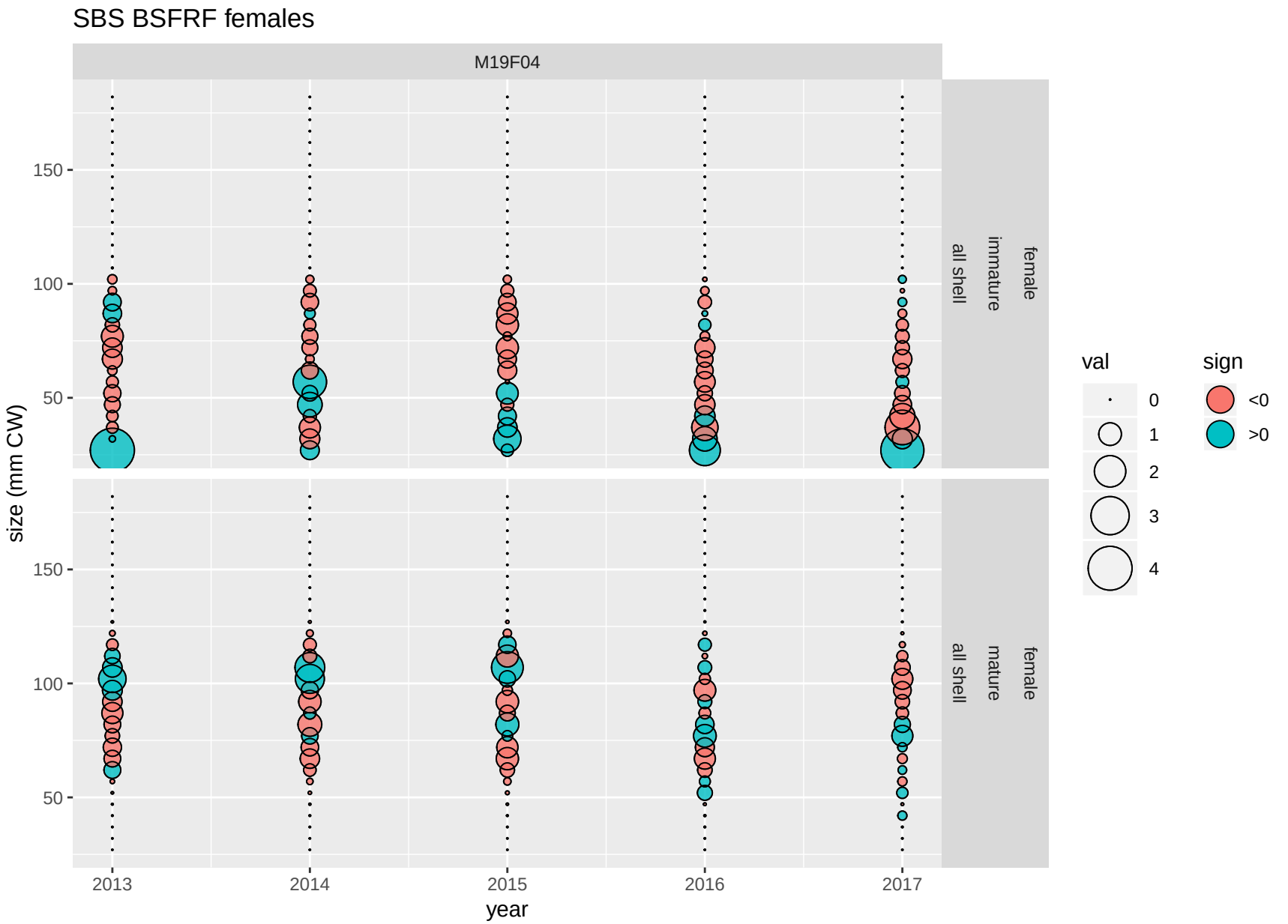


Figure 38: Pearson's residuals for female proportions-at-size from the SBS BSFRF females for scenario M19F04.

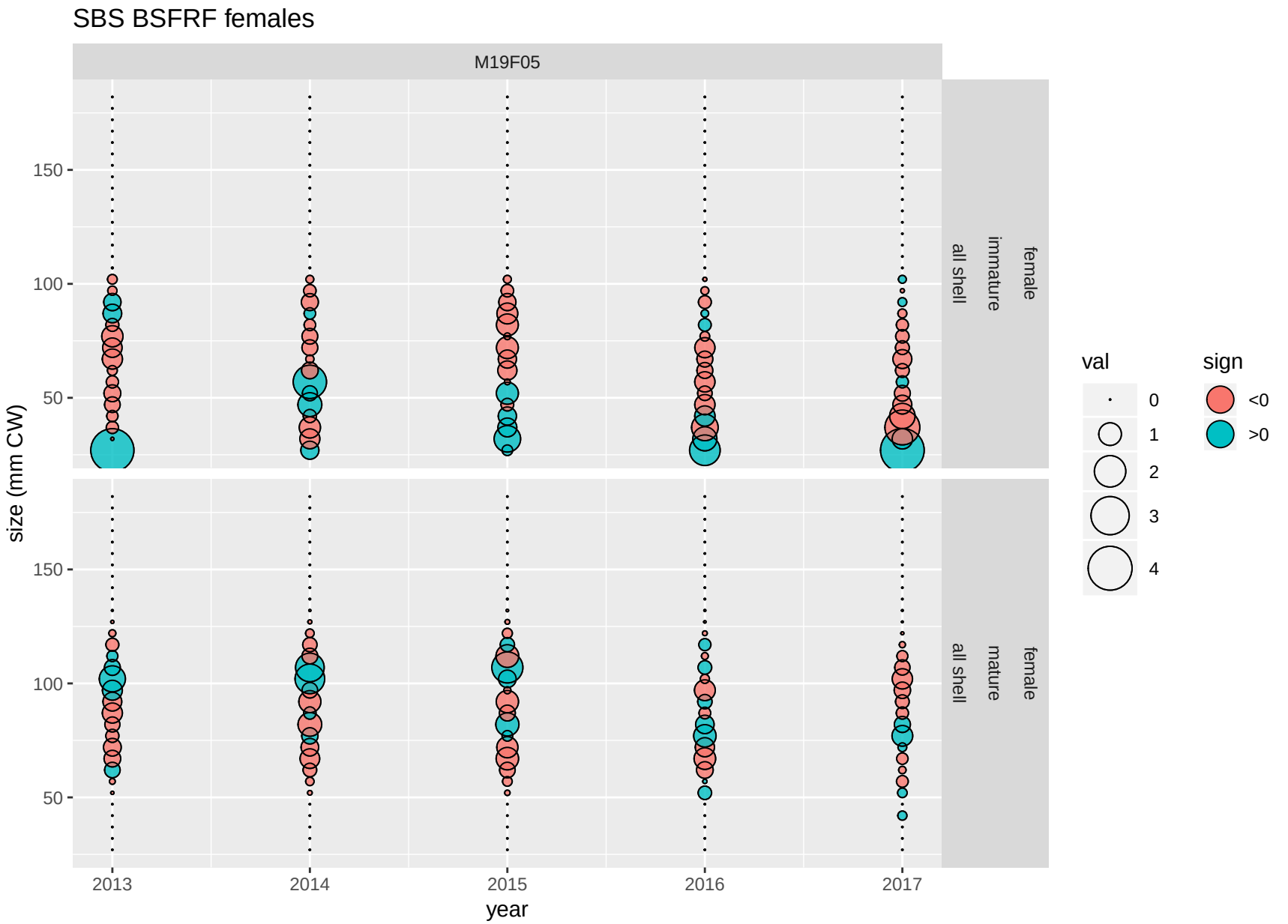


Figure 39: Pearson's residuals for female proportions-at-size from the SBS BSFRF females for scenario M19F05.

Effective sample sizes for survey size compositions

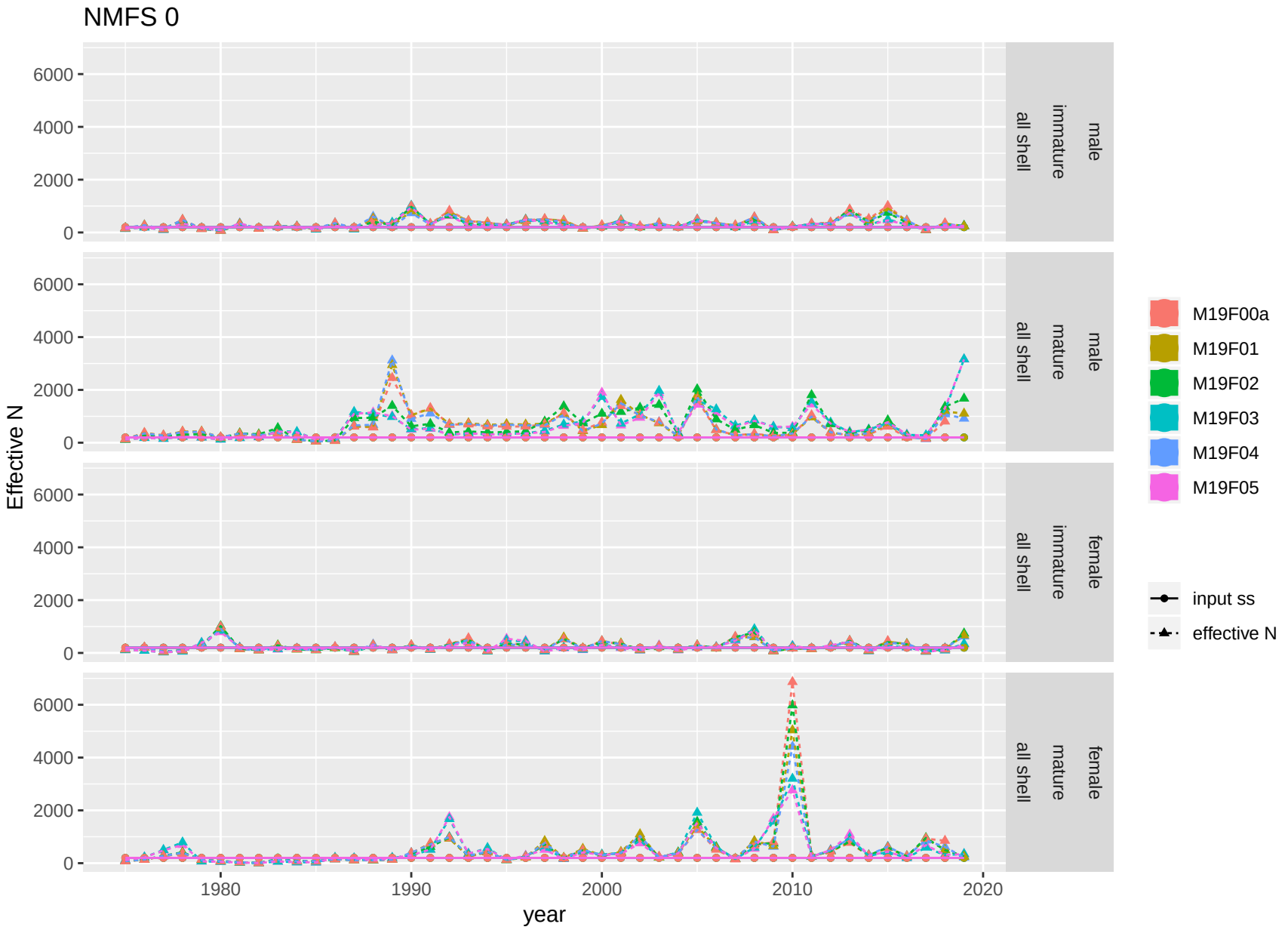


Figure 40: Input and effective sample sizes from retained catch size compositions from the NMFS 0.

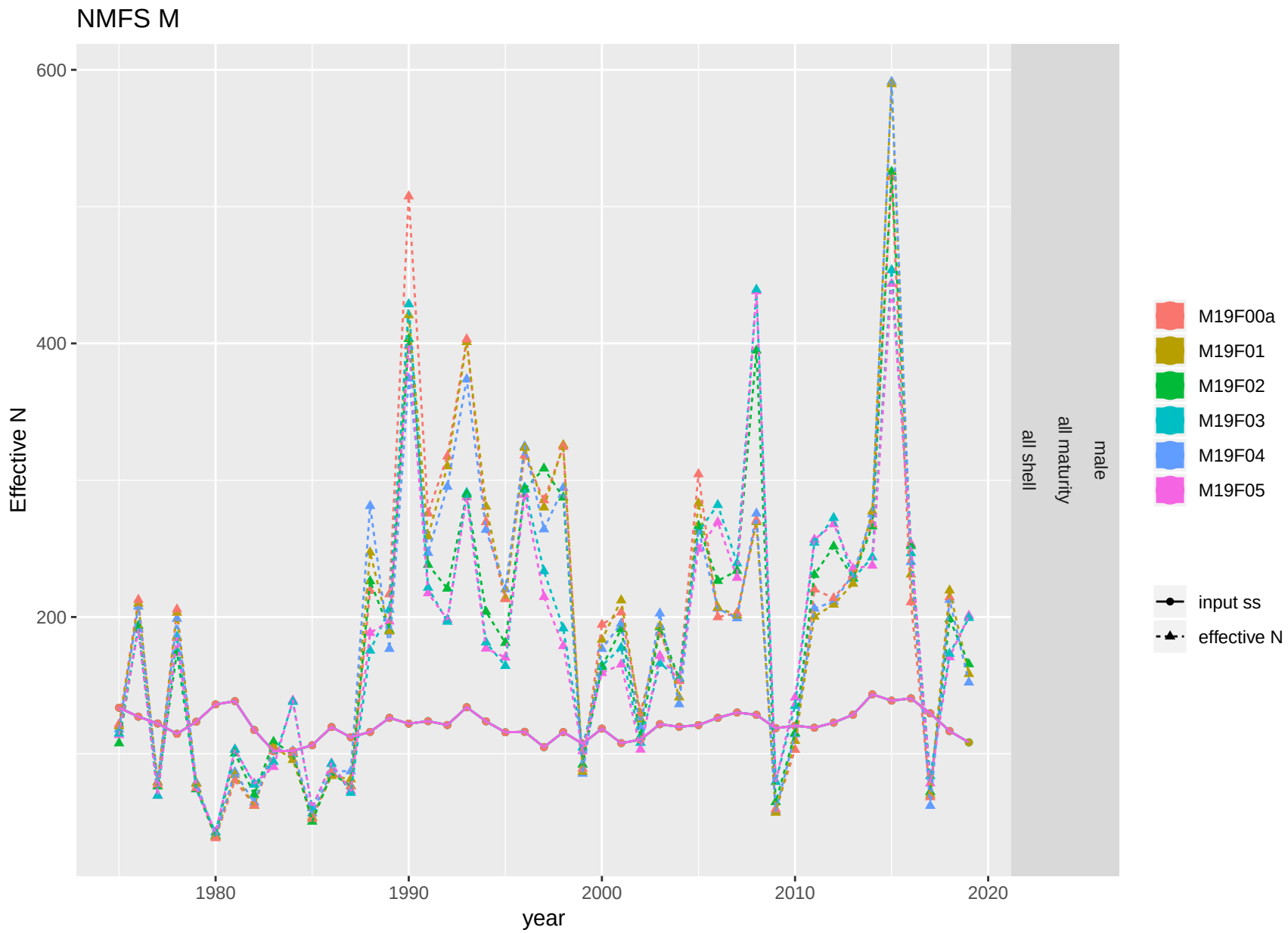


Figure 41: Input and effective sample sizes from retained catch size compositions from the NMFS M.

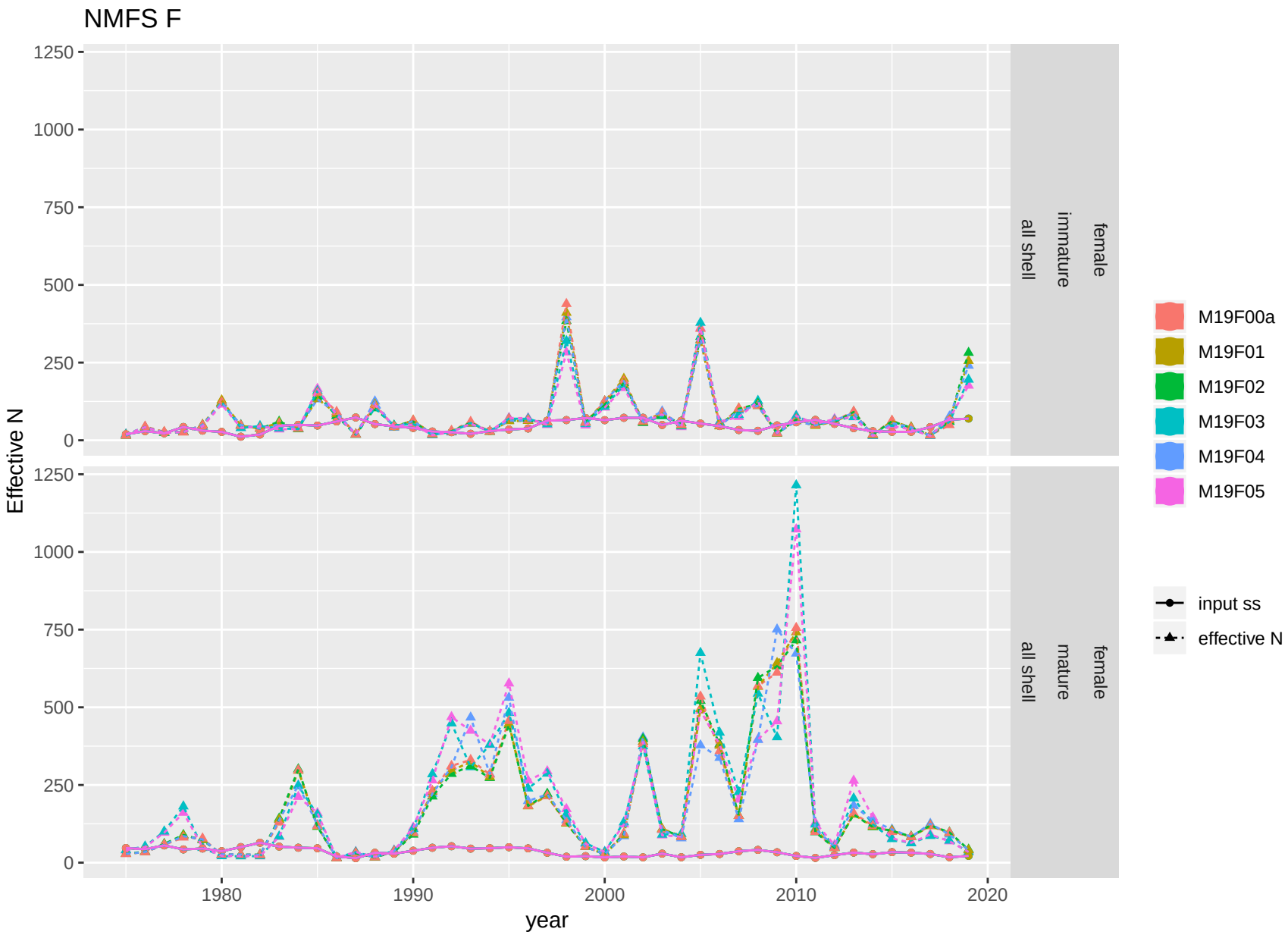


Figure 42: Input and effective sample sizes from retained catch size compositions from the NMFS F.

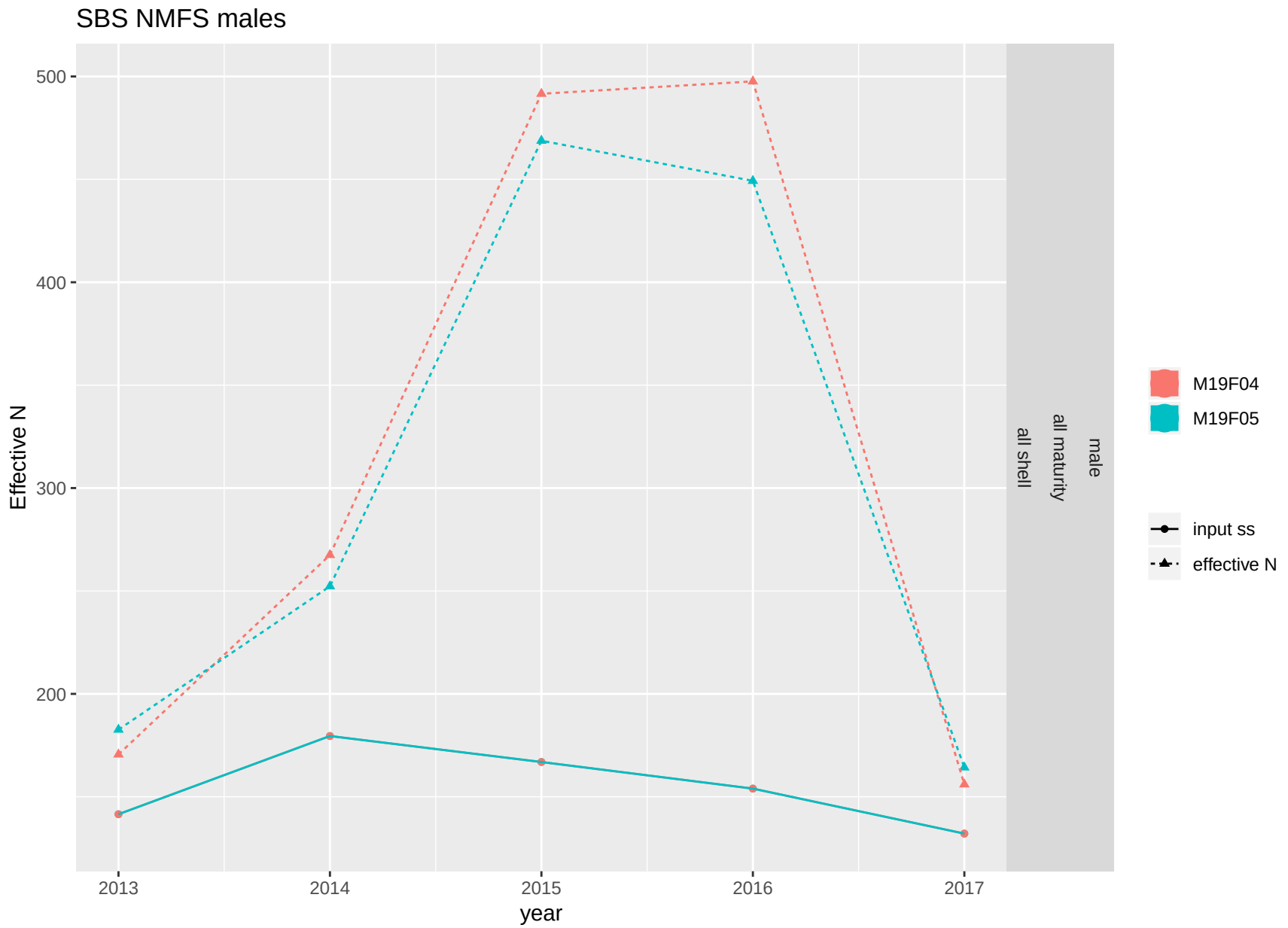


Figure 43: Input and effective sample sizes from retained catch size compositions from the SBS NMFS males.

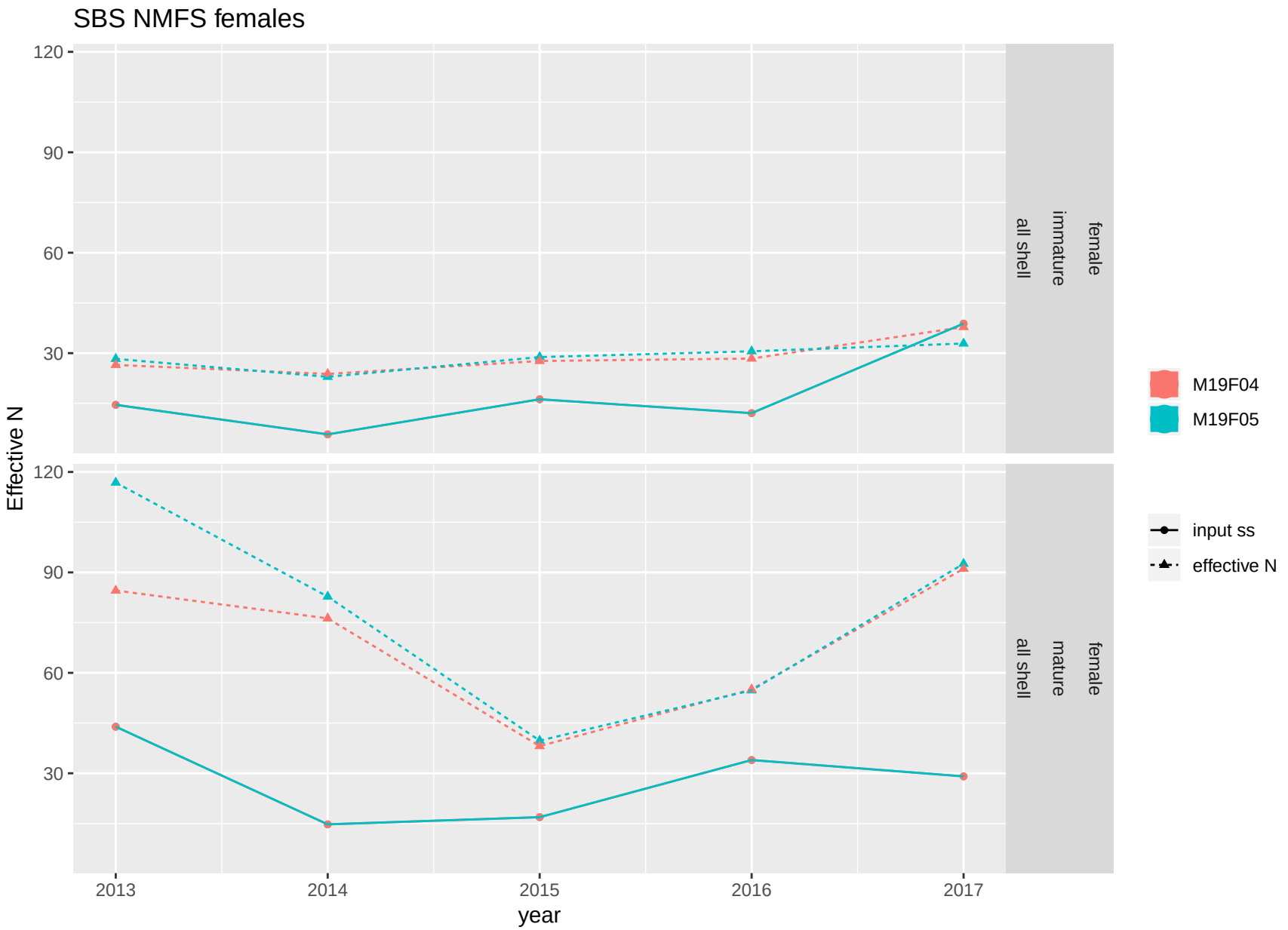


Figure 44: Input and effective sample sizes from retained catch size compositions from the SBS NMFS females.

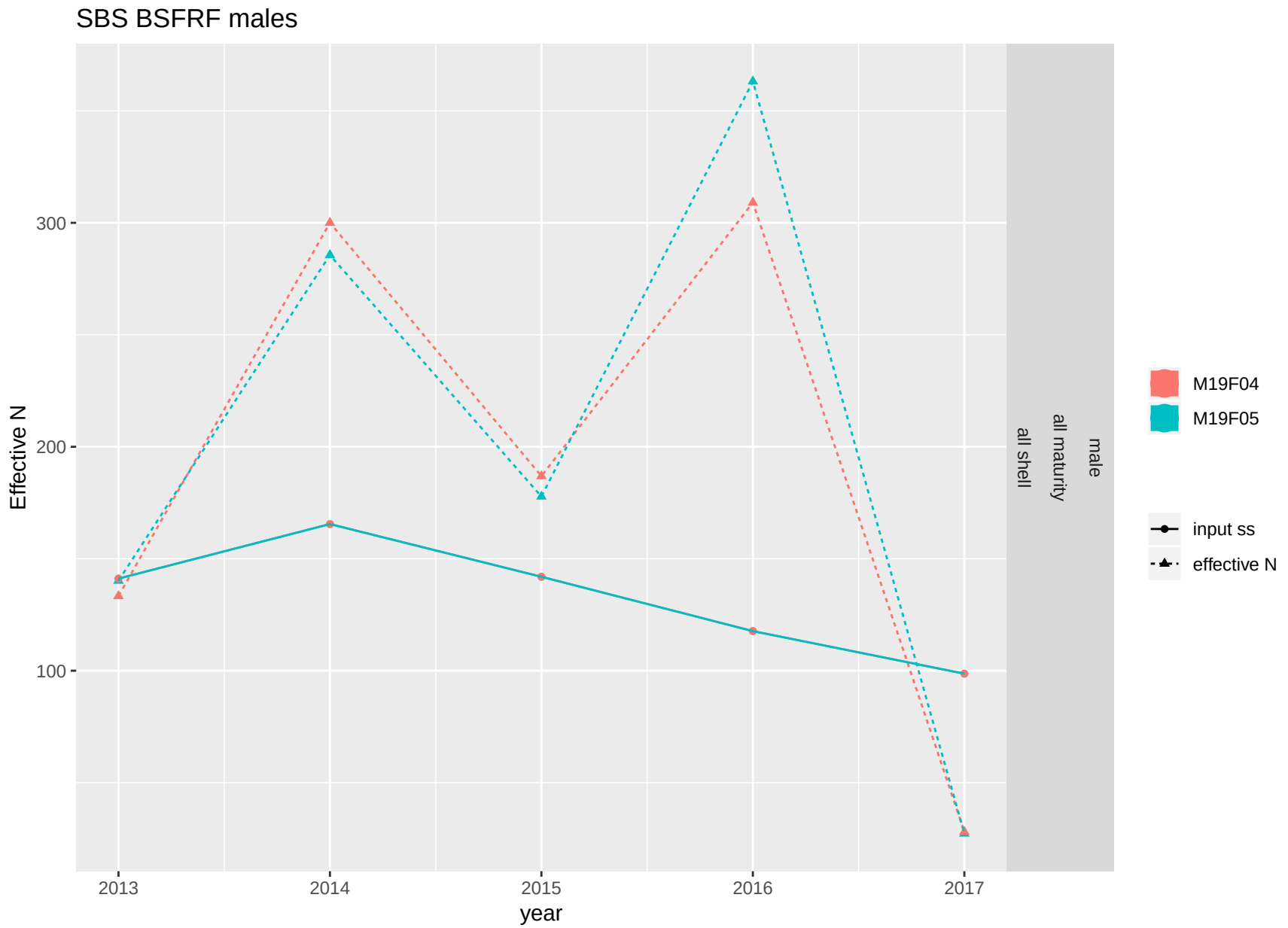


Figure 45: Input and effective sample sizes from retained catch size compositions from the SBS BSFRF males.

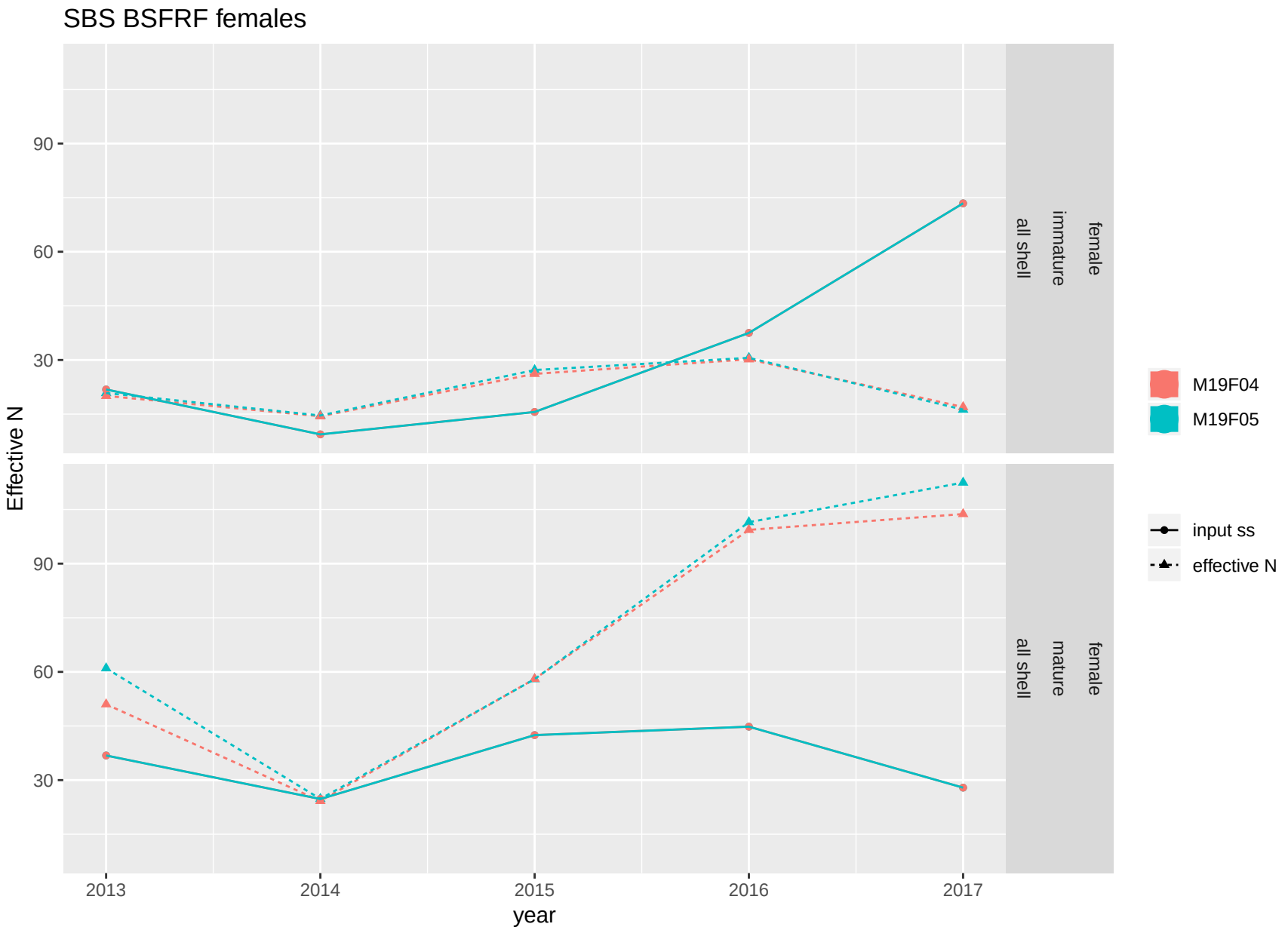


Figure 46: Input and effective sample sizes from retained catch size compositions from the SBS BSFRF females.