2021 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Executive Summary

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

2. Catches: trends and current levels.
Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The NPFMC annually determines the overfishing limit (OFL) and acceptable biological catch (ABC) levels for Tanner crab in the EBS, while the Alaska Department of Fish and Game (ADFG) determines total allowable catches (TACs) separately for areas east and west of 166º W 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.

As a result of the 2012 stock assessment, it was determined that the stock was no longer overfished. The OFL for 2012/13 was determined to be 19,020 t while the ABC was set to 8,170 t based on an adopted “stair-step approach” to re-opening the fishery. In accordance with the State’s harvest strategies for Tanner crab, however, ADFG set the TAC to 0 in both State management areas and closed the directed fishery. The OFL for the following year (2013/14) was determined to be 25,350 t, with an ABC of 17,820 t set using the stair-step approach. ADFG subsequently set the TAC at 746 t (1,645,100 lbs) for the area west of 166º W and at 664 t (1,463,000 lbs) for the area east of 166º W following the State’s harvest control rules. On closing, 80% (594 t) of the TAC was taken in the western area while 99% (654 t) was taken in the eastern area.

The OFL for 2014/15 was determined to be 31,480 t, the largest in all years. The ABC was set at 25,120 t following the end of the stair-step approach to setting ABC. State TACs were set at 3,005 t (6,625,000 lbs) for the area west of 166º W and at 3,847 t (8,480,100 lbs) for the area east of 166º W. On closing, 79% (2,369 t) of the TAC was taken in the western area while 100% (3,829 t) was taken in the eastern area. For 2015/16, The OFL was determined to be 27,190 t (ABC was 21,750 t) while the State TACs were set at 3,808 t (8,396,100 lbs) and 5,113 t (11,272,000 lbs) for the western and eastern areas, respectively. On closing, essentially 100% of the TAC was taken in both areas (3,770 t [8,396,100 lbs] in the western area, 5,108 t [11,260,586 lbs] in the eastern area).

Based on the 2016 assessment (Stockhausen, 2016), the NPFMC determined an OFL and ABC of 25,610 t and 20,490 t, respectively, for the 2016/17 season. However, mature female Tanner crab biomass fell below the threshold set in the State of Alaska’s harvest strategy to open the fishery in either management area; consequently, the TAC for 2016/17 was set to 0 in both management areas and no directed harvest occurred. In 2017/18, the OFL and ABC were very similar to those of 2016/17 (25,420 t and 20,330 t, respectively). ADFG determined that a directed fishery could occur in the area west of 166º W longitude and the TAC was set at 1,134 t (2,500,300 lbs), of which 100% was taken. The OFL for the 2018/19 season decreased to 20,870 t, with an ABC of 16,700 t, and again only the area west of 166º W was opened by ADFG to directed fishing (with a TAC of 1,106 t [2,439,000 lbs]); the resulting harvest (1,106 t [2,433,686 lbs]) was slightly larger than the TAC. The 2019/20 OFL was 28,860 t (the ABC was 23,090 t), but no directed occurred in 2019/20 because mature female biomass once again fell below the State's threshold for opening either management area for the directed fishery. For 2020/21, the OFL was determined to be 21,130 t. Mature female biomass exceeded the State's threshold to open the directed fishery in the area west of 166º W, but not in the eastern area; TAC was set to 1,065 t (2,348,000 lbs) in the western area while the directed fishery was closed in the eastern area. Retained catch in the directed fishery in the west was 655 t (1,444,410 lbs), only 62% of the TAC.

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. Total bycatch in the directed fishery in 2020/21 was 925 t. No bycatch occurred in the directed fishery in 2019/20 because it was closed. The average bycatch over the last five years the fishery was open (i.e., since 2014/15) in the directed fishery was 837 t. Tanner crab are also taken as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a very minor extent, in the scallop fishery. Over the last five years, the snow crab fishery has been the major source of Tanner crab bycatch among these fisheries, averaging ~1,100 t for the 5-year period 2016/17-2020/21. Bycatch in the snow crab fishery in 2020/21 was extremely small at129 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 180 t. Bycatch in the groundfish fisheries in 2020/21 was 125 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 93 t over the 5-year time period. In 2020/21, this fishery accounted for only 6 t of Tanner crab bycatch.

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

3. Stock biomass: trends and current levels relative to virgin or historic levels

For EBS Tanner crab, spawning stock biomass is expressed as mature male biomass (MMB) at the time of mating (mid-February). From the author's preferred model (21.22a), estimated MMB for 2020/21 was 56.3 thousand t. MMB has been on a declining trend since 2014/15 when it peaked at 118.8 thousand t, and it is approaching the very low levels seen in the mid-1990s to early 2000s (1993 to 2003 average: 48.1 thousand t).

4. Recruitment: trends and current levels relative to virgin or historic levels.

From the author's preferred model (21.22a), the estimated total recruitment for 2021 (the number of crab entering the population on July 1) is 997.7 million crab. However, this estimate is informed only by the 2021 NMFS EBS shelf bottom trawl survey and, as such, is highly uncertain. The estimate for last year is 90.1 million crab, but this appears to be partly an artifact associated with the missing 2020 NMFS survey. Average recruitment over the previous 10 years (2010-2009) is 332.5 million crab, which is ~15% less than the long-term (1982+) mean of 390 million crab obtained from the MCMC analysis.

5. Management performance

Historical status and catch specifications for eastern Bering Sea Tanner crab, with 2021/22 values based on the author's recommended model, 21.22a, and MCMC results.

(a) in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.31	56.15	0.00	0.00	0.54	28.86	23.09
2020/21	17.97	56.34	1.07	0.66	0.96	21.13	16.90
2021/22		42.57				27.17	21.74

(b) in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2017/18	33.40	95.49	2.50	2.50	5.22	56.03	44.83
2018/19	45.27	182.09	2.44	2.44	4.18	46.01	36.82
2019/20	40.36	123.77	0.00	0.00	1.20	63.62	50.89
2020/21	39.61	124.19	2.35	1.44	2.11	46.58	37.26
2021/22		93.85				59.89	47.91

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

6. Basis for the OFL

a) in 1000's t.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY}	F_{OFL} (yr^{-1})	Years to define B_{MSY}	Natural Mortality (yr^{-1})
2017/18	3a	29.17	47.04	1.49	0.75	1982-2017	0.23
2018/19	3a	21.87	23.53	1.08	0.93	1982-2018	0.23
2019/20	3b	41.07	39.55	0.96	1.08	1982-2019	0.23
2020/21	3b	36.62	35.31	0.96	0.93	1982-2019	0.23
2021/22	3a	35.94	42.57	1.18	1.17	1982-2020	0.23

b) in millions lbs.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY}	F_{OFL} (yr^{-1})	Years to define B_{MSY}	Natural Mortality (yr^{-1})
2017/18	3a	64.30	103.70	1.49	0.75	1982-2017	0.23
2018/19	3a	48.21	51.87	1.08	0.93	1982-2018	0.23
2019/20	3b	90.53	87.18	0.96	1.08	1982-2019	0.23
2020/21	3b	80.72	77.84	0.96	0.93	1982-2019	0.23
2021/22	3a	79.23	93.85	1.18	1.17	1982-2020	0.23

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

Current male spawning stock biomass (MMB), as projected for 2021/22, is estimated at 42.57 thousand t. B_{MSY} for this stock is calculated to be 35.94 thousand t, so MSST is 17.97 thousand t. Because current MMB > MSST, **the stock is not overfished**. Total catch mortality (retained + discard mortality in all fisheries, using a discard mortality rate of 0.321 for pot gear and 0.8 for trawl gear) in 2019/20 was 0.96 thousand t, which was less than the OFL for 2020/21 (21.13 thousand t); consequently, **overfishing did not occur**. The OFL for 2021/22, based on the author's preferred model (21.22a), is 27.17 thousand t. The ABC_{max} for 2021/22, based on the p^* ABC, is 27.14 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 21.74 thousand t.

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

A. Summary of Major Changes

1. Changes (if any) to the management of the fishery.
The SOA's harvest control rule (HCR) for setting TAC in the directed Tanner crab fisheries has undergone three revisions in the past 6 years (Daly et al., 2020). In 2015, the minimum preferred harvest size used to compute TAC for the area east of 166º W longitude was changed from 140 mm CW (5.5 inches; including the lateral spines) to 127 mm CW (5.0 inches), the preferred size used to compute TAC for the area west of 166º W longitude. In 2017, the criteria used to determine mature female biomass (MFB) was changed from an area-specific one based on carapace width to one based on morphology (the same as that used by the NMFS EBS shelf bottom trawl survey), the definition of 'long-term average' for calculating average mature biomass was changed from 1975-2010 to 1982-2016, the spatial range for calculating average MFB was expanded to include the entire NMFS EBS shelf bottom trawl survey area, and a so-called 'error band system' was introduced to account for survey uncertainty such that the exploitation rate on industry preferred-size males used to calculate was gradually reduced when the lower 95% confidence interval of the point estimate of MFB fell below 40% of the long-term average (replacing a requirement to close the fisheries when MFB fell below the 40% threshold; ADF&G, 2017; Daly et al., 2020). In March 2020, the harvest control rule was again changed based on results from an extensive management strategy evaluation (MSE) conducted with input from industry stakeholders, NMFS and academic scientists, and ADF&G managers (Daly et al., 2020; Shipley et al., 2021). The current HCR (HCR 4_1 in Daly et al., 2020) defines the period for calculating average mature biomass as 1982-2018 and implements sliding scales for exploitation rates on mature males which are functions of the ratios of MMB and MFB to their long-term averages.

The directed Tanner crab fishery east of 166º W longitude has been closed since 2016/17 because mature female Tanner crab biomass in the area has consistently failed to meet the criteria defined in the State's harvest strategy to open the fishery. The directed fishery west of 166º W longitude was also closed in 2016/17 and 2019/20, but was prosecuted in 2017/, 2018/19, and 2020/21.

2. Changes to the input data

Changes to the input data to the assessment consist of: 1) area-swept biomass and size compositions from the 2021 NMFS EBS shelf bottom trawl survey; 2) revised male maturity ogives from the NMFS survey based on a reanalysis of existing chela height/carapace width data augmented with observations from the 2021 survey; 3) new retained catch biomass and size compositions in the directed fishery; 3) expanded total catch and bycatch biomass and size compositions for 2020/21 crab fishery observer sampling in the directed, snow crab, and Bristol Bay red king crab fisheries; 4) expanded total bycatch biomass and size compositions for 2020/21 groundfish observer sampling. The following table summarizes data sources that have been updated for this assessment:

Table: Updated data sources.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019, 2021	no 2020 survey	NMFS
	size compositions	1975-2019, 2021	no 2020 survey	
	male maturity data	2006+	revised data + 2021 survey	
NMFS/BSFRF	molt-increment data	2015-17, 2019	no new data	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	no new data	BSFRF
	size compositions	2013-17	no new data	
Directed fishery	historical retained catch (numbers, biomass)	1965/66-1996/97	not updated	2018 assessment
	historical retained catch size compositions	1980/81-2009/10	not updated	2018 assessment
	retained catch (numbers, biomass)	2005/06-2020/21	East of W166 closed 2020/21	ADFG
	retained catch size compositions	2013/14-2020/21	East of W166 closed 2020/21	ADFG
	total catch (abundance, biomass)	1991/92-2020/21	East of W166 closed 2020/21	ADFG
	total catch size compositions	1991/92-2020/21	East of W166 closed 2020/21	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2020/21		ADFG
	total bycatch (abundance, biomass)	1990/91-2021/21		ADFG
	total bycatch size compositions	1990/91-2020/21		ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2020/21		ADFG
	total bycatch (abundance, biomass)	1990/91-2020/21		ADFG
	total bycatch size compositions	1990/91-2020/21		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)	1991/92-2020/21	now using AKRO algorithm for 2016/17+	NMFS/AKFIN
	total bycatch size compositions	1991/92-2020/21		

3. Changes to the assessment methodology.

The assessment model framework, TCSAM02, is described in detail in Appendix 1. There have been a number of recent changes to the model structure as new capabilities have been developed and new data types have been added. The model accepted for the 2019 assessment, "19.03", differed rather substantially from the 2017 and 2018 assessment models by: 1) adding a likelihood component to fit annual male maturity ogives determined from chela height-to-carapace width ratios in the NMFS survey (the maturity ogives represent a new data source); 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 model fit revised time series data for retained and total catch biomass since 1990/91 provided by ADFG for the directed Tanner crab, snow crab and Bristol Bay red king crab fisheries. The model accepted for the 2020 assessment, "20.07", built on 19.03 by incorporating BSFRF trawl survey data from its cooperative "side-by-side" (SBS) catch comparison studies with the NMFS EBS shelf bottom trawl survey in order to better fix the scale of the NMFS survey data. Empirical availability curves for the BSFRF were determined outside the assessment model (Stockhausen, 2020; Appendix 3). These were used in the model to relate the BSFRF estimates of absolute abundance (at spatial scales smaller than the stock distribution) and the stock abundance estimated by the assessment model. The model model "20.07u" is the base model for this assessment, and represents last year's assessment model, 20.07, with the addition of new fishery and survey data for 2020/21 as outlined in the previous section.

The additional uncertainty introduced into the assessment due to the lack of a 2020 NMFS EBS shelf bottom trawl survey was evaluated in the 2020 assessment (Stockhausen, 2020; Appendix 2) for assessment models 19.03 and 19.03(2020) using: 1) retrospective analyses in which the terminal year was sequentially dropped from the 19.03 dataset, re-run, and compared with results from the same model run without NMFS survey data in the terminal year and 2) model runs with simulated 2020 survey biomass data that bracketed the range of the value expected if the survey had been conducted. However, it appears that the lack of a 2020 survey has also had further (unanticipated) effects on model results once the 2021 survey data is added. More specifically, the estimated recruitment deviation

The author-preferred model for this assessment is Model 21.22a, which differs from 20.07 in a number of respects, perhaps the most substantial being that the likelihoods used to fit fishery biomass data in 21.22a are based on lognormal error distributions, similar to the likelihoods used for survey data, rather than normal error distributions as previously used. This changes the emphasis in fitting the fishery catch biomass data from an absolute scale to a relative scale.

4. Changes to the assessment results
Changes in the assessment results are moderate, reflecting the absence of data from the cancelled 2020 NMFS EBS shelf bottom trawl survey, apparent poor recruitment in 2019/20, and changes to the preferred assessment model. Average recruitment (1982-2018) was estimated at 370 million in last year's assessment, but it is slightly higher at 390 million from the author's preferred model this year. F_{MSY} is larger this year (1.17 yr^{-1} this year vs. 0.93 yr^{-1} last year), but B_{MSY} is smaller (35.94 thousand t vs. 36.62 thousand t). The stock has returned to Tier 3a after two years in Tier 3b because the ratio of projected MMB to B_{MSY} is above 1. Because both average recruitment and F_{MSY} were estimated larger than last year, this year's OFL ended up being smaller larger than that for 2020/21 by 29%.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets (May/June 2021, September/October 2020) of SSC and CPT comments on assessments in general. [Note: for continuity with the previous assessment, the following may include comments prior to the most recent two sets.]

June 2021 SSC Meeting
SSC Comment: Crab assessment should generally follow the default groundfish practice of projecting the current year's catches if one or more fisheries are incomplete at the time of the assessment.
Response (9/21): Noted.

May 2021 CPT Meeting
CPT Comment: No general comments.
Response (9/21): none.

Oct 2020 SSC Meeting

SSC Comment: the SSC requests that the CPT consider developing a standard approach for projecting the upcoming year's biomass that does not include removing the entire OFL for stocks where recent mortality has been substantially below the OFL. This may appreciably change the projected biomass levels for stocks such as Tanner crab, where actual catch mortality has been less than 10% of the OFL.
Response (updated 9/21): The code to project the stock forward for fishing mortality models other than the OFL has not yet been developed for Tanner crab. This capability exists in Gmacs and provides additional motivation for moving the assessment to a Gmacs-based model.

SSC Comment: the SSC encouraged authors to work together to create a standard approach for creating priors on selectivity and catchability from these (BSFRF/NMFS side-by-side trawl) data for use in the respective assessments. A hierarchical comparison of all species pooled, separated species, and separated sexes may be helpful for understanding where statistically supported differences exist. Where sample sizes are modest (e.g., snow crab), bootstrapping, or a sample size-weighted estimate rather than a raw average may be useful for aggregating across years.
Response (updated 9/21): A substantial amount of work has been done to develop a standard approach, using Tanner crab as a test case. See the eAgenda item from the May 2021 CPT Meeting.

Response (updated 9/20): An option to use such priors has also been added to the Tanner crab assessment model code, but has not yet been utilized. Results from a preliminary attempt to develop priors on sex/size-specific catchability (q *x* selectivity) and availability were presented for Tanner crab in the May 2020 CPT Report. Further work estimating catchability outside the assessment model using catch ratio analysis of the BSFRF/NMFS side-by-side trawl data using GAMMs is underway but incomplete (see Appendix 4 for an interim report). A model (20.10) using the "best" estimates (from a limited, preliminary set of candidate models) of sex-specific catchability from this analysis is presented in this chapter, however, the estimated catchability curves are used as "known" in the assessment model rather than as priors partly because the uncertainty associated with the curves has not yet been adequately characterized and partly because assuming the curves are known reduces the complexity of the model. The suggested hierarchical comparison is an intriguing suggestion, and can be addressed in future research.

September 2020 CPT Meeting

CPT Comment: No general comments.
Response (9/21): none.

2. Responses to the most recent two sets (May/June 2021, September/October 2020) 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 2021 SSC Meeting

SSC Comment: The SSC supports the CPT recommended models for September 2021: …Model 20.07, …Model 21.22,… Model 21.22 + pre-specification of growth increments per molt based on external estimates."
Response (9/21): Done. The latter model is denoted "21.24" here.

SSC Comment: The SSC supports CPT recommendations for model development including exploration of methods for reducing the complexity of assumed selectivity and model sensitivity to penalties on time-varying parameters, and exploration of the impact in changing the timeframe for the model.
Response (9/21): See responses to CPT comment below.

SSC Comment: The SSC further requests that September 2021 documentation include plots of standardized residuals for size compositions to ensure residuals are on a reasonable scale following implementation of the Dirichlet-multinomial likelihood.
Response (9/21): Pearson's residuals for fits to size composition data are provided in Appendices D-G. Extreme residuals (absolute value>4) are indicated ("X" marks the spot).

SSC Comment: The SSC also cautions that fixing the Dirichlet-multinomial variance parameter at a large value (specifying the nominal sample size) makes sense, but that support for this weighting must be re-checked for every new alternative model considered in future assessments to ensure data weighting remains consistent with model fit.
Response (9/21): Alternative models with nominal Dirichlet-multinomial likelihoods were first run with the variance parameter estimated. If found to be at the upper bound for a particular dataset, the likelihood was converted to multinomial to allow more straightforward comparison with the base model that used only multinomial likelihoods.

SSC Comment: The SSC supports continued exploration of VAST indices within this assessment and research to evaluate optimal methods for addressing changes in index uncertainty in the context of data weighting.
Response (9/21): No models using VAST indices were requested for this assessment. Jon Richar (NMFS, Kodiak) was able to provide the indices to the assessment author, but time constraints did not allow running models with these data. Continued exploration of the use of VAST data for this assessment will continue.

SSC Comment: the SSC sees no need for continued exploration of the two area-specific VAST models, indicating a preference for post-hoc apportionment from a single model covering the entire Tanner crab stock as needed for spatial management measures.
Response: Done.

May 2021 CPT Meeting
CPT Comment: The CPT recommended the following three models for September 2021: the Base model 20.07 from September 2020, Model 21.22, which implemented the all changes that eliminated the problem of parameters hitting bounds and uses the Dirichlet-multinomial likelihood for size compositions, Model 21.22 + pre-specifying the growth increments per molt based on estimates obtained outside of the model.
Response (9/21): The requested models are addressed in this assessment. The author's preferred model is one based on 21.22. In May, the MLE for 21.22 had no parameters at a bound, which is one reason why it was selected for evaluation in September. The author's preferred model, 21.22a, changed two functions used to describe selectivity from logistic to ascending half-normal and fixed parameters defining the minimum size at full selection for the NMFS EBS Shelf Survey and the BBRKC fishery.

CPT Comment: The data may not support so many selectivity parameters. A reduction in the number of selectivity parameters may be needed.
Response (9/21): The author assumes this comment refers to the number of *estimated* parameters, and agrees. The number of estimated selectivity parameters in the author's preferred model for 2021 (21.22a) has been reduced by XX over that in the 2020 assessment model by re-parameterizing functions used to describe selectivity in the NMFS EBS shelf survey, the snow crab fishery, the BBRKC fishery, and groundfish fisheries from logistic functions to ascending half-normal functions and fixing the size at which crab are fully-selected when these parameters were estimated at upper bounds in intermediate model formulations.

CPT Comment: The CVs for the VAST-based index could be selected about a loess-based smoother rather than the VAST output.
Response (9/21): This is an interesting idea and will be examined for the January 2022 CPT Meeting.

CPT Comment: Some selectivity parameters may be estimated with an AR1 or random walk approach within some year blocks.
Response (9/21): The size at 50% selected for males in the directed fishery is currently modeled as a random walk process, which provides some ability to deal with the growing number of instances in which the directed fishery is conducted in only one management area. In this instance, the author is concerned that selectivity changes functional shape in for a particular year from asymptotic to dome-shaped depending on which combination of management areas is open, rather than that the parameters for a given shape vary. In his recently-defended dissertation, Lee Cronin-Fine found that using time blocks may be more effective from a practical standpoint than using random walks/AR1 processes to model temporal variability in selectivity. However, this is certainly an area open to continued research.

CPT Comment: The early data is not very good and may have an inappropriate influence on some parameter estimates. One approach is to start the model in 1982 and to estimate size compositions and total abundance in the initial year.
Response (9/21): This is a good suggestion but requires either a new capability added to the existing stock assessment model or transition to Gmacs. If the former, this will be addressed at either the January or May 2022 CPT meeting. If the latter, it will probably not be addressed until 2023.

CPT Comment: It may be beneficial to look at the early assessments to see how earlier models fit the data, especially the early data.
Response (9/21): The data fitted in the model has undergone a number of changes over the years (e.g., survey “MMB” was originally, now total male survey biomass is fit; the survey data underwent “standardization” in 2015, etc.), so direct comparisons make little sense. However, doing so would reveal “change points” in the assessment, which may help diagnostically.

October 2020 SSC Meeting
SSC Comment: Serious concerns remain about model convergence. A small percentage of models converge and it is not clear if the model is converging on a global minimum. This should remain a top priority for future work. Efforts should strive to reduce the number of parameters and minimize the number of parameters hitting bounds. Posterior correlations should be thoroughly examined to look for potential sources of the convergence issues.
Response (9/21): Selectivity functions have been re-parameterized from logistic-based functions, which only approach 1 (and thus the size at full selection) asymptotically to ones based on the half-normal that have a maximum value of 1 and reach it at a well-defined size without extraneous normalization. Parameters defining the fully-selected size in the NMFS EBS shelf survey and BBRKC fishery have been fixed at defensible maximum sizes (~largest size seen in the data) when they would otherwise have been estimated at an upper bound. The author’s preferred model, 21.22a, has no parameters on a bound.

SSC Comment: The assessment should include retrospective analyses of each viable candidate model.
Response: Retrospective analyses were conducted for both 21.22a (the only viable candidate with no parameters at bounds) and 20.07u, the base model with 2020/21 data.

SSC Comment: The SSC agreed with the CPT not to use the MCMC runs, and asks that next year’s assessment include a rationale if MCMC is used to recommend management advice.
Response: Using the delta-approximation to estimate uncertainty in a complex model can result in biased estimates. Thus, basing the OFL and max ABC (the p-star ABC) on MCMC runs should be, when possible, the preferred approach (as used in this assessment). However, MCMC runs entail a considerable processing burden and it would simplify the assessment process if they could be avoided. This will

involve a fair amount of re-coding because the OFL/ABC calculations using MCMC do not use ADMB's automatic diferentiation ("AD") variables (AD is not used to obtain derived quantities like the OFL and ABC, so it was more efficient from a computer memory standpoint to code them as non-AD variables). However, it will be relatively efficient to, at the same time as converting the OFL/ABC calculations to AD variables, add some form of the requested projection code to the assessment model.

SSC Comment: The SSC also endorses Alaska Bering Sea Crabbers' (ABSC) request to include raw numbers used for PSC limits in a table in the EBS Tanner crab SAFE consistent with EBS snow crab (see Table 11 in the EBS snow crab SAFE), if it is practical to do so.
Response (9/21): The requested information has been added to the SAFE chapter (Table 51). Note that the abundance information is also (and has been in previous assessments) provided in csv format by year, sex, maturity state, shell condition, and size as a zipped file ("TannerCrab.PopSizeStructure.csv.zip") on the eAgenda web page for this meeting (and previous meetings).

SSC Comment: The State of Alaska's harvest control rule was recently changed and involves females. This leads to a disconnect between the federal catch specification process represented by this assessment and state fishery management. Thus, regarding future research, the SSC recommends exploring a stock-recruit relationship incorporating females, including an examination of different hypotheses about the roles of females in stock dynamics. Also, as noted in the assessment, the State manages this fishery as two separate areas but this assessment considers a single EBS-wide stock. In summary, modifications to the assessment should be considered to the extent practicable that bridge these state-federal disconnects and facilitate application of the stock assessment to the State's harvest strategy for fishery management.
Response (9/21): The author supports the ideas for future research outlined in this comment. As a note, the State's harvest strategy has always involved consideration of females—although previously as thresholds to opening the fisheries and currently to determine the maximum exploitation rate allowed on males.

SSC Comment: In response to SSC comments, the authors suggested that the current model cannot do likelihood profiles because of lack of functionality of ADMB. The SSC suggests that ADMB has the functionality to do likelihood profiles through the software, and looks forward to reporting of these results in next year's SAFE. It may be helpful to help diagnose convergence issues if the sensitivity to each data source is explored.
Response (9/21): In the author's experience, the ADMB software provides the ability to perform likelihood profiling on a specific variable, with the output written to a file being the total objective function values (the likelihood profile) as a function of the variable profiled over. Several variables can be profiled simultaneously. However, what is of interest here is not only how the total objective function depends on the variable being profiled, but on how the individual components of the likelihood change. The author has developed R code that allows one to obtain the values for the individual components (and any other model output). Results from likelihood profiling on male mean growth parameters were presented to the CPT in the Tanner crab report for the May 2021 CPT Meeting.

SSC Comment: In Table 35 on p. 94, the heading refers to old model numbering, but the column headings utilize new model naming conventions. Please revise the header to utilize the new model naming conventions. The same applies to Table 36 on p. 95. Please check for other instances.
Response (9/21): The author appreciates the notification. Table captions have been checked in this document for consistency with model naming conventions.

September 2020 CPT Meeting
CPT Comment: Evaluate the use of half-normal curves for selectivity rather than logistic functions.
Response (9/21): Half-normal curves have been adopted for use to describe selectivity of both sexes in the NMFS EBS Shelf Survey and BBRKC fishery bycatch. This process is taking a step-by-step approach, as well as an "if it ain't broke, don't rush to fix it" sense of prioritization. The logistic function descriptions

for the aforementioned surveys and fisheries were problematic in one form or another. The change to half-normal seems to be an improvement, and applying it to the other fleets will continue.

CPT Comment: To improve model performance, evaluate the use of a bounding function to the likelihood to keep parameters from approaching bounds.
Response (9/21): This is a good suggestion and will be followed up on prior to the May 2022 CPT Meeting.

CPT Comment: It is somewhat disconcerting how many model parameters are devoted to modeling bycatch, which is not important in the stock dynamics (see report section on PSC limits). Consider ways to model bycatch fisheries more parsimoniously. It was noted that using a low accumulator size might help to address these issues.
Response (9/21): The author similarly finds it disconcerting and supports this research suggestion. There would probably be no impact on current stock dynamics if current bycatch in the BBRKC fishery (at least) were completely ignored. However, the assessment uses data (and associated annual parameter estimates) on current bycatch and effort to estimate bycatch levels in the past (pre-1990, when bycatch was thought to be much larger) based on contemporaneous effort data and a bycatch-to-effort ratio estimated from current data. Consequently, the parameters influencing estimates of current bycatch need to themselves be estimated. It will be worthwhile determining if anything is lost by estimating a constant fishing mortality rate, rather than an annually varying one, for (say) the post-1996 period for bycatch in the BBRKC fishery.

CPT Comment: Survey catchability in the early period is still hitting the parameter bound. Evaluate using a prior for survey catchability in the early period that is the same as the prior for catchability used for the main part of the survey time series.
Response (9/21): Given the different spatial coverage of the NMFS survey in pre-1982 and post-1981 periods, it seems unlikely that using the same prior on catchability for both periods can be justified. Fortunately, this issue became moot (for the time being) because catchability is no longer estimated at its lower bound (the bounds on these parameters were increased in the new models presented at the May 2021 CPT Meeting and considered here—the 21.XX models).

CPT Comment: Evaluate potential conflicts between data sets in the assessment using likelihood profiles and other approaches.
Response (9/21): Likelihood profiles were used to examine the conflicts among datasets with regard to changes in the estimated mean post-molt growth parameter for males, with results reported at the May 2021 CPT Meeting.

CPT Comment: Evaluate methods for model tuning or estimation of additional variance terms to address issues with model giving too much weight to fitting survey biomass estimates.
Response (9/21): The models considered in this assessment do not fit to VAST model-based survey estimates, so additional variance terms were not employed. This remains an area for future research, however.

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; Murphy, 2020). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit (Figure 1). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although males less than the industry-preferred size (>125 mm CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 60°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

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

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

4. Life history characteristics

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

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

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

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

b. Growth

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

Growth in immature Tanner crab larger than approximately 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). Rugolo and Turnock (2012a) derived growth relationships for male and female Tanner crab from data on observed growth in males to approximately 140 mm carapace width (CW) and in females to approximately 115 mm CW collected near Kodiak Island in the Gulf of Alaska (Munk, unpublished.; Donaldson et al. 1981). These relationships were used as priors for estimated growth parameters in older (2012-2016) assessments (Rugolo and Turnock, 2012; Stockhausen, 2013; 2014; 2015; 2016). 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. In Models 20.07u, 21.22, and 21.22a, the molt increment data is fit simultaneously with all other assessment data "inside" the assessment model; in Model 21.24, the molt increment data was fit "outside the model" in a previous analysis (Stockhausen, 2019a) and used to fix relevant parameters on mean post-molt size in the model.

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). Jon Richar (AFSC Kodiak) has recently (May, 2021) conducted a revised analysis of the weight-at-size data for Tanner crab that incorporates shell condition as a factor in the analysis. The CPT, however, has not had a chance to review models based on the new relationships; thus, this assessment uses the previously-established relationships. The parameter values for the relationships used in this assessment 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, all models include fits to 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 (J. Richar, AFSC Kodiak, pers. comm.), 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.

g. Mortality

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

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

5. Brief summary of management history.

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

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

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

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

Most recently, the harvest strategy was changed in March 2020 based on results from an extensive management strategy evaluation (MSE) conducted with input from industry stakeholders, NMFS and academic scientists, and ADF&G managers (Daly et al., 2020; Shipley et al., 2021). The current HCR (Figure 3; HCR 4_1 in Daly et al., 2020) defines the period for calculating average mature biomass as 1982-2018 and implements sliding scales for exploitation rates on mature males which are functions of the ratios of MMB and MFB to their long-term averages. One particularly notable change is that there is no longer a threshold for opening the fisheries based on MFB.

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

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; Figure 4). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery. Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand t in 1977/78. Landings fell sharply after the peak in 1977/78 through the early 1980s, and domestic fishing was closed in 1985/86 and 1986/87 due to depressed stock status. In 1987/88, the fishery re-opened and landings rose again in the late-1980s to a second peak in 1990/91 at 16.61 thousand t, and then fell sharply through the mid-1990s. It was formally declared overfished by NMFS in 1999. 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 coincident with rationalization of the crab fisheries and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Table 3). 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. Additionally, the stock was once again declared overfished by NMFS in 2012 based on low survey estimates of mature male biomass. However, following a change in Tier level from 4 to 3 based on development and acceptance of a Tier 3 assessment model later in 2012, the stock was declared to no longer be overfished under Tier 3 rules. Tthe female stock metrics surpassed the State harvest strategy thresholds 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. In 2014, TAC was set at 6,625,000 lbs (3,005 t) for the area west of 166º W and at 8,480,000 lbs (3,846 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. In 2015, TAC was set at 8,396,000 lbs (3,808 t) in the western area and 11,272,000 lbs (5,113 t) in the eastern area. On closing, essentially 100% of the TAC was taken in each area (3,798 t in the west, 5,111 t in the east). The total retained catch in 2015/16 (8,910 t) was the largest taken in the fishery since 1992/93 (Tables 1, 2; Figures **4** and 5). The directed fisheries in both areas were closed in 2016/17 because mature female biomass in the NMFS EBS Bottom Trawl Survey did not exceed the threshold set in the SOA’s harvest strategy to allow them to open. Total retained catch was thus 0 in 2016/17. In 2017/18, the SOA allowed a limited directed fishery west of 166º W longitude but closed the fishery east of 166º W. Essentially, the entire TAC (1,130 t) was taken in 2017/18. The 2018/19 season followed a similar pattern, with the directed fishery closed in the eastern area and open in the western area (with a TAC of 1.106 thousand t). The entire TAC was again harvested in 2018/19. The directed fisheries in both subdistricts were again closed in 2018/19 because mature male biomass failed to achieve the required threshold in either the eastern or western management areas. In 2020/21, the State criteria for opening the fishery were met in the western area, and the TAC was set to 1,065 t. At the close of the fishery (March 31, by State regulation), 655 t had been harvested.

Tanner crab can be incidentally retained in the snow crab and BBRKC fisheries, up to a limit of 5% of the target species. In general, incidental retention in these fisheries has been small compared with that of the directed fishery (Table 4, Figure 5), although the snow crab fishery was responsible for a sizable fraction of the landed catch in 2005/06 and 2006/07.

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 (Tabled 5-7; Figures 8 and 9). 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. In the early-1970s, the groundfish fisheries contributed substantially to total bycatch losses (although bycatch in the crab fisheries was undocumented at the time). From the early 1990s (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 snow crab fishery has generally accounted for the largest proportion of Tanner crab taken as bycatch, accounting for 363 t on average over the past 5 years (compared with 186 t for the directed fishery and 100 t for the groundfish fisheries, respectively, during the same time frame).

D. Data

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

1. Summary of new information

Fishery data for total and retained catch in the directed fishery, and for bycatch in the snow crab and BBRKC fisheries was provided by ADFG (Ben Daly, ADFG, pers. comm.). Data on bycatch in the groundfish fisheries from the groundfish observer program and the AKRO was downloaded from AKFIN Answers (https://akfin.psmfc.org) on Aug. 3, 2021.

The directed fishery in 2020/21 was conducted only in the area west of 166º W longitude. Retained catch in the directed fishery was 655 t, about 65% of the TAC (1,065 t; Tables 3, 4, Figures 4, 5). The snow crab and BBRKC fisheries are allowed to retain incidentally-caught legal-sized Tanner crab males up to 5% of the target catch. In 2020/21, the snow crab fishery harvested 2.3 t of incidentally-retained Tanner crab while the BBRKC fishery took 0.0 t (Table 4). The mode for the size composition of retained catch in 2020/21 was shifted to somewhat smaller sizes when compared with those for 2017/18 and 2018/19 (Figure 6). Only about 40% of the retained catch was new shell crab. This exceeded the percentage of new shell crab in 2018/19 (26%), but was less than the percentage in other recent years (Figure 7).

The total catch of Tanner crab (females, sublegal males, legal males) during 2020/21 in the directed, snow crab, BBRKC, and groundfish fisheries, based on crab and groundfish fishery observer sampling, was 1,843 t (Table 5, Figure 8). Using the subtraction method (discards = total catch – retained catch) and applying gear-specific discard mortality rates of 0.321 for pot and fixed gear and 0.800 for trawl gear, total Tanner crab mortality due to all fisheries was 1,086 t (Table 6, Figure 9), with the majority due to retention in the directed fishery. The total mortality associated with Tanner crab bycatch was 429 t in 2020/21, which was almost identical to that in 2019/20 (Table 7), despite the lack of a directed fishery in 2019/20. The majority of bycatch mortality in 2020/21 was attributed to the directed fishery (297 t) while in 2019/20 it was attributed to bycatch in the snow crab fishery (327 t). The mode for the male total catch size compositions in the directed fishery was similar to that in 2018/19 (a year in which the fishery was also closed east of 166º W), but the distribution was somewhat skewed to smaller sizes while that in 2018/19 was skewed to larger sizes (Figures 10, 11). The size composition for female total bycatch in the directed fishery was centered on the same size range in 2020/21 as in 2018/19, but was marginally less extensive. Total bycatch size compositions for males dominated those for females in the snow crab and BBRKC fisheries (Figures 12, 13), reflecting the much smaller bycatch of females relative to males in those fisheries. Size compositions in the snow crab fishery, conducted primarily west of 166º W, were shifted to only slightly smaller sizes than in the directed fishery in 2020/21, in contrast to earlier years when the directed fishery was prosecuted in both and the shift was more pronounced. Observed bycatch of Tanner crab in the BBRKC fishery was negligible in 2020/21 (only 4 females were sampled, and only 106 males). In previous years, male bycatch size compositions in the BBRKC fishery, which is conducted primarily east of 166º W, have been shifted to larger sizes than in the directed fishery even when the directed fishery is conducted east of 166º W.

Tanner crab bycatch in the groundfish fisheries was shifted to small sizes (with a mode ~75 mm CW) for both males and females in 2020/21 whereas the mode for males in 2019/20 was much larger (~125 mm CW; Figures 14, 15)

Effort in the directed fishery was marginally higher in 2020/21 (35,000 potlifts; Table 8) compared with the last year the directed fishery was open (30,000 potlifts), while effort was reduced in the snow crab and BBRKC fisheries from last year (172,000 this year vs. 189,000 last year in the snow crab fishery; 21,000 this year vs. 35,000 last year in the BBRKC fishery).

Over 3,300 males were sampled for size composition in the retained catch data in 2020/21, almost identical to the number sampled in 2018/19 (Table 9). For total catch size compositions, approximately 18,000 males and 1,000 females were sampled at sea by crab fishery observers in the directed fishery. In contrast, only 800 males and 10 females were sampled in 2020/21 as bycatch in the snow crab (a reduction of a factor of 10 from the previous year), while even smaller numbers (100 males and 4 females) were sampled by observers as bycatch in the BBRKC fishery (Table 10). In the groundfish fisheries, observers sampled approximately 2,500 females and 7,400 males taken as bycatch for size composition data in 2020/21 (Table 11).

Tanner crab biomass in the 2021 NMFS EBS shelf bottom survey increased marginally for both sexes in both State management areas over the very low values obtained in the 2019 survey, with males increasing from 28 thousand t to 31 thousand t and females increasing from 9.6 thousand t to 11.7 thousand t for the entire EBS (Table 12, Figure 16). For females, it was the largest value since 2015 but for males it was the second smallest since 2002. It was also the lowest biomass of industry preferred-size males since before 2002. In terms of abundance in the survey, the results were a little more complex (Table 13, Figure 17).

Males were down from 161 million in 2019 to 155 million in 2021 in the western management area, but up in the eastern area (59 million in 2021 from 47 million in 2019). Comparisons for female abundance exhibited similar patterns. For preferred-size males, biomass in the EBS was the lowest since 1999 (4.4 thousand t), split fairly evenly between the eastern and western management areas (2.4 vs. 2.0 thousand t; Table 14, Figure 16). Old shell males dominated the preferred-size male biomass over new shell males by ~4:1 in the western area, while new shell males were more prevalent in the eastern area. Similar trends were evident in the estimated abundances of industry preferred-size males in the survey (Table 15, Figure 17).

Recent size compositions from the NMFS EBS shelf survey (2017-2021) indicate relatively large numbers of small crab entering the stock in the western management area (Figures 18, 19) compared with both the eastern management area and surveys in 2015 and 2016. However, these recruitment pulses are not particularly evident in subsequent years and have not contributed to increases in stock biomass as may have been expected.

Male maturity ogive data used in the assessment was updated this year using data from the 2021 survey and a new size-specific cutpoint analysis to characterize new shell males as immature or mature based on chela height to carapace width ratios (J. Richar, NMFS Kodiak, pers. comm.). In addition to data from the 2021 survey, the new dataset (Figure 20) includes more samples from earlier surveys, including expanded sample sizes for the 2006 and 2007 surveys and new data from the 2009 and 2011 surveys.

No new molt increment (growth) data was collected this year (Figure 21). The last collection occurred in 2019.

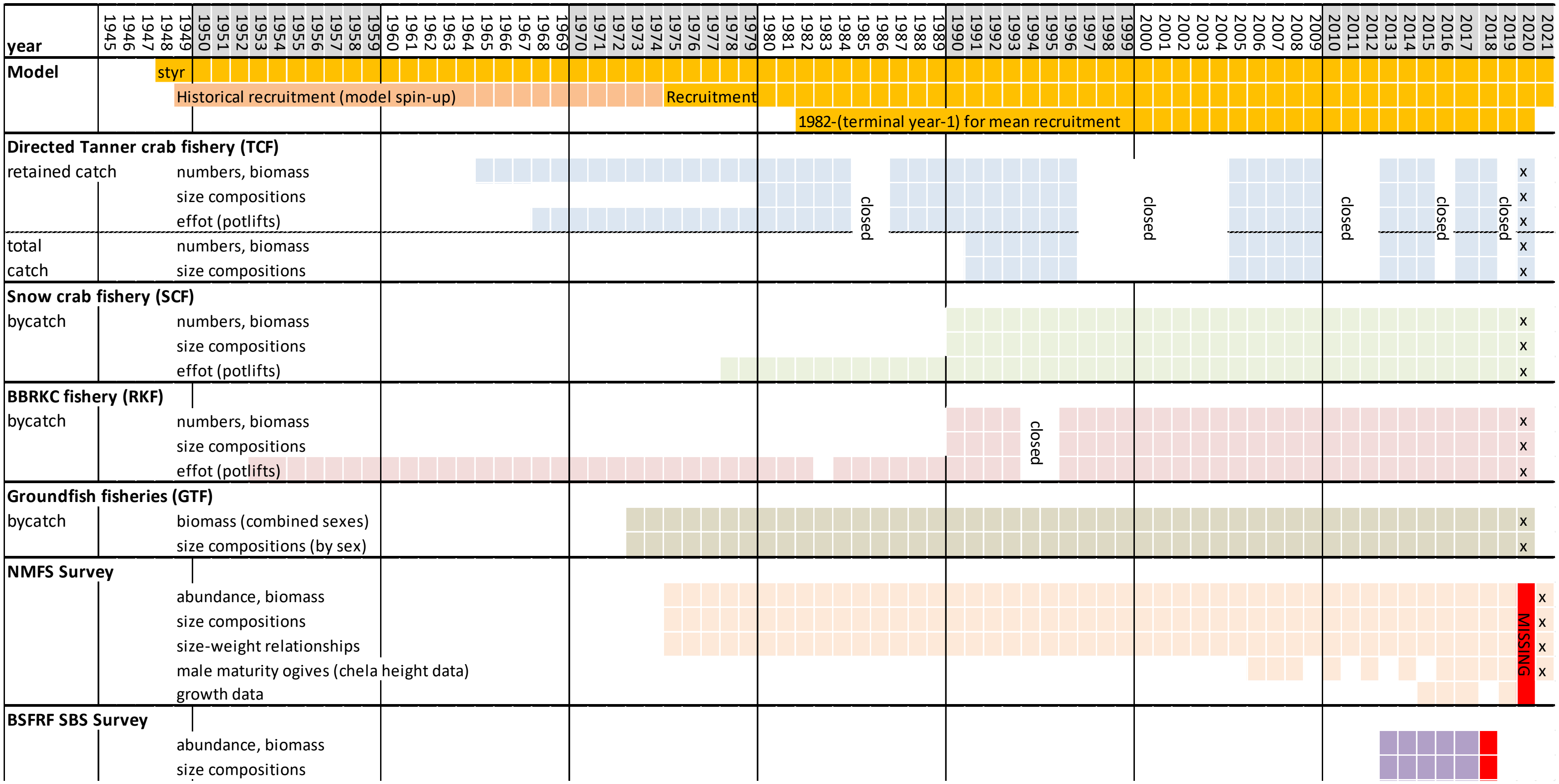
The following table summarizes data sources that have been updated for this assessment:

Table A. Data sources updated for 2020/21.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019, 2021	no 2020 survey	NMFS
	size compositions	1975-2019, 2021	no 2020 survey	
	male maturity data	2006+	revised data + 2021 survey	
NMFS/BSFRF	molt-increment data	2015-17, 2019	no new data	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	no new data	BSFRF
	size compositions	2013-17	no new data	
Directed fishery	historical retained catch (numbers, biomass)	1965/66-1996/97	not updated	2018 assessment
	historical retained catch size compositions	1980/81-2009/10	not updated	2018 assessment
	retained catch (numbers, biomass)	2005/06-2020/21	East of W166 closed 2020/21	ADFG
	retained catch size compositions	2013/14-2020/21	East of W166 closed 2020/21	ADFG
	total catch (abundance, biomass)	1991/92-2020/21	East of W166 closed 2020/21	ADFG
	total catch size compositions	1991/92-2020/21	East of W166 closed 2020/21	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2020/21		ADFG
	total bycatch (abundance, biomass)	1990/91-2021/21		ADFG
	total bycatch size compositions	1990/91-2020/21		ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2020/21		ADFG
	total bycatch (abundance, biomass)	1990/91-2020/21		ADFG
	total bycatch size compositions	1990/91-2020/21		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)	1991/92-2020/21	now using AKRO algorithm for 2016/17+	NMFS/AKFIN
	total bycatch size compositions	1991/92-2020/21		

The following table summarizes the data coverage in the assessment:

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



2. Data presented as time series

For the data presented in this document, the convention is that 'year' refers to the year in which the NMFS bottom trawl survey was conducted (nominally July 1, yyyy), while the 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 by fishery year. More detailed information on retained catch in the directed domestic pot fishery prior to the crab fishery rationalization in 2005 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), number of vessels participating in the directed fishery, and the fishery season. Table 3 lists federal management quantities overfishing limits and acceptable biological catches (OFLs and ABCs), State total allowable catches (TACs) by management area, and retained catch by management area following rationalization in 2005. Figures 4 and 5 summarize the retained catch history.

Directed fisheries for Tanner crab in the EBS began in 1965. Retained catch has followed a "boom-and-bust" cycle over the years, with the fishery experiencing periods of rapidly increasing catches followed by rapidly declining ones, after which it is closed for a time during which the stock partially recovers. Retained catch increased rapidly from 1965 to 1975, reaching ~ 25,000 t in 1970. It declined to ~13,000 t in 1973/74 coinciding with the termination of Russian fishing and the beginning of the domestic pot fishery. It increased again, this time to its highest level, in 1977/78 (~35,000 t) as the domestic fishery developed rapidly, but it subsequently declined and the fishery was closed in 1985/86 and 1986/87. In the late 1980s and early 1990s, the fishery experienced another, somewhat smaller, "boom" followed by a "bust" and closure of the fishery from 1997/98 to 2004/05. From 2005/06 to 2009/10, the fishery experienced its smallest boom-and-bust cycle, peaking at only ~1,000 t retained catch, and was closed again from 2010/11 to 2012/13. The fishery was re-opened in 2013/14, and retained catch increased each subsequent year until 2016/17 as TACs increased (Figures 4 and 5). The retained catch for 2015/16 (8,878 t) was the largest since 1992/1993. 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 it 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 166º W longitude. In 2019/20, the directed fisheries in both areas were closed because mature male biomass failed to exceed the threshold in either management to open the fishery. Finally, in 2020/21, the fishery in the eastern management area was closed to directed fishing while a TAC of 1,065 t was set for the western area. At the end of the season, only 655 t (~65% of the TAC) was harvested.

Retention of legal-sized male Tanner crab incidentally-caught in the snow crab and BBRKC fisheries is allowed up to 5% of the target species. In general, incidental retention of Tanner crab in these fisheries has been small relative to retention in the directed fishery (Table 4). To simplify the assessment, incidentally-retained catch is attributed to the directed fishery.

b. Information on bycatch and discards

Total catch estimates for Tanner crab in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries are provided in Table 5 and Figure 8. ADFG "at-sea" crab observer sampling programs started in 1989 but sampling in the different fisheries was initially inconsistent. The assessment uses catch data from the snow crab and BBRKC fisheries starting in 1990/91 and in 1991/92 from the directed fishery. Annual bycatch in the groundfish fisheries, based on NMFS groundfish observer programs, is available starting in 1973/74, but crab sex is not distinguished. A value of 0.321 is used in the assessment model for "discard mortality" in the crab fisheries to convert observed bycatch to (unobserved) mortality (Stockhausen, 2014; Tables 6 and 7, Figure 9). For the groundfish fisheries, a value of 0.800 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. When gear type is distinguished, a value of 0.321 is used for bycatch by fixed gear and 0.800 for bycatch by trawl gear. Mortality associated with the handling process can be estimated outside the assessment model for bycatch in the groundfish and non-directed crab fisheries (most or all Tanner crab bycatch is discarded), but estimates of "discard mortality" for males in the directed fishery obtained outside the assessment model can be problematic if (due to sampling error) estimated total catch is less than reported retained catch.

Estimated bycatch mortality in the groundfish fisheries (gear type not distinguished) was highest (~15,000 t) in the early 1970s, but it declined substantially by1977 to ~2,000 t with the curtailment of foreign fishing fleets (Stockhausen, 2017). It declined further in the 1980s (to ~500 t) but increased somewhat in the late 1980s to a peak of ~2,000 t in the early 1990s before undergoing another (gradual) decline until 2008, after which it has fluctuated annually below ~300 t to the present (~88.3 t in 2020/21).

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 and scaled to annual catch abundance, is shown in Figure 6 for the entire EBS from 1980/81 to 1996/97 and by fishery management area since rationalization of the crab fisheries in 2005/06. These indicate a shift to somewhat smaller sizes since 2013/14, compared with 2005/06-2009/10. As noted previously, the SOA changed its harvest strategy for calculating TACs to reflect a smaller minimum industry-preferred size of 125 mm CW east of 166° W longitude. The proportion of new shell crab in the retained catch had been decreasing since 2013/14, when the stock was declared no longer overfished, but 2020/21 saw an increase in this proportion relative to the last open fishing season (Figure 7).

Expanded total catch (retained + discards) size compositions from at-sea crab fishery observer sampling are presented by sex for the directed fishery in Figures 10 and 11, in the snow crab fishery in Figure 12, in the BBRKC fishery in Figure 13, and in the groundfish fisheries in Figures 14 and 15. 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 somewhat larger males than the snow crab fishery, but somewhat smaller males than the BBRKC fishery (although many more than either of the other two), 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 14 and 15 for 1991/92 to 2020/21. These fisheries, targeting a variety of groundfish stocks and using a variety of gear types, take a much larger size range of Tanner crab as bycatch than does the pot gear used in the crab fisheries—perhaps even providing support for recruitment events (see, e.g., the peaks in relative abundance at small sizes in the size compositions for 2003/04 and 2004/05; Figure 11).

Raw (number of individuals measured) and scaled sample sizes for size composition data from the various fisheries are given in Tables 9-11. It is worthwhile pointing out the small number of Tanner crab measured by observers in both the snow crab and, particularly, the BBRKC fisheries in 2020/21.

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 12 and 13, Figures16 and 17). Estimated biomass of male crab in the survey time series started at its maximum (295 thousand t) in 1975, decreased rapidly to a low (15 thousand t) in 1985, and rebounded quickly to a smaller peak (146 thousand t) in 1991 (Table 8). After 1991, male survey biomass decreased again, reaching a minimum of 14,600 t in 1997. Recovery following this decline was slow and male survey biomass did not peak again until 2007 (104 thousand t), after which it has fluctuated more rapidly—decreasing within two years by over 50% to a minimum in 2009 (47 thousand t), followed by a doubling to a peak in 2014 (109 thousand t). Since 2014 the trend has been a steady decline until 2021, with male biomass in 2019 at its lowest point (28 thousand t) since 2000 (Table 12). In 2021, male survey biomass increased over the low in 2019 by ~10% to 31 thousand t. Trends in female survey biomass have generally been in synchrony with those for males, although the changes for females precede those for males by a year or two (reflecting different growth patterns). Changes in biomass in the eastern and western management areas were also fairly synchronized (Figure 17). Preferred-size male survey biomass has been declining steadily east of 166º W (and in the EBS as a whole) since 2014, but was increasing up to 2016 in the west. Since then, it has also been declining rather steadily in the western area. The ratio of new shell to old shell preferred-size males crab across the EBS dropped dramatically after 2015, when the ratio was almost 1:1. In 2018 and 2019, the ratio was almost 1:18 new shell to old shell crab in terms of biomass. However, it increased to 1:1.4 in 2021, suggesting some recruitment into the preferred size range as well as some mortality on oldshell males.

Data from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies are incorporated into several models in this assessment. 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 22, while estimates of area-swept biomass for the study areas are compared in Figure 23 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

Line and bubble plots of NMFS EBS bottom survey size compositions for Tanner crab by sex and fishery region are shown in Figures 18 and 19. 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 was evidence for new recruitment in the western area in 2017-2021, with perhaps some spillover to the eastern area lagged by a year at slightly larger sizes. However, the 2017-2019 cohorts seem to be absent from the 2021 survey.

Based on the total abundance size compositions from the BSFRF-NMFS SBS studies (Figure 24), the BSFRF nephrops gear is in general (as expected) more selective for Tanner crab than the NMFS 83-112 gear, particularly at smaller sizes (< 60 mm CW). 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 24, survey year 2017).

The annual estimated proportions by size of new shell mature males relative to all new shell males in the survey are given in Table 17 and Figure 24

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.

Annual maturity ogives for new shell males, based on chela height collections from the NMFS EBS bottom trawl survey, are shown in Figure 20 (Table 17) 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 166º W 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 8).

Annual sex/size-specific curves describing empirical availability for the BSFRF SBS surveys relative to the NMFS EBS survey are plotted in Figure 27 for males and females. Previous work suggested that fitting the NMFS survey data from the SBS study areas to estimate availability to the BSFRF gear led to confounding in the assessment because of the circular relationships among availability, catchability, and the SBS and EBS-level survey data, so these curves were determined outside the assessment model to break the confounding and allow the BSFRF SBS data to inform NMFS EBS-level survey catchability.

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 21) is included in the parameter optimization for every model 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 are depicted in Figure 22.

c. Size distribution at recruitment

The nominal size distribution for recruits to the population in the assessment model is presented in Figure 23.

4. Information on any data sources that were available, but were excluded from the assessment.
Annual estimates of biomass and abundance in the NMFS EBS bottom trawl survey using VAST software were provided by Jon Richar (AFSC Kodiak). These estimates represent an alternative to the design-based expansion of survey catch data that is currently used to provide stock-level indices of abundance to the assessment. Recent attempts to fit the VAST estimates in the assessment model in place of the design-based ones (e.g., see the May 2021 CPT Report) has been have been problematic, at best. If the VAST estimates can be used with the assessment model, it is clear that this is not simply a matter of "plugging them in" in place of the design-based ones. Given the ultra-compressed nature of this year's assessment time frame due to the timing of the NMFS EBS survey schedule, time was simply not available to pursue incorporating the VAST data into the assessment.

Recent spatial patterns of catch and CPUE in the directed fishery and bycatch fisheries are presented in Appendix B, while patterns in the NMFS bottom trawl surveys are given in Appendix C. The assessment model is does not explicitly consider space, so although these patterns may be informative in a holistic sense, they are not utilized directly in the assessment. There has been some suggestion 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 more or less absent during the 2018, 2019, and 2021 surveys, but the distribution of mature males did not change markedly.

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

E. Analytic Approach

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

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

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

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

More recently, the model code was restructured to function in a management strategy evaluation (MSE) mode and allow retrospective analyses. Since the 2020 assessment, the Dirichlet-Multinomial likelihood for size composition data (Thorson et al, 2016) has been added as an option, as has the ability to specify apply "tail compression" when fitting size composition data. One capability the current code lacks that the CPT and SSC have requested is the ability to do multi-year projections under different fishing mortality models. The code for the TCSAM02 model framework is publicly available on GitHub[2].

2. Model Description

a. Overall modeling approach

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

In brief, crab enter the modeled population as recruits following a truncated size distribution based on the gamma probability distribution (see Figure 26 for the nominal shape). 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 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

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

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

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 Dirichlet-Multinomial likelihood (Thorson et al., 2016) has been added as an option to the multinomial likelihood when fitting size composition data. Additionally, the ability to apply "tail compression" on size composition data has been implemented. Furthermore, "use flags" have been added to all annual catch data (abundance time series, biomass time series, size compositions) to allow the user to selectively "turn off" fits to individual years in input data files by changing the associated "flag" from 1 to 0. Results from several models incorporating the Dirichlet-Multinomial likelihood and tail compression techniques were presented by the author at the May 2021 CPT meeting; the recommended 21.XX models discussed in this assessment utilize both techniques.

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 2020 assessment (Model 20.07 from Stockhausen 2020) provides the baseline model configuration against which subsequent alternative models are evaluated in this assessment. Model 21.22 provides the base from which other alternative models (21.22a and 21.24) were derived.

Table C. Description of population processes and parameterization in models 20.07 and 21.22.

process	time blocks	20.07 description	21.22 description
Population rates and quantities			
Population built from annual recruitment			
Recruitment	1949-1974	ln-scale mean + annual devs constrained as AR1 process	no change
	1975+	ln-scale mean + annual devs	no change
	1949+	sigma-R fixed	estimated
Growth	1949+	sex-specific	no change
		mean post-molt size: power function of pre-molt size	no change
		post-molt size: gamma distribution conditioned on pre-molt size	no change
Maturity	1949+	sex-specific	no change
		size-specific probability of terminal molt	no change
		logit-scale parameterization	no change
Natural mortalty	1949-1979,	estimated sex/maturity state-specific multipliers on base rate	no change
	1985+	priors on multipliers based on uncertainty in max age	no change
	1980-1984	estimated "enhanced mortality" period multipliers	no change

Table D: Description of model characteristics for the directed ("TCF") and snow crab ("SCF") fisheries.

Fishery/process	time blocks	20.07 description	21.22 description
TCF	directed Tanner crab fishery		
capture rates	pre-1965	male nominal rate	no change
	1965+	male ln-scale mean + annual devs	no change
	1949+	ln-scale female offset	no change
male selectivity	1949-1990	ascending logistic	no change
	1991-1996	annually-varying ascending logistic	no change
	2005+	annually-varying ascending logistic	no change
female selectivity	1949+	ascending logistic	no change
male retention	1949-1990, 1991-1996, 2005-2009, 2013-2015, 2017, 2018	ascending logistic	no change
% retained	pre-1988	100%	no change
	1991-1996	estimated	fixed at 100%
	2005-2009	estimated	fixed at 100%
	2013+	estimated	fixed at 100%
SCF	bycatch in snow crab fishery		
capture rates	pre-1978	nominal rate on males	no change
	1979-1991	extrapolated from effort	no change
	1992+	male ln-scale mean + annual devs	no change
	1949+	ln-scale female offset	no change
male selectivity	1949-1996	dome-shaped (double logistic)	dome-shaped (double normal)
	1997-2004	dome-shaped (double logistic)	dome-shaped (double normal)
	2005+	dome-shaped (double logistic)	dome-shaped (double normal)
female selectivity	1949-1996	ascending logistic	no change
	1997-2004	ascending logistic	no change
	2005+	ascending logistic	no change

Table E: Description of model characteristics for the BBRKC ("RKF") and groundfish fisheries ("GF").

Fishery/process	time blocks	20.07 description	21.22 description
RKF	bycatch in BBRKC fishery		
capture rates	pre-1952	nominal rate on males	no change
	1953-1991	extrapolated from effort	no change
	1992+	male ln-scale mean + annual devs	no change
	1949+	ln-scale female offset	no change
male selectivity	1949-1996	ascending logistic	ascending normal, asymptote fixed
	1997-2004	ascending logistic	ascending normal, asymptote fixed
	2005+	ascending logistic	ascending normal, asymptote fixed
female selectivity	1949-1996	ascending logistic	ascending normal
	1997-2004	ascending logistic	ascending normal
	2005+	ascending logistic	ascending normal
GTF	bycatch in groundfish fisheries		
capture rates	pre-1973	male ln-scale mean from 1973+	no change
	1973+	male ln-scale mean + annual devs	no change
	1973+	ln-scale female offset	no change
male selectivity	1949-1986	ascending logistic	no change
	1987-1996	ascending logistic	no change
	1997+	ascending logistic	no change
female selectivity	1949-1986	ascending logistic	no change
	1987-1996	ascending logistic	no change
	1997+	ascending logistic	no change

Table F: Description of model characteristics for the NMFS and BSFRF surveys.

process	time blocks	20.07description	21.22 description
Surveys			
NMFS EBS trawl survey			
male survey q	1975-1981	ln-scale	no change
	1982+	ln-scale w/ prior based on Somerton's underbag experiment	no change
female survey q	1975-1981	ln-scale	no change
	1982+	ln-scale w/ prior based on Somerton's underbag experiment	no change
male selectivity	1975-1981	ascending logistic	no change
	1982+	ascending logistic	no change
female selectivity	1975-1981	ascending logistic	ascending normal, fixed asymptote
	1982+	ascending logistic	ascending normal, fixed asymptote
BSFRF SBS trawl surveys			
male catchability	2016-2017	fixed at 1 for all sizes	no change
male availability	2016-2017	empirically-determined outside the model	no change
female catchability	2016-2017	fixed at 1 for all sizes	no change
female availability	2016-2017	empirically-determined outside the model	no change

Table G. Description of model likelihood components.

Component	Type	included in optimization	Likelihood	20.07 distribution	21.22 distribution
TCF: retained catch	biomass	yes	males only	norm2	lognormal
	size comp.s	yes	males only	multinomial	no change
TCF: total catch	biomass	yes	by sex	norm2	lognormal
	size comp.s	yes	by sex	multinomial	no change
SCF: total catch	biomass	yes	by sex	norm2	lognormal
	size comp.s	yes	by sex	multinomial	no change
RKF: total catch	biomass	yes	by sex	norm2	lognormal
	size comp.s	yes	by sex	multinomial	no change
GF All: total catch	abundance	yes	by sex	norm2	lognormal
	biomass	yes	by sex	norm2	lognormal
	size comp.s	yes	by sex	multinomial	no change
NMFS "M" survey (males only, no maturity)	biomass	yes	all males	lognormal	lognormal
	size comp.s	yes	all males	multinomial	no change
NMFS "F" survey (females only, w/ maturity)	biomass	yes	by maturity classification	lognormal	no change
	size comp.s	yes	by maturity classification	multinomial	no change
BSFRF "M" survey (males only, no maturity)	biomass	yes	all males	lognormal	no change
	size comp.s	yes	all males	multinomial	D-M
BSFRF "F" survey (females only, w/ maturity)	biomass	yes	by maturity classification	lognormal	no change
	size comp.s	yes	by maturity classification	multinomial	D-M
growth data	EBS only	yes	by sex	gamma	no change
male maturity ogive data	EBS only	yes	males only	binomial	no change

The NMFS "M" survey refers to data from the NMFS survey in which male survey abundance/biomass is not categorized by maturity state outside the model (males in the M survey have "undetermined" maturity). The NMFS "F" survey is simply the female portion of the NMFS survey data configured as a separate data file to accompany the NMFS "M" survey data file.

Three additional models were evaluated as part of this assessment: 20.07u, 21.24, and 21.22a. Model 20.07u is simply the 2020 assessment model 20.07 updated with the new data for 2020/21. Model 21.24 is a model recommended by the CPT at its May 2021 meeting: it is identical to 21.22 except that growth is estimated outside the model. Model 20.07 fit the growth increment data in the assessment for males surprisingly poorly, indicating a conflict with other data in the assessment. This author suggested it might improve model stability and verisimilitude to fix the growth parameters based on fits external to the assessment process, and 21.24 is the result of that suggestion.

When Model 21.22 was run with 2019/20 data prior to the May CPT meeting, the converged model had no parameters hitting a bound. Run with the 2020/21 data, five parameters were found to be hitting their bounds. Model 21.22a is the result of "tweaking" 21.22 to obtain a model in which no parameters were estimated at a bound. This involved reparameterizing the functions used to describe selectivity for males in the NMFS EB shelf survey as half-normal, rather than logistic, functions and fixing (rather than estimating) several parameters:

1) the ln-scale parameter determining σ_R^2, the recruitment variance
2) the size-at-full selection in the half-normal function used to describe female bycatch selectivity in the BBRKC fishery in the pre-1997 time block (to the same value, 140 mm CW, as used in the other time blocks for BBRKC fishery selectivity
3) for the double-normal function used for male bycatch selectivity in the snow crab fishery in the pre-1997 time block:
    a. the plateau parameter (to 0: no plateau; similar to the other two time blocks)
    b. the parameter controlling the width of the descending limb (to 1 mm CW)
4) the size-at-full selection in the half-normal functions used to describe NMFS female survey selectivity in both survey selectivity time periods (1975-1981, 1982+), to 130 mm CW
5) the size-at-full selection in the describing NMFS survey selectivity for males, to 180 mm CW

In addition, a N(0,1) prior was put on the estimated ln-scale recruitment devs to force the parameter determining the recruitment 2020 recruitment away from the lower bound set on the devs.

With these changes, Model 21.22a successfully converged to a solution with no parameters at a bound.

Table H. Characteristics of models evaluated as part of this assessment.

model scenario	number of parameters	objective function value	max gradient	Jitter runs	# runs converged to MLE	scenario description
20.07	349	3,429.39	0.0003	400	47	2020 assessment model
20.07u	355	3,619.43	0.0001	139	51	2020 asessment model with updated 2020/21 data
21.22	353	2,939.77	0.0011	347	313	CPT/SSC recommended alternative
21.22a	346	3,014.12	0.0001	--	--	21.22 updated to eliminate parameters at bounds
21.24	349	3,132.07	0.0006	360	8	CPT/SSC recommended alternative: 21.22 with growth estimated outside model

The number of estimated parameters, the final value of the objective function, and the maximum gradient of the objective function at the converged solution are listed in the table above for the five models considered in this assessment. The total objective function values can't be directly compared between models 20.07u and the 21.XX models because different likelihood functions are used to fit the fishery catch biomass data and some elements of the size composition data, and because tail compression was applied to all the size composition data. Due to time constraints, Model 21.22a was not jittered to verify that the solution corresponded to its global maximum, rather than a local minimum.

Model 21.22a is the author's preferred model, as justified below.

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

The following table summarizes basic model results based on the MLE from the 2020 assessment model (21.22a) and the models considered below in more detail. The author's preferred model is 21.22a.

Table I. MLE-based results for various management quantities. The units are millions for recruitment and 1000,s t for biomass-related quantities.

case	objFun	max gradient	avg. recruitment	B100	Bmsy	2020/21 MMB	Fmsy	MSY	Fofl	OFL	2021/22 MMB	status ratio
20.07	3,429.4	0.000250	374.4	105.0	36.8	66.9	0.98	16.9	0.94	21.1	35.3	0.96
20.07u	3,619.4	0.000107	423.0	103.5	36.2	80.1	1.23	17.2	1.23	26.1	41.9	1.16
21.22	2,939.8	0.001051	371.3	99.7	34.9	82.0	1.11	16.0	1.11	26.7	43.1	1.24
21.24	3,132.1	0.000110	517.2	129.8	45.4	94.4	1.55	19.7	1.55	33.1	48.6	1.07
21.22a	3,014.1	0.000592	396.9	103.6	36.3	82.3	1.19	16.8	1.19	27.2	42.8	1.18

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

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

d. Convergence status and convergence criteria

Convergence to the maximum likelihood estimate in each model was evaluated using initial parameter jittering to start a set of model runs at starting values randomly-selected from within a large fraction of the available parameter space and selecting the run which minimized the final objective function value (i.e., maximized the likelihood) over the set of jittered model runs. Ideally, all model runs should arrive at the same global minimum on the objective function hypersurface. In practice, some runs will converge to a local minimum on the hypersurface, rather than the global minimum, and some runs will simply fail to converge at all. The latter can be distinguished because the final gradient of the objective function with respect to the parameters exhibits values that are not close to zero. However, runs that converge to any minimum on the hypersurface should have gradient values that are identically zero (or “close” to zero, from a practical standpoint). Thus, runs that end at a local minimum cannot be distinguished from runs that end at the global minimum based solely on the size of the final gradients. Consequently, the global minimum solution can only be selected by starting the model at many locations within the available parameter space and selecting the “one” run that achieves the minimum over all the model runs (ideally, many of the runs should achieve the minimum).

For this assessment, convergence was evaluated by making 100’s of jittered runs for each model to find the parameter values that resulted in the model’s minimum objective function value (i.e., maximum likelihood value). Convergence characteristics are reported in Table H.

Bounds (limits) were placed on all parameters in the models considered in this assessment to constrain final estimates to sensible values and facilitate parameter optimization by limiting the space over which to search for the combination of parameters that result in the minimum objective function value. However, global minima with parameters estimated on a bound are generally problematic for estimated parameter uncertainty with ADMB using either its approximation based on the model hessian or full MCMC. Thus, parameters at bounds are a concern. Parameters that were estimated at a bound in the model run with the smallest objective function value are listed in Table 21 for the models. Model 20.07a had 12 parameters estimated at a bound, one more than were estimated at a bound in 20.07. Models 21.22 and 21.24, recommended by the CPT and SSC for this assessment, were the results of considerable effort prior to the May 2021 CPT Meeting to, in part, develop models in which no estimated parameters were estimated at a bound. However, with the addition of the new data for 2021, several parameters were estimated at bounds in these models (five for 21.22 and ten for 21.24). Consequently, 21.22a was developed as a “tweak” on

21.22 which resulted in no parameters estimated at a bound. After some iterations, it was found that reparameterizing the functions used to describe selectivity for males in the NMFS EB shelf survey as half-normal, rather than logistic, functions and fixing (rather than estimating) several parameters:

1) the ln-scale parameter determining σ_R^2, the recruitment variance
2) the size-at-full selection in the half-normal function used to describe female bycatch selectivity in the BBRKC fishery in the pre-1997 time block (to the same value, 140 mm CW, as used in the other time blocks for BBRKC fishery selectivity
3) for the double-normal function used for male bycatch selectivity in the snow crab fishery in the pre-1997 time block:
    a. the plateau parameter (to 0: no plateau; similar to the other two time blocks)
    b. the parameter controlling the width of the descending limb (to 1 mm CW)
4) the size-at-full selection in the half-normal functions used to describe NMFS female survey selectivity in both survey selectivity time periods (1975-1981, 1982+), to 130 mm CW
5) the size-at-full selection in the describing NMFS survey selectivity for males, to 180 mm CW

In addition, a N(0,1) prior was put on the estimated ln-scale recruitment devs to force the parameter determining the recruitment 2020 recruitment away from the lower bound set on the devs. This resulted in a solution with no parameters at bounds and a valid hessian (as validated by Cole Monahan's "adnuts" invertibility test).

e. Sample sizes assumed for the compositional data

Actual and input sample sizes used for compositional data are listed in Tables 9-11 for fishery-related size compositions. Actual samples sizes for survey size compositions are listed in Table 16. Input sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for fishery-related input sample sizes. Otherwise, input sample sizes were scaled as described in Stockhausen (2014, Appendix 5) using the formula:

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

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

f. Parameter sensibility

As noted above, all parameters estimated at a bound are identified in Table 21for all models. All parameter values and associated standard error estimates (using ADMB's inverted hessian approximation) are listed in Tables 23-34—parameters estimated at a bound have very small error estimates.

Almost all of the parameters estimated at a bound in the Models 20.07 and 20.07u are related to fishery or survey selectivity in some manner, the exceptions being pGrBeta[1] in 20.07 and pDevsLnR in 20.07u. pGrBeta[1] is the scale factor for the gamma distribution used to reflect variability in annual growth. The estimated value for this parameter did not occur at its upper bound in 20.07u, reflecting the influence of new data (e.g., 2020/21 size compositions) on its estimate. It should be noted that this parameter was estimated at its lower bound in Model 21.24, but this was clearly linked to fixing the estimates for mean growth in that model.

pDevsLnR (index 46 in the "current" recruitment time period; Table 24) was also estimated at its lower bound, -5, in Models 21.22 and 21.24. It represents the estimated ln-scale deviation from mean recruitment entering the population July 1, 2020. The size compositions from the 2021 NMFS EBS shelf survey (Figures 18 and 19)seem to support an estimate of very low recruitment in 2020, so this may not be an unreasonable result even though it seems a bit extreme in terms of its actual value. However, it also seems to be associated with the missing 2020 survey. Some simple simulations (Appendix J) suggest that the estimate for recruitment for the year of a missing survey is biased low in the year a new survey is added, and that the effect takes several years to disappear as subsequent surveys are added. A small penalty on ln-scale recruitment deviations was added in Model 21.22a, with the effect of moving the problematic recruitment deviation off its lower bound with little impact on resulting recruitment (Table 48, Figure 51).

The remaining parameters estimated at a bound in 20.07 or 20.07u were related to selectivity in the fisheries or surveys in one form or another (Table 21). All of these parameters were dealt with in developing Model 21.22 for the May 2021 CPT Meeting by changing most asymptotic selectivity functions from logistic functions to half-normal functions. Logistic functions approach, but never reach, 1, so there is confounding between the parameters characterizing the curve (e.g., size at 50% selected and difference to size at 95% selected) and the parameter characterizing full selection (e.g., survey q or fishing mortality). Changing from a logistic function to a half-normal function removes this confounding because the half-normal actually reaches its maximum value of 1 within the range defined for the parameter (size-at-1) that determines the location of the peak of the normal function. Upper limits on the fully-selected size parameter were based on NMFS survey size compositions, with the limit reflecting the maximum size seen in the survey. In developing 21.22 with 2020 data, it was found that several fully-selected size parameters associated with bycatch in the BBRKC fishery and survey selectivity for females were estimated at their upper bounds, so these were fixed at that limit (Table 31).

With the addition of 2020/21 data to 21.22, it was found that several parameters were now estimated at a bound that had not previously been the case. This included: 1) the recruitment deviation for 2020 (discussed previously); 2) pS1[25], the size at full selection for female selectivity in the BBRKC fishery prior to 1997; 3) pS2[2], the difference between the sizes at 50%- and 95%-selected for males in the NMFS EBS shelf survey; and 4) pS3[1] and pS4[1], parameters controlling the location and shape of the descending limb of the double-normal function used to describe selectivity for male Tanner crab in the snow crab fishery prior to 1997. Model 21.22a was designed to fix these problems. As noted previously, a small penalty was placed on recruitment deviations in the 1975+ time period to remove the estimate from the bound. pS1[25] was fixed to its upper limit, consistent with how similar parameters were treated. To deal with pS2[2] hitting its upper bound, the selectivity function describing male selectivity in the NMFS EBS shelf survey after 1981 was changed from a logistic curve to a half-normal curve and the fully-selected size was fixed at its upper limit (179 mm CW). pS3[1], which determined the width of the plateau of the double normal selectivity function used to describe male selectivity in the snow crab fishery in the pre-1997 time period, was set to its lower bound (0.001), effectively setting the plateau width to 0 (consistent with what was done in the other two time snow crab fishery time periods). Finally, pS4[1], which determined the width of the descending limb of male bycatch in the pre-1997 time period, was set to its lower limit (1 mm CW). These latter changes appear to have been driven by the addition of the 1990/91 and 1991/92 bycatch size compositions in the snow crab fishery to the model data (see Figure 12). These compositions indicate the fishery captured a substantial number of large males > 150 mm CW in both years, inconstant with dome-shaped selectivity, while in later years very few were captured (consistent with previous estimates of dome-shaped selectivity in this time period).

Time did not permit a similar exercise to be conducted with Model 21.24, which had 10 parameters estimated at a bound.

Several parameters related to fishing mortality in the directed fishery in 1969/70-1972/73 contributed to unreasonably large estimates of total fishing mortality and catch taken during these years in Models 21.22 and 21.22a. The ln-scale fishing mortality deviations estimated in these years had value ranging from 2 to 4, resulting in estimates of fully-selected fishing mortality in the directed fishery during these years ranging up to 30. However, the population during this period is still “spinning up” and the only data used to constrain the model is retained catch biomass data from the foreign and domestic fleets; no size composition data is available and the catch taken by the foreign fleets is most likely highly uncertain. These estimates do not appear to have substantial follow-on effects.

Several other parameters were found to be estimated with large uncertainty. The estimate of the CV for recruitment variability (pRCV) in Model 21.22 was found to be (a whopping) 771. This parameter was fixed to an arithmetic-scale value of 0.5 in the other models. The estimates of fully-selected size for females in the BBRKC fishery during the time periods 1997-2004 and 2005+ (pS1[26] and pS1[27], respectively) for Models 21.22 and 21.22a were fairly uncertain, with standard errors of 25 and 15 mm CW. Additionally, the standard error estimated for the width of the half-normal selectivity curve for females in the BBRKC fishery during 1997-2004 in Models 21.22 and 21.22a was fairly large at 11 mm CW, when the estimate was only 16.8 mm CW.

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

The main criteria used to choose among the alternative models were minimization of estimated parameters at bounds, reasonableness of all parameters and derived quantities, and fits to the data.

h. Residual analysis

Standardized residuals to model fits were plotted and examined for all data components. Fits to fishery catch biomass and survey biomass time series are shown in Figures 28-37. Residuals are shown in a standardized format for each data source: on the upper row, a time series plot of grouped “lollipops” indicating the z-score from each model for each year with data; on the lower row, bar charts comparing the values for summary statistics (median absolute deviation, MA; median absolute relative error, MARE; and root mean square error, RMSE). For the fishery data, these plots show the fits to each data source separately for the 20.XX and 21.XX models because the associated likelihoods and weighting imply different error bars.

Fits to the growth data are shown in Figure 38. Fits to the male maturity data are shown in Figure 39; separate plots are provided for Model 20.07 and the remaining models because the data is different.

Due to the large number of plots involved, the fits to individual size compositions, associated residuals plots, and plots of effective N’s are provided as appendices to the chapter (Appendices D-I). Individual appendices are provided for the 20.XX and 21.XX models separately due to differences in the data used in the fits resulting from the tail compression applied in the 21.XX models. Harmonic means for the effective sample size results from the model fits are listed in Table 39.

i. Evaluation of the model(s)

From a visual standpoint, all of the models fit the fisheries catch biomass data very well. Z-scores for the retained catch data were small for all models, but particularly small for the 20.XX models, suggesting potential overfitting of this data relative to the assumed error distributions (Figure 28). The RMSE statistic was higher for the 21.XX models compared with the 20.XX models, but the MAD and MARE statistics were smaller.

For the total catch crab fishery data, the 21.XX models exhibited sex-specific offsetting residuals due to the change to a lognormal error distribution to describe the likelihoods, combined with the assumption common to all models that capture rates on females were proportional to those on males (Figures 29-32). Thus, positive z-scores in the fits to male catch biomass would be offset (from a mean perspective) by corresponding negative z-scores in fits to the female data. The summary statistics indicated the 20.XX models fit the data better than the 21.XX models for total male catch in the directed fishery, while the statistics were much more similar across all models for female total catch in the directed fishery. The summary results for fits to total male catch biomass were similar to those for the directed fishery, but favored the 21.XX models more clearly for the fits to the female catch data. For bycatch in the BBRKC fishery, the statistics favored the 21.XX models for both male and female catch data because the overall size of the catch was much smaller than that in the directed or snow crab fisheries. Similar observations hold for fits to the catch in the groundfish fisheries, which does not distinguish between the sexes. However, the z-scores for the fits to the groundfish bycatch data reveal an interesting pattern that has been noted in previous assessments: the fits to the data appear to be much better before 1991 than after. Why this would be the case is unclear; it coincides with the implementation of the Catch Accounting System by NMFS, but it is unknown if this bears any relationship to the observation.

Normal distributions were assumed for the fishery catch biomass likelihoods in the 20.XX models, with an effective standard deviation of 0.16 thousand t in order to fit the time series well. Consequently, the assumed sampling error is independent of catch size, which seems unlikely given the range of observed values across the fisheries, ranging from almost 0 to over 35 thousand t. Given the small levels of female bycatch observed in most of the fisheries, these data consequently have little effect on model convergence (which may be a worthwhile simplification considering that capture rates on fully-selected females are assumed to have the same temporal pattern as those for males). The lognormal likelihoods with fixed cv's used in the 21.XX models align the error assumptions for fishery data with those made for survey data, but the use of lognormal likelihoods also reduces the relative influence of large catches over small ones, which may be undesirable for estimates of removals from the population. This concern was reduced by defining a minimum absolute error (0.01 t) for the fishery data. In practice, only female bycatch data was subject to this lower bound. Time did not permit exploring the sensitivity of 21.XX model runs to this lower bound.

The fits to the NMFS EBS shelf survey data are much poorer than those to the fishery data for all the models (Figures 33-35). The fits to male survey biomass exhibit a number of extreme negative outliers (z-scores < -4) from 1983 to 1986 across all models, and again in 1986 and 1987. The fits to the 2021 male survey biomass all appear to be extreme negative outliers. None of the summary statistics favors one model above the others. The pattern of z-scores for mature females similar to that for immature females, but tends to lag the latter by a year up to about 1992, after which the patterns do not appear related. In 2021, the z-score for immature female survey biomass borders on the negative extreme while that for mature females is quite close to 0. As for males, the summary statistics do not favor a single model.

Fits to the BSFRF SBS data are similar for all of the alternative models except 21.24, which the summary statistics identify as a consistent poor performer even if they don't consistently favor one of the other models.

All of the models fit the available growth data for females similarly well, and all except 21.24 fit the male growth data similarly poorly (Figure 38). Model 21.24 fit the male growth data better because the growth parameters were estimated outside the assessment model and fixed inside. However, fixing growth based strictly on the best fits to the molt increment data alone changes other model results substantially, in particular leading to much poorer fits to the male maturity ogive data (Figure 39) in 21.24 compared with the other models. The maturity ogive and size composition data apparently imply larger molt increments and faster maturation than the molt increment data alone would suggest.

Fits to mean size compositions in the directed and bycatch fisheries are illustrated in Figures 40-42. In the 21.XX models, tail proportions in the observed size compositions are accumulated into the next largest size bin for left-side tails (next smallest size bin for right-side tails) until a cumulative proportion of 5% is achieved. The predicted proportions are then accumulated to the same bins prior to evaluating the likelihood. Thus, the data actually fit differ somewhat in the tails between the 20.XX and 21.XX models and thus the fits are presented in separate plots. The fits to the mean size compositions exhibit some sharp edges in the 21.XX models that are not apparent in the 20.XX models. Although the associated likelihood values (Table 36) appear to indicate better fits using the tail compression, these are not valid comparisons.

Examination of the fits to the annual size compositions in detail, as well as the residuals, reveals the effect that the tail compression has on the observed and predicted proportions (Appendices H and I). In general, applying the tail compression seems to have little real effect on the fit to the tails of the size compositions. Where the tail proportions are overestimated in the uncompressed 20.XX models, the tail proportions also tend to be overestimated in the tail-compressed 21.XX models. For example, compare the fits for 1984 in Figure 1, Appendix H to the same plot in Appendix I: proportions are overestimated in the lefthand tail but well-estimated in the righthand tail. In 1977 (same figures), the proportions are again overestimated in the lefthand tails but, in this instance, both underestimated in the righthand tails. Because the likelihoods are not comparable, it is difficult to say which fit is better.

As a further check on the effects of the tail compression, 21.22a was re-run with no tail compression applied to any size composition data ("21.22b"). Time constraints did not allow a complete exploration of the new model, but a brief review of the results for model fits to biomass data, estimated recruitment, estimated model processes suggested the results were only slightly different from 21.22a, as can be seen in a comparison of management-related quantities for the two models in the following table:

Table J. Comparison of management quantities from 21.22a with a model using no tail compression but otherwise identical structure (21.22b):

case	objective function	max gradient	avg. recruitment	B100	Bmsy	2020/21 MMB	Fmsy	MSY	Fofl	OFL	2021/22 MMB
21.22a	3,014.1	0.000592	396.9	103.6	36.3	82.3	1.19	16.8	1.19	27.2	42.8
21.22b	3,173.6	0.000113	408.5	106.3	37.2	83.4	1.22	17.3	1.22	27.8	43.1

The objective function values are not comparable, but the management quantities only differ by 3%, at most. While applying tail compression may improve statistical robustness in other circumstances, it did not appear to be particularly helpful here, and simply complicated the comparison between models. The insensitivity of the results probably has to do with the correlation structure across size classes imposed by the growth processes (molt increment, terminal molt schedule): the estimated tail structure is not flexible enough in terms of potential variation across adjacent size classes for the tail compression to have an effect on the shape of the predicted tails.

Estimated capture rates in the directed fishery (Figure 43) in Models 21.22 and 21.22a show spikes in catchability in the 1969/70-1972/73 time frame that do not appear in the other models. These appear to be associated with the model start-up, population build-up, and the requirement to fit early catch data in the foreign fleet period. However, their influence does not seem to extend much beyond 1975, when NMFS survey data is first available to inform model processes. Differences among the models in the period 1975-1985 reflect different levels of estimated recruitment a few years before (compare trends in Figure 50). Otherwise, no red flags stand out for any of the predicted capture rates.

The estimated selectivity and retention functions in the directed fishery are practically identical across all the models (Figure 44). Of interest, though, is that the retention fraction for large crab in Model 20.07u during the 2005-2010 period is estimated at ~ 60% (with 95% CI of (0.2, 0.9)). It was also estimated in 20.07, but was so close to 100% that it was fixed in the 21.XX models as a simplification. While this is certainly not reason enough to reject 21.22a for status determination, it may be worth revisiting in the future this issue of whether retention was close to 100% across all time periods.

In the bycatch fisheries, the estimated selectivities were either similar across all models or shifted to larger sizes in the 21.XX models (Figure 45), such that differences in fully-selected capture rates (Figure 44) were buffered by differences in estimated selectivity in order to fit the catch biomass data equally well. One slightly surprising result is the effective change in the selectivity pattern for bycatch of males by the snow crab fishery in the prior to the late 1990s (labelled "1990" in Figure 45). The assumed functions are double logistic for the 20.XX models and double normal for the 21.XX models in all three selectivity time blocks, and the estimated curves are indistinguishable in the 1997-2004 and 200%+ time blocks, but in the pre-1997 time block the curves in the 21.XX models suggest selectivity is more half-normal in shape, increasing to a maximum at ~160 mm CW, then dropping almost immediately to near-zero, whereas the 20.XX models suggest selectivity is dome-shaped with a peak at ~125 mm CW. These changes can be traced back to the manner in which the 20.XX and 21.XX models fit the male bycatch size compositions in the early 1990s and possibly reflect only small changes in the likelihoods associated with the relatively poor fits to the early 1990s size compositions (Figure 35, Appendices H and I). These poor fits are driven by a fairly dramatic change in the nature of the observed proportions from being right-skewed toward larger sizes in 1990/91 and 1991/92 (favoring increasing selectivity with size) to left-skewed toward smaller sizes after 1991/92 (more consistent with dome-shaped selectivity). It would be worthwhile in the future to explore fitting different selectivity functions to these two sub-blocks.

Estimated selectivity patterns in the NMFS EBS shelf survey (Figures 46) exhibit some differences among the models, particularly for male selectivity before 1982. There seems to be a real ambiguity in the estimated selectivity for males in the pre-1982 time frame: the more gradually-increasing curves are similar to that estimated in Model 19.03, the 2019 assessment model (Stockhausen, 2019b), and the estimated curve from the 2020 assessment (Stockhausen, 2020) has switched from the rapidly rising curve (20.07) to the more gradual curve (20.07u) with the addition of new data for 2020/21. When estimated catchability (Figure 47) is factored in, the differences among the resulting capture probability curves (fully-selected catchability x selectivity; Figure 48) are even more diverse, although all models except 21.22 estimate similar curves for males post-1981. Model 21.24 stands out as an outlier, implying the smallest capture probability across all size classes for both sexes in both survey selectivity time periods. The 20.07u and 21.22a models exhibit similar capture probability curves for males in both time periods across the entire model size range, and up to ~115 mm CW for females

Parameter estimates and the resulting schedules for biological processes in the model (natural mortality, growth, and terminal molt) are very similar across all the models, except for 21.24 (Figure 49). Mean growth (molt increment) was fixed in Model 21.24, apparently resulting in reduced probability-at-size of undergoing terminal molt in males relative to the other models, as well as slightly reduced "typical" natural mortality rates.

The estimated recruitment time series exhibit substantially different patterns during model "spin up" until 1970. After 1970, all the models exhibit similar temporal patterns, but Model 21.24 stands apart with a higher mean (Figured 50, 51). The models also exhibit different spin-up patterns in mature biomass (Figures 50, 51) and population abundance and biomass trends (Figures 52, 53) which, for all models except 21.24, converge somewhat later than recruitment patterns (by 1975) due to the "inertia" associated with the estimated growth and maturity processes. The temporal trajectories for biomass and abundance in Model 21.24 don't converge to those of the other models until 10 years later, after which they fluctuate in temporal patterns similar to the other models, but at a higher mean level.

In summary, Model 21.24 stands out as an outlier among the alternative models. Growth was fixed in this model based on estimates obtained outside the model because male growth appears to be poorly estimated within the model (at least, estimated mean growth for males does not fit the growth data very well). This led to a delayed schedule of terminal molt for males fairly different than that obtained in the other models, but this did not improve fits to the available male maturity data (they were, in fact , much worse). In addition, Model 21.24 had the largest number of parameters estimated at a bound. The converged model for Model 20.07u had only one less parameter estimated at a bound. Model 21.22 (as with 21.24) incorporated a number of changes that were considered to be improvements on the 2020 assessment model 20.07 (and consequently 20.07u), including using lognormal likelihoods for fishery catch biomass data and re-parameterized selectivity functions based on the normal distribution that removed ambiguities associated with logistic functions and "fully-selected" parameters. In May 2021, 21.22 was the first Tanner crab model to be fit with no parameters hitting a bound. Unfortunately, the new data added for the 2021 assessment "broke" the 21.22 model in this respect. Thus, the author's preferred model is 21.22a because it follows on from Model 21.22, has no parameters hitting bounds, unlike any of the other models, and fits all of the datasets reasonably well. All of the estimated parameters in 21.22a have reasonable values, with the exception of three related to directed fishing mortality in the 1969/70 to 1972/73 period. As discussed previously, these are associated with model "spin-up" and the rather unreliable data from the foreign fisheries and have little to no effect on population trends after the NMFS survey data begins in 1975. Model 21.22a also has better retrospective performance than 20.07u (see Section 4.f.i).

4. Results (best model(s))

Model 21.22a was selected as the author's preferred model for the 2021 assessment, as discussed in detail at the end of the previous section.

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

Effective sample sizes for size composition data fit in the model are listed in Table 27. For Models 20.07 and 20.07u, a weighting factor of 20 (corresponding to a standard deviation of 0.158 t) was applied to all fishery catch biomass likelihood components to achieve close fits to the catch biomass time series. For these models, a normal likelihood was used to assess the fit to data and the standard deviation associated with all data was taken to be 500 t. In Models 21.22, 21.24, and 21.22a, a lognormal likelihood was used to fit the data. The following CV's and minimum standard deviations were assumed to apply to the fishery catch biomass data:

Table K. Assumed CV's for fishery catch biomass data.

fishery	catch type	time period	CV
directed fishery	retained	1965-1979	10%
		1980	3%
		1996+	1%
	total	1990+	20%
snow crab	total	1990+	20%
BBRKC	total	1990+	20%
groundfish	total	1973	20%

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 22-35. Parameters estimated at a bound are listed for each model in Table 21. No parameters were estimated at bounds in Model 21.22a, while up to 12 were at a bound in the other models.

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

Estimates for mature survey biomass are listed in Tables 41 and 42 for males and females, respectively. Estimates for mature biomass at mating are listed in Tables 44 and 45. Due to the size of the tables, the numbers at size for females and males by year in 5 mm CW size bins for models 20.07u and 21.22a are available online at the eAgenda for the September 2021 CPT Meeting as zipped csv files (as noted in the caption for Table 46). Total annual abundance and biomass estimates for the author's preferred model, 21.22a, are given by sex in Table 51.

iii. Recruitment time series

The estimated recruitment time series from the models are listed in Tables 47 and 48.

iv. Time series of catch divided by biomass.

Time series of catch divided by biomass (i.e., exploitation rate) are listed in Tables 49 and 50.

c. Graphs of estimates

Graphs of estimated quantities are shown in Figures 43-53.

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

Graphs of estimated total catch selectivity in the directed fishery are shown in Figure 44 and in Figure 45 for the bycatch fisheries. Estimated retention curves for the directed fishery are shown in Figure 45. Graphs of selectivity, fully-selected catchability, and capture probability curves for the NMFS EBS shelf survey are shown Figures 46-48. Natural mortality estimates are shown in Figure 49, as are terminal molt probabilities and mean post-molt size. Estimated recruitment is shown in Figures 50 and 51.

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

Mature male and female biomass trends (MMB and MFB) are shown in Figures 50 and 51. Estimates of the time trends in population abundance and biomass for mature and immature components of the stock are shown in Figures 52-53.

iii. Estimated full selection F over time

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

iv. Estimated fishing mortality versus estimated spawning stock biomass

Estimated total fishing mortality (retained + discards) is plotted against spawning stock biomass (MMB) for the author's preferred model, 21.22a, in Figure 54.

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

Fits to a stock-recruit relationship were not evaluated.

e. Evaluation of the fit to the data:

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

Graphs of fits to observed catches are provided in Figures 28 and 29 for retained and total catch, respectively, in the directed fishery, as well as in Figures 30-32 for total catch in the snow crab, BBRKC, and groundfish fisheries. Fits to survey biomass time series for both the NMFS EBS shelf survey and the BSFRF SBS surveys are shown in Figure 33.

ii. Graphs of model fits to survey numbers

Fits to survey abundance time series for both the NMFS EBS shelf survey and the BSFRF SBS surveys are shown in Figure 33. Note that these fits are not included in the model objective function but serve as an independent diagnostic of model fit.

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

See Appendix I for model fits to annual catch proportions by size class for Model 21.22a.

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

See Appendix I for model fits to annual survey proportions by size class for Model 21.22a.

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

Marginal distributions for fits to the compositional data in Model 21.22a are shown in Figures 40-42.

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

Time series plots of input and implied effective sample sizes for compositional data for Model 21.22a are presented for fishery compositional data in Appendix E and for survey compositional data in Appendix G.

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

Root mean square error (RMSEs) for fits to various datasets are provided in Table 38, but no comparison is available with the cv's assumed for the indices. The author requests guidance on how the cv's for time series indices should be combined to compare with the RMSEs.

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

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

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

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

Retrospective analyses were conducted for both 20.07u and 21.22a. The analysis for both models used 8 peels (ending in 2013), with the model re-fit after each removal of the terminal year's data. The analysis was limited to 2013-2021 because no BSFRF SBS surveys for Tanner crab are available before 2013. For each model, time series plots of recruitment and MMB were made to identify potential patterns in how the terminal year's estimate for each peel differed from the model result using the complete dataset. Relative bias in the terminal year estimates was quantified using Mohn's rho (Mohn, 1999). The retrospective patterns don't indicate any apparent problems with MMB, but additional data (decreasing the number of peels) always reduces the estimates of recruitment (Figures 55-58). Mohn's rho was 4.73 and 0.37 for the recruitment patterns for 20.07u and 21.22a, respectively, while the corresponding values for MMB were 0.0142 and -0.00191. These comparisons suggest that 21.22a has somewhat better retrospective properties than 20.07u.

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

Plots of estimated time series of recruitment and mature biomass for the author's preferred model, 21.22a, are shown in Figure 59 with those from previous assessments.

g. Uncertainty and sensitivity analyses

MCMC runs were completed for model 21.22a to explore model uncertainty. Two independent chains were run using ADMB's standard random walk model MCMC algorithm, each with 10 million iterations per chain. Each chain took over 3 days to complete. The individual chains were thinned by a factor of 10,000 and the initial 200 thinned samples were dropped from each prior to analysis. Trace plots (Figure 60) indicate the degree of mixing was poor (but better than in previous assessment) and the samples within each chain were still highly correlated even after the extensive thinning. However, histograms and pairs plots of OFL-related quantities from the combined chains appear to have reasonable characteristics (Figures 61 and 62).

As a technical note, ADMB's alternative MCMC "no U-turn sampling" algorithm (i.e., NUTS) was also tried for the MCMC runs. Diagnostics suggested this method would take about 20 days to finish given the current model configuration, so an attempt to use it were terminated after 24 hours.

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 2020/21 was 21.13 thousand t while the total catch mortality was 1.086 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 retained catch data and estimates of discards using the "subtraction method" (discards estimate = total catch estimate – retained catch) by fleet for 2020/21 (Table 6). 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. $\beta<\frac{B}{B_{35\%}*}\leq 1$	$F_{OFL}=F^{*}_{35\%}\frac{\frac{B}{B^{*}_{35\%}}-\alpha}{1-\alpha}$	$ABC\leq(1-b_y)*OFL$
		c. $\frac{B}{B_{35\%}*}\leq\beta$	Directed fishery $F = 0$ $F_{OFL}\leq F_{MSY}^{\dagger}$	

and is based on an estimate of "current" spawning biomass at mating (B above, taken as the projected MMB at mating in the assessment year) and spawning biomass per recruit (SBPR)-based proxies for F_{MSY} and B_{MSY}. In the above equations, α=0.1 and β=0.25. For Tanner crab, the proxy for F_{MSY} is $F_{35\%}$, the fishing mortality that reduces the SBPR to 35% of its value for an unfished stock. Thus, if $\phi(F)$ is the SBPR at fishing mortality F, then $F_{35\%}$ is the value of fishing mortality that yields $\phi(F) = 0.35 \cdot \phi(0)$. The Tier 3 proxy for B_{MSY} is $B_{35\%}$, the equilibrium biomass achieved when fishing at $F_{35\%}$, where $B_{35\%}$ is simply 35% of the unfished stock biomass. Given an estimate of average recruitment, $\bar{R}$, then $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2020/21 require estimates of B = $MMB_{2021/22}$ (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 63). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than ½ $B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

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

To calculate F_{MSY}, the fishery capture rate for males in the directed fishery is adjusted until the long term (equilibrium) MMB-at-mating is 35% of its unfished value (i.e., $B = 0.35 \cdot B_0 = B_{35\%} = B_{MSY}$). This calculation depends on the assumed bycatch F's on Tanner crab in the snow crab, BBRKC and groundfish fisheries. Since 2017, the average F over the last 5 years for each of the bycatch fisheries is used in these calculations. Fishery selectivity curves were set using the average curve over the last 5 years for each fishery, as in previous assessments (e.g., Stockhausen 2020).

The determination of B_{MSY}=$B_{35\%}$ for Tanner crab depends on the selection of an appropriate time period over which to calculate average recruitment ($\bar{R}$). Following discussion in 2012 and 2013, the SSC endorsed an averaging period of 1982+. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. This issue was revisited at the May 2018 CPT meeting with regard to whether or not the final year should be included in the calculation, but no definitive recommendations were made. In 2020, the NMFS EBS shelf bottom trawl survey was canceled due to health and safety concerns associated with the COVID-19 pandemic. This resulted in enormous uncertainty in the estimate of terminal year recruitment, which was subsequently dropped from the averaging time frame. The missing survey continues to influence recruitment estimates near the end of the time series. This year, the estimate for recruitment entering the population on July 1, 2020 was extremely small in all the models considered here: the associated ln-scale recruitment deviation hit its lower bound in all models except the author's preferred one, in which case a mild prior had been used to prevent the extreme results obtained in the other models. Simulation testing (Appendix J) indicates similar effects associated with the missing survey may continue with diminishing effect over several years. However, the low estimate recruitment also appears to be consistent with size compositions from the NMFS EBS shelf survey this year. Consequently, average recruitment for the preferred model was calculated using the period 1982-2020.

The value of $\bar{R}$ for this period from MCMC runs of the author's preferred model is 389.88 million. This estimate of average recruitment is similar to that from the 2020 assessment model (369.69 million). The value of B_{MSY}=$B_{35\%}$ for $\bar{R}$ is 35.94 thousand t, which is somewhat smaller than that obtained in the 2020 assessment (36.62 thousand t).

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

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

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

where *C* is total catch (biomass), $F_{f,x,z}$ is the fishing mortality in fishery *f* on crab in size bin *z* by sex (*x*), $F_{.,x,z} = \sum_f F_{f,x,z}$ is the total fishing mortality by sex on crab in size bin *z*, $w_{x,z}$ is the mean weight of crab in size bin *z* by sex, M_x is the sex-specific rate of natural mortality, δt is the time from July 1 to the time of the fishery (0.625 yr), and $N_{x,z}$ is the numbers by sex in size bin *z* on July 1, 2021 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 2021/22 were calculated based on the resulting parameter values. This should be repeated a large number of times to approximate the distribution of OFL given the full model uncertainty. For this assessment, two chains of 10 million MCMC steps each were generated from the author's preferred model (21.22a), with the OFL and associated quantities calculated at each step. The chains were initialized from the converged model state using a "burn in" of 2 million steps and subsequently thinned by a factor of 2,000 to reduce serial autocorrelation in the MCMC sampling. This resulted in about 1,600 MCMC samples with which to characterize the distribution of the OFL.

Trace plots for the OFL and related quantities (Figure 60) indicate that mixing within the chains was fairly poor, with subsequent samples in each chain substantially autocorrelated when they should have been independent. However, histograms and pairs plots for the combined chains appear reasonable. **Despite the poor mixing characteristics of the MCMC sampling, the median value of across all chains was taken as the OFL for 2020/21. The median tends to be insensitive to outliers, and thus may perform better than, for example, a mean, under these circumstances. As such, the OFL for 2020/21 from the author's preferred model (21.22a) is 27.17 thousand t** (Figure 64)**.**

The B_{MSY} proxy, $B_{35\%}$, from the author's preferred model is 35.94 thousand t, so MSST = 0.5 B_{MSY} = 19.97 thousand t. Because current projected B = 42.57 thousand t > MSST, **the stock is not overfished**. Because current projected $B > B_{MSY}$, the **stock falls into Tier 3a**. The population state (directed F vs. MMB) is plotted starting in 1975 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. However, because determining the P* ABC relies on an uncertainty distribution for the OFL derived from the MCMC results, its validity seems highly dubious this year.

For the author's preferred model, 21.22a, the P* ABC (ABC_{max}) is 27.14 thousand t while the 20% Buffer ABC is 21.74 thousand t. As noted, the value for the P* ABC is questionable given the poor MCMC performance. In addition, the author remains concerned that the OFL calculation, based on $F_{35\%}$ as a proxy for F_{MSY}, is overly optimistic regarding the actual productivity of the stock. Fishery-related mortality similar to the P* ABC level has occurred only in the latter half of the 1970s and in 1992/93, coincident with collapses in stock biomass to low levels. This suggests that $F_{35\%}$ may not be a realistic proxy for F_{MSY} and/or that MMB may not be a good proxy for reproductive success, as are currently assumed for this stock. In addition, the estimates of survey catchability for this stock remain problematic and contribute to this year's inflated OFL recommendation (relative to last year's) despite a continued decline in survey biomass across the last few years. Given this uncertainty concerning the stock, **the**

author recommends using the 20% buffer previously adopted by the SSC for this stock to calculate ABC. Consequently, the author's recommended ABC is 21.74 thousand t.

The following tables summarize the OFL/ABC results for model 21.22a based on the MCMC results:

Table L: OFL/ABC results for model 21.22a based on MCMC results.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.31	56.15	0.00	0.00	0.54	28.86	23.09
2020/21	17.97	56.34	1.07	0.66	0.96	21.13	16.90
2021/22		42.57				27.17	21.74

G. Rebuilding Analyses

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

H. Data Gaps and Research Priorities

Information on growth-per-molt has been collected in the EBS on Tanner crab and incorporated into the assessment. It would be helpful to have more information on growth associated with the terminal molt, because it seems likely this has different characteristics than previous molts. A better understanding of drivers of natural mortality and recruitment variability is another key to improving the ecological basis for the assessment. More comprehensive information regarding thermal tolerances and temperature-dependent effects on molting frequency and movement would be helpful to assess potential impacts of the EBS cold pool on recruitment processes and the stock distribution. Furthermore, 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 also needs to be carefully reconsidered. How, and whether or not, the differences in the directed fishery in areas east and west 166^{o} W longitude should be explicitly represented in the assessment model need to be addressed. This is particularly relevant now that the eastern management area has been closed for several years, which has implications for whether an asymptotic function remains a reasonable description of selectivity in the directed fishery. The question of whether or not bycatch in the groundfish fisheries should be split into fixed gear- and trawl-related components to better capture changes in bycatch selectivity needs to be revisited.

Incorporating the BSFRF side-by-side (SBS) surveys into the assessment in the best way possible is also a matter for continued exploration. A catch ratio analysis using the SBS survey data outside the model (presented at the May, 2021 CPT meeting) provided initial estimates of year-specific NMFS survey selectivity that account for variations in stock abundance across different depths and benthic substrates. This analysis needs to be drawn to a conclusion and incorporated, at least as an option, into the assessment model framework

Development of a GMACS version of the Tanner crab model is also a priority and will proceed now that a GMACS model for snow crab has been developed.

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). Pacific cod spawning biomass is estimated to have increased rapidly in the early 1980s, concomitant with a period of rapid decline in Tanner crab biomass (modeled as a period of high but unexplained natural mortality in the assessment). Subsequently, Pacific cod spawning biomass declined rapidly in the late 1980s and early 1990s. At the same time, the Tanner crab stock first increased in the late 1980s but then decreased in the early 1990s, possibly lagging the continued decline in Pacific cod spawning biomass by a year or two. After 1993, cod spawning biomass continued a very gradual decline until 2010, after which it has been increasing fairly rapidly (Thompson et al. 2021). However, Tanner crab biomass began to increase in 2000, reached a relative peak in 2008, and has fluctuated since then. It is not immediately apparent that trends in Pacific cod spawning biomass have a direct effect on Tanner crab biomass.

2. Effects of Tanner crab fishery on ecosystem

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

Table M. Potential effects of the Tanner crab fishery on the ecosystem.

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. Acknowledgments

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Table captions

Figure captions

Tables

Table 1. Retained catch (males) in directed Tanner crab fisheries (1965/66-1996/97). Catch units are metric tons. Foreign fishing ended in 1979. A ‘c’ appended to the year denotes a closure of the directed domestic fishery (1984/85 and 1985/86). The domestic fishery was closed from 1997/98 until 2005/06 (see Tables 2-4 for subsequent values).

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

Table 2. Retained catch (males) in the US domestic pot fishery from 1968 to 2004/05 (Fitch et al., 2012). Total crab caught and total harvest include deadloss. The "Fishery Year" YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADFG year (in parentheses, if different from the "Fishery Year") indicates the year ADFG assigned to the fishery season in compiled reports.

year (ADFG year)	Total Crab (no.)	Total Harvest (lbs)	GHL/TAC (millions lbs)	Vessels (no.)	Season
1968/69 (1969)	353,300	1,008,900			
1969/70 (1970)	482,300	1,014,700			
1970/71 (1971)	61,300	166,100			
1971/72 (1972)	42,061	107,761			
1972/73 (1973)	93,595	231,668			
1973/74 (1974)	2,531,825	5,044,197			
1974/75	2,773,770	7,028,378		28	
1975/76	8,956,036	22,358,107		66	
1976/77	20,251,508	51,455,221		83	
1977/78	26,350,688	66,648,954		120	
1978/79	16,726,518	42,547,174		144	
1979/80	14,685,611	36,614,315	28-36	152	11/01-05/11
1980/81 (1981)	11,845,958	29,630,492	28-36	165	01/15-04/15
1981/82 (1982)	4,830,980	11,008,779	12-16	125	02/15-06/15
1982/83 (1983)	2,286,756	5,273,881	5.6	108	02/15-06/15
1983/84 (1984)	516,877	1,208,223	7.1	41	02/15-06/15
1984/85 (1985)	1,272,501	3,036,935	3	44	01/15-06/15
1985/86 (1986)	---closed---				
1986/87 (1987)	---closed---				
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
1990/91	16,608,625	40,081,555	42.8	255	11/20-03/25
1991/92	12,924,102	31,794,382	32.8	285	11/15-03/31
1992/93	15,265,865	35,130,831	39.2	294	11/15-03/31
1993/94	7,235,898	16,892,320	9.1	296	11/01-11/10, 11/20-01/01
1994/95 (1994)	3,351,639	7,766,886	7.5	183	11/01-11/21
1995/96 (1995)	1,877,303	4,233,061	5.5	196	11/01-11/16
1996/97 (1996)	734,296	1,806,077	6.2	196	11/01-11/05, 11/15-11/27
1997/98-2004/05	---closed---				

Table 3. Federal fishery management quantities (OFL, ABC), State of Alaska TACs, and retained catch biomass in the directed Tanner crab following crab fishery rationalization (FMP Amendments 18 and 19, 2005). Revised OFL definitions were approved in 2008; ABCs were not established until 2011 (FMP Amendment 38). TACs set to 0 indicate closure of the directed fishery in the associated State management area.

	OFL	ABC	TAC (mt)			Harvest (mt)			TAC (lbs)			Harvest (lbs)		
year	(mt)	(mt)	East 166W	West166W	total	East 166W	West166W	total	East 166W	West166W	total	East 166W	West166W	total
2005/06	–	–	0	735	735	0	245	245	0	1,620,000	1,620,000	0	539,105	539,105
2006/07	–	–	851	496	1,347	631	156	787	1,875,000	1,093,900	2,968,900	1,391,617	342,888	1,734,505
2007/08	–	–	1,563	987	2,550	710	151	861	3,444,900	2,176,000	5,620,900	1,565,270	333,144	1,898,414
2008/09	7,040	–	1,253	697	1,951	807	47	854	2,763,100	1,537,100	4,300,200	1,778,806	103,963	1,882,769
2009/10	2,270	–	612	0	612	592	0	592	1,350,100	0	1,350,100	1,306,055	0	1,306,055
2010/11	1,610	–	0	0	0	0	0	0	0	0	0	0	0	0
2011/12	2,750	2,480	0	0	0	0	0	0	0	0	0	0	0	0
2012/13	19,020	8,170	0	0	0	0	0	0	0	0	0	0	0	0
2013/14	25,350	17,820	664	746	1,410	654	594	1,248	1,463,000	1,645,100	3,108,100	1,442,420	1,308,701	2,751,121
2014/15	31,480	25,180	3,847	3,005	6,852	3,829	2,369	6,198	8,480,100	6,625,100	15,105,200	8,442,125	5,222,067	13,664,192
2015/16	27,190	21,750	5,113	3,808	8,921	5,108	3,770	8,878	11,272,000	8,396,100	19,668,100	11,260,586	8,312,120	19,572,706
2016/17	25,610	20,490	0	0	0	0	0	0	0	0	0	0	0	0
2017/18	25,420	20,330	0	1,134	1,134	0	1,117	1,118	0	2,500,300	2,500,300	262	2,463,626	2,463,888
2018/19	20,870	16,700	0	1,106	1,106	0	1,104	1,104	0	2,439,000	2,439,000	0	2,433,686	2,433,686
2019/20	28,860	23,090	0	0	0	0	0	0	0	0	0	0	0	0
2020/21	21,130	16,900	0	1,065	1,065	0	655	655	0	2,348,000	2,348,000	0	1,444,410	1,444,410

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

	TCF						SCF		RKF	
	West 166W		East 166W		all EBS		all EBS		all EBS	
year	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)
2005	255,859	244,534	0	0	255,859	244,534	188,118	187,689	0	0
2006	164,719	155,532	581,024	631,228	745,743	786,760	175,904	171,439	4,456	4,593
2007	151,525	151,112	677,661	709,995	829,186	861,107	90,148	86,478	7,830	7,978
2008	48,171	47,157	758,002	806,854	806,173	854,011	3,300	2,535	20,896	23,235
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	4,817,144	3,770,319	5,998,876	5,107,722	10,816,020	8,878,041	39,012	30,253	1,386	1,350
2016	0	0	0	0	0	0	1,733	1,177	33	21
2017	1,322,542	1,117,483	139	119	1,322,681	1,117,602	17,688	15,018	25	17
2018	1,376,977	1,103,903	0	0	1,376,977	1,103,903	4,013	3,409	18	12
2019	0	0	0	0	0	0	125	84	0	0
2020	870,634	655,174	0	0	870,634	655,174	3,017	2,328	1	1

Table 5. Total catch biomass (retained + discarded) of Tanner crab in various fisheries, as estimated from observer data. Discard mortality has not been included. Units are metric tons. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GF: groundfish fisheries. All catch in the directed fishery prior to 1991 is retained catch.

	TCF crab pot all EBS		SCF crab pot all EBS		RKF crab pot all EBS		GF			all fleets
							fixed all EBS	trawl all EBS	all gear all EBS	all gear all EBS
year	male	female	male	female	male	female	all sexes	all sexes	all sexes	all sexes
1965	1,920.0	–	–	–	–	–	–	–	–	1,920.0
1966	2,440.0	–	–	–	–	–	–	–	–	2,440.0
1967	13,590.0	–	–	–	–	–	–	–	–	13,590.0
1968	18,010.0	–	–	–	–	–	–	–	–	18,010.0
1969	27,490.0	–	–	–	–	–	–	–	–	27,490.0
1970	25,500.0	–	–	–	–	–	–	–	–	25,500.0
1971	20,720.0	–	–	–	–	–	–	–	–	20,720.0
1972	16,900.0	–	–	–	–	–	–	–	–	16,900.0
1973	13,030.0	–	–	–	–	–	–	–	17,735.5	30,765.5
1974	15,360.0	–	–	–	–	–	–	–	24,448.6	39,808.6
1975	17,660.0	–	–	–	–	–	–	–	9,407.5	27,067.5
1976	30,020.0	–	–	–	–	–	–	–	4,699.2	34,719.2
1977	35,530.0	–	–	–	–	–	–	–	2,776.0	38,306.0
1978	21,090.0	–	–	–	–	–	–	–	1,868.8	22,958.8
1979	19,000.0	–	–	–	–	–	–	–	3,397.4	22,397.4
1980	13,426.3	–	–	–	–	–	–	–	2,113.7	15,540.1
1981	4,989.5	–	–	–	–	–	–	–	1,474.2	6,463.7
1982	2,390.4	–	–	–	–	–	–	–	449.1	2,839.5
1983	548.8	–	–	–	–	–	–	–	671.3	1,220.2
1984	1,428.8	–	–	–	–	–	–	–	644.1	2,072.9
1985	–	–	–	–	–	–	–	–	399.2	399.2
1986	–	–	–	–	–	–	–	–	648.6	648.6
1987	997.9	–	–	–	–	–	–	–	639.6	1,637.5
1988	3,179.7	–	–	–	–	–	–	–	462.7	3,642.3
1989	11,113.0	–	–	–	–	–	–	–	671.3	11,784.3
1990	18,189.1	–	7,081.2	105.7	3,722.4	35.6	–	–	943.5	30,077.5
1991	25,817.3	1,886.1	8,360.2	144.0	1,970.3	27.2	148.3	2,394.9	2,543.2	40,748.2

Table 5 (cont.). Total catch biomass (retained + discarded) of Tanner crab in various fisheries, as estimated from observer data. Discard mortality has not been included. Units are metric tons. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GF: groundfish fisheries.

	TCF						SCF		RKF		GF			all fleets
	crab pot						crab pot		crab pot		fixed	trawl	all gear	all gear
	West 166W		East 166W		all EBS		all EBS		all EBS		all EBS	all EBS	all EBS	all EBS
year	male	female	male	female	male	female	male	female	male	female	all sexes	all sexes	all sexes	all sexes
1992	–	–	–	–	37,007.4	1,703.6	2,487.2	162.5	1,316.7	19.0	102.7	2,656.9	2,759.6	45,456.1
1993	–	–	–	–	11,853.9	996.3	2,874.4	400.4	3,130.8	149.3	23.5	1,734.5	1,758.0	21,163.0
1994	–	–	–	–	7,315.4	841.6	1,345.1	194.2	–	–	23.9	2,072.1	2,096.0	11,792.4
1995	–	–	–	–	5,065.5	1,064.9	1,021.0	120.9	–	–	127.9	1,397.0	1,524.9	8,797.3
1996	–	–	–	–	300.4	56.7	1,960.7	119.6	270.0	2.4	118.0	1,476.5	1,594.5	4,304.4
1997	–	–	–	–	–	–	1,963.7	92.7	160.1	1.7	63.9	1,116.0	1,180.0	3,398.1
1998	–	–	–	–	–	–	655.9	80.4	115.2	1.7	88.0	847.1	935.0	1,788.2
1999	–	–	–	–	–	–	131.8	11.2	75.1	2.2	84.8	545.9	630.6	850.9
2000	–	–	–	–	–	–	312.8	6.1	66.4	1.4	53.1	688.4	741.5	1,128.2
2001	–	–	–	–	–	–	545.3	20.5	42.2	1.0	124.7	1,060.5	1,185.2	1,794.2
2002	–	–	–	–	–	–	167.2	13.8	61.3	1.6	95.5	623.6	719.1	962.9
2003	–	–	–	–	–	–	64.7	7.0	54.9	1.8	20.4	403.4	423.8	552.3
2004	–	–	–	–	–	–	134.6	39.9	49.8	1.6	64.9	610.2	675.1	901.0
2005	684.6	23.8	–	–	–	–	1,162.8	16.3	41.4	1.0	133.1	488.1	621.2	2,551.0
2006	579.2	72.3	1,132.1	48.8	–	–	1,527.2	85.5	29.5	1.5	345.9	371.2	717.1	4,193.4
2007	679.9	14.8	1,779.1	29.3	–	–	1,861.6	52.1	60.6	1.4	474.4	220.6	694.9	5,173.7
2008	119.1	1.5	1,177.8	6.7	–	–	1,100.3	24.9	279.9	2.5	287.6	245.3	532.9	3,245.6
2009	–	–	664.6	2.3	–	–	1,559.6	15.7	186.5	1.1	225.3	148.8	374.2	2,803.9
2010	–	–	–	–	–	–	1,453.3	9.2	31.9	0.6	117.9	113.5	231.4	1,726.3
2011	–	–	–	–	–	–	2,141.3	13.3	17.5	0.1	76.4	127.6	204.0	2,376.1
2012	–	–	–	–	–	–	1,564.3	10.3	42.1	1.3	46.1	107.2	153.3	1,771.3
2013	933.1	11.4	746.2	12.1	–	–	1,841.8	15.6	128.9	1.3	181.6	166.8	348.4	4,038.7
2014	3,057.0	30.5	5,306.6	8.8	–	–	5,330.0	50.7	305.4	1.0	261.3	174.4	435.7	14,525.7
2015	5,467.6	29.4	6,761.4	28.2	–	–	3,919.2	16.8	205.0	5.6	276.0	85.3	361.2	16,794.3
2016	–	–	–	–	–	–	2,575.7	16.7	175.7	4.2	154.5	144.6	299.1	3,071.4
2017	1,362.5	38.5	–	–	–	–	1,081.7	6.8	183.6	1.4	111.1	49.4	160.5	2,835.0
2018	1,598.4	34.7	–	–	–	–	879.7	8.9	74.0	0.1	120.5	55.7	176.2	2,772.1
2019	–	–	–	–	–	–	1,003.3	15.1	18.0	0.0	43.2	102.7	145.9	1,182.3
2020	1,547.2	33.3	–	–	–	–	130.8	0.7	6.3	0.1	23.6	100.9	124.5	1,842.8

Table 6. Estimated total catch mortality (retained + discarded) of Tanner crab in various fisheries, as estimated using the subtraction method from retained catch and observer data on total catch. Assumed discard mortality rates of 0.321 for crab pot and fixed gear fisheries and 0.800 for trawl fisheries have been applied on a gear-specific basis. Units are metric tons. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GF: groundfish fisheries. All catch in the directed fishery prior to 1991 is retained catch. The handling mortality for trawl gear is applied to all catch in the groundfish fisheries prior to 1991.

	TCF crab pot all EBS		SCF crab pot all EBS		RKF crab pot all EBS		GF			all fleets
							fixed all EBS	trawl all EBS	all gear all EBS	all gear all EBS
year	male	female	male	female	male	female	all sexes	all sexes	all sexes	all sexes
1965	1,920.0	–	–	–	–	–	–	–	–	1,920.0
1966	2,440.0	–	–	–	–	–	–	–	–	2,440.0
1967	13,590.0	–	–	–	–	–	–	–	–	13,590.0
1968	18,010.0	–	–	–	–	–	–	–	–	18,010.0
1969	27,490.0	–	–	–	–	–	–	–	–	27,490.0
1970	25,500.0	–	–	–	–	–	–	–	–	25,500.0
1971	20,720.0	–	–	–	–	–	–	–	–	20,720.0
1972	16,900.0	–	–	–	–	–	–	–	–	16,900.0
1973	13,030.0	–	–	–	–	–	–	–	14,188.4	27,218.4
1974	15,360.0	–	–	–	–	–	–	–	19,558.9	34,918.9
1975	17,660.0	–	–	–	–	–	–	–	7,526.0	25,186.0
1976	30,020.0	–	–	–	–	–	–	–	3,759.4	33,779.4
1977	35,530.0	–	–	–	–	–	–	–	2,220.8	37,750.8
1978	21,090.0	–	–	–	–	–	–	–	1,495.0	22,585.0
1979	19,000.0	–	–	–	–	–	–	–	2,717.9	21,717.9
1980	13,426.3	–	–	–	–	–	–	–	1,691.0	15,117.3
1981	4,989.5	–	–	–	–	–	–	–	1,179.3	6,168.9
1982	2,390.4	–	–	–	–	–	–	–	359.2	2,749.7
1983	548.8	–	–	–	–	–	–	–	537.1	1,085.9
1984	1,428.8	–	–	–	–	–	–	–	515.3	1,944.1
1985	–	–	–	–	–	–	–	–	319.3	319.3
1986	–	–	–	–	–	–	–	–	518.9	518.9
1987	997.9	–	–	–	–	–	–	–	511.7	1,509.6
1988	3,179.7	–	–	–	–	–	–	–	370.1	3,549.8
1989	11,113.0	–	–	–	–	–	–	–	537.1	11,650.1
1990	18,189.1	–	2,273.1	33.9	1,194.9	11.4	–	–	754.8	22,457.2
1991	18,081.4	605.4	2,683.6	46.2	632.5	8.7	47.6	1,915.9	1,963.5	24,021.4

Table 6 (cont.). Estimated total catch mortality (retained + discarded) of Tanner crab in various fisheries, as estimated using the subtraction method from retained catch and observer data on total catch. Assumed discard mortality rates of 0.321 for crab pot and fixed gear fisheries and 0.800 for trawl fisheries have been applied on a gear-specific basis. Units are metric tons. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GF: groundfish fisheries.

	TCF crab pot						SCF crab pot		RKF crab pot		GF			all fleets
	West 166W		East 166W		all EBS		all EBS		all EBS		fixed all EBS	trawl all EBS	all gear all EBS	all gear all EBS
year	male	female	male	female	male	female	male	female	male	female	all sexes	all sexes	all sexes	all sexes
1992	–	–	–	–	22,689.8	546.8	798.4	52.2	422.7	6.1	33.0	2,125.5	2,158.5	26,674.5
1993	–	–	–	–	9,010.1	319.8	922.7	128.5	1,005.0	47.9	7.5	1,387.6	1,395.1	12,829.2
1994	–	–	–	–	4,750.6	270.2	431.8	62.3	–	–	7.7	1,657.7	1,665.4	7,180.2
1995	–	–	–	–	2,928.8	341.8	327.8	38.8	–	–	41.0	1,117.6	1,158.7	4,795.9
1996	–	–	–	–	821.0	18.2	629.4	38.4	86.7	0.8	37.9	1,181.2	1,219.1	2,813.5
1997	–	–	–	–	–	–	630.3	29.7	51.4	0.5	20.5	892.8	913.3	1,625.4
1998	–	–	–	–	–	–	210.6	25.8	37.0	0.5	28.2	677.7	705.9	979.8
1999	–	–	–	–	–	–	42.3	3.6	24.1	0.7	27.2	436.7	463.9	534.6
2000	–	–	–	–	–	–	100.4	1.9	21.3	0.4	17.1	550.7	567.8	691.9
2001	–	–	–	–	–	–	175.0	6.6	13.5	0.3	40.0	848.4	888.4	1,083.9
2002	–	–	–	–	–	–	53.7	4.4	19.7	0.5	30.7	498.8	529.5	607.8
2003	–	–	–	–	–	–	20.8	2.3	17.6	0.6	6.6	322.7	329.3	370.5
2004	–	–	–	–	–	–	43.2	12.8	16.0	0.5	20.8	488.2	509.0	581.5
2005	385.8	7.6	–	–	–	–	500.7	5.2	13.3	0.3	42.7	390.5	433.2	1,346.2
2006	291.5	23.2	792.0	15.7	–	–	606.7	27.5	12.6	0.5	111.0	297.0	408.0	2,177.6
2007	320.8	4.8	1,053.2	9.4	–	–	656.3	16.7	24.9	0.5	152.3	176.4	328.7	2,415.2
2008	70.3	0.5	925.9	2.1	–	–	354.9	8.0	105.6	0.8	92.3	196.2	288.6	1,756.7
2009	–	–	615.6	0.7	–	–	501.8	5.0	65.6	0.4	72.3	119.1	191.4	1,380.5
2010	–	–	–	–	–	–	467.3	2.9	10.2	0.2	37.8	90.8	128.6	609.3
2011	–	–	–	–	–	–	688.8	4.3	5.6	0.0	24.5	102.1	126.6	825.3
2012	–	–	–	–	–	–	502.9	3.3	13.5	0.4	14.8	85.7	100.5	620.7
2013	702.6	3.6	683.8	3.9	–	–	597.9	5.0	45.7	0.4	58.3	133.5	191.7	2,234.7
2014	2,589.6	9.8	4,303.5	2.8	–	–	1,720.8	16.3	100.6	0.3	83.9	139.5	223.4	8,967.1
2015	4,315.1	9.4	5,638.6	9.1	–	–	1,278.6	5.4	66.7	1.8	88.6	68.2	156.8	11,481.5
2016	–	–	–	–	–	–	827.6	5.4	56.4	1.4	49.6	115.7	165.2	1,056.0
2017	1,196.1	12.4	–	–	–	–	357.4	2.2	58.9	0.5	35.7	39.5	75.2	1,702.7
2018	1,262.6	11.1	–	–	–	–	284.7	2.8	23.8	0.0	38.7	44.6	83.3	1,668.4
2019	–	–	–	–	–	–	322.1	4.8	5.8	0.0	13.9	82.1	96.0	428.8
2020	941.5	10.7	–	–	–	–	43.6	0.2	2.0	0.0	7.6	80.7	88.3	1,086.3

Table 7. Estimated bycatch mortality (discards) of Tanner crab in various fisheries, as estimated using the subtraction method from retained catch and observer data on total catch. Assumed discard mortality rates of 0.321 for crab pot and fixed gear fisheries and 0.800 for trawl fisheries have been applied on a gear-specific basis. Units are metric tons. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GF: groundfish fisheries. All catch in the directed fishery prior to 1991 is retained catch. The handling mortality for trawl gear is applied to all catch in the groundfish fisheries prior to 1991.

	TCF crab pot all EBS		SCF crab pot all EBS		RKF crab pot all EBS		GF fixed all EBS	GF trawl all EBS	GF all gear all EBS	all fleets all gear all EBS
year	male	female	male	female	male	female	all sexes	all sexes	all sexes	all sexes
1973	–	–	–	–	–	–	–	–	14,188.4	14,188.4
1974	–	–	–	–	–	–	–	–	19,558.9	19,558.9
1975	–	–	–	–	–	–	–	–	7,526.0	7,526.0
1976	–	–	–	–	–	–	–	–	3,759.4	3,759.4
1977	–	–	–	–	–	–	–	–	2,220.8	2,220.8
1978	–	–	–	–	–	–	–	–	1,495.0	1,495.0
1979	–	–	–	–	–	–	–	–	2,717.9	2,717.9
1980	–	–	–	–	–	–	–	–	1,691.0	1,691.0
1981	–	–	–	–	–	–	–	–	1,179.3	1,179.3
1982	–	–	–	–	–	–	–	–	359.2	359.2
1983	–	–	–	–	–	–	–	–	537.1	537.1
1984	–	–	–	–	–	–	–	–	515.3	515.3
1985	–	–	–	–	–	–	–	–	319.3	319.3
1986	–	–	–	–	–	–	–	–	518.9	518.9
1987	–	–	–	–	–	–	–	–	511.7	511.7
1988	–	–	–	–	–	–	–	–	370.1	370.1
1989	–	–	–	–	–	–	–	–	537.1	537.1
1990	–	–	2,273.1	33.9	1,194.9	11.4	–	–	754.8	4,268.1
1991	3,657.2	605.4	2,683.6	46.2	632.5	8.7	47.6	1,915.9	1,963.5	9,597.2

Table 7 (cont.). Estimated bycatch mortality (discards) of Tanner crab in various fisheries, as estimated using the subtraction method from retained catch and observer data on total catch. Assumed discard mortality rates of 0.321 for crab pot and fixed gear fisheries and 0.800 for trawl fisheries have been applied on a gear-specific basis. Units are metric tons. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GF: groundfish fisheries.

	TCF crab pot						SCF crab pot		RKF crab pot		GF			all fleets
	West 166W		East 166W		all EBS		all EBS		all EBS		fixed all EBS	trawl all EBS	all gear all EBS	all gear all EBS
year	male	female	male	female	male	female	male	female	male	female	all sexes	all sexes	all sexes	all sexes
1992	–	–	–	–	6,768.7	546.8	798.4	52.2	422.7	6.1	33.0	2,125.5	2,158.5	10,753.4
1993	–	–	–	–	1,344.4	319.8	922.7	128.5	1,005.0	47.9	7.5	1,387.6	1,395.1	5,163.5
1994	–	–	–	–	1,212.5	270.2	431.8	62.3	–	–	7.7	1,657.7	1,665.4	3,642.2
1995	–	–	–	–	1,010.1	341.8	327.8	38.8	–	–	41.0	1,117.6	1,158.7	2,877.2
1996	–	–	–	–	–	18.2	629.4	38.4	86.7	0.8	37.9	1,181.2	1,219.1	1,992.5
1997	–	–	–	–	–	–	630.3	29.7	51.4	0.5	20.5	892.8	913.3	1,625.4
1998	–	–	–	–	–	–	210.6	25.8	37.0	0.5	28.2	677.7	705.9	979.8
1999	–	–	–	–	–	–	42.3	3.6	24.1	0.7	27.2	436.7	463.9	534.6
2000	–	–	–	–	–	–	100.4	1.9	21.3	0.4	17.1	550.7	567.8	691.9
2001	–	–	–	–	–	–	175.0	6.6	13.5	0.3	40.0	848.4	888.4	1,083.9
2002	–	–	–	–	–	–	53.7	4.4	19.7	0.5	30.7	498.8	529.5	607.8
2003	–	–	–	–	–	–	20.8	2.3	17.6	0.6	6.6	322.7	329.3	370.5
2004	–	–	–	–	–	–	43.2	12.8	16.0	0.5	20.8	488.2	509.0	581.5
2005	141.3	7.6	–	–	–	–	313.0	5.2	13.3	0.3	42.7	390.5	433.2	913.9
2006	136.0	23.2	160.8	15.7	–	–	435.2	27.5	8.0	0.5	111.0	297.0	408.0	1,214.8
2007	169.7	4.8	343.2	9.4	–	–	569.8	16.7	16.9	0.5	152.3	176.4	328.7	1,459.7
2008	23.1	0.5	119.1	2.1	–	–	352.4	8.0	82.4	0.8	92.3	196.2	288.6	876.9
2009	–	–	23.2	0.7	–	–	500.1	5.0	57.2	0.4	72.3	119.1	191.4	777.9
2010	–	–	–	–	–	–	466.1	2.9	10.2	0.2	37.8	90.8	128.6	608.1
2011	–	–	–	–	–	–	686.7	4.3	5.6	0.0	24.5	102.1	126.6	823.2
2012	–	–	–	–	–	–	501.8	3.3	13.5	0.4	14.8	85.7	100.5	619.6
2013	109.0	3.6	29.5	3.9	–	–	588.0	5.0	39.4	0.4	58.3	133.5	191.7	970.6
2014	220.9	9.8	474.2	2.8	–	–	1,706.3	16.3	96.8	0.3	83.9	139.5	223.4	2,750.9
2015	544.8	9.4	530.8	9.1	–	–	1,248.3	5.4	65.4	1.8	88.6	68.2	156.8	2,571.8
2016	–	–	–	–	–	–	826.4	5.4	56.4	1.4	49.6	115.7	165.2	1,054.8
2017	78.7	12.4	–	–	–	–	342.4	2.2	58.9	0.5	35.7	39.5	75.2	570.2
2018	158.7	11.1	–	–	–	–	281.3	2.8	23.8	0.0	38.7	44.6	83.3	561.1
2019	–	–	–	–	–	–	322.0	4.8	5.8	0.0	13.9	82.1	96.0	428.7
2020	286.3	10.7	–	–	–	–	41.2	0.2	2.0	0.0	7.6	80.7	88.3	428.8

Table 8. Effort data (potlifts) in the crab fisheries, by area. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery. Hyphens indicate years with no effort.

year	SCF all EBS	RKF all EBS
1953	–	30,083
1954	–	17,122
1955	–	28,045
1956	–	41,629
1957	–	23,659
1958	–	27,932
1959	–	22,187
1960	–	26,347
1961	–	72,646
1962	–	123,643
1963	–	181,799
1964	–	180,809
1965	–	127,973
1966	–	129,306
1967	–	135,283
1968	–	184,666
1969	–	175,374
1970	–	168,059
1971	–	126,305
1972	–	208,469
1973	–	194,095
1974	–	212,915
1975	–	205,096
1976	–	321,010
1977	–	451,273
1978	190,746	406,165
1979	255,102	315,226
1980	435,742	567,292
1981	469,091	536,646
1982	287,127	140,492
1983	173,591	0
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 8 (cont.). Effort data (potlifts) in the crab fisheries, by area. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery. Hyphens indicate years with no effort.

	TCF			SCF	RKF
year	West 166W	East 166W	all EBS	all EBS	all EBS
1990	479	493,820	494,299	1,382,908	262,761
1991	140,050	360,864	500,914	1,278,502	227,555
1992	166,670	508,922	675,592	969,209	206,815
1993	40,100	286,620	326,720	716,524	254,389
1994	21,282	228,254	249,536	507,603	697
1995	46,454	201,988	248,442	520,685	547
1996	8,533	64,989	73,522	754,140	77,081
1997	–	–	–	930,794	91,085
1998	–	–	–	945,533	145,689
1999	–	–	–	182,634	151,212
2000	–	–	–	191,200	104,056
2001	–	–	–	326,977	66,947
2002	–	–	–	153,862	72,514
2003	–	–	–	123,709	134,515
2004	–	–	–	75,095	97,621
2005	6,346	–	6,346	117,375	116,320
2006	4,517	15,273	19,790	86,328	72,404
2007	7,268	26,441	33,709	140,857	113,948
2008	2,336	19,401	21,737	163,537	139,937
2009	–	6,635	6,635	137,292	119,261
2010	–	–	–	147,478	132,183
2011	–	–	–	270,602	45,784
2012	–	–	–	225,627	38,842
2013	23,062	16,613	39,675	225,245	46,589
2014	68,695	72,768	141,463	279,183	57,725
2015	84,933	130,302	215,235	202,526	48,763
2016	–	–	–	118,548	33,608
2017	19,284	11	19,295	114,673	49,169
2018	29,833	–	29,833	119,484	31,975
2019	–	–	–	188,958	35,033
2020	34,914	–	34,914	171,678	21,346

Table 9. Sample sizes for retained and total catch-at-size in the directed fishery. raw = number of individuals sampled. input = scaled sample size used in assessment.

	Retained Catch		Total Catch			
	male		male		female	
year	raw	input	raw	input	raw	input
1980	13,310	96	–	–	–	–
1981	11,311	81	–	–	–	–
1982	13,519	97	–	–	–	–
1983	1,675	12	–	–	–	–
1984	2,542	18	–	–	–	–
1988	12,380	89	–	–	–	–
1989	35,956	200	–	–	–	–
1990	83,590	200	51	0	34	0
1991	127,227	200	31,252	170	5,605	30
1992	125,395	200	54,836	172	8,755	28
1993	71,622	200	40,388	159	10,471	41
1994	27,658	199	5,792	42	2,132	15
1995	19,276	139	5,589	40	3,119	22
1996	4,430	32	352	3	168	1
2005	705	5	19,715	142	1,107	8
2006	2,940	21	24,226	169	4,432	31
2007	5,827	42	61,546	190	3,318	10
2008	3,490	25	29,166	196	646	4
2009	2,417	17	17,289	124	147	1
2013	4,553	33	17,291	124	710	5
2014	14,371	103	85,120	197	1,191	3
2015	24,320	175	119,843	197	1,624	3
2017	3,470	25	18,785	135	1,721	12
2018	3,306	24	28,338	187	2,036	13
2020	3,323	24	17,639	127	1,054	8

Table 10. Sample sizes for total bycatch-at-size in the snow crab ("SCF") and Bristol Bay red king crab ("RKF) fisheries, from crab observer sampling. raw = number of individuals. input = scaled sample size used in assessment.

	SCF				RKF			
	male		female		male		female	
year	raw	input	raw	input	raw	input	raw	input
1990	14,032	101	478	3	1,580	11	43	0
1991	11,708	84	686	5	2,273	16	89	1
1992	6,280	45	859	6	2,056	15	105	1
1993	6,969	50	1,542	11	7,359	53	1,196	9
1994	2,982	21	1,523	11	–	–	–	–
1995	1,898	14	428	3	–	–	–	–
1996	3,265	23	662	5	114	1	5	0
1997	3,970	29	657	5	1,030	7	41	0
1998	1,911	14	324	2	457	3	20	0
1999	976	7	82	1	207	1	14	0
2000	1,237	9	74	1	845	6	44	0
2001	3,113	22	160	1	456	3	39	0
2002	982	7	118	1	750	5	50	0
2003	688	5	152	1	555	4	46	0
2004	833	6	707	5	487	4	44	0
2005	9,807	71	368	3	983	7	70	1
2006	10,391	75	1,256	9	746	5	68	0
2007	13,797	99	728	5	1,360	10	89	1
2008	8,455	61	722	5	3,797	27	121	1
2009	11,057	79	474	3	2,871	21	70	1
2010	12,073	87	250	2	582	4	28	0
2011	9,453	68	189	1	323	2	4	0
2012	11,004	79	270	2	618	4	48	0
2013	12,935	93	356	3	2,110	15	60	0
2014	24,878	179	804	6	3,110	22	32	0
2015	19,839	143	230	2	2,175	16	186	1
2016	16,369	118	262	2	3,220	23	246	2
2017	5,598	40	109	1	3,782	27	86	1
2018	6,145	44	233	2	1,283	9	6	0
2019	8,881	64	423	3	357	3	3	0
2020	820	6	10	0	106	1	4	0

Table 11. Sample sizes for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. raw = number of individuals measured. input = scaled sample size used in the assessment.

	fixed				trawl				total			
	female		male		female		male		female		male	
year	raw	input	raw	input	raw	input	raw	input	raw	input	raw	input
1973	0	0.0000	0	0.000	0	0.000	0	0.000	4554	32.740	6310	45.365
1974	0	0.0000	0	0.000	0	0.000	0	0.000	3200	23.006	4984	35.832
1975	0	0.0000	0	0.000	0	0.000	0	0.000	1678	12.064	2502	17.988
1976	0	0.0000	0	0.000	0	0.000	0	0.000	13366	96.093	13900	99.933
1977	0	0.0000	0	0.000	0	0.000	0	0.000	16772	120.580	21370	153.637
1978	0	0.0000	0	0.000	0	0.000	0	0.000	27330	169.431	37192	230.569
1979	0	0.0000	0	0.000	0	0.000	0	0.000	22698	149.285	38120	250.715
1980	0	0.0000	0	0.000	0	0.000	0	0.000	11834	85.079	25612	184.135
1981	0	0.0000	0	0.000	0	0.000	0	0.000	8130	58.450	12196	87.682
1982	0	0.0000	0	0.000	0	0.000	0	0.000	16012	115.117	26878	193.236
1983	0	0.0000	0	0.000	0	0.000	0	0.000	16610	119.416	36726	264.038
1984	0	0.0000	0	0.000	0	0.000	0	0.000	27542	133.783	54806	266.217
1985	0	0.0000	0	0.000	0	0.000	0	0.000	25456	141.990	46256	258.010
1986	0	0.0000	0	0.000	0	0.000	0	0.000	15252	109.653	29720	213.669
1987	0	0.0000	0	0.000	0	0.000	0	0.000	31714	161.128	47016	238.872
1988	0	0.0000	0	0.000	0	0.000	0	0.000	14252	102.463	21172	152.214
1989	0	0.0000	0	0.000	0	0.000	0	0.000	82468	163.017	119886	236.983
1990	0	0.0000	0	0.000	0	0.000	0	0.000	22424	129.033	47090	270.967
1991	290	2.0849	1116	8.023	3189	22.927	5701	40.987	3479	25.012	6817	49.010
1992	39	0.2804	601	4.321	1136	8.167	2527	18.168	1175	8.448	3128	22.488
1993	25	0.1797	683	4.910	333	2.394	534	3.839	358	2.574	1217	8.749
1994	126	0.9059	1133	8.146	1694	12.179	2495	17.938	1820	13.085	3628	26.083
1995	44	0.3163	162	1.165	2625	18.872	3742	26.903	2669	19.188	3904	28.067
1996	439	3.1561	2442	17.556	2961	21.288	5864	42.159	3400	24.444	8306	59.715
1997	217	1.5601	1650	11.862	3683	26.479	8299	59.665	3900	28.039	9949	71.527
1998	627	4.5077	3870	27.823	3813	27.413	8235	59.205	4440	31.921	12105	87.028
1999	719	5.1692	3553	25.544	3803	27.341	7500	53.920	4522	32.510	11053	79.464
2000	227	1.6320	5144	36.982	2860	20.562	7751	55.725	3087	22.194	12895	92.707
2001	303	2.1784	6950	49.966	2780	19.987	8838	63.540	3083	22.165	15788	113.506
2002	831	5.9744	8571	61.620	2418	17.384	6830	49.104	3249	23.358	15401	110.724
2003	923	6.6358	4589	32.992	1810	13.013	4983	35.825	2733	19.649	9572	68.817
2004	560	4.0261	5413	38.916	3900	28.039	8431	60.614	4460	32.065	13844	99.530
2005	389	2.7967	8816	63.382	3320	23.869	8969	64.482	3709	26.665	17785	127.863
2006	824	5.9241	9270	66.646	2223	15.982	6633	47.687	3047	21.906	15903	114.333
2007	1175	8.4475	7235	52.015	2644	19.009	8913	64.079	3819	27.456	16148	116.094
2008	1770	11.6424	15832	104.137	2465	16.214	10339	68.006	4235	27.856	26171	172.144
2009	688	4.9463	12916	92.858	2013	14.472	6127	44.049	2701	19.419	19043	136.908
2010	956	6.8731	11264	80.981	1648	11.848	4402	31.648	2604	18.721	15666	112.629
2011	386	2.7751	8709	62.612	3877	27.873	7650	54.999	4263	30.648	16359	117.611
2012	836	6.0103	9192	66.085	2267	16.298	3994	28.714	3103	22.309	13186	94.799
2013	3489	19.9434	22471	128.446	2592	14.816	6437	36.794	6081	34.759	28908	165.241
2014	2061	9.4676	33529	154.022	2201	10.111	5747	26.400	4262	19.578	39276	180.422
2015	5152	30.7729	24488	146.267	629	3.757	3215	19.203	5781	34.530	27703	165.470
2016	1206	8.6704	14811	106.482	3224	23.179	3920	28.182	4430	31.849	18731	134.665
2017	1265	9.0946	11548	83.023	477	3.429	2035	14.630	1742	12.524	13583	97.654
2018	200	1.4379	4131	29.699	1129	8.117	3066	22.043	1329	9.555	7197	51.742
2019	157	1.1287	2581	18.556	2457	17.664	5363	38.557	2614	18.793	7944	57.113
2020	414	2.9764	2155	15.493	2116	15.213	5217	37.507	2530	18.189	7372	53.000

Table 12. 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 12 (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
2021	18,411	12,727	31,138	7,842	3,879	11,721

Table 13. Trends in Tanner crab abundance (millions of individuals) in the NMFS EBS summer bottom trawl survey, by sex and area.

		male			female	
year	W166	E166	all EBS	W166	E166	all EBS
1975	138.814	398.843	537.657	72.862	179.541	252.403
1976	152.409	231.307	383.716	134.647	165.103	299.749
1977	218.104	163.029	381.133	309.737	156.982	466.719
1978	166.910	125.124	292.034	197.238	92.771	290.010
1979	164.030	32.790	196.820	167.300	20.753	188.053
1980	556.254	90.857	647.111	539.580	66.075	605.655
1981	212.903	55.395	268.299	278.950	51.276	330.226
1982	145.547	44.534	190.081	448.570	45.850	494.420
1983	142.561	53.870	196.431	206.372	48.478	254.850
1984	93.036	40.451	133.487	129.134	35.820	164.955
1985	37.012	20.463	57.475	39.587	16.177	55.764
1986	62.731	57.820	120.551	32.397	46.107	78.505
1987	107.198	151.665	258.863	87.804	136.549	224.354
1988	237.862	187.456	425.318	168.010	140.710	308.720
1989	206.609	333.150	539.759	145.227	240.905	386.132
1990	195.564	235.472	431.035	182.543	200.222	382.765
1991	227.961	213.623	441.584	193.300	187.707	381.007
1992	145.024	160.397	305.421	145.647	59.026	204.672
1993	81.545	93.812	175.357	69.043	27.795	96.838
1994	66.779	52.188	118.967	63.469	29.669	93.139
1995	53.724	34.659	88.383	63.720	35.858	99.578
1996	39.265	51.145	90.409	41.229	47.062	88.291
1997	31.827	44.344	76.171	31.592	45.825	77.418
1998	56.468	32.758	89.226	51.264	20.154	71.419
1999	88.367	60.248	148.614	89.794	33.913	123.707
2000	77.476	49.559	127.035	64.273	31.565	95.838

Table 13 (cont). Trends in Tanner crab abundance (millions of individuals) in the NMFS EBS summer bottom trawl survey, by sex and area.

	male			female		
year	W166	E166	all EBS	W166	E166	all EBS
2001	154.998	132.565	287.563	148.270	119.356	267.626
2002	137.937	58.959	196.896	130.684	47.198	177.882
2003	187.919	56.675	244.594	172.304	25.578	197.881
2004	236.732	30.548	267.281	197.612	13.149	210.761
2005	290.526	59.360	349.886	276.389	55.380	331.769
2006	359.300	104.083	463.383	254.557	51.044	305.601
2007	359.599	76.932	436.530	165.747	42.013	207.761
2008	172.920	79.881	252.801	102.063	33.593	135.655
2009	141.034	48.878	189.912	100.583	45.979	146.563
2010	159.891	54.354	214.245	113.568	40.252	153.820
2011	229.497	151.234	380.732	177.927	100.972	278.899
2012	252.509	190.311	442.820	147.665	118.156	265.821
2013	223.536	179.636	403.172	145.126	94.026	239.151
2014	208.392	137.791	346.182	134.066	59.794	193.860
2015	125.115	80.164	205.279	81.734	42.094	123.828
2016	137.389	54.142	191.530	84.708	9.141	93.849
2017	142.181	50.361	192.542	136.747	15.478	152.226
2018	214.794	57.460	272.254	196.581	38.481	235.062
2019	160.994	46.940	207.934	178.921	34.016	212.937
2021	155.236	59.288	214.524	132.913	37.556	170.468

Table 14. 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 shell	new shell	old shell	all shell	new shell	old shell	all shell
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 14 (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 shell	new shell	old shell	all shell	new shell	old shell	all shell
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
2021	416	1,590	2,006	1,447	956	2,403	1,863	2,546	4,409

Table 15. Trends in abundance for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (in millions of individuals).

		W166			E166			all EBS	
year	new shell	old shell	all shell	new shell	old shell	all shell	new shell	old shell	all shell
1975	66.706	3.129	69.835	156.363	7.320	163.683	223.068	10.450	233.518
1976	42.108	1.754	43.862	63.542	10.425	73.967	105.650	12.179	117.829
1977	26.617	7.258	33.875	55.271	8.487	63.759	81.888	15.745	97.633
1978	3.591	7.183	10.774	44.489	11.691	56.180	48.080	18.874	66.955
1979	5.335	4.610	9.945	11.108	4.047	15.156	16.443	8.658	25.101
1980	14.802	1.916	16.718	24.363	13.118	37.481	39.165	15.034	54.199
1981	7.784	2.903	10.688	4.026	14.097	18.123	11.811	17.000	28.811
1982	8.065	8.210	16.275	3.492	6.377	9.869	11.557	14.587	26.144
1983	3.357	4.704	8.061	6.917	2.732	9.649	10.274	7.436	17.710
1984	0.820	4.520	5.340	4.898	3.946	8.845	5.719	8.466	14.185
1985	0.784	1.283	2.067	4.413	1.381	5.795	5.197	2.664	7.861
1986	0.213	0.870	1.083	0.981	2.742	3.723	1.194	3.612	4.806
1987	4.658	0.917	5.575	6.307	4.039	10.345	10.965	4.956	15.921
1988	12.210	1.241	13.451	18.560	3.515	22.074	30.769	4.756	35.525
1989	17.061	3.608	20.670	46.330	4.812	51.141	63.391	8.420	71.811
1990	26.645	4.216	30.860	38.932	9.361	48.293	65.577	13.576	79.153
1991	17.264	11.383	28.647	39.106	18.355	57.462	56.371	29.738	86.109
1992	11.892	8.616	20.509	50.821	21.453	72.274	62.713	30.069	92.782
1993	5.078	3.723	8.801	27.129	16.372	43.501	32.207	20.095	52.302
1994	1.575	5.751	7.326	10.707	18.458	29.165	12.282	24.209	36.491
1995	0.569	7.622	8.191	1.370	16.935	18.305	1.939	24.558	26.497
1996	0.154	5.271	5.425	0.302	17.040	17.343	0.456	22.312	22.768
1997	0.220	1.323	1.543	0.454	4.957	5.411	0.674	6.280	6.954
1998	0.619	0.922	1.541	1.395	3.155	4.550	2.014	4.077	6.091
1999	0.387	0.505	0.892	2.022	2.256	4.278	2.409	2.760	5.169
2000	0.347	0.544	0.891	5.647	3.921	9.567	5.994	4.465	10.459

Table 15 (cont.). Trends in abundance for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (millions of individuals).

		W166			E166			all EBS	
year	new shell	old shell	all shell	new shell	old shell	all shell	new shell	old shell	all shell
2001	0.635	1.785	2.419	5.136	4.621	9.757	5.770	6.406	12.176
2002	0.546	1.140	1.686	1.087	8.110	9.197	1.633	9.250	10.883
2003	0.615	3.019	3.634	1.895	7.156	9.051	2.510	10.175	12.685
2004	1.431	2.626	4.057	2.150	5.277	7.426	3.581	7.903	11.484
2005	11.621	7.088	18.710	3.110	6.588	9.698	14.731	13.676	28.407
2006	5.239	20.689	25.928	2.674	8.262	10.936	7.913	28.951	36.864
2007	11.886	10.728	22.614	5.023	6.765	11.788	16.909	17.493	34.401
2008	12.211	6.294	18.505	17.411	4.518	21.929	29.622	10.812	40.435
2009	9.162	5.856	15.018	3.293	6.402	9.695	12.455	12.258	24.713
2010	12.360	6.754	19.114	3.702	5.364	9.066	16.062	12.118	28.180
2011	10.018	8.845	18.863	1.866	8.110	9.976	11.884	16.954	28.839
2012	3.051	5.218	8.269	4.229	6.042	10.270	7.279	11.259	18.539
2013	7.150	3.614	10.764	15.045	4.524	19.569	22.195	8.138	30.334
2014	9.947	6.192	16.140	18.764	11.735	30.499	28.711	17.927	46.639
2015	11.343	8.298	19.641	11.442	12.676	24.119	22.785	20.975	43.760
2016	7.580	17.080	24.661	3.349	10.545	13.894	10.929	27.625	38.554
2017	1.231	15.589	16.819	2.054	13.889	15.943	3.284	29.478	32.762
2018	1.422	15.823	17.245	0.149	9.100	9.250	1.571	24.923	26.494
2019	0.301	6.608	6.909	0.460	5.666	6.125	0.761	12.274	13.034
2021	0.632	2.243	2.875	2.047	1.311	3.357	2.679	3.553	6.232

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.

		male		female		
		undetermined		immature	mature	
year	no. hauls	new shell	old shell	new shell	new shell	old shell
1975	136	6,499	319	1,023	1,860	699
1976	214	4,250	203	1,097	1,303	311
1977	155	3,647	359	694	1,180	616
1978	230	4,090	679	1,949	632	1,259
1979	237	1,383	206	387	290	304
1980	320	6,839	522	1,418	1,468	568
1981	305	6,014	872	522	1,097	1,201
1982	342	3,076	2,045	754	409	2,382
1983	353	3,424	1,095	2,112	180	2,153
1984	355	2,331	1,378	1,879	258	1,530
1985	353	1,369	367	745	198	449
1986	353	2,418	432	1,484	181	330
1987	355	5,605	436	4,230	445	391
1988	370	7,837	385	3,735	1,753	520
1989	373	7,246	912	3,089	1,241	869
1990	370	7,615	1,195	3,102	1,502	1,300
1991	371	6,805	2,881	2,259	1,283	2,568
1992	355	4,616	1,905	1,494	808	2,204
1993	374	3,495	1,700	753	540	1,335
1994	374	1,705	1,795	920	109	1,291
1995	375	1,040	1,530	745	136	1,057
1996	374	1,143	1,393	815	95	961
1997	375	1,551	448	1,326	167	502
1998	374	2,359	561	1,710	154	273
1999	372	3,366	465	2,628	194	508
2000	371	3,373	575	2,249	242	345

Table16 (cont.). Raw 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.

		male		female		
		undetermined		immature	mature	
year	no. hauls	new shell	old shell	new shell	new shell	old shell
2001	374	4,614	767	3,678	364	644
2002	374	4,363	1,079	3,585	335	498
2003	375	5,652	1,340	2,832	916	751
2004	374	5,355	1,665	3,922	357	656
2005	372	5,776	1,265	3,352	634	906
2006	375	7,980	3,384	4,363	1,332	1,321
2007	375	6,679	2,905	2,429	1,310	1,394
2008	374	4,872	1,950	1,646	564	1,776
2009	375	3,886	1,919	2,408	362	1,316
2010	375	4,656	1,510	3,050	242	941
2011	375	7,210	1,938	5,044	470	702
2012	375	7,078	1,271	3,611	941	526
2013	375	8,266	1,316	2,917	1,396	996
2014	375	6,977	2,807	2,211	482	1,584
2015	375	4,445	2,815	1,302	440	1,361
2016	375	3,109	3,661	1,175	370	1,247
2017	375	2,433	3,537	1,984	189	1,125
2018	375	5,503	2,551	4,666	434	702
2019	375	4,737	1,045	3,810	648	541
2021	375	4,950	777	3,014	1,116	873

Table 17. Male maturity ogives from special collections during NMFS EBS shelf surveys, representing estimates of the ratio of the abundance of immature males to new shell mature males (presumably having just undergone the terminal molt to functional maturity). Immature males are distinguished from mature males based on based on their chela height to carapace width (both measured to 0.1mm) ratios and size-specific cutlines determined for each survey.

		2006		2007		2008		2009		2010		2011		2012
size bin	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)
65	208	0.0243	39	0.0253	128	0.0312	38	0.0000	120	0.0577	22	0.0455	196	0.0000
75	430	0.0950	119	0.0843	166	0.0903	13	0.0769	94	0.0426	6	0.0000	119	0.0763
85	365	0.2236	152	0.3439	105	0.3293	44	0.0455	100	0.2504	4	0.0000	149	0.1888
95	275	0.3589	314	0.4001	116	0.5092	31	0.4194	119	0.5966	4	0.5000	118	0.2288
105	190	0.5059	243	0.3393	132	0.5520	35	0.3143	101	0.6044	3	0.3333	56	0.3016
115	120	0.6788	111	0.5828	105	0.7061	28	0.6490	83	0.8069	2	0.5000	49	0.5107
125	71	0.9100	57	0.8764	113	0.9559	33	0.8787	75	0.7870	4	1.0000	26	0.7308
135	24	0.9591	21	0.9048	54	0.9816	34	0.9412	53	0.8497	1	1.0000	19	1.0000

Table17 (cont.). Male maturity ogives from special collections during NMFS EBS shelf surveys, representing estimates of the ratio of the abundance of immature males to new shell mature males (presumably having just undergone the terminal molt to functional maturity). Immature males are distinguished from mature males based on based on their chela height to carapace width (both measured to 0.1mm) ratios and size-specific cutlines determined for each survey.

		2014		2016		2017		2018		2019		2021
size bin	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)	ss	Pr(mature)
65	54	0.0559	9	0.1111	91	0.0659	139	0.1063	172	0.0174	213	0.0376
75	56	0.0713	32	0.1250	135	0.0370	116	0.1107	151	0.0727	279	0.0503
85	74	0.2431	42	0.1429	126	0.1905	93	0.4098	152	0.1504	236	0.1436
95	61	0.4044	43	0.4419	122	0.4098	90	0.4332	136	0.5644	250	0.3160
105	80	0.3992	29	0.5517	99	0.5556	66	0.7727	72	0.6925	227	0.4670
115	69	0.6087	57	0.8772	67	0.7164	29	0.8966	46	0.8694	115	0.7043
125	41	0.8537	79	0.9873	60	0.7167	27	0.9630	19	0.9469	73	0.9178
135	21	0.9048	70	1.0000	29	0.8966	16	1.0000	5	1.0000	12	1.0000

Table 18. Survey biomass estimates (in t) and associated CVs from the BSFRF/NMFS collaborative side-by-side catchability studies conducted from 2013-2017.

	females								males			
	immature				mature				undetermined			
	BSFRF		NMFS		BSFRF		NMFS		BSFRF		NMFS	
year	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
2013	1,562	0.446	522	0.378	8,369	0.484	3,050	0.460	56,571	0.554	21,109	0.381
2014	379	0.329	148	0.334	3,428	0.326	1,252	0.348	42,969	0.210	30,866	0.242
2015	165	0.430	255	0.617	2,633	0.423	713	0.444	23,271	0.204	16,802	0.222
2016	1,275	0.312	202	0.331	11,016	0.286	2,654	0.290	56,414	0.182	29,183	0.145
2017	5,430	0.169	759	0.279	15,984	0.302	4,662	0.334	69,448	0.188	30,719	0.152

Table 19. Survey abundance estimates (in numbers of crab) and associated CVs from the BSFRF/NMFS collaborative side-by-side catchability studies conducted from 2013-2017.

	females								males			
	immature				mature				undetermined			
	BSFRF		NMFS		BSFRF		NMFS		BSFRF		NMFS	
year	Abundance	CV	Abundance	CV	Abundance	CV	Abundance	CV	Abundance	CV	Abundance	CV
2013	17,953,150	0.339	4,107,750	0.338	35,131,997	0.488	12,970,123	0.460	139,196,965	0.514	47,029,901	0.356
2014	5,743,414	0.393	2,202,041	0.502	14,409,767	0.328	5,285,271	0.382	90,888,373	0.204	60,447,261	0.243
2015	5,515,649	0.525	3,095,876	0.547	11,801,080	0.466	3,139,849	0.518	48,908,660	0.195	33,320,301	0.247
2016	51,210,787	0.278	5,185,519	0.365	62,792,962	0.307	15,343,471	0.306	170,059,785	0.203	66,643,522	0.166
2017	371,444,912	0.173	40,627,495	0.353	107,464,850	0.291	30,759,624	0.343	443,396,703	0.141	88,021,575	0.146

Table 20. Sample sizes from the BSFRF/NMFS collaborative side-by-side catchability studies conducted from 2013-2017. raw: number of crab measured. input: scaled sample size used as input sample size when fitting assessment model.

	females								males			
	immature				mature				undetermined			
	BSFRF		NMFS		BSFRF		NMFS		BSFRF		NMFS	
year	raw	input	raw	input	raw	input	raw	input	raw	input	raw	input
2013	99	22	134	134	167	37	404	404	640	141	1,302	1,302
2014	25	9	58	58	66	25	149	149	441	166	1,814	1,814
2015	29	16	97	97	79	42	101	101	264	142	998	998
2016	318	38	179	179	380	45	503	503	998	118	2,281	2,281
2017	1,902	73	1,020	1,020	723	28	764	764	2,556	99	3,471	3,471

Table 21.Parameters from all model scenarios that were estimated within 1% of bounds. TCF: Tanner crab fishery, SCF: snow crab fishery; RKF: BBRCK fishery; GF: groundfish fisheries. z50: size at 50% selected; z95: size at 95% selected. “1” indicates parameter at upper bound, “-1” indicates parameter at lower bound, “—” indicates parameter not at bound.

category	process	name	label	20.07	20.07u	21.22	21.24	21.22a
fisheries	fisheries	pLgtRet[1]	TCF: logit-scale max retention (pre-1997)	1	1	–	–	–
population processes	growth	pGrBeta[1]	both sexes	1	–	–	−1	–
	recruitment	pDevsLnR	current recruitment period	–	−1	−1	−1	–
selectivity	selectivity	pS1[1]	z50 for NMFS survey selectivity (males, pre-1982)	–	1	–	–	–
		pS1[17]	z50 for GF.AllGear selectivity (males, 1987-1996)	–	–	–	1	–
		pS1[2]	z50 for NMFS survey selectivity (males, 1982+)	–	–	–	1	–
		pS1[23]	z95 for RKF selectivity (males, 1997-2004)	1	1	–	–	–
		pS1[24]	z95 for RKF selectivity (males, 2005+)	1	1	–	–	–
		pS1[25]	size at 1 for RKF selectivity (females, pre-1997)	–	–	1	1	–
		pS1[27]	z95 for RKF selectivity (females, 2005+)	1	1	–	–	–
		pS1[3]	size at 1 for NMFS survey selectivity (females, pre-1982)	–	–	–	1	–
		pS1[4]	z50 for NMFS survey selectivity (females, 1982+)	1	1	–	–	–
		pS2[10]	ascending slope for SCF selectivity (males, pre-1997)	−1	−1	–	–	–
		pS2[2]	z95-z50 for NMFS survey selectivity (males, 1982+)	–	1	1	1	–
		pS2[4]	z95-z50 for NMFS survey selectivity (females, 1982+)	1	1	–	–	–
		pS2[6]	slope for TCF retention (1997+)	–	–	–	1	–
		pS3[1]	scaled increment for descending z-at-1 for SCF selectivity (males, pre-1997)	–	–	−1	−1	–
		pS4[1]	descending slope for SCF selectivity (males, pre-1997)	−1	−1	–	–	–
			descending width for SCF selectivity (males, pre-1997)	–	–	−1	−1	–
surveys	surveys	pQ[1]	NMFS trawl survey: males, 1975-1981	−1	−1	–	–	–
		pQ[3]	NMFS trawl survey: females, 1975-1981	−1	–	–	–	–

Table 22. Final values for non-vector parameters related to recruitment, natural mortality, and growth. Parameters with values whose standard error is NA are fixed, not estimated.

			20.07		20.07u		21.22		21.24		21.22a	
process	name	label	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
recruitment	pLnR[1]	historical recruitment period	$6.229e+00$	0.4509600	$6.508e+00$	0.45062	$6.605e+00$	0.57717	$7.719e+00$	$6.358e-01$	$6.715e+00$	0.58547
	pLnR[2]	current recruitment period	$5.615e+00$	0.4947700	$5.724e+00$	0.06106	$5.628e+00$	0.06962	$5.982e+00$	$6.212e-02$	$5.764e+00$	0.07012
	pRa[1]	fixed value	$2.105e+00$	0.0427140	$2.187e+00$	0.03432	$2.204e+00$	0.03161	$2.158e+00$	$3.616e-02$	$2.235e+00$	0.03169
	pRb[1]	fixed value	$1.117e+00$	0.1167200	$1.295e+00$	0.09116	$1.346e+00$	0.08296	$1.305e+00$	$9.635e-02$	$1.386e+00$	0.08001
	pRCV[1]	full model period	$-6.931e-01$	NA	$-6.931e-01$	NA	$-1.705e+00$	771.87000	$1.332e+00$	$1.574e+03$	$-7.000e-01$	NA
	pRX[1]	full model period	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA	$-1.110e-16$	NA
natural mortality	pDM1[1]	multiplier for immature crab	$1.041e+00$	0.0444900	$1.054e+00$	0.04471	$1.038e+00$	0.04684	$8.971e-01$	$3.664e-02$	$1.021e+00$	0.04707
	pDM1[2]	multiplier for mature males	$1.272e+00$	0.0376600	$1.325e+00$	0.03734	$1.284e+00$	0.03774	$1.227e+00$	$3.414e-02$	$1.303e+00$	0.03797
	pDM1[3]	multiplier for mature females	$1.412e+00$	0.0356130	$1.411e+00$	0.03613	$1.348e+00$	0.03751	$1.283e+00$	$3.501e-02$	$1.335e+00$	0.03748
	pDM2[1]	1980-1984 multiplier for mature males	$1.986e+00$	0.1814600	$2.319e+00$	0.21514	$2.305e+00$	0.23023	$2.854e+00$	$2.783e-01$	$2.353e+00$	0.24839
	pDM2[2]	1980-1984 multiplier for mature females	$1.716e+00$	0.1375900	$1.890e+00$	0.15036	$1.960e+00$	0.16947	$2.301e+00$	$1.881e-01$	$1.957e+00$	0.16857
	pM[1]	base ln-scale M	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA	$-1.470e+00$	NA
growth	pGrA[1]	males	$3.255e+01$	0.2507200	$3.245e+01$	0.23423	$3.260e+01$	0.27964	$3.225e+01$	NA	$3.245e+01$	0.25802
	pGrA[2]	females	$3.374e+01$	0.2671600	$3.329e+01$	0.26965	$3.379e+01$	0.33656	$3.262e+01$	NA	$3.363e+01$	0.31445
	pGrB[1]	males	$1.688e+02$	0.9169800	$1.658e+02$	0.70560	$1.673e+02$	0.79359	$1.545e+02$	NA	$1.663e+02$	0.75580
	pGrB[2]	females	$1.148e+02$	0.5914600	$1.154e+02$	0.57669	$1.147e+02$	0.64575	$1.142e+02$	NA	$1.150e+02$	0.61369
	pGrBeta[1]	both sexes	$1.000e+00$	0.0004148	$7.964e-01$	0.09756	$9.703e-01$	0.12406	$5.000e-01$	$2.855e-05$	$8.501e-01$	0.10400

Table 23. Final values for annual recruitment “devs” in the “historical” period up to 1975. Index begins in 1948.

	20.07		20.07u		21.22		21.24		21.22a	
index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
1	−1.40362	1.5980	−1.4295	1.6015	−0.59360	1.7596	−0.42437	1.6333	−0.49592	1.7780
2	−1.40046	1.4529	−1.4266	1.4562	−0.59248	1.6258	−0.41973	1.4950	−0.49509	1.6452
3	−1.39290	1.3135	−1.4195	1.3163	−0.58989	1.4960	−0.40933	1.3666	−0.49315	1.5158
4	−1.37921	1.1820	−1.4067	1.1838	−0.58539	1.3712	−0.39179	1.2500	−0.48977	1.3909
5	−1.35692	1.0606	−1.3855	1.0611	−0.57841	1.2530	−0.36547	1.1471	−0.48451	1.2718
6	−1.32243	0.9523	−1.3523	0.9511	−0.56821	1.1431	−0.32843	1.0599	−0.47676	1.1603
7	−1.27047	0.8598	−1.3016	0.8571	−0.55383	1.0438	−0.27846	0.9902	−0.46579	1.0587
8	−1.19296	0.7859	−1.2249	0.7819	−0.53405	0.9578	−0.21332	0.9389	−0.45060	0.9698
9	−1.07711	0.7320	−1.1086	0.7273	−0.50733	0.8880	−0.13126	0.9054	−0.42995	0.8969
10	−0.90128	0.6977	−0.9291	0.6932	−0.47173	0.8372	−0.03214	0.8865	−0.40226	0.8435
11	−0.62583	0.6823	−0.6424	0.6795	−0.42491	0.8078	0.08214	0.8771	−0.36557	0.8126
12	−0.18006	0.6849	−0.1739	0.6844	−0.36386	0.8006	0.21049	0.8736	−0.31730	0.8061
13	0.49619	0.6904	0.5218	0.6895	−0.28385	0.8148	0.35465	0.8740	−0.25349	0.8232
14	1.26861	0.6801	1.2800	0.6776	−0.17663	0.8463	0.51801	0.8752	−0.16755	0.8594
15	1.70356	0.6560	1.6888	0.6544	−0.02771	0.8861	0.70182	0.8719	−0.04833	0.9041
16	1.69654	0.6468	1.6715	0.6487	0.18949	0.9171	0.89937	0.8611	0.12444	0.9386
17	1.48954	0.6543	1.4797	0.6558	0.52201	0.9105	1.08202	0.8553	0.39022	0.9368
18	1.31065	0.6531	1.3271	0.6518	1.00009	0.8545	1.17009	0.8866	0.80303	0.8819
19	1.26123	0.6355	1.2891	0.6321	1.50808	0.7683	1.00009	0.9364	1.35730	0.7867
20	1.33193	0.6128	1.3123	0.6143	1.76582	0.6604	0.46458	0.8810	1.67168	0.6671
21	1.36506	0.6002	1.2092	0.6081	1.51530	0.6739	−0.04899	0.7832	1.21092	0.6788
22	1.11237	0.5668	0.9386	0.5723	0.99958	0.6698	−0.19179	0.7162	0.66147	0.6779
23	0.62489	0.5357	0.6648	0.5347	0.47861	0.6541	−0.45406	0.6971	0.36427	0.6566
24	0.08358	0.5369	0.2371	0.5370	−0.09163	0.6572	−0.87292	0.7018	−0.09311	0.6611
25	−0.20879	0.5341	−0.0495	0.5366	−0.52692	0.6566	−1.10379	0.7045	−0.48210	0.6613
26	−0.03211	0.5556	0.2300	0.5491	−0.50853	0.7268	−0.81740	0.7409	−0.17208	0.7021

Table 24. Final values for annual recruitment “devs” in the “current” period from 1975. Index being in 1975.

	20.07		20.07u		21.22		21.24		21.22a	
index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
1	1.373e + 00	0.5260	1.424190	0.27502	1.58808	0.24636	1.95201	0.23498	1.34374	0.31402
2	1.685e + 00	0.5157	2.079318	0.16525	2.05054	0.19043	2.29374	0.18414	1.95233	0.19762
3	1.389e + 00	0.5218	1.631686	0.20133	1.67698	0.23851	1.49144	0.31011	1.58569	0.22807
4	2.866e − 01	0.6087	0.652829	0.35858	0.62652	0.53508	0.30908	0.74015	0.65974	0.40538
5	−3.727e − 01	0.6839	0.009171	0.44411	0.08461	0.65765	0.52951	0.46802	−0.17736	0.55445
6	−5.777e − 01	0.6753	−0.455515	0.54242	−0.37516	0.72223	−0.31688	0.78129	−0.17714	0.40939
7	−5.010e − 02	0.5518	0.151108	0.26588	0.18448	0.32417	0.51790	0.29218	−0.01713	0.29742
8	−1.072e − 01	0.5488	−0.005258	0.26944	−0.15745	0.33532	−0.01074	0.36939	−0.15650	0.28750
9	1.010e + 00	0.5048	1.184767	0.11924	1.15901	0.11999	1.44678	0.10826	1.08265	0.11734
10	8.945e − 01	0.5116	1.036900	0.15139	0.84628	0.17147	0.73635	0.20117	0.78270	0.17062
11	9.062e − 01	0.5150	0.965344	0.17570	1.05339	0.16019	0.91180	0.16960	0.94362	0.16442
12	1.076e + 00	0.5102	1.269425	0.13822	1.03646	0.15769	1.04193	0.13913	0.95506	0.15599
13	1.044e + 00	0.5092	1.074769	0.15848	0.89197	0.16650	0.26246	0.23494	0.78670	0.16605
14	2.287e − 01	0.5337	0.403194	0.21347	0.49235	0.21253	0.05942	0.23261	0.34809	0.21201
15	−2.777e − 01	0.5377	−0.139498	0.23076	−0.36130	0.31376	−0.24703	0.25709	−0.43508	0.27252
16	−1.747e + 00	0.7723	−1.666241	0.65273	−0.80458	0.38063	−1.57481	0.71087	−0.89838	0.31276
17	−1.302e + 00	0.5735	−1.210016	0.31972	−1.23990	0.42391	−1.41590	0.44690	−1.32027	0.33282
18	−1.421e + 00	0.5651	−1.260527	0.28554	−1.21401	0.31647	−1.04417	0.28447	−1.29114	0.26296
19	−1.283e + 00	0.5505	−1.190220	0.27308	−1.25506	0.30996	−1.04041	0.31485	−1.33088	0.26996
20	−1.271e + 00	0.5540	−1.131958	0.27465	−1.07615	0.27687	−0.84336	0.27950	−1.11002	0.24409
21	−6.278e − 01	0.5211	−0.450044	0.17578	−0.52952	0.19035	−0.34272	0.18775	−0.62715	0.18151
22	−7.860e − 01	0.5369	−0.782178	0.24906	−0.78306	0.25492	−0.89671	0.30836	−0.85127	0.23729
23	−5.550e − 03	0.5065	0.167874	0.12091	0.18367	0.12121	0.32473	0.11968	0.07983	0.11839
24	−8.584e − 01	0.5438	−0.797163	0.24641	−0.91795	0.27162	−0.80880	0.29302	−0.93610	0.24755
25	5.830e − 01	0.5019	0.731974	0.10202	0.72150	0.10226	0.92838	0.09799	0.61543	0.10031
26	−3.657e − 01	0.5532	−0.322552	0.27790	−0.47034	0.30766	−0.58146	0.39535	−0.51012	0.28166
27	9.343e − 01	0.5026	1.090818	0.10388	1.11609	0.10339	1.21899	0.10583	1.00971	0.10116
28	−2.540e − 01	0.5661	−0.188084	0.30303	−0.21396	0.32108	0.05655	0.29884	−0.24117	0.29403
29	1.109e + 00	0.5016	1.233558	0.10319	1.21704	0.10811	1.09391	0.12181	1.09959	0.10849
30	4.674e − 01	0.5139	0.601932	0.15398	0.68819	0.15320	0.47984	0.16877	0.60042	0.14973
31	−5.401e − 01	0.5581	−0.450770	0.27734	−0.46036	0.30934	−0.59923	0.33393	−0.57916	0.28467
32	−8.983e − 01	0.5862	−0.843131	0.34348	−1.03125	0.47371	−1.37180	0.63279	−1.04070	0.36952
33	−8.211e − 01	0.5885	−0.755831	0.34514	−0.38047	0.28426	0.02201	0.25036	−0.48887	0.26209
34	2.457e − 01	0.5411	0.297098	0.25194	−0.01988	0.29169	0.83754	0.16710	−0.07782	0.27419
35	1.429e + 00	0.5022	1.557290	0.10351	1.54709	0.09694	1.25583	0.12443	1.44627	0.09403
36	5.632e − 01	0.5177	0.532562	0.18420	0.55933	0.19889	−0.14816	0.25754	0.43978	0.19955
37	−2.811e − 01	0.5325	−0.259018	0.20906	−0.10463	0.21715	−0.33346	0.21685	−0.28533	0.20591
38	−1.610e + 00	0.6621	−1.709239	0.48575	−1.89711	0.70298	−2.08941	0.77577	−1.58460	0.39100
39	−4.983e − 01	0.5123	−0.494651	0.14738	−0.44905	0.16138	−0.61280	0.17722	−0.62306	0.15758
40	−1.237e + 00	0.5473	−1.239266	0.24883	−1.11455	0.25016	−1.06826	0.25461	−1.15008	0.22630
41	−7.379e − 01	0.5246	−0.798952	0.19305	−0.84975	0.21060	−0.69910	0.21912	−0.95307	0.20307
42	−7.126e − 01	0.5486	−0.802288	0.24674	−0.71533	0.22502	−0.51275	0.22944	−0.78508	0.21293
43	1.304e + 00	0.4998	1.197021	0.08326	1.14475	0.08651	1.21455	0.08786	1.03531	0.08603
44	6.462e − 01	0.5346	0.329860	0.20273	0.30990	0.20305	0.23615	0.22189	0.23456	0.19838
45	1.470e + 00	0.5252	0.928735	0.14565	0.91782	0.14332	0.90945	0.15291	0.76742	0.14863
46	1.272e − 06	22.1160	−4.999990	0.03014	−4.99999	0.01915	−4.99999	0.02430	−1.26293	0.62572
47	–	–	1.400966	0.17101	1.32477	0.17139	1.42761	0.17293	1.14171	0.17475

Table 25. Final values for parameters related to the probability of terminal molt. Index corresponds to 5-mm size bin starting at 50 mm CW for females and 60 mm CW for males.

		20.07		20.07u		21.22		21.24		21.22a	
label	index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
females 50-105 mmCW (entire model period)	1	−6.6199	0.98152	−6.74144	1.00420	−5.284463	1.19810	−5.08175	1.12590	−5.34142	1.21490
	2	−4.8912	0.44402	−4.96205	0.45512	−4.062119	0.56099	−3.95765	0.52932	−4.10929	0.56933
	3	−3.2101	0.20121	−3.23641	0.20212	−2.881705	0.24861	−2.88835	0.24825	−2.91568	0.25027
	4	−1.6890	0.11161	−1.66288	0.11048	−1.698278	0.14700	−1.76216	0.14666	−1.71361	0.14724
	5	−0.4119	0.08685	−0.40011	0.08646	−0.563941	0.09288	−0.60669	0.08653	−0.57842	0.09229
	6	0.3318	0.08883	0.33505	0.08753	0.273529	0.09310	0.19606	0.08156	0.25956	0.09191
	7	0.6212	0.09835	0.65014	0.09668	0.576149	0.10484	0.52962	0.09124	0.57081	0.10367
	8	1.1886	0.13488	1.26054	0.13339	1.069739	0.13925	1.01169	0.11497	1.07017	0.13746
	9	2.3437	0.24695	2.41066	0.23955	1.942839	0.23003	1.75515	0.18042	1.95964	0.22847
	10	3.8151	0.50794	3.84412	0.48569	2.843612	0.42820	2.54149	0.31263	2.86654	0.42636
	11	5.3707	1.07070	5.36063	1.03440	3.777669	0.97599	3.43745	0.77096	3.80481	0.97449
males 60-150 mmCW (entire model period)	1	−3.2374	0.31312	−2.88359	0.21299	−3.017617	0.22416	−3.05349	0.23000	−2.91297	0.21518
	2	−3.5912	0.31138	−3.51749	0.28809	−3.505972	0.28885	−3.46309	0.27602	−3.45450	0.29159
	3	−3.1055	0.26829	−2.95516	0.23639	−2.957919	0.23702	−2.91578	0.22181	−2.91186	0.23918
	4	−2.4289	0.17080	−2.16777	0.13197	−2.220954	0.13392	−2.32986	0.13932	−2.15567	0.13337
	5	−1.9078	0.14523	−1.52611	0.11706	−1.565627	0.11985	−1.66302	0.11745	−1.49020	0.11826
	6	−1.5342	0.12008	−1.32582	0.10284	−1.313926	0.10422	−1.30972	0.09641	−1.29688	0.10527
	7	−0.9341	0.10384	−0.81557	0.09324	−0.774812	0.09695	−0.79684	0.08631	−0.76915	0.09783
	8	−0.5495	0.09369	−0.34431	0.08369	−0.370249	0.08838	−0.61597	0.08211	−0.33395	0.08828
	9	−0.4329	0.09394	−0.24948	0.08470	−0.326956	0.08979	−0.49420	0.08187	−0.29102	0.08975
	10	−0.2131	0.09299	−0.06695	0.08416	0.009041	0.09027	−0.09645	0.08060	0.01495	0.08980
	11	0.2580	0.10531	0.36078	0.08907	0.416523	0.09525	0.31187	0.08171	0.43636	0.09508
	12	1.0239	0.14165	0.93849	0.11438	1.036290	0.13112	0.53964	0.08497	0.95404	0.12212
	13	1.9467	0.17625	1.57786	0.12973	1.782208	0.15825	1.07318	0.09887	1.69878	0.15390
	14	3.3276	0.28173	2.93935	0.26252	2.794748	0.27499	1.22182	0.10800	2.72566	0.26754
	15	4.4826	0.33641	3.66337	0.24483	3.160644	0.28964	1.70976	0.15003	3.09124	0.28259
	16	6.0669	0.72738	5.35543	0.58151	3.698099	0.48032	2.43870	0.23519	3.68702	0.48607
	17	7.8238	1.52200	7.35671	1.26340	4.808799	1.04220	3.00121	0.49613	4.85579	1.04720

Table 26. Final values for non-vector parameters related to fisheries, surveys, and the Dirichlet-Multinomial likelihood. Parameters with values whose standard error is NA are fixed, not estimated.

			20.07		20.07u		21.22		21.24		21.22a	
process	name	label	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
fisheries	pDC2[1]	TCF: female offset	−1.9987	2.396e−01	−2.1154	3.707e−01	−2.3996	0.20681	−2.6384	0.22674	−2.5050	0.20801
	pDC2[2]	SCF: female offset	−3.2115	5.924e−01	−3.3587	6.068e−01	−1.9635	0.28263	−1.8498	0.29701	−2.0173	0.28214
	pDC2[3]	GTF: female offset	−0.8495	7.597e−02	−0.9602	8.349e−02	−0.8700	0.08355	−0.7242	0.09784	−0.9898	0.09264
	pDC2[4]	RKF: female offset	−1.4092	2.286e+00	−1.6813	2.442e+00	−2.3487	0.63511	−2.5279	0.65444	−2.4803	0.63574
	pHM[1]	handling mortality for pot fisheries	0.3210	NA	0.3210	NA	0.3210	NA	0.3210	NA	0.3210	NA
	pHM[2]	handling mortality for groundfish trawl fisheries	0.8000	NA	0.8000	NA	0.8000	NA	0.8000	NA	0.8000	NA
	pLgtRet[1]	TCF: logit-scale max retention (pre-1997)	14.9989	4.089e+00	14.9986	5.381e+00	14.9000	NA	14.9000	NA	14.9000	NA
	pLgtRet[2]	TCF: logit-scale max retention (2005-2009)	14.8106	6.700e+02	0.5930	5.380e−01	14.9000	NA	14.9000	NA	14.9000	NA
	pLgtRet[3]	TCF: logit-scale max retention (2013+)	14.9716	1.124e+02	3.0413	1.549e+00	14.9000	NA	14.9000	NA	14.9000	NA
	pLnC[1]	TCF: base capture rate, pre-1965 (=0.05)	−2.9957	NA	−2.9957	NA	−2.9957	NA	−2.9957	NA	−2.9957	NA
	pLnC[2]	TCF: base capture rate, 1965+	−1.6849	7.926e−02	−1.6615	8.375e−02	−1.5370	0.12595	−2.0878	0.18645	−1.3265	0.12814
	pLnC[3]	SCF: base capture rate, pre-1978 (=0.01)	−4.6052	NA	−4.6052	NA	−4.6052	NA	−4.6052	NA	−4.6052	NA
	pLnC[4]	SCF: base capture rate, 1992+	−3.5124	1.056e−01	−3.6265	1.078e−01	−3.6363	0.07096	−4.0032	0.07158	−3.6507	0.07028
	pLnC[5]	DUMMY CAPTURE RATE	−4.1807	NA	−4.1807	NA	−4.1807	NA	−4.1807	NA	−4.1807	NA
	pLnC[6]	GTF: base capture rate, ALL YEARS	−4.9089	5.642e−02	−4.9855	5.949e−02	−4.9739	0.05850	−5.1764	0.05806	−4.9165	0.05861
	pLnC[7]	RKF: base capture rate, pre-1953 (=0.02)	−3.9120	NA	−3.9120	NA	−3.9120	NA	−3.9120	NA	−3.9120	NA
	pLnC[8]	RKF: base capture rate, 1992+	−3.7216	1.144e−01	−3.6500	1.165e−01	−4.7750	0.09952	−4.7943	0.10160	−4.7478	0.09941
surveys	pQ[1]	NMFS trawl survey: males, 1975-1981	−0.6931	1.064e−05	−0.6931	2.076e−05	−1.2747	0.11081	−1.8977	0.10815	−0.6549	0.10728
	pQ[2]	NMFS trawl survey: males, 1982+	−0.7151	5.119e−02	−0.7011	5.240e−02	−0.6744	0.05279	−1.0274	0.04757	−0.6343	0.05031
	pQ[3]	NMFS trawl survey: females, 1975-1981	−0.6931	2.227e−03	−0.5745	4.975e−01	−1.1816	0.28723	−1.5638	0.14472	−0.9880	0.13293
	pQ[4]	NMFS trawl survey: females, 1982+	−0.6694	5.017e−02	−0.8921	5.439e−02	−1.1611	0.07457	−1.6036	0.07226	−1.2543	0.07538
	pQ[5]	BSFRF SBS	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
Dirichlet-Multinomial	pLnDirMul[1]	ln(theta) parameter for NMFS M	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[10]	ln(theta) parameter for RKF total male catch	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[11]	ln(theta) parameter for RKF total female catch	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[12]	ln(theta) parameter for GF All total male catch	0.0000	NA	0.0000	NA	–	–	–	–	–	–
		ln(theta) parameter for GF All total male+female catch	–	–	–	–	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[13]	ln(theta) parameter for GF All total female catch	0.0000	NA	0.0000	NA	–	–	–	–	–	–
	pLnDirMul[2]	ln(theta) parameter for NMFS F	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[3]	ln(theta) parameter for BSFRF SBS M	0.0000	NA	0.0000	NA	0.9702	0.24952	1.0286	0.25623	0.9448	0.24815
	pLnDirMul[4]	ln(theta) parameter for BSFRF SBS F	0.0000	NA	0.0000	NA	2.5396	0.24499	2.5476	0.24527	2.5297	0.24481
	pLnDirMul[5]	ln(theta) parameter for TCF retained catch	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[6]	ln(theta) parameter for TCF total male catch	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[7]	ln(theta) parameter for TCF total female catch	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[8]	ln(theta) parameter for SCF total male catch	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA
	pLnDirMul[9]	ln(theta) parameter for SCF total female catch	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA	0.0000	NA

Table 27. Final values for fishing mortality "devs" for the directed fishery. The index starts in 1965 and does not include years when the fishery was completely closed.

	20.07		20.07u		21.22		21.24		21.22a	
index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
1	−0.49515	0.49119	−0.50697	0.48944	−1.13863	0.8489	−1.67065	1.0429	−1.458652	0.8675
2	−0.72236	0.37806	−0.73421	0.37548	−0.93617	0.7040	−1.54559	0.9590	−1.249296	0.7182
3	0.49006	0.33667	0.48619	0.33375	0.91233	0.6587	0.09044	0.9181	0.592145	0.6597
4	0.34434	0.31174	0.34038	0.31106	1.51129	0.6592	0.30973	0.8946	1.170177	0.6431
5	0.53228	0.30146	0.51388	0.30410	2.81230	1.2133	0.65985	0.8601	2.333972	0.9293
6	0.38548	0.30049	0.34738	0.30430	4.32916	0.9609	0.46485	0.7600	4.121946	0.7829
7	0.17443	0.29139	0.11757	0.29399	2.52218	1.4775	0.07400	0.5792	4.734865	0.6810
8	−0.02347	0.25879	−0.09062	0.25913	0.64332	0.5453	−0.31227	0.3822	2.116776	1.2425
9	−0.30385	0.19500	−0.36217	0.19609	−0.36809	0.3118	−0.68345	0.2431	−0.001303	0.3380
10	−0.14585	0.12787	−0.17356	0.13436	−0.51509	0.2087	−0.52294	0.2033	−0.344289	0.2172
11	0.08335	0.09680	0.08544	0.10478	−0.36811	0.1780	−0.23827	0.2102	−0.215492	0.1837
12	0.88940	0.09146	0.89297	0.10079	0.35866	0.1756	0.51093	0.2170	0.534756	0.1800
13	1.67823	0.10141	1.63755	0.11516	1.00432	0.1943	1.02442	0.2244	1.287688	0.2078
14	1.98334	0.12984	1.80075	0.14889	1.11367	0.2440	0.89430	0.2341	1.565886	0.2923
15	2.78861	0.21892	2.24677	0.20031	1.52346	0.3125	1.13801	0.2447	2.054475	0.3957
16	2.25982	0.16762	2.01697	0.16743	1.38719	0.2412	1.47910	0.2309	1.776460	0.2686
17	0.47248	0.10844	0.40868	0.11422	0.01910	0.1528	0.69499	0.2044	0.089783	0.1531
18	−0.60704	0.12245	−0.68348	0.12555	−0.94523	0.1329	−0.37559	0.1897	−1.027157	0.1355
19	−1.69648	0.24838	−1.75905	0.24868	−2.29911	0.1330	−1.96320	0.1895	−2.447669	0.1371
20	−0.72507	0.17410	−0.75739	0.17855	−0.97571	0.1449	−0.74258	0.1977	−1.143152	0.1495
21	−1.14443	0.21532	−1.16702	0.21665	−1.34785	0.1279	−1.02036	0.1848	−1.532399	0.1310
22	−0.28238	0.10452	−0.28197	0.10747	−0.40508	0.1275	0.12528	0.1846	−0.586882	0.1305
23	0.90892	0.07898	0.90346	0.08256	0.78430	0.1290	1.36089	0.1854	0.593532	0.1318
24	1.61925	0.08392	1.63552	0.08797	1.51722	0.1351	2.01816	0.1881	1.331416	0.1377
25	1.79541	0.11672	1.87681	0.13398	1.74876	0.1620	2.44989	0.2160	1.590444	0.1649
26	1.84815	0.10553	1.94133	0.12123	2.09591	0.1612	2.73119	0.2133	1.925011	0.1639
27	1.48009	0.13358	1.46441	0.14389	1.78334	0.1718	2.40687	0.2203	1.621890	0.1732
28	0.79968	0.15122	0.73747	0.15661	1.17223	0.1864	1.74913	0.2382	0.995611	0.1881
29	0.36137	0.16784	0.21074	0.16154	0.67148	0.2094	1.20233	0.2863	0.485739	0.2141
30	−0.28752	0.41009	0.02036	0.36918	0.06115	0.1707	0.27555	0.2234	−0.159819	0.1727
31	−2.16169	0.20532	−1.51227	0.28088	−2.26387	0.1351	−1.63904	0.1918	−2.453514	0.1375
32	−1.65930	0.13602	−1.17400	0.21091	−1.65454	0.1352	−1.02137	0.1915	−1.837678	0.1375
33	−1.60870	0.11553	−1.28983	0.19759	−1.81417	0.1347	−1.23048	0.1917	−2.004581	0.1373
34	−1.79398	0.15198	−1.29029	0.22984	−1.96811	0.1357	−1.32544	0.1926	−2.147043	0.1380
35	−1.14621	0.25828	−0.72099	0.31755	−1.76491	0.1761	−0.90868	0.2389	−1.935934	0.1780
36	−1.65648	0.13477	−1.58179	0.17356	−1.94682	0.1332	−1.42274	0.1922	−2.136240	0.1357
37	−0.54224	0.08445	−0.46692	0.10115	−0.69260	0.1292	−0.05025	0.1884	−0.875653	0.1319
38	−0.23743	0.08121	−0.17951	0.09785	−0.37332	0.1280	0.16592	0.1881	−0.569367	0.1310
39	−1.92653	0.13898	−1.74867	0.17733	−2.08114	0.1285	−1.72571	0.1883	−2.285763	0.1313
40	−1.72856	0.13199	−1.56896	0.17840	−1.93582	0.1289	−1.60024	0.1879	−2.137527	0.1316
41	–	–	−1.63495	0.22300	−2.17701	0.1307	−1.82696	0.1888	−2.373162	0.1333

Table 28. Final values for fishing mortality "devs" for the snow crab fishery. The indices for 20.07 and 20.07u start in 1992. Those for the other scenarios start in 1990.

	20.07		20.07u		21.22		21.24		21.22a	
index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
1	0.54048	0.10414	0.56230	0.10491	0.83785	0.1586	0.94753	0.1619	0.84278	0.1574
2	0.86620	0.09692	0.87332	0.09777	1.11077	0.1593	1.24059	0.1629	1.11756	0.1579
3	0.31015	0.17908	0.30826	0.17913	0.68393	0.1599	0.80978	0.1636	0.69245	0.1584
4	0.27596	0.23360	0.27402	0.23288	1.39606	0.1605	1.49796	0.1645	1.40492	0.1592
5	1.17514	0.13992	1.18311	0.13993	0.85472	0.1602	0.91580	0.1640	0.85947	0.1588
6	0.88551	0.16549	0.87774	0.17177	0.69697	0.1592	0.71702	0.1625	0.69750	0.1578
7	−0.12670	0.34620	−0.12176	0.34602	1.24293	0.1594	1.23988	0.1620	1.24079	0.1581
8	−0.97226	0.54328	−0.96054	0.54280	0.72964	0.1799	0.56280	0.1842	0.71183	0.1801
9	−0.70710	0.48495	−0.69172	0.48446	0.22097	0.1791	0.05091	0.1836	0.20166	0.1794
10	−0.41102	0.38006	−0.39334	0.38081	−1.50672	0.2067	−1.65948	0.2110	−1.52264	0.2070
11	−1.10342	0.49869	−1.09469	0.49849	−0.74315	0.2114	−0.84806	0.2149	−0.75457	0.2117
12	−1.39602	0.49798	−1.38203	0.49985	−0.39532	0.2021	−0.45208	0.2059	−0.40303	0.2023
13	−1.44001	0.46866	−1.43184	0.46943	−1.59751	0.2096	−1.63188	0.2127	−1.60559	0.2096
14	−0.10984	0.20282	−0.06902	0.20356	−2.73146	0.2147	−2.73773	0.2177	−2.73443	0.2148
15	0.02779	0.16261	0.05647	0.16353	−1.70329	0.1885	−1.75812	0.1921	−1.70721	0.1885
16	0.09813	0.14052	0.13994	0.14171	−0.07982	0.1893	−0.03063	0.1896	−0.07628	0.1893
17	−0.52357	0.20548	−0.48645	0.20633	0.62629	0.1555	0.66106	0.1559	0.62838	0.1555
18	−0.12390	0.15877	−0.09984	0.15968	0.35206	0.1553	0.39075	0.1557	0.35747	0.1552
19	−0.03348	0.16836	−0.00637	0.16924	−0.44345	0.1799	−0.38374	0.1805	−0.43950	0.1799
20	0.51362	0.12851	0.55259	0.12981	−0.15830	0.1891	−0.18155	0.1898	−0.16265	0.1891
21	0.16759	0.16097	0.23037	0.16198	−0.05336	0.1944	−0.15535	0.1950	−0.06158	0.1945
22	0.05911	0.14174	0.14480	0.14311	0.44415	0.1902	0.35213	0.1908	0.43934	0.1903
23	0.97011	0.08884	1.04109	0.09057	0.14758	0.1921	0.13609	0.1927	0.15278	0.1921
24	0.76573	0.09602	0.83350	0.09743	0.03739	0.1877	0.15710	0.1880	0.05179	0.1876
25	0.54665	0.11524	0.62169	0.11643	0.71935	0.1524	0.84693	0.1537	0.72923	0.1525
26	−0.14707	0.21601	−0.05481	0.21742	0.61812	0.1832	0.67357	0.1861	0.62285	0.1834
27	−0.18330	0.25750	−0.07599	0.25978	0.47690	0.1855	0.46483	0.1875	0.47841	0.1857
28	0.07555	0.23536	0.20009	0.23748	−0.08046	0.1954	−0.12212	0.1964	−0.08018	0.1954
29	–	–	−1.03087	0.52685	−0.09180	0.1953	−0.11924	0.1959	−0.08838	0.1952
30	–	–	–	–	0.19647	0.1907	0.16946	0.1911	0.20047	0.1907
31	–	–	–	–	−1.80752	0.2002	−1.75422	0.2004	−1.79364	0.2001

Table 29. Final values for BBRKC fishing mortality “devs” vectors. The indices for 20.07 and 20.07u start in 1992. Those for the other scenarios start in 1990.

	20.07		20.07u		21.22		21.24		21.22a	
index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
1	0.47078	0.1864	0.48577	0.1882	3.6537	0.2077	3.650270	0.2075	3.66550	0.2077
2	1.50020	0.1229	1.49417	0.1245	3.3485	0.2216	3.418415	0.2235	3.36857	0.2219
3	0.11501	0.3428	0.08562	0.3388	3.2136	0.2327	3.265452	0.2333	3.23784	0.2336
4	0.24516	0.4228	0.22322	0.4185	4.5858	0.2091	4.555789	0.2066	4.61607	0.2106
5	0.21181	0.4214	0.19284	0.4178	2.3654	0.2363	2.059440	0.2326	2.35186	0.2362
6	0.18106	0.4164	0.16397	0.4135	1.0375	0.2528	0.745738	0.2507	1.00828	0.2527
7	0.15695	0.4086	0.14125	0.4064	0.7748	0.2477	0.526667	0.2486	0.74615	0.2476
8	0.11249	0.3956	0.09955	0.3944	0.3377	0.2439	0.151195	0.2467	0.31183	0.2440
9	0.08075	0.3819	0.06995	0.3815	0.1087	0.2410	0.002644	0.2453	0.08943	0.2412
10	0.02620	0.3667	0.01404	0.3659	−0.5053	0.2669	−0.525945	0.2715	−0.51681	0.2672
11	−0.06956	0.3456	−0.07535	0.3462	−0.3257	0.2360	−0.273977	0.2432	−0.33189	0.2365
12	−0.13114	0.3293	−0.13847	0.3296	−0.6313	0.2351	−0.554077	0.2427	−0.63723	0.2355
13	−0.22784	0.3129	−0.22823	0.3143	−0.9571	0.2346	−0.855943	0.2427	−0.95741	0.2352
14	−0.26504	0.3031	−0.27107	0.3035	−1.3314	0.2472	−1.181270	0.2481	−1.32758	0.2473
15	−0.17260	0.2873	−0.16902	0.2895	−1.8346	0.3301	−1.683159	0.3304	−1.82759	0.3301
16	−0.28280	0.2847	−0.28685	0.2854	−1.2750	0.2115	−1.148680	0.2126	−1.27146	0.2116
17	−0.34279	0.2939	−0.35517	0.2933	0.1049	0.2107	0.232721	0.2114	0.11382	0.2108
18	−0.26361	0.3068	−0.27470	0.3063	−0.3616	0.2103	−0.262035	0.2114	−0.35976	0.2104
19	−0.18404	0.3170	−0.18718	0.3179	−2.0249	0.3078	−2.048117	0.3083	−2.03274	0.3078
20	−0.16481	0.3091	−0.14828	0.3135	−2.4764	0.5200	−2.579836	0.5201	−2.48616	0.5200
21	−0.15780	0.2836	−0.12440	0.2896	−1.4606	0.2428	−1.534924	0.2429	−1.46369	0.2428
22	−0.26810	0.2837	−0.24410	0.2873	−0.4484	0.2116	−0.365463	0.2114	−0.43627	0.2116
23	−0.22472	0.2941	−0.20296	0.2973	0.1960	0.2116	0.420315	0.2121	0.21493	0.2117
24	−0.12154	0.3098	−0.09539	0.3140	−0.1962	0.2092	−0.026983	0.2106	−0.18815	0.2093
25	−0.12020	0.3269	−0.08313	0.3336	−0.2284	0.2092	−0.191136	0.2102	−0.22713	0.2093
26	−0.10381	0.3394	−0.06079	0.3475	−0.0190	0.2100	−0.059208	0.2105	−0.02109	0.2101
27	–	–	−0.02529	0.3587	−0.7322	0.2107	−0.781437	0.2111	−0.73153	0.2107
28	–	–	–	–	−1.9941	0.5082	−2.025538	0.5083	−1.99089	0.5083
29	–	–	–	–	−2.9244	1.0889	−2.930917	1.0901	−2.91690	1.0891

Table 30. Final values for fishing mortality "devs" vectors for the groundfish fisheries. Indices start in 1973.

	20.07		20.07u		21.22		21.24		21.22a	
index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
1	1.405784	0.09478	1.35147	0.09645	1.294698	0.2238	0.70083	0.2233	1.52303	0.2225
2	1.813630	0.07214	1.77038	0.07519	1.648557	0.2134	1.16395	0.2152	1.85199	0.2124
3	1.002674	0.06659	0.95509	0.06970	0.820735	0.2119	0.37841	0.2139	1.00674	0.2103
4	0.511354	0.07406	0.44056	0.07679	0.311821	0.2112	−0.13832	0.2133	0.47352	0.2085
5	0.232912	0.09564	0.12306	0.09822	0.003638	0.2124	−0.48907	0.2136	0.14544	0.2083
6	0.005654	0.12762	−0.14647	0.12977	−0.258004	0.2138	−0.76961	0.2139	−0.13689	0.2090
7	0.667458	0.08949	0.45778	0.09195	0.354664	0.2164	−0.13926	0.2142	0.45922	0.2129
8	0.305249	0.11956	0.10998	0.11986	0.015612	0.2115	−0.41030	0.2091	0.09274	0.2100
9	0.096725	0.15627	−0.04745	0.15627	−0.119410	0.2042	−0.49642	0.2046	−0.08779	0.2038
10	−0.721439	0.36812	−0.80940	0.36324	−1.025823	0.2016	−1.39390	0.2031	−1.02951	0.2018
11	−0.169415	0.30905	−0.21661	0.30850	−0.282691	0.2028	−0.64975	0.2043	−0.30435	0.2036
12	0.026172	0.33541	0.02156	0.33710	−0.010357	0.2069	−0.36139	0.2074	−0.03618	0.2082
13	−0.416764	0.45327	−0.41758	0.45163	−0.497863	0.2035	−0.83156	0.2047	−0.52876	0.2044
14	−0.218697	0.33598	−0.23878	0.33246	−0.230255	0.1983	−0.52714	0.2005	−0.26820	0.1987
15	−0.403528	0.33052	−0.37301	0.33048	−0.394654	0.2022	−0.09674	0.2009	−0.40843	0.2031
16	−0.817799	0.37867	−0.79388	0.37953	−0.886944	0.2016	−0.55321	0.2011	−0.90554	0.2026
17	−0.611333	0.30063	−0.58935	0.30196	−0.598627	0.2005	−0.25906	0.2004	−0.61868	0.2015
18	−0.295974	0.23211	−0.27337	0.23405	−0.228470	0.2006	0.11468	0.2003	−0.24752	0.2017
19	0.357807	0.06611	0.36284	0.07358	0.610481	0.1491	0.98987	0.1494	0.59753	0.1508
20	0.643964	0.06154	0.63112	0.06984	0.881664	0.1494	1.22453	0.1502	0.86531	0.1513
21	0.286325	0.07776	0.26215	0.08426	0.563585	0.1491	0.86054	0.1503	0.54359	0.1511
22	0.825022	0.06708	0.79923	0.07410	1.045596	0.1500	1.29051	0.1512	1.02084	0.1520
23	0.769751	0.07610	0.73830	0.08238	0.953946	0.1499	1.14882	0.1509	0.92520	0.1517
24	0.873797	0.08004	0.85339	0.08615	1.127871	0.1517	1.31247	0.1517	1.09785	0.1533
25	1.466362	0.07866	1.51090	0.08002	1.612049	0.1488	1.59722	0.1492	1.55831	0.1492
26	1.367350	0.08827	1.41941	0.08936	1.467910	0.1472	1.47141	0.1480	1.41470	0.1477
27	0.748933	0.13554	0.79868	0.13652	0.934459	0.1464	0.96593	0.1474	0.88414	0.1468
28	0.744309	0.12647	0.80364	0.12751	0.969808	0.1466	1.04435	0.1475	0.92321	0.1470
29	0.892609	0.09899	0.94499	0.10021	1.190001	0.1468	1.29704	0.1475	1.14678	0.1472
30	0.157799	0.15884	0.21673	0.16005	0.483203	0.1466	0.61387	0.1476	0.44174	0.1470
31	−0.249800	0.18941	−0.19214	0.19084	−0.069797	0.1462	0.08203	0.1474	−0.10832	0.1467
32	0.054890	0.12639	0.11739	0.12752	0.222712	0.1461	0.38780	0.1473	0.18586	0.1466
33	−0.318535	0.15509	−0.25115	0.15635	−0.109293	0.1461	0.06360	0.1473	−0.14466	0.1466
34	−0.359106	0.14821	−0.28567	0.14949	−0.135757	0.1462	0.03992	0.1474	−0.17067	0.1467
35	−0.103081	0.11495	−0.02514	0.11635	−0.047830	0.1461	0.12476	0.1471	−0.08202	0.1466
36	−0.434125	0.15394	−0.36682	0.15528	−0.387876	0.1456	−0.24053	0.1467	−0.42518	0.1461
37	−0.796118	0.22248	−0.74589	0.22401	−0.763589	0.1447	−0.66284	0.1460	−0.80739	0.1452
38	−1.062620	0.29450	−1.00779	0.29718	−1.111672	0.1445	−1.04911	0.1455	−1.15736	0.1449
39	−0.626897	0.20428	−0.54401	0.20585	−0.810650	0.1446	−0.73137	0.1454	−0.85102	0.1451
40	−1.201285	0.29502	−1.09428	0.29944	−1.309814	0.1453	−1.15378	0.1459	−1.34157	0.1457
41	−0.844255	0.19990	−0.72365	0.20205	−0.754257	0.1456	−0.52050	0.1463	−0.78090	0.1459
42	−0.783027	0.19282	−0.67065	0.19463	−0.666898	0.1449	−0.43028	0.1463	−0.69723	0.1454
43	−0.900344	0.24511	−0.79290	0.24743	−0.799239	0.1445	−0.62348	0.1460	−0.83484	0.1450
44	−0.773687	0.26119	−0.65784	0.26371	−0.726678	0.1446	−0.60581	0.1458	−0.76493	0.1451
45	−1.189613	0.38415	−1.06793	0.39196	−1.309873	0.1446	−1.20957	0.1455	−1.34806	0.1450
46	−1.016578	0.36277	−0.86155	0.37042	−1.018298	0.1451	−0.91122	0.1459	−1.05480	0.1455
47	−0.942512	0.32220	−0.72303	0.33081	−0.925678	0.1460	−0.79121	0.1465	−0.95725	0.1463
48	–	–	−0.77231	0.31742	−1.032710	0.1480	−0.82711	0.1479	−1.05971	0.1482

Table 31. Final values for the “pS1” parameters related to selectivity functions. Parameters with values whose standard error is NA are fixed, not estimated.

			20.07		20.07u		21.22		21.24		21.22a	
	name	label	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
selectivity	pS1[1]	size at 1 for NMFS survey selectivity (males, pre-1982)	–	–	–	–	–	–	–	–	179.000	NA
		z50 for NMFS survey selectivity (males, pre-1982)	51.378	1.816e+00	90.000	2.159e−04	51.982	2.183400	53.554	2.824e+00	–	–
	pS1[10]	ascending z-at-1 for SCF selectivity (males, pre-1997)	–	–	–	–	159.985	3.569100	164.854	3.153e+00	160.095	2.850900
		ascending z50 for SCF selectivity (males, pre-1997)	114.588	1.883e+00	116.567	1.799e+00	–	–	–	–	–	–
	pS1[11]	ascending z-at-1 for SCF selectivity (males, 1997-2004)	–	–	–	–	117.483	6.903000	119.057	6.901e+00	118.179	6.689500
		ascending z50 for SCF selectivity (males, 1997-2004)	95.324	3.234e+00	97.203	3.408e+00	–	–	–	–	–	–
	pS1[12]	ascending z-at-1 for SCF selectivity (males, 2005+)	–	–	–	–	124.246	1.283800	125.984	1.354e+00	124.476	1.277200
		ascending z50 for SCF selectivity (males, 2005+)	105.521	1.126e+00	106.994	1.127e+00	–	–	–	–	–	–
	pS1[13]	ascending z50 for SCF selectivity (females, pre-1997)	75.412	4.729e+00	75.602	4.724e+00	91.869	7.948300	96.675	8.386e+00	92.344	8.019100
	pS1[14]	ascending z50 for SCF selectivity (females, 1997-2004)	77.232	4.551e+00	77.354	4.557e+00	72.006	5.069000	73.620	4.876e+00	72.036	5.061000
	pS1[15]	ascending z50 for SCF selectivity (females, 2005+)	80.286	3.790e+00	80.517	3.872e+00	107.502	7.085500	110.108	7.077e+00	107.784	7.131000
	pS1[16]	z50 for GF.AllGear selectivity (males, pre-1987)	54.155	1.796e+00	58.666	2.453e+00	55.221	2.201300	56.808	2.537e+00	59.813	3.067000
	pS1[17]	z50 for GF.AllGear selectivity (males, 1987-1996)	58.585	4.946e+00	68.822	5.472e+00	61.689	5.936500	120.000	2.252e−03	68.694	6.715100
	pS1[18]	z50 for GF.AllGear selectivity (males, 1997+)	86.630	2.210e+00	95.097	2.330e+00	94.600	2.488400	111.420	3.233e+00	97.271	2.553400
	pS1[19]	z50 for GF.AllGear selectivity (females, pre-1987)	–	–	–	–	43.261	1.748100	45.575	2.199e+00	43.726	1.858100
		z50 for GF.AllGear selectivity (males, pre-1987)	43.691	1.510e+00	44.358	1.602e+00	–	–	–	–	–	–
	pS1[2]	size at 1 for NMFS survey selectivity (males, 1982+)	–	–	–	–	–	–	–	–	179.000	NA
		z50 for NMFS survey selectivity (males, 1982+)	49.498	2.982e+00	68.830	4.008e+00	64.240	4.383000	69.000	5.516e−04	–	–
	pS1[20]	z50 for GF.AllGear selectivity (females, 1987-1996)	–	–	–	–	40.291	2.189100	99.356	2.727e+01	39.897	2.162800
		z50 for GF.AllGear selectivity (males, 1987-1996)	41.517	1.924e+00	42.495	2.195e+00	–	–	–	–	–	–
	pS1[21]	z50 for GF.AllGear selectivity (females, 1997+)	–	–	–	–	88.201	2.953900	102.606	3.695e+00	87.373	3.172800
		z50 for GF.AllGear selectivity (males, 1997+)	81.866	2.450e+00	84.641	2.674e+00	–	–	–	–	–	–
	pS1[22]	size at 1 for RKF selectivity (males, pre-1997)	–	–	–	–	179.900	NA	179.900	NA	179.900	NA
		z95 for RKF selectivity (males, pre-1997)	149.585	4.425e+00	151.179	4.049e+00	–	–	–	–	–	–
	pS1[23]	size at 1 for RKF selectivity (males, 1997-2004)	–	–	–	–	179.900	NA	179.900	NA	179.900	NA
		z95 for RKF selectivity (males, 1997-2004)	180.000	8.954e−04	180.000	8.543e−04	–	–	–	–	–	–
	pS1[24]	size at 1 for RKF selectivity (males, 2005+)	–	–	–	–	179.900	NA	179.900	NA	179.900	NA
		z95 for RKF selectivity (males, 2005+)	180.000	1.390e−04	180.000	1.306e−04	–	–	–	–	–	–
	pS1[25]	size at 1 for RKF selectivity (females, pre-1997)	–	–	–	–	140.000	0.018535	140.000	1.684e−02	139.900	NA
		z95 for RKF selectivity (females, pre-1997)	119.216	2.657e+01	119.857	2.734e+01	–	–	–	–	–	–
	pS1[26]	size at 1 for RKF selectivity (females, 1997-2004)	–	–	–	–	126.495	25.958000	126.582	2.483e+01	126.015	25.857000
		z95 for RKF selectivity (females, 1997-2004)	118.987	4.422e+01	120.460	4.799e+01	–	–	–	–	–	–
	pS1[27]	size at 1 for RKF selectivity (females, 2005+)	–	–	–	–	126.544	15.907000	128.562	1.566e+01	126.159	15.816000
		z95 for RKF selectivity (females, 2005+)	140.000	1.658e−01	140.000	9.097e−02	–	–	–	–	–	–
	pS1[28]	z50 for TCF retention (2005-2009)	137.695	3.038e−01	137.730	4.977e−01	139.678	1.013500	139.359	1.065e+00	139.725	1.002100
	pS1[29]	z50 for TCF retention (2013+)	125.306	5.556e−01	125.408	6.912e−01	124.981	0.682240	125.536	6.934e−01	125.060	0.678340
	pS1[3]	size at 1 for NMFS survey selectivity (females, pre-1982)	–	–	–	–	118.623	17.214000	130.000	4.995e−02	129.900	NA
		z50 for NMFS survey selectivity (females, pre-1982)	77.604	2.995e+00	94.255	1.799e+01	–	–	–	–	–	–
	pS1[4]	size at 1 for NMFS survey selectivity (females, 1982+)	–	–	–	–	129.900	NA	129.900	NA	129.900	NA
		z50 for NMFS survey selectivity (females, 1982+)	69.000	2.760e−04	69.000	4.426e−04	–	–	–	–	–	–
	pS1[5]	z50 for TCF retention (pre-1991)	138.344	3.542e−01	138.764	3.985e−01	138.537	0.857000	138.828	7.267e−01	138.671	0.777610
	pS1[6]	z50 for TCF retention (1991-1996)	138.451	3.590e−01	138.740	3.921e−01	137.750	0.256260	137.712	1.065e−01	137.746	0.199750
	pS1[7]	DUMMY VALUE	4.884	NA	4.884	NA	4.500	NA	4.500	NA	4.500	NA
	pS1[8]	ln(z50) for TCF selectivity (males)	4.856	7.120e−03	4.849	7.157e−03	4.852	0.007566	4.884	7.053e−03	4.856	0.007486
	pS1[9]	z50 for TCF selectivity (females)	94.726	2.469e+00	94.531	2.447e+00	93.914	2.504400	95.148	2.693e+00	93.923	2.545900

Table 32. Final values for the “pS2” parameters related to selectivity functions. Parameters with values whose standard error is NA are fixed, not estimated.

			20.07		20.07u		21.22		21.24		21.22a	
	name	label	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
selectivity	pS2[1]	width for NMFS survey selectivity (males, pre-1982)	–	–	–	–	–	–	–	–	66.89242	2.558500
		z95-z50 for NMFS survey selectivity (males, pre-1982)	21.51475	$2.678e+00$	79.53529	$5.424e+00$	23.63544	3.504000	27.52155	$5.006e+00$	–	–
	pS2[10]	ascending slope for SCF selectivity (males, pre-1997)	0.10000	$4.332e-06$	0.10000	$4.057e-06$	–	–	–	–	–	–
		ascending width for SCF selectivity (males, pre-1997)	–	–	–	–	33.53857	1.858200	33.96041	$1.580e+00$	33.18869	1.656400
	pS2[11]	ascending slope for SCF selectivity (males, 1997-2004)	0.21186	$6.134e-02$	0.19618	$5.203e-02$	–	–	–	–	–	–
		ascending width for SCF selectivity (males, 1997-2004)	–	–	–	–	15.34522	3.647500	15.64277	$3.461e+00$	15.52980	3.493300
	pS2[12]	ascending slope for SCF selectivity (males, 2005+)	0.18486	$1.371e-02$	0.18045	$1.238e-02$	–	–	–	–	–	–
		ascending width for SCF selectivity (males, 2005+)	–	–	–	–	14.50812	0.719500	14.68934	$7.072e-01$	14.45919	0.707270
	pS2[13]	slope for SCF selectivity (females, pre-1997)	0.16651	$6.359e-02$	0.16649	$6.308e-02$	0.08660	0.025095	0.07997	$2.049e-02$	0.08447	0.024245
	pS2[14]	slope for SCF selectivity (females, 1997-2004)	0.26103	$1.219e-01$	0.26066	$1.207e-01$	0.33539	0.310300	0.29994	$2.117e-01$	0.33273	0.305130
	pS2[15]	slope for SCF selectivity (females, 2005+)	0.19937	$5.558e-02$	0.19642	$5.486e-02$	0.08156	0.014145	0.08214	$1.352e-02$	0.08079	0.014043
	pS2[16]	slope for GF.AllGear selectivity (males, pre-1987)	0.12136	$1.151e-02$	0.10044	$1.032e-02$	0.10789	0.011564	0.09361	$1.090e-02$	0.09069	0.010723
	pS2[17]	slope for GF.AllGear selectivity (males, 1987-1996)	0.07454	$1.711e-02$	0.05233	$7.886e-03$	0.05614	0.012237	0.02455	$1.707e-03$	0.04587	0.008112
	pS2[18]	slope for GF.AllGear selectivity (males, 1997+)	0.07162	$3.441e-03$	0.06311	$2.628e-03$	0.06071	0.002671	0.05177	$2.036e-03$	0.05913	0.002525
	pS2[19]	slope for GF.AllGear selectivity (females, pre-1987)	0.15516	$2.026e-02$	0.14631	$1.896e-02$	0.14093	0.020403	0.11876	$1.840e-02$	0.13438	0.019629
	pS2[2]	width for NMFS survey selectivity (males, 1982+)	–	–	–	–	–	–	–	–	90.86617	3.089800
		z95-z50 for NMFS survey selectivity (males, 1982+)	59.15246	$6.865e+00$	100.00000	$1.633e-03$	100.00000	0.001155	100.00000	$1.675e-04$	–	–
	pS2[20]	slope for GF.AllGear selectivity (females, 1987-1996)	0.18414	$4.528e-02$	0.16085	$4.342e-02$	0.16963	0.054638	0.02079	$6.296e-03$	0.17126	0.056272
	pS2[21]	slope for GF.AllGear selectivity (females, 1997+)	0.07490	$4.688e-03$	0.07184	$4.452e-03$	0.06397	0.004067	0.05776	$3.238e-03$	0.06395	0.004224
	pS2[22]	ln(z95-z50) for RKF selectivity (males, pre-1997)	2.90894	$1.468e-01$	2.89061	$1.346e-01$	–	–	–	–	–	–
		width for RKF selectivity (males, pre-1997)	–	–	–	–	19.91359	0.811960	18.98028	$7.256e-01$	19.71234	0.794840
	pS2[23]	ln(z95-z50) for RKF selectivity (males, 1997-2004)	3.45586	$7.652e-02$	3.41890	$7.294e-02$	–	–	–	–	–	–
		width for RKF selectivity (males, 1997-2004)	–	–	–	–	28.16585	2.195600	26.57043	$1.926e+00$	27.93039	2.149600
	pS2[24]	ln(z95-z50) for RKF selectivity (males, 2005+)	3.42878	$3.665e-02$	3.39338	$3.488e-02$	–	–	–	–	–	–
		width for RKF selectivity (males, 2005+)	–	–	–	–	27.98593	1.029500	25.80652	$8.457e-01$	27.68538	1.001300
	pS2[25]	ln(z95-z50) for RKF selectivity (males, pre-1997)	2.73135	$5.612e-01$	2.73677	$5.541e-01$	–	–	–	–	–	–
		width for RKF selectivity (males, pre-1997)	–	–	–	–	17.68445	2.029100	17.32973	$1.967e+00$	17.65114	2.029600
	pS2[26]	ln(z95-z50) for RKF selectivity (males, 1997-2004)	2.80343	$8.624e-01$	2.82044	$8.595e-01$	–	–	–	–	–	–
		width for RKF selectivity (males, 1997-2004)	–	–	–	–	16.85944	11.023000	16.42768	$1.031e+01$	16.77483	11.039000
	pS2[27]	ln(z95-z50) for RKF selectivity (males, 2005+)	2.99522	$2.064e-01$	2.98534	$2.066e-01$	–	–	–	–	–	–
		width for RKF selectivity (males, 2005+)	–	–	–	–	16.33378	5.632700	16.38602	$5.372e+00$	16.26298	5.626000
	pS2[28]	slope for TCF retention (2005-2009)	1.99965	$4.714e-01$	1.99913	$1.168e+00$	0.62452	0.235050	0.70948	$3.060e-01$	0.62043	0.228510
	pS2[29]	slope for TCF retention (2013+)	0.56464	$1.037e-01$	0.54518	$1.014e-01$	0.60766	0.254780	0.53653	$2.253e-01$	0.59625	0.248760
	pS2[3]	width for NMFS survey selectivity (females, pre-1982)	–	–	–	–	38.05140	6.765000	41.44327	$2.214e+00$	41.33826	2.217500
		z95-z50 for NMFS survey selectivity (females, pre-1982)	50.04102	$5.316e+00$	57.76081	$1.045e+01$	–	–	–	–	–	–
	pS2[4]	width for NMFS survey selectivity (females, 1982+)	–	–	–	–	75.71709	5.320600	75.47670	$4.848e+00$	78.99429	6.103500
		z95-z50 for NMFS survey selectivity (females, 1982+)	100.00000	$2.802e-04$	100.00000	$1.749e-04$	–	–	–	–	–	–
	pS2[5]	slope for TCF retention (pre-1991)	0.75041	$1.223e-01$	0.73169	$1.159e-01$	0.83323	0.393850	0.75425	$2.436e-01$	0.78671	0.301310
	pS2[6]	slope for TCF retention (1997+)	0.94305	$2.261e-01$	0.86281	$1.782e-01$	1.99953	0.635280	1.99989	$1.473e-01$	1.99965	0.472120
	pS2[7]	slope for TCF selectivity (males, pre-1997)	0.11744	$6.651e-03$	0.12034	$6.691e-03$	0.11942	0.007444	0.11646	$5.919e-03$	0.11792	0.007139
	pS2[8]	slope for TCF selectivity (males, 1997+)	0.15951	$7.644e-03$	0.16690	$7.351e-03$	0.15999	0.007463	0.15350	$6.302e-03$	0.16071	0.007370
	pS2[9]	slope for TCF selectivity (females)	0.19244	$2.157e-02$	0.19295	$2.128e-02$	0.18188	0.022012	0.17914	$2.112e-02$	0.18040	0.022065

Table 33. Final values for the “pS3” and pS4 parameters related to selectivity functions. Parameters with values whose standard error is NA are fixed, not estimated.

			20.07		20.07u		21.22		21.24		21.22a	
	name	label	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
selectivity	pS3[1]	ln(dz50-az50) for SCF selectivity (males, pre-1997)	3.3608	$1.405e-01$	3.3961	$1.481e-01$	–	–	–	–	–	–
		scaled increment for descending z-at-1 for SCF selectivity (males, pre-1997)	–	–	–	–	$8.535e-06$	0.008535	$1.156e-06$	0.001156	0.001	NA
	pS3[2]	ln(dz50-az50) for SCF selectivity (males, 1997-2004)	3.8252	$1.587e-01$	3.8077	$1.740e-01$	–	–	–	–	–	–
		scaled increment for descending z-at-1 for SCF selectivity (males, 1997-2004)	–	–	–	–	$1.000e-03$	NA	$1.000e-03$	NA	0.001	NA
	pS3[3]	ln(dz50-az50) for SCF selectivity (males, 2005+)	3.5221	$6.085e-02$	3.4962	$6.476e-02$	–	–	–	–	–	–
		scaled increment for descending z-at-1 for SCF selectivity (males, 2005+)	–	–	–	–	$1.000e-03$	NA	$1.000e-03$	NA	0.001	NA
	pS4[1]	descending slope for SCF selectivity (males, pre-1997)	0.1000	$1.153e-05$	0.1000	$1.585e-05$	–	–	–	–	–	–
		descending width for SCF selectivity (males, pre-1997)	–	–	–	–	$1.000e+00$	0.017245	$1.000e+00$	0.001725	1.100	NA
	pS4[2]	descending slope for SCF selectivity (males, 1997-2004)	0.1615	$1.030e-01$	0.1619	$1.149e-01$	–	–	–	–	–	–
		descending width for SCF selectivity (males, 1997-2004)	–	–	–	–	$1.970e+01$	8.359500	$2.234e+01$	11.690000	19.376	8.294
	pS4[3]	descending slope for SCF selectivity (males, 2005+)	0.1951	$2.508e-02$	0.1929	$2.621e-02$	–	–	–	–	–	–
		descending width for SCF selectivity (males, 2005+)	–	–	–	–	$1.329e+01$	1.263300	$1.386e+01$	1.582300	13.255	1.277

Table 34. Final values for the devs parameters related to selectivity in the directed fishery. Parameters with values whose standard error is NA are fixed, not estimated.

	20.07		20.07u		21.22		21.24		21.22a	
index	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.	estimate	std. dev.
1	0.08956	0.010622	0.10471	0.01356	0.08385	0.01774	0.09049	0.01591	0.08749	0.01766
2	0.03695	0.009587	0.06243	0.01164	0.06131	0.01595	0.06602	0.01492	0.06337	0.01589
3	0.11525	0.012428	0.10999	0.01481	0.10775	0.01553	0.11118	0.01429	0.11006	0.01541
4	0.07212	0.016911	0.08570	0.02154	0.11780	0.02005	0.12789	0.01762	0.12025	0.01991
5	0.02219	0.023415	0.02472	0.02817	0.10793	0.02967	0.13779	0.02638	0.11242	0.02942
6	0.16353	0.036252	0.13564	0.04578	0.13057	0.01723	0.12274	0.01710	0.12889	0.01735
7	−0.06427	0.015988	−0.05137	0.01523	−0.05004	0.01498	−0.04689	0.01399	−0.05155	0.01480
8	−0.06627	0.016380	−0.04861	0.01553	−0.05068	0.01540	−0.03795	0.01415	−0.05073	0.01517
9	−0.10699	0.014981	−0.09021	0.01428	−0.09608	0.01440	−0.09586	0.01372	−0.09736	0.01421
10	0.02754	0.013031	0.03975	0.01256	0.03144	0.01257	0.02885	0.01176	0.03028	0.01245
11	0.19292	0.015054	0.19368	0.01382	0.17431	0.01372	0.16694	0.01362	0.17226	0.01356
12	−0.02313	0.015545	−0.01073	0.01497	−0.01985	0.01517	−0.03174	0.01456	−0.02214	0.01504
13	−0.08819	0.012271	−0.06966	0.01264	−0.08194	0.01330	−0.08267	0.01209	−0.08221	0.01308
14	−0.12739	0.013176	−0.10740	0.01417	−0.12019	0.01491	−0.11652	0.01348	−0.12057	0.01466
15	−0.09926	0.018392	−0.08382	0.01727	−0.08587	0.01735	−0.09325	0.01647	−0.08746	0.01714
16	−0.14420	0.016255	−0.12552	0.01511	−0.13137	0.01566	−0.14287	0.01472	−0.13241	0.01541
17	–	–	−0.16904	0.01625	−0.17893	0.01727	−0.20437	0.01727	−0.18047	0.01707

Table 35. Availability parameters used in all scenarios (all fixed).

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

Table 36. Objective function values for all data components from the model scenarios. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. n.at.z: size compositions. Note that values are not comparable between 20.07u and the remaining scenarios due to the use of different likelihoods.

				Model Scenarios				
category	**fleet**	**data type**	**sex**	**20.07**	**20.07u**	**21.22**	**21.24**	**21.22a**
surveys data	**NMFS**	**biomass**	**male**	**65.33**	**57.84**	**65.66**	**115.06**	**61.36**
		n.at.z		**411.35**	**455.95**	**385.70**	**400.42**	**405.87**
		biomass	**female**	**139.92**	**155.00**	**162.41**	**200.27**	**164.70**
		n.at.z		**330.88**	**338.09**	**293.72**	**289.69**	**293.16**
	SBS BSFRF	**biomass**	**male**	**-1.02**	**-0.90**	**-1.05**	**4.40**	**-1.12**
		n.at.z		**153.24**	**152.04**	**289.49**	**284.50**	**290.32**
		biomass	**female**	**-6.64**	**-4.13**	**-3.62**	**13.58**	**-1.92**
		n.at.z		**146.29**	**150.17**	**229.71**	**227.63**	**231.46**
fisheries data	TCF (RC)	biomass	male	8.13	5.22	-137.72	-135.94	-137.37
		n.at.z	male	55.13	56.43	52.71	47.15	54.91
	TCF (TC)	biomass	female	9.28	0.77	67.49	64.86	66.93
			male	3.69	6.46	8.52	8.36	9.07
		n.at.z	female	13.74	15.25	12.75	12.68	12.67
			male	89.33	92.67	79.82	57.76	76.77
	SCF	biomass	female	1.91	1.92	10.94	10.92	11.01
			male	16.44	16.69	-21.62	-20.71	-21.47
		n.at.z	female	14.57	14.47	17.53	16.79	17.51
			male	119.65	118.19	86.34	85.64	86.14
	RKF	biomass	female	0.06	0.06	17.31	17.88	17.23
			male	25.79	25.18	-40.25	-39.78	-40.18
		n.at.z	female	2.91	2.96	2.23	2.25	2.24
			male	70.64	70.35	33.45	35.86	33.86
	GF All	abundance	all sexes	3.45	3.39	-36.00	-36.26	-36.18
		biomass	all sexes	32.03	34.07	-67.43	-66.86	-67.54
		n.at.z	female	262.14	260.23	226.18	236.93	222.84
			male	276.68	294.87	284.14	328.70	287.35
growth data	--	**molt increment**	**female**	**252.78**	**243.36**	**252.01**	**225.63**	**246.95**
			male	**296.49**	**281.47**	**287.80**	**234.09**	**282.48**
maturity ogive data	--	male maturity ogives	male	107.27	221.22	209.82	297.17	206.49

Table 37. Objective function values for all non-data components from the model scenarios.

category	type	element	level	20.07	20.07u	21.22	21.24	21.22a	description
penalties	maturity	smoothness	1	0.8	2.0	1.3	0.9	1.4	male probability of terminal molt bby size
			2	1.1	1.0	0.6	0.5	0.6	male probability of terminal molt bby size
priors	fisheries	pDevsLnC	1	138.5	130.6	0.0	0.0	0.0	annual devs for directed fishery
			2	32.1	33.7	0.0	0.0	0.0	annual devs for snow crab fishery
			3	57.2	57.1	0.0	0.0	0.0	annual devs for groundfish fisheries
			4	153.4	158.7	0.0	0.0	0.0	annual devs for BBRKC fishery
	natural mortality	pDM1	1	0.0	0.0	0.0	0.0	0.0	multiplier for immature crab
			2	12.7	19.0	14.1	8.3	16.3	multiplier for mature males
			3	31.9	31.7	22.1	13.9	20.3	multiplier for mature females
	recruitment	pDevsLnR	1	48.3	48.1	47.8	47.1	47.7	prior to 1975 (devs are AR1 process)
			2	0.1	0.2	0.2	0.2	63.2	after 1975
	surveys	pQ	2	28.5	27.4	25.4	52.4	22.4	male fully-selected NMFS survey catchability, after 1982
			4	25.0	42.1	62.2	90.1	68.7	female fully-selected NMFS survey catchability, after 1982

Table 38. Root mean square errors (RMSE) for data components from the model scenarios. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. Abundance values were not included in the model fits.

				Model Scenarios				
category	fleet	sex	data type	20.07	20.07u	21.22	21.24	21.22a
surveys data	NMFS	male	abundance	3.40	3.34	3.34	3.58	0.00
			biomass	2.60	2.53	2.59	2.98	2.56
		female	abundance	5.49	5.60	5.56	5.87	0.00
			biomass	4.99	5.09	5.15	5.44	5.17
	SBS BSFRF	male	abundance	1.73	1.68	1.77	2.23	1.72
			biomass	1.58	1.59	1.57	2.16	1.56
		female	abundance	2.98	3.18	3.38	3.60	3.41
			biomass	1.90	2.35	2.41	4.44	2.66
fisheries data	TCF (RC)	male	abundance					
			biomass	8.56	2.22	0.43	0.52	0.45
	TCF (TC)	female	abundance	5.97	15.35	3.93	4.06	3.93
		male	abundance	1.08	4.29	1.94	1.95	1.96
		female	biomass	4.69	6.25	3.23	3.18	3.22
		male	biomass	1.69	5.21	2.06	2.05	2.08
	SCF	female	abundance	0.00	4.68	2.98	2.88	2.98
		male	abundance	0.00	2.71	1.12	1.14	1.12
		female	biomass	2.78	2.70	1.55	1.55	1.55
		male	biomass	3.40	3.50	1.36	1.38	1.36
	RKF	female	abundance	0.00	2.93	0.89	0.93	0.89
		male	abundance	0.00	18.13	0.68	0.66	0.69
		female	biomass	1.32	1.21	0.52	0.56	0.52
		male	biomass	18.27	18.27	0.33	0.37	0.33
	GF All	all sexes	abundance	0.58	0.55	0.92	0.91	0.91
		all sexes	biomass	1.04	1.11	0.65	0.67	0.65
growth data	--	female	molt	0.28	0.28	0.28	0.32	0.29
		male	increment	0.56	0.54	0.53	0.43	0.53
maturity ogive data	--	male	male maturity ogives	19.35	28.60	26.55	29.80	26.00

Table 39. Harmonic means of effective sample sizes used for size composition data. Effective sample sizes were estimated using the McAllister-Ianelli approach. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries.

			Model Scenarios				
category	**fleet**	**sex**	**20.07**	**20.07u**	**21.22**	**21.24**	**21.22a**
surveys data	**NMFS**	**male**	**156.19**	**142.41**	**117.76**	**126.03**	**105.99**
		female	**54.35**	**54.15**	**40.47**	**39.19**	**40.53**
	SBS BSFRF	**male**	**54.97**	**51.45**	**40.53**	**48.15**	**40.42**
		female	**18.65**	**17.85**	**15.83**	**16.02**	**15.64**
fisheries data	TCF (RC)	male	115.11	103.99	52.03	65.01	52.22
	TCF (TC)	female	59.71	55.00	35.40	34.53	35.44
		male	152.78	185.94	94.41	106.44	**98.27**
	SCF	female	38.48	34.96	13.84	14.99	13.93
		male	76.46	75.92	54.98	54.21	54.97
	RKF	female	17.03	15.83	17.10	17.41	17.04
		male	36.56	37.11	49.90	50.46	49.85
	GF All	female	170.19	171.75	151.61	135.71	153.91
		male	192.16	184.36	144.17	127.11	141.34

Table 40. Comparison of estimated rates of natural mortality (“M”) by maturity state and sex for different time periods. “elevated”: 1980-84 (mature crab only), “typical”: remaining model time period.

	immature	mature			
	all	female		male	
case	typical	typical	elevated	typical	elevated
20.07	0.24	0.32	0.56	0.29	0.58
20.07u	0.24	0.32	0.61	0.30	0.71
21.22	0.24	0.31	0.61	0.30	0.68
21.24	0.21	0.30	0.68	0.28	0.81
21.22a	0.23	0.31	0.60	0.30	0.71

Table 41. Comparison of observed and predicted (total) male survey biomass (in 1000's t) from the model scenarios.

	observed	predicted				
year		20.07	20.07u	21.22	21.24	21.22a
1975	294.88	252.64	217.45	180.33	177.45	180.27
1976	157.02	211.42	185.80	151.32	149.04	156.15
1977	138.50	168.82	149.61	122.71	124.77	125.65
1978	98.30	137.23	119.66	103.45	108.19	99.56
1979	51.42	130.98	113.82	101.52	103.38	94.74
1980	152.48	127.41	118.53	104.73	104.00	101.15
1981	79.92	106.78	99.73	82.73	77.77	87.64
1982	65.85	82.17	91.72	98.14	116.83	92.80
1983	37.98	61.93	66.68	70.43	86.02	68.75
1984	30.50	46.81	47.72	50.40	60.62	49.74
1985	14.90	39.65	38.23	40.15	45.73	39.66
1986	21.59	48.18	47.34	48.45	53.04	48.12
1987	45.50	61.37	60.73	60.68	62.15	60.49
1988	99.21	76.14	75.74	73.96	72.38	74.14
1989	132.80	87.77	87.44	83.71	80.38	84.15
1990	132.42	90.82	90.32	84.79	80.43	85.17
1991	145.79	84.28	83.90	77.08	73.37	77.36
1992	127.58	74.93	75.41	67.87	65.44	68.28
1993	73.27	57.63	59.13	52.24	53.04	52.66
1994	48.33	44.75	46.13	40.52	43.52	40.98
1995	34.98	34.73	35.93	32.31	36.11	32.76
1996	30.76	27.73	28.56	26.40	30.08	26.78
1997	14.63	23.89	24.24	22.77	26.06	23.09
1998	15.00	21.91	22.11	21.19	23.98	21.46
1999	21.53	22.23	22.35	21.76	23.90	21.97
2000	23.33	24.33	24.27	23.94	25.17	24.06
2001	29.25	28.15	28.07	28.01	28.31	28.05
2002	27.41	33.05	32.92	32.96	32.66	32.94
2003	37.80	40.04	39.87	40.06	39.02	39.94
2004	38.87	48.48	48.20	48.57	46.61	48.37
2005	63.74	57.09	56.70	57.55	54.61	57.27
2006	101.53	65.10	64.45	65.82	61.80	65.52
2007	104.18	70.84	70.01	71.82	67.09	71.56
2008	84.90	72.91	72.29	74.26	69.51	74.33
2009	47.41	69.07	69.16	70.89	68.80	71.64
2010	49.00	62.02	61.89	63.52	64.70	64.37
2011	62.66	58.94	57.71	59.41	60.75	59.74
2012	80.11	63.27	60.46	62.37	60.40	61.87
2013	103.37	74.05	69.96	71.89	64.22	70.92
2014	108.91	80.70	76.61	78.06	67.40	77.56
2015	74.23	72.99	69.68	70.93	63.66	71.13
2016	69.62	58.17	55.15	56.58	53.95	56.94
2017	54.20	49.71	46.47	48.14	46.84	48.44
2018	47.08	43.86	39.92	41.74	40.66	41.84
2019	28.67	42.90	37.25	39.11	37.68	38.92
2021	31.56	–	48.31	50.33	43.59	49.22

Table 42. Comparison of observed and estimated mature female survey biomass (in 1000's t) from the model scenarios.

	observed	predicted				
year		20.07	20.07u	21.22	21.24	21.22a
1975	31.42	48.28	44.63	48.38	47.83	44.18
1976	31.16	41.11	38.71	41.09	40.20	38.27
1977	38.57	34.14	33.04	33.90	33.56	32.53
1978	25.75	29.38	29.12	28.97	28.85	28.64
1979	10.45	28.27	28.42	27.92	27.41	28.06
1980	63.78	29.17	30.19	29.47	28.89	29.87
1981	42.58	24.49	24.94	23.68	22.24	24.53
1982	64.14	20.74	22.36	22.31	23.43	21.63
1983	20.43	14.80	15.58	15.46	15.94	15.21
1984	14.91	10.36	10.57	10.53	10.66	10.48
1985	5.55	7.94	7.85	7.79	7.69	7.82
1986	3.37	8.97	9.05	8.90	8.93	8.95
1987	5.14	11.36	11.54	11.07	11.07	11.14
1988	25.37	14.24	14.46	13.55	13.49	13.61
1989	19.40	16.80	16.94	15.68	15.24	15.69
1990	37.69	18.85	18.87	17.11	16.10	17.06
1991	44.76	19.68	19.57	17.42	15.95	17.30
1992	26.23	18.49	18.31	16.28	14.66	16.12
1993	11.64	15.68	15.56	13.97	12.69	13.84
1994	9.85	12.46	12.41	11.37	10.55	11.29
1995	12.40	9.67	9.65	9.06	8.54	9.02
1996	9.58	7.58	7.58	7.24	6.93	7.24
1997	3.40	6.12	6.13	5.92	5.81	5.95
1998	2.28	5.22	5.25	5.12	5.12	5.15
1999	3.83	4.84	4.88	4.77	4.81	4.81
2000	4.13	4.91	4.94	4.85	4.82	4.87
2001	4.56	5.32	5.36	5.25	5.17	5.26
2002	4.47	6.04	6.09	5.96	5.86	5.95
2003	8.40	7.18	7.24	7.03	6.95	7.00
2004	4.73	8.63	8.68	8.43	8.33	8.37
2005	11.58	10.26	10.32	10.05	9.90	9.95
2006	14.94	11.88	11.93	11.69	11.45	11.56
2007	13.44	13.51	13.47	13.27	12.68	13.08
2008	11.66	14.15	14.06	13.85	13.21	13.64
2009	8.48	13.03	12.94	12.78	12.54	12.61
2010	5.47	11.09	11.00	10.95	11.05	10.85
2011	5.41	9.91	9.83	9.87	10.06	9.80
2012	12.36	10.96	10.76	10.76	10.55	10.66
2013	17.85	13.85	13.40	13.14	12.09	12.96
2014	14.86	15.54	14.87	14.43	12.95	14.18
2015	11.21	14.52	13.76	13.43	12.17	13.18
2016	7.63	12.15	11.41	11.31	10.39	11.11
2017	7.11	9.94	9.26	9.31	8.61	9.17
2018	4.97	8.28	7.65	7.78	7.23	7.67
2019	4.85	7.37	6.73	6.89	6.40	6.81
2021	8.55	–	9.05	9.04	7.81	8.88

Table 43. Comparison of observed and estimated immature female survey biomass (in 1000's t) from the model scenarios.

	observed	predicted				
year		20.07	20.07u	21.22	21.24	21.22a
1975	9.55	4.85	4.55	4.37	3.92	4.42
1976	6.37	4.14	4.19	3.63	3.78	3.98
1977	14.47	4.87	4.84	4.46	4.56	4.77
1978	6.81	6.36	6.11	6.16	6.08	6.28
1979	2.66	7.15	6.92	7.12	7.18	7.20
1980	13.51	6.11	6.06	6.12	6.51	6.31
1981	1.52	3.92	3.97	3.96	4.45	4.18
1982	1.71	3.22	3.79	3.96	5.33	4.06
1983	2.27	2.92	3.27	3.46	4.58	3.58
1984	2.23	3.72	4.00	4.08	4.93	4.22
1985	0.99	5.12	5.35	5.40	5.96	5.53
1986	2.69	6.66	6.89	6.72	7.12	6.85
1987	14.99	7.64	7.77	7.40	7.40	7.49
1988	10.17	7.80	7.82	7.36	6.85	7.36
1989	11.81	7.34	7.27	6.64	5.88	6.59
1990	9.86	5.98	5.86	5.32	4.56	5.24
1991	7.01	4.00	3.92	3.69	3.17	3.61
1992	1.98	2.25	2.24	2.27	2.09	2.23
1993	1.06	1.24	1.25	1.39	1.38	1.38
1994	1.20	0.87	0.87	1.00	1.04	1.01
1995	1.05	0.86	0.88	0.95	1.05	0.97
1996	1.43	0.97	0.99	1.03	1.17	1.06
1997	1.39	1.26	1.31	1.36	1.52	1.39
1998	1.96	1.55	1.58	1.63	1.77	1.66
1999	2.85	2.08	2.13	2.22	2.41	2.25
2000	2.47	2.49	2.54	2.62	2.85	2.64
2001	6.27	3.23	3.33	3.45	3.78	3.48
2002	5.49	3.81	3.88	4.01	4.43	4.04
2003	4.66	4.64	4.73	4.92	5.25	4.94
2004	4.08	5.22	5.31	5.57	5.74	5.59
2005	10.37	5.41	5.44	5.72	5.73	5.69
2006	13.24	5.13	5.09	5.29	5.15	5.24
2007	5.58	4.04	3.99	4.12	4.21	4.09
2008	2.84	2.75	2.71	2.77	3.35	2.78
2009	2.54	2.83	2.87	3.00	3.39	3.05
2010	3.77	3.94	3.92	4.10	4.10	4.15
2011	10.34	5.56	5.38	5.56	5.09	5.54
2012	11.65	6.20	5.87	5.93	5.20	5.85
2013	6.37	4.94	4.59	4.63	4.12	4.53
2014	2.45	2.91	2.64	2.74	2.57	2.68
2015	1.65	1.71	1.51	1.63	1.58	1.61
2016	1.12	1.36	1.19	1.30	1.28	1.29
2017	1.38	2.02	1.75	1.87	1.89	1.89
2018	5.02	3.09	2.54	2.69	2.63	2.72
2019	4.92	5.32	3.94	4.13	3.91	4.11
2021	3.34	–	5.34	5.33	5.59	5.31

Table 44. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the model scenarios (model start to 1980).

	female					male				
year	20.07	20.07u	21.22	21.24	21.22a	20.07	20.07u	21.22	21.24	21.22a
1948	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1949	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1950	0.0075	0.0188	0.0264	0.0462	0.0320	0.0045	0.0122	0.0199	0.0326	0.0280
1951	0.1240	0.2019	0.5453	0.9234	0.6775	0.0888	0.1677	0.3880	0.5079	0.4835
1952	0.7972	1.0779	3.0900	6.2967	3.8381	0.8138	1.1724	3.3381	4.1426	3.9581
1953	2.3679	3.0562	8.5382	21.4525	10.6530	3.8420	4.6762	13.8640	19.3374	16.2535
1954	4.3165	5.5199	15.1401	44.8154	18.9716	9.6123	11.1071	31.8466	56.7350	37.5750
1955	6.0027	7.6606	20.8671	68.6695	26.2062	15.3950	17.7424	49.5936	113.5010	59.0892
1956	7.2922	9.2971	25.2294	88.3881	31.7135	19.8578	22.8900	63.1942	170.7443	75.6356
1957	8.2903	10.5620	28.4978	104.0099	35.8291	23.2639	26.7777	73.2462	217.1009	87.7736
1958	9.1169	11.6085	30.9914	116.8549	38.9461	25.9763	29.8432	80.7567	253.5549	96.7360
1959	9.8844	12.5806	32.9624	128.1631	41.3726	28.3402	32.4994	86.5467	283.6198	103.5220
1960	10.7168	13.6423	34.6103	139.0198	43.3489	30.6745	35.1319	91.2124	310.2666	108.8453
1961	11.7946	15.0423	36.1007	150.4241	45.0697	33.3395	38.1958	95.1694	335.9370	113.1884
1962	13.4757	17.2987	37.5835	163.3365	46.7052	37.0201	42.5816	98.8490	363.0374	117.0365
1963	16.6537	21.7160	39.2094	178.7094	48.4182	43.2083	50.3114	102.6498	393.8629	120.8160
1964	23.6227	31.4412	41.1551	197.5710	50.3887	55.8609	66.5867	107.1311	431.0361	125.1118
1965	38.7765	51.9270	43.6617	221.2216	52.8476	82.9262	101.1581	112.2699	480.0837	130.0787
1966	65.7043	86.9988	47.1502	251.3455	56.1627	140.6703	171.0500	118.9792	540.3187	136.2394
1967	100.0610	130.6871	52.3032	289.9797	60.8714	221.1789	265.3656	114.8450	602.4997	130.9337
1968	130.2929	168.8747	61.0447	339.0257	68.5489	311.7031	368.8241	113.2714	682.8845	127.1306
1969	147.8204	191.5394	76.1857	396.7943	81.9619	367.3459	434.5119	102.5888	779.5264	115.1251
1970	153.8629	200.2757	96.7192	453.2465	100.0458	389.6279	463.8937	84.0794	903.3252	85.6610
1971	154.7137	201.8688	139.5897	488.4965	123.3057	394.7758	473.2001	161.3009	1031.3144	86.3904
1972	154.8815	200.1580	185.4747	485.3728	167.2079	397.0575	474.5567	307.6496	1112.1773	181.7150
1973	152.3591	192.9090	211.1249	445.3909	191.6362	397.2309	465.5912	436.8368	1101.6295	312.0744
1974	143.1965	178.4057	208.4726	387.3594	188.2777	378.8504	432.4114	479.5628	996.7265	361.5147
1975	127.7656	159.3151	187.2470	329.6146	170.0300	342.7646	385.9475	450.6081	857.1074	345.0582
1976	108.1072	137.3651	157.9972	276.5042	146.3181	271.0905	311.0516	367.8172	702.6090	284.2637
1977	89.5091	117.1283	130.2583	231.2711	124.1817	187.2805	226.5961	270.3576	556.1303	208.7774
1978	78.0466	105.1068	113.0998	202.0124	110.9672	137.0092	178.4243	207.8565	452.3723	162.7266
1979	75.2712	104.5651	110.9553	196.7385	110.4302	105.9163	155.6109	181.2493	388.6578	143.5125
1980	68.3964	93.7134	97.5742	164.5124	98.5682	97.1181	131.7361	154.6861	270.9206	125.4672

Table 45. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the model scenarios (1981 to model end).

			female					male		
year	20.07	20.07u	21.22	21.24	21.22a	20.07	20.07u	21.22	21.24	21.22a
1981	57.27	76.28	77.30	124.24	79.87	103.24	124.89	139.67	201.27	121.69
1982	44.35	57.75	57.58	90.42	60.72	98.57	112.68	119.66	171.46	110.90
1983	31.45	39.93	39.70	61.17	42.50	77.49	84.66	88.11	132.49	84.49
1984	22.02	27.08	27.01	40.88	29.27	53.24	55.15	57.67	87.89	55.95
1985	19.74	24.38	24.28	37.78	26.45	48.08	50.43	52.57	82.27	52.08
1986	22.64	28.55	28.04	44.34	30.54	54.18	59.71	60.78	93.90	61.18
1987	28.86	36.69	35.03	55.34	38.18	67.80	76.73	76.20	109.08	77.48
1988	36.07	45.79	42.80	67.32	46.59	88.45	100.83	96.62	131.65	99.03
1989	42.25	53.32	49.26	75.58	53.41	97.58	112.53	104.89	147.10	108.18
1990	47.00	58.93	53.41	79.46	57.72	94.40	109.84	100.88	145.75	104.23
1991	48.60	60.49	53.89	78.01	58.04	99.05	115.34	100.98	144.52	104.40
1992	45.23	56.11	49.86	71.20	53.59	91.02	106.84	88.39	130.80	91.48
1993	38.31	47.67	42.82	61.68	46.02	82.00	96.08	77.62	118.15	80.29
1994	30.46	38.04	34.94	51.37	37.64	68.00	80.39	65.90	104.71	68.32
1995	23.68	29.62	27.92	41.66	30.17	53.18	63.12	53.74	89.30	55.83
1996	18.60	23.29	22.33	33.89	24.23	42.70	49.80	43.67	73.68	45.38
1997	15.08	18.94	18.36	28.52	20.00	35.36	40.99	36.80	61.68	38.23
1998	12.96	16.33	15.94	25.27	17.41	31.00	35.78	32.69	54.07	33.96
1999	12.11	15.30	14.97	23.86	16.35	29.72	34.16	31.84	50.60	33.01
2000	12.37	15.58	15.27	24.01	16.62	31.12	35.56	33.61	50.40	34.68
2001	13.42	16.94	16.58	25.83	17.99	34.72	39.40	37.86	53.19	38.86
2002	15.32	19.36	18.89	29.41	20.42	40.43	45.98	44.45	59.77	45.51
2003	18.26	23.05	22.34	34.97	24.07	48.49	55.13	53.71	70.61	54.87
2004	21.93	27.62	26.78	41.83	28.77	59.92	67.80	65.84	85.38	67.08
2005	26.03	32.78	31.88	49.68	34.20	71.64	80.76	79.40	102.89	80.81
2006	30.10	37.80	37.04	57.29	39.65	84.38	94.76	93.18	120.80	94.75
2007	34.13	42.57	41.92	63.27	44.76	95.53	107.21	106.47	138.63	108.16
2008	35.41	44.04	43.47	65.59	46.41	107.55	118.96	118.72	152.49	120.19
2009	32.29	40.14	39.85	61.89	42.66	106.71	118.15	117.51	157.99	119.51
2010	27.47	34.12	34.15	54.47	36.67	93.88	104.05	103.30	150.48	105.57
2011	24.81	30.81	31.02	49.90	33.36	80.36	88.90	88.77	133.76	90.78
2012	27.96	34.34	34.23	52.84	36.71	78.29	86.49	86.85	124.30	88.41
2013	35.27	42.70	41.74	60.53	44.56	94.48	102.59	103.05	130.60	103.95
2014	38.94	46.62	45.30	64.28	48.25	111.32	119.13	118.03	141.73	118.79
2015	35.94	42.60	41.84	59.93	44.53	105.62	112.77	110.79	142.13	112.10
2016	30.00	35.25	35.18	51.04	37.49	93.73	99.18	97.90	134.38	99.31
2017	24.57	28.63	28.99	42.27	30.95	77.18	80.52	80.57	114.68	81.79
2018	20.51	23.72	24.23	35.60	25.93	64.23	65.81	66.78	95.08	67.62
2019	18.43	21.04	21.62	31.65	23.16	56.15	56.89	58.04	81.75	58.73
2020	–	22.74	23.24	32.40	24.81	–	54.13	55.84	74.55	56.34

Table 46. Estimated population size (millions) on July 1 of year. from the model scenarios 20.07u and 21.22a.
<<Table too large: available online in the zip file "TannerCrab.PopSizeStructure.csv.zip".>>

Table 47. Comparison of estimates of recruitment (in millions) from the model scenarios (model start to 1980).

year	20.07	20.07u	21.22	21.24	21.22a
1948	124.69	160.58	408.25	1472.60	502.21
1949	125.09	161.05	408.70	1479.45	502.63
1950	126.04	162.18	409.76	1494.93	503.60
1951	127.78	164.28	411.61	1521.38	505.31
1952	130.66	167.81	414.49	1561.95	507.98
1953	135.24	173.47	418.75	1620.89	511.92
1954	142.45	182.49	424.81	1703.94	517.57
1955	153.93	197.03	433.29	1818.63	525.49
1956	172.84	221.33	445.03	1974.16	536.46
1957	206.07	264.86	461.16	2179.88	551.52
1958	271.42	352.80	483.26	2443.77	572.13
1959	423.87	563.60	513.68	2778.47	600.42
1960	833.53	1130.08	556.47	3209.31	639.99
1961	1804.59	2412.25	619.46	3778.84	697.42
1962	2787.90	3630.15	718.93	4541.37	785.72
1963	2768.39	3568.15	893.33	5533.25	933.91
1964	2250.75	2945.43	1245.73	6642.08	1218.24
1965	1882.06	2528.53	2009.35	7253.59	1840.83
1966	1791.32	2434.29	3339.43	6119.57	3204.27
1967	1922.55	2491.24	4321.21	3582.23	4387.97
1968	1987.32	2247.17	3363.62	2143.44	2767.95
1969	1543.56	1714.51	2008.32	1858.21	1597.85
1970	948.01	1303.78	1192.82	1429.53	1187.02
1971	551.73	850.07	674.41	940.34	751.32
1972	411.86	638.27	436.39	746.48	509.20
1973	491.45	844.08	444.50	994.03	694.27
1974	1083.32	1271.89	1360.55	2790.10	1221.10
1975	1479.69	2448.87	2160.53	3926.71	2244.19
1976	1101.13	1565.17	1487.04	1760.34	1555.35
1977	365.56	588.10	520.13	539.64	616.16
1978	189.07	308.97	302.53	672.72	266.78
1979	154.03	194.13	191.03	288.57	266.84
1980	261.06	356.09	334.30	664.95	313.14

Table 48. Comparison of estimates of recruitment (in millions) from the model scenarios (1981 to model end).

year	20.07	20.07u	21.22	21.24	21.22a
1981	246.58	304.54	237.49	391.93	272.40
1982	753.23	1001.08	885.88	1683.44	940.51
1983	671.37	863.48	647.97	827.30	696.78
1984	679.29	803.85	797.08	985.96	818.43
1985	804.92	1089.52	783.70	1122.99	827.85
1986	779.45	896.80	678.26	515.06	699.57
1987	345.02	458.18	454.83	420.42	451.17
1988	207.93	266.29	193.69	309.45	206.17
1989	47.85	57.85	124.34	82.02	129.72
1990	74.67	91.29	80.45	96.15	85.07
1991	66.26	86.79	82.56	139.44	87.59
1992	76.05	93.12	79.24	139.97	84.17
1993	77.04	98.70	94.77	170.45	104.98
1994	146.50	195.20	163.70	281.21	170.14
1995	125.07	140.03	127.04	161.60	135.98
1996	272.96	362.11	334.03	548.15	345.02
1997	116.34	137.95	111.01	176.45	124.92
1998	491.70	636.54	571.96	1002.44	589.46
1999	190.41	221.74	173.68	221.49	191.26
2000	698.68	911.31	848.66	1340.52	874.35
2001	212.90	253.66	224.44	419.21	250.28
2002	831.84	1051.13	938.80	1182.90	956.58
2003	438.03	558.92	553.22	640.12	580.67
2004	159.93	195.06	175.42	217.58	178.50
2005	111.78	131.75	99.12	100.49	112.51
2006	120.75	143.77	190.01	404.97	195.37
2007	350.91	412.06	272.51	915.40	294.70
2008	1146.14	1452.96	1305.90	1390.82	1352.94
2009	482.03	521.46	486.33	341.60	494.50
2010	207.22	236.29	250.37	283.83	239.47
2011	54.86	55.41	41.70	49.03	65.31
2012	166.76	186.68	177.42	214.65	170.84
2013	79.64	88.66	91.20	136.12	100.86
2014	131.23	137.70	118.85	196.90	122.82
2015	134.59	137.25	135.94	237.24	145.28
2016	1011.05	1013.42	873.33	1334.58	897.02
2017	523.79	425.78	378.97	501.68	402.75
2018	1193.62	774.95	696.02	983.65	686.21
2019	274.48	2.06	1.87	2.67	90.09
2020	–	1242.69	1045.58	1651.48	997.72

Table 49. Comparison of exploitation rates (i.e., catch divided by biomass) from the model scenarios (model start to 1980).

year	20.07	20.07u	21.22	21.24	21.22a
1949	0.00054	0.00053	0.00060	0.00051	0.00058
1950	0.00111	0.00095	0.00114	0.00084	0.00103
1951	0.00196	0.00161	0.00189	0.00131	0.00172
1952	0.00302	0.00253	0.00280	0.00186	0.00261
1953	0.00490	0.00406	0.00462	0.00245	0.00434
1954	0.00774	0.00637	0.00714	0.00338	0.00672
1955	0.01000	0.00843	0.00916	0.00481	0.00873
1956	0.01131	0.00967	0.01035	0.00620	0.00993
1957	0.01157	0.00995	0.01081	0.00697	0.01041
1958	0.01183	0.01019	0.01117	0.00742	0.01078
1959	0.01165	0.01002	0.01129	0.00759	0.01092
1960	0.01130	0.00965	0.01140	0.00766	0.01104
1961	0.01097	0.00922	0.01178	0.00781	0.01144
1962	0.00978	0.00804	0.01212	0.00791	0.01180
1963	0.00848	0.00689	0.01242	0.00797	0.01214
1964	0.00751	0.00613	0.01213	0.00774	0.01191
1965	0.01073	0.00888	0.01358	0.00542	0.01256
1966	0.01081	0.00908	0.01438	0.00557	0.01352
1967	0.03067	0.02601	0.04994	0.01285	0.04665
1968	0.03440	0.02935	0.05773	0.01493	0.05462
1969	0.04537	0.03878	0.09661	0.01963	0.08770
1970	0.04207	0.03598	0.16359	0.01801	0.16630
1971	0.03543	0.03038	0.06276	0.01523	0.20128
1972	0.03222	0.02791	0.03025	0.01402	0.05819
1973	0.03947	0.03392	0.03108	0.01579	0.03840
1974	0.05332	0.04605	0.03989	0.02202	0.04737
1975	0.04804	0.04172	0.03498	0.01992	0.04089
1976	0.07865	0.06719	0.05488	0.03094	0.06309
1977	0.11315	0.09385	0.07578	0.04071	0.08832
1978	0.09454	0.07365	0.05925	0.02938	0.07317
1979	0.12479	0.08296	0.06457	0.02971	0.08222
1980	0.08130	0.06003	0.04958	0.02526	0.05889

Table 50. Comparison of exploitation rates (i.e., catch divided by biomass) from the model scenarios (1981 to model end).

year	20.07	20.07u	21.22	21.24	21.22a
1981	0.0354	0.0278	0.0251	0.0150	0.0255
1982	0.0183	0.0147	0.0139	0.0083	0.0137
1983	0.0089	0.0072	0.0064	0.0037	0.0062
1984	0.0186	0.0155	0.0157	0.0092	0.0150
1985	0.0065	0.0055	0.0063	0.0041	0.0060
1986	0.0083	0.0069	0.0078	0.0051	0.0073
1987	0.0151	0.0127	0.0140	0.0089	0.0132
1988	0.0234	0.0201	0.0225	0.0148	0.0214
1989	0.0626	0.0546	0.0596	0.0420	0.0572
1990	0.1063	0.0945	0.0980	0.0697	0.0944
1991	0.0889	0.0762	0.0848	0.0601	0.0812
1992	0.1146	0.0976	0.1152	0.0818	0.1106
1993	0.0676	0.0600	0.0786	0.0532	0.0753
1994	0.0481	0.0390	0.0476	0.0306	0.0452
1995	0.0399	0.0324	0.0353	0.0213	0.0333
1996	0.0239	0.0244	0.0288	0.0176	0.0272
1997	0.0212	0.0174	0.0176	0.0108	0.0167
1998	0.0143	0.0118	0.0131	0.0081	0.0124
1999	0.0073	0.0059	0.0060	0.0037	0.0057
2000	0.0074	0.0061	0.0067	0.0042	0.0063
2001	0.0084	0.0068	0.0080	0.0050	0.0076
2002	0.0045	0.0036	0.0038	0.0024	0.0036
2003	0.0032	0.0026	0.0021	0.0014	0.0020
2004	0.0040	0.0033	0.0031	0.0020	0.0029
2005	0.0077	0.0081	0.0066	0.0045	0.0063
2006	0.0108	0.0108	0.0116	0.0080	0.0112
2007	0.0133	0.0124	0.0115	0.0082	0.0111
2008	0.0097	0.0097	0.0082	0.0056	0.0080
2009	0.0083	0.0078	0.0063	0.0042	0.0060
2010	0.0041	0.0035	0.0029	0.0019	0.0028
2011	0.0056	0.0048	0.0039	0.0027	0.0038
2012	0.0038	0.0033	0.0027	0.0019	0.0026
2013	0.0112	0.0100	0.0090	0.0066	0.0087
2014	0.0394	0.0360	0.0344	0.0263	0.0335
2015	0.0564	0.0523	0.0514	0.0386	0.0500
2016	0.0073	0.0067	0.0057	0.0041	0.0055
2017	0.0125	0.0126	0.0109	0.0076	0.0106
2018	0.0132	0.0135	0.0115	0.0079	0.0111
2019	0.0035	0.0036	0.0030	0.0021	0.0029
2020	–	0.0086	0.0059	0.0043	0.0057

Table 51. Estimated population abundance (millions) and biomass (1000's t) on July 1, YYYY from the author's preferred model, 21.22a

		abundance			biomass	
	female	male	total	female	male	total
year	(millions)	(millions)	(millions)	(1000's t)	(1000's t)	(1000's t)
1949	251.10	251.10	502.21	2.98	2.99	5.97
1950	449.77	449.76	899.52	7.90	8.35	16.25
1951	606.94	607.02	1,213.96	15.38	17.99	33.37
1952	730.72	731.31	1,462.04	25.68	34.88	60.56
1953	827.07	828.84	1,655.92	37.67	60.94	98.61
1954	901.35	904.62	1,805.97	48.95	91.88	140.83
1955	959.19	963.57	1,922.76	58.02	119.39	177.42
1956	1,005.92	1,010.87	2,016.79	64.92	140.24	205.16
1957	1,046.13	1,051.25	2,097.38	70.22	155.67	225.88
1958	1,083.77	1,088.90	2,172.66	74.41	167.37	241.78
1959	1,122.53	1,127.57	2,250.11	77.93	176.60	254.52
1960	1,166.28	1,171.21	2,337.50	81.11	184.35	265.46
1961	1,219.76	1,224.59	2,444.34	84.27	191.45	275.72
1962	1,289.91	1,294.60	2,584.52	87.76	198.57	286.34
1963	1,388.67	1,393.20	2,781.87	92.00	206.56	298.57
1964	1,539.86	1,544.25	3,084.11	97.66	216.54	314.20
1965	1,800.36	1,804.78	3,605.14	106.05	230.51	336.56
1966	2,315.97	2,320.28	4,636.25	120.16	252.10	372.26
1967	3,402.93	3,406.92	6,809.86	146.70	289.65	436.35
1968	4,849.49	4,839.04	9,688.53	189.75	338.49	528.25
1969	5,175.35	5,146.68	10,322.03	237.71	404.30	642.00
1970	4,831.20	4,759.86	9,591.06	285.24	475.35	760.58
1971	4,297.05	4,110.20	8,407.24	316.98	507.83	824.81
1972	3,585.42	3,280.34	6,865.76	317.32	504.37	821.68
1973	2,984.55	2,722.85	5,707.39	312.10	586.09	898.20
1974	2,594.00	2,379.46	4,973.46	284.61	595.53	880.14
1975	2,552.84	2,364.52	4,917.36	250.60	536.90	787.50
1976	3,056.92	2,896.91	5,953.82	227.84	473.94	701.78
1977	3,124.46	2,972.27	6,096.73	213.79	406.88	620.67
1978	2,715.33	2,557.00	5,272.33	206.65	354.81	561.46
1979	2,219.31	2,069.24	4,288.55	203.81	348.35	552.16
1980	1,820.13	1,669.97	3,490.10	196.95	354.32	551.27

Table 51 (cont.). Estimated population abundance (millions) and biomass (1000's t) on July 1, YYYY from the author's preferred model, 21.22a

	abundance			biomass		
year	female (millions)	male (millions)	total (millions)	female (1000's t)	male (1000's t)	total (1000's t)
1981	1,330.30	1,203.37	2,533.68	149.29	284.87	434.15
1982	990.27	897.47	1,887.74	108.74	225.92	334.66
1983	1,113.69	1,045.57	2,159.26	81.61	167.88	249.49
1984	1,132.64	1,084.45	2,217.09	66.42	127.12	193.54
1985	1,234.31	1,200.67	2,434.98	62.71	109.57	172.28
1986	1,375.76	1,352.80	2,728.56	74.06	134.28	208.33
1987	1,419.81	1,405.19	2,825.00	85.98	165.65	251.63
1988	1,326.20	1,316.96	2,643.16	94.81	196.22	291.03
1989	1,126.37	1,118.72	2,245.09	98.42	216.05	314.47
1990	926.63	908.51	1,835.14	96.43	214.56	310.99
1991	744.36	706.47	1,450.82	88.83	192.43	281.26
1992	601.04	557.14	1,158.18	77.01	166.95	243.96
1993	488.43	434.44	922.87	63.53	128.70	192.23
1994	415.52	365.88	781.40	51.42	100.42	151.83
1995	395.29	354.87	750.16	42.14	80.91	123.05
1996	366.17	334.34	700.50	35.42	67.08	102.51
1997	450.03	425.29	875.32	32.18	59.53	91.71
1998	408.72	389.76	798.48	30.26	56.26	86.52
1999	609.30	595.23	1,204.53	32.40	59.54	91.94
2000	569.20	559.61	1,128.80	34.55	65.40	99.95
2001	878.48	872.29	1,750.76	41.25	77.76	119.01
2002	809.80	806.02	1,615.83	46.59	90.48	137.07
2003	1,107.42	1,106.50	2,213.92	56.10	110.01	166.10
2004	1,152.86	1,154.87	2,307.73	64.94	131.39	196.34
2005	985.11	989.53	1,974.64	71.14	151.57	222.70
2006	816.93	822.69	1,639.62	74.34	168.26	242.60
2007	722.88	728.44	1,451.33	74.21	178.26	252.47
2008	696.90	702.02	1,398.92	70.15	179.42	249.57
2009	1,206.58	1,211.77	2,418.34	69.54	173.91	243.45
2010	1,182.93	1,187.90	2,370.84	68.38	160.56	228.94
2011	1,038.73	1,044.17	2,082.91	70.23	154.65	224.88
2012	836.97	843.46	1,680.43	73.81	161.78	235.59
2013	727.27	736.14	1,463.41	75.84	179.09	254.93
2014	603.05	611.90	1,214.95	71.42	186.49	257.90
2015	516.26	516.28	1,032.54	62.12	166.78	228.90
2016	461.72	451.04	912.77	52.23	133.61	185.83
2017	797.90	790.65	1,588.55	48.68	117.06	165.74
2018	819.23	813.65	1,632.88	47.20	105.06	152.26
2019	979.42	975.08	1,954.51	51.07	103.47	154.53
2020	807.90	806.45	1,614.36	55.54	111.28	166.82
2021	1,124.00	1,125.19	2,249.19	65.16	133.00	198.16

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.

case	average recruitment millions	Bmsy (1000's t)	current MMB (1000's t)	Fmsy per year	MSY (1000's t)	Fofl per year	OFL (1000's t)	projected MMB (1000's t)	status ratio
20.07	374.43	36.77	66.87	0.98	16.94	0.94	21.13	35.33	0.96
20.07u	422.96	36.22	80.13	1.23	17.17	1.23	26.14	41.93	1.16
21.22	371.33	34.90	81.98	1.11	16.03	1.11	26.68	43.14	1.24
21.24	517.18	45.45	94.37	1.55	19.65	1.55	33.14	48.62	1.07
21.22a	396.90	36.27	82.27	1.19	16.84	1.19	27.20	42.78	1.18

Figures

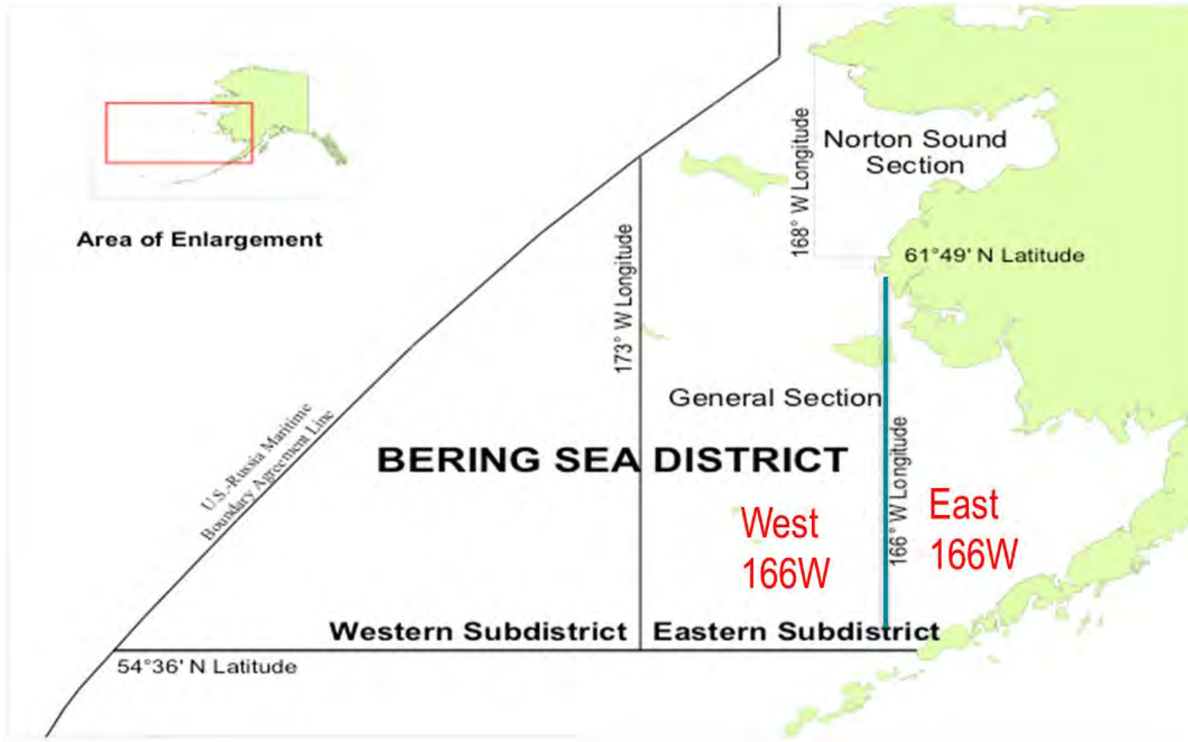

Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

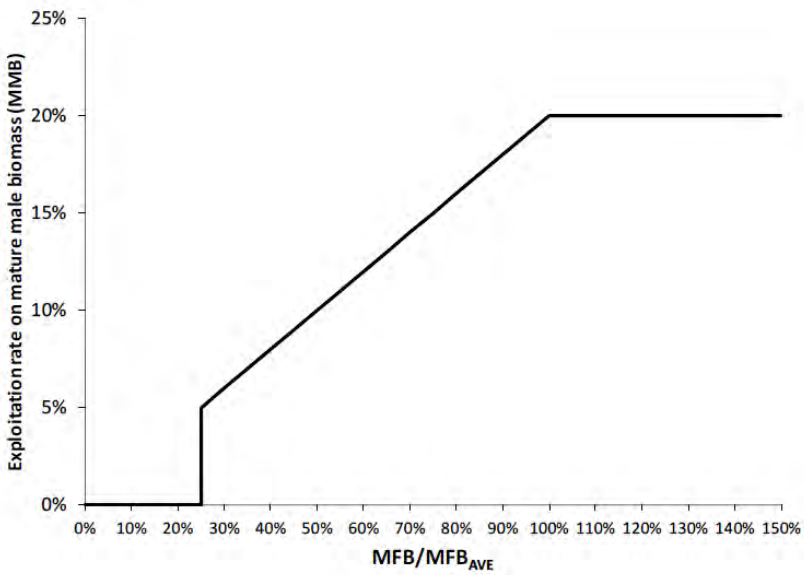

Figure 2. Sloping control rule used by ADFG from 2011 to 2019 as part of its TAC setting process to determine the maximum exploitation rate on mature male biomass as a function of the ratio of current mature female biomass (MFB) to MFB averaged over some time period.

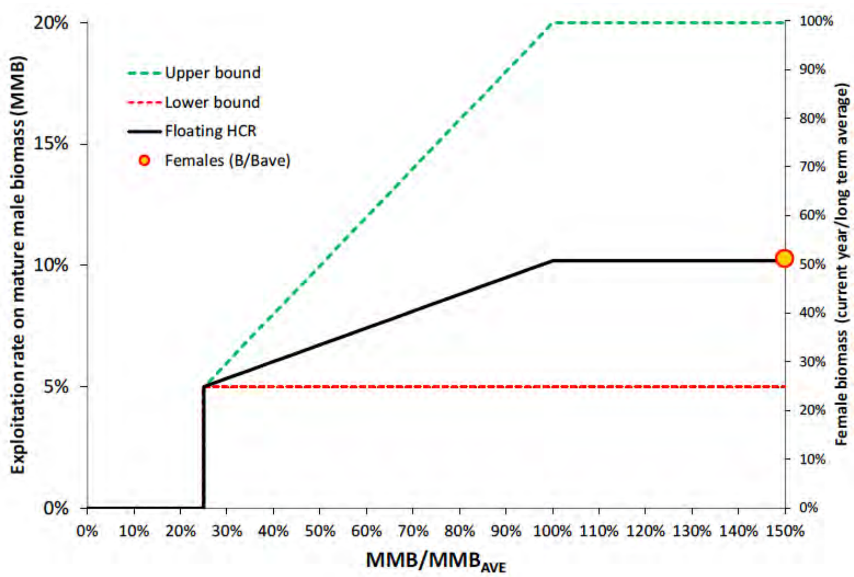

Figure 3. New ADFG "floating" sloping control rule to determine the maximum exploitation rate on mature male biomass (MMB) as a function of the ratio of current MMB to the average MMB over 1982-2018. The ratio of current mature female biomass (MFB) to MFB averaged over 1982-2018 is used to determine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

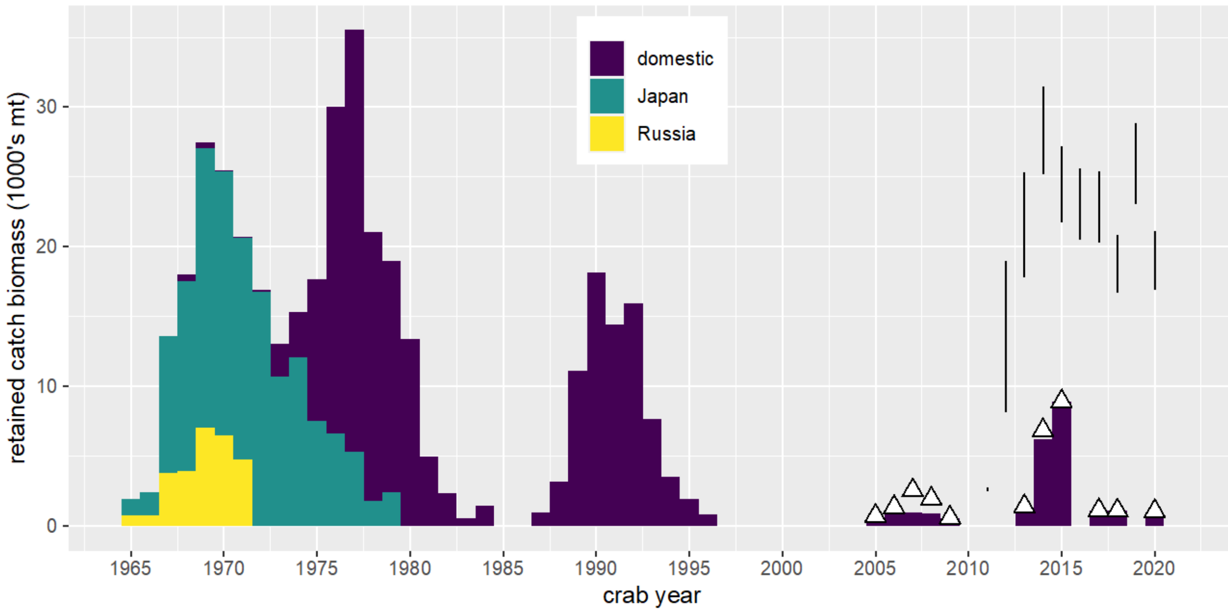

Figure 4. Total retained catch (males, 1000’s t) in the directed fisheries (foreign [1965-1979] and domestic [1968-]) for Tanner crab. The bars indicate the OFL and ABC (upper and lower limits, respectively; values start in 2011/12); the triangles indicate the TAC (values start in 2005/06, following rationalization).

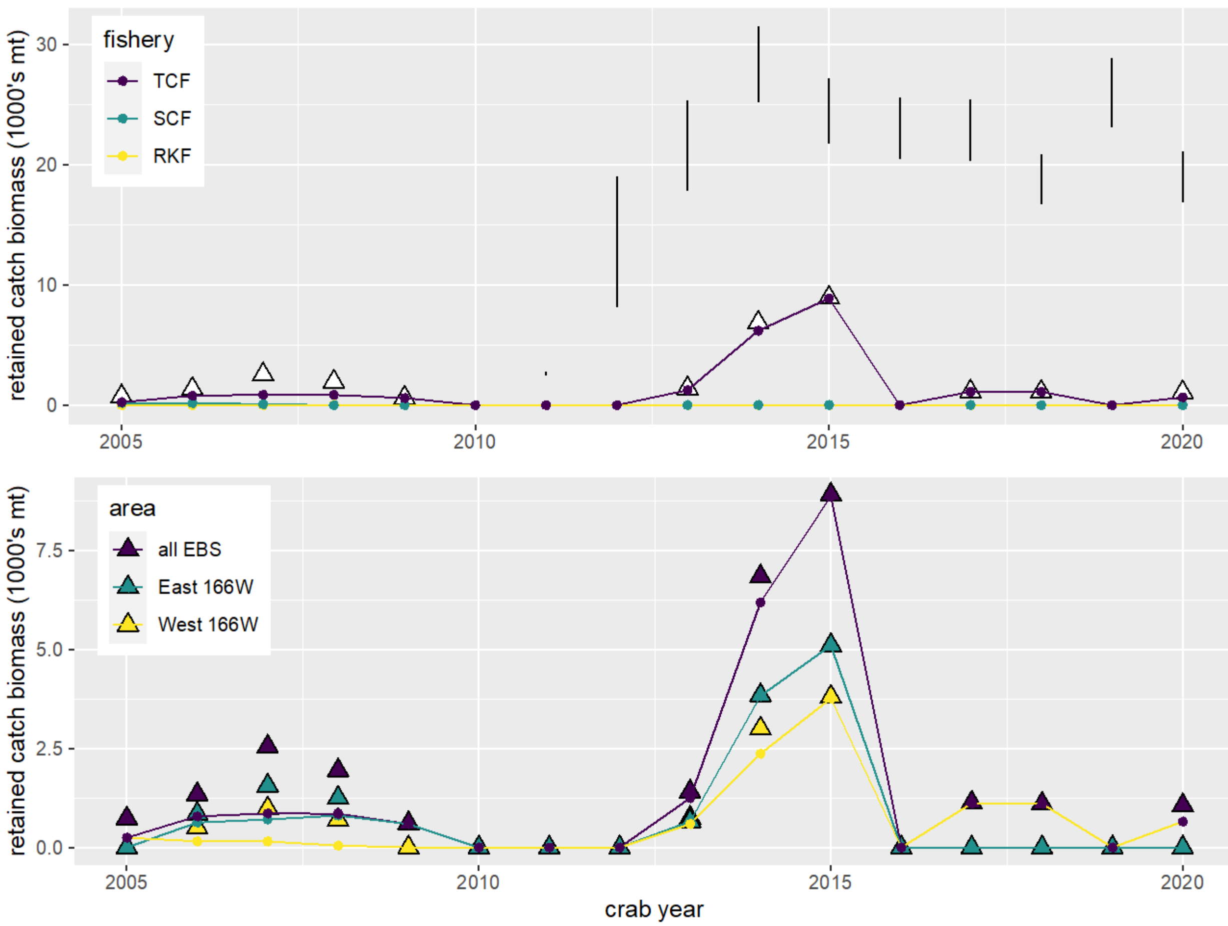

Figure 5. Upper plot: time series of retained catch biomass (1000's t) in the directed Tanner crab (TCF), snow crab (SCF), and BBRKC (RKF) fisheries since 2005. The bars indicate the OFL and ABC (upper and lower limits, respectively; values start in 2011/12); the triangles indicate the total (area-combined) TAC. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch. Lower plot: retained catch biomass (1000's t) by SOA management area. The triangles indicate the area-combined ("all EBS") and area-specific ("East 166W", "West 166W") TACS. The directed fisheries in both SOA management areas were both closed from 2010/11 to 2012/13, as well as in 2016/17 and 2019/20. The directed fishery in the eastern area was also closed in 2005/06, 2017/18, 2018/19, and 2020/21.

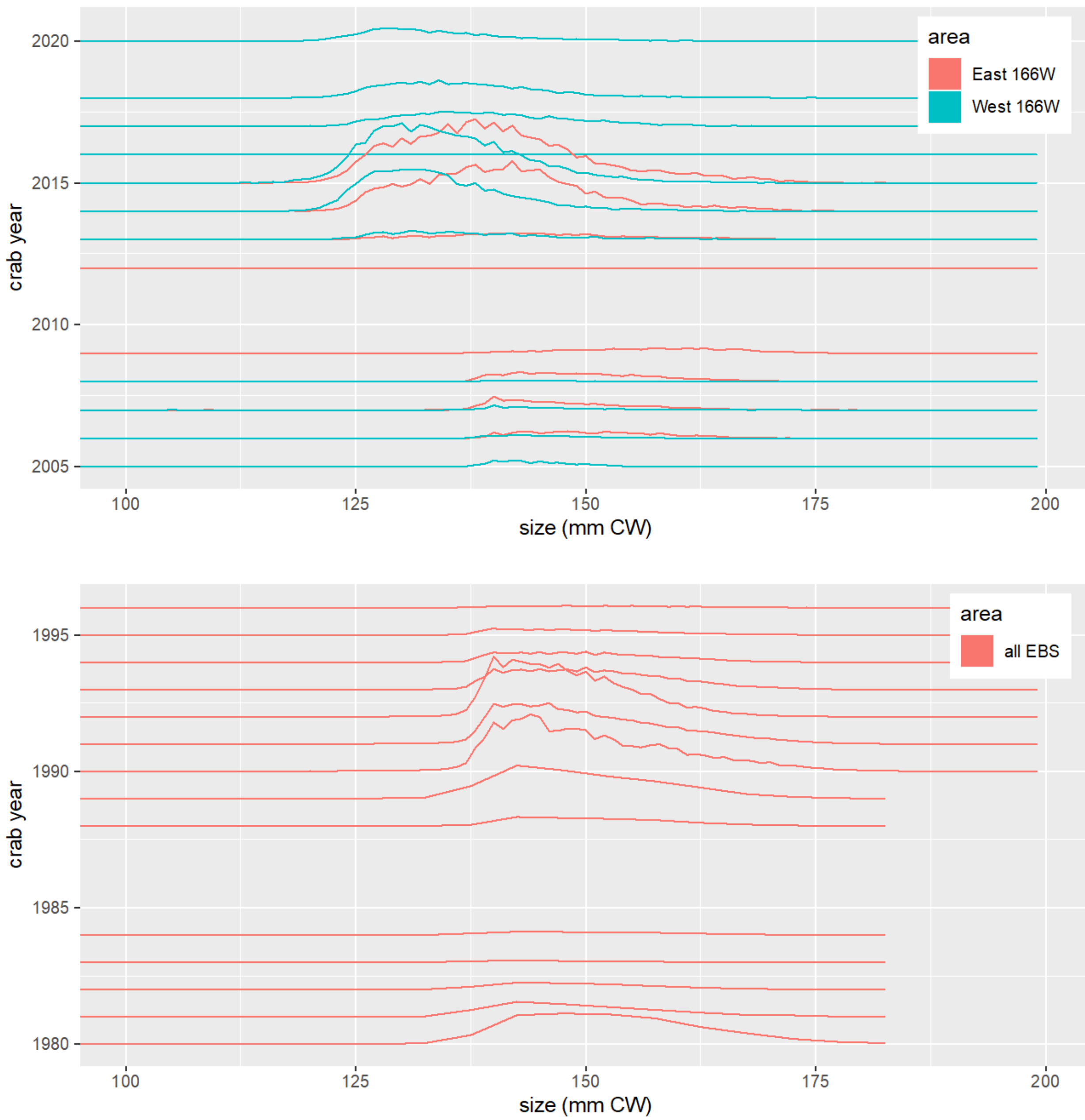

Figure 6. Upper plot: retained catch size compositions in the directed fishery by State management area since rationalization (2005). Lower plot: retained catch size compositions in the directed fishery prior to rationalization (aggregated across management areas). The directed fishery was closed from 1996/97 to 2004/05. The relative height of each size composition reflects retained catch abundance for the associated crab fishery year relative to others within the same plot, but scales differ between the two plots.

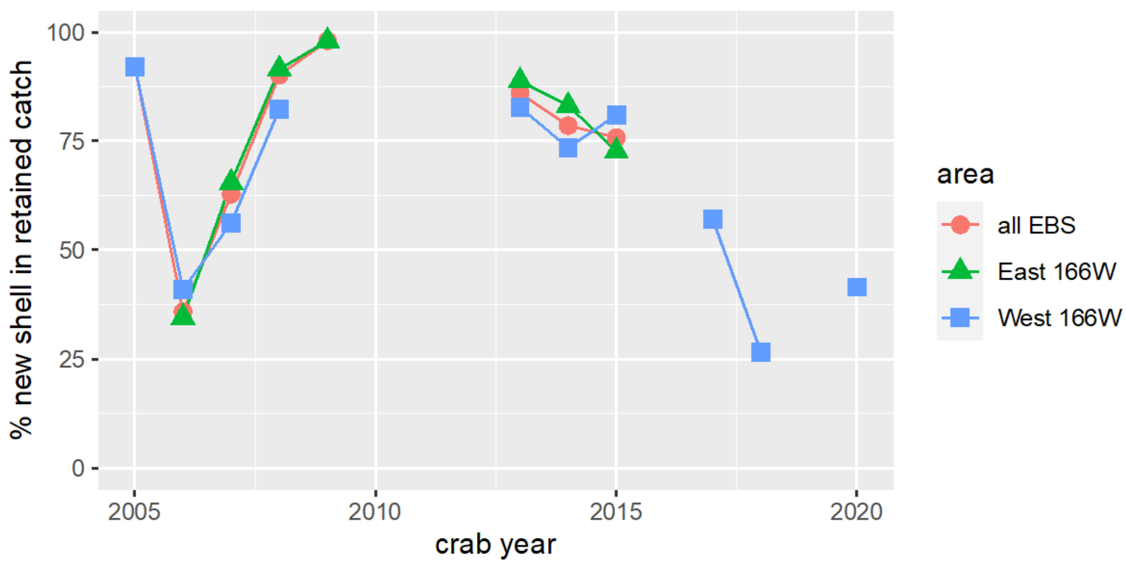

Figure 7. The fraction of new shell males to all males in the retained catch for the directed fishery.

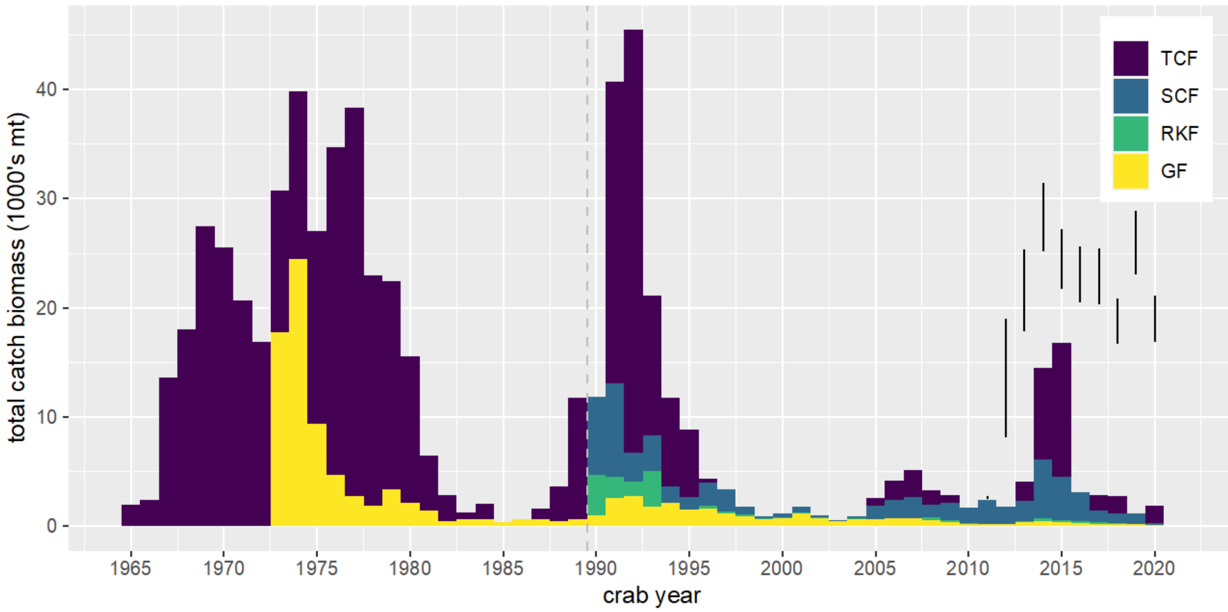

Figure 8. Total catch (retained + discards) estimates for Tanner crab (males and females combined, 1,000’s t) in the directed Tanner crab (TCF), snow crab (SCF), Bristol Bay red king crab (RKF), and groundfish fisheries (GF). The bars indicate the OFL and ABC (upper and lower limits, respectively; values start in 2011/12). Bycatch reporting began in 1973 for the groundfish fisheries and in the 1990/91 for the crab fisheries. **Discard mortality has not been applied to this data** (see Figure 7).

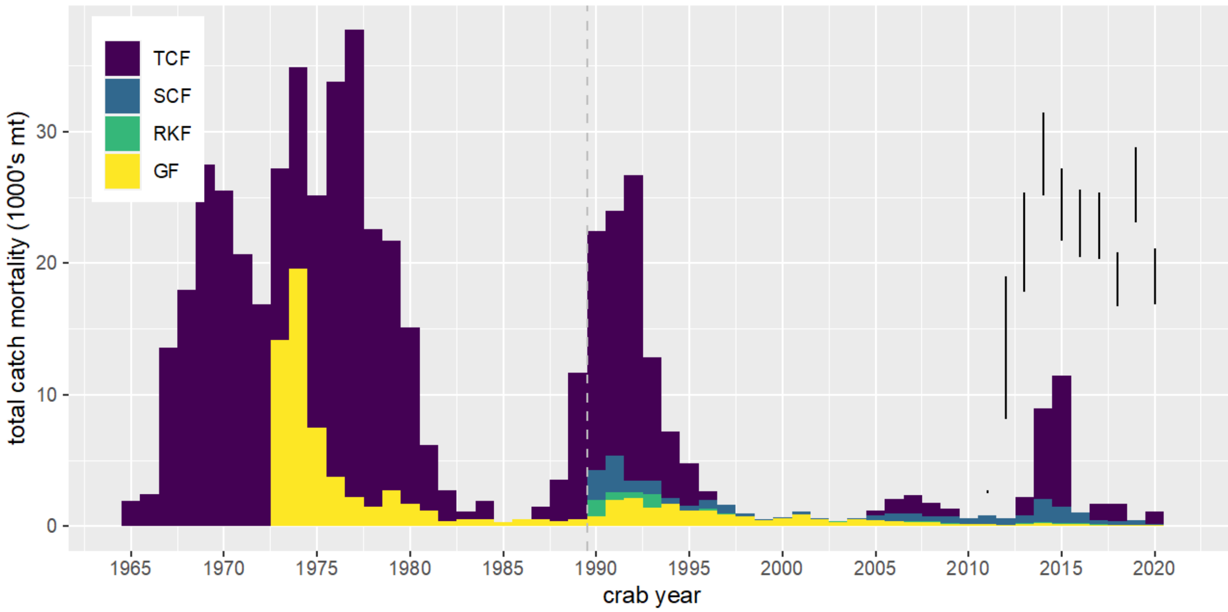

Figure 9. Total catch (retained + discards) mortality estimates for Tanner crab (males and females combined, 1,000's t) in the directed Tanner crab (TCF), snow crab (SCF), Bristol Bay red king crab (RKF), and groundfish fisheries (GF). The bars indicate the OFL and ABC (upper and lower limits, respectively; values start in 2011/12). Bycatch reporting began in 1973 for the groundfish fisheries and in 1990/91 for the crab fisheries. Assumed discard mortality rates were applied to discards by gear type (0.321: crab pots and fixed gear in the groundfish fisheries; 0.800: trawl gear in the groundfish fisheries) to estimate total catch mortality. For the directed fishery ("TCF"), annual "discard" mortality was estimated by subtracting the retained catch biomass from the total catch to estimate discards prior to applying handling mortality.

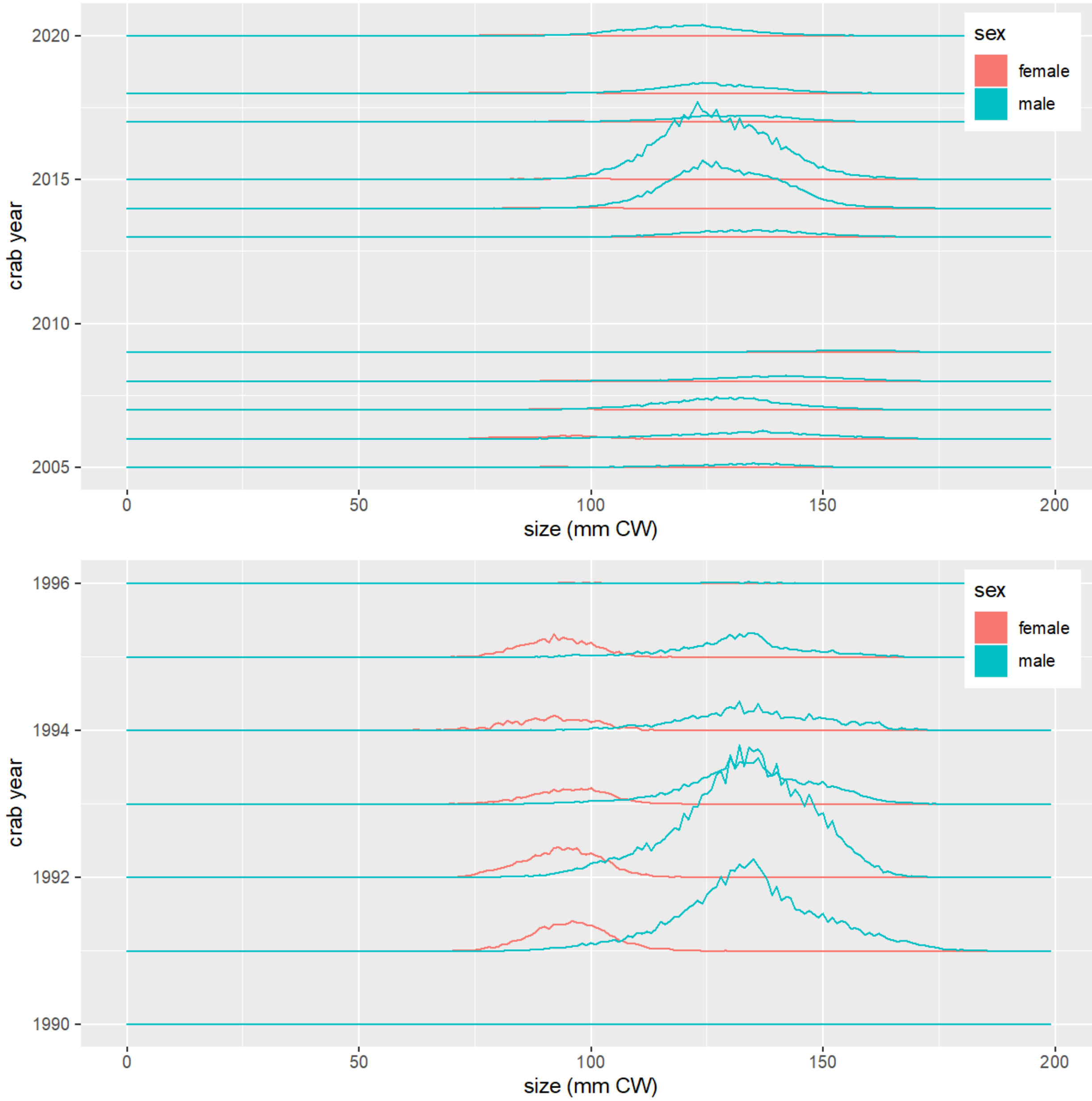

Figure 10. Total catch size compositions in the directed fishery by sex (aggregated over State management area). Data starts in 1991. Upper plot: since rationalization (2005). Lower plot: total catch size compositions in the directed fishery prior to rationalization (aggregated across management areas). The directed fishery was closed from 1996/97 to 2004/05. The relative height of each size composition reflects total catch abundance by sex for the associated crab fishery year relative to others within the same plot, but scales differ between the two plots.

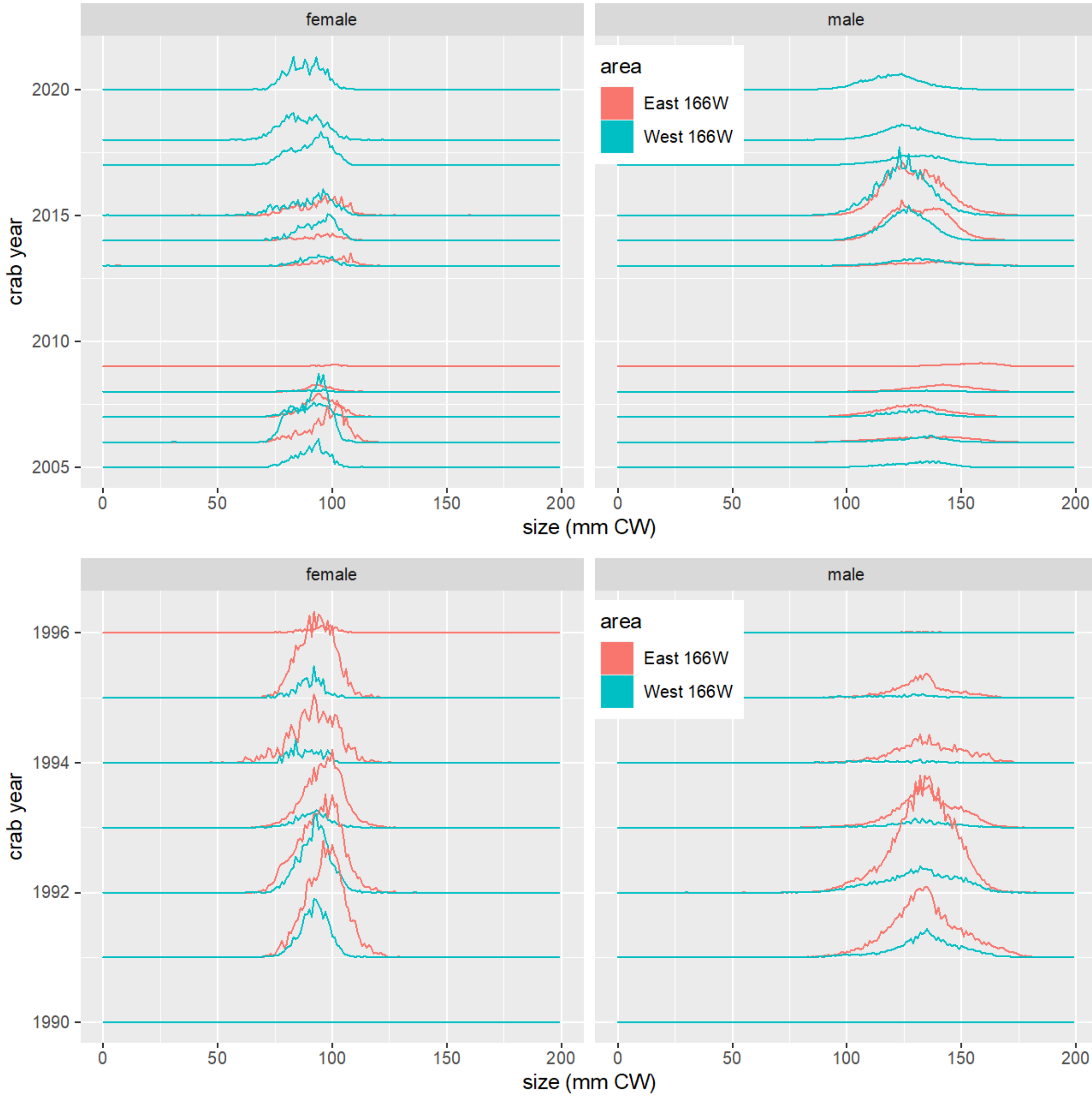

Figure 11. Total catch size compositions in the directed fishery by sex and State management area (1991+). Upper plots: since rationalization (2005). Lower plot: prior to rationalization. The directed fishery was closed from 1996/97 to 2004/05. The relative height of each size composition reflects total catch abundance by sex for the associated crab fishery year relative to others within the same plot panel, but scales differ between the panels to better show details within a panel.

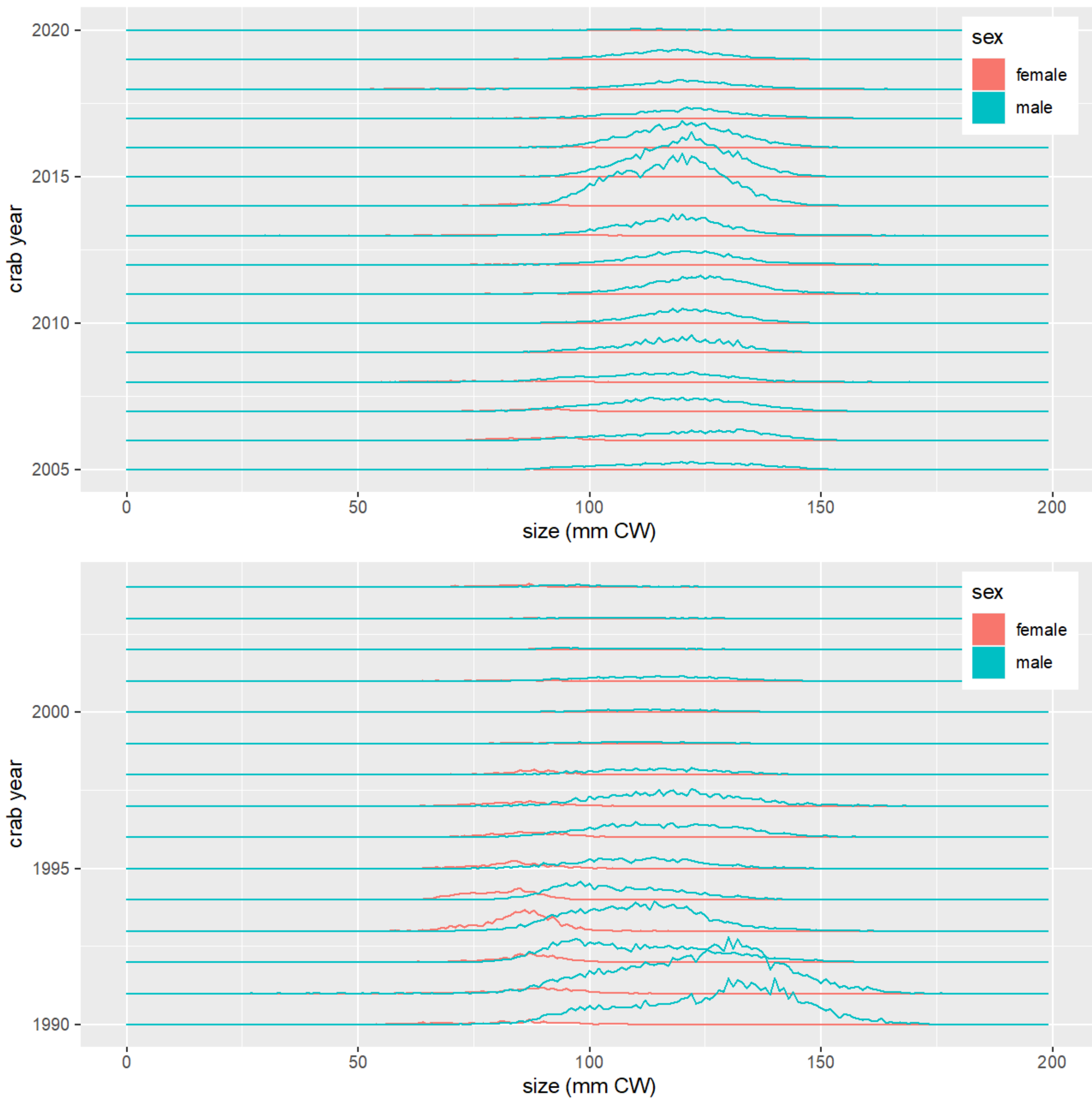

Figure 12. Total bycatch size compositions in the snow crab fishery by sex (1990+). Data starts in 1990. Upper plots: since rationalization (2005). Lower plot: prior to rationalization. The relative height of each size composition reflects total bycatch abundance by sex for the associated crab fishery year relative to others within the same plot, but scales differ between the plots to better show details within a plot.

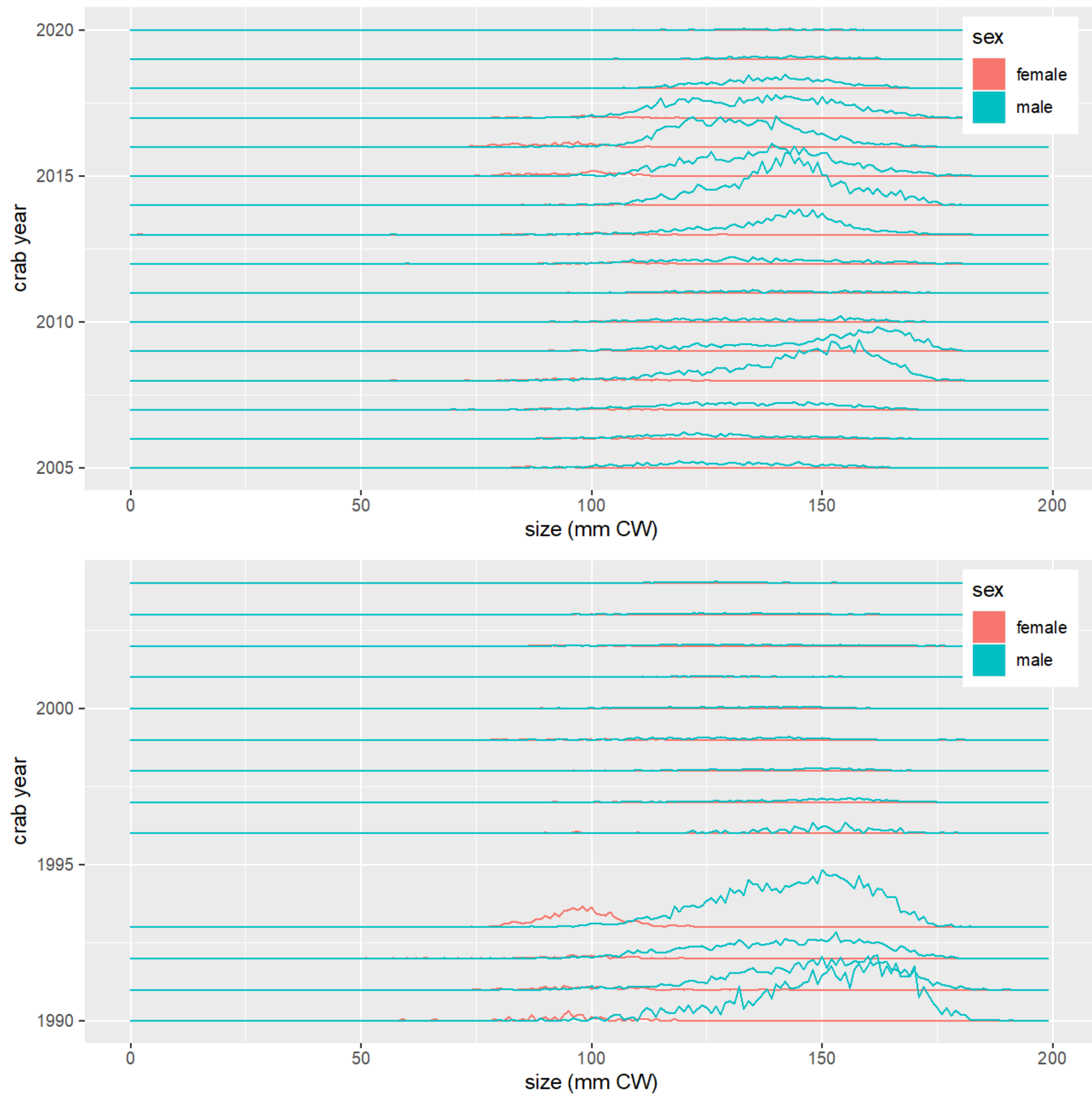

Figure 13. Total bycatch size compositions in the BBRKC fishery by sex (1990+). Data starts in 1990. Upper plots: since rationalization (2005). Lower plot: prior to rationalization. The BBRKC fishery was closed in19964/95 and 1995/96. The relative height of each size composition reflects total bycatch abundance by sex for the associated crab fishery year relative to others within the same plot, but scales differ between the plots to better show details within a plot.

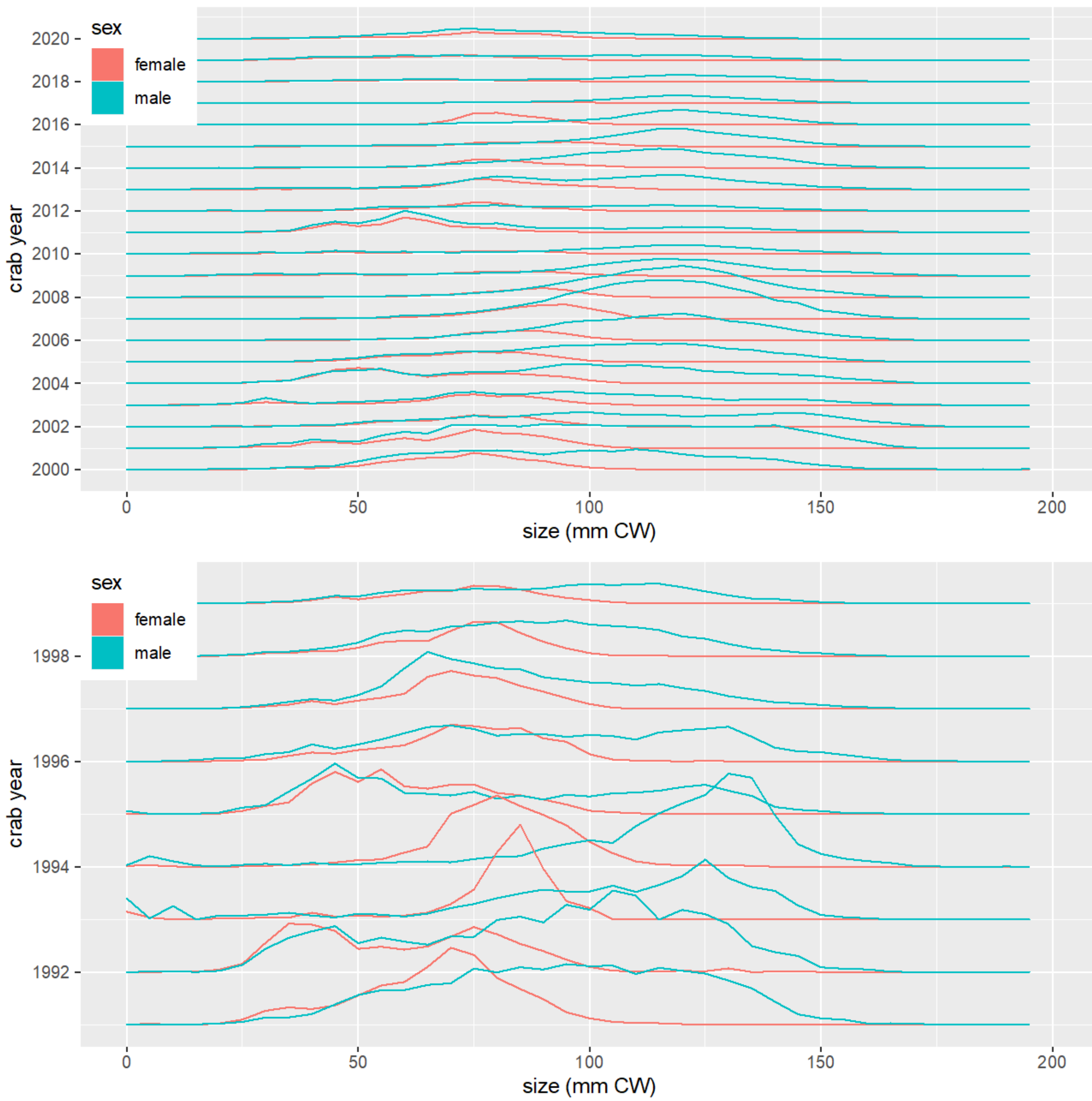

Figure 14. Total bycatch size compositions in the groundfish fisheries by sex (1991+). Upper plots: since 2000/01. Lower plot: prior to 2000/01. The relative height of each size composition reflects total catch abundance by sex for the associated crab fishery year relative to others within the same plot panel, but scales differ between the panels to better show details within a panel.

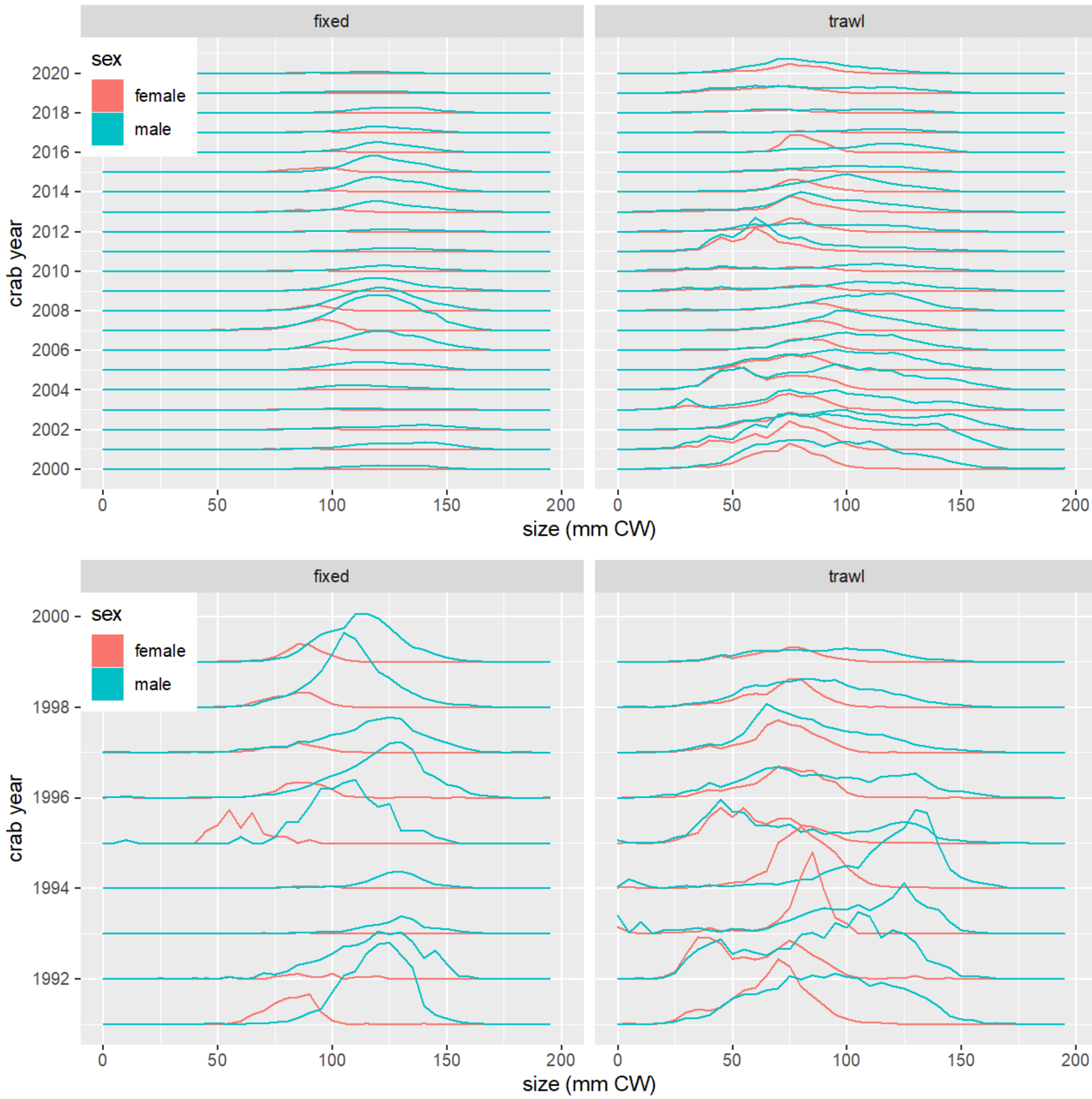

Figure 15. Total bycatch size compositions in the groundfish fisheries by sex and gear type (1991+). Upper plots: since rationalization (2005). Lower plot: prior to rationalization. The relative height of each size composition reflects total catch abundance by sex for the associated crab fishery year relative to others within the same plot panel, but scales differ between the panels to better show details within a panel.

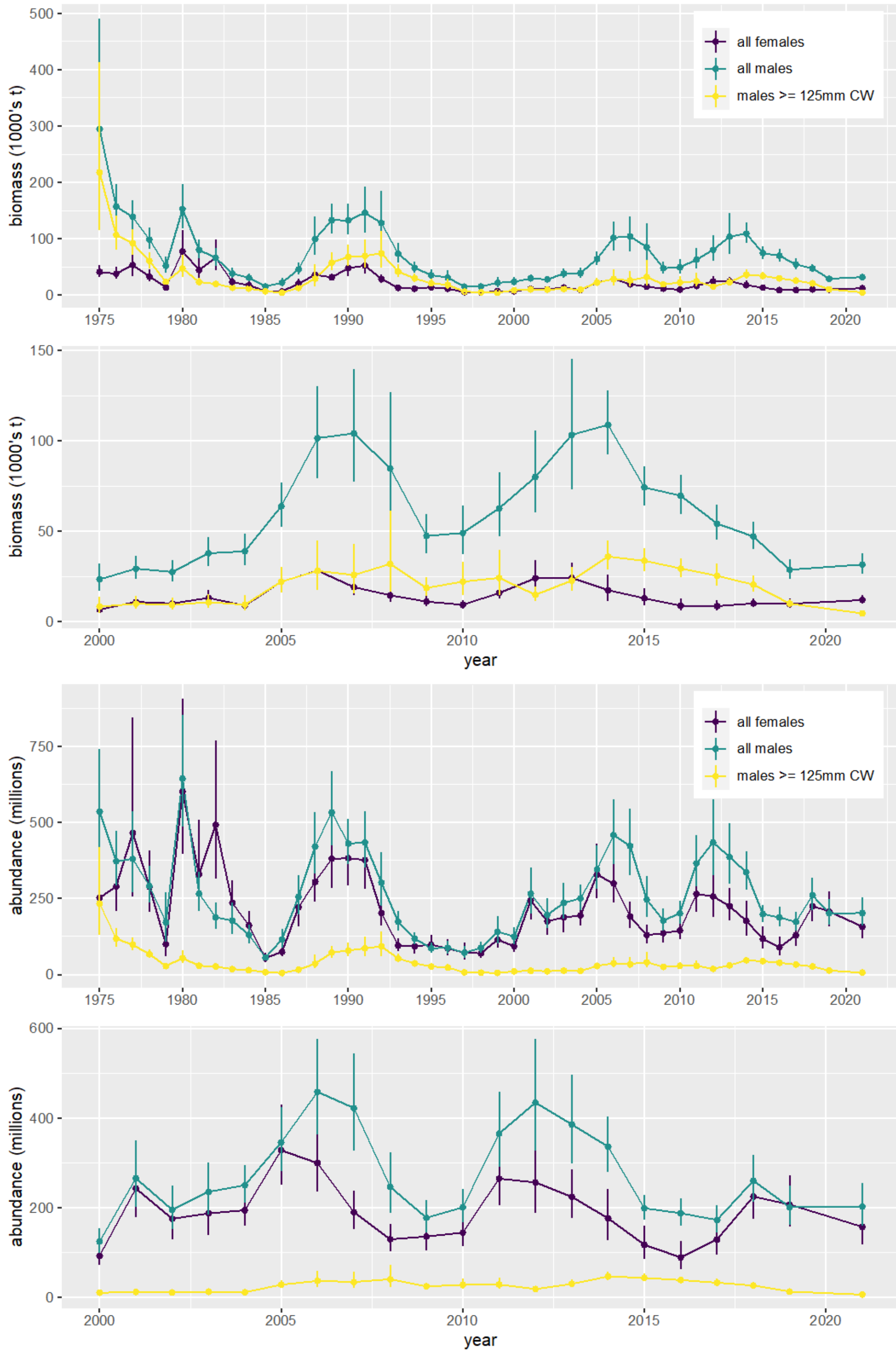

Figure 16. Annual estimates of area-swept biomass (upper plots) and abundance (lower plots) from the NMFS EBS bottom trawl survey by sex. The lower plot in each pair shows the trends since 2000. The biomass/abundance trends for industry-preferred size males are also shown.

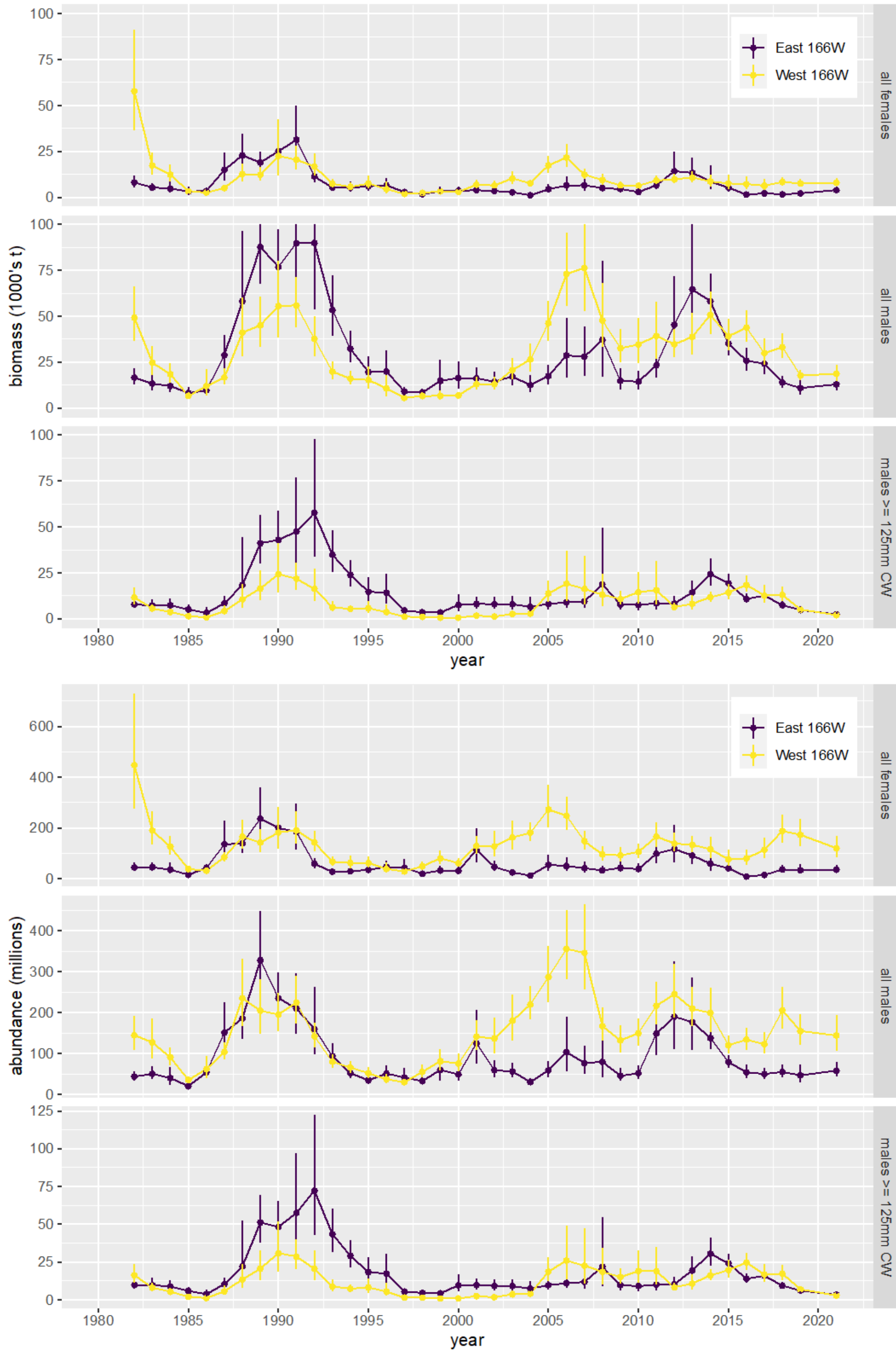

Figure 17. Annual estimates of area-swept biomass (upper plots) and abundance (lower plots) from the NMFS EBS bottom trawl survey by State management area, sex, and maturity state (for females). The biomass/abundance trends for industry-preferred size males are also shown.

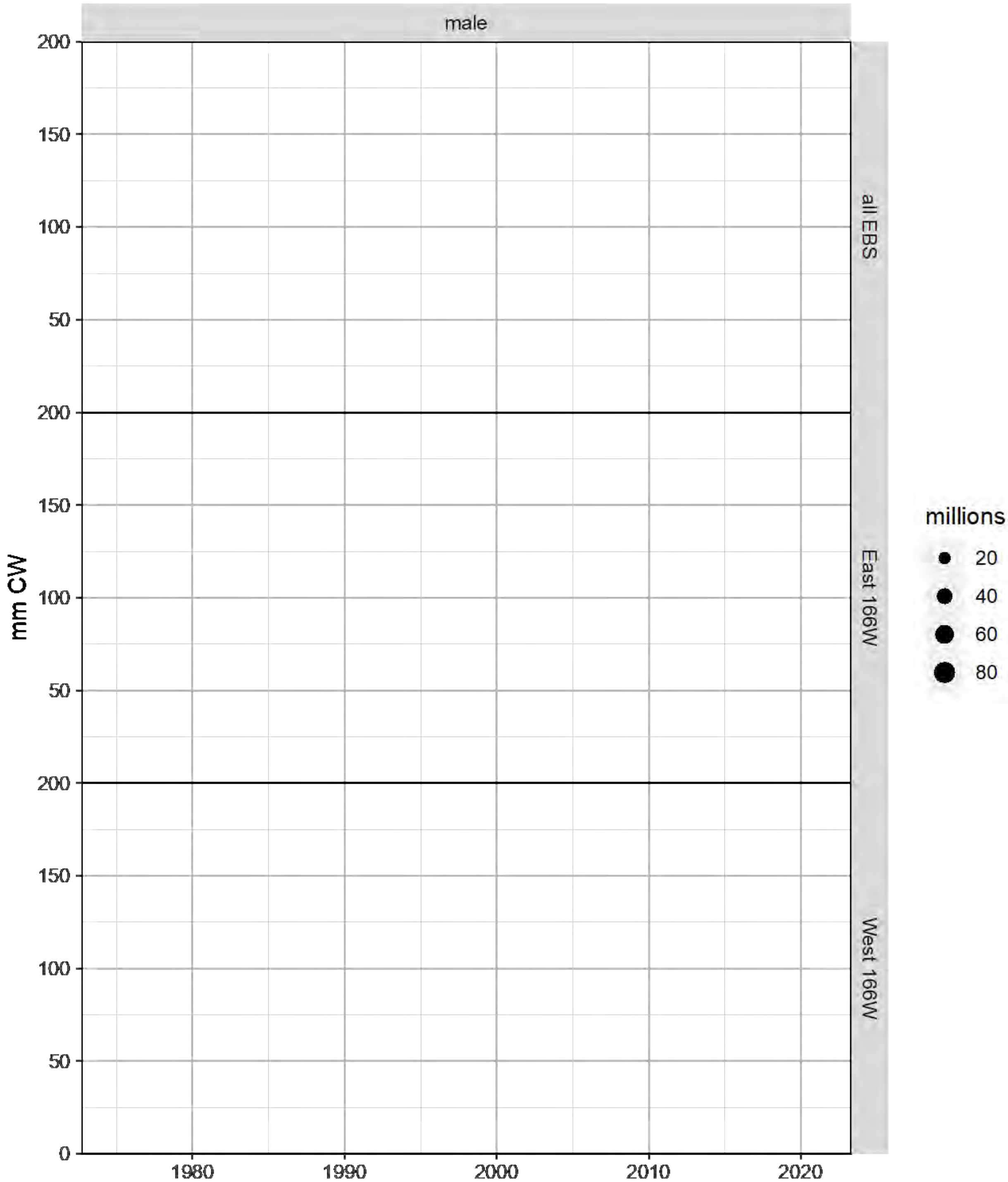

Figure 18. Annual size compositions, by 5-mm CW bin, from the NMFS EBS bottom trawl survey for males by State management area for 1975-2000. The size compositions are truncated for crab < 25 mm CW. The assessment model aggregates crab > 185 mm CW into the 180-185 mm CW bin.

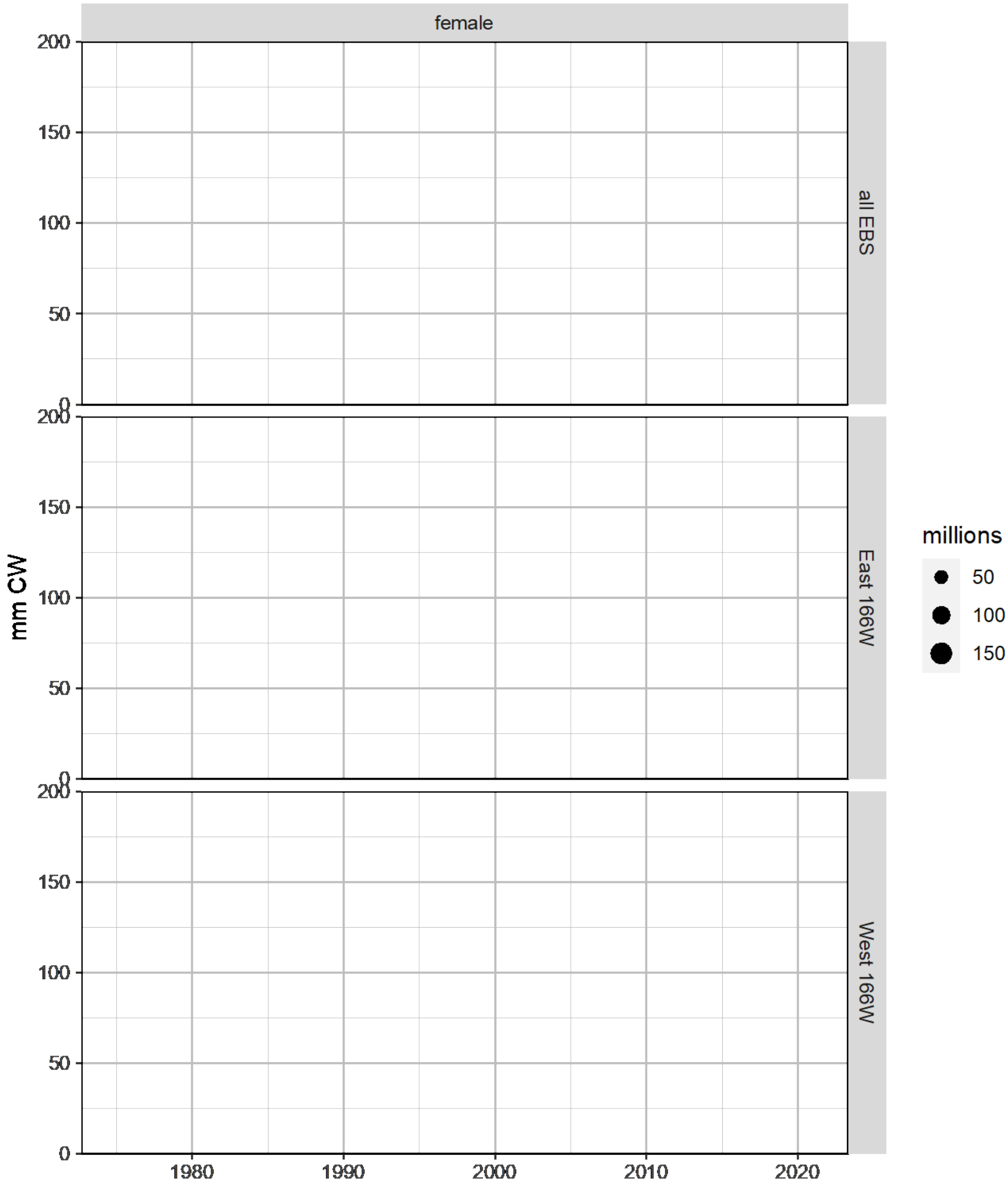

Figure 18 (cont.). Annual size compositions, by 5-mm CW bin, from the NMFS EBS bottom trawl survey for females by State management area for 1975-2000. The size compositions are truncated for crab < 25 mm CW. The assessment model aggregates crab > 185 mm CW into the 180-185 mm CW bin.

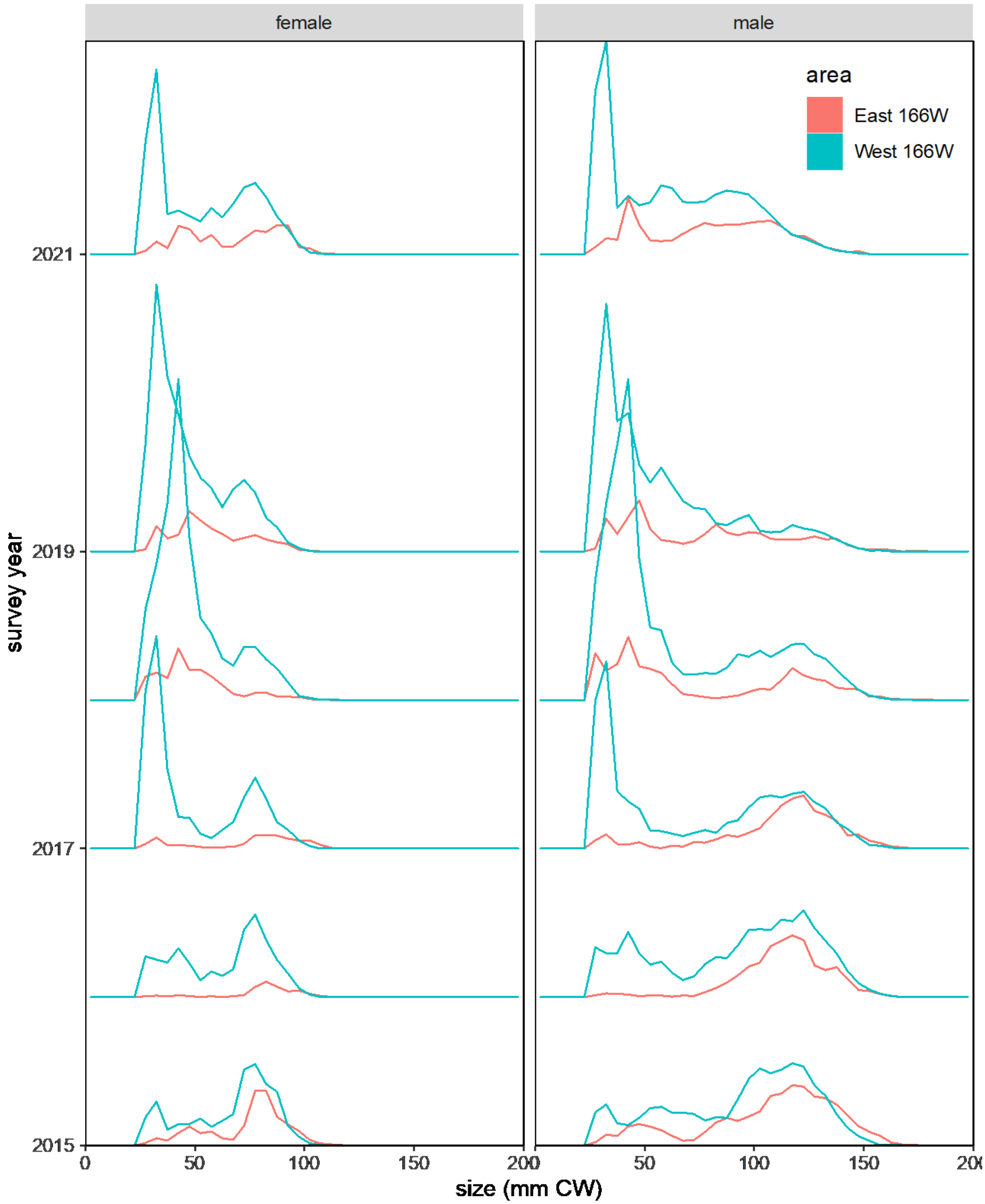

Figure 19. Recent annual size compositions, by 5-mm CW bin, from the NMFS EBS bottom trawl survey by sex and State management area for 1975-2000. The size compositions are truncated for crab < 25 mm CW. The assessment model aggregates crab > 185 mm CW into the 180-185 mm CW bin.

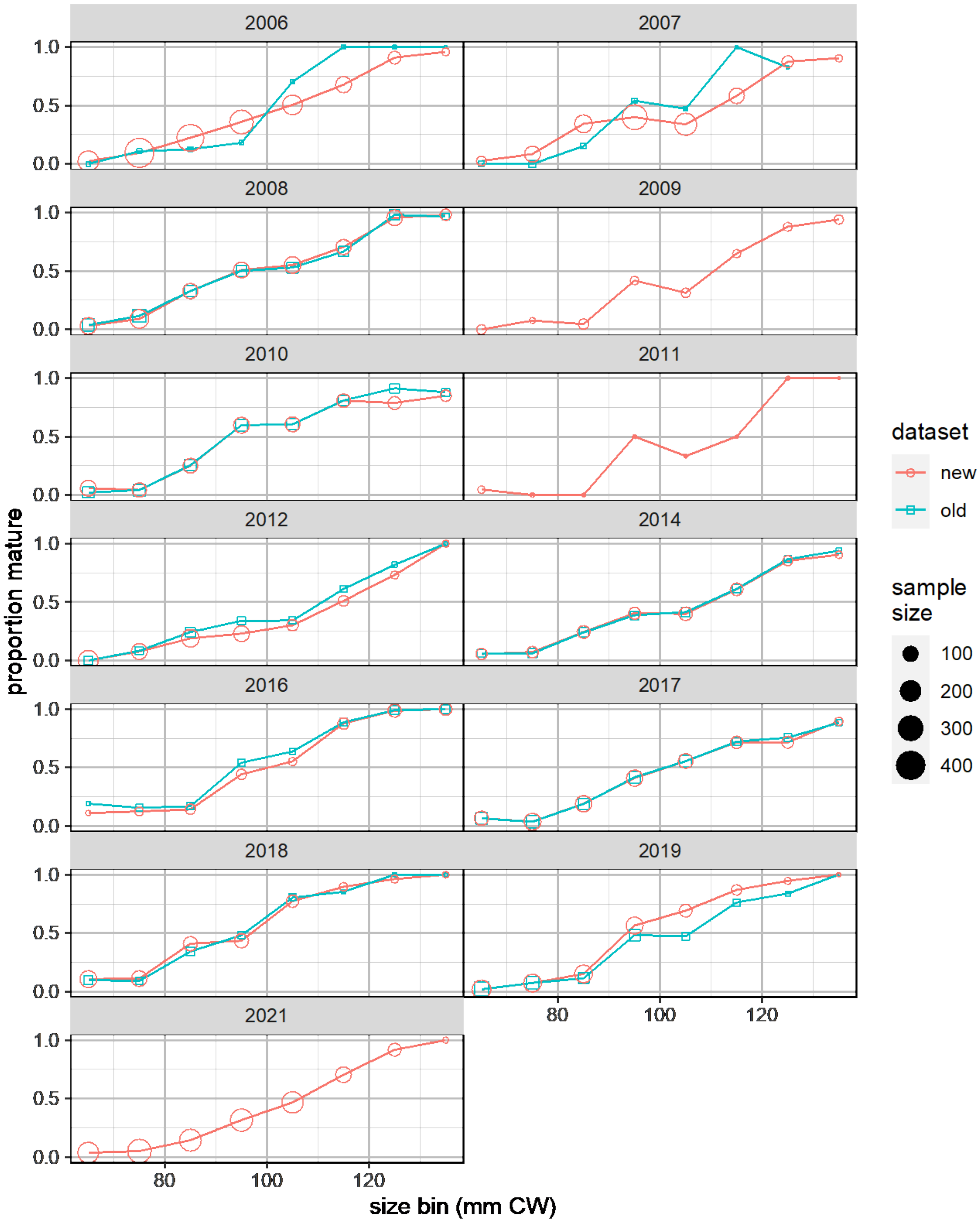

Figure 20. Male maturity ogives (the fraction of new shell mature males, relative to all new shell males) from the NMFS EBS bottom trawl survey as determined from chela height:carapace width ratios for years when chela heights were collected with 0.1 mm precision. The “old” dataset was used in the 2020 assessment. The “new” dataset is based on a revised size-specific cutline analysis and additional data not included in the “old” dataset (J. Richar, NMFS Kodiak, pers. comm.).

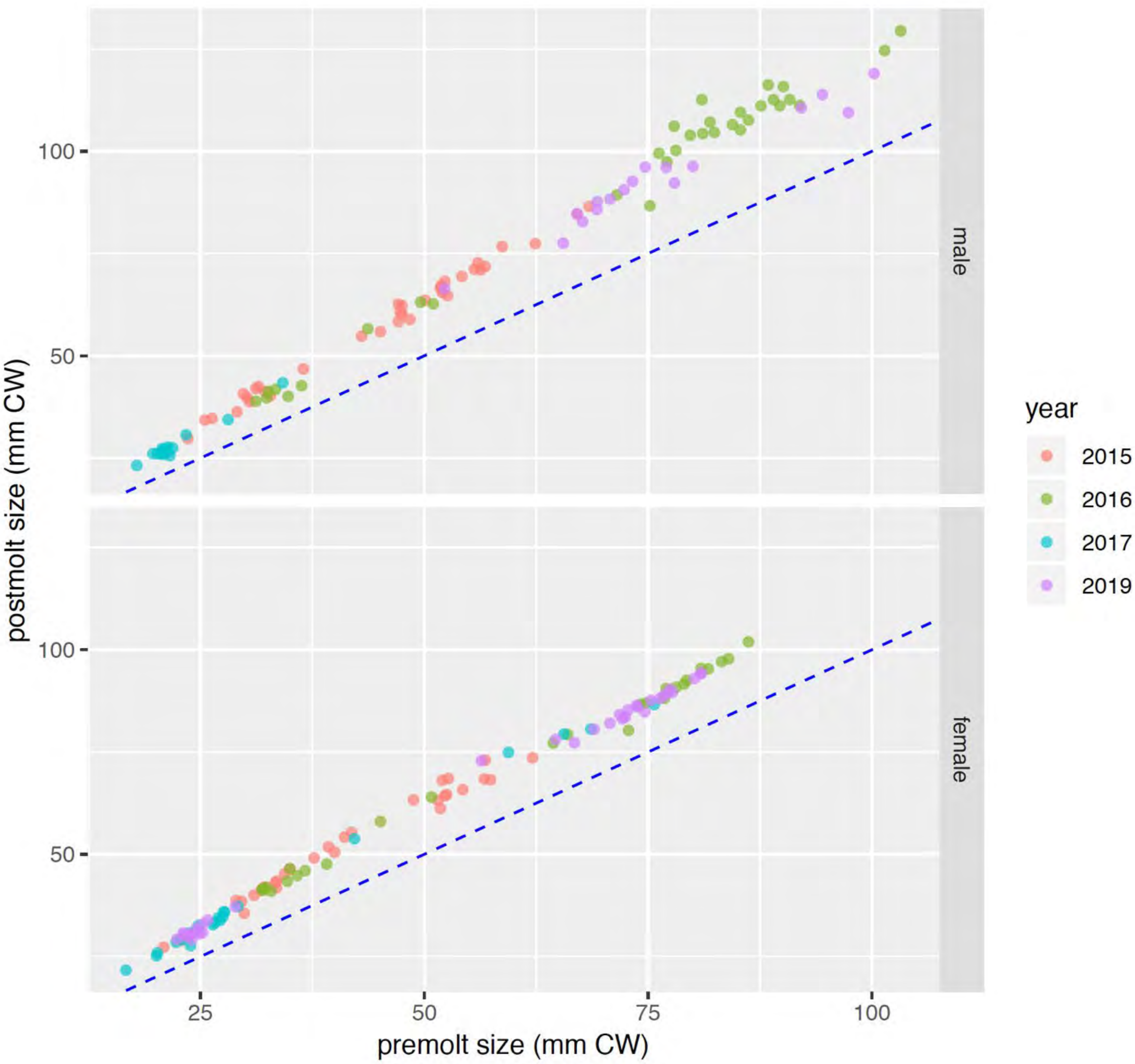

Figure 21. Molt increment data collected collaboratively by NMFS, BSFRF, and ADFG.

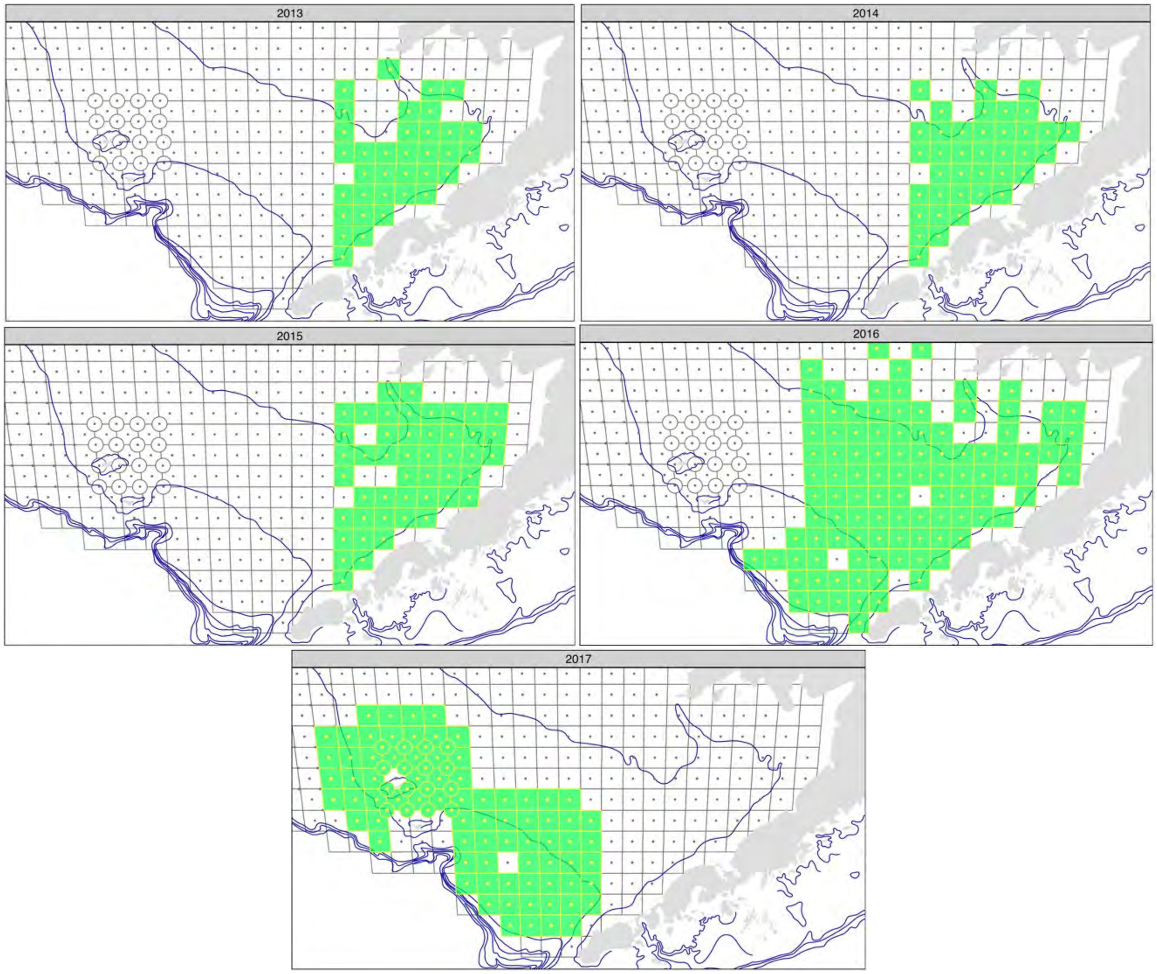

Figure 22. Spatial footprints (stations occupied in green) during the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. Squares and circles represent stations in the standard NMFS EBS bottom trawl survey (which extends beyond the area shown in the maps).

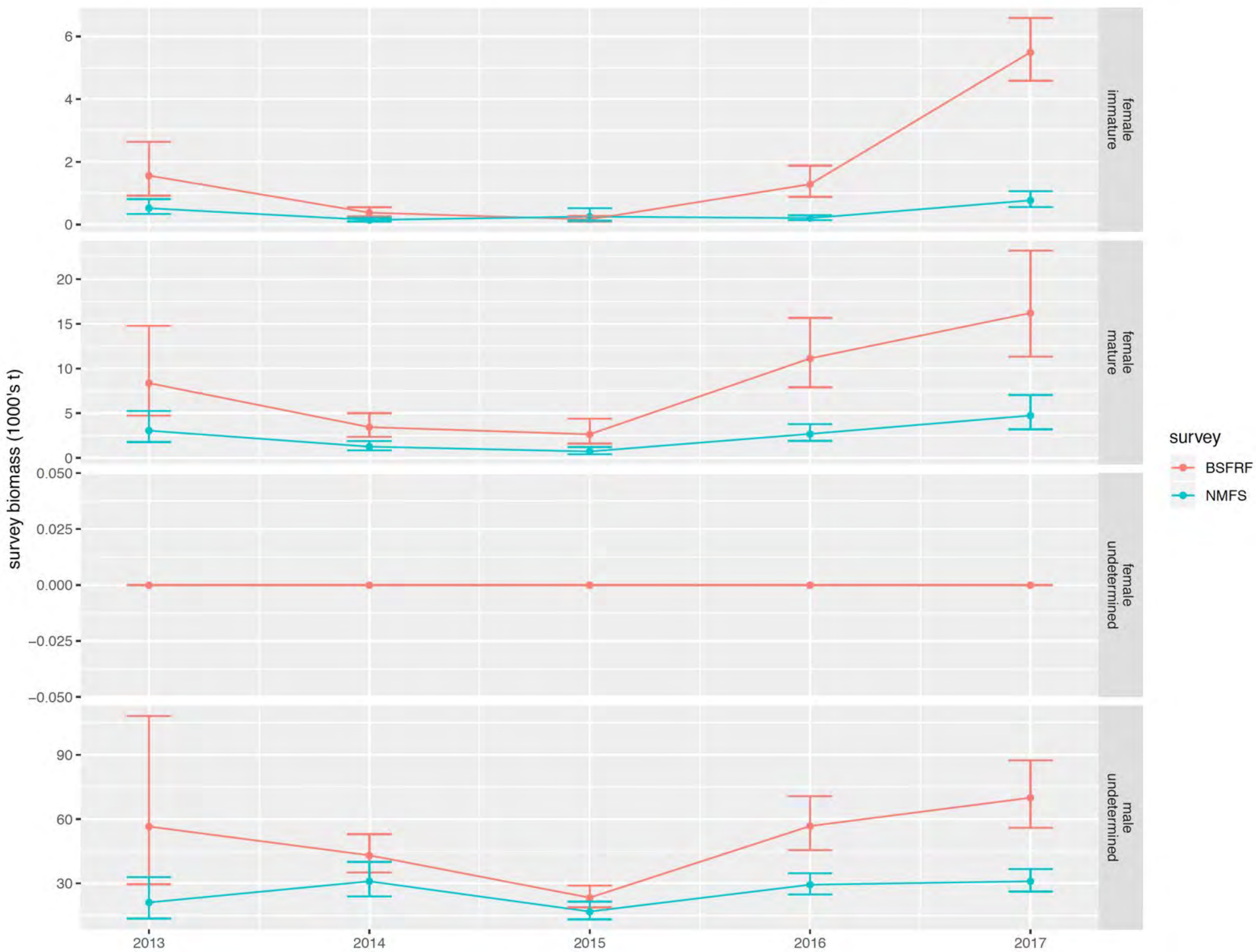

Figure 23. Annual estimates of area-swept biomass from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. The SBS studies had different spatial footprints each year, so annual changes in biomass do not necessarily reflect underlying population trends. Red lines: BSFRF; green lines: NMFS.

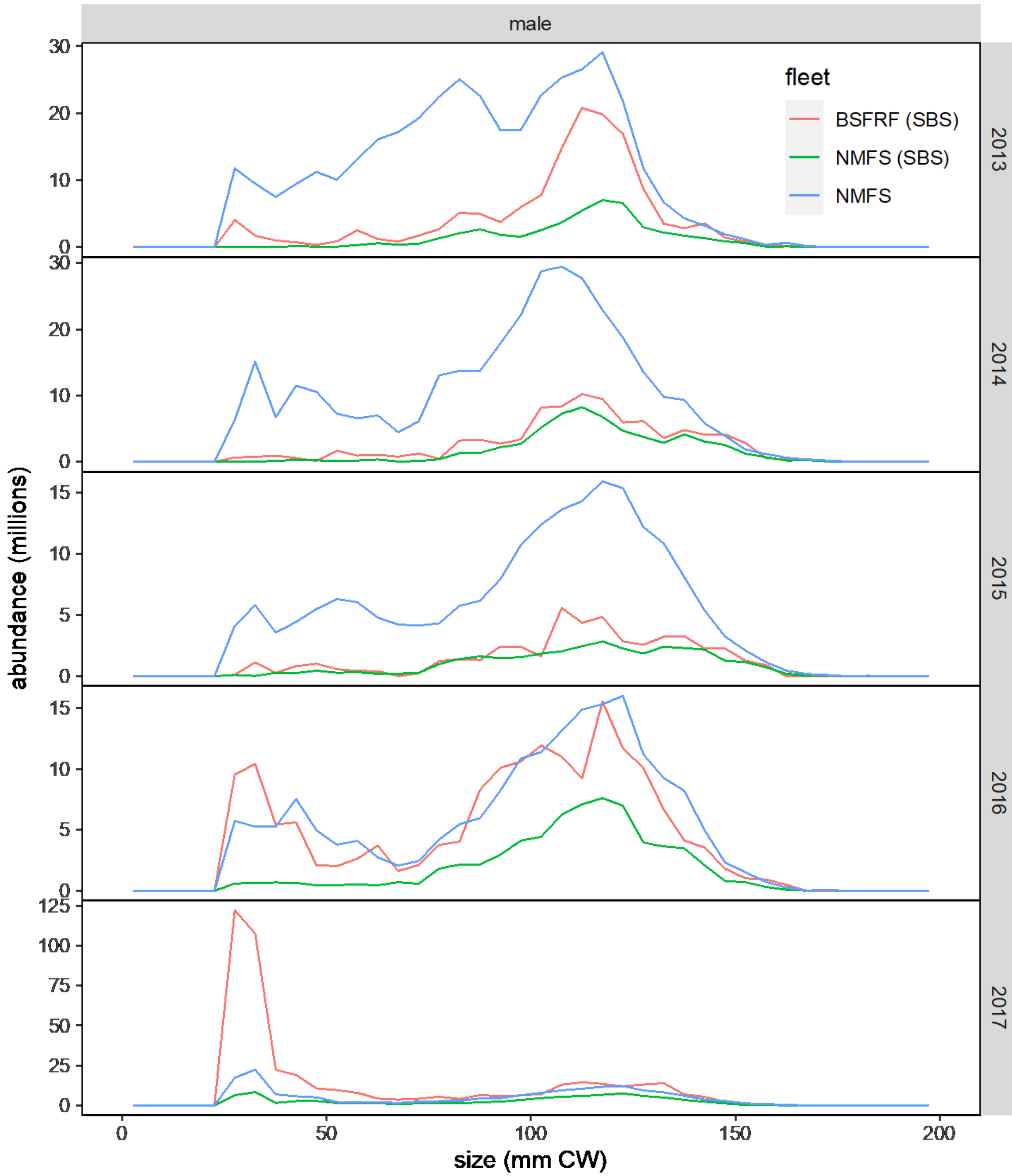

Figure 24. Annual size compositions of area-swept abundance for males from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. BSFRF (SBS): using modified nephrops bottom trawl (red); NMFS (SBS): standard NMFS survey gear and protocols (green). Also shown is the NMFS survey size composition (“NMFS”) for the entire EBS for each year (blue).

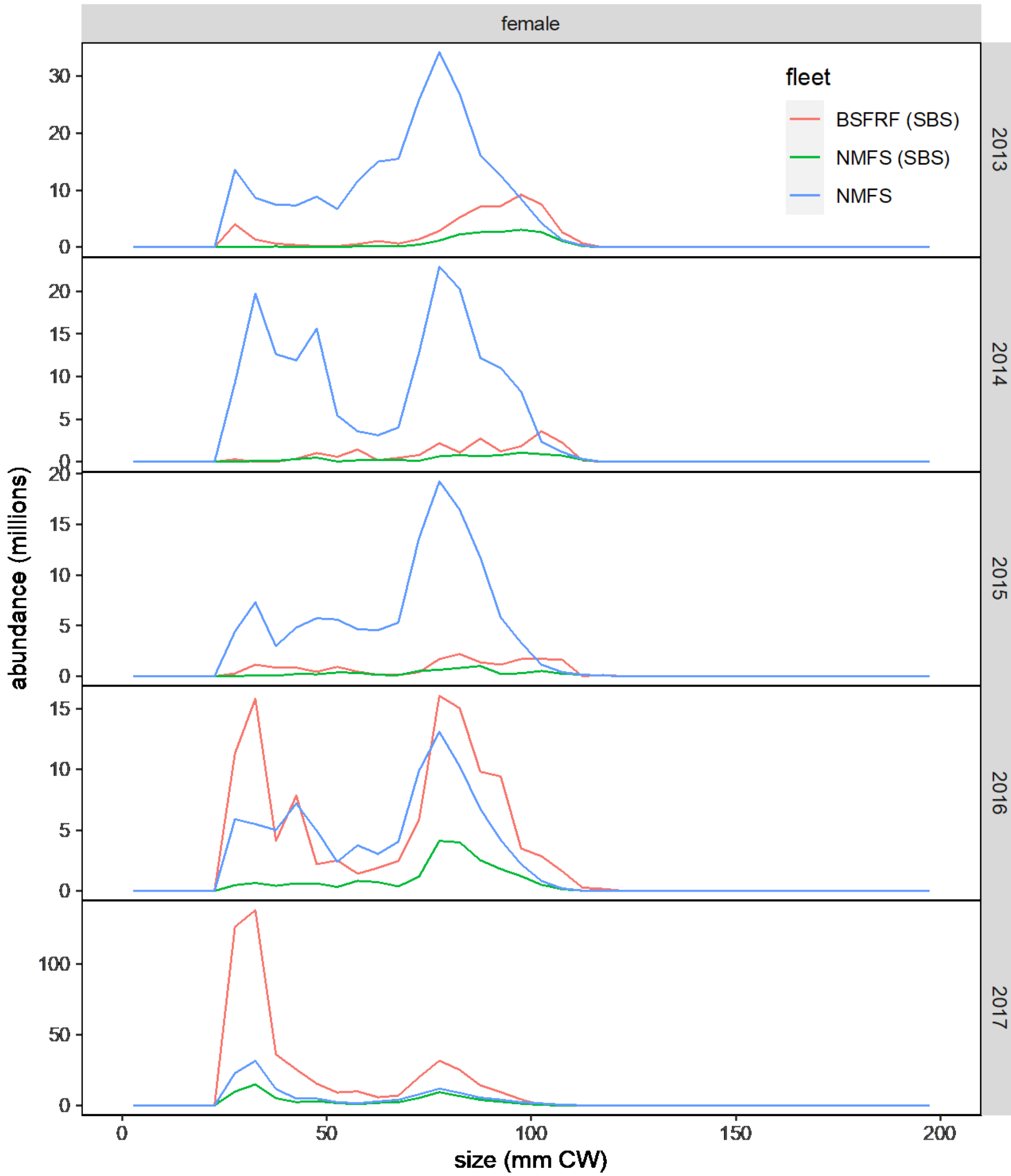

Figure 24 (cont.). Annual size compositions of area-swept abundance for females from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. BSFRF (SBS): using modified nephrops bottom trawl (red); NMFS (SBS): standard NMFS survey gear and protocols (green). Also shown is the NMFS survey size composition (“NMFS”) for the entire EBS for each year (blue).

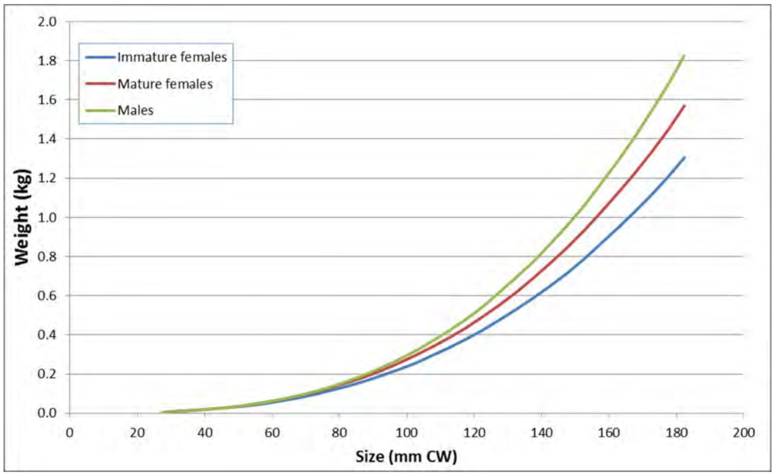

Figure 25. Size-weight relationships developed from NMFS EBS summer trawl survey data.

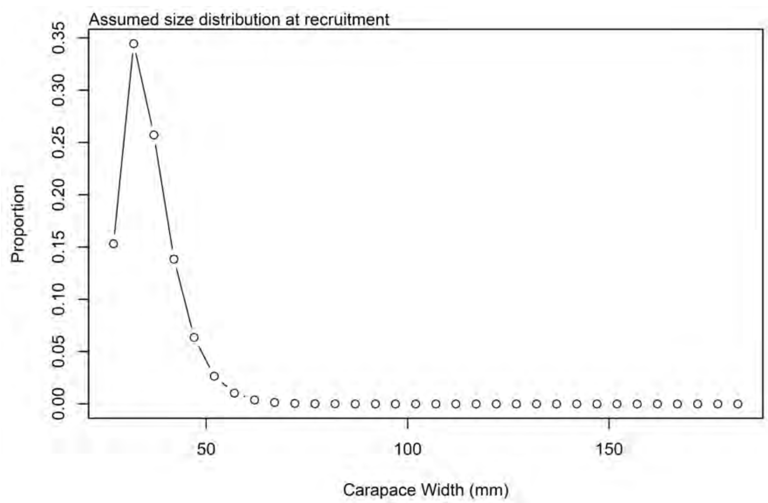

Figure 26. Nominal size distribution for recruits entering the population.

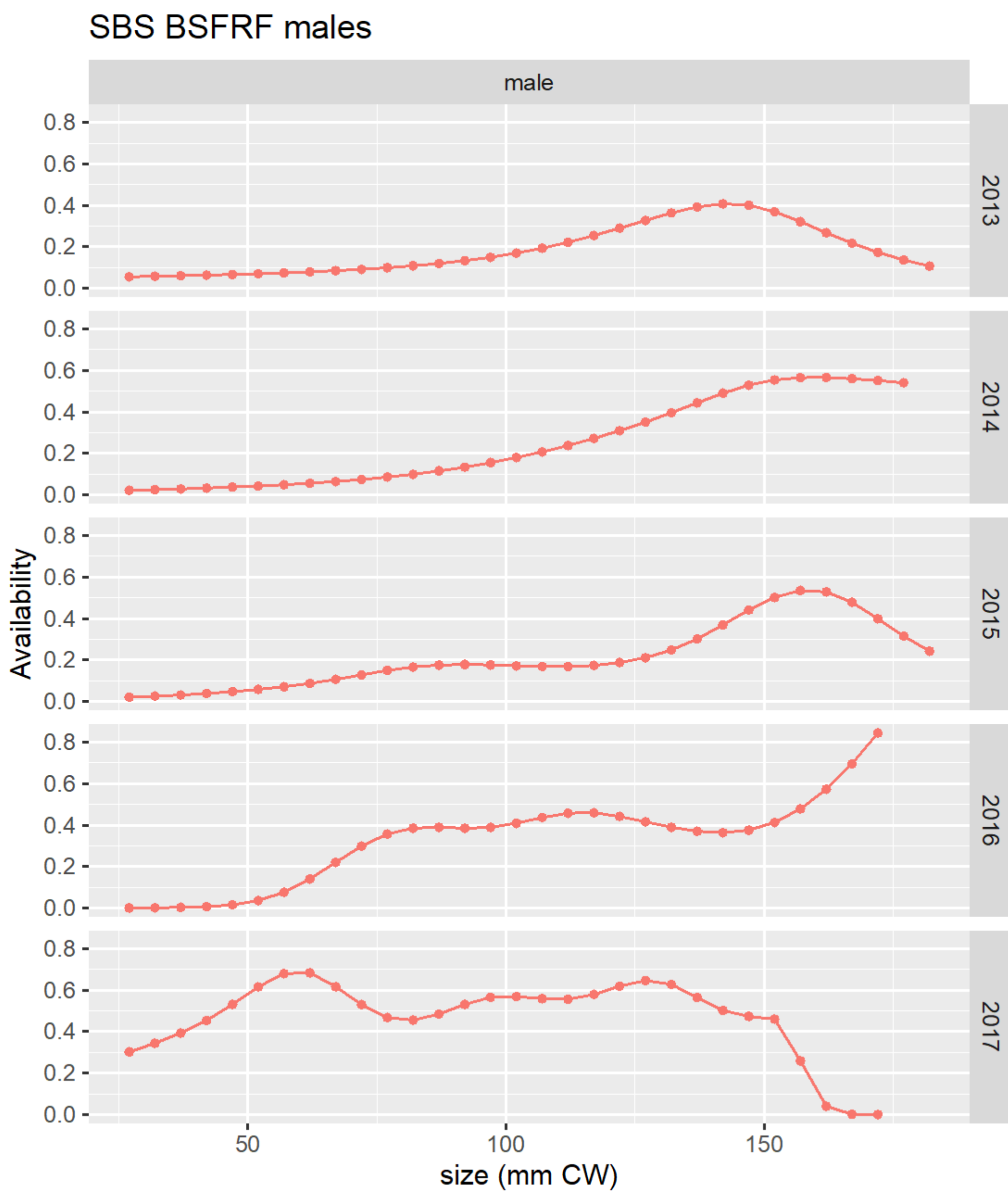

Figure 27. Upper: Empirical availability for males in SBS study areas, by year.

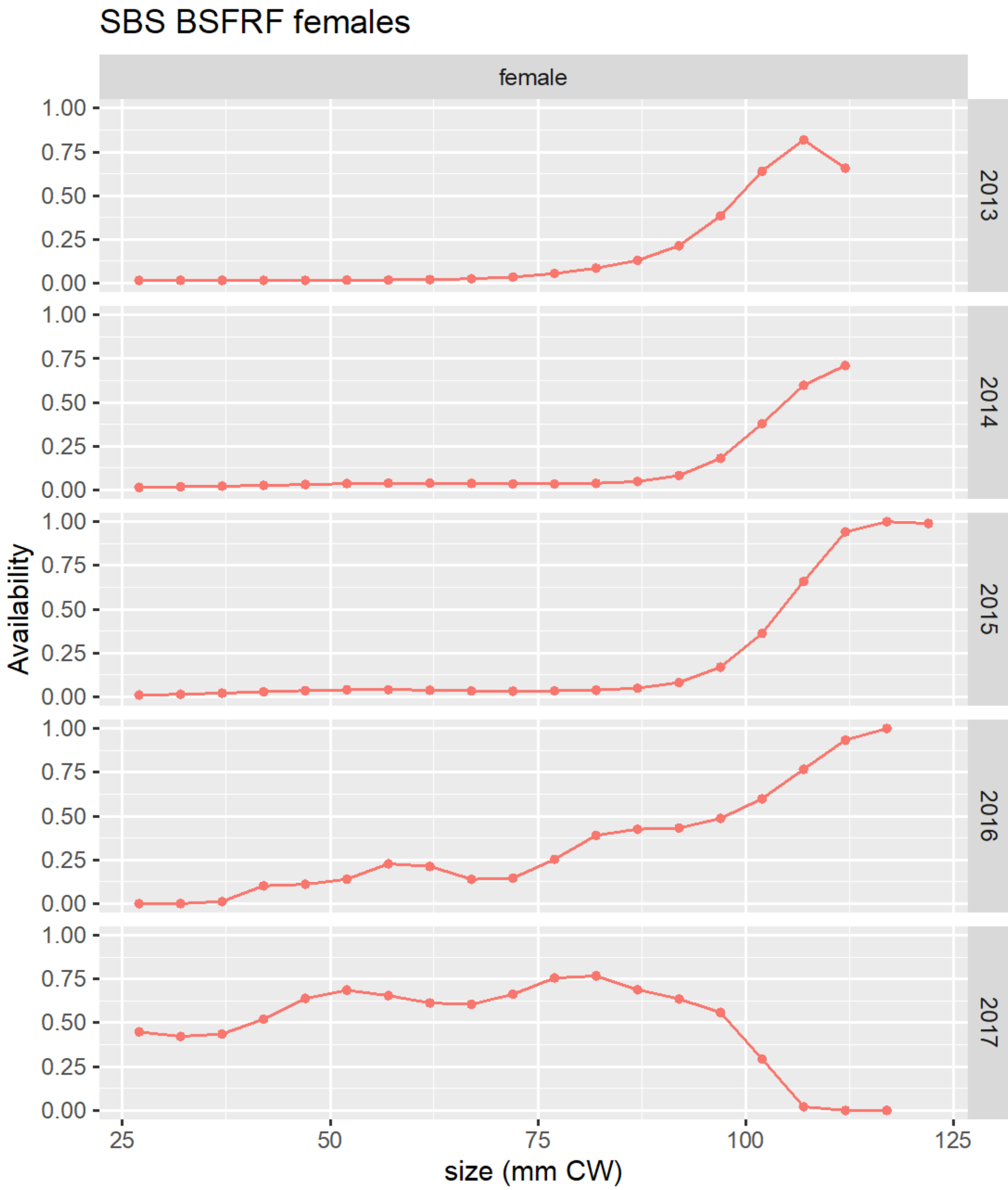

Figure 27 (cont.). Upper: Empirical availability for females in SBS study areas, by year.

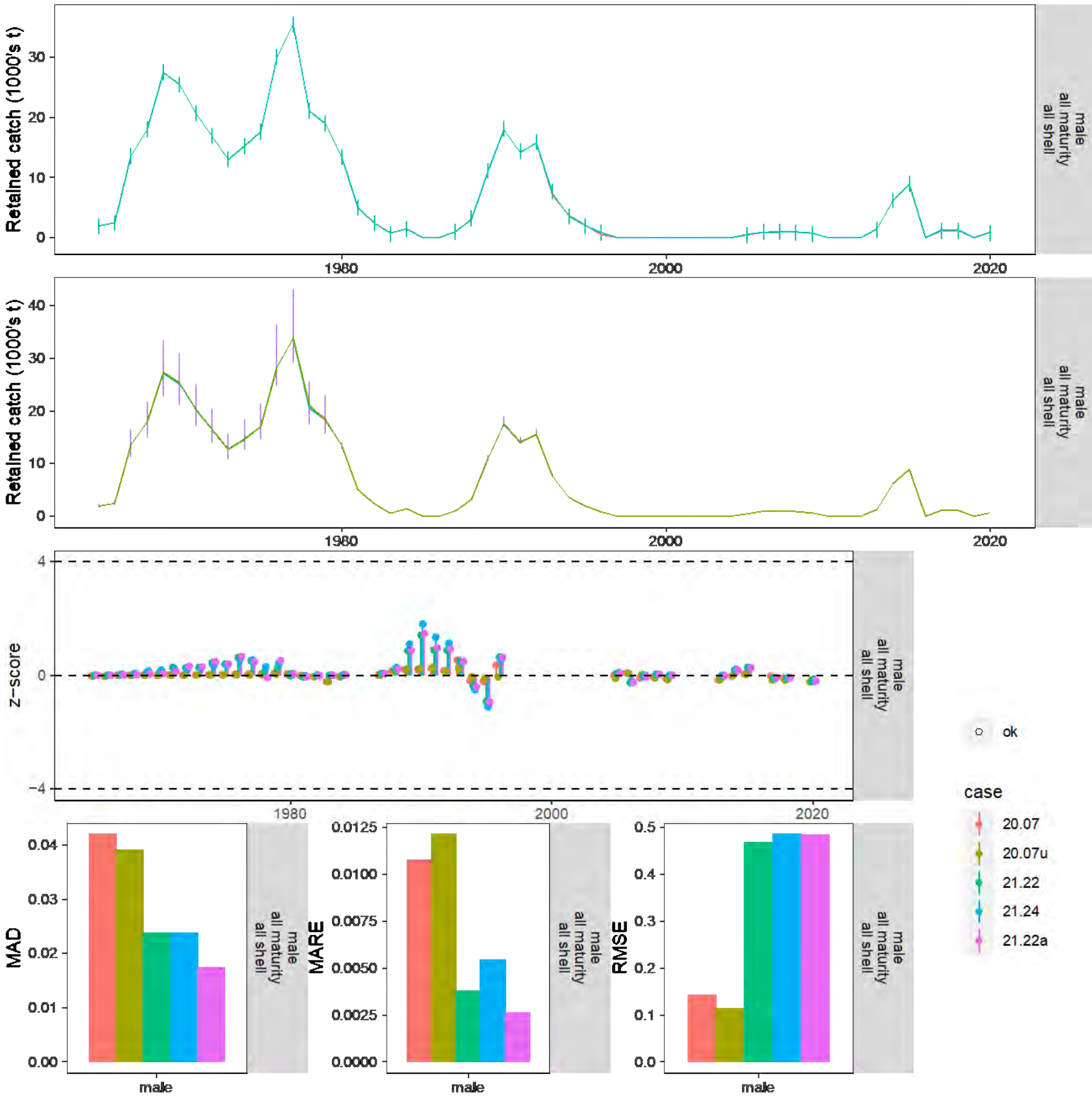

Figure 28. Fits to retained catch biomass in the directed fishery (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s “norm2” likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

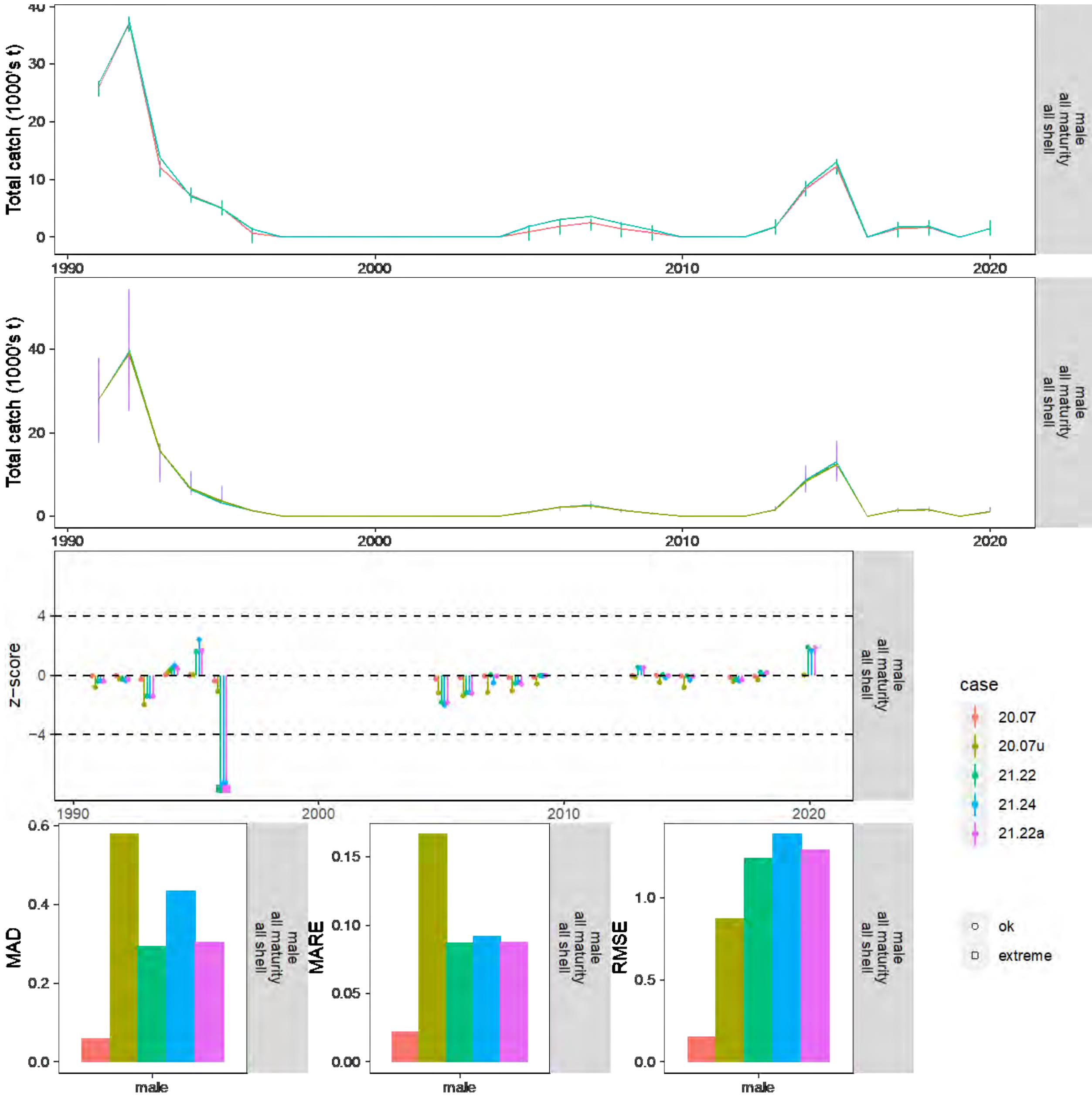

Figure 29. Fits to total male catch biomass in the directed fishery (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s “norm2” likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

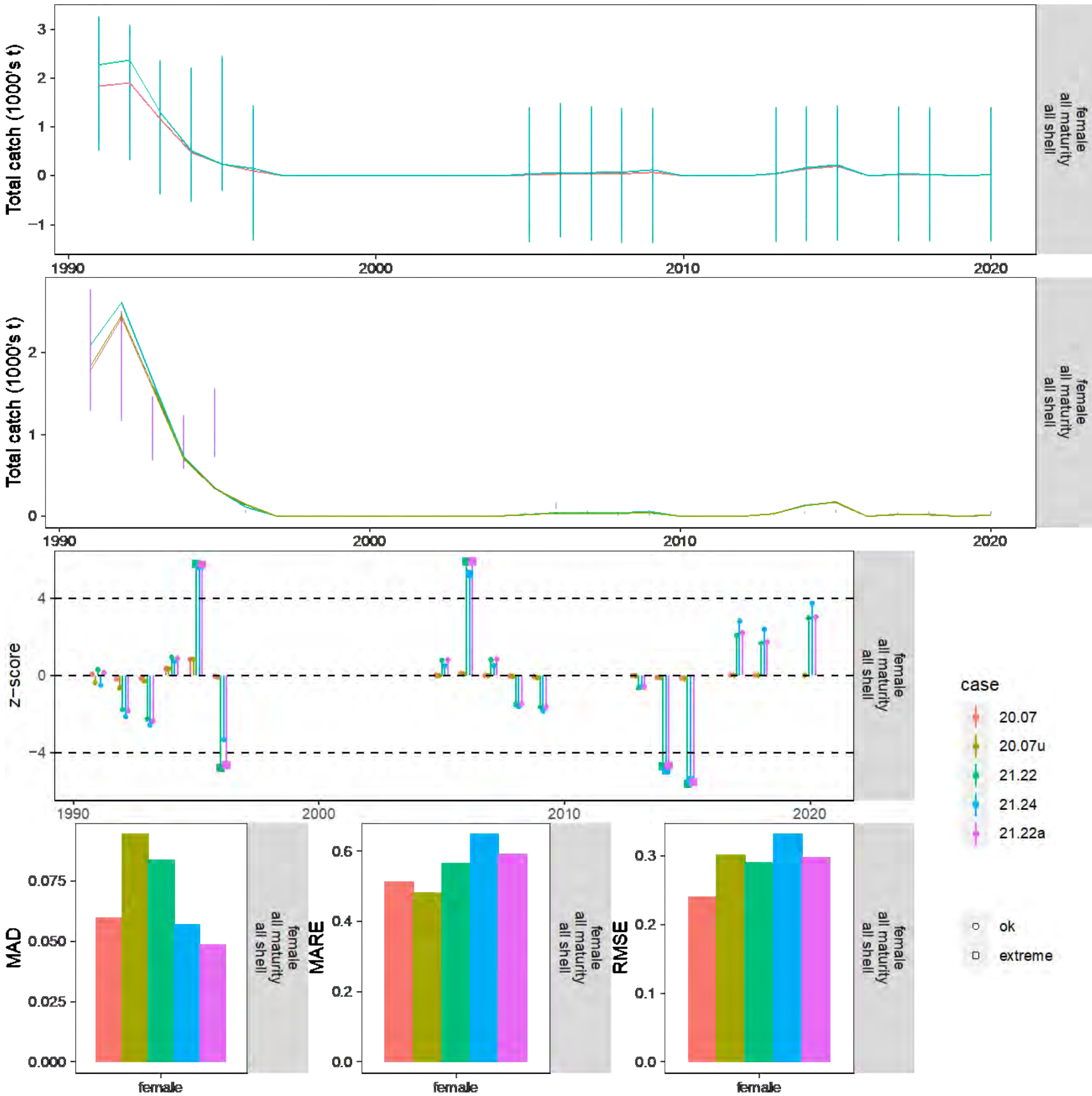

Figure 29 (cont.). Fits to total female catch biomass in the directed fishery (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s "norm2" likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

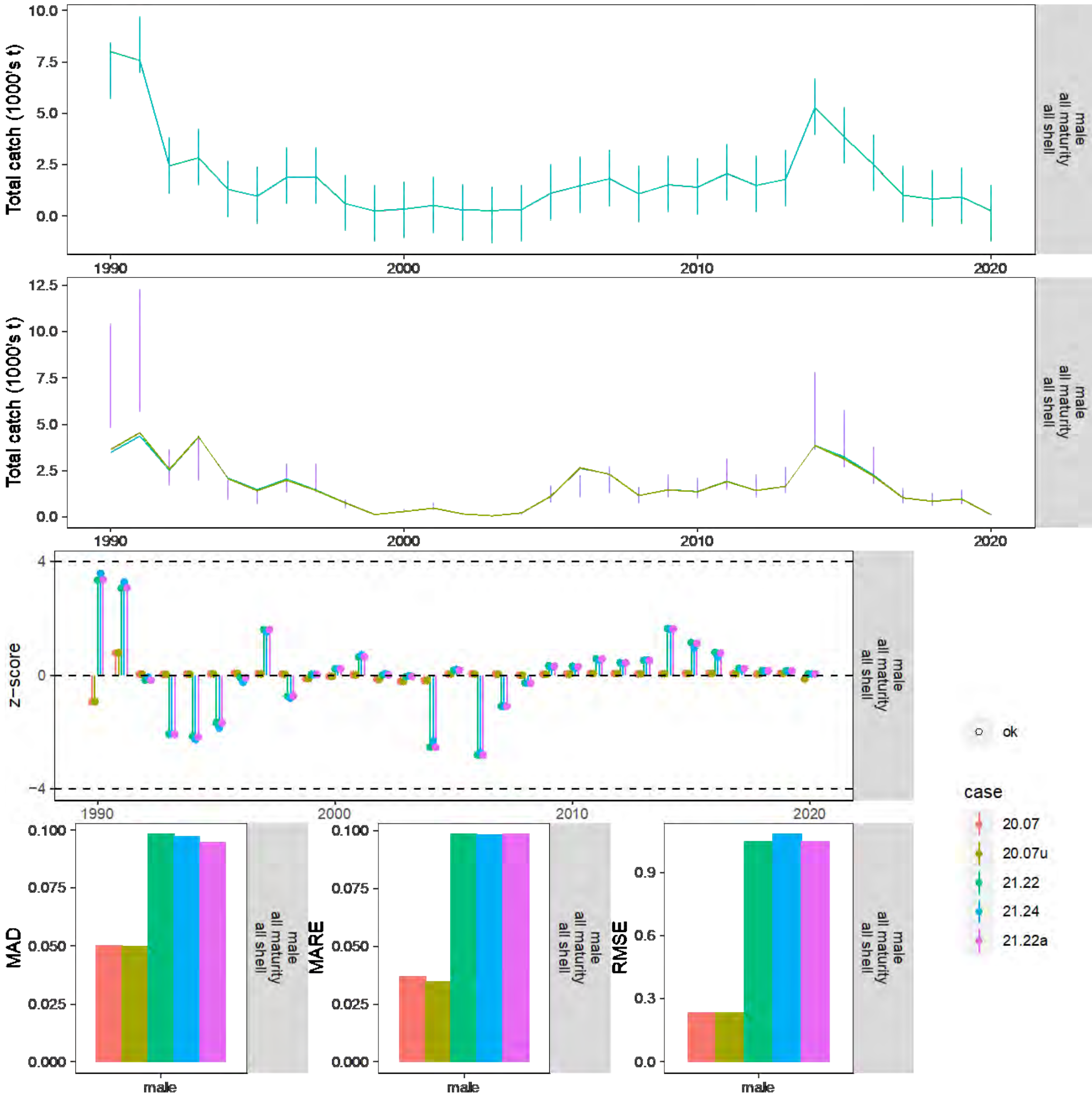

Figure 30. Fits to total male catch biomass in the snow crab fishery (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s "norm2" likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

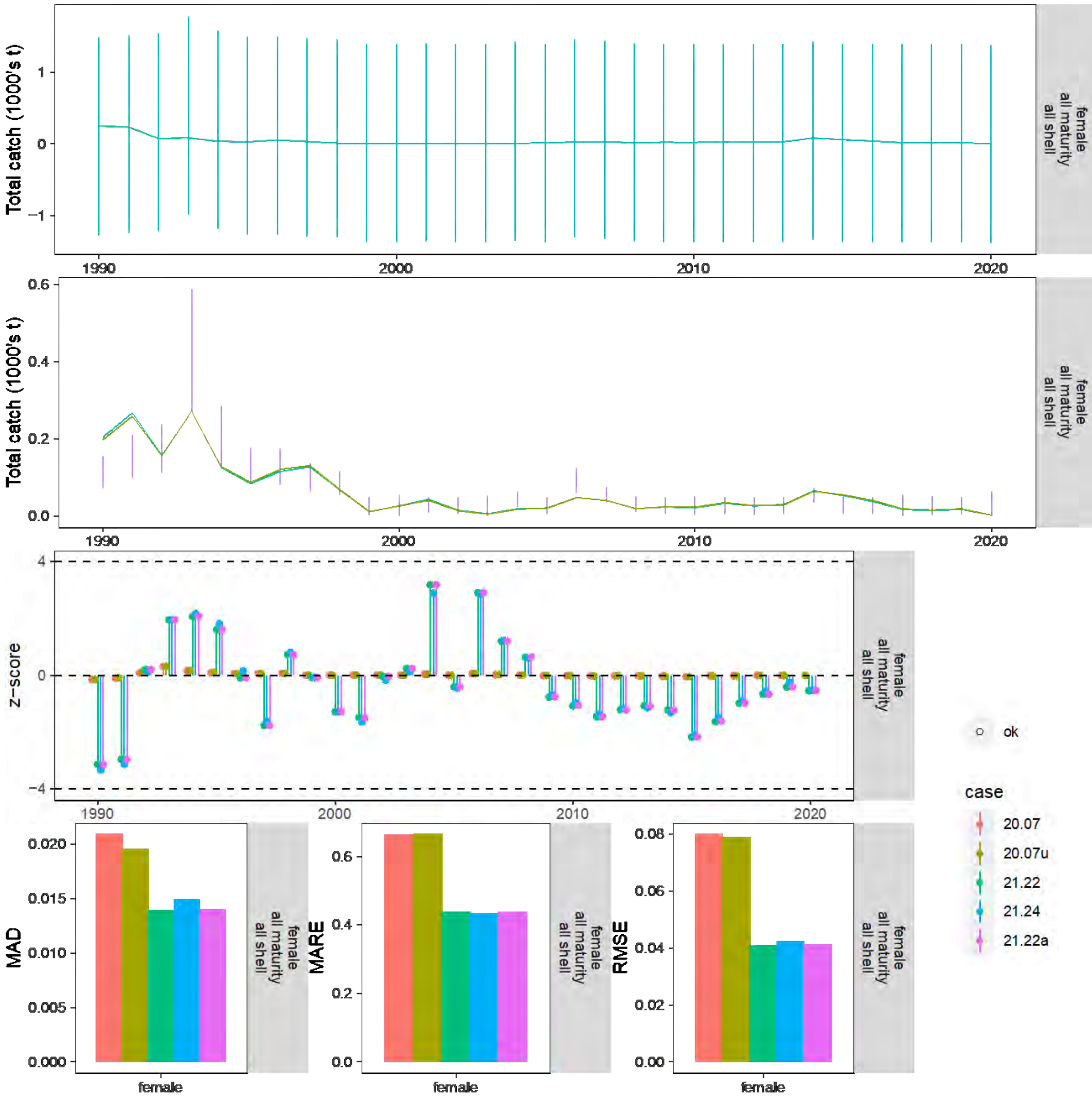

Figure 30 (cont.). Fits to total female catch biomass in the snow crab fishery (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s "norm2" likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

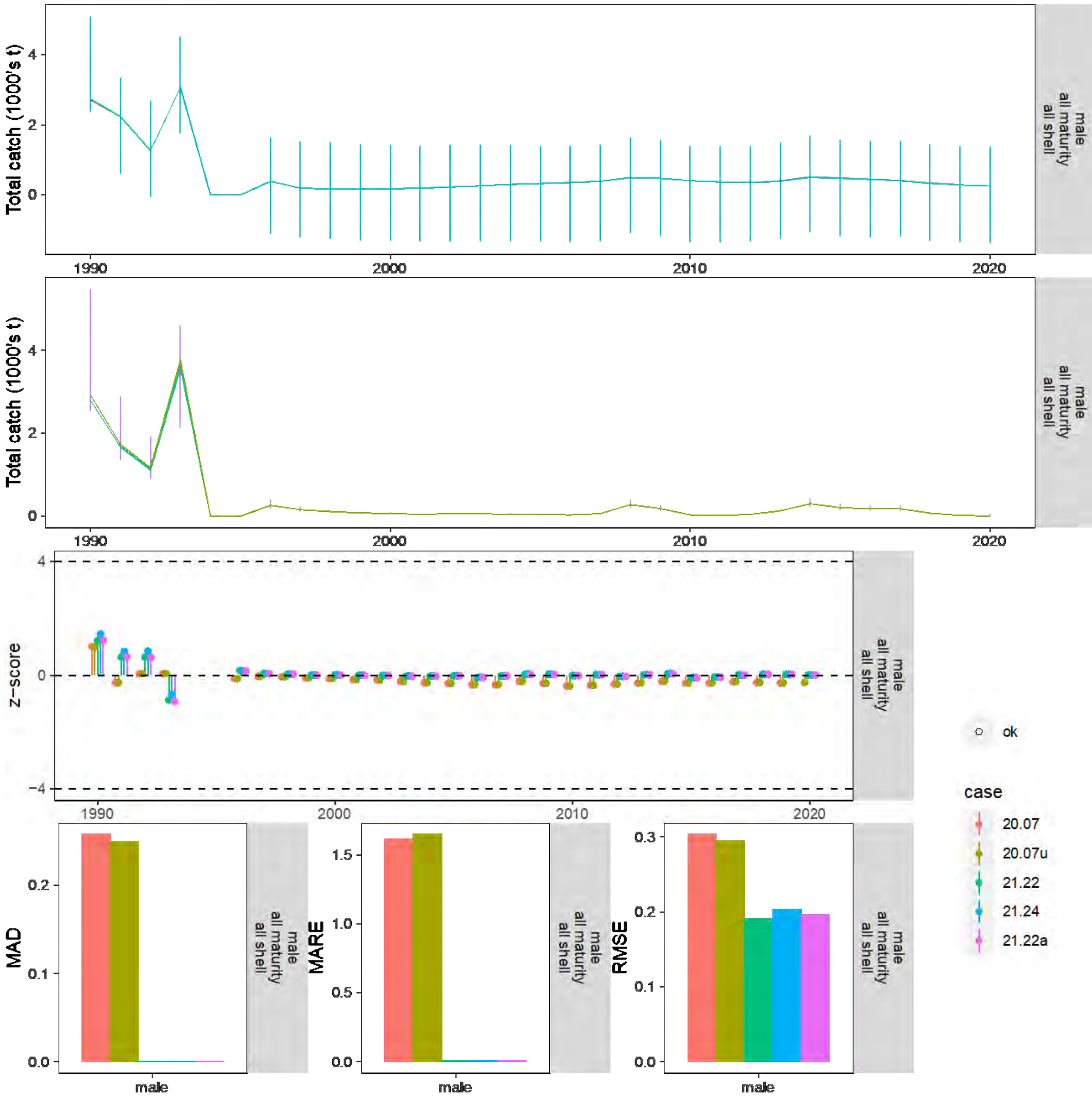

Figure 31. Fits to total male catch biomass in the BBRKC fishery (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s “norm2” likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

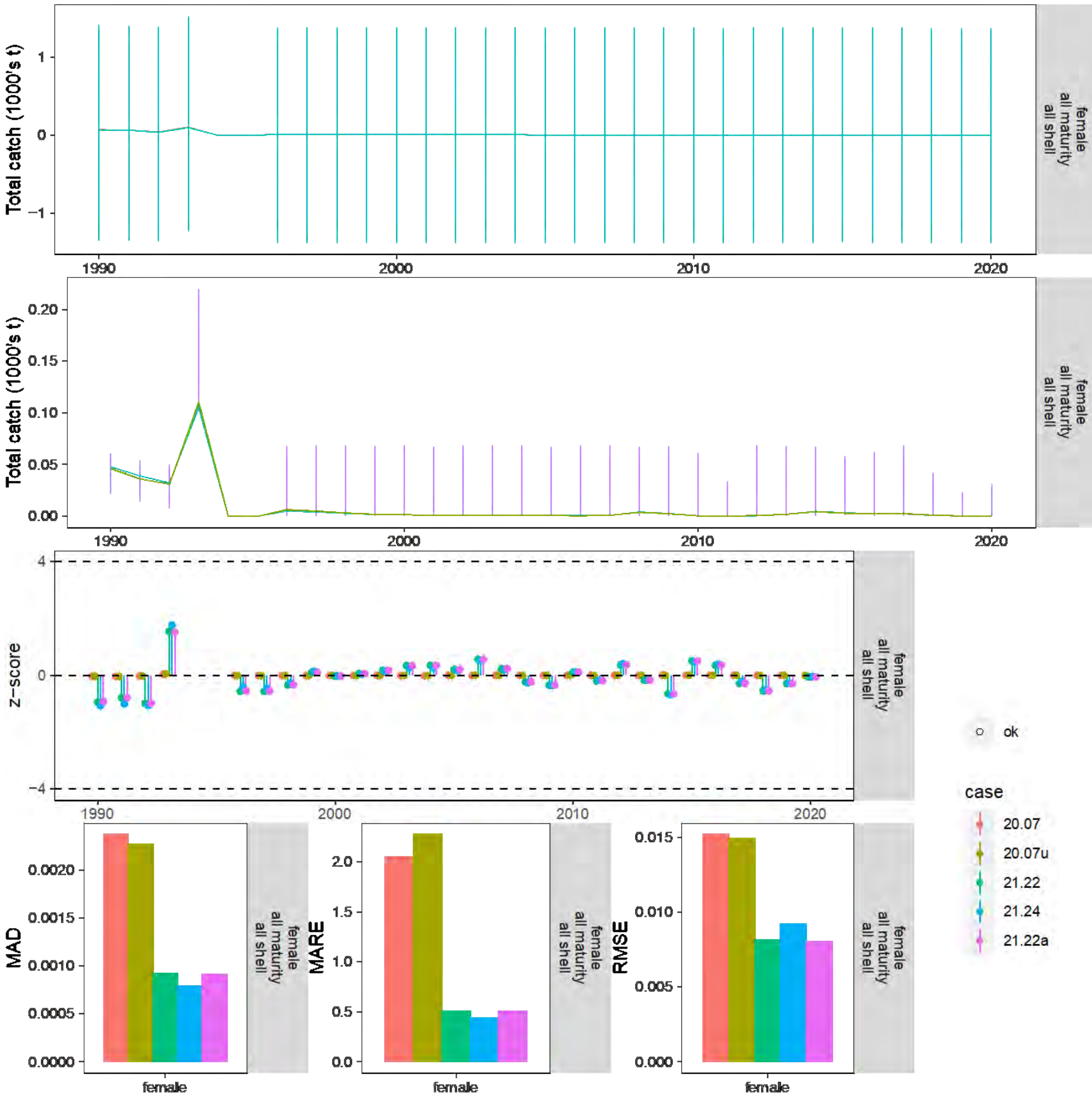

Figure 31 (cont.). F Fits to total female catch biomass in the BBRKC fishery (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s "norm2" likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

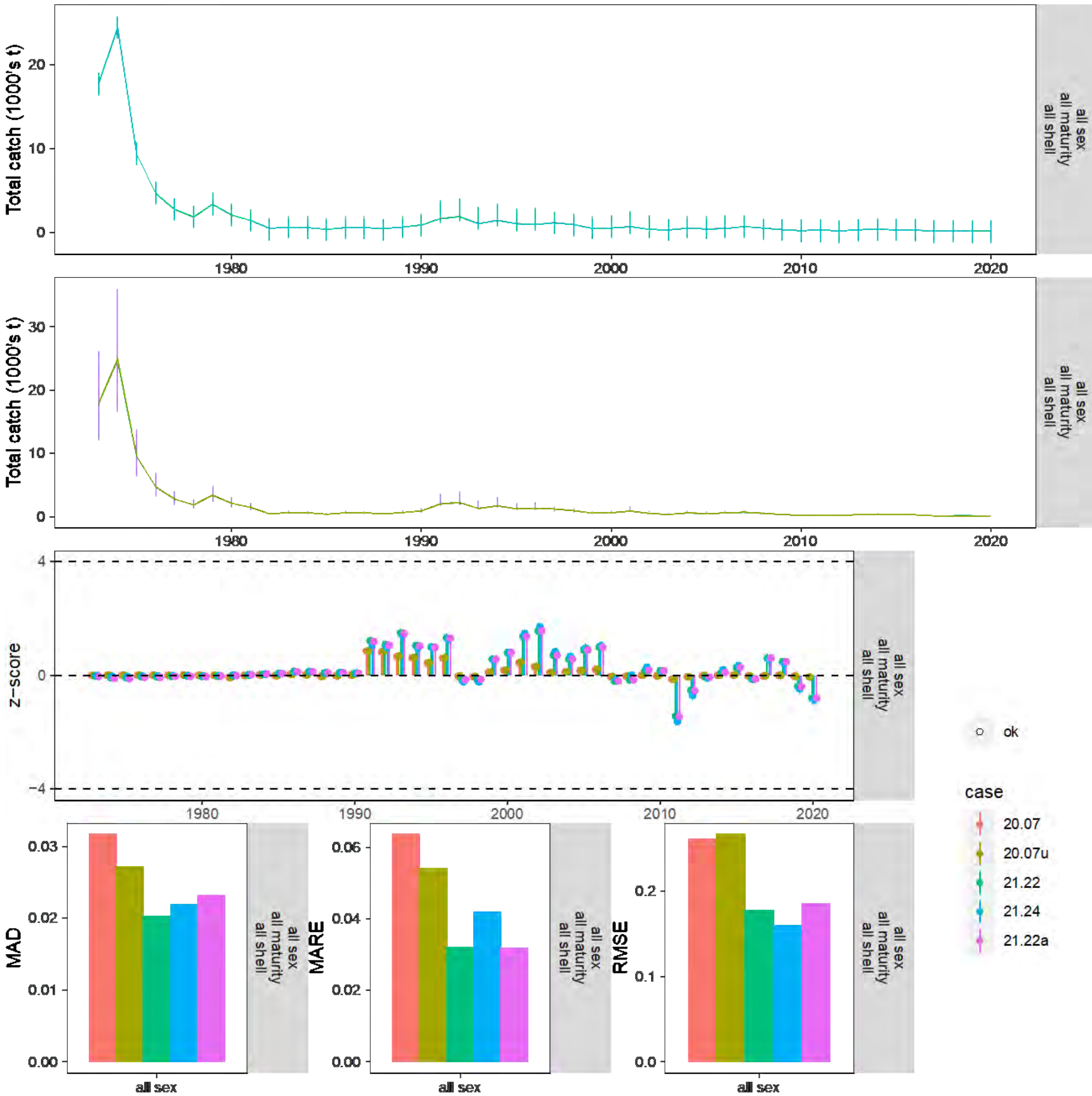

Figure 32. Fits to total catch biomass in the groundfish fisheries (upper two row) and residuals analysis plots (lower two rows). The fit for scenarios 20.07 and 20.07u (with error bars based on s "norm2" likelihood with a weight of 20) are shown in the uppermost row; the fits to scenarios 21.22, 21.24, and 21.22a. (with error bars based on a lognormal likelihood).

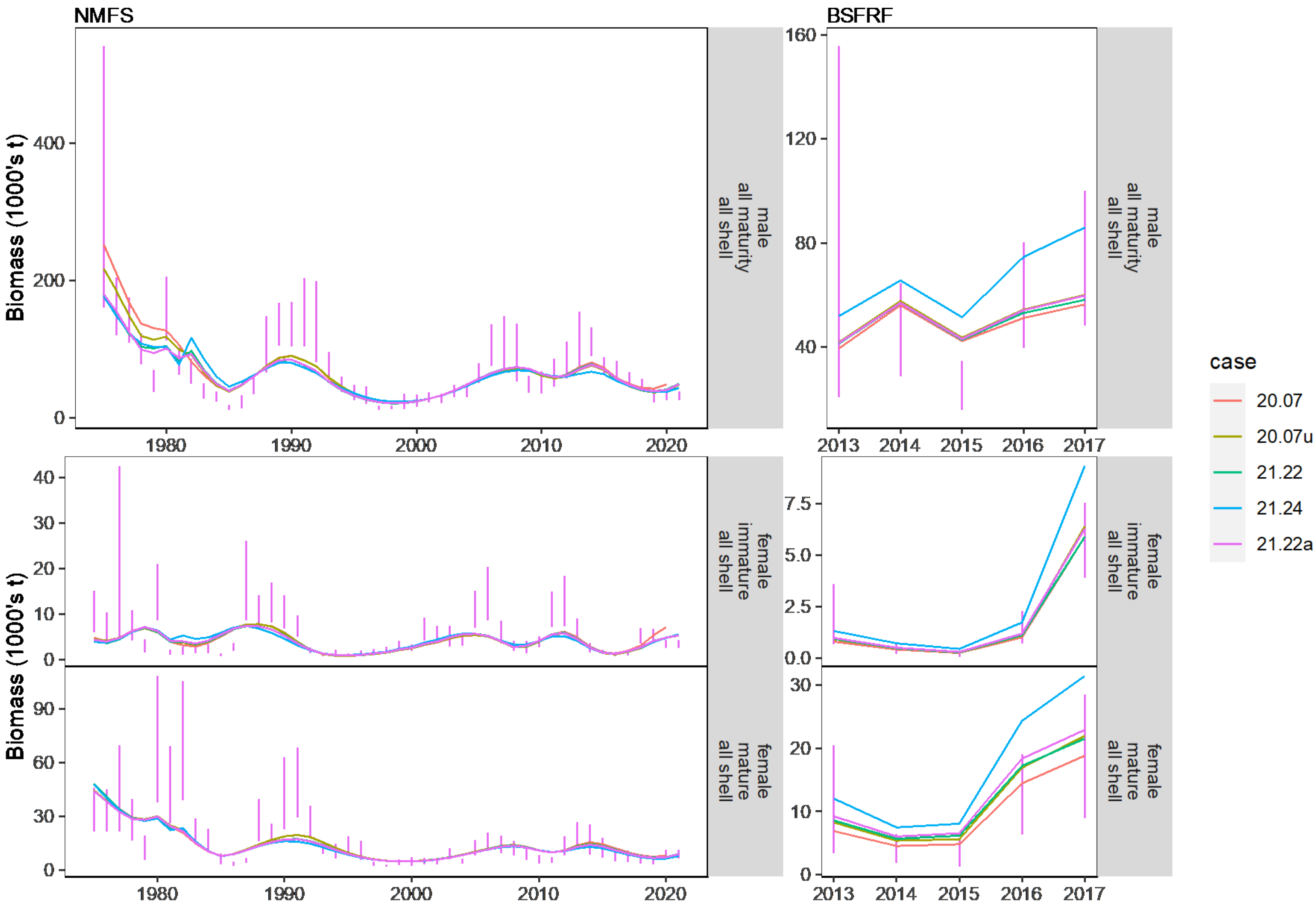

Figure 33. Fits to time series of all male (upper graph), immature female (center graph), and mature female (lower plot) biomass from the NMFS EBS shelf bottom trawl survey (left column) and the BSFRF SBS trawl survey (right column). Confidence intervals are 95%.

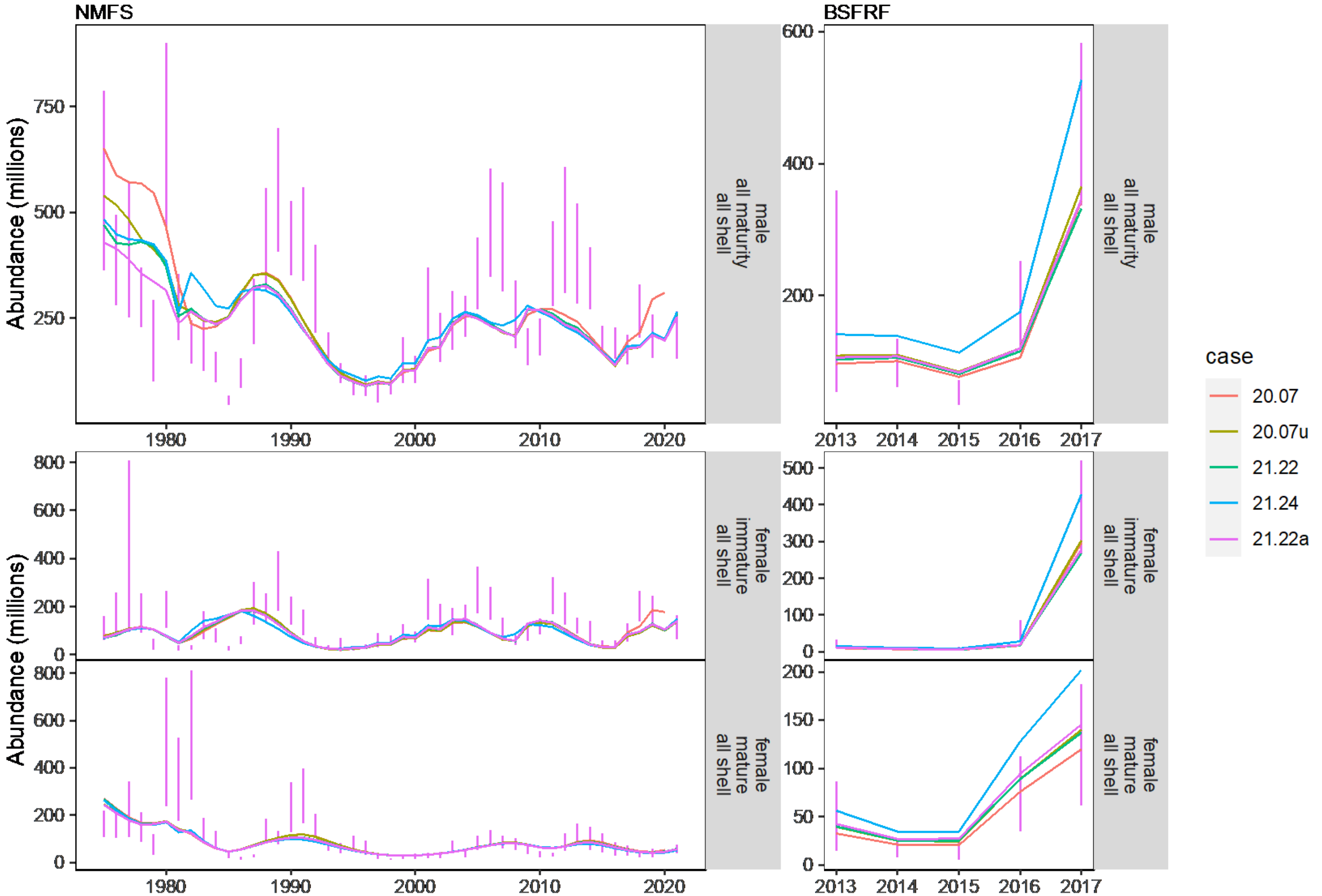

Figure 33 (cont.). Fits to time series of all male (upper graph), immature female (center graph), and mature female (lower plot) abundance from the NMFS EBS shelf bottom trawl survey (left column) and the BSFRF SBS trawl survey (right column). Note that these fits are not included in the model objective function and simplyprovide a diagnostic check. Confidence intervals are 95%.

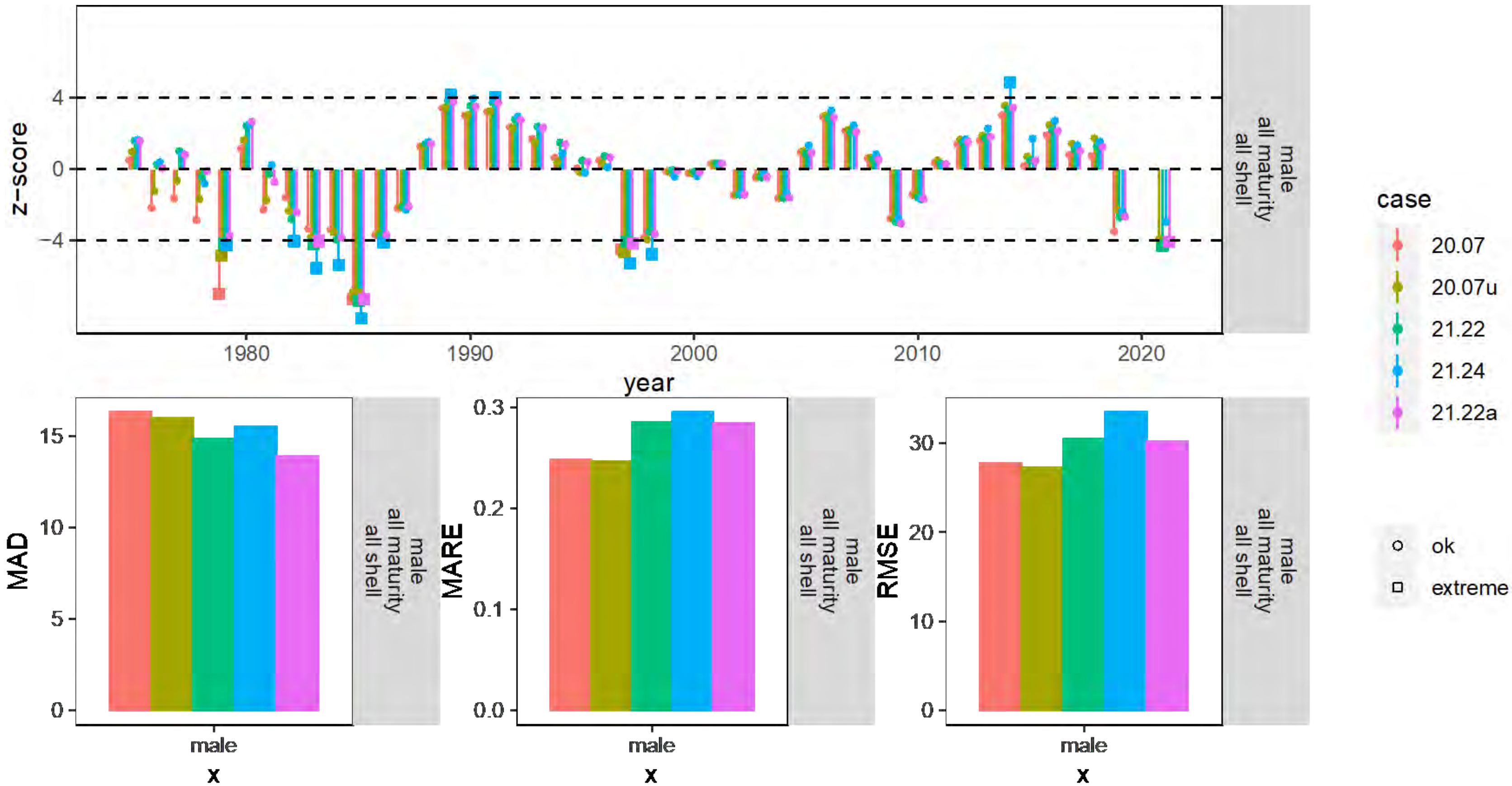

Figure 34. Residuals analysis by model scenario for fits to male biomass in the NMFS EBS bottom trawl survey. Upper row: annual z-scores; bottom row: 1) MAD: median absolute deviations, 2) MARE: median absolute relative error; 3) RMSE: root mean square error.

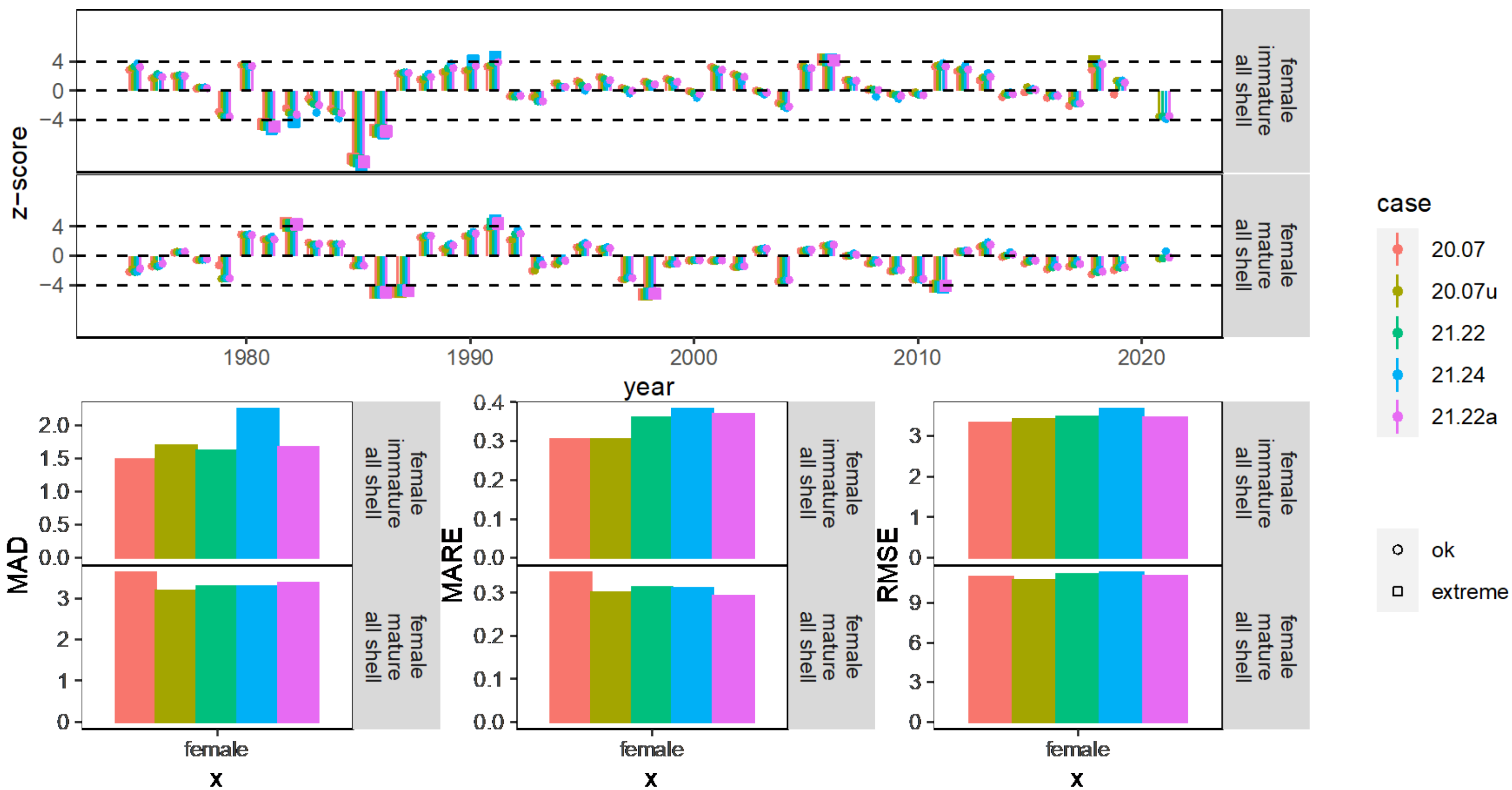

Figure 35. Residuals analysis by model scenario for fits to female biomass in the NMFS EBS bottom trawl survey. Upper row: annual z-scores; bottom row: 1) MAD: median absolute deviations, 2) MARE: median absolute relative error; 3) RMSE: root mean square error.

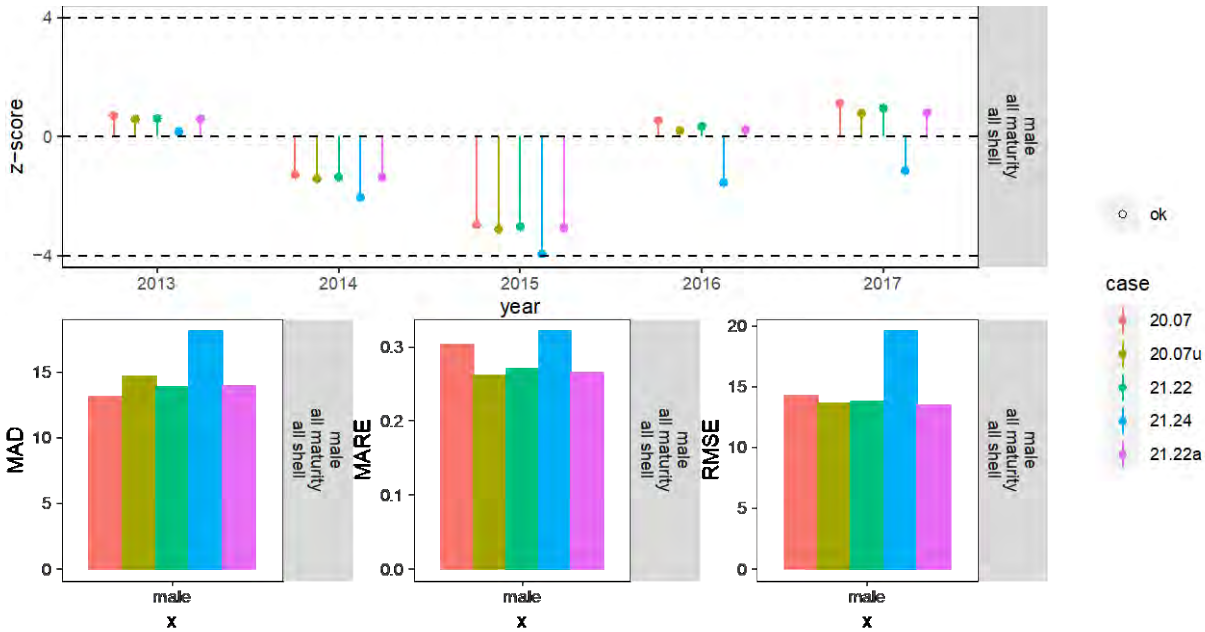

Figure 36. Residuals analysis by model scenario for fits to male biomass in the BSFRF SBS bottom trawl survey. Upper row: annual z-scores; bottom row: 1) MAD: median absolute deviations, 2) MARE: median absolute relative error; 3) RMSE: root mean square error.

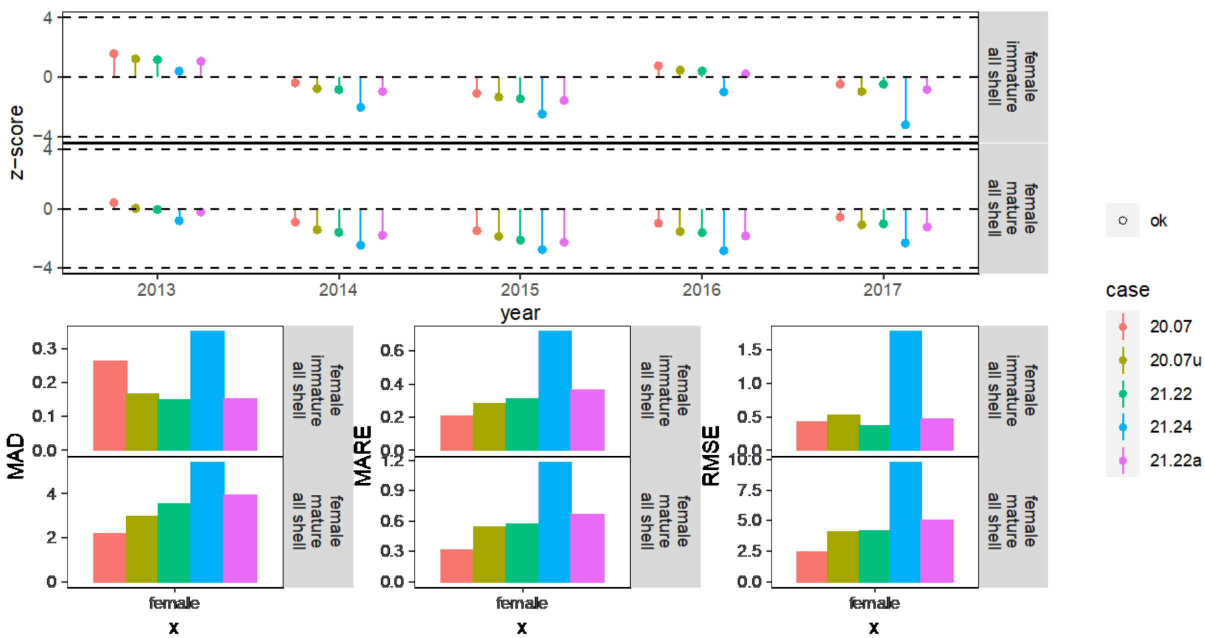

Figure 37. Residuals analysis by model scenario for fits to female biomass in the BSFRF SBS bottom trawl survey. Upper row: annual z-scores; bottom row: 1) MAD: median absolute deviations, 2) MARE: median absolute relative error; 3) RMSE: root mean square error.

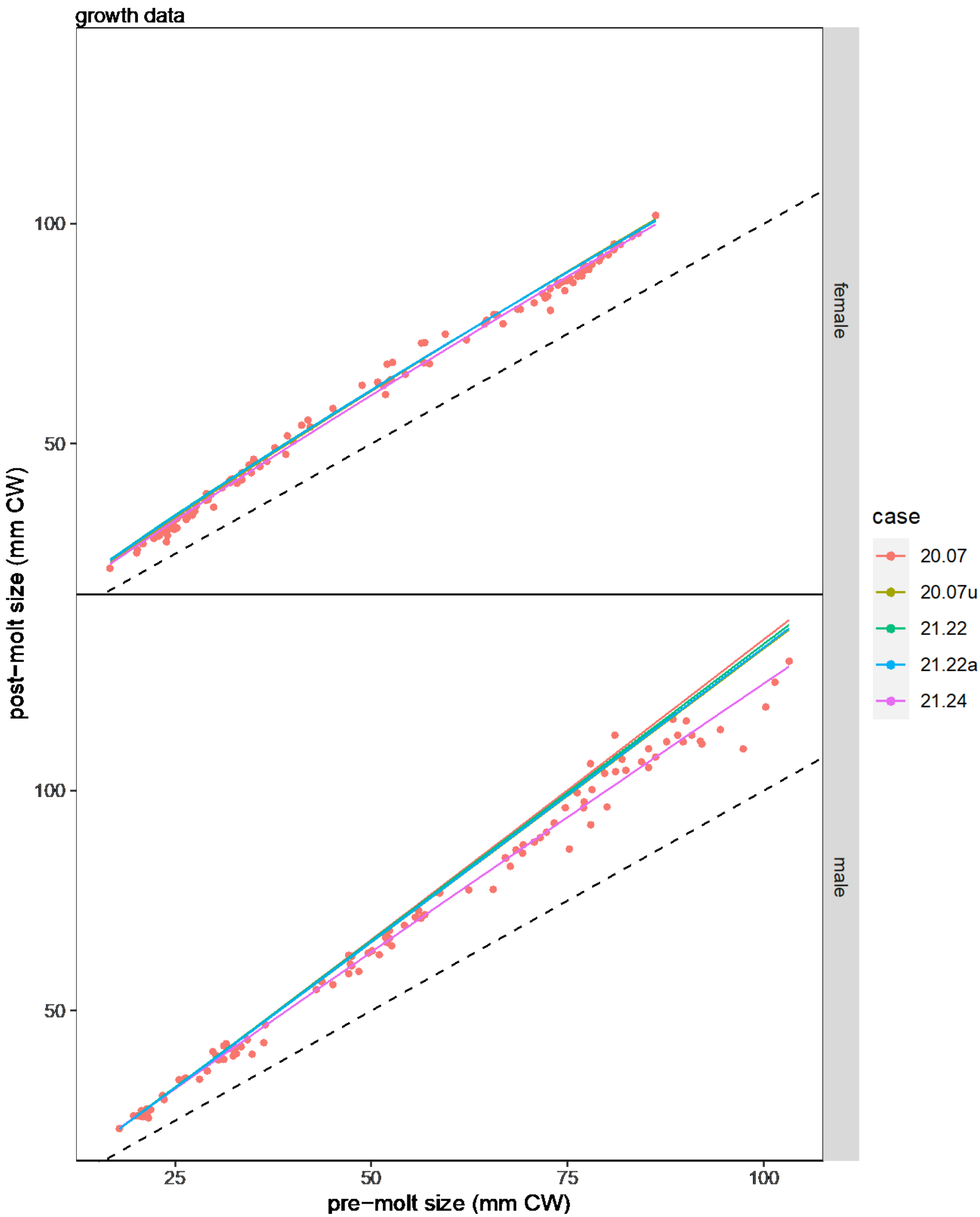

Figure 38. Fits to molt increment data for all scenarios.

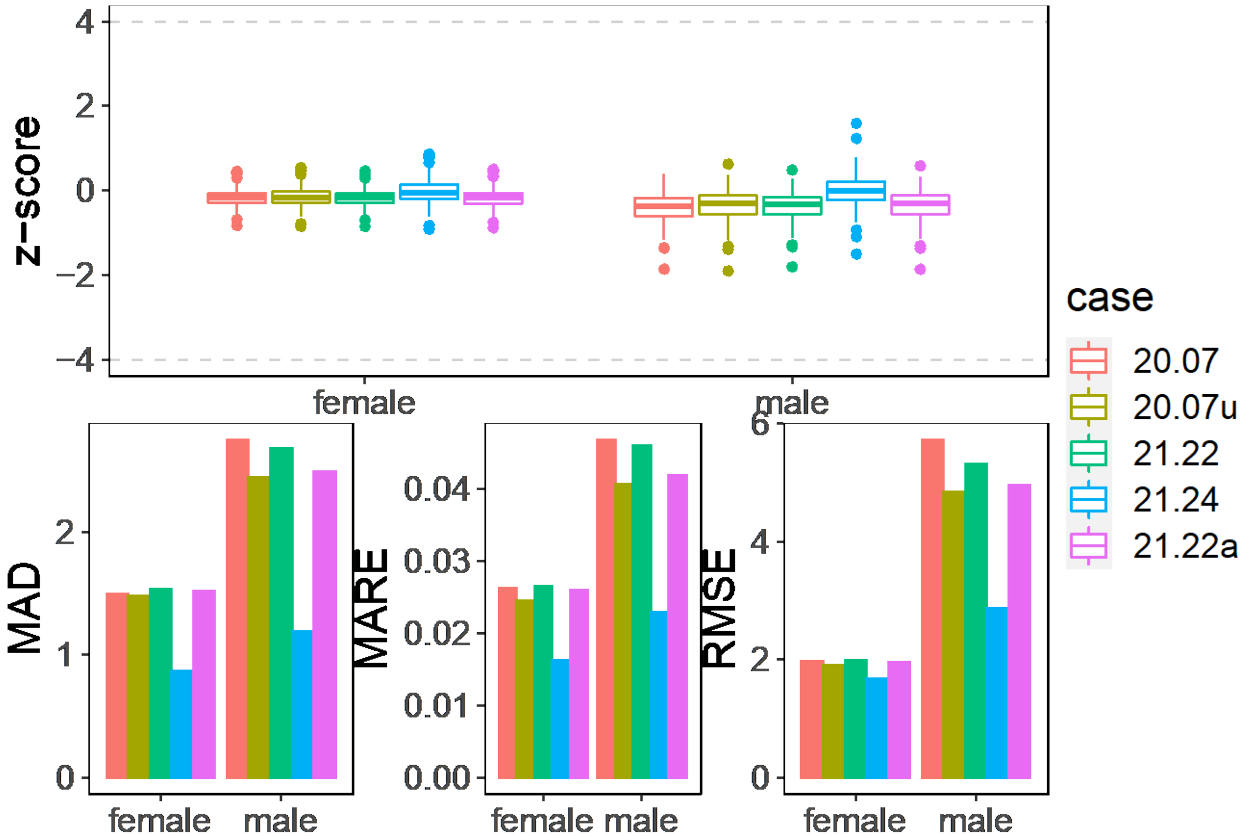

Figure 38 (cont.). Residuals analysis for fits to molt increment data for all scenarios.

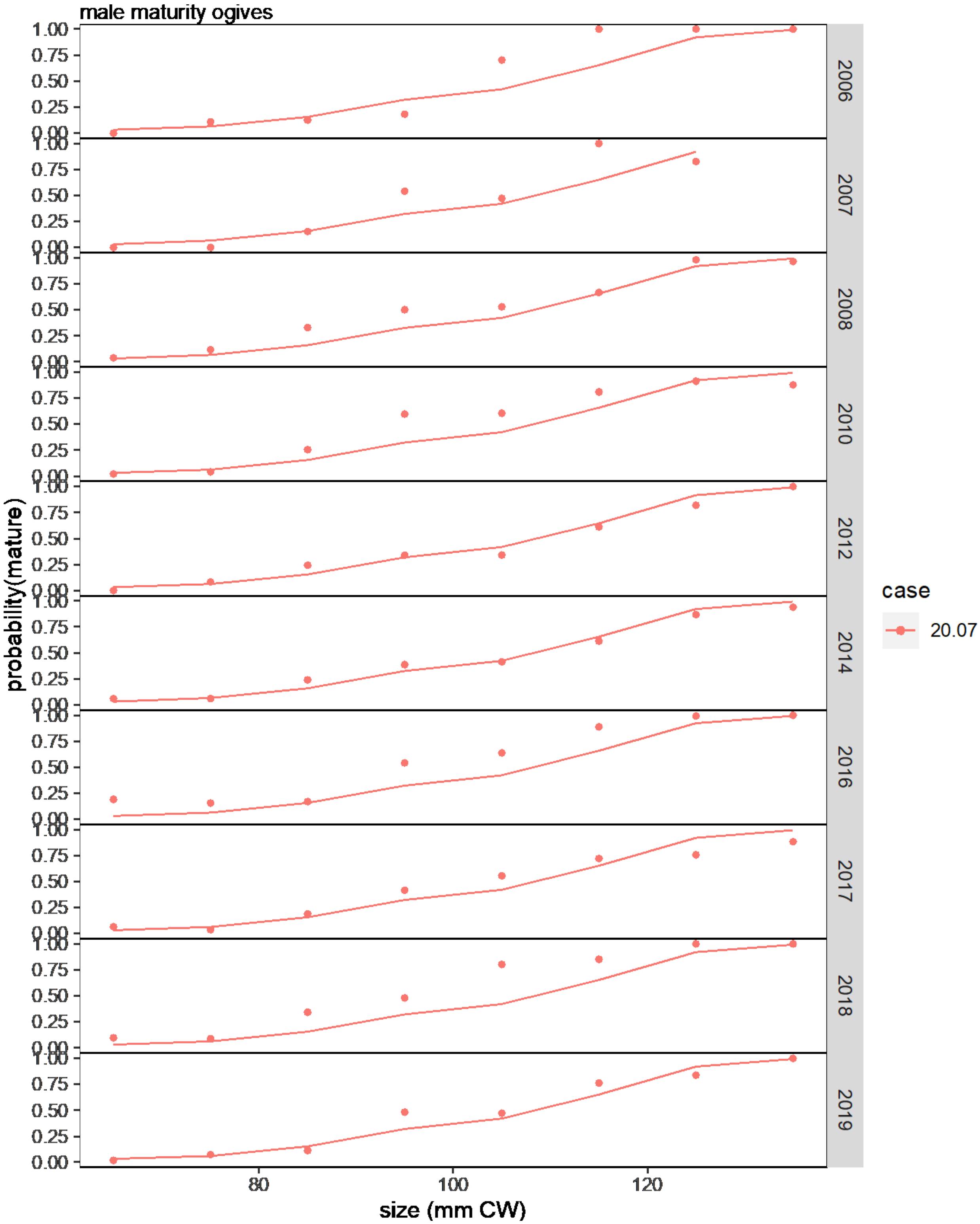

Figure 39. Fits to male maturity ogive data for scenario 20.07.

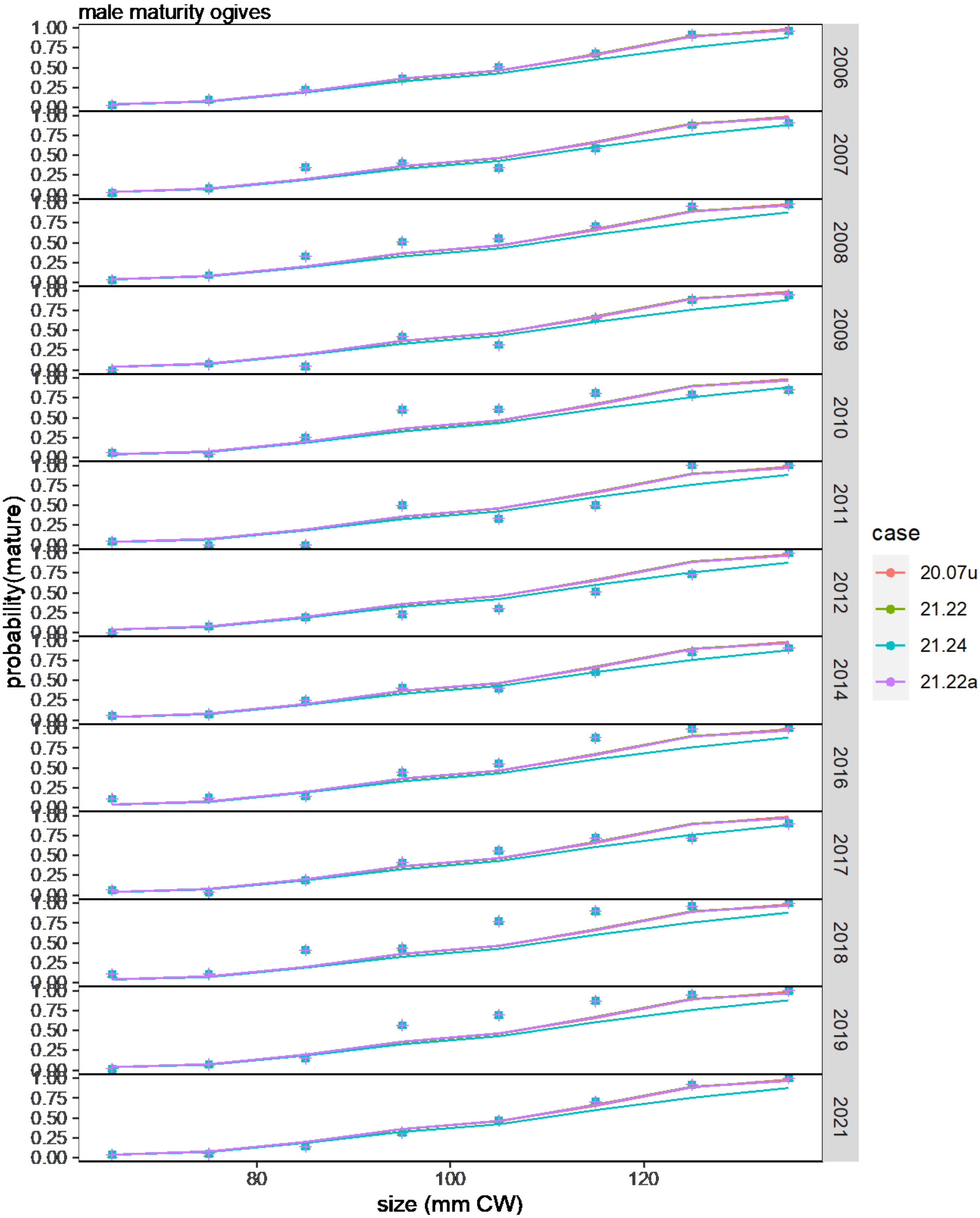

Figure 39 (cont.). Fits to male maturity ogive data for scenarios 20.07u, 21.22, 21.24, and 21..22a.

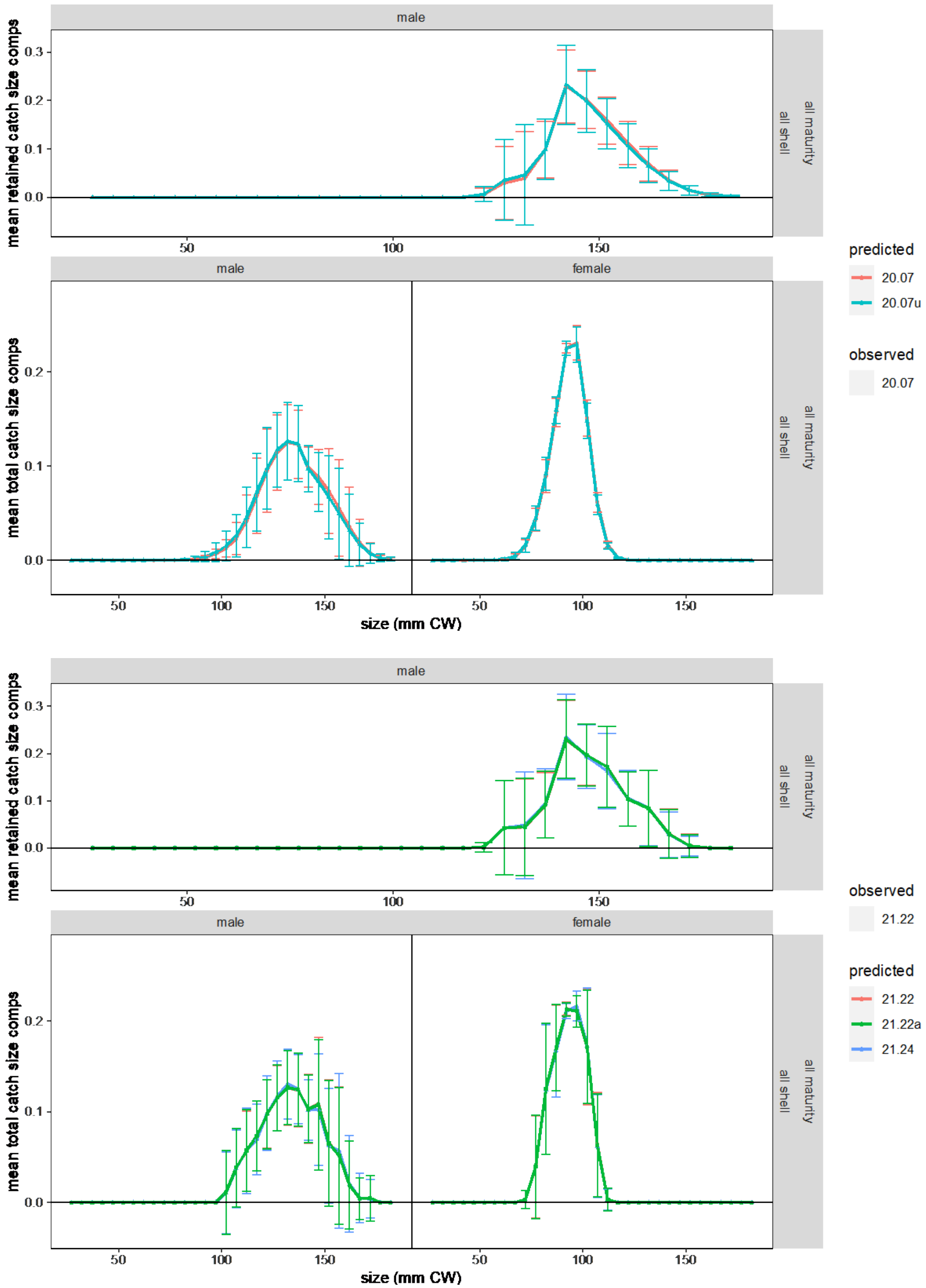

Figure 40. Fits to directed fishery mean size compositions. Scenarios 20.07 and 20.07u: upper two rows; 21.XX scenarios: lower two rows. The upper plot in each pair shows retained catch, the lower shows total catch. The data in the 21.XX scenarios has had tail compression applied prior to fitting (hence the “observed” data is different between the upper and lower sets of plots).

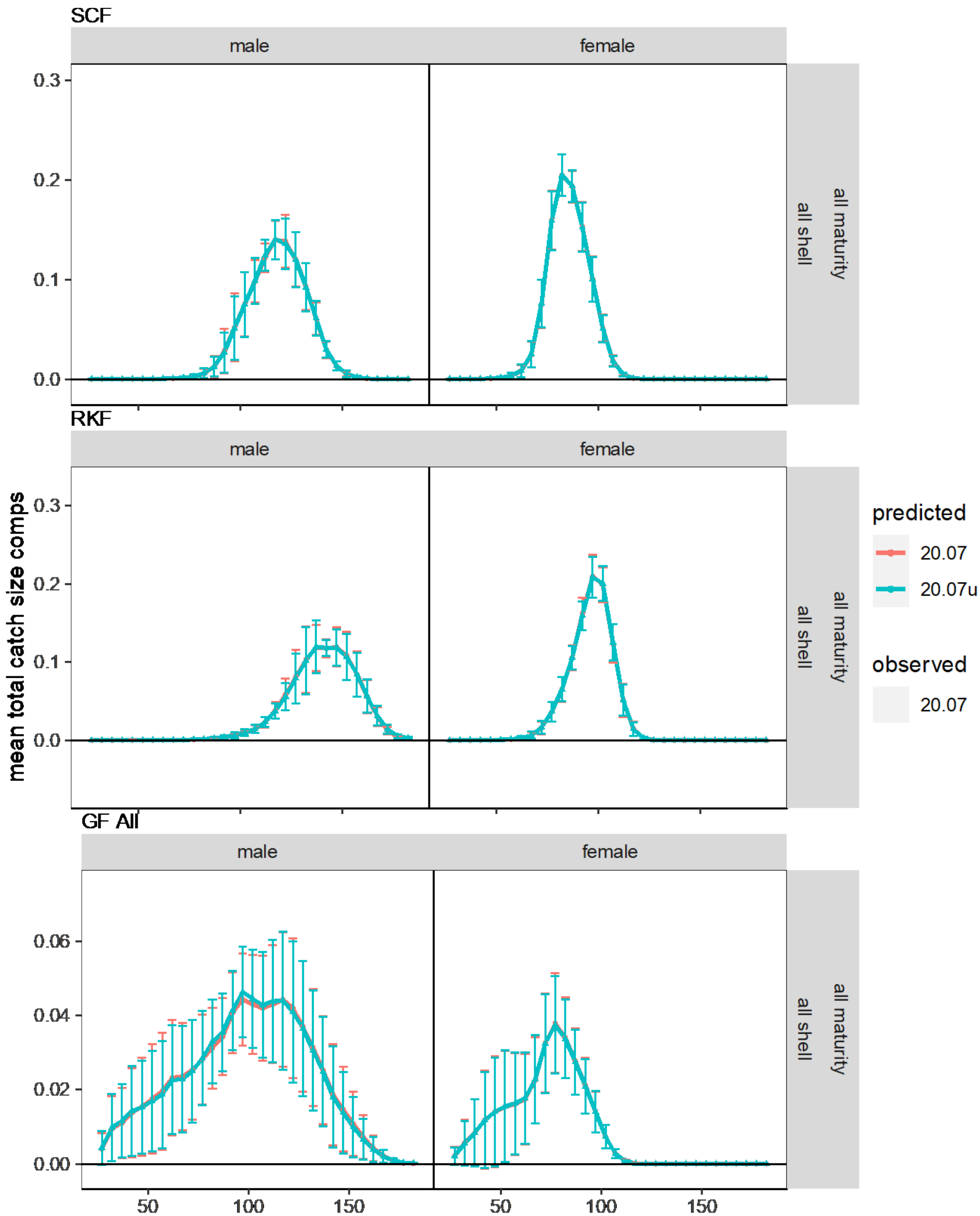

Figure 41. Fits to bycatch fishery size compositions for Scenarios 20.07 and 20.07u. SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries.

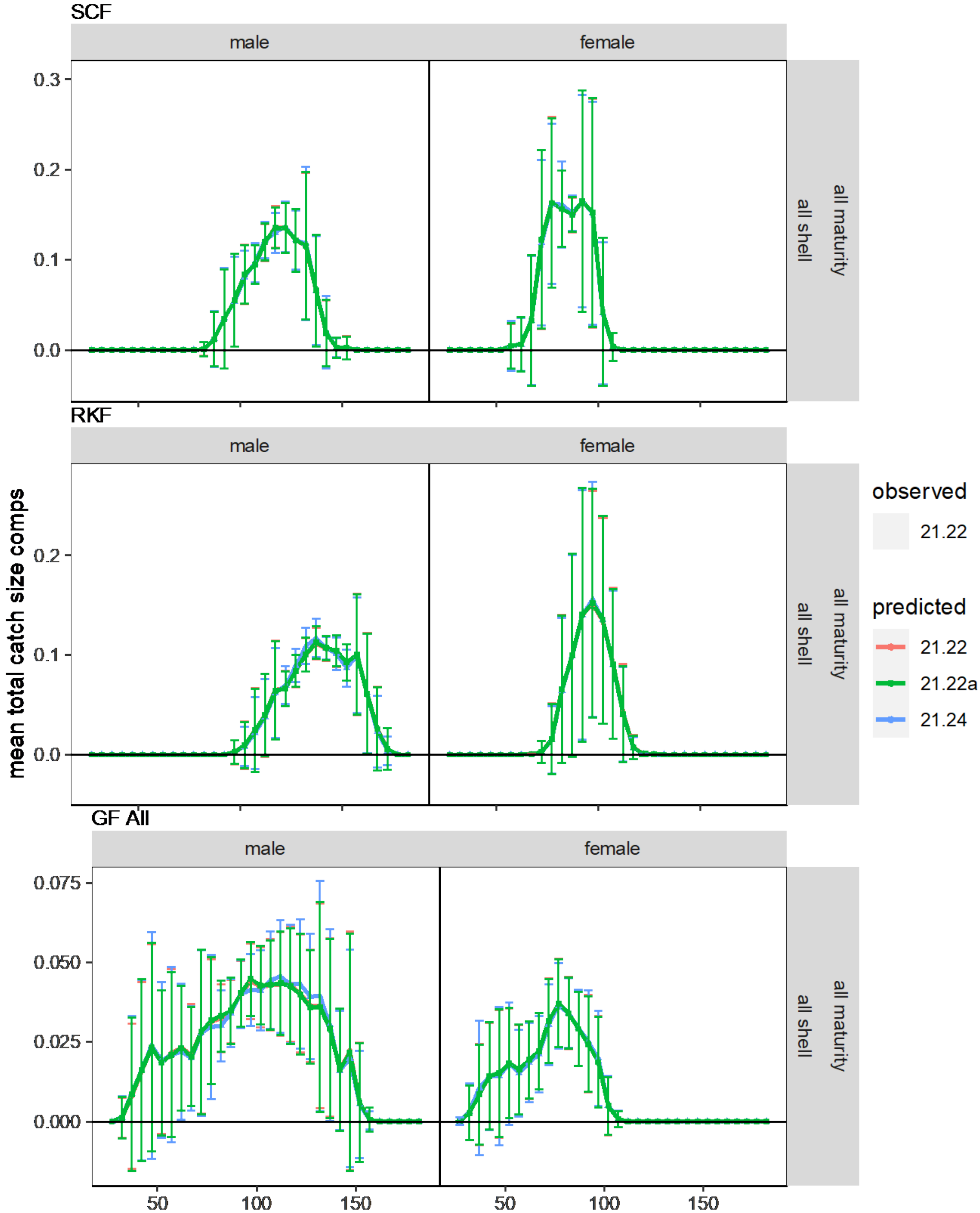

Figure 41 (cont.). Fits to bycatch fishery size compositions for the 21.XX scenarios. SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. The data in the 21.XX scenarios has had tail compression applied prior to fitting (hence the “observed” data is different between the upper and lower sets of plots).

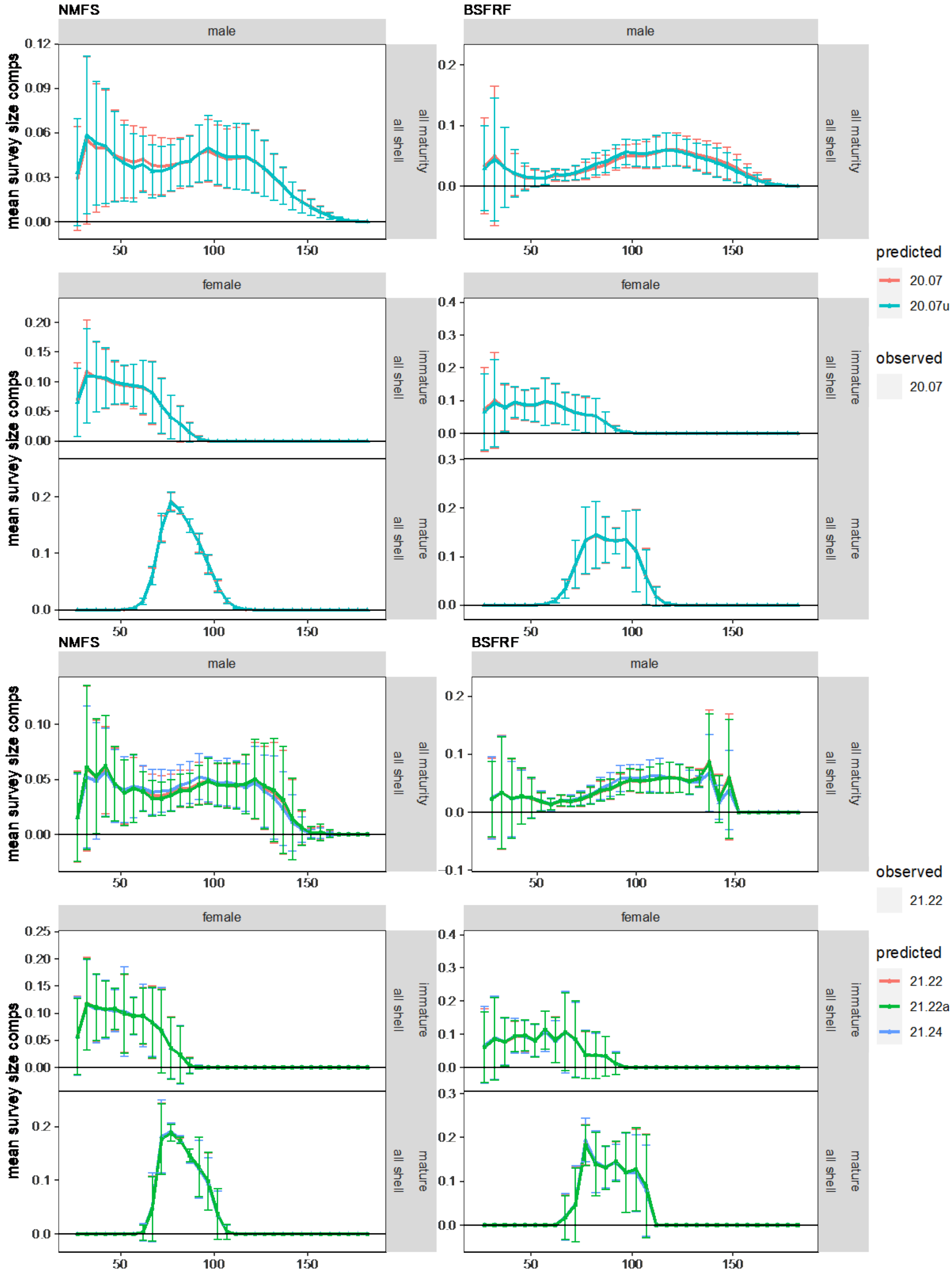

Figure 42. Fits to mean survey size compositions. Scenarios 20.07 and 20.07u: upper two rows; 21.XX scenarios: lower two rows. The data in the 21.XX scenarios has had tail compression applied prior to fitting (hence the “observed” data is different between the upper and lower sets of plots).

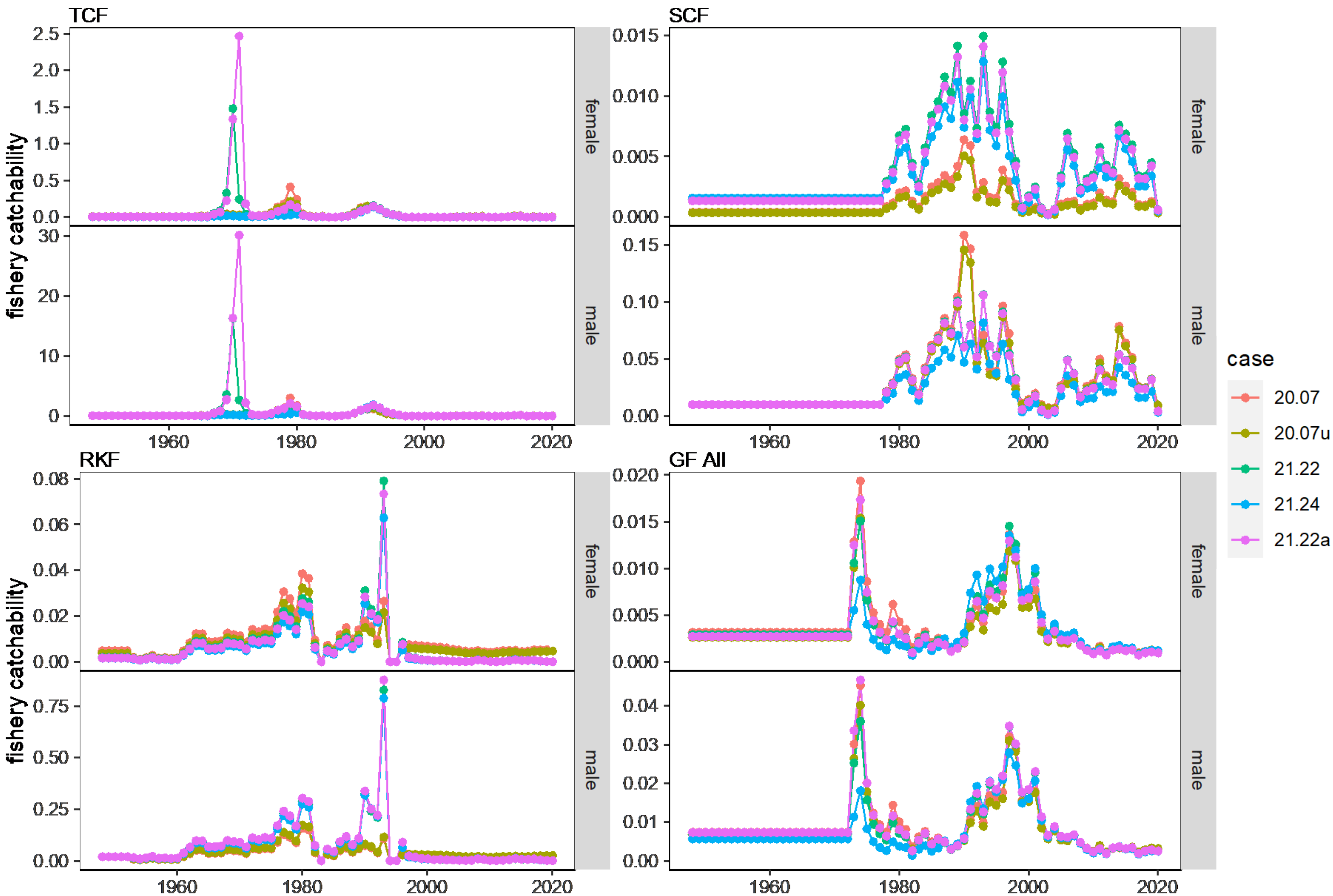

Figure 43. Fully-selected catchability (capture rates) in all fisheries from all model scenarios.

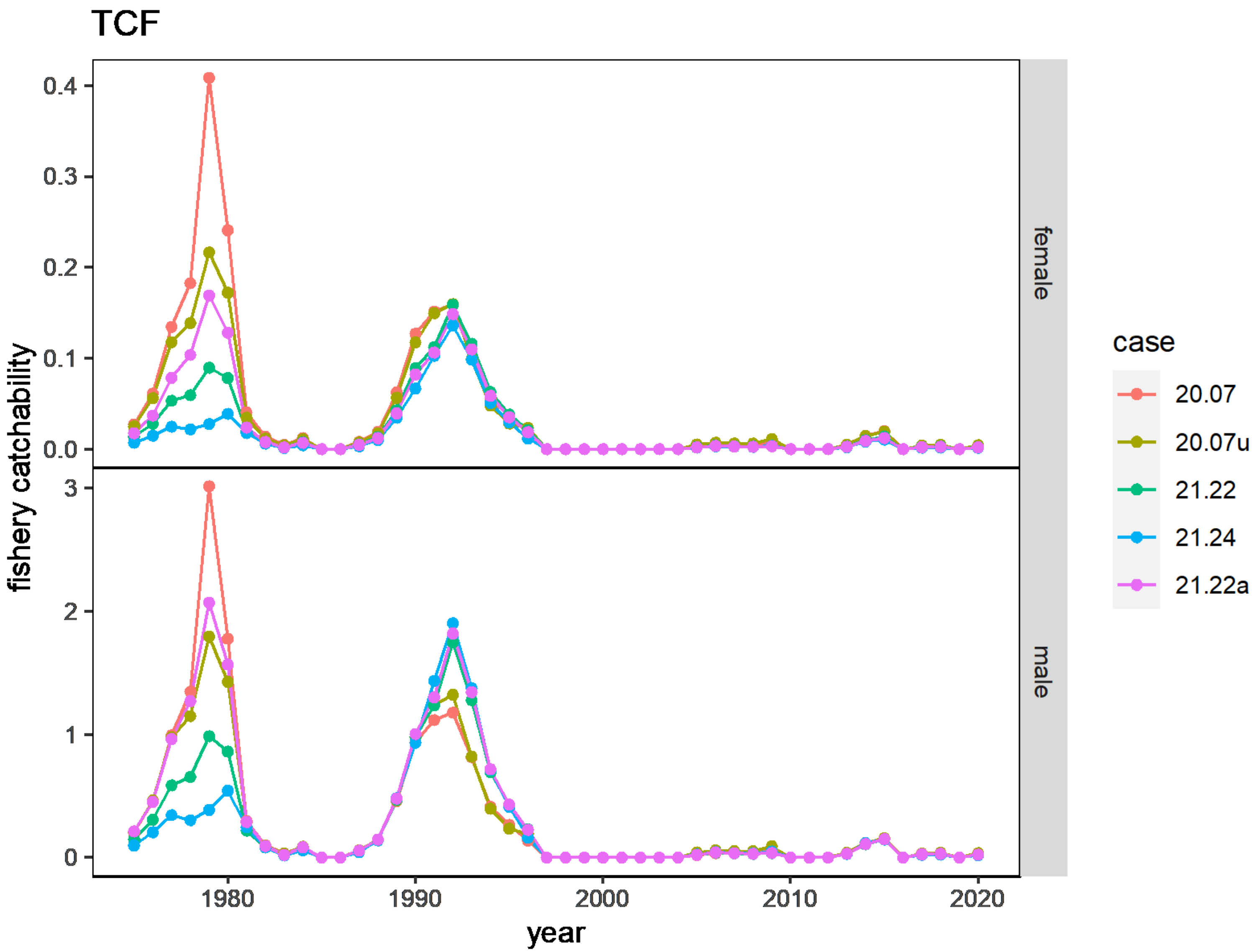

Figure 43 (cont.). Fully-selected catchability (capture rates) in the directed fishery (detail since 1975).

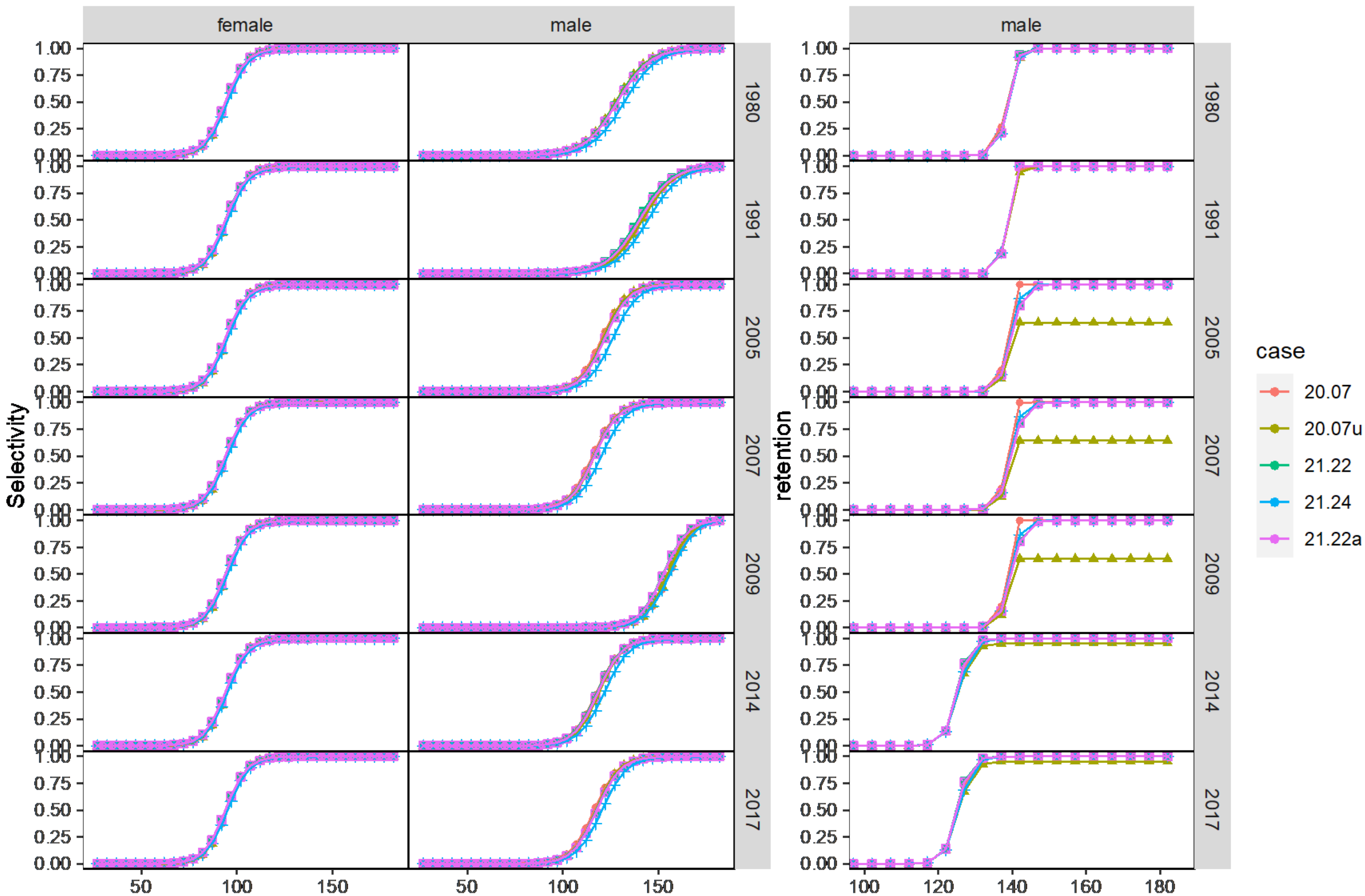

Figure 44. Directed fishery selectivity (left) and retention (right) curves from all scenarios. The size-at-50%-selected parameter for males varies annually for 1991+. In Scenarios 20.07 and 20.07u, maximum retain fractions are estimated; in the remaining scenarios, these were fixed to 1 (full retention of large crab).

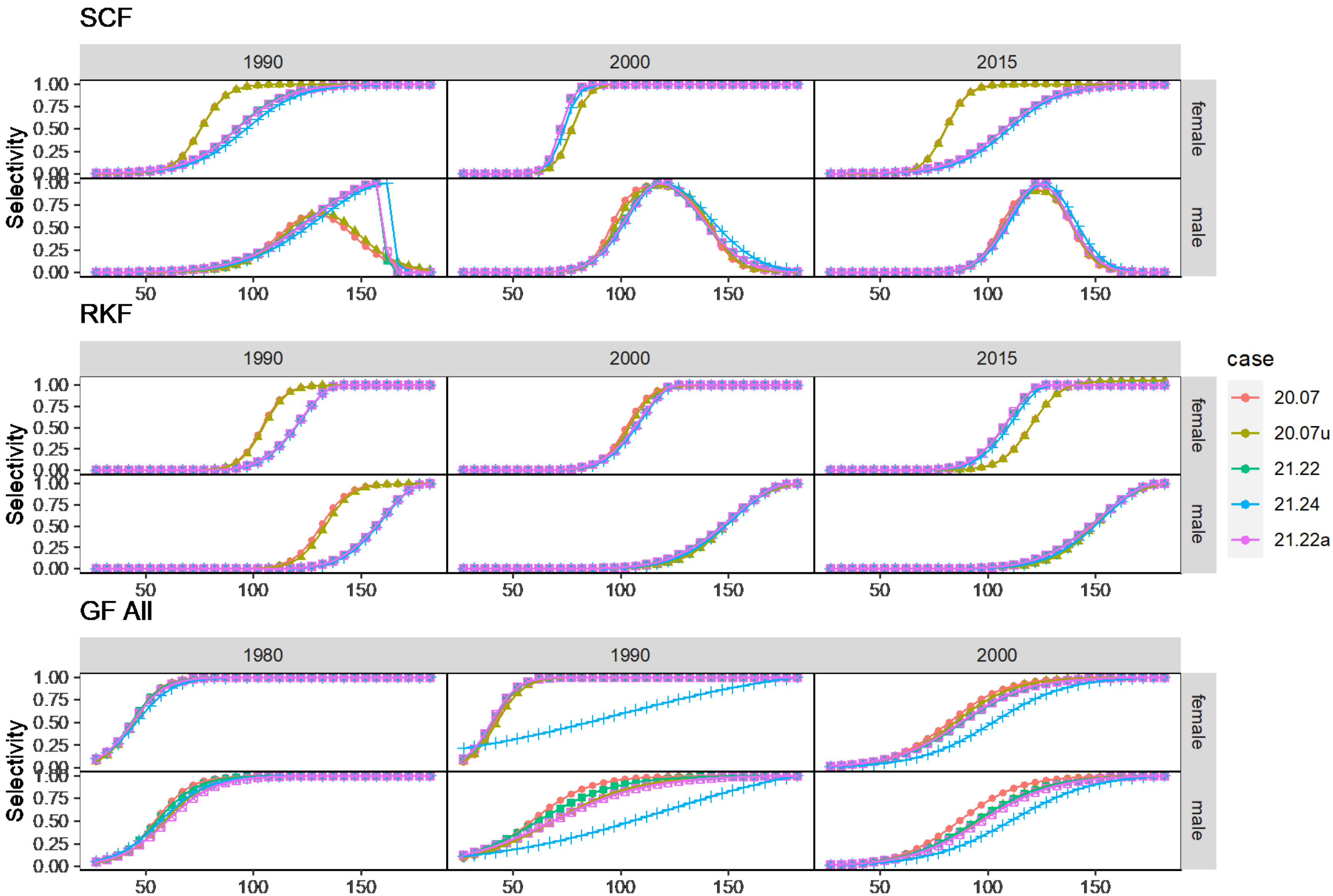

Figure 45. Bycatch selectivity curves from all scenarios for the snow crab fishery ("SCF"; pre-1997, 1997-2004, 2005+), the BBRKC fishery ("RKF", pre-1997, 1997-2004, 2005+), and the groundfish fisheries ("GF All"; ???)

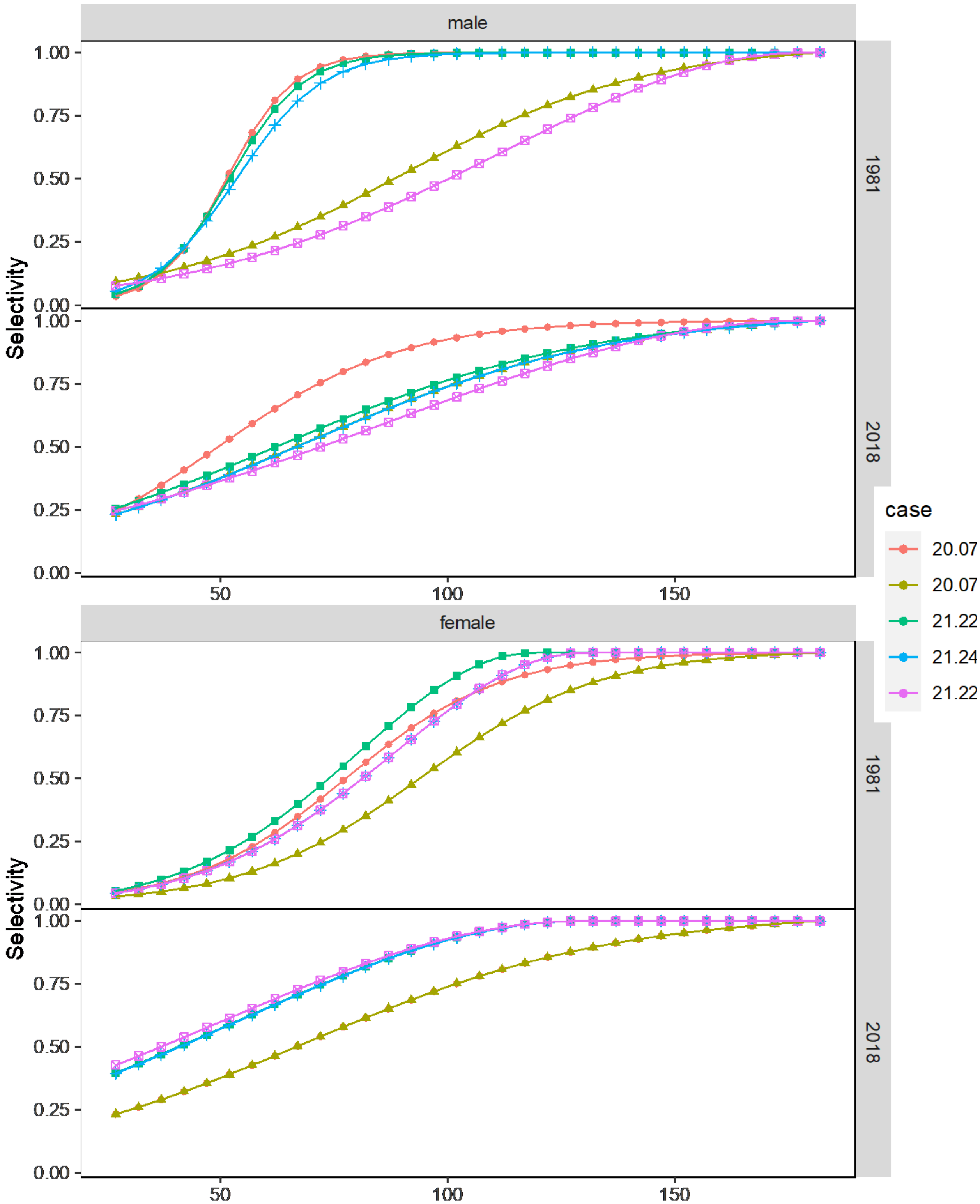

Figure 46. NMFS survey selectivity functions for all scenarios for the 1975-1981 and 1982+ time periods.

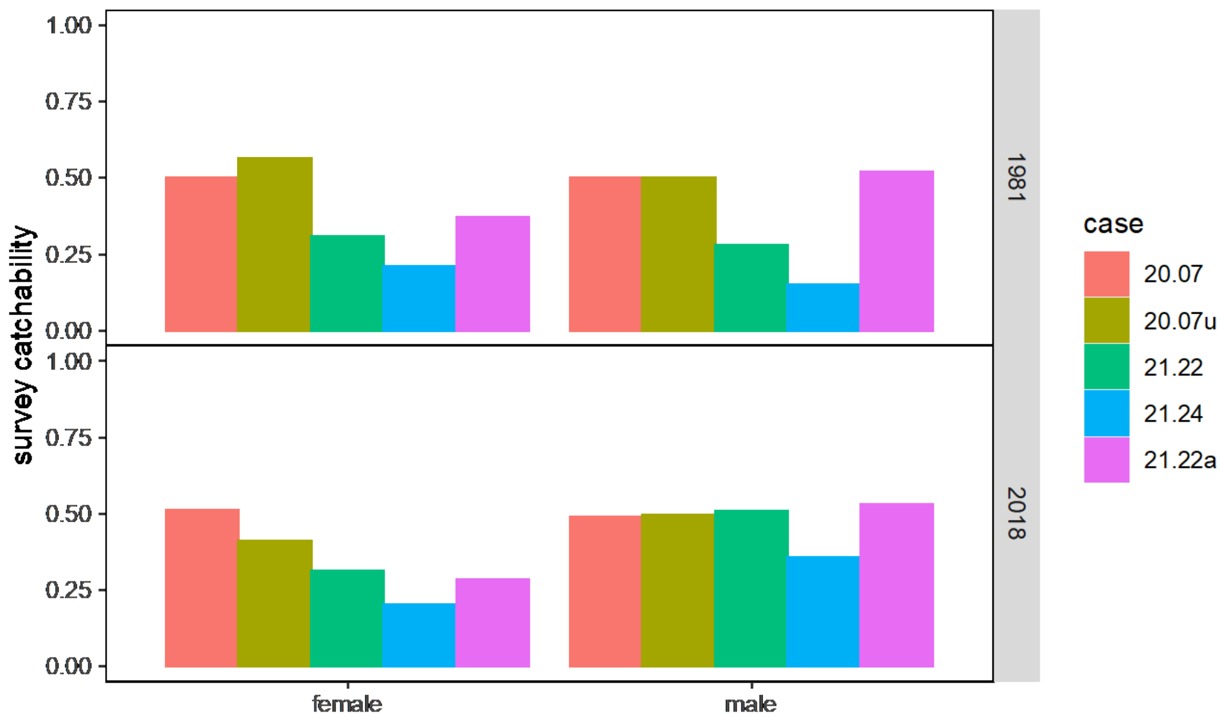

Figure 47. NMFS survey catchabilities from all scenarios for the 1975-1981 and 1982+ time periods.

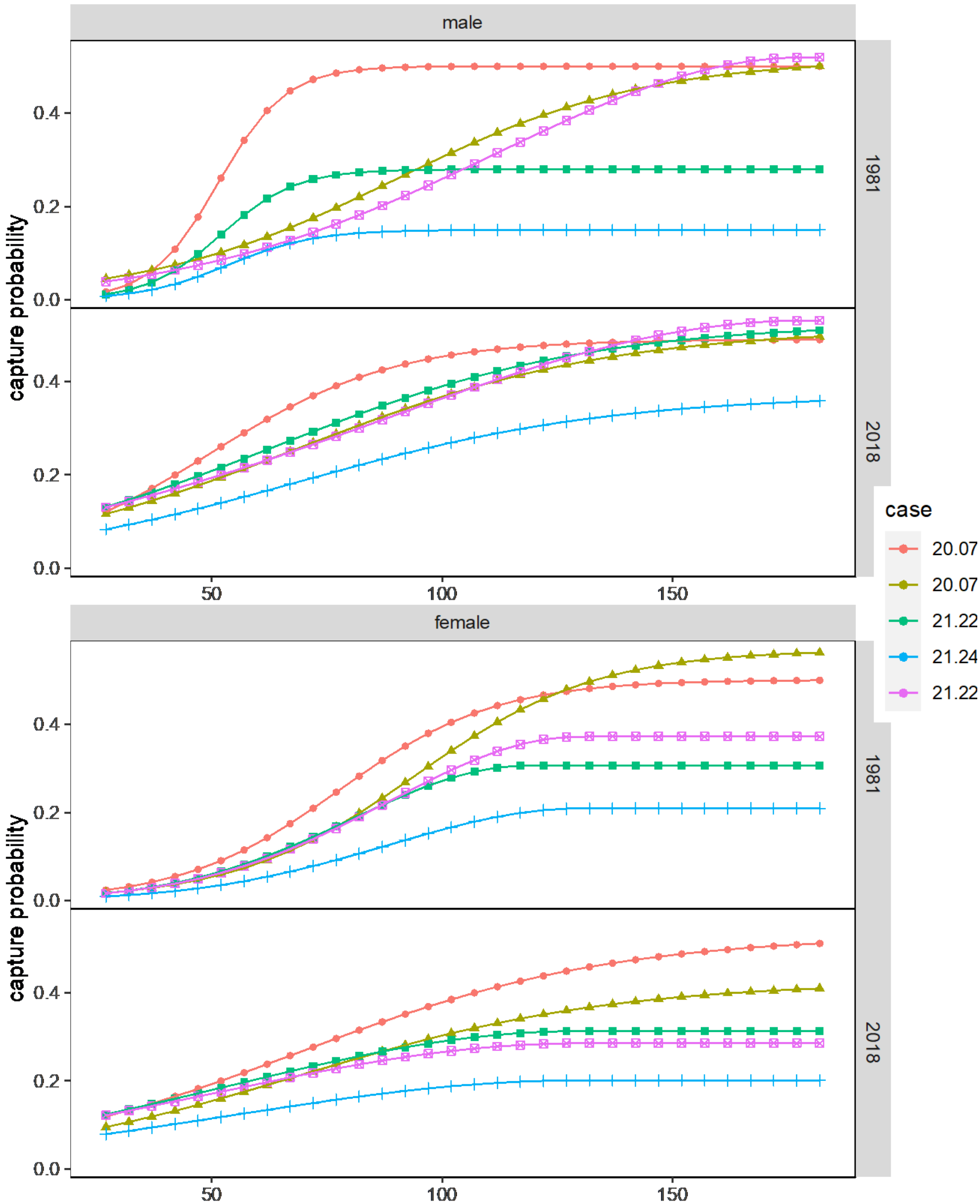

Figure 48. NMFS survey capture probabilities (fully-selected catchability x selectivity) for males from all scenarios for the 1975-1981 and 1982+ time periods.

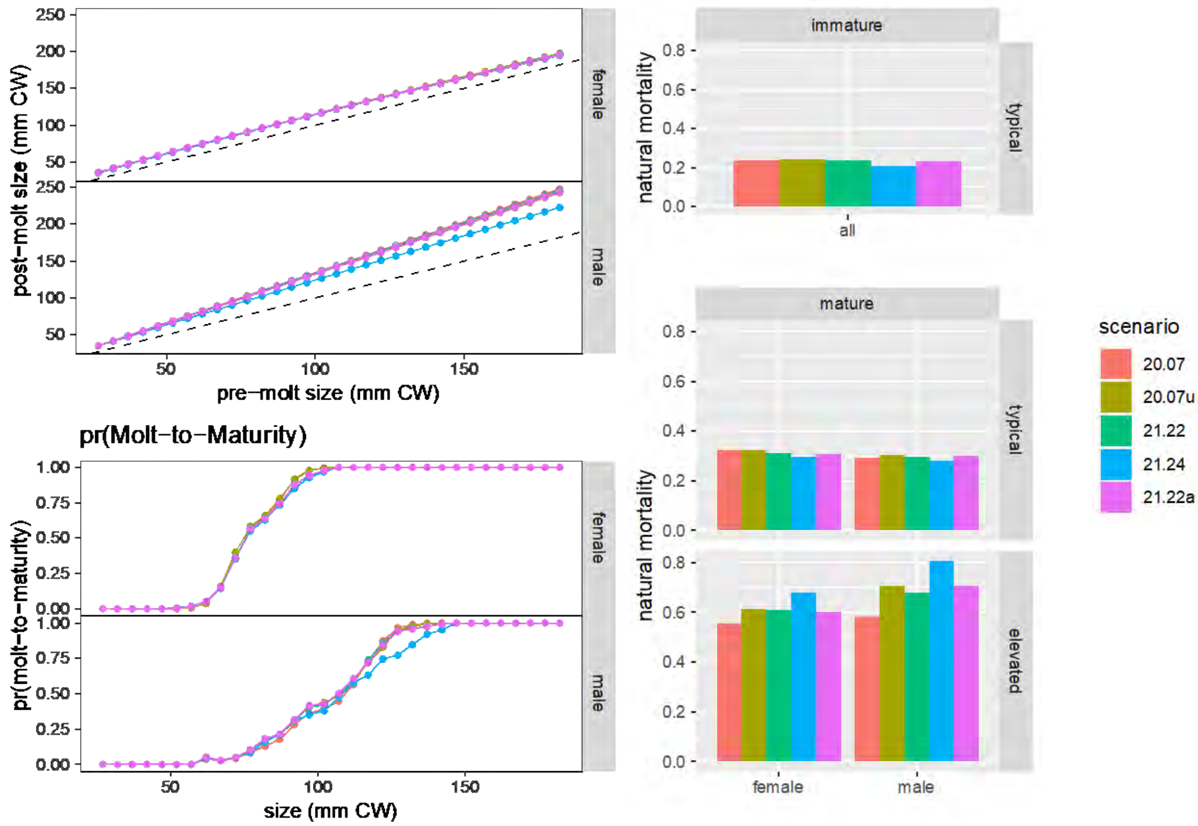

Figure 49. Estimates from all scenarios of mean growth (upper left plot), the probability of molt-to-maturity (lower left plot), and natural mortality by sex and maturity state (plots in righthand column). For natural mortality estimates, "elevated" refers to the 1980-1984 time period while "typical" refers to the rest of the model time period.

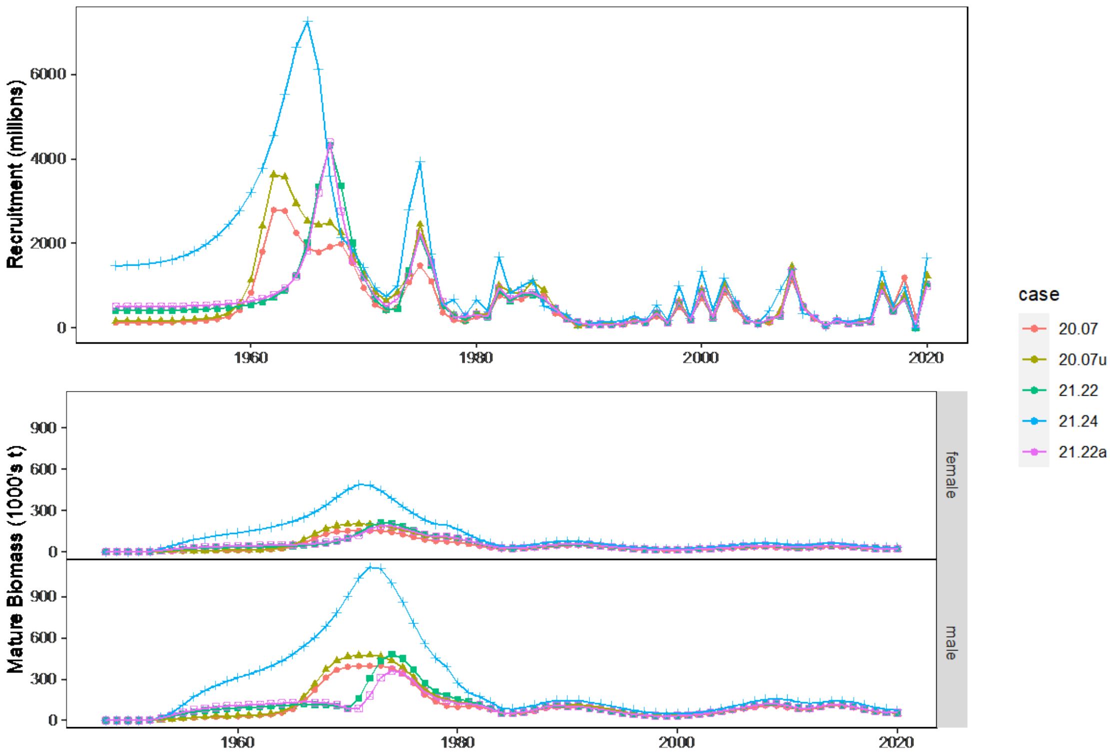

Figure 50. Estimated recruitment (upper plot) and mature biomass (lower plot) time series from all scenarios, entire model time period.

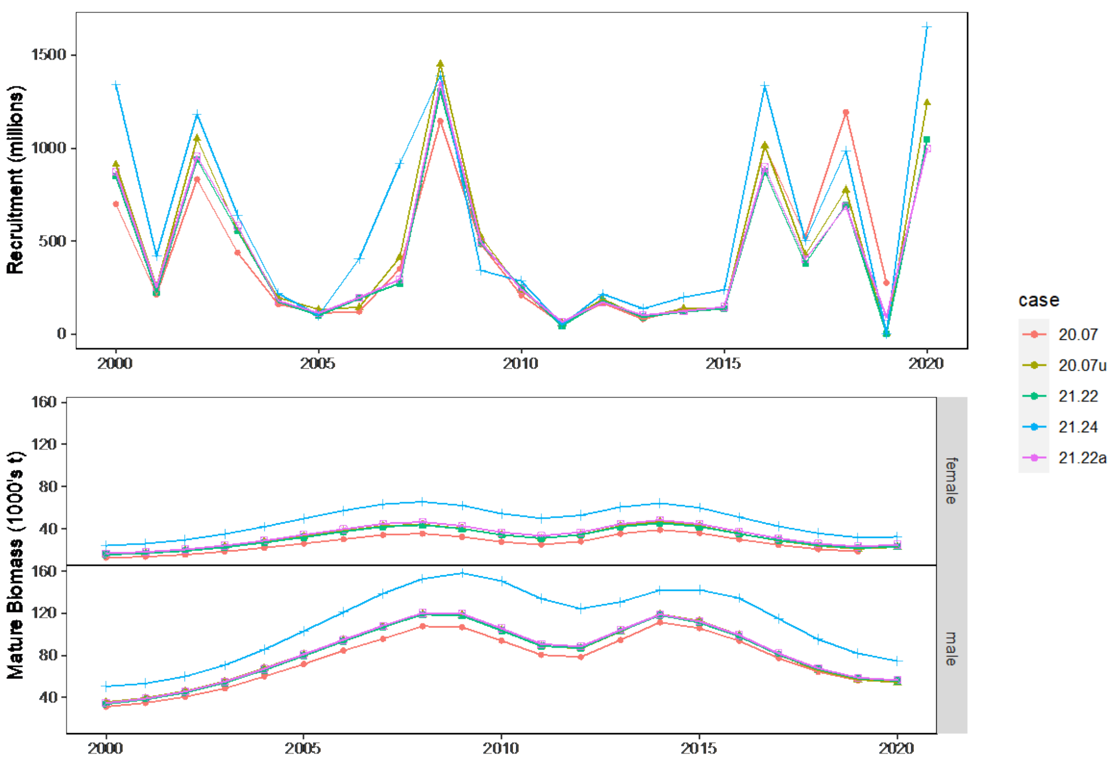

Figure 51. Estimated recruitment (upper plot) and mature biomass (lower plot) time series from all scenarios, recent time period.

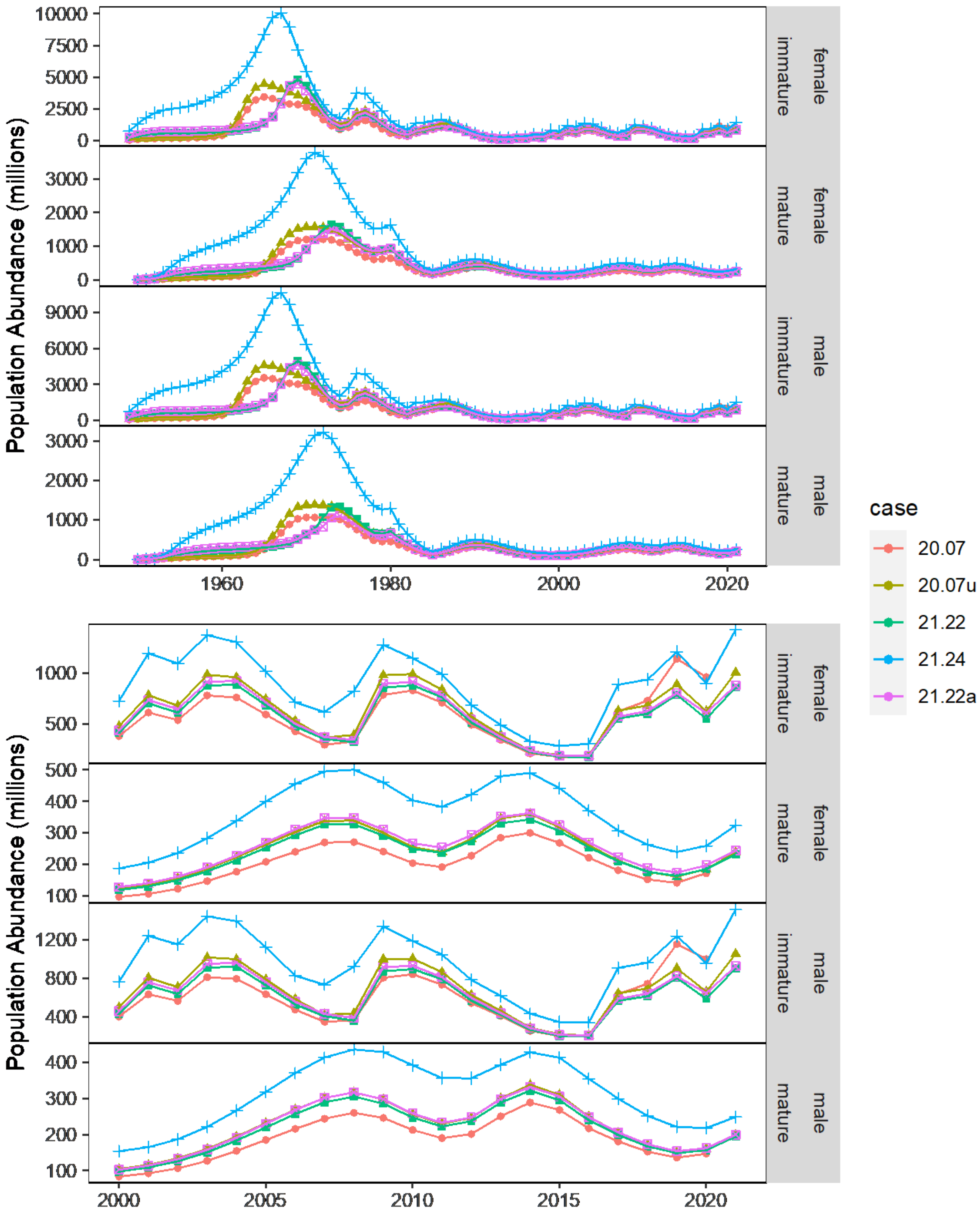

Figure 52. Time series of estimated population abundance (on July 1) time series by population category for all scenarios.

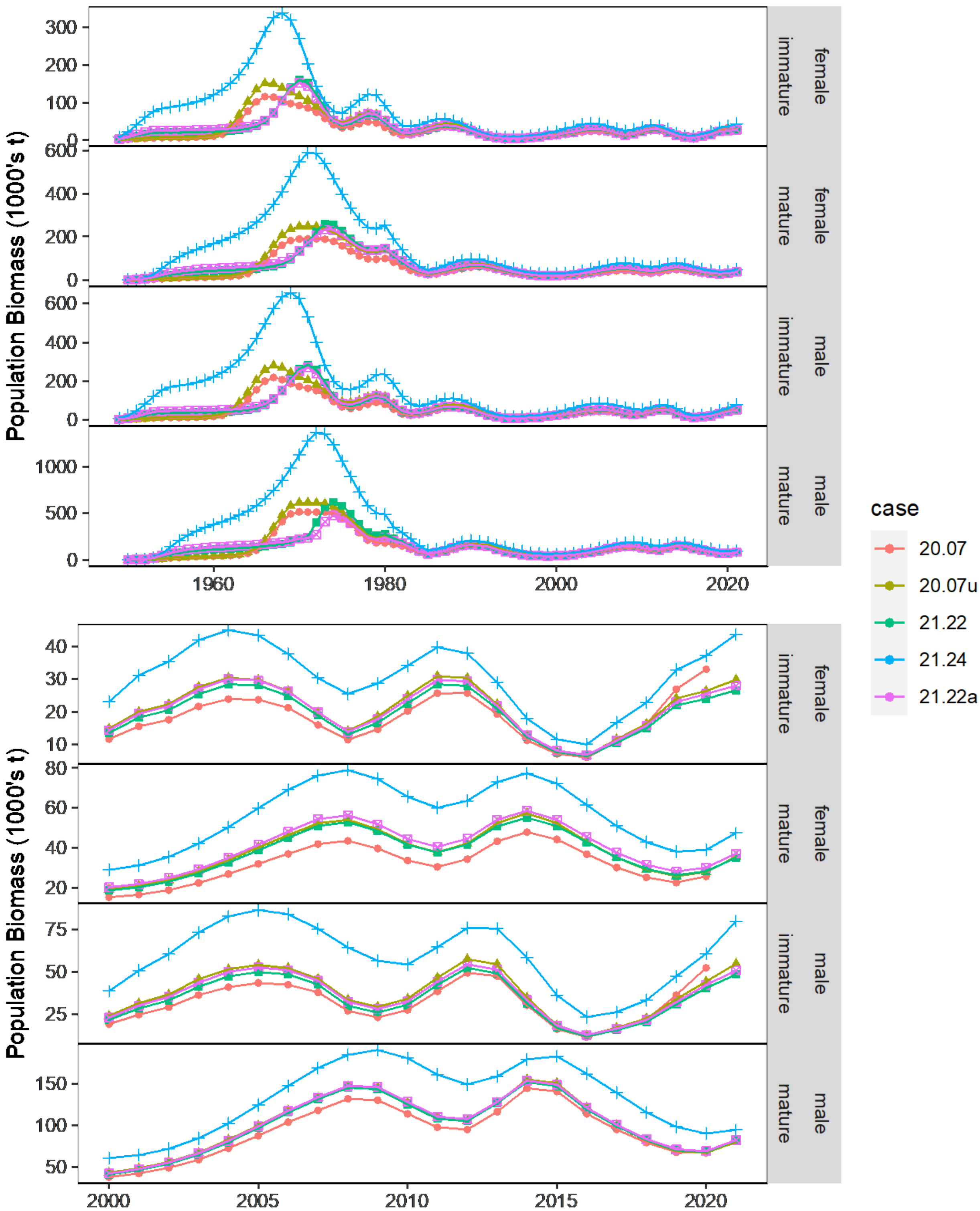

Figure 53. Estimated time series of population biomass (on July 1) by population category for all scenarios. Upper plots: entire model time period. Lower plots: recent time period.

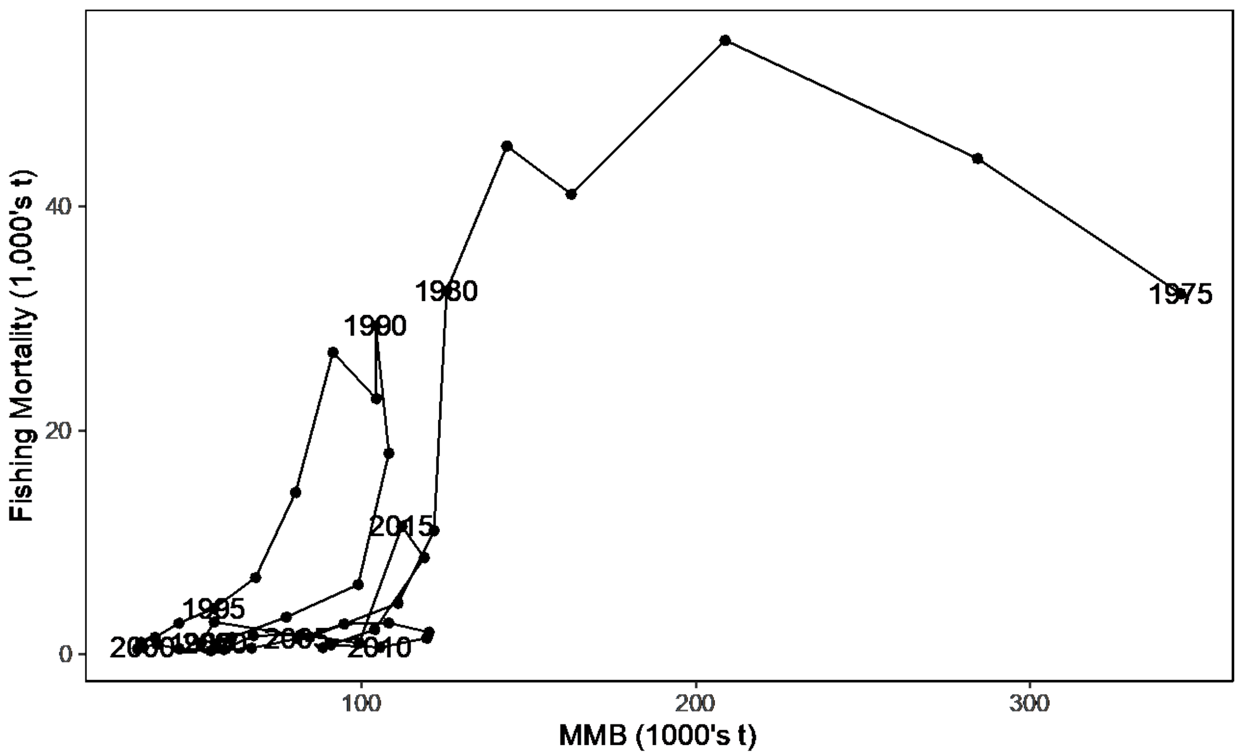

Figure 54. Estimated time series of total (retained + discards) fishing mortality vs. MMB for Scenario 21.22a.

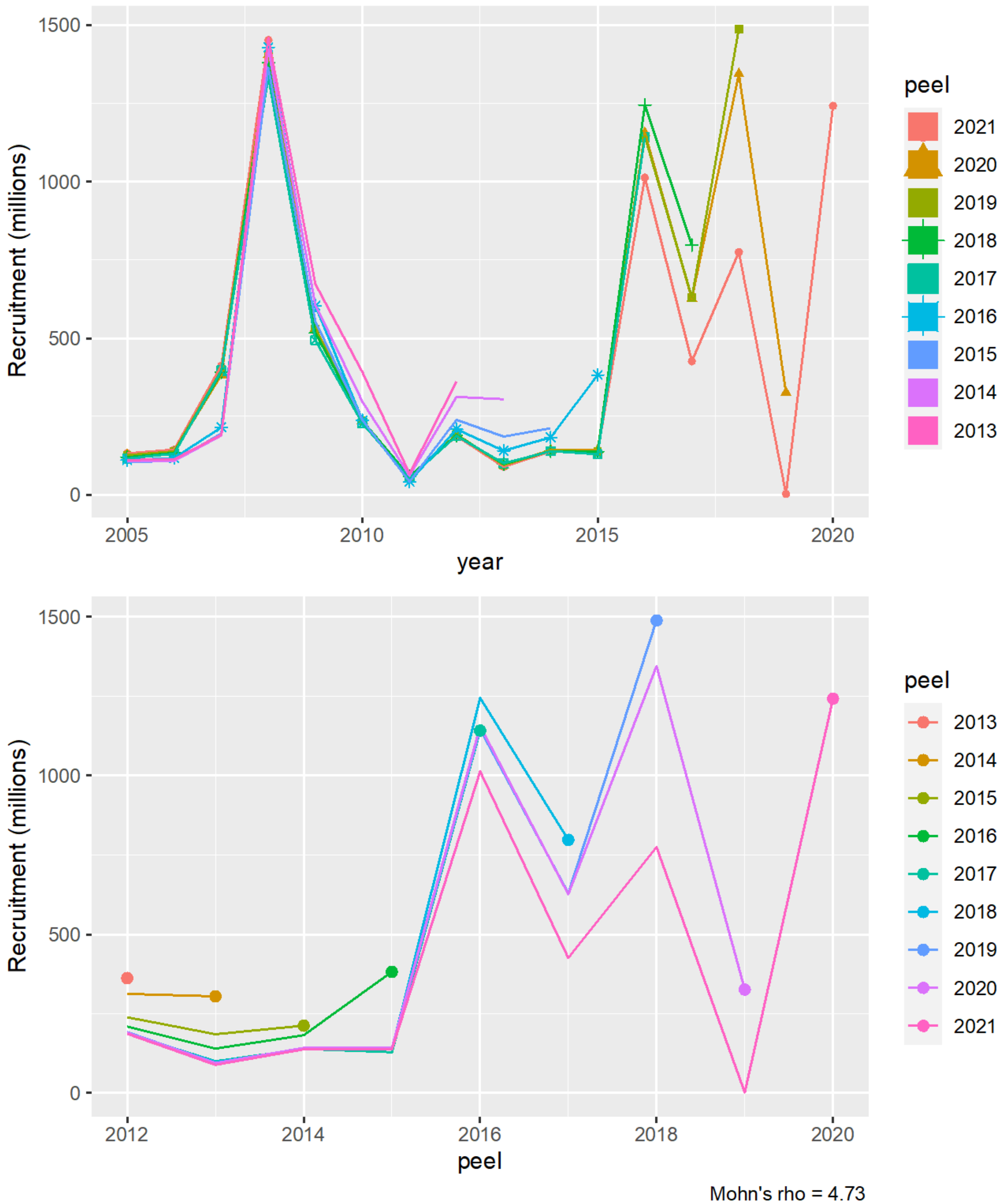

Figure 55. Retrospective patterns in recruitment in for Scenario 20.07u. (Note: legend colors are different between the plots).

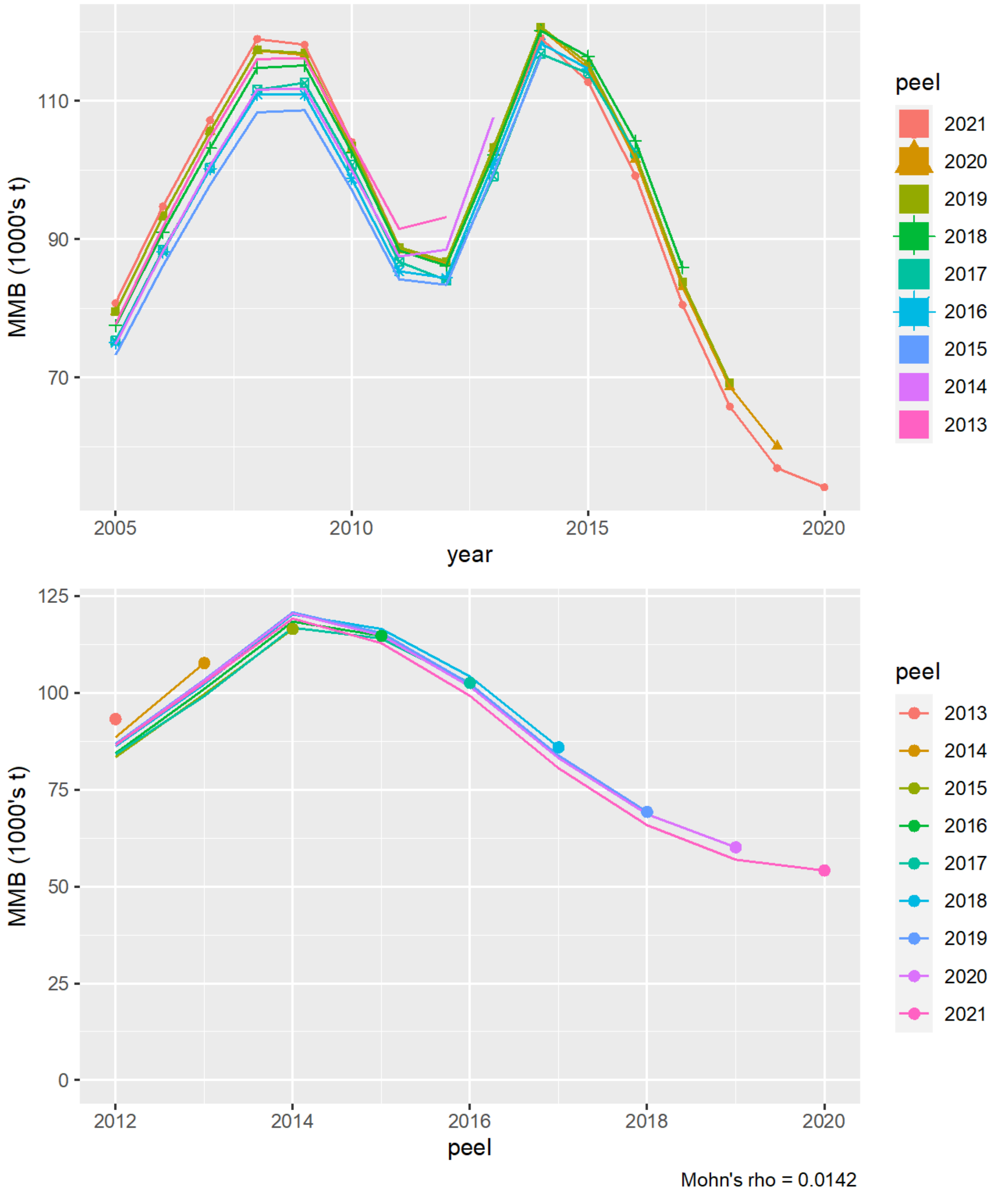

Figure 56. Retrospective patterns in MMB for 20.07u. (Note: legend colors are different between the plots).

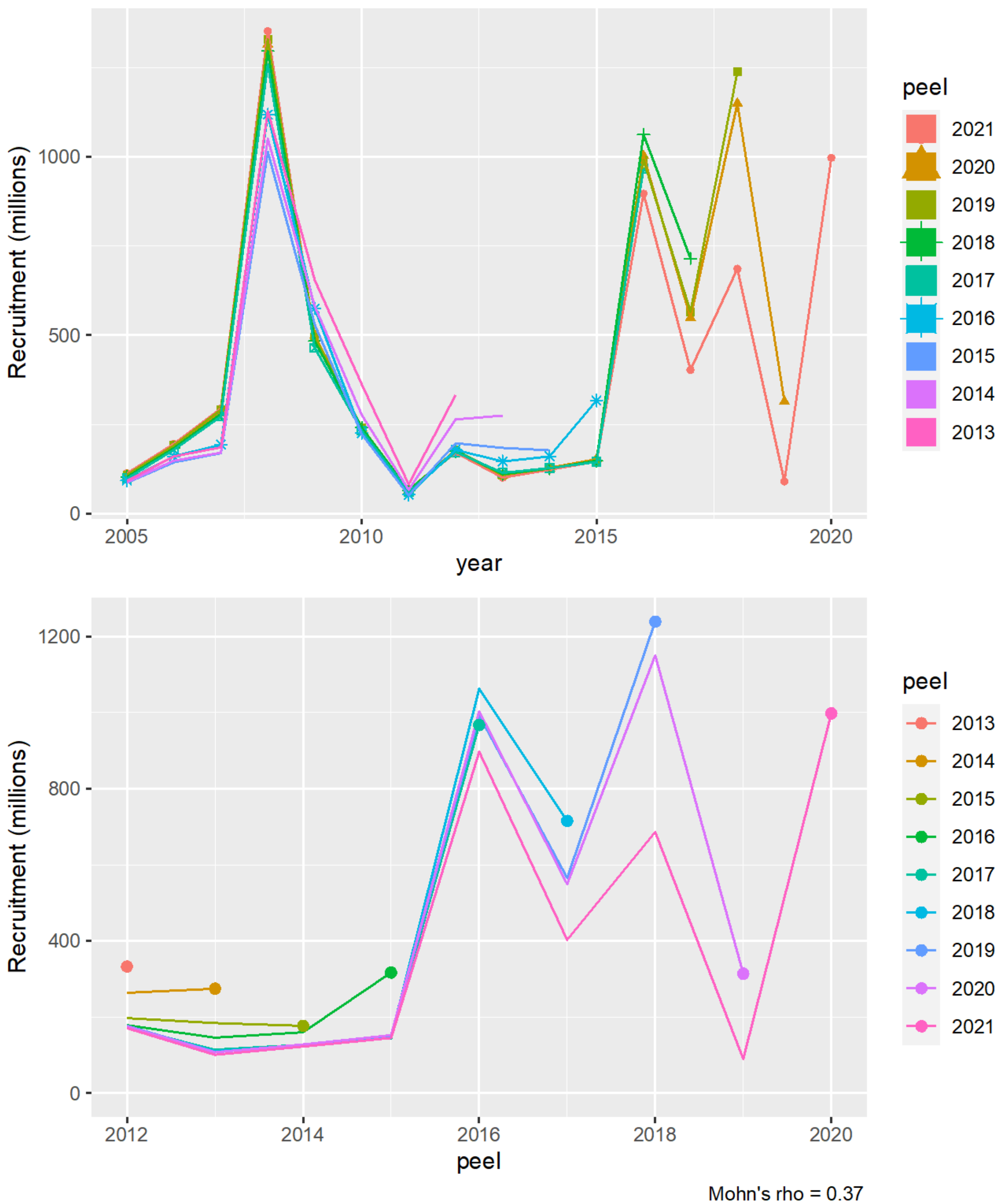

Figure 57. Retrospective patterns in recruitment in for Scenario 21.22a. (Note: legend colors are different between the plots).

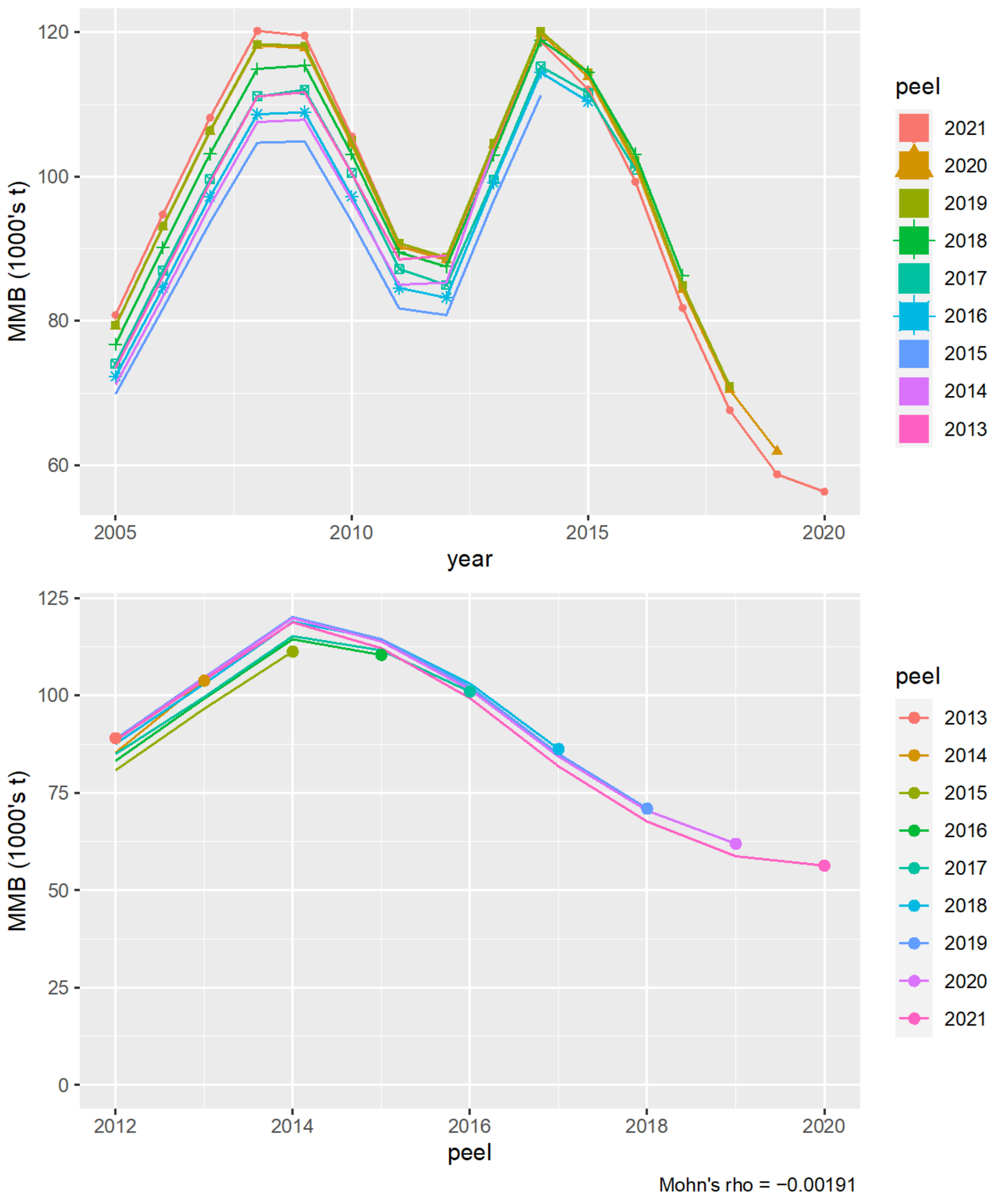

Figure 58. Retrospective patterns in MMB for 21.22a. (Note: legend colors are different between the plots).

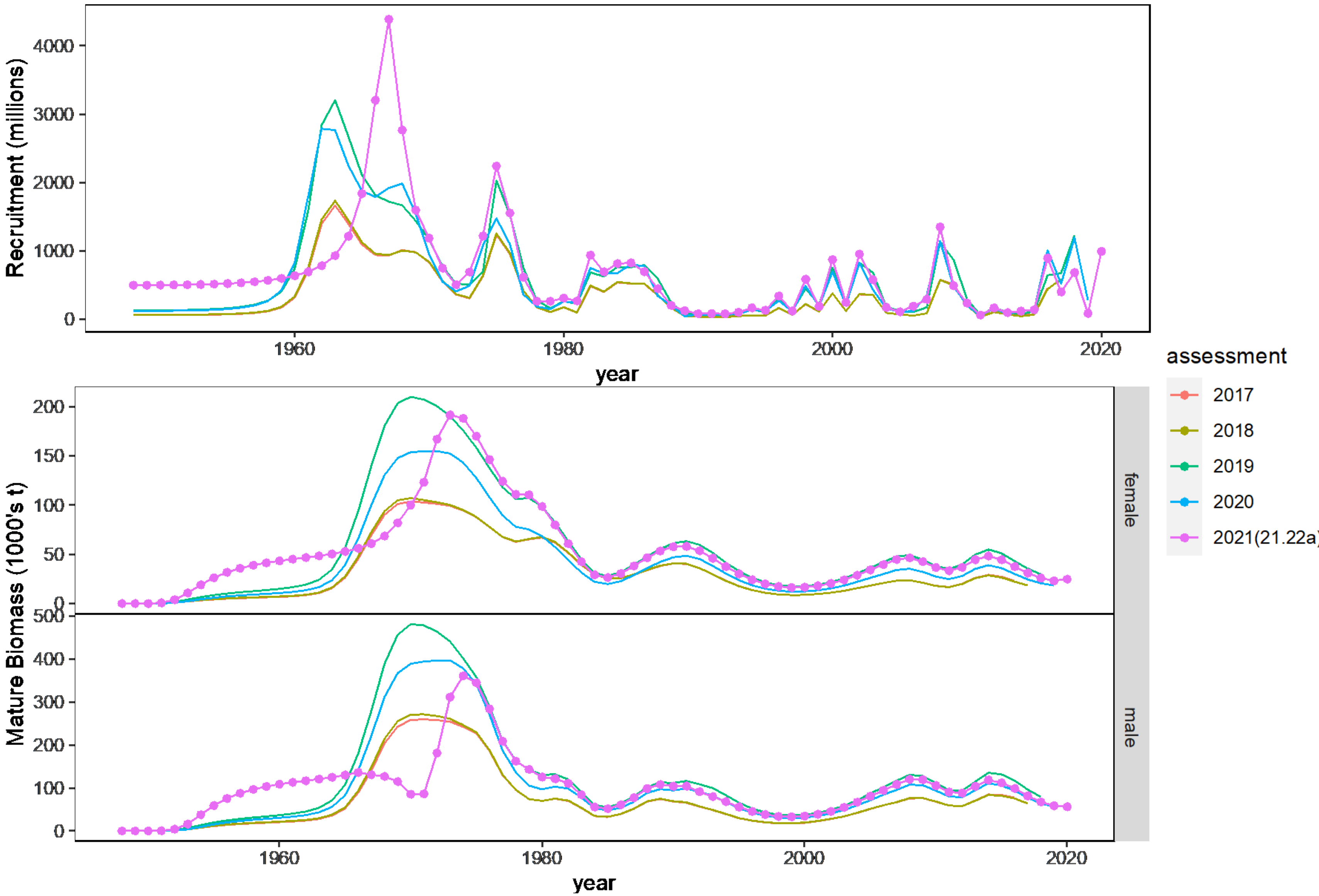

Figure 59. Comparison of the author's preferred scenario, 21.22a, with previous assessment results for recruitment (uppermost plot) and mature biomass (lower two plots).

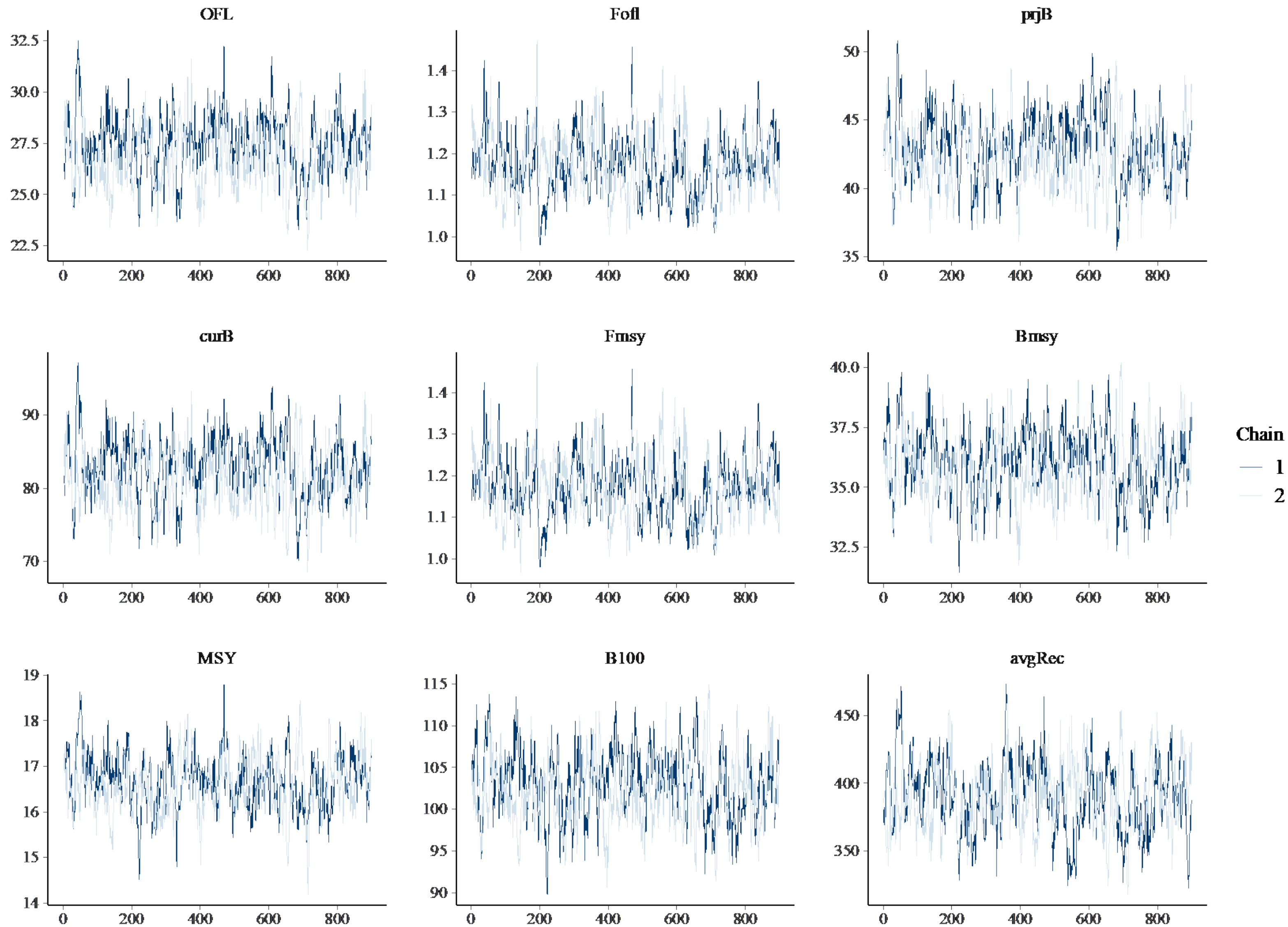

Figure 60. Traces for OFL-related quantities from 2 MCMC chains for Scenario 21.22a. Chains were run using ADMB's standard MCMC algorithm for 10 million iterations, with a 1 million step burn-in and every 10,000th iteration saved.

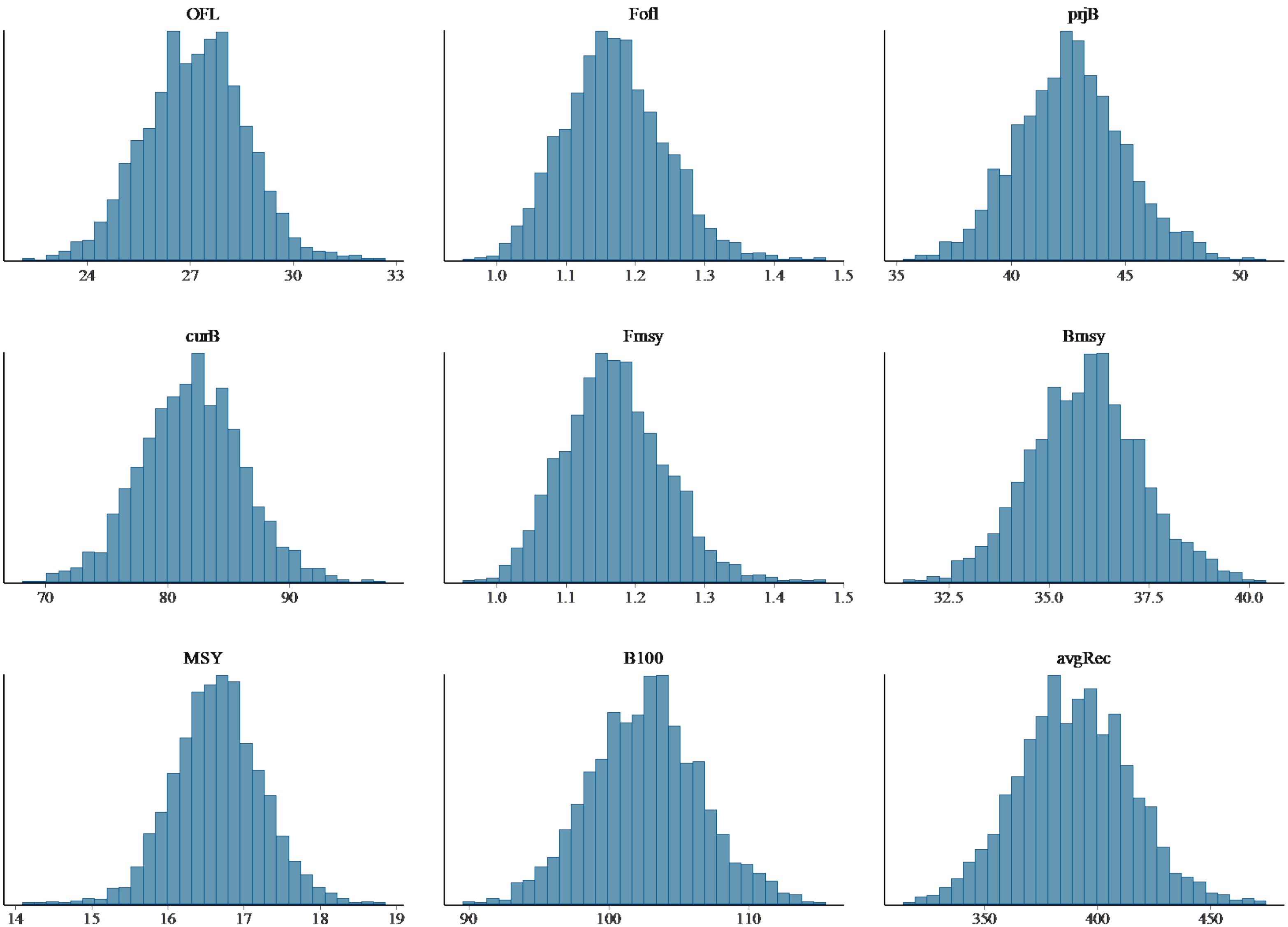

Figure 61. Histograms for OFL-related quantities from 2 MCMC chains for Scenario 21.22a. Chains were run using ADMB's standard MCMC algorithm for 10 million iterations, with a 1 million step burn-in and every 10,000th iteration saved.

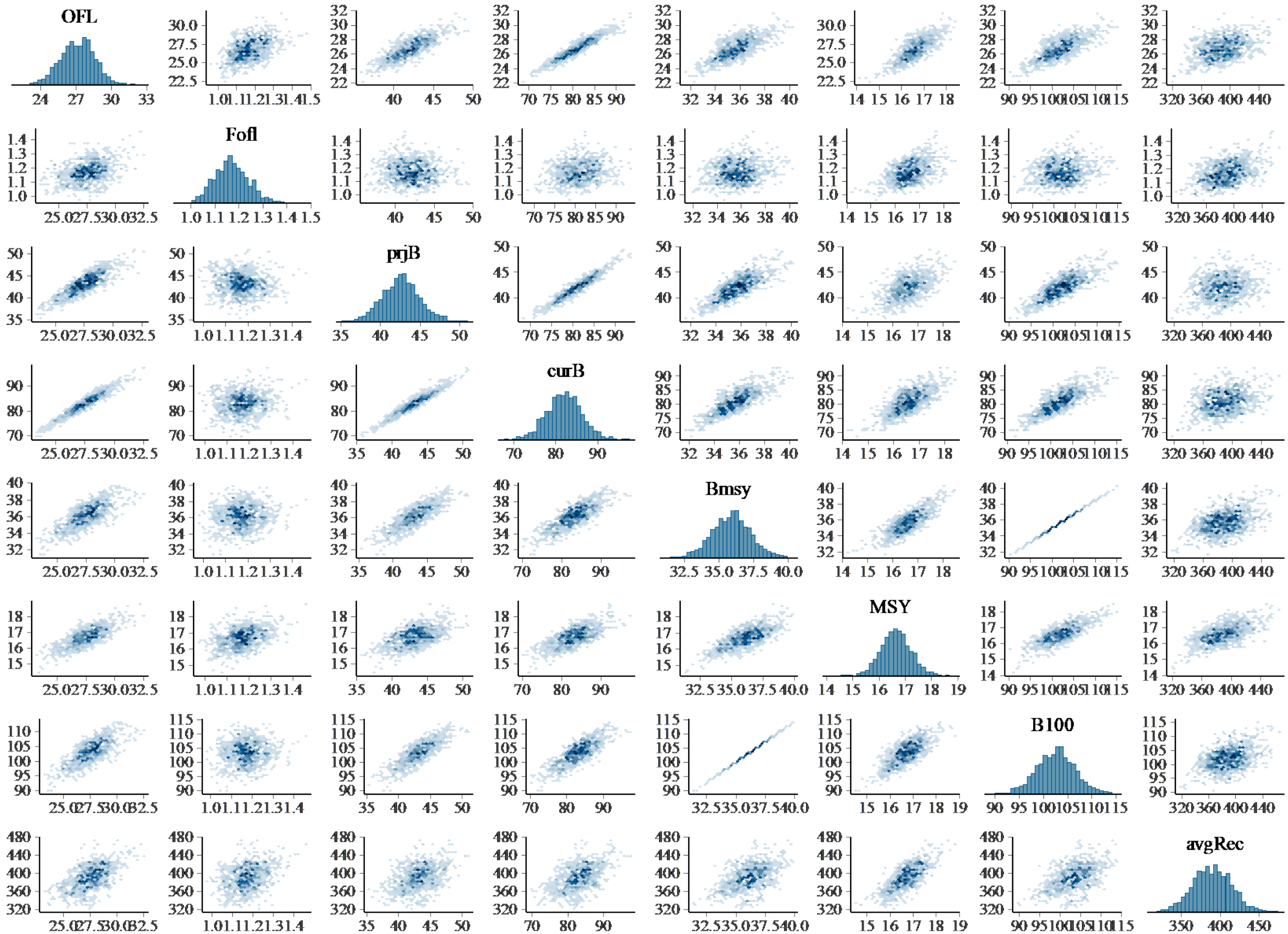

Figure 62. Pairs plots for OFL-related quantities from 2 MCMC chains for Scenario 21.22a. Chains were run using ADMB's standard MCMC algorithm for 10 million iterations, with a 1 million step burn-in and every 10,000th iteration saved.

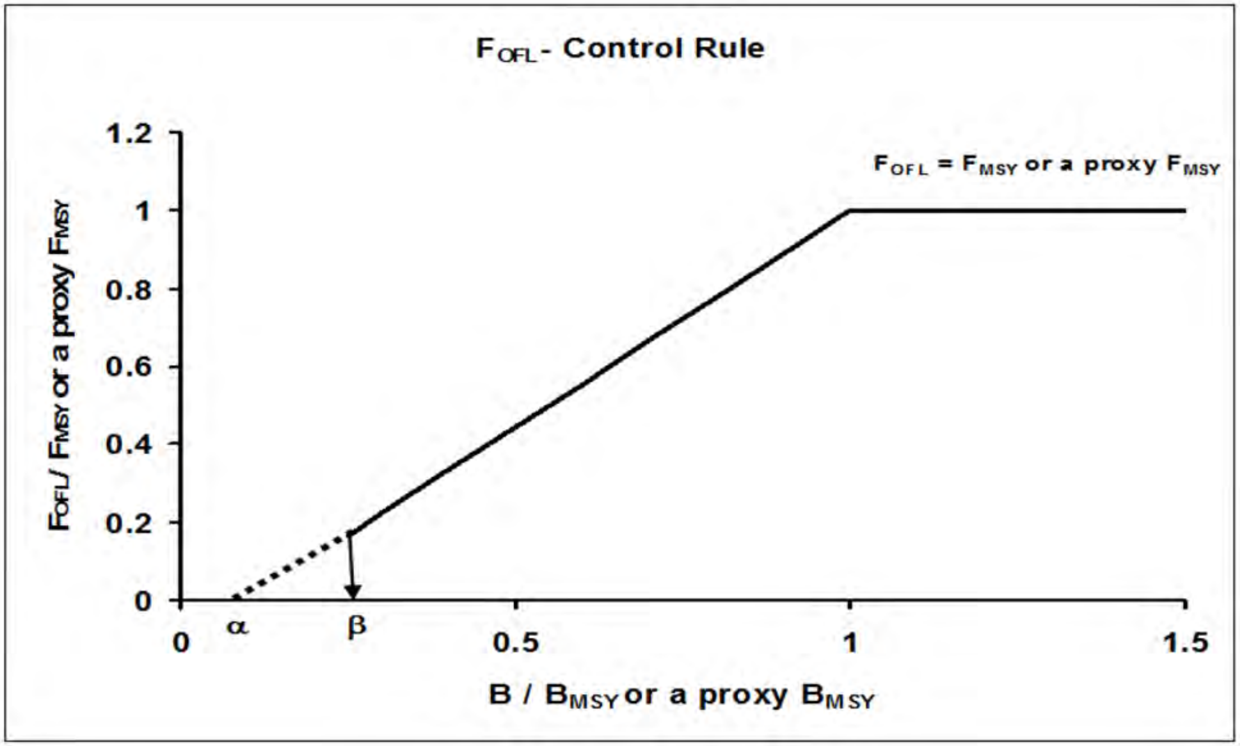

Figure 63. The F_{OFL} harvest control rule.

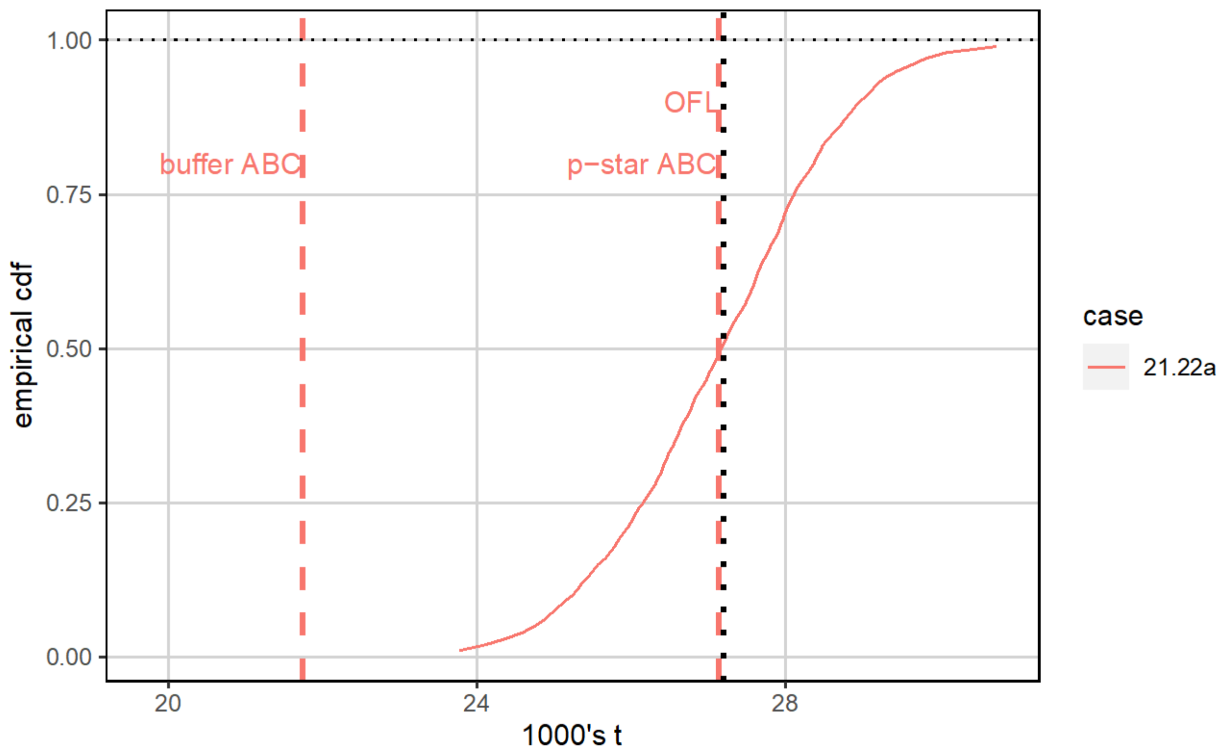

Figure 64. The MCMC OFL, p-star ABC, and 20% buffer ABC from the author's preferred model, scenario 21.22a. 2 MCMC chains were merged to obtain the empirical distribution determining the p-star ABC. The dotted vertical line indicates the estimated OFL at the MLE.

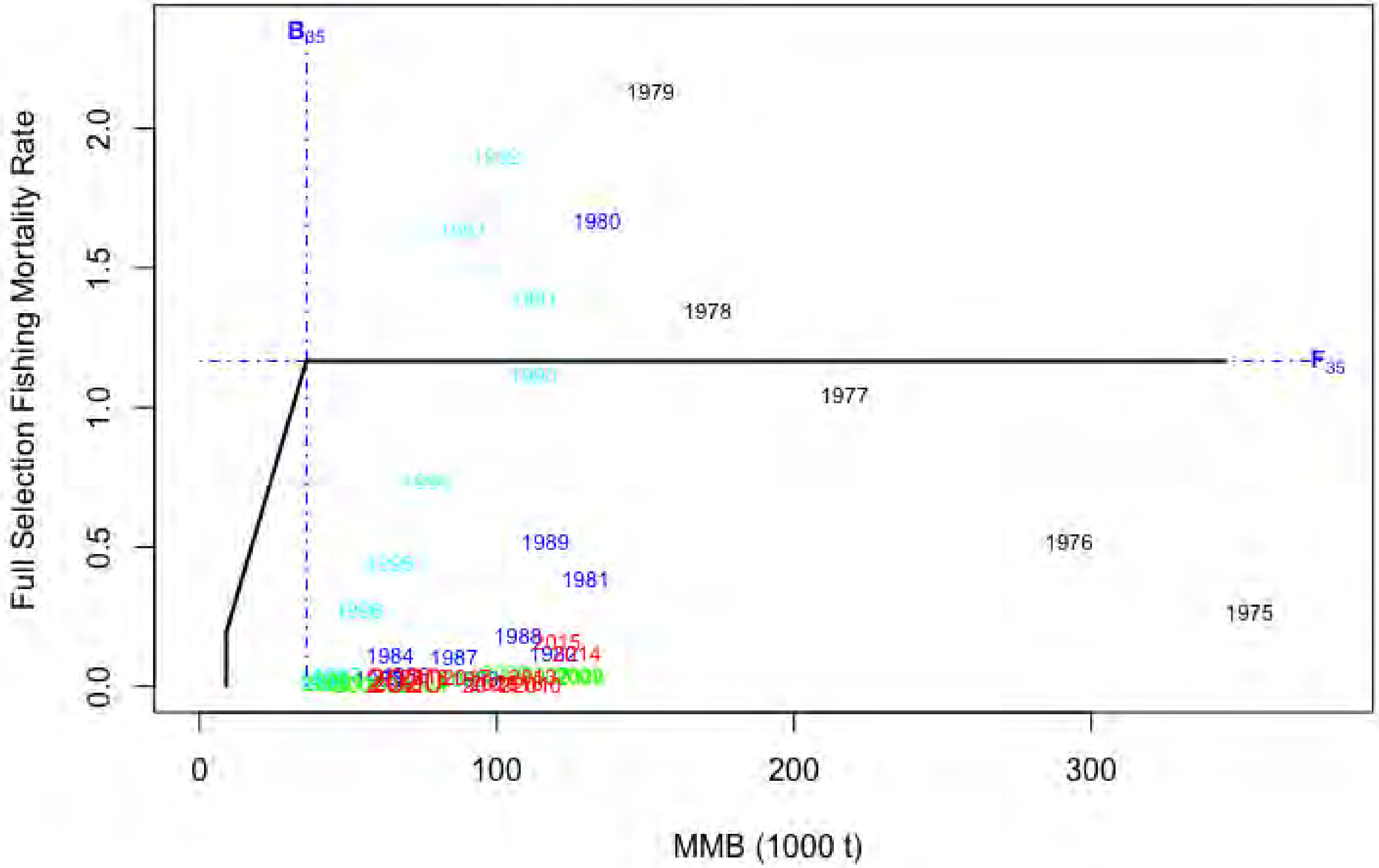

Figure 65. Quad plot for the author's preferred model, Scenario 21.22a. Estimated values are shown starting in 1975.

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

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Alaska Fisheries Science Center
September 2021

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 2021 assessment model code is available at "202009CPTVersion"). TCSAM02 was first used for the Tanner crab assessment in 2017 (Stockhausen, 2017) and will be used until a transition is made to Gmacs (the Generalized Model for Alaska Crab Stocks). Gmacs is intended to be used for all crab stock assessments conducted for the North Pacific Fisheries Management Council (NPFMC), including both lithodid (king crab) and *Chionoecetes* (Tanner and snow crab) stocks, while TCSAM02 is specific to *Chionoecetes* biology (i.e., terminal molt).

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

New features (2021 assessment):

1. Dirichlet-Multinomial likelihood for fitting size composition data added as an option.
2. Ability to specify "tail compression" (on a by-dataset basis) when fitting size composition data.
3. "Use flags" (with values 0 or 1) have been added to input data files to allow aggregate catch data and size composition data inputs to be easily removed (or added back in) from any likelihood at an annual level.
4. Ascending normal and double-normal (with plateau) selectivity functions have been implemented as options.
5. Outputs reflecting model fits have been expanded.

New features (2020 assessment):

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

Model Description

A. General population dynamics

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

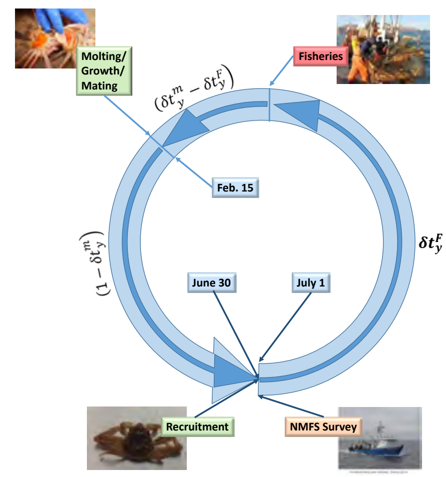

Fig. 1. Timing of annual events in TCSAM02 when fisheries occur before molting/growth/mating.

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 ($\delta t_y^F \le \delta t_y^m$) 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 $\delta t_y^F \le \delta t_y^m$

Step A1.1: Survival prior to fisheries

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

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

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

Step A1.2: Prosecution of the fisheries

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

$n^2_{y,x,m,s,z} = e^{-F^T_{y,x,m,s,z}} \cdot n^1_{y,x,m,s,z}$	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^m_y (generally Feb. 15). The numbers surviving to δt^m_y in year *y* are given by:

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

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_y^m (generally Feb. 15). The numbers surviving at δt_y^m in year *y* are given by:

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

$n_{y,x,MAT,NS,z}^2 = \phi_{y,x,z} \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n_{y,x,IMM,NS,z'}^1$	A2.2a
$n_{y,x,IMM,NS,z}^2 = (1 - \phi_{y,x,z}) \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n_{y,x,IMM,NS,z'}^1$	A2.2b
$n_{y,x,MAT,OS,z}^2 = n_{y,x,MAT,OS,z}^1 + n_{y,x,MAT,NS,z}^1$	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_y^F). The numbers surviving at δt_y^F in year *y* are then given by:

$n_{y,x,m,s,z}^3 = e^{-M_{y,x,m,s,z} \cdot (\delta t_y^F - \delta t_y^m)} \cdot n_{y,x,m,s,z}^2$	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_y^F in year *y*. The numbers that remain after the fisheries are prosecuted are given by:

$n_{y,x,m,s,z}^4 = e^{-F_{y,x,m,s,z}^T} \cdot n_{y,x,m,s,z}^3$	A2.4

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

Step 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:

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

B. Parameter specification

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

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

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

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

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

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

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

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

C. Model processes: natural mortality

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

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

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

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

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

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

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

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

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

$\delta\mu^2_{\{y,x,m,s\}\in\{T=1980-1984,X=x,M=MAT,S=ALL\}} = \delta M^T_{x,MAT}$	C.4g

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

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

D. Model processes: growth

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

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

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

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

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

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

$\alpha_{t,x,z'} = \left[\bar{z}_{t,x,z'} - z'\right]/\beta_{t,x}$	Mean molt increment, scaled by $\beta_{t,x}$	D.2d
$\bar{z}_{t,x,z'} = e^{a_{t,x}} \cdot z'^{b_{t,x}}$	Mean size after molt, given pre-molt size z'	D.2e

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

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

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

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

E. Model processes: maturity (terminal molt)

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

$n^{+}_{y,x,IMM,NS,z} = \left(1 - \phi_{t,x,z}\right) \cdot n_{y,x,IMM,NS,z}$	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:

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

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

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

F. Model processes: recruitment

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

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

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

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

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

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

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

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

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

$\beta_t = e^{pLnRb_t}$	gamma distribution shape parameter	F.8

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

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

G. Selectivity and retention functions

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

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

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

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

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

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

H. Fisheries

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

I. Surveys

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

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

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

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

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

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

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

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

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

J. Model fitting: objective function equations

The TCSAM02 model is fit by minimizing an objective function, $\mathcal{O}$, 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 can be fitted using a multinomial or Dirchlet-Multinomial likelihood (Thorson et al. 2019). The multinomial likelihood is:

$\ln(\mathcal{L}) = \sum_y n_{y,c} \cdot \sum_z \{p_{y,c,z}^{obs} \cdot \ln(p_{y,c,z}^{mod} + \delta) - p_{y,c,z}^{obs} \cdot \ln(p_{y,c,z}^{obs} + \delta)\}$	multinomial log-likelihood	J.2a

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, $p_{y,c,z}^{obs}$ 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), $p_{y,c,z}^{mod}$ is the corresponding model-estimated size composition, and δ is a small constant.

The Dirichlet-Multinomial likelihood, applied to a single size composition with sample size n_t, observed proportions $\tilde{\pi}_t$, and predicted proportions π_t, is

$\mathcal{L}(\tilde{\boldsymbol{\pi}}_t; \boldsymbol{\pi}_t, \theta, n_t) = \int \text{Multinomial}(n_t\tilde{\boldsymbol{\pi}}_t \vert \boldsymbol{\pi}_t^*, n_t)\text{Dirichlet}(\boldsymbol{\pi}_t^* \vert \boldsymbol{\pi}_t, \theta)d\boldsymbol{\pi}_t^*$ $= \frac{\Gamma(n_t+1)}{\prod_{i=1}^{n_i}\Gamma(n_t\tilde{\pi}_{a,t}+1)} \frac{\Gamma(\theta n_t)}{\Gamma(n_t+\theta n_t)} \prod_{a=1}^{n_a} \frac{\Gamma(n_t\pi_{a,t}+\theta n_t\pi_{a,t})}{\Gamma(\theta n_t\pi_{a,t})}$	multinomial log-likelihood	J.2b

where θ is an estimated parameter related to the effective sample size.

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

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

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

$\mathrm{L}_m = \sum_{y,z} n_{y,z} \cdot \left\{p_{y,z}^{obs} \cdot \ln\left(p_{y,z}^{mod} + \delta\right) + \left(1 - p_{y,z}^{obs}\right) \cdot \ln\left(1 - p_{y,z}^{mod} + \delta\right)\right\}$	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:

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

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

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

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

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

K. Devs vectors
For TCSAM02 to accommodate arbitrary numbers of fisheries and time blocks, it is necessary to be able to define arbitrary numbers of "devs" vectors. This is currently not possible using the ADMB C++ libraries, so TCSAM02 uses an alternative implementation of devs vectors from that implemented in ADMB. For the 2017 assessment, an *n*-element "devs" vector was implemented using an *n*-element bounded parameter vector. with the final element of the "devs" vector defined as $-\sum_{n-1} v_i$, where v_i was the ith value of the parameter (or devs) vector, so that the sum over all elements of the devs vector was

identically 0. Penalties were placed on the final element of the devs vector to ensure it was bounded in the same manner as the parameter vector. However, this approach was problematic when initializing the model with the values for the n-1 elements that defined the n-element devs vector, the value of the n-th element ($-\sum_{n-1} v_i$) was not guaranteed to satisfy the bounds placed on the vector. Thus, this approach was revised to allow specification of all n element values (the $v_n = -\sum_{n-1} v_i$ constraint was removed) while the likelihood penalty was changed to ensure the sum of the elements was 0. The new approach also has the advantage that it more closely follows the one used in ADMB to define "devs" vectors. Test runs with both approaches showed no effect on convergence to the MLE solution.

L. Priors for model parameters

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

indicator	**parameters**	**constants**	**description**
none	none	none	no prior applied
ar1_normal	μ, σ	none	random walk with normal deviates
cauchy	x_0, γ	none	Cauchy pdf
chisquare	υ	none	χ^2 pdf
constant	min, max	none	uniform pdf
exponential	λ	none	exponential pdf
gamma	r, μ	none	gamma pdf
invchisquare	υ	none	inverse χ^2 pdf
invgamma	r, μ	none	inverse gamma pdf
invgaussian	μ, λ	none	inverse Gaussian pdf
lognormal	median, CV	none	lognormal pdf
logscale_normal	median, CV	none	normal pdf on ln-scale
normal	μ, σ	none	normal pdf
scaled_invchisquare	υ, s	none	inverse χ^2 scaled pdf
scaledCV_invchisquare	υ, CV	none	inverse χ^2 pdf, scaled by CV
t	υ	none	t distribution
truncated_normal	μ, σ	min, max	truncated normal pdf

M. Parameters and other information determined outside the model

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

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

where

sex	**maturity state**	$a_{x,m}$	$b_{x,m}$
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 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.

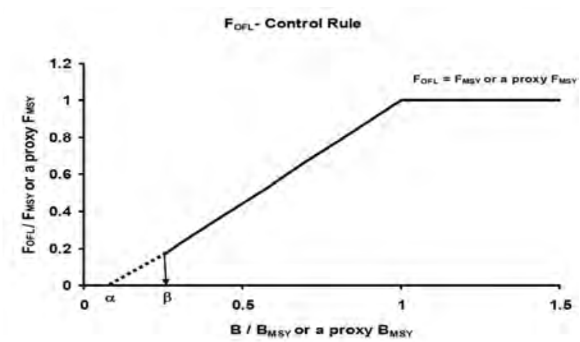

Fig. 2. The F_{OFL} harvest control rule.

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

N.1 Equilibrium conditions

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

N.1.1 Population states

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

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

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

N.1.2 Population processes

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

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

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

N.1.3 Population dynamics

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

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

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

N.1.4 Equilibrium equations

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

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

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

N.1.5 Equilibrium solution

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

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

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

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

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

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

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

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

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

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

where (for completeness):

$$A = S_{2in} \cdot (1 - \Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \quad \text{(N.17)}$$
$$B = S_{2in} \cdot (1 - \Theta_{io}) \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \quad \text{(N.18)}$$
$$C = S_{2io} \cdot (1 - \Phi_{in}) \cdot S_{1in} \quad \text{(N.19)}$$
$$D = S_{2io} \cdot (1 - \Phi_{io}) \cdot S_{1io} \quad \text{(N.20)}$$
$$E = S_{2mn} \cdot \Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \quad \text{(N.21)}$$
$$F = S_{2mn} \cdot \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \quad \text{(N.22)}$$
$$G = S_{2mo} \cdot S_{1mn} \quad \text{(N.23)}$$
$$H = S_{2mo} \cdot S_{1mo} \quad \text{(N.24)}$$

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

N.2 OFL calculations

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

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

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