Bristol Bay Red King Crab Stock Assessment 2023

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Executive Summary

1. **Stock**: Red king crab (RKC), *Paralithodes camtschaticus*, in Bristol Bay, Alaska.

2. **Catches**: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lb (58,943 t). The catch declined dramatically in the early 1980s and remained at low levels during the last three decades. After rationalization, catches were relatively high before the 2010/11 season but have been on a declining trend since 2014. The retained catch in 2020/21 was approximately 2.65 million lb (1,257 t), compared to 4.5 million lb (2,027 t) in 2018/19, following a reduction in total allowable catch (TAC). The directed pot fishery was closed in 2021/22 and 2022/23 due to low mature female abundance in accordance with the State of Alaska harvest strategy. The magnitude of bycatch from groundfish trawl and fixed gear fisheries has been stable and small relative to stock abundance during the last 10 years. The decline of the directed pot fishery crab/pot lift (CPUE) has been much less than the retained catch decline, with the 2020/21 CPUE having about 12.5% reduction from the average CPUE during the recent 20 years.

3. **Stock biomass**: Estimated mature biomass increased dramatically in the mid-1970s, then decreased precipitously in the early 1980s. Estimated mature crab abundance increased during 1985-2007 with mature females being about four times more abundant in 2007 than in 1985 and mature males being about two times more abundant in 2007 than in 1985. Estimated mature abundance has steadily declined since 2007. The projected mature male biomass in 2023 is approximately 34% of the estimated mean survey biomass for the entire time series. The estimated mature female survey biomass has also been very low during the last four years, but the 2023 estimated value increased to approximately 52% of the mean.

4. **Recruitment**: Estimated recruitment was high during the 1970s and early 1980s and has generally been low since 1985 (1979-year class). During 1984-2022, estimated recruitment was above the historical average (1976-2022 reference years) only in 1984, 1986, 1990, 1995, 1999, 2002, 2005, 2006, and 2010. Estimated recruitment was extremely low during the last 13 years, and even lower during the recent eight years. With the low recruitment in recent years, the projected mature biomass is expected to decline during the next few years with a below-average fishing mortality of 0.167 to 0.25 yr^{-1}.

5. **Management performance**: The stock was above Minimum Stock Size Threshold (MSST) in 2022/23 (85% of B_{MSY}) and hence was not overfished. Since total catch was below the OFL (overfishing limit), overfishing did not occur. The projection using the lowest recruitment periods during 2013-2022 would not likely result in "approaching an overfished condition" based on the current harvest strategy. The relatively low MSST in 2018/19 and $B_{35\%}$ in 2019/20 below was caused by a problem of the previous GMACS (General model for assessing crustacean stocks) version using the only sex ratio of recruitment in the terminal year for $B_{35\%}$ computation in 2019. The lower estimated male recruitment ratio in the terminal year in 2019 resulted in a lower mean male recruitment for $B_{35\%}$ computation. The current version of GMACS uses an average of sex ratios of recruitment during the

reference period to estimate $B_{35\%}$, which results in a stable sex ratio (about 50%) for the reference point calculation.
The ABC (acceptable biological catch) buffer was increased from 10% to 20% in 2018, and an additional buffer of 5% was added in 2020 due to the lack of a 2020 survey. A 20% buffer was recommended by the Crab Plan Team (CPT) and Scientific and Statistical Committee (SSC) for ABC estimation since 2021/22. Reoccurring concerns for this stock are still present (cold pool distributional shifts, declining trends in mature biomass, lack of large recruitment pulses, retrospective patterns), as well as low mature female biomass the last two years, all contribute to a recommended 20% buffer for 2023/24. Tables below represent the status and catch specifications for model 23.0a in 1,000 t and million lb (Tables 1 and 2).

Table 1: Status and catch specifications (1000 t) for the CPT recommended model (23.0a).

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2019/20	12.72	14.24	1.72	1.78	2.22	3.40	2.72
2020/21	12.12	13.96	1.20	1.26	1.57	2.14	1.61
2021/22	12.01	16.64	0	0.02	0.10	2.23	1.78
2022/23	9.68	18.34	0	0.02	0.07	3.04	2.43
2023/24		14.98				4.42	3.54

Table 2: Status and catch specifications (million lb) for the CPT recommended model (23.0a).

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2019/20	28.0	31.4	3.80	3.91	4.89	7.50	6.00
2020/21	26.7	30.8	2.77	2.65	3.47	4.72	3.54
2021/22	26.5	36.7	0	0.04	0.22	4.91	3.92
2022/23	21.34	40.44	0	0.05	0.16	6.70	5.35
2023/24		33.02				9.75	7.8

6. **Basis for the OFL**:

Table 3: Basis for the OFL (1000 t) from the CPT recommended model (23.0a).

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	Basis for B_{MSY}	Natural mortality
2019/20	3b	21.2	16.0	0.75	0.22	1984-2018	0.18
2020/21	3b	25.4	14.9	0.59	0.16	1984-2019	0.18
2021/22	3b	24.2	14.9	0.62	0.17	1984-2020	0.18
2022/23	3b	24.03	17.0	0.71	0.20	1984-2021	0.18
2023/24	3b	19.36	14.98	0.77	0.302	1984-2022	0.18

Table 4: Basis for the OFL (million lb) from the CPT recommended model (23.0a).

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	Basis for B_{MSY}	Natural mortality
2019/20	3b	46.8	35.2	0.75	0.22	1984-2018	0.18
2020/21	3b	56.1	32.9	0.59	0.16	1984-2019	0.18
2021/22	3b	53.4	33.0	0.62	0.17	1984-2020	0.18
2022/23	3b	53.0	37.4	0.71	0.20	1984-2021	0.18
2023/24	3b	42.68	33.02	0.77	0.302	1984-2022	0.18

A. Summary of Major Changes

1. Changes in Management of the Fishery

There are no new changes in management of the fishery.

2. Changes to the Input Data

a. Updated groundfish fisheries bycatch data during 1986-2022.
b. Updated crab fisheries data: directed, cost-recovery, and bycatch.
c. Updated NMFS survey data for 2023, biomass and length compositions.
d. Updated length composition data for directed and non-directed fisheries.

3. Changes in Assessment Methodology

a. Updated version of GMACS (version 2.01.M.01, 2023-03-13) is used.
b. The analyses of terminal years of recruitment are updated.
c. Three models are compared in this report (See Section E.3.a for details). These models are designed for evaluating starting the model in 1985 and estimating M for males:

21.1b: base model accepted in 2022

22.0: model 21.1b + starting in 1985.

23.0a: model 21.1b + estimating a constant base M for males.

4. Changes in Assessment Results

Three model scenarios are compared in this report. In the May 2023 draft report the accepted model in 2022 (21.1b) was presented using the newest version of GMACS, and this had minimal impact to model results. Model 21.1b is considered the base model and was used to compare to the other model scenarios.

The two additional models considered: model 22.0 (1985 start date) and model 23.0a (estimated base M for males). Model 22.0, which starts the model in 1985 rather that the 1975 start date of the base model (21.1b), was used to evaluate model starting year. Model 22.0 is the reduced time series data version of model 21.1b and the overall results are similar. The notable differences are smaller $B_{35\%}$ (19,967 t vs 21,719 t) and NMFS survey catchability (0.94 vs 0.97), and higher OFL (3,917 t vs 3,522 t) for model 22.0. These differences are likely caused by a high recruitment in 1984 (associated with the very high M) being used for $B_{35\%}$ computation for model 21.1b and more influence of BSFRF survey data for model 22.0. Model 23.0a uses the entire time series but estimates a base M for males (0.23 compared to fixing at 0.18 for the base model). This model has a slightly reduced total likelihood compared to model 21.1b, slightly increased annual mature male biomass - with the exception of the last four years, and results in an estimated $B_{35\%}$ about 10% lower than model 21.1b. A higher M also results in higher $F_{35\%}$ and OFL for model 23.0a.

Moving the starting year to 1985 greatly simplifies this model by removing early years of high biomass and subsequent dramatic decline in biomass in the early 80s. Additionally, a 1985 start date coincides to gear changes in the NMFS trawl survey in the early 80s. However, retrospective patterns for this model suggest increased retrospective bias which is a cause for concern. Considerations for M estimation are whether to estimate a base M for males for the whole time series or keep the base M for males fixed at 0.18. Estimating the base M for males does reduce the retrospective bias from model 21.1b. The concern with estimating a base M for males for the whole time series is potential confounding with estimating trawl survey catchability, however trawl survey catchability in this model has a fairly strict prior.

For specification in 2023/24, model 21.1b or model 23.0a are recommended. The base model - 21.1b - has been used, with minimal updates, for the past two seasons and is consistent in its approach of keeping a fixed base M of 0.18 and not removing early data. Model 23.0a, however, is a strong contender having similar trends, more realistic natural mortality estimates, and an improved retrospective bias. Model 22.0 is not recommended due to the larger retrospective bias. Based on CPT recommendations model 23.0a results are presented in the specification tables in the executive summary but values for management-related quantities for all models are summarized in Tables 1, 15, and 17.

B. Responses to SSC and CPT

CPT and SSC Comments on Assessments in General

Response to SSC Comments (June 2022, Oct 2022):

"The SSC recommends that the RKC authors work together to complete a stock structure template for June 2023."

Response: A draft stock structure template for RKC in the Bering Sea will be presented at the May 2023 CPT meeting.

"The SSC suggests that the CPT develop guidelines for when to change model start dates"

Response: This topic was taken up at the Jan 2023 CPT meeting, with some basic guidelines presented in those minutes that included keeping data unless there was a strong reason (environmental, poor data quality, model instability) to exclude the data and data exclusion did not lead to drastic model output changes. Model 22.0, where data starts in 1985 vs 1975, is presented in this document.

Response to SSC Comments (from February 2022):

"The SSC supports the CPT general recommendations that all stock assessments include results from the currently accepted model with new data (base model) so that changes in model performance can be assessed. Values for management-related quantities for all models that may be recommended by the CPT or SSC should also be available."

Response: We have followed these recommendations.

CPT and SSC Comments on BBRKC assessment

Response to CPT Comments (from May 2021):

"The CPT was concerned that the 'information' content of the data with respect to natural mortality could be related to strong assumptions elsewhere in the model, and recommended further exploration of natural mortality after September and suggested attending the June 2021 CAPAM workshop on natural mortality, which may provide some insights into best practices. A large increase in estimated natural mortality would likely increase fishing mortality reference points, with management implications."

Response: Model runs in May 2022 addressed some variations on M. Estimated M values in the length-based crab models tend to have higher values than the other approaches, and confounding among estimated M, survey selectivity/catchability, and recruitment in a length-based model makes it difficult to accurately estimate M in the model. Among the models presented here four address variations in M for males, including higher fixed M values and estimated M for males.

"The CPT was interested in more exploration of the retrospective patterns, which seem to have increased since the last assessment despite no new data being added. Reported Mohn's rhos were starting to reach concerning magnitudes in the proposed models?"

Response: The catch and bycatch updates in May 2022 made the retrospective patterns slightly worse than before. Higher than expected BSFRF survey biomass during 2007-2008 and 2013-2016 and NMFS survey biomass in 2014 likely caused these biases. Also, much lower than expected NMFS survey biomass during 2018-2019 and 2021-2022 results in lower biomass estimates in recent years. The biases for total abundance are much smaller than mature male biomass. Explorations further, since May 2022, on retrospective patterns are underway but not presented here.

Response to CPT Comments (from September 2021):

"When projecting the stock to determine whether it is approaching an overfished condition, identify the uncertainties included and ignored in the projection. It is particularly important to distinguish those that are captured in the projection (i.e. those associated with the model) and the additional uncertainties that form the basis for the ABC buffer."

Response: Uncertainties are discussed in the projection section here and will be included in the final SAFE in Sept. 2023.

"When projecting MMB, label figures with the date to which it is projected (e.g., Feb. 15, 2022), not just the year (which can lead to confusion)."

Response: We followed this recommendation.

"Consider a model in which the data starts in 1985 (as suggested by the CIE reviewers)."

Response: Model 22.0 start in 1985, and was presented in May 2022, Sept 2023, and in this document. After discussions during the Jan/Feb council cycle the author is uncertain whether removing the early part of the time series is appropriate. However, this model is presented here as an option.

Response to CPT Comments (from May 2022):

"The CPT recommended examining how the initial conditions of abundance are treated as a future analysis"

Response: This has not yet been addressed, but is on the list for future work.

Response to CPT Comments (from May 2023):

"The CPT notes that confidence intervals for the estimated MMB and parameter names on the tables would be useful."

Response: MMB figures now have the associated confidence intervals and some parameter names are added to the model parameters tables.

"Future work recommendations include: reconsidering which growth parameters are estimated vs. specified, specifying all growth parameters outside of the model, a more through consideration of how to estimate survey catchability from BSFRF data without the strong prior on catchability that has been historically used, reconsider the shape of the survey selectivity curve, and revisit the blocking of the molting probability estimated from the tagging data."

Response: These will be addressed, as possible, in model runs for May 2024.

Response to SSC Comments specific to this assessment (from June 2021):

"The SSC supports exploring more modern methods for estimating natural mortality, but notes that this method still relies strongly on the maximum age for BBRKC. The SSC recommends continued research to validate the ages for this stock."

Response: We agree with this suggestion. The maximum age was determined by old tagging data, and due to funding and personnel constraint, age validation for BBRKC is more likely a long-term goal than a short-term project.

"The likelihood profile suggests that the values of M for male and female might be similar and that the current difference may be because of the constraint of base M to a low value. When M is misspecified, it can be the cause of a strong positive retrospective pattern, which BBRKC has. The SSC would have liked to have seen compositional fits and a retrospective analysis for model 19.6 or some model with a higher M value, particularly to see if it fits the plus group better. Despite the increase in F35%, there was not a commensurate increase in OFL. An exploration of the underlying reasons for this outcome is needed."

Response: Based on our past modelling experience, when M values for males and females are estimated separately, estimated M values tended to be always higher for females than for males. The likelihood profile was created through fixing M values for males and estimating M values for females, and when the fixed M values for males were very high, estimated M values for females tended to be similar to M values for males. The increase in F35% but not a commensurate increase in OFL is due to reduction of mature male biomass caused by the high M.

As a reference, we copied the likelihood profile computed in May 2020 below. Model 19.6 uses male base M of 0.257 estimated by Then et al. (2015), and the likelihood profile of base M from 0.1 to 0.4 is as follow:

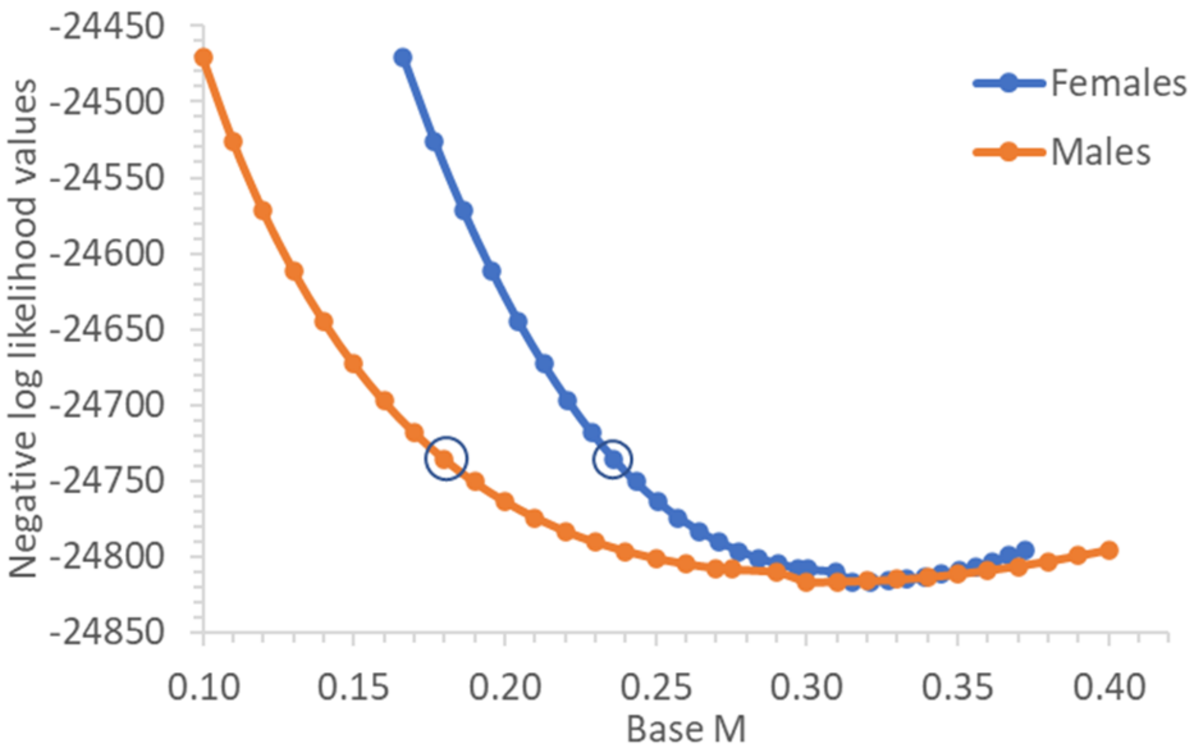

Figure 1: Likelihood profile on M from May 2020 and 2021, current values of M are circled on the profile.

It appears that the maximum likelihood value is achieved with a base M of 0.31 for males and 0.321 for females.

In May 2023, models 23.0, 23.0a, 23.0b, and 23.3 all involved variations of higher base M values for males. Higher base M values did not appear to improve the plus group fittings.

"In addition to the CPT recommended models (19.3d, 19.3e, and 19.3g), the SSC recommends a simplified version of model 19.3d that estimates one natural mortality parameter across sex and time, and one shared catchability and selectivity curve for the NMFS trawl survey to help make several selectivity parameters better defined."

Response: We named this as model 21.0 and included it in the September 2021 assessment.

"The SSC requests that the current crab management zones be included in the maps of VAST model-derived spatial distributions of BBRKC."

Response: We will ask Dr. Jon Richar to add the current crab management zones to the VAST spatial plots.

"The SSC also looks forward to the summary report from the March 2021 CIE Review for this stock."

Response: The summary report of the 2021 CIE review is included in Appendix D of the last full SAFE (see link in summary above).

Response to SSC Comments specific to this assessment (from October 2021):

"The SSC requests that in addition to temperature effects on the timing of the molt-mate cycle, the authors explore other potential drivers (e.g., prey quality or quantity) that could underlie the incomplete molt-mate cycle observed in 2021. Based on NMFS trawl survey female biomass estimates, the State of Alaska closed the BBRKC fishery. Next year's assessment should estimate the probability that the stock is currently in the overfished condition."

Response: NMFS staff did an evaluation of re-tow survey protocol in Spring 2022, no changes were adopted at that time. Probabilities in the overfished condition for some models were estimated in September 2021, September 2022, and September 2023. Model 23.2, presented in May 2023, was an exploration of the base model (21.1b) without the retow data for females. This model does not drastically affect the federal harvest control rules, but does estimate a lower biomass for females which would directly affect the State harvest strategy.

"The SSC recommends that authors should carefully consider assessment implications of the stock boundaries given the evidence of crabs outside of the managed area. The SSC suggests that the authors should still be able to use data from outside stock boundaries, even if not used in the input survey abundance estimates. For example, the abundance seen outside stock boundaries could be treated as covariate informing catchability within the model. This analysis seems particularly important for females that are increasingly outside of the current stock boundaries and are at low abundance, triggering the State closure. The SSC recommends that the authors formulate separate survey abundance time series inside and outside of the defined area that could prove useful in the assessment model (e.g., informing catchability). If this is not an option in the stock assessment, then it highlights the need for ESRs or ESPs to track movement of these crabs both through survey results and developing indices from local knowledge."

Response: The current version of GMACS seems not to be able to use the Northern RKC survey index to inform BBRKC survey catchability. We tried to add a model to include both BBRKC and Northern RKC data, but the groundfish fisheries bycatch is not currently available in the Northern area. In the last full SAFE - September 2022 - we plotted more proportional data of the Northern RKC in Figures 35a and 35b. Overall, the proportions of different size groups of the Northern RKC during a recent dozen years are higher than in the past and do not trend higher except for mature females in 2021. The high survey mature female abundance in the Northern area in 2021 was primarily from three tows and one of them is more than 50% of total mature females. The survey abundance of the Northern RKC will continue to be plotted in the SAFE report in the future. After migration patterns between BBRKC and the Northern RKC are fully understood, we will model them in the stock assessment.

"The SSC supports the BSFRF collaborative work with ADF&G and NMFS to tag BBRKC."

Response: We fully support tagging efforts, especially those to understand seasonal movement and the flow of individuals in or out of the Bristol Bay management area.

"It would be useful to investigate if there is a mechanism for higher natural mortality or fishing mortality for females only during that early time period while following the CPT recommendation of looking at model 21.0 with constant but separate Ms by sex. Since Model 21.0 estimates a very high level of fishing mortality, but does seem to account for the decline in large females, there may be a fishery selectivity issue in that period. If the modelers choose not to continue to use historic data prior to 1985, this suggestion may not be useful."

Response: Figuring out the exact causes of high mortality in the early 1980s is always difficult and we summarize the potential causes in Appendix A of the last full SAFE, section C-vi, "Potential Reasons for High Mortality during the Early 1980s". The directed fishery does not catch many large females and small crab, so it is difficult to remove these crab from the fishery. If this period of high natural mortality was a concern, it would be preferred to start the model in 1985, which has two advantages: avoiding the early 1980s period so that a constant M over time can be used, and the same NMFS survey gear throughout the whole model time period.

"The SSC supports continued exploration of the use of VAST estimates for this assessment, particularly if their use will inform mechanisms underlying shifting distributions outside of the current management area."

Response: We also support improvement of VAST estimates and are willing to provide feedback to Jon for further improvement. In general the CPT has not prioritized using VAST output in crab models, we hope to revisit this soon.

Response to SSC Comments specific to this assessment (from June 2022):

The SSC noted that during preliminary model runs in May, a full document need not be produced, but one that focuses a summary of model features and runs would be sufficient.

Response: The May 2023 proposed model run document reflects these changes, focusing on model runs and explorations. Model structure and historical information is linked to via the NPFMC website in the summary section and not repeated in this document. The author welcomes further suggestions on the "proposed model" run documents since the CPT does not formally have a format for these.

"The SSC recommends exploring how to estimate both catchabilities (NMFS trawl survey and BSFRF survey), but with a linked prior to influence them to scale together (i.e., assume some approximate value of how much higher q is for that survey)."

Response: This is on the authors list of future work to be addressed with explorations of catchability for both surveys, but has not yet been explored in this document.

Response to SSC Comments specific to this assessment (from October 2022):

"The SSC recommends that a high priority be placed on trying to isolate factors that reduce the retrospective bias in mature male biomass."

Response: The author agrees that this should be a high priority, however explorations are still ongoing.

"The SSC recommends investigation of the highly biased fits to the BSFRF index and suggests that the current approach of inflating the variance to account for lack of fit is inappropriate when obvious bias is present."

Response: We agree with this recommendation, and are investigating this avenue along with exploring catchability for both surveys.

"The accumulation of large males and particularly large females in the plus group indicates length bin groups may need to be re-evaluated."

Response: We acknowledge this observation and have extending the size bins on the list of further work for this model.

"The SSC noted that the NMFS and the State determined that the survey re-tows would not be conducted in 2022, despite meeting the threshold to do so. The SSC requests an examination from the assessment author of the potential value of these re-tows, and whether re-tows provide a more or less accurate index of abundance."

Response: Model 23.2 was presented in May 2023 as a bookend for the model output without any retow data. If the CPT and SSC wish to see more variations of this model we can provide them, i.e., removing some years and not all as one possibility. While female re-tow data does not highly affect male model outcomes it does affect fishery closures since the State of Alaska harvest strategy uses a mature female threshold for opening.

C. Introduction

1. Scientific Name

Red king crab (RKC), *Paralithodes camtschaticus*, in Bristol Bay, Alaska.

2. Distribution

Red king crab inhabit intertidal waters to depths >200 m of the North Pacific Ocean from British Columbia, Canada, to the Bering Sea, and south to Hokkaido, Japan, and are found in several areas of the Aleutian Islands, eastern Bering Sea, and the Gulf of Alaska.

3. Stock Structure

The State of Alaska divides the Aleutian Islands and eastern Bering Sea into three management registration areas to manage RKC fisheries: Aleutian Islands, Bristol Bay, and Bering Sea (ADF&G 2012). The Bristol Bay area includes all waters north of the latitude of Cape Sarichef (54°36' N lat.), east of 168°00' W long., and south of the latitude of Cape Newenham (58°39' N lat.) and the fishery for RKC in this area is managed separately from fisheries for RKC outside of this area; i.e., the red king crab in the Bristol Bay area are assumed to be a separate stock from red king crab outside of this area. This report summarizes the stock assessment results for the Bristol Bay RKC stock.

4. Life History

Red king crab have a complex life history. Fecundity is a function of female size, ranging from tens of thousands to hundreds of thousands (Haynes 1968; Swiney et al. 2012). The eggs are extruded by females, fertilized in the spring, and held by females for about 11 months (Powell and Nickerson 1965). Fertilized eggs are hatched in the spring, most during April-June (Weber 1967). Primiparous females are bred a few weeks earlier in the season than multiparous females. Larval duration and juvenile crab growth depend on temperature (Stevens 1990; Stevens and Swiney 2007). Male and female RKC mature at 5–12 years old, depending on stock and temperature (Stevens 1990; Loher et al. 2001) and may live >20 years (Matsuura and Takeshita 1990). Males and females attain a maximum size of 227 mm and 195 mm carapace length (CL), respectively (Powell and Nickerson 1965). Female maturity is evaluated by the size at which females are observed to carry egg clutches. Male maturity can be defined by multiple criteria including spermataphore production and size, chelae vs. carapace allometry, and participation in mating in situ (reviewed by Webb 2014). For management purposes, females >89 mm CL and males >119 mm CL are assumed to be mature for Bristol Bay RKC. Juvenile RKC molt multiple times per year until age 3 or 4; thereafter, molting continues annually in females for life and in males until maturity. Male molting frequency declines after attaining functional maturity.

5. Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States. A review of the history of the Bristol Bay RKC fishery is provided in Fitch et al. (2012) and Otto (1989). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974. The Russian fleet fished for RKC from 1959 to 1971. The Japanese fleet employed primarily tanglenets with a very small proportion of catch from trawls and pots. The Russian fleet used only tanglenets. United States trawlers started fishing Bristol Bay RKC in 1947, but the effort and catch declined in the 1950s. The domestic RKC pot fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lb (58,943 t), worth an estimated $115.3 million ex-vessel value. The catch declined dramatically in the early 1980s and has remained at low levels during the last two decades (Tables 9 and 10). After the early 1980s stock collapse, the Bristol Bay RKC fishery took place during a short period in the fall (usually lasting about a week) with the catch quota based on the stock assessment conducted the previous summer (Zheng and Kruse 2002). Beginning with the 2005/2006 season, new regulations associated with fishery rationalization resulted in an increase in the duration of the fishing season (October 15 to January 15). With the implementation of crab rationalization, the annual guideline harvest level (GHL) was changed to a total allowable catch (TAC). Before rationalization, the implementation errors were quite high for some years and sum of actual catches from 1980 to 2007 was about 6% less than the sum of GHL/TAC over that period.

6. Management History

King and Tanner crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through a federal king and Tanner crab fishery management plan (FMP). Under the FMP, management measures are divided into three categories: (1) fixed in the FMP, (2) frame-worked in the FMP, and (3) discretion of the State of Alaska. The State of Alaska is responsible for determining and establishing the GHL/TAC under the framework in the FMP. Harvest strategies for the Bristol Bay RKC fishery have changed over time. Two major management objectives for the fishery are to maintain a healthy stock that ensures reproductive viability and to provide for sustained levels of harvest over the long term (ADF&G 2012). In attempting to meet these objectives, the GHL/TAC is coupled with size-sex-season restrictions. Only males $\geq$ 6.5 in carapace width (equivalent to 135mm CL) may be harvested and no fishing is allowed during molting and mating periods (ADF&G 2012). Specification of TAC is based on a harvest rate strategy. Before 1990, harvest rates on legal males were based on population size, abundance of prerecruits to the fishery, postrecruit abundance, and rates varied from less than 20% to 60% (Schmidt and Pengilly 1990). In 1990, the harvest strategy was modified, and a 20% mature male harvest rate was applied to the abundance of mature-sized ($\geq$ 120 mm CL) males with a maximum 60% harvest rate cap of legal ($\geq$ 135 mm CL) males (Pengilly and Schmidt 1995). In addition, a minimum threshold of 8.4 million mature-sized females ($\geq$ 90 mm CL) was added to existing management measures to avoid recruitment overfishing (Pengilly and Schmidt 1995). Based on a new assessment model and research findings (Zheng et al. 1995a, 1995b, 1997a, 1997b), the Alaska Board of Fisheries adopted a new harvest strategy in 1996. That strategy had two mature male harvest rates: 10% when effective spawning biomass (ESB) is between 14.5 and 55.0 million lb and 15% when ESB is at or above 55.0 million lb (Zheng et al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. A threshold of 14.5 million lb of ESB was also added. In 1997, a minimum threshold of 4.0 million lb was established as the minimum GHL for opening the fishery and maintaining fishery viability and manageability when the stock abundance is low. The Board modified the current harvest strategy in 2003 by adding a mature harvest rate of 12.5% when the ESB is between 34.75 and 55.0 million lb and in 2012 eliminated the minimum GHL threshold. The current harvest strategy is illustrated in (Figure 2).

D. Data

1. Summary of New Information

a. Updated groundfish fisheries bycatch data during 1986-2022.
b. Updated crab fishery data: directed, cost-recovery, and bycatch data for 2022/2023
c. Updated survey data for 2023
d. Updated length-frequencies distributions for all data sets for 2022/2023

Data types and availability periods are illustrated in Figure 3.

2. Catch Data

Data on landings of Bristol Bay RKC by length and year and catch per unit effort from 1960 to 1973 were obtained from annual reports of the International North Pacific Fisheries Commission (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the Alaska Department of Fish and Game from 1974 to 2020 (Tables 9 and 10). Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013) (Table 11). Sample sizes for catch by length and sex are summarized in Table 12. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

a. Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Tables 9 and 10 and illustrated in Figure 4. Retained catch and estimated bycatch from the directed fishery include the general, open-access fishery (prior to rationalization), or the individual fishery quota (IFQ) fishery (after rationalization), as well as the Community Development Quota (CDQ) fishery and the ADF&G cost-recovery harvest. Starting in 1973, the fishery generally occurred during the late summer and fall. Before 1973, a small portion of retained catch in some years was caught from April to June. The years in Tables 9 and 10 are defined as crab year from July 1 to June 30. Bycatch data for the cost-recovery fishery before 2006 were not available. In this report, pot fisheries include both the directed fishery and RKC bycatch in the Tanner crab pot fishery, and trawl fisheries and fixed gear fisheries are groundfish fisheries. Observers did not separate retained and discarded catch of legal-sized crab after 2017 in the directed pot fishery, so the male discarded biomass from the directed fishery has been estimated by the subtraction method (subtracting the retained catch from the estimated total catch) since 2018 (B. Daly, ADF&G, personal communication).

b. Catch Size Composition

Retained catches by length and shell condition and bycatches by length, shell condition, and sex were obtained for stock assessments. From 1960 to 1966, only retained catch length compositions from the Japanese fishery were available. Retained catches from the Russian and U.S. fisheries were assumed to have the same length compositions as the Japanese fishery during this period. From 1967 to 1969, the length compositions from the Russian fishery were assumed to be the same as those from the Japanese and U.S. fisheries. After 1969, foreign catch declined sharply and only length compositions from the U.S. fishery were used to distribute catch by length.

c. Catch per Unit Effort

Catch per unit effort (CPUE) is defined as the number of retained crab per tan (a unit fishing effort for tanglenets) for the Japanese and Russian tanglenet fisheries and the number of retained crab per potlift for the U.S. fishery (Table 10). Soak time, while an important factor influencing CPUE, is difficult to standardize. Furthermore, complete historical soak time data from the U.S. fishery are not available. Based on the approach of Balsiger (1974), all fishing effort from Japan, Russia, and U.S. were standardized to the Japanese tanglenet from 1960 to 1971, and the CPUE was standardized as crab per tan. Except for the peak-to-crash years of the late 1970s and early 1980s, the correspondence between U.S. fishery CPUE and area-swept survey abundance is poor (Figure 5). Due to the difficulty in estimating commercial fishing catchability and crab availability to the NMFS annual trawl survey data, commercial CPUE data were not used in the model.

3. National Marine Fisheries Service (NMFS) Survey Data

The NMFS has conducted annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conducted this multispecies, crab-groundfish survey during the summer. Stations were sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of approximately 140,000 nm^2. Since 1972, the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2023 were provided by NMFS. Due to survey data quality issues, only survey data after 1974 are used in the assessment models.

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach (Figure 6 and 7). Until the late 1980s, NMFS used a post-stratification approach, but subsequently treated Bristol Bay as a single stratum; the estimates shown for Bristol Bay in Figures 5 – 7 were made without post-stratification. If multiple tows were made at a single station in a given year, the average of the abundances from all tows within that station was used as the estimate of abundance for that station. The new time series since 2015 discards all "hot spot" tows. We used the new area-swept estimates provided by NMFS in 2023. The VAST estimated biomasses were not considered in this year's assessment but may be considered in the future.

In addition to the standard surveys conducted in early June (late May to early June in 1999 and 2000), a portion of the distribution of Bristol Bay RKC was resurveyed in 1999, 2000, 2006-2012, and 2021 to better assess mature female abundance. Resurveys performed in late July, about six weeks after the standard survey, included 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), 32 stations (2007-2009), 23 stations (2010), and 20 stations (2011, 2012, and 2021) with high female densities. The resurveys were necessary because a high proportion of mature females had not yet molted or mated when sampled during the standard survey time. Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey periods. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000, presumably because most mature females had not molted prior to the standard surveys. As in 2006, area-swept estimates of males >89 mm CL, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different (P=0.74, 0.74 and 0.95; paired t-test of sample means) between the standard survey and resurvey tows. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 were significantly different (P=0.03; paired t-test) between the standard survey and resurvey tows. Resurvey stations were close to shore during 2010-2012, and mature and legal male abundance estimates were lower for the re-tow than the standard survey. Following the CPT recommendation, we used the standard survey data for male abundance estimates and only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundances during resurvey years.

4. Bering Sea Fisheries Research Foundation Survey Data (BSFRF)

The BSFRF conducted trawl surveys for Bristol Bay RKC in 2007 and 2008 with a small-mesh trawl net and 5-minute tows (S. Goodman, BSFRF, pers. com.). The surveys occurred at similar times as the NMFS standard surveys and covered about 97% of the Bristol Bay survey area. Few Bristol Bay RKC were found outside the BSFRF survey area. Because of the small mesh size, the BSFRF surveys were expected to catch more RKC within the swept area. Crab abundances of different size groups were estimated by the kriging method. Mature male abundances were estimated to be 22.331 million crab (CV = 0.0634) in 2007 and 19.747 million crab (CV = 0.0765) in 2008. BSFRF also conducted a side-by-side survey concurrent with the NMFS trawl survey during 2013-2016 in Bristol Bay. In May 2017, survey biomass and size composition estimates from 2016 BSFRF side-by-side trawl survey data were updated. Ratios of NMFS survey abundances/total NMFS and BSFRF side-by-side trawl survey abundances are illustrated in Figures 8 and 9, and ratios of NMFS survey abundances/BSFRF side-by-side trawl survey abundances are shown in Figures 10 – 12.

As a comparison to the estimated NMFS survey catchability (0.896) at 162.5 mm CL by the double-bag experiment (Weinberg et al. 2004), we computed an overall ratio (q=0.891) of NMFS survey abundances/BSFRF side-by-side trawl survey abundances for legal crab ($\geq$ 135mm carapace length) as follow:

$$q = \frac{\sum_{y=2013,l=135mm}^{y=2016,l=\infty} r_{y,l} n_{y,l}}{\sum_{y=2013,l=135mm}^{y=2016,l=\infty} n_{y,l}}$$

where $r_{y,l}$ is the ratio of NMFS survey abundance/BSFRF side-by-side trawl survey abundance in year y and length group l, and $n_{y,l}$ is the combined survey abundance of side-by-side surveys in year y and length group l. Due to small catch, all haul data were combined to compute the ratios for each length group and year.

E. Analytic Approach

1. History of Modeling Approaches for this Stock

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, ADF&G developed a length-based analysis (LBA) in 1994 that incorporates multiple years of data and multiple data sources in the estimation procedure (Zheng et al. 1995a). Annual abundance estimates of the Bristol Bay RKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995 (Figure 2). An alternative length-based model (research model) was developed in 2004 to include small size crab to determine federal overfishing limits. Given that the crab abundance declined sharply during the early 1980s, the LBA estimated natural mortality for different periods of years, whereas the research model estimated additional mortality beyond a base constant natural mortality during 1980-1984. In this report, we present only the research model that was fit to the data from 1975 to 2023.

2. Model Description

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). The model combines multiple sources of survey, catch, and bycatch data using a maximum likelihood approach to estimate abundance, recruitment, selectivity, fishing mortality, catch, and bycatch of commercial pot fisheries and groundfish trawl fisheries. Since 2019, GMACS (General Model for Alaska Crab Stocks) has been used for this stock assessment. A full model description is provided in Appendix A.

a-f. See Appendix A

g. Critical assumptions of the model:

i. The base natural mortality is kept constant at 0.18 yr_1 for males, shell condition, and length and was estimated assuming a maximum age of 25 and applying the 1% rule (Zheng 2005).
ii. Survey and fisheries selectivities are a function of length and were constant over shell condition. Selectivities may or may not be a function of sex except for groundfish fisheries bycatch selectivities, which are the same for both sexes. Two different NMFS survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2023, based on modifications to the trawl gear used in the assessment survey.
iii. Growth is a function of length. For females, growth-per-molt increments as a function of length are estimated for three periods (1975-1982, 1983-1993, and 1994-2023) based on sizes at maturity. Once mature, female red king crab have a much smaller growth increment per molt.
iv. Annual molting probabilities are an inverse logistic function of length for males. Females are assumed to molt annually.
v. Annual fishing seasons for the directed fishery are short.

vi. The prior mean for NMFS survey catchability (Q) is estimated to be 0.896 with a standard deviation of 0.025 for some models, based on a trawl experiment by Weinberg et al. (2004); Q is assumed to be constant over time and is estimated in the model. The BSFRF survey catchability is assumed to be 1.0. The prior mean of 0.896 for NMFS survey Q (at 162.5 mm carapace length) is also close to the abundance-weighted average ratio of 0.891 for crab $\geq$ 135 mm CL across four years of side-by-side NMFS and BSFRF survey data (Figure 12).

vii. Males mature at sizes $\geq$ 120 mm CL. For convenience, female abundance is summarized at sizes $\geq$ 90 mm CL as an index of mature females.

viii. Measurement errors are assumed to be normally distributed for length compositions and are log-normally distributed for biomasses.

h. Changes to the above since previous assessment: see Section A.3 for changes to the assessment methodology.

i. Outline of methods used to validate the code used to implement the model and whether the code is available: Assessment results by GMACS have been compared to the previous assessment models, and the code is online and available from the author.

3. Model Selection and Evaluation

a. Alternative model configurations (models):

21.1b: the base model for September 2021 with accepted updates in May 2022 (12 below) and 2023 (13 below). Basic features of this model include:

(1) An estimated constant M for males during 1980-1984, a constant (base) M of 0.18 for males during the other years, and an estimated constant multiplier being used to multiply male M for female M. That is, M for females is relative to M for males each year.

(2) Including BSFRF survey data during 2007-2008 and 2013-2016.

(3) Estimating a constant NMFS survey catchability over time in the model and assuming BSFRF survey catchability to be 1.0.

(4) Assuming the BSFRF survey selectivities as the availability to the NMFS trawl survey because the BSFRF survey gear has very small mesh sizes and has tighter contact to the sea floor. This implies that crab occurring in nearshore areas are not available to trawl survey gears.

(5) Two levels of molting probabilities for males: one before 1980 and one after 1979, based on survey shell condition data. Each level has two parameters.

(6) Estimating effective sample size from observed sample sizes. Stage-1 effective sample sizes are estimated as min ($0.25 * n$, N) for trawl surveys and min ($0.05 * n$, N) for catch and bycatch, where n is the sum of observed sample sizes for two sexes, and N is the maximum sample size (200 for trawl surveys, 150 for retained catch and total males from the directed pot fishery and 50 for females from the pot fishery and for both males and females from the Tanner crab and groundfish fisheries). There is justification for enforcing a maximum limit to effective sample sizes because the number of length measurements is large (Fournier et al. 1998).

(7) Standard survey data for males and NMFS survey re-tow data (if available during cold years) for females.

(8) Estimating initial year length compositions.

(9) Using total observer male biomass and total observer male length composition data in the directed pot fishery to replace discarded male biomass and discarded male length composition data.

(10) Using total male selectivity and retained proportions in the directed pot fishery to replace retained selectivity and discarded male selectivity; and due to high grading problems in some years since rationalization, estimating two logistic curves for retained proportions: one before rationalization (before 2005) and another after 2004.

(11) Equal annual effective sample sizes of male and female length compositions for all size composition data sets.

(12) Updated groundfish fisheries bycatch data.

(13) Uses the recently updated version of GMACS (version 2.01.M.01).

22.0: model 21.1b + starting in 1985
- data prior to 1985 are not used in the model, otherwise the same as 21.1b

23.0a: model 21.1b + estimating a base M for males
- base M for males estimated using a log-normal prior with a mean of 0.18 and a CV of 0.04

b. Progression of results: see the new results at the beginning of the report.
c. Evidence of search for balance between realistic and simpler models: NA.
d. Convergence status/criteria: ADMB default convergence criteria.
e. Sample sizes for length composition data: observed sample sizes are summarized in Table 12.
f. Credible parameter estimates: All estimated parameters seem to be credible and within bounds.
g. Model selection criteria: The likelihood values are used to select among alternatives that could be legitimately compared by that criterion.
h. Residual analysis: Residual plots are illustrated in various figures.
i. Model evaluation is provided under Results, below.
j. Jittering: The Stock Synthesis Approach is used to perform jittering to find the optimum:
The Jitter factor of 0.1 is multiplied by a random normal deviation $rdev = N(0,1)$, to a transformed parameter value based upon the predefined parameter:

$$temp = 0.5 * rdev * Jitter * ln(\frac{P_{max} - P_{min} + 0.0000002}{P_{val} - P_{min} + 0.0000001} - 1)$$

with the final jittered starting parameter value back-transformed as:

$$P_{new} = P_{min} + (\frac{P_{max} - P_{min}}{1.0 + exp(-2.0 * temp)})$$

where P_{max} and P_{min} are upper and lower bounds of parameters and P_{val} is the estimated parameter value before the jittering. Jittering results are not updated and presented in this report.

Assessment Methodology

This assessment model again uses the modeling framework GMACS and is detailed in Appendix A. An updated version of GMACS (version 2.01.M.01, 2023-03-13) was used.

4. Results

a. Effective sample sizes and weighting factors

i. CVs are assumed to be 0.03 for retained catch biomass, 0.04 for total male biomass, 0.07 for pot bycatch biomasses, 0.10 for groundfish bycatch biomasses, and 0.23 for recruitment sex ratio. Models also estimate sigmaR for recruitment variation and have a penalty on M variation and many prior-densities.

ii. Initial trawl survey catchability (Q) is estimated to be 0.896 with a standard deviation of 0.025 (CV about 0.03) based on the double-bag experiment results (Weinberg et al. 2004). These values are used to set a prior for estimating Q in all models.

iii. Harmonic means of implied sample sizes and maximum caps of effective sample sizes for models 21.1b, 22.0, and 23.0a are summarized in Table 13.

b. Parameter estimates and tables

i. Negative log-likelihood values and parameter estimates are summarized in Tables 17 – 20 for all three models.

ii. Natural mortality estimates are shown in Table 14 for three models.

iii. Area-swept estimates of mature female abundance and model estimates of effective spawning biomass (Zheng et al. 1995b) during 2011-2022 for groundfish fisheries bycatch calculation are provided in Table 16.

iv. Abundance and biomass time series are provided in Tables 21 – 23 for models 21.1b, 22.0, and 23.0a.

v. Recruitment time series for models 21.1b, 22.0, 22.0a are provided in Tables 21 – 23.

vi. Time series of catch biomass is provided in Tables 9 and 10.

Length-specific fishing mortality is equal to selectivity-at-length times the full selection fishing mortality. Estimated full pot fishing mortalities for females and full fishing mortalities for groundfish fisheries bycatch are low due to low bycatch and handling mortality rates less than 1.0. Estimated recruits varied greatly among years (Tables 21 – 23). Estimated selectivities for female pot bycatch are close to 1.0 for all mature females, and the estimated full fishing mortalities for female pot bycatch are lower than those for male retained catch and bycatch (Tables 18 – 20 for models 21.1b, 22.0, and 23.0a).

c. Graphs of estimates

i. Estimated selectivities by length are provided in Figures 13, 14, and 21 and estimated molting probabilities by length are illustrated in Figures 15 and 16.

One of the most important results is estimated trawl survey selectivity (Figures 13). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. These estimated survey selectivities are generally smaller than the capture probabilities in Figure A1 because survey selectivities include capture probabilities and crab availability. The NMFS survey catchability is estimated to be 0.896 from the trawl experiment. The reliability of estimated survey selectivities will greatly affect the application of the model to fisheries management. Under- or over-estimates of survey selectivities will cause a systematic upward or downward bias of abundance estimates, respectively. Information about crab availability in the survey area at survey times will help estimate the survey selectivities. Higher estimated natural mortalities generally result in lower NMFS survey selectivities, while the estimated survey selectivities after 1981 are similar among the models.

For all models, estimated molting probabilities during 1975-2023 (Figures 15 and 16) are generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crab, possibly due to changes in molting probabilities over time or shell aging errors. Overestimates or underestimates of oldshell crab will result in lower or higher estimates of male molting probabilities.

ii. Estimated male and female survey biomasses are shown for NMFS surveys (Figures 17 and 18) and BSFRF surveys (19 and 20). Absolute mature male biomasses are illustrated in Figures 24 and 25. Mature female abundance (a trigger in the State harvest strategy) is illustrated in Figure 26.

The survey male biomass estimates in 2023 decreased from 2022, however they are still higher than the low values of 2018, 2019, and 2021. Survey female biomass estimates increased higher than the last four years of survey estimates, however this higher estimate was due to one large tow of approximately one-third of the mature females resulting in high variability about these estimates. Estimated population biomass increased dramatically in the mid-1970s then decreased precipitously in the early 1980s. Estimated biomass had increased during 1985-2003 for males and during 1985-2007 for females, then declined, and have steadily declined since the late 2000s (Figures 17, 18, 24, and 25). Absolute mature male biomasses for all models have a similar trend over time (Figures 24 and 25). Among the three models, model estimated relative NMFS survey biomasses are similar for two models 21.1b and 22.0. Model 23.0a estimates a constant M for males, resulting in slightly higher NMFS survey biomass estimates in the early part of the time series and lower in recent years than the other models. All models fit the catch and bycatch biomasses very well.

The fit to BSFRF survey data and estimated survey selectivities are illustrated in Figures 19 and 20, but are all similar in their results.

iii. Estimated recruitment time series are plotted in Figures 27 and 28 for models 21.1b, 22.0, and 23.0a. Recruitment is estimated at the end of year in GMACS and is moved up one year for the beginning of next year. Estimated recruitment time series for models 21.1b, 22.0, and 23.0a are similar. Estimated recruitments among models with higher M values are generally higher.

Like the results of previous models, the terminal year recruitment analysis with model 21.1b suggests the estimated recruitment in the last year should not be used for estimating $B_{35\%}$ (Figure 61 and 62).

iv. Estimated fishing mortality rates are plotted against mature male biomass in Figures 29, 30, and 31 for models 21.1b, 22.0, and 23.0a, and estimated M and directed pot fishing mortality values over time are illustrated in Figure 32 and 33 for models 21.1b, 22.0, and 23.0a.

The average of estimated male recruits from 1984 to 2022 for models starting in 1975 and from 1986 to 2022 for models starting in 1985 (Figure 28) and mature male biomass per recruit are used to estimate $B_{35\%}$. The full fishing mortalities for the directed pot fishery at the time of fishing are plotted against mature male biomass on Feb. 15 (Figures 29, 30, and 31). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figures 29, 30, and 31). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998-1999, 2005, 2007-2010, and 2014-2019 in the model presented, but below the $F_{35\%}$ limits in the other post-1995 years.

For model 21.1b, estimated full pot fishing mortalities ranged from 0.00 to 2.27 during 1975-2020, with estimated values over 0.40 during 1975-1982, 1984-1987, 1990-1991, 1993, 1998 and 2007-2009 (Table 21, Figures 29 and 30). For model 22.0, estimated full pot fishing mortalities ranged from 0.00 to 0.70 during 1985-2020, with estimated values over 0.40 in the same years as model 21.1b. Estimated fishing mortalities for pot female and groundfish fisheries bycatches are generally small and less than 0.07.

For model 21.1b, estimated M values are 0.89 during 1980-1984 and 0.18 for the other years for males, and 1.17 during 1980-1984 and 0.24 for the other years for females, with estimated female M values equaling to 1.325 times male M values (Figure 32). For model 22.0, estimated M values 0.18 for all years for males, and 0.23 for females, with estimated female M values equaling to 1.327 times male M values. For model 23.0a, estimated M for males is 0.23, higher than the fixed value of 0.18 in the other models, while M for females is estimated at 0.27, only slightly higher than the base model. Biologically, females mature earlier than males and likely have higher M values. M values for all models are listed in Table 14.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with model 21.1b (Figure 34). Annual stock productivities are illustrated in Figure 35. Stock productivity (recruitment/mature male biomass) is generally lower during the last 20 years (Figure 35). However, there are high variations for the relation of stock productivity against mature male biomass.

Egg clutch data collected during summer surveys may provide information about mature female reproductive conditions (Figures 36 and 37). Although egg clutch data are subject to rating errors as well as sampling errors, data trends over time may be useful. Proportions of empty clutches for newshell mature females >89 mm CL are high in some years before 1990 but have been low since 1990 (Figure 36). The highest proportion of empty clutches (0.2) was in 1986, and primarily involved soft shell females (shell condition 1). Clutch fullness fluctuated annually around average levels during two periods: before 1991 and after 1990 (Figure 36). The average clutch fullness is similar for these two periods (Figure 36). Egg clutch fullness in the last ten years appears to oscillate up and down from the later period average but still remains higher than 75%.

d. Evaluation of the fit to the data.

i. Observed vs. estimated catches are plotted in Figure 38, with bycatch mortalities from different sources shown in Figure 38 for all models.

ii. Model fits to NMFS survey biomass are shown in Figure 17 and 18 with a standardized residual plot in Figure 39 for models 21.1b, 22.0, and 23.0a.

iii. Model fits to catch and survey proportions by length are illustrated in Figures 40 – 50 and residual bubble plots are shown in Figures 51 – 56.

All models fit the fishery biomass data well and the survey biomass reasonably well (Figures 17, 18, 38). Because the model estimates annual fishing mortality for directed pot male catch, pot female bycatch, and trawl and fixed gear bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences. All models fit the NMFS area-swept biomass data almost identically (Figures 17 and 18). All models also fit the length composition data well (Figures 40 – 50). Modal progressions are tracked well in the trawl survey data, particularly beginning in mid-1990s (Figures 43 and 44). Cohorts first seen in the trawl survey data in 1975, 1986, 1990, 1995, 1999, 2002 and 2005 can be tracked over time. Some cohorts can be tracked over time in the pot bycatch as well (Figure 40), but the bycatch data did not track the cohorts as well as the survey data. Groundfish bycatch data provide little information to track modal progression.

Residuals of survey biomasses and proportions of length are plotted to examine their patterns. Residuals were calculated as observed minus predicted and standardized by the estimated standard deviation. Residuals of survey biomasses did not show any consistent patterns for all models (Figures 51 – 56). Generally, residuals of proportions of survey males and females appear to be random over length and year for all models (Figures 51 – 56). Models with higher base M values like model 23.0a improve the plus group (males > 160 mm CL and females > 140mm CL) fittings slightly.

e. Retrospective and historical analyses

Retrospective analyses were conducted for this report using the 2023 models. The 2023 model hindcast results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data.

i. Retrospective analysis (retrospective bias in base model or models).
   The performance of the 2023 model includes sequentially excluding one-year of data. Model 21.1b produces some upward biases during 2013-2023 with higher terminal year estimates of mature male biomass in 2014-2022 (Figure 57). Higher than expected BSFRF survey biomass during 2007-2008 and 2013-2016 and NMFS survey biomass in 2014 likely caused these biases. Also, much lower than expected NMFS survey biomass during 2018-2019 results in lower biomass estimates in 2020 and 2021. Model 22.0, with starting year of 1985 has a similar result (Figure 58), but with higher bias values. Mohn's rho calculations for these retrospective runs were high (0.242 to 0.418) but were reduced some in model 23.0a, which estimates a base M for males in the model.
   Ratios of estimated retrospective recruitments to terminal estimates in 2023 as a function of number of years estimated in the model show converging to 1.0 as the number of years increases (Figure 61). Standard deviations of the ratios drop sharply from one year estimated in the model to two years (Figure 62), showing great uncertainty of recruitment estimates for terminal years. Based on these results, we suggest not using recruitment estimates in a terminal year for overfishing/overfished determination.

f. Uncertainty and sensitivity analyses.

i. Estimated standard deviations of parameters are summarized in Tables 18 – 20 for models 21.1b, 22.0, and 23.0a. Estimated standard deviations of mature male biomass are listed in Tables 21 – 23.

ii. Probabilities for mature male biomass and OFL in 2023 were illustrated in Figures 63 and 64 for model 21.1b using the MCMC approach.

iii. Probabilities for mature male biomass below the minimum threshold (0.5* $B_{35\%}$) in 2023 were plotted in Figure 65 for model 21.1b using the MCMC approach.

iv. Sensitivity analysis for handling mortality rate was included in the SAFE report in May 2010. The baseline handling mortality rate for the directed pot fishery was set at 0.2. A 50% reduction and 100% increase respectively resulted in 0.1 and 0.4 as alternatives. Overall, a higher handling mortality rate resulted in slightly higher estimates of mature abundance, and a lower rate resulted in a minor reduction of estimated mature abundance. Differences of estimated legal male abundance and mature male biomass were small for these handling mortality rate changes.

v. Sensitivity of weights. Sensitivity of weights was examined in the SAFE report in May 2010. Weights to biomasses (trawl survey biomass, retained catch biomass, and bycatch biomasses) were reduced to 50% or increased to 200% to examine their sensitivity to abundance estimates. Weights to the penalty terms (recruitment variation and sex ratio) were respectively reduced or increased. Overall, estimated biomasses were similar under different weights except during the mid-1970s. The variation of estimated biomasses in the mid-1970s was mainly caused by the changes in estimates of additional mortalities in the early 1980s.

vi. Jittering. Models 21.1b and 23.0a underwent jittering (using 100 iterations of sd =0.1) with both models converging on the MLE >95% of the time. Those jitter runs that did not converge to the MLE were not an improvement to the MLE.

g. Comparison of alternative model scenarios.

Sensitivity to data weighting comparisons, based on the data through 2010, were reported in the SAFE report in May 2011. Estimating length proportions in the initial year (scenario 1a) resulted in a better fit of survey length compositions at an expense of 36 more parameters than model 1. Abundance and biomass estimates with model 1a were similar between models. Using only standard survey data (scenario 1b) resulted in a poorer fit of survey length compositions and biomass than scenarios using both standard and re-tow data (scenarios 1, 1a, and 1c) and had the lowest likelihood value. Although the likelihood value was higher for using both standard survey and re-tow data for males (scenario 1) than using only standard survey for males (scenario 1c), estimated abundances and biomasses were almost identical. The higher likelihood value for scenario 1 over scenario 1c was due to trawl bycatch length compositions.

In the SAFE report in September 2020, seven models were compared. The population biomass estimates in 2020 were slightly higher than those in 2019. Absolute mature male biomasses for all models had a similar trend over time. Among the seven models, model estimated relative NMFS survey biomasses and mature biomasses were similar, especially for models 19.0a and 19.0b and for models 19.3 and 19.3a. Biomass estimates for models 19.0a and 19.0b were higher during recent years than the other five model scenarios. As expected, model 19.3b estimated a higher trawl survey catchability (>1.0), thus resulting in overall lower absolute biomass estimates. Differences of biomass estimates between models 19.0a and 19.0b and models 19.3, 19.3a, 19.3l, and 19.3h could largely be explained by different structures of natural mortality. All seven models fitted the catch and bycatch biomasses very well.

The SAFE report in 2021 and 2022 were also focused on the themes of different structures of natural mortality and potential data time series reductions. Additionally, model exploration in May 2023 began explorations on survey catchability estimation, but those are not explored in the models here since they were not deemed appropriate for model selection at this time.

In this report (September 2023), three models are compared. For negative likelihood value comparisons (Table 17), only models 21.1b and 23.0a can be compared since model 22.0 does not have the same data time series. Model 23.0a has a higher negative likelihood value than the base model 21.1b. High base M values estimated inside the models generally result in significantly higher total likelihood values.

Model 21.1b - which was the accepted model in 2022 - is considred the “base” model for this assessment with only the GMACS version and updated data different from 2022 reported models. Model explorations in May 2023 presented the differences in this model with updates to GMACS in detail. Model 21.1b is used to compare the other two model scenarios, both of which were presented in May 2023 and chosen as potential candidates for specification setting.

Model 23.0a estimates a base M for males in model 21.1b instead of fixing this base at 0.18. Estimating a base M for males reduces total likelihood compared to model 21.1b, slightly increases annual mature male biomass estimates in most years, and results in an estimated $B_{35\%}$, about 10% lower than model 21.1b. A high M also results in higher $F_{35\%}$ and OFL for model 23.0a. The resulting stock status for model 23.0a is very similar to model 21.1b (0.77% of B_{MSY} compared to 0.76%, Table 15). Model 23.0a does have a lower trawl survey catchability estimate (0.94 vs 0.97), however this estimate is similar to that of model 22.0, and still considered to be a realistic estimate.

Model 22.0 starts the data time series in 1985, it is the short data version of model 21.1b and the overall results are similar. The notable differences are smaller B35% (19,967 t vs 21,719 t) and NMFS survey catchability (0.94 vs 0.97), and higher OFL (3,917 t vs 3,522 t) for model 22.0. These differences are probably caused by a high recruitment in 1984 (associated with the very large M) being used for $B_{35\%}$ computation for model 21.1b and more influence of BSFRF survey data for model 22.0. However, the terminal year estimate of MMB was nearly identical for model 22.0. While this model is appealing due to reductions in parameters estimated and removal of the mortality event in the early 80s, the larger retrospective pattern contributes to this model not being the best for characterization of the present and future of this stock and therefore is not recommended for specifications.

Based on the model results, it appears that the choice of preferred models depends on estimation of M. Considerations of M estimation are whether to estimate a base M for males for the whole time series versus a fixed base M. Model 23.0a estimates M using a log-normal prior with a mean of 0.18 and a CV of 0.04, which has a fairly tight prior but does result in a higher estimate of M for males and females which appears appropriate for this population. While estimating natural mortality and trawl survey catchability for the entire time series can be confounding, the current priors on both of these estimations are fairly strict and keep them from straying much from their data based means.

Based on the above considerations, model 21.1b is still recommended (a fixed base M of 0.18 for males) for specification setting for September 2023. However, model 23.0a would be an appropriate step towards a potentially more realistic natural mortality for this stock, and can be considered for specifications also. Ideally it would be good to have a better understanding of the interplay between estimating survey catchabiltiy and natural mortality within this model before moving forward with estimating both. Due to the strict nature of both of the priors (natural mortality and catchability) in model 23.0a this interplay is minimal. Based on CPT recommendations from the September 2023 meeting, model 23.0a was put forward for specifications for 2023/24 season. Values for specifications are presented for model 23.0a (Tables 1 and 3), but values for the other models are presented in Table 15.

F. Calculation of the OFL and ABC

1. Bristol Bay RKC is currently placed in Tier 3b (NPFMC 2007).
2. For Tier 3 stocks, estimated biological reference points include $B_{35\%}$ and $F_{35\%}$. Estimated model parameters are used to conduct mature male biomass-per-recruit analysis.
3. Specification of the OFL:

The Tier 3 OFL is calculated using the F_{OFL} control rule:

$$F_{OFL} = \begin{cases} 0_{directedpot} & \frac{B}{B^*} \leq \beta \\ F^* \frac{(\frac{B}{B^*} - \alpha)}{1-\alpha} & \beta < \frac{B}{B^*} \leq 1 \\ F^* & \frac{B}{B^*} > 1 \end{cases} \tag{1}$$

Where

B = a measure of the productive capacity of the stock such as spawning biomass or fertilized egg production. A proxy of B is mature male biomass (MMB) estimated at the time of primiparous female mating (February 15).

$F^* = F_{35\%}$, a proxy for F_{MSY}, which is a full selection instantaneous F that will produce MSY at the MSY producing biomass.

$B^* = B_{35\%}$, a proxy for B_{MSY}, which is the value of biomass at the MSY producing level.

β = a parameter with restriction that $0 \leq \beta < 1$. A default value of 0.25 is used.

α = a parameter with restriction that $0 \leq \alpha \leq \beta$. A default value of 0.1 is used.

Because trawl bycatch fishing mortality is not related to pot fishing mortality, average trawl bycatch fishing mortality during 2018 to 2022 is used for the per recruit analysis as well as for projections in the next section. Some discards of legal males occurred after the Individual Fishery Quota (IFQ) fishery started in 2005, but the discard rates were much lower during 2007-2013 than in 2005 after the fishing industry minimized discards of legal males. However, due to high proportions of large oldshell males, the discard rate increased greatly in 2014. The current models estimate two levels of retained proportions before 2005 and after 2004. The retained proportions after 2004 and total male selectivities are used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2016-2022 are used for per recruit analysis and projections. For the models in 2023, the averages are the same since they are constant over time during at least the last 15 years.

Average recruitments during 1984-2022 for models starting in 1975 and during 1986-2022 for models starting in 1985 are used to estimate $B_{35\%}$ (Figure 28). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 34. The period of 1984-2022 corresponds to the 1976/77 regime shift, and the recruitment period 1984-present has been used since 2011 to set the overfishing limits. Several factors support our recommendation. First, estimated recruitment was lower after 1983 than before 1984, which corresponded to brood years 1978 and later, after the 1976/77 regime shift. Second, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay, whereas the recent spawning stock has been concentrated in the middle of Bristol Bay. Oceanic current flows favor larvae hatched in the southern Bristol Bay (see the section on Ecosystem Considerations for SAFE reports in 2008 and 2009). Finally, stock productivity (recruitment/mature male biomass) was higher before the 1976/1977 regime shift.

The control rule is used for stock status determination. If total catch exceeds OFL estimated at B, then "overfishing" occurs. If B equals or declines below $_{50\%}$ B_{MSY} (i.e., MSST), the stock is "overfished." If B/B_{MSY} or $B/B_{MSYproxy}$ equals or declines below β, then the stock productivity is severely depleted, and the directed fishery is closed.

The estimated probability distributions of MMB in 2024 are illustrated in Figures 63 and 64 for model 21.1b. Based on SSC suggestions in 2011, $ABC = 0.9 * OFL$ and in October 2018, $ABC = 0.8 * OFL$. The CPT then recommended $ABC = 0.8 * OFL$ in May 2018 (accepted by the SSC), which is used to estimate ABC in this report. Due to the stock being at low levels and the lack of a 2020 survey, the CPT recommended an additional 5% buffer in September 2020, resulting in $ABC = 0.75 * OFL$ for 2020. A 20% buffer was suggested by the CPT for 2021 and 2022, and is recommended by the author in 2023 for similar reasons as 2022.

MCMC runs with 500,000 replicates and 500 draws with model 21.1b are used for estimating the probability of estimated mature male biomass being below the minimum threshold ($0.5 * B_{35}$) (Figure 65). The probability (converted to a percentage) is estimated to be about 0% for model 21.1b (Figure 66).

Status and catch specifications (1,000 t) (model 23.0a):

Table 5: Status and catch specifications (1000 t) for model 23.0a.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2019/20	12.72	14.24	1.72	1.78	2.22	3.40	2.72
2020/21	12.12	13.96	1.20	1.26	1.57	2.14	1.61
2021/22	12.01	16.64	0	0.02	0.10	2.23	1.78
2022/23	9.68	18.34	0	0.02	0.07	3.04	2.43
2023/24		14.98				4.42	3.54

Status and catch specifications (million lb, model 23.0a):

Table 6: Status and catch specifications (million lb) for model 23.0a.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2019/20	28.0	31.4	3.80	3.91	4.89	7.50	6.00
2020/21	26.7	30.8	2.77	2.65	3.47	4.72	3.54
2021/22	26.5	36.7	0	0.04	0.22	4.91	3.92
2022/23	21.34	40.44	0	0.05	0.16	6.70	5.35
2023/24		33.02				9.75	7.8

The biological reference points and OFL are illustrated in Tables 15 and 17 for all models, these are based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2022.

Table 7: Basis for the OFL (1000 t) from model 23.0a.

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	Basis for B_{MSY}	Natural mortality
2019/20	3b	21.2	16.0	0.75	0.22	1984-2018	0.18
2020/21	3b	25.4	14.9	0.59	0.16	1984-2019	0.18
2021/22	3b	24.2	14.9	0.62	0.17	1984-2020	0.18
2022/23	3b	24.03	17.0	0.71	0.20	1984-2021	0.18
2023/24	3b	19.36	14.98	0.77	0.302	1984-2022	0.18

Table 8: Basis for the OFL (million lb) from model 23.0a.

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	Basis for B_{MSY}	Natural mortality
2019/20	3b	46.8	35.2	0.75	0.22	1984-2018	0.18
2020/21	3b	56.1	32.9	0.59	0.16	1984-2019	0.18
2021/22	3b	53.4	33.0	0.62	0.17	1984-2020	0.18
2022/23	3b	53.0	37.4	0.71	0.20	1984-2021	0.18
2023/24	3b	42.68	33.02	0.77	0.302	1984-2022	0.18

G. Rebuilding Analysis

NA, not applicable for this stock

H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:

a. Information about changes in natural mortality in the early 1980s,
b. Un-observed trawl bycatch in the early 1980s,
c. Natural mortality,
d. Crab availability to the trawl surveys,
e. Juvenile crab abundance,
f. Female growth per molt as a function of size and maturity,
g. Changes in male molting probability over time,
h. A better understanding of larval distribution and subsequent recruit distribution.

2. Research priorities:

a. Estimating natural mortality,
b. Estimating crab availability to the trawl surveys,
c. Surveying juvenile crab abundance in nearshore,
d. Studying environmental factors that affect the survival rates from larvae to recruitment.

I. Projections and outlook

1. Projections

Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections is a random selection from estimated recruitments during 2013-2022, a low recruitment period. Four levels of fishing mortality for the directed pot fishery are used in the projections: 0, 0.083, 0.167 and 0.25. A fishing mortality of 0.167 is similar to the estimated F_{ofl} of 0.149 in 2020/2021 with model 21.1b. MCMC runs with 500,000 replicates and 500 draws are used for the projection.

As expected, projected mature male biomasses are much higher without the directed fishing mortality than under other positive mortality values. At the end of 10 years, projected mature male biomass is below $B_{35\%}$ for all models with a fishing mortality of 0.083 or higher due to low recruitments for both models 21.1b and 23.0a (Figures 66 and 68). Due to the poor recruitment in recent years, the projected biomass is expected to decline during the next few years with a fishing mortality of greater than F = 0.167.

Even though the stock was not overfished in 2022/23, there is still a question whether the stock is "approaching an overfished condition", which is defined as "when it is projected that there is more than a 50 percent chance that the biomass of the stock or stock complex will decline below the MSST within two years" by the National Standards 1 (NS1). If the stock is not fished more than a fishing mortality of 0.25 for the directed pot fishery in the 2023/2024 and 2024/2025 seasons, the projection using the lowest recruitment periods during 2013-2022 would not likely result in "approaching an overfished condition" for model 21.1b (Figure 67). With additional low recruitment estimate used to compute $B_{35\%}$, the estimated MSST would decline further in 2024.

The projections are subject to many uncertainties. Constant population parameters estimated in the models used for the projections include M, growth, and fishery selectivities. The uncertainty of abundance and biomass estimates in the terminal year also affects the projections. Uncertainties of the projections caused by these constant parameters and abundance estimates in the terminal year would be reduced by the 20% ABC buffer. However, if an extreme event occurs, like a sharp increase of M during the projection period, the ABC buffer would be inadequate, and the projections might underestimate uncertainties. The largest uncertainty is likely from recruitments used for the projections. Higher or lower assumed recruitments would cause too optimistic or too pessimistic projections. Overall, recruitments and M used for projections are main factors for projection uncertainties.

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a steady to declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figures 6 and 7). Most individuals from the 1997-year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and the legal population by 2014 (Figures 6 and 7). However, no additional strong cohorts were observed in the survey data after this cohort through 2010 (Figure 6, 7, 69 and 70). A huge tow of juvenile crab of size 45-55 mm in 2011 was not tracked during 2012-2023 surveys and is unlikely to be a strong cohort. The high survey abundances of large males and mature females in 2014 cannot be explained by the survey data during the previous years and were also inconsistent with the 2016-2022 survey results (Figures 69 and 70). Due to lack of recruitment, mature and legal crab may continue to decline next year in the presence of fishing pressure.

Even with the closure of the directed fishery the past two seasons both recruitment and abundance of male and female crab have held steady, showing only small increases or decreases, and without evidence of better recruitment. The increase in females in this years survey would be promising, but it is confounded by the contribution of one large tow to the increase instead of an increased catch throughout Bristol Bay. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely in the near future.

Although mature crab abundance in Bristol Bay has declined in recent years, mature crab abundance and biomass north of Bristol Bay has been generally stable during last 16 years (Figures 73 and 72). Overall, the proportions of different size groups of the Northern RKC during a recent dozen years are higher than in the past and do not trend higher except for mature females in 2021. The high survey caught mature female abundance in the Northern area in 2021 was primarily from three tows and one of them is more than 50% of total mature females. The survey abundance of the Northern RKC will continue to be provided in figures in the SAFE report in the future. After migration patterns between BBRKC and the Northern RKC are more fully understood, we will examine their relationships and model them in the stock assessment.

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Tables

Table 9: Bristol Bay red king crab annual catch and bycatch mortality biomass (t) from July 1 to June 30. A handling mortality rate of 0.20 for the directed pot, 0.25 for the Tanner fishery, 0.80 for trawl, and 0.50 for fixed gear was assumed to estimate bycatch mortality biomass. The male bycatch biomass in the directed pot fishery is not estimated outside of a model and not included in this Table. Pot bycatch and Tanner crab fishery bycatch are estimated through expanding the mean observer bycatch per pot to total fishery pot. The pot male bycatch after 2017 is estimated through the subtraction method (B. Daly, ADFG, pers. com.). The trawl and fixed gear fishery bycatches are obtained from the NMFS database. The directed pot bycatch before 1990 and Tanner crab fishery bycatch before 1991 are not available from the observer data and thus not included in this table. These include recently updated estimates from the pot fisheries observer data in 2022.

	Retained				Bycatch			
Year	US	Cost Recovery	Foreign	Total	Females	Trawl	Fixed	Tanner
1953	1331.30		4705.60	6036.90				
1954	1149.90		3720.40	4870.20				
1955	1029.20		3712.70	4741.90				
1956	973.40		3572.90	4546.40				
1957	339.70		3718.10	4057.80				
1958	3.20		3541.60	3544.80				
1959	0.00		6062.30	6062.30				
1960	272.20		12200.70	12472.90				
1961	193.70		20226.60	20420.30				
1962	30.80		24618.70	24649.60				
1963	296.20		24930.80	25227.00				
1964	373.30		26385.50	26758.80				
1965	648.20		18730.60	19378.80				
1966	452.20		19212.40	19664.60				
1967	1407.00		15257.00	16664.10				
1968	3939.90		12459.70	16399.60				
1969	4718.70		6524.00	11242.70				
1970	3882.30		5889.40	9771.70				
1971	5872.20		2782.30	8654.50				
1972	9863.40		2141.00	12004.30				
1973	12207.80		103.40	12311.20				
1974	19171.70		215.90	19387.60				
1975	23281.20		0.00	23281.20				
1976	28993.60		0.00	28993.60		682.80		
1977	31736.90		0.00	31736.90		1249.90		
1978	39743.00		0.00	39743.00		1320.60		
1979	48910.00		0.00	48910.00		1331.90		
1980	58943.60		0.00	58943.60		1036.50		
1981	15236.80		0.00	15236.80		219.40		
1982	1361.30		0.00	1361.30		574.90		
1983	0.00		0.00	0.00		420.40		
1984	1897.10		0.00	1897.10		1094.00		
1985	1893.80		0.00	1893.80		390.10		
1986	5168.20		0.00	5168.20		200.60		
1987	5574.20		0.00	5574.20		186.40		
1988	3351.10		0.00	3351.10		598.40		
1989	4656.00		0.00	4656.00		175.20		
1990	9236.20	36.60	0.00	9272.80	639.20	259.90		

1991	7791.80	93.40	0.00	7885.10	46.80	349.40		1401.80
1992	3648.20	33.60	0.00	3681.80	395.30	293.50		244.40
1993	6635.40	24.10	0.00	6659.60	628.30	401.40		54.60
1994	0.00	42.30	0.00	42.30	0.40	87.30		10.80
1995	0.00	36.40	0.00	36.40	0.30	82.10		0.00
1996	3812.70	49.00	0.00	3861.70	1.00	90.80	41.40	0.00
1997	3971.90	70.20	0.00	4042.10	36.50	57.50	22.50	0.00
1998	6693.80	85.40	0.00	6779.20	553.90	186.10	18.50	0.00
1999	5293.50	84.30	0.00	5377.90	5.60	150.50	50.10	0.00
2000	3698.80	39.10	0.00	3737.90	164.40	81.70	4.70	0.00
2001	3811.50	54.60	0.00	3866.20	120.80	192.80	35.30	0.00
2002	4340.90	43.60	0.00	4384.50	9.10	151.20	29.20	0.00
2003	7120.00	15.30	0.00	7135.30	356.90	136.90	12.70	0.00
2004	6915.20	91.40	0.00	7006.70	171.80	173.50	15.20	0.00
2005	8305.00	94.70	0.00	8399.70	405.40	124.70	19.90	0.00
2006	7005.30	137.90	0.00	7143.20	37.50	151.70	19.60	3.80
2007	9237.90	66.10	0.00	9303.90	159.90	154.10	32.30	1.80
2008	9216.10	0.00	0.00	9216.10	144.80	136.60	15.60	4.00
2009	7226.90	45.50	0.00	7272.50	88.30	94.90	5.80	1.60
2010	6728.50	33.00	0.00	6761.50	118.50	83.20	2.40	0.00
2011	3553.30	53.80	0.00	3607.10	25.00	56.20	10.90	0.00
2012	3560.60	61.10	0.00	3621.70	11.20	34.10	18.40	0.00
2013	3901.10	89.90	0.00	3991.00	98.10	66.90	55.10	28.50
2014	4530.00	8.60	0.00	4538.60	84.90	34.50	118.70	42.00
2015	4522.30	91.40	0.00	4613.70	239.10	45.10	77.40	84.20
2016	3840.40	83.40	0.00	3923.90	123.40	67.30	29.70	0.00
2017	2994.10	99.60	0.00	3093.70	53.40	91.70	130.00	0.00
2018	1954.10	72.40	0.00	2026.50	150.10	78.00	154.70	0.00
2019	1719.80	55.50	0.00	1775.30	43.30	80.70	45.10	0.00
2020	1200.60	56.40	0.00	1257.00	15.20	80.70	37.60	0.00
2021	0.00	17.40	0.00	17.40	5.90	34.40	40.30	0.00
2022	0.00	23.10	0.00	23.10	0.90	15.20	25.30	0.00

Table 10: Annual retained catch (millions of crab) and catch per unit effort (CPUE) of the Bristol Bay red king crab fishery.

	Japanese Tanglenet		Russian Tanglenet		US Pot		Standardized
Year	Catch	CPUE	Catch	CPUE	Catch	CPUE	CPUE
1960	1.95	15.20	2.00	10.40	0.088		15.80
1961	3.03	11.80	3.44	8.90	0.062		12.90
1962	4.95	11.30	3.02	7.20	0.01		11.30
1963	5.48	8.50	3.02	5.60	0.101		8.60
1964	5.89	9.20	2.80	4.60	0.123		8.50
1965	4.22	9.30	2.23	3.60	0.223		7.70
1966	4.21	9.40	2.56	4.10	0.14	52	8.10
1967	3.76	8.30	1.59	2.40	0.397	37	6.30
1968	3.85	7.50	0.55	2.30	1.278	27	7.80
1969	2.07	7.20	0.37	1.50	1.749	18	5.60
1970	2.08	7.30	0.32	1.40	1.683	17	5.60
1971	0.89	6.70	0.26	1.30	2.405	20	5.80
1972	0.87	6.70			3.994	19	
1973	0.23				4.826	25	
1974	0.48				7.71	36	
1975					8.745	43	
1976					10.603	33	
1977					11.733	26	
1978					14.746	36	
1979					16.809	53	
1980					20.845	37	
1981					5.308	10	
1982					0.541	4	
1983					No directed	fishery	
1984					0.794	7	
1985					0.796	9	
1986					2.1	12	
1987					2.122	10	
1988					1.236	8	
1989					1.685	8	
1990					3.13	12	
1991					2.661	12	
1992					1.208	6	
1993					2.27	9	
1994					No directed	fishery	
1995					No directed	fishery	
1996					1.264	16	
1997					1.338	15	
1998					2.238	15	
1999					1.923	12	
2000					1.272	12	
2001					1.287	19	
2002					1.484	20	
2003					2.51	18	
2004					2.272	23	
2005					2.763	30	
2006					2.477	31	
2007					3.154	28	
2008					3.064	22	

2009	2.553	21
2010	2.41	18
2011	1.298	28
2012	1.176	30
2013	1.272	27
2014	1.501	26
2015	1.527	31
2016	1.281	38
2017	0.997	20
2018	0.63	20
2019	0.549	16
2020	0.455	21
2021	No directed	fishery
2022	No directed	fishery

Table 11: Total observer catch and bycatch (metric ton) of Bristol Bay red king crab. No handling mortality rates are applied. These include recently updated estimates from the pot fishery observer data in 2022. Directed pot fishery data are the result of the cost-recovery fishery since the directed fishery was closed for the 2021/22 and 2022/23 seasons

	Directed Pot Total		Bycatch Fisheries		
Year	Males	Females	Trawl	Fixed	Tanner
1975			0		
1976			853.494		
1977			1,562.31		
1978			1,650.78		
1979			1,664.93		
1980			1,295.63		
1981			274.229		
1982			718.61		
1983			525.554		
1984			1,367.55		
1985			487.576		
1986			250.758		
1987			233.045		
1988			747.996		
1989			219.023		
1990	11621.80	3196.20	324.883		
1991	9792.90	233.90	436.783		5,580.84
1992	5916.20	1976.30	366.816		962.846
1993	9516.80	3141.50	501.77		218.112
1994	62.30	1.88	109.129		39.395
1995	52.80	1.61	102.623		0
1996	3845.20	5.10	113.495	82.86	0
1997	3758.80	182.70	71.862	44.98	0
1998	15644.80	2769.30	232.58	36.92	0
1999	12112.30	28.00	188.101	100.24	0
2000	6579.70	821.90	102.161	9.45	0
2001	5711.50	604.00	241.011	70.55	0
2002	6961.40	45.60	189.018	58.38	0
2003	12166.50	1784.40	171.114	25.35	0
2004	10692.00	859.20	216.889	30.42	0
2005	13615.90	2027.10	155.924	39.80	0
2006	9254.00	187.40	189.66	39.13	15.217
2007	13871.90	799.40	192.571	64.66	7.142
2008	14894.90	724.20	170.754	31.16	16.07
2009	12218.80	441.30	118.672	11.61	6.499
2010	10095.40	592.60	104.005	4.94	0
2011	5665.30	124.80	70.286	21.73	0
2012	4495.50	55.90	42.641	36.90	0
2013	5305.90	490.70	83.613	110.21	113.063
2014	8113.80	424.30	43.129	237.37	137.786
2015	6726.80	1195.60	56.41	154.78	639.573
2016	5651.80	617.20	84.127	59.42	0
2017	4077.20	266.90	114.624	260.01	0
2018	3423.20	750.40	97.561	309.42	0
2019	3144.60	218.00	100.915	90.29	0
2020	2299.70	76.10	100.842	75.13	0
2021	33.80	29.40	42.99	80.60	0

2022	28.30	4.60	18.97	50.58	0

Table 12: Annual sample sizes (>64 mm CL) in numbers of crab for trawl surveys, retained catch, directed pot, Tanner crab, trawl, and fixed gear fishery bycatches of Bristol Bay red king crab.

	Trawl Survey		Retained	Pot Total		Bycatch Combined		
Year	Males	Females	Catch	Males	Females	Trawl	Fixed	Tanner
1975	2,815	2,042	29,570					
1976	2,699	1,466	26,450			3,003		
1977	2,734	2,424	32,596			14,703		
1978	2,735	2,793	27,529			10,439		
1979	1,158	1,456	27,900			10,049		
1980	1,917	1,301	34,747			87,152		
1981	591	664	18,029			91,806		
1982	1,911	1,948	11,466			131,469		
1983	1,343	733	0			309,374		
1984	1,209	778	4,404			505,115		
1985	790	414	4,582			200,460		
1986	959	341	5,773			2,126		
1987	1,123	1,011	4,230			998		
1988	708	478	9,833			630		
1989	764	403	32,858			4,641		
1990	729	535	7,218	2,544	696	908		
1991	1,180	490	36,928	4,696	375	275		3,131
1992	509	357	25,550	4,775	2,379	333		965
1993	725	576	32,942	10,200	5,944	5		497
1994	416	239	0	0	0	571		17
1995	685	407	0	0	0	120		
1996	755	753	8,896	642	11	1,209	756	
1997	1,280	702	16,143	10,016	906	339	1,269	
1998	1,067	1,123	17,116	24,537	9,655	1,430	1,036	
1999	765	618	18,685	6,892	40	629	1,602	
2000	734	730	14,143	32,709	8,470	729	591	
2001	599	736	13,735	25,135	5,436	795	5,029	
2002	972	826	16,837	32,317	706	1,139	3,503	
2003	1,360	1,250	18,178	44,600	12,474	516	1,872	
2004	1,852	1,271	22,465	38,772	6,666	636	2,184	
2005	1,198	1,563	27,971	94,622	26,782	1,040	2,146	
2006	1,178	1,432	18,451	73,315	3,991	1,168	1,868	140
2007	1,228	1,305	22,809	115,507	12,691	1,225	785	53
2008	1,228	1,183	24,997	89,771	8,564	1,596	1,164	145
2009	837	941	19,336	97,868	6,055	1,170	1,089	193
2010	708	1,004	20,347	69,276	6,872	901	513	
2011	531	912	10,904	42,931	1,920	439	1,190	
2012	585	707	9,084	21,404	563	281	2,977	
2013	647	569	10,396	32,332	6,051	481	8,523	814
2014	1,107	1,257	9,718	31,216	2,663	261	4,285	631
2015	615	681	11,971	24,533	7,457	409	4,472	2,872
2016	378	812	11,003	30,030	5,832	617	4,329	
2017	385	508	10,067	30,002	4,043	718	1,415	
2018	285	359	7,825	25,635	9,840	893	5,382	
2019	273	299	8,134	25,999	2,894	823	863	
2020			3,850	16,650	961	764	246	
2021	324	247	101	1,100	1433	503	120	
2022	401	319	100	1088	299			
2023	407	435						

Table 13: Comparison of harmonic means of implied sample sizes and maximum caps (N) of effective sample sizes for models 21.1b, 22.0, and 23.0a.

	N	21.1b	22.0	23.0a
Retained catch	150	158.43	163.53	167.87
Pot total males	150	211.69	212.84	214.64
Pot total females	50	29.14	29.00	29.33
Trawl bycatch	50	58.13	56.40	62.46
Tanner fishery bycatch	50	25.34	25.15	25.72
Fixed gear bycatch	50	42.27	42.08	42.86
NMFS survey	200	174.13	199.14	178.10
BSFRF survey	200	117.90	114.36	125.81

Table 14: Natural mortality estimates for model scenarios during different year blocks.

Model	Sex	baseM	1980-84	1985-22
21.1b (2023)	Female	0.24	1.17	
21.1b (2023)	Male	0.18	0.89	
22.0 1985	Female			0.23
22.0 1985	Male			0.18
23.0a Mest	Female	0.27	1.15	
23.0a Mest	Male	0.23	0.99	

Table 15: Management quantities for all models. Report quantities are derived from maximum likelihood estimates. Average recruitment (Avg Rec) is males and females combined in millions of animals.

Model	Current MMB	B35	MMB/B_{MSY}	F35	F_{OFL}	OFL	Avg Rec	Male M
21.1b (2023)	16.48	21.72	0.76	0.30	0.22	3.52	14.85	0.18
22.0 1985	16.48	19.97	0.83	0.30	0.24	3.92	13.62	0.18
23.0a Mest	14.98	19.36	0.77	0.40	0.30	4.42	21.18	0.23

Table 16: Area-swept estimates of mature female abundance (million crab >89mm) and model estimates of effective spawning biomass (ESB, LBA model from Zheng et al. 1995b; 1000 t) during 2011-2023 for groundfish fisheries bycatch (prohibited species catch, PSC) calculation. (*mature female abundance in 2020 is the model projected value). Note that PSC limits apply to previous-year ESB.

Year	Mature Female Abundance	Effective Spawning Biomass (1000t)
2011	28.52	19.54
2012	21.121	20.03
2013	15.694	22.38
2014	38.58	23.27
2015	18.666	21.10
2016	22.633	19.15
2017	18.497	18.04
2018	9.106	15.09
2019	8.587	12.71
2020	9.668*	11.39
2021	6.432	9.46
2022	8.004	8.89
2023	11.054	9.32

Table 17: Comparisons of negative log-likelihood values and some parameters for all model scenarios.

Component	base m21.1b	m23.0a	m22.0
Pot-ret-catch	-60.77	-61.84	-34.83
Pot-totM-catch	28.49	27.75	28.42
Pot-F-discC	-57.44	-57.45	-57.44
Trawl-discC	-65.13	-65.14	-52.67
Tanner-M-discC	-43.54	-43.54	-26.12
Tanner-F-discC	-43.48	-43.51	-26.07
Fixed-discC	-37.42	-37.42	-37.42
Traw-suv-bio	-37.28	-38.98	-46.15
BSFRF-sur-bio	-2.94	-4.82	-3.37
Pot-ret-comp	-3991.77	-3998.15	-3191.10
Pot-totM-comp	-2443.63	-2444.35	-2444.63
Pot-discF-comp	-1493.90	-1494.87	-1493.41
Trawl-disc-comp	-5937.57	-5945.91	-4782.21
Tanner-disc-comp	-1274.30	-1276.69	-1273.35
Fixed-disc-comp	-3486.24	-3483.07	-3487.49
Trawl-sur-comp	-7130.66	-7137.97	-5651.22
BSFRF-sur-comp	-843.09	-844.78	-841.91
Recruit-dev	72.95	73.83	43.06
Recruit-ini	0.00	0.00	0.00
Recruit-sex-R	78.49	78.50	62.18
$Log_f dev_0$	0.00	0.00	0.00
M-deviation	43.92	40.42	0.00
Sex-specific-R	0.00	0.01	0.13
Ini-size-struct	30.82	33.58	50.80
PriorDensity	265.30	250.58	231.58
Tot-likelihood	-26429.18	-26473.80	-23033.23
Tot-likeli-no-PD	-26163.88	-26223.23	-22801.65
Tot-parameter	378.00	379.00	314.00
MMB_{35}	21718.77	19361.24	19967.36
MMB-terminal	16480.20	14975.92	16481.06
F_{35}	0.30	0.40	0.30
F_{ofl}	0.22	0.30	0.24
OFL	3522.29	4424.14	3916.66
ABC	2817.83	3539.32	3133.32
NMFS Q	0.97	0.94	0.94

Table 18: Summary of estimated model parameter values and standard deviations for model 21.1b for Bristol Bay red king crab.

Index	Name	Value	StdDev	index	name	value	stddev
1	M offset	0.2739	0.0138	47	log-slx-pars[1]	4.7608	0.0082
2	logRini	19.8190	0.0488	48	$log - slx - pars[2]$	2.2714	0.0458
3	logRbar	16.1720	0.1370	49	$log - slx - pars[3]$	4.5126	0.0165
4	rect scale-var male	0.7004	0.1250	50	$log - slx - pars[4]$	2.0491	0.1084
5	rect scale-var fem	-0.5304	0.2247	51	$log - slx - pars[5]$	5.1631	0.0595
6	dev size class 2	0.9575	0.4194	52	$log - slx - pars[6]$	2.8582	0.0452
7	dev size class 3	0.6521	0.4674	53	$log - slx - pars[7]$	4.7219	0.2188
8	dev size class 4	0.8596	0.3318	54	$log - slx - pars[8]$	2.1638	0.3059
9	dev size class 5	0.7087	0.3044	55	$log - slx - pars[9]$	4.7463	0.0775
10	dev size class 6	0.5452	0.2945	56	$log - slx - pars[10]$	0.9000	0.3035
11	dev size class 7	0.5007	0.2770	57	$log - slx - pars[11]$	4.7870	0.0222
12	dev size class 8	0.3438	0.2773	58	$log - slx - pars[12]$	2.3329	0.0863
13	dev size class 9	0.3784	0.2639	59	$log - slx - pars[13]$	4.0895	0.1956
14	dev size class 10	0.4107	0.2583	60	$log - slx - pars[14]$	2.2357	0.4015
15	dev size class 11	0.1840	0.2812	61	$log - slx - pars[15]$	3.7549	0.6262
16	dev size class 12	0.1620	0.2771	62	$log - slx - pars[16]$	3.2493	0.4070
17	dev size class 13	0.0561	0.2868	63	$log - slx - pars[17]$	4.4282	0.0288
18	dev size class 14	0.1714	0.2625	64	$log - slx - pars[18]$	2.4212	0.0709
19	dev size class 15	-0.0061	0.2036	65	$log - slx - pars[19]$	4.9232	0.0015
20	dev size class 16	-0.2357	0.1957	66	$log - slx - pars[20]$	0.6747	0.0533
21	dev size class 17	-0.3883	0.1978	67	$log - slx - pars[21]$	4.9321	0.0020
22	dev size class 18	-0.7366	0.2114	68	$log - slx - pars[22]$	0.7186	0.0990
23	dev size class 19	-1.1967	0.2326	69	$log - fbar[1]$	-1.6673	0.0424
24	dev size class 20	-1.2417	0.2349	70	$log - fbar[2]$	-4.3416	0.0751
25	dev size class 1 f	1.2834	0.6755	71	$log - fbar[3]$	-5.5892	0.2909
26	dev size class 2 f	1.4473	0.4616	72	$log - fbar[4]$	-6.5084	0.0705
27	dev size class 3 f	1.3906	0.3675	73	$log - fdev[1]$	0.9136	0.1188
28	dev size class 4 f	1.1656	0.3362	74	$log - fdev[1]$	0.8714	0.0906
29	dev size class 5 f	1.0791	0.2955	75	$log - fdev[1]$	0.7824	0.0743
30	dev size class 6 f	0.5974	0.3188	76	$log - fdev[1]$	0.8759	0.0604
31	dev size class 7 f	0.2118	0.3529	77	$log - fdev[1]$	1.0872	0.0541
32	dev size class 8 f	-0.0262	0.3615	78	$log - fdev[1]$	1.9548	0.0563
33	dev size class 9 f	-0.2151	0.3547	79	$log - fdev[1]$	2.4908	0.1194
34	dev size class 10 f	-0.5471	0.3742	80	$log - fdev[1]$	0.9171	0.1770
35	dev size class 11 f	-0.9334	0.3857	81	$log - fdev[1]$	-8.7942	0.1261
36	dev size class 12 f	-1.1914	0.3903	82	$log - fdev[1]$	1.2519	0.1125
37	dev size class 13 f	-1.4218	0.3888	83	$log - fdev[1]$	1.3254	0.0894
38	dev size class 14 f	-1.7911	0.3769	84	$log - fdev[1]$	1.4907	0.0733
39	dev size class 15 f	-1.8971	0.3728	85	$log - fdev[1]$	1.0240	0.0643
40	dev size class 16 f	-1.8388	0.3526	86	$log - fdev[1]$	0.0849	0.0531
41	m beta	0.9669	0.1825	87	$log - fdev[1]$	0.1991	0.0476
42	fem beta	1.4454	0.1214	88	$log - fdev[1]$	0.8477	0.0389
43	molt prob1	142.4900	1.7326	89	$log - fdev[1]$	0.8623	0.0415
44	molt-cv1	0.0579	0.0101	90	$log - fdev[1]$	0.3484	0.0462
45	molt prob2	139.9800	0.5900	91	$log - fdev[1]$	1.0177	0.0508
46	molt-cv2	0.0707	0.0033	92	$log - fdev[1]$	-4.1351	0.0487
93	$log - fdev[1]$	-4.5473	0.0422	143	$log - fdev[2]$	0.1119	0.1039
94	$log - fdev[1]$	-0.0773	0.0408	144	$log - fdev[2]$	-0.1674	0.1037
95	$log - fdev[1]$	-0.0286	0.0412	145	$log - fdev[2]$	-0.9286	0.1030
96	$log - fdev[1]$	0.8877	0.0437	146	$log - fdev[2]$	-0.1601	0.1029

97	$log-fdev[1]$	0.5304	0.0428	147	$log-fdev[2]$	-0.4595	0.1026
98	$log-fdev[1]$	-0.0566	0.0412	148	$log-fdev[2]$	-0.5527	0.1024
99	$log-fdev[1]$	-0.1361	0.0408	149	$log-fdev[2]$	-0.3201	0.1024
100	$log-fdev[1]$	-0.0247	0.0397	150	$log-fdev[2]$	-0.5954	0.1023
101	$log-fdev[1]$	0.4387	0.0384	151	$log-fdev[2]$	-0.4262	0.1020
102	$log-fdev[1]$	0.3962	0.0385	152	$log-fdev[2]$	-0.3489	0.1021
103	$log-fdev[1]$	0.6865	0.0390	153	$log-fdev[2]$	-0.3753	0.1023
104	$log-fdev[1]$	0.4391	0.0384	154	$log-fdev[2]$	-0.7326	0.1024
105	$log-fdev[1]$	0.8043	0.0383	155	$log-fdev[2]$	-0.8816	0.1023
106	$log-fdev[1]$	0.9760	0.0400	156	$log-fdev[2]$	-1.3459	0.1020
107	$log-fdev[1]$	0.7919	0.0407	157	$log-fdev[2]$	-1.8676	0.1021
108	$log-fdev[1]$	0.6609	0.0400	158	$log-fdev[2]$	-1.1533	0.1023
109	$log-fdev[1]$	0.0241	0.0388	159	$log-fdev[2]$	-1.7176	0.1025
110	$log-fdev[1]$	-0.0523	0.0378	160	$log-fdev[2]$	-1.3343	0.1031
111	$log-fdev[1]$	0.1347	0.0376	161	$log-fdev[2]$	-0.8092	0.1045
112	$log-fdev[1]$	0.4639	0.0379	162	$log-fdev[2]$	-0.3763	0.1065
113	$log-fdev[1]$	0.5360	0.0400	163	$log-fdev[2]$	-0.4417	0.1086
114	$log-fdev[1]$	0.5352	0.0449	164	$log-fdev[2]$	-0.3477	0.1111
115	$log-fdev[1]$	0.4455	0.0529	165	$log-fdev[2]$	-0.3768	0.1129
116	$log-fdev[1]$	0.2550	0.0620	166	$log-fdev[2]$	-1.3634	0.1134
117	$log-fdev[1]$	0.1953	0.0694	167	$log-fdev[2]$	-2.3064	0.1149
118	$log-fdev[1]$	-0.2388	0.0721	168	$log-fdev[3]$	-0.1164	0.0682
119	$log-fdev[1]$	-4.6866	0.0712	169	$log-fdev[3]$	0.6699	0.0682
120	$log-fdev[1]$	-4.7690	0.0704	170	$log-fdev[3]$	1.2283	0.0682
121	$log-fdev[2]$	0.2419	0.1247	171	$log-fdev[3]$	1.0927	0.0682
122	$log-fdev[2]$	0.6801	0.1165	172	$log-fdev[3]$	1.3825	0.0682
123	$log-fdev[2]$	0.6588	0.1106	173	$log-fdev[3]$	1.4243	0.0682
124	$log-fdev[2]$	0.7342	0.1090	174	$log-fdev[3]$	0.9927	0.0682
125	$log-fdev[2]$	1.4516	0.1117	175	$log-fdev[3]$	0.4764	0.0682
126	$log-fdev[2]$	1.2246	0.1308	176	$log-fdev[3]$	-0.9874	0.0682
127	$log-fdev[2]$	2.5078	0.1315	177	$log-fdev[3]$	-0.5787	0.0682
128	$log-fdev[2]$	2.2296	0.1190	178	$log-fdev[3]$	-1.0994	0.0682
129	$log-fdev[2]$	3.4537	0.1163	179	$log-fdev[3]$	-0.2563	0.0682
130	$log-fdev[2]$	2.2496	0.1114	180	$log-fdev[3]$	0.9401	0.0682
131	$log-fdev[2]$	1.1873	0.1113	181	$log-fdev[3]$	1.4182	0.0682
132	$log-fdev[2]$	0.7329	0.1089	182	$log-fdev[3]$	3.2422	0.0755
133	$log-fdev[2]$	1.5068	0.1046	183	$log-fdev[3]$	1.2884	0.0949
134	$log-fdev[2]$	0.0746	0.1036	184	$log-fdev[3]$	0.5871	0.1209
135	$log-fdev[2]$	0.5289	0.1036	185	$log-fdev[3]$	-0.7543	0.0815
136	$log-fdev[2]$	0.9539	0.1048	186	$log-fdev[3]$	-2.1386	0.0735
137	$log-fdev[2]$	0.7909	0.1051	187	$log-fdev[3]$	-2.9910	0.0925
138	$log-fdev[2]$	1.2704	0.1079	188	$log-fdev[3]$	-2.4123	0.1123
139	$log-fdev[2]$	-0.4997	0.1049	189	$log-fdev[3]$	-3.4950	0.0757
140	$log-fdev[2]$	-0.7897	0.1034	190	$log-fdev[3]$	-0.8486	0.0937
141	$log-fdev[2]$	-0.7230	0.1036	191	$log-fdev[3]$	-0.1237	0.1113
142	$log-fdev[2]$	-1.1886	0.1035	192	$log-fdev[3]$	1.0591	0.1333
193	$log-fdev[4]$	0.5581	0.1030	243	$log-fdov[1]$	-1.1676	0.0785
194	$log-fdev[4]$	-0.1048	0.1021	244	$log-fdov[1]$	-1.8840	0.0781
195	$log-fdev[4]$	-0.3206	0.1027	245	$log-fdov[1]$	0.1371	0.0780
196	$log-fdev[4]$	0.6006	0.1019	246	$log-fdov[1]$	-0.2697	0.0781
197	$log-fdev[4]$	-1.8269	0.1014	247	$log-fdov[1]$	0.7877	0.0785
198	$log-fdev[4]$	0.1279	0.1011	248	$log-fdov[1]$	0.2371	0.0800
199	$log-fdev[4]$	-0.1302	0.1007	249	$log-fdov[1]$	-0.4174	0.0826
200	$log-fdev[4]$	-0.9636	0.1006	250	$log-fdov[1]$	0.9058	0.0865

201	$log - fdev[4]$	-0.7899	0.1004	251	$log - fdov[1]$	-0.1694	0.0895
202	$log - fdev[4]$	-0.5165	0.1003	252	$log - fdov[1]$	-0.6953	0.0901
203	$log - fdev[4]$	-0.5631	0.1000	253	$log - fdov[1]$	2.8968	0.0896
204	$log - fdev[4]$	-0.0163	0.1000	254	$log - fdov[1]$	1.2413	0.0898
205	$log - fdev[4]$	-0.7163	0.1004	255	$log - fdov[3]$	-0.0000	0.0962
206	$log - fdev[4]$	-1.7133	0.1001	256	$log - fdov[3]$	0.0001	0.0962
207	$log - fdev[4]$	-2.5481	0.0997	257	$log - fdov[3]$	0.0003	0.0963
208	$log - fdev[4]$	-1.0676	0.0994	258	$log - fdov[3]$	0.0002	0.0963
209	$log - fdev[4]$	-0.5125	0.0993	259	$log - fdov[3]$	0.0004	0.0963
210	$log - fdev[4]$	0.6269	0.0993	260	$log - fdov[3]$	0.0001	0.0963
211	$log - fdev[4]$	1.4777	0.0994	261	$log - fdov[3]$	-0.0001	0.0963
212	$log - fdev[4]$	1.1606	0.0997	262	$log - fdov[3]$	-0.0002	0.0962
213	$log - fdev[4]$	0.3295	0.1004	263	$log - fdov[3]$	-0.0002	0.0962
214	$log - fdev[4]$	1.9314	0.1016	264	$log - fdov[3]$	-0.0001	0.0962
215	$log - fdev[4]$	2.1884	0.1027	265	$log - fdov[3]$	-0.0001	0.0962
216	$log - fdev[4]$	0.9856	0.1040	266	$log - fdov[3]$	0.0001	0.0962
217	$log - fdev[4]$	0.7804	0.1057	267	$log - fdov[3]$	0.0004	0.0962
218	$log - fdev[4]$	0.7715	0.1070	268	$log - fdov[3]$	0.0008	0.0963
219	$log - fdev[4]$	0.2512	0.1092	269	$log - fdov[3]$	1.5517	0.1690
220	$log - foff[1]$	-2.7448	0.0396	270	$log - fdov[3]$	1.8070	0.1203
221	$log - foff[3]$	-0.1036	0.4149	271	$log - fdov[3]$	0.5731	0.1421
222	$log - fdov[1]$	1.9426	0.0836	272	$log - fdov[3]$	-3.4377	0.1082
223	$log - fdov[1]$	-0.7302	0.0828	273	$log - fdov[3]$	-2.1316	0.1444
224	$log - fdov[1]$	1.9421	0.0841	274	$log - fdov[3]$	-0.7745	0.1255
225	$log - fdov[1]$	1.7744	0.0858	275	$log - fdov[3]$	0.0419	0.1322
226	$log - fdov[1]$	-0.4582	0.0846	276	$log - fdov[3]$	0.3868	0.1027
227	$log - fdov[1]$	-0.2258	0.0824	277	$log - fdov[3]$	0.9394	0.1676
228	$log - fdov[1]$	-3.7226	0.0813	278	$log - fdov[3]$	0.1583	0.1525
229	$log - fdov[1]$	-0.3543	0.0820	279	$log - fdov[3]$	0.8840	0.1671
230	$log - fdov[1]$	1.4261	0.0823	280	rec-dev-est	1.1089	0.2653
231	$log - fdov[1]$	-2.8064	0.0815	281	rec-dev-est	0.6603	0.2932
232	$log - fdov[1]$	1.1234	0.0807	282	rec-dev-est	1.1136	0.2384
233	$log - fdov[1]$	0.8492	0.0806	283	rec-dev-est	1.6938	0.2055
234	$log - fdov[1]$	-1.8978	0.0800	284	rec-dev-est	1.9597	0.2148
235	$log - fdov[1]$	1.1895	0.0801	285	rec-dev-est	1.1627	0.2565
236	$log - fdov[1]$	0.3967	0.0802	286	rec-dev-est	2.4345	0.1640
237	$log - fdov[1]$	0.9277	0.0796	287	rec-dev-est	1.4802	0.1782
238	$log - fdov[1]$	-1.2564	0.0791	288	rec-dev-est	1.0973	0.1655
239	$log - fdov[1]$	-0.2176	0.0791	289	rec-dev-est	-0.7272	0.2478
240	$log - fdov[1]$	-0.4845	0.0794	290	rec-dev-est	0.3481	0.1616
241	$log - fdov[1]$	-0.7522	0.0796	291	rec-dev-est	-0.8087	0.2423
242	$log - fdov[1]$	-0.2721	0.0794	292	rec-dev-est	-1.2347	0.2742
293	rec-dev-est	-0.9696	0.2210	339	logit-rec-prop-est	0.2249	0.4165
294	rec-dev-est	-0.0248	0.1625	340	logit-rec-prop-est	-0.1054	0.4545
295	rec-dev-est	-0.4839	0.1825	341	logit-rec-prop-est	0.4154	0.3822
296	rec-dev-est	-1.9423	0.3554	342	logit-rec-prop-est	-0.0802	0.1668
297	rec-dev-est	-0.8543	0.1959	343	logit-rec-prop-est	0.1809	0.2416
298	rec-dev-est	-1.9743	0.4168	344	logit-rec-prop-est	0.7068	0.7173
299	rec-dev-est	1.0212	0.1454	345	logit-rec-prop-est	0.2500	0.2838
300	rec-dev-est	-0.8946	0.2571	346	logit-rec-prop-est	-0.3047	0.6764
301	rec-dev-est	-1.5594	0.3362	347	logit-rec-prop-est	-0.2839	0.0866
302	rec-dev-est	-0.5418	0.1972	348	logit-rec-prop-est	1.3209	0.6446
303	rec-dev-est	0.4557	0.1540	349	logit-rec-prop-est	0.4112	0.6329
304	rec-dev-est	-0.5294	0.2223	350	logit-rec-prop-est	0.5011	0.3216

305	rec-dev-est	-0.5048	0.2384	351	logit-rec-prop-est	-0.0401	0.1402
306	rec-dev-est	0.8824	0.1527	352	logit-rec-prop-est	0.2166	0.3611
307	rec-dev-est	-0.5931	0.2632	353	logit-rec-prop-est	-0.5522	0.3756
308	rec-dev-est	-0.6566	0.2613	354	logit-rec-prop-est	-0.4728	0.1241
309	rec-dev-est	0.6189	0.1550	355	logit-rec-prop-est	-0.4069	0.4247
310	rec-dev-est	-0.1138	0.1807	356	logit-rec-prop-est	-0.0094	0.4364
311	rec-dev-est	-0.4985	0.1875	357	logit-rec-prop-est	-0.3851	0.1381
312	rec-dev-est	-1.0812	0.2349	358	logit-rec-prop-est	-0.0794	0.2361
313	rec-dev-est	-0.9518	0.2344	359	logit-rec-prop-est	0.3627	0.2781
314	rec-dev-est	0.0295	0.1766	360	logit-rec-prop-est	-0.1878	0.3691
315	rec-dev-est	-0.5126	0.2259	361	logit-rec-prop-est	-0.4417	0.3584
316	rec-dev-est	-1.0539	0.2306	362	logit-rec-prop-est	-0.7824	0.1944
317	rec-dev-est	-1.3729	0.2207	363	logit-rec-prop-est	-0.4576	0.3175
318	rec-dev-est	-1.8383	0.2667	364	logit-rec-prop-est	-0.5404	0.3449
319	rec-dev-est	-1.3622	0.2298	365	logit-rec-prop-est	-0.2384	0.3306
320	rec-dev-est	-0.7046	0.1724	366	logit-rec-prop-est	-0.3179	0.4277
321	rec-dev-est	-1.5169	0.2433	367	logit-rec-prop-est	-0.3592	0.3367
322	rec-dev-est	-0.8475	0.1907	368	logit-rec-prop-est	0.2842	0.2153
323	rec-dev-est	-1.5416	0.2770	369	logit-rec-prop-est	0.5167	0.4432
324	rec-dev-est	-1.5340	0.2716	370	logit-rec-prop-est	0.6098	0.2836
325	rec-dev-est	-1.6594	0.2882	371	logit-rec-prop-est	-0.1925	0.4561
326	rec-dev-est	-0.8932	0.2357	372	logit-rec-prop-est	0.3735	0.4701
327	rec-dev-est	-1.3340	0.3508	373	logit-rec-prop-est	0.5544	0.5227
328	logit-rec-prop-est	-0.0843	0.4264	374	logit-rec-prop-est	0.1438	0.3470
329	logit-rec-prop-est	-0.8587	0.5198	375	logit-rec-prop-est	-0.2362	0.5730
330	logit-rec-prop-est	-0.2347	0.3548	376	m-dev-est[1]	1.5980	0.0292
331	logit-rec-prop-est	-0.4360	0.2668	377	survey-q[1]	0.9680	0.0251
332	logit-rec-prop-est	0.0866	0.2537	378	$log - add - cv[2]$	-0.7750	0.2728
333	logit-rec-prop-est	0.2636	0.3347				
334	logit-rec-prop-est	0.3608	0.1401				
335	logit-rec-prop-est	0.4040	0.2304				
336	logit-rec-prop-est	-0.0648	0.1765				
337	logit-rec-prop-est	0.4403	0.4533				
338	logit-rec-prop-est	-0.4756	0.1656				

Table 19: Summary of estimated model parameter values and standard deviations for model 23.0a for Bristol Bay red king crab.

Index	Name	Value	StdDev	index	name	value	stddev
1	M males	0.2318	0.0065	47	molt-cv2	0.0687	0.0034
2	M offset	0.1511	0.0185	48	$log - slx - pars[1]$	4.7815	0.0083
3	logRini	20.0190	0.0590	49	$log - slx - pars[2]$	2.2786	0.0424
4	logRbar	16.5130	0.1436	50	$log - slx - pars[3]$	4.5656	0.0189
5	rect scale-var male	0.7638	0.1264	51	$log - slx - pars[4]$	2.2325	0.0907
6	rect scale-var fem	-0.5830	0.2145	52	$log - slx - pars[5]$	5.1331	0.0453
7	dev size class 2	1.0828	0.4281	53	$log - slx - pars[6]$	2.7830	0.0406
8	dev size class 3	0.7376	0.4877	54	$log - slx - pars[7]$	4.7191	0.2337
9	dev size class 4	0.9567	0.3339	55	$log - slx - pars[8]$	2.1670	0.3047
10	dev size class 5	0.7947	0.3034	56	$log - slx - pars[9]$	4.7363	0.0906
11	dev size class 6	0.6106	0.2925	57	$log - slx - pars[10]$	0.9031	0.3027
12	dev size class 7	0.5506	0.2736	58	$log - slx - pars[11]$	4.8083	0.0217
13	dev size class 8	0.3720	0.2743	59	$log - slx - pars[12]$	2.3330	0.0767
14	dev size class 9	0.3846	0.2618	60	$log - slx - pars[13]$	4.1631	0.1150
15	dev size class 10	0.3996	0.2555	61	$log - slx - pars[14]$	2.2419	0.3295
16	dev size class 11	0.1577	0.2774	62	$log - slx - pars[15]$	4.0732	0.2604
17	dev size class 12	0.1209	0.2732	63	$log - slx - pars[16]$	3.5909	0.4034
18	dev size class 13	-0.0034	0.2841	64	$log - slx - pars[17]$	4.4676	0.0273
19	dev size class 14	0.0894	0.2641	65	$log - slx - pars[18]$	2.5605	0.0766
20	dev size class 15	-0.0787	0.2038	66	$log - slx - pars[19]$	4.9234	0.0015
21	dev size class 16	-0.3239	0.1966	67	$log - slx - pars[20]$	0.6765	0.0525
22	dev size class 17	-0.4817	0.1988	68	$log - slx - pars[21]$	4.9323	0.0020
23	dev size class 18	-0.8343	0.2124	69	$log - slx - pars[22]$	0.7223	0.0977
24	dev size class 19	-1.2965	0.2331	70	$log - fbar[1]$	-1.7100	0.0439
25	dev size class 20	-1.3406	0.2354	71	$log - fbar[2]$	-4.3773	0.0755
26	dev size class 1 f	1.3360	0.7880	72	$log - fbar[3]$	-5.7052	0.3304
27	dev size class 2 f	1.5444	0.4942	73	$log - fbar[4]$	-6.5343	0.0751
28	dev size class 3 f	1.4441	0.3822	74	$log - fdev[1]$	0.8957	0.1207
29	dev size class 4 f	1.1954	0.3507	75	$log - fdev[1]$	0.8609	0.0912
30	dev size class 5 f	1.1145	0.3028	76	$log - fdev[1]$	0.7821	0.0752
31	dev size class 6 f	0.6386	0.3227	77	$log - fdev[1]$	0.8751	0.0615
32	dev size class 7 f	0.2334	0.3564	78	$log - fdev[1]$	1.0881	0.0557
33	dev size class 8 f	-0.0048	0.3595	79	$log - fdev[1]$	1.9587	0.0589
34	dev size class 9 f	-0.2030	0.3501	80	$log - fdev[1]$	2.5121	0.1137
35	dev size class 10 f	-0.5457	0.3688	81	$log - fdev[1]$	0.9623	0.1538
36	dev size class 11 f	-0.9405	0.3802	82	$log - fdev[1]$	-8.7023	0.1032
37	dev size class 12 f	-1.2002	0.3850	83	$log - fdev[1]$	1.4238	0.0999
38	dev size class 13 f	-1.4328	0.3837	84	$log - fdev[1]$	1.4629	0.0919
39	dev size class 14 f	-1.8195	0.3727	85	$log - fdev[1]$	1.5506	0.0778
40	dev size class 15 f	-1.9277	0.3691	86	$log - fdev[1]$	1.0415	0.0671
41	dev size class 16 f	-1.8706	0.3491	87	$log - fdev[1]$	0.0746	0.0547
42	m beta	0.9740	0.1871	88	$log - fdev[1]$	0.1836	0.0487
43	fem beta	1.3991	0.1226	89	$log - fdev[1]$	0.8291	0.0399
44	molt prob1	143.0000	1.7373	90	$log - fdev[1]$	0.8341	0.0430
45	molt-cv1	0.0558	0.0097	91	$log - fdev[1]$	0.3180	0.0476
46	molt prob2	141.1900	0.6119	92	$log - fdev[1]$	0.9766	0.0519
93	$log - fdev[1]$	-4.1904	0.0492	143	$log - fdev[2]$	-1.1997	0.1036
94	$log - fdev[1]$	-4.5887	0.0425	144	$log - fdev[2]$	0.0992	0.1041
95	$log - fdev[1]$	-0.1000	0.0409	145	$log - fdev[2]$	-0.1916	0.1040
96	$log - fdev[1]$	-0.0337	0.0413	146	$log - fdev[2]$	-0.9561	0.1033

97	$log-fdev[1]$	0.8844	0.0440	147	$log-fdev[2]$	-0.1792	0.1032
98	$log-fdev[1]$	0.5036	0.0435	148	$log-fdev[2]$	-0.4695	0.1028
99	$log-fdev[1]$	-0.0862	0.0418	149	$log-fdev[2]$	-0.5651	0.1026
100	$log-fdev[1]$	-0.1511	0.0413	150	$log-fdev[2]$	-0.3342	0.1025
101	$log-fdev[1]$	-0.0314	0.0400	151	$log-fdev[2]$	-0.6109	0.1024
102	$log-fdev[1]$	0.4279	0.0387	152	$log-fdev[2]$	-0.4440	0.1021
103	$log-fdev[1]$	0.3851	0.0388	153	$log-fdev[2]$	-0.3717	0.1023
104	$log-fdev[1]$	0.6775	0.0393	154	$log-fdev[2]$	-0.4022	0.1026
105	$log-fdev[1]$	0.4216	0.0386	155	$log-fdev[2]$	-0.7660	0.1028
106	$log-fdev[1]$	0.7858	0.0387	156	$log-fdev[2]$	-0.9229	0.1027
107	$log-fdev[1]$	0.9539	0.0409	157	$log-fdev[2]$	-1.3835	0.1023
108	$log-fdev[1]$	0.7547	0.0420	158	$log-fdev[2]$	-1.8944	0.1024
109	$log-fdev[1]$	0.6098	0.0415	159	$log-fdev[2]$	-1.1676	0.1025
110	$log-fdev[1]$	-0.0285	0.0400	160	$log-fdev[2]$	-1.7240	0.1026
111	$log-fdev[1]$	-0.0929	0.0387	161	$log-fdev[2]$	-1.3363	0.1032
112	$log-fdev[1]$	0.1068	0.0383	162	$log-fdev[2]$	-0.8027	0.1045
113	$log-fdev[1]$	0.4386	0.0385	163	$log-fdev[2]$	-0.3540	0.1063
114	$log-fdev[1]$	0.5084	0.0402	164	$log-fdev[2]$	-0.3985	0.1084
115	$log-fdev[1]$	0.5119	0.0442	165	$log-fdev[2]$	-0.2857	0.1107
116	$log-fdev[1]$	0.4370	0.0509	166	$log-fdev[2]$	-0.3046	0.1124
117	$log-fdev[1]$	0.2702	0.0590	167	$log-fdev[2]$	-1.2860	0.1127
118	$log-fdev[1]$	0.2312	0.0658	168	$log-fdev[2]$	-2.2207	0.1141
119	$log-fdev[1]$	-0.1941	0.0683	169	$log-fdev[3]$	-0.1163	0.0682
120	$log-fdev[1]$	-4.6342	0.0676	170	$log-fdev[3]$	0.6699	0.0682
121	$log-fdev[1]$	-4.7048	0.0673	171	$log-fdev[3]$	1.2283	0.0682
122	$log-fdev[2]$	0.2348	0.1256	172	$log-fdev[3]$	1.0926	0.0682
123	$log-fdev[2]$	0.6808	0.1173	173	$log-fdev[3]$	1.3824	0.0682
124	$log-fdev[2]$	0.6643	0.1115	174	$log-fdev[3]$	1.4242	0.0682
125	$log-fdev[2]$	0.7431	0.1103	175	$log-fdev[3]$	0.9927	0.0682
126	$log-fdev[2]$	1.4692	0.1132	176	$log-fdev[3]$	0.4764	0.0682
127	$log-fdev[2]$	1.2510	0.1255	177	$log-fdev[3]$	-0.9874	0.0682
128	$log-fdev[2]$	2.5449	0.1224	178	$log-fdev[3]$	-0.5787	0.0682
129	$log-fdev[2]$	2.2925	0.1129	179	$log-fdev[3]$	-1.0994	0.0682
130	$log-fdev[2]$	3.5424	0.1126	180	$log-fdev[3]$	-0.2563	0.0682
131	$log-fdev[2]$	2.3227	0.1122	181	$log-fdev[3]$	0.9401	0.0682
132	$log-fdev[2]$	1.2198	0.1126	182	$log-fdev[3]$	1.4182	0.0682
133	$log-fdev[2]$	0.7320	0.1100	183	$log-fdev[3]$	3.2430	0.0758
134	$log-fdev[2]$	1.4900	0.1054	184	$log-fdev[3]$	1.2810	0.1059
135	$log-fdev[2]$	0.0502	0.1041	185	$log-fdev[3]$	0.5511	0.1271
136	$log-fdev[2]$	0.4934	0.1042	186	$log-fdev[3]$	-0.7692	0.0854
137	$log-fdev[2]$	0.9075	0.1056	187	$log-fdev[3]$	-2.1203	0.0742
138	$log-fdev[2]$	0.7468	0.1058	188	$log-fdev[3]$	-2.9806	0.0990
139	$log-fdev[2]$	1.2109	0.1085	189	$log-fdev[3]$	-2.4158	0.1186
140	$log-fdev[2]$	-0.5487	0.1052	190	$log-fdev[3]$	-3.5068	0.0757
141	$log-fdev[2]$	-0.8266	0.1036	191	$log-fdev[3]$	-0.8373	0.0966
142	$log-fdev[2]$	-0.7493	0.1037	192	$log-fdev[3]$	-0.1100	0.1203
193	$log-fdev[3]$	1.0782	0.1481	243	$log-fdov[1]$	-0.2552	0.0799
194	$log-fdev[4]$	0.5319	0.1033	244	$log-fdov[1]$	-1.1339	0.0791
195	$log-fdev[4]$	-0.1164	0.1024	245	$log-fdov[1]$	-1.8477	0.0785
196	$log-fdev[4]$	-0.3359	0.1031	246	$log-fdov[1]$	0.1682	0.0784
197	$log-fdev[4]$	0.5736	0.1023	247	$log-fdov[1]$	-0.2354	0.0785
198	$log-fdev[4]$	-1.8535	0.1017	248	$log-fdov[1]$	0.8310	0.0789
199	$log-fdev[4]$	0.1090	0.1013	249	$log-fdov[1]$	0.2867	0.0802
200	$log-fdev[4]$	-0.1457	0.1009	250	$log-fdov[1]$	-0.3677	0.0824

201	$log-fdev[4]$	-0.9819	0.1008	251	$log-fdov[1]$	0.9450	0.0854
202	$log-fdev[4]$	-0.8062	0.1006	252	$log-fdov[1]$	-0.1385	0.0880
203	$log-fdev[4]$	-0.5347	0.1005	253	$log-fdov[1]$	-0.6617	0.0886
204	$log-fdev[4]$	-0.5833	0.1002	254	$log-fdov[1]$	2.9322	0.0886
205	$log-fdev[4]$	-0.0364	0.1002	255	$log-fdov[1]$	1.2716	0.0893
206	$log-fdev[4]$	-0.7387	0.1006	256	$log-fdov[3]$	-0.0000	0.0962
207	$log-fdev[4]$	-1.7420	0.1004	257	$log-fdov[3]$	0.0001	0.0962
208	$log-fdev[4]$	-2.5820	0.0999	258	$log-fdov[3]$	0.0003	0.0962
209	$log-fdev[4]$	-1.0972	0.0996	259	$log-fdov[3]$	0.0003	0.0963
210	$log-fdev[4]$	-0.5316	0.0995	260	$log-fdov[3]$	0.0004	0.0963
211	$log-fdev[4]$	0.6176	0.0994	261	$log-fdov[3]$	0.0001	0.0963
212	$log-fdev[4]$	1.4737	0.0995	262	$log-fdov[3]$	-0.0001	0.0963
213	$log-fdev[4]$	1.1636	0.0998	263	$log-fdov[3]$	-0.0001	0.0962
214	$log-fdev[4]$	0.3441	0.1005	264	$log-fdov[3]$	-0.0001	0.0962
215	$log-fdev[4]$	1.9614	0.1017	265	$log-fdov[3]$	-0.0001	0.0962
216	$log-fdev[4]$	2.2364	0.1028	266	$log-fdov[3]$	-0.0001	0.0962
217	$log-fdev[4]$	1.0474	0.1041	267	$log-fdov[3]$	0.0000	0.0962
218	$log-fdev[4]$	0.8488	0.1056	268	$log-fdov[3]$	0.0003	0.0962
219	$log-fdev[4]$	0.8446	0.1068	269	$log-fdov[3]$	0.0006	0.0963
220	$log-fdev[4]$	0.3335	0.1090	270	$log-fdov[3]$	1.4897	0.1588
221	$log-foff[1]$	-2.7574	0.0445	271	$log-fdov[3]$	1.7778	0.1278
222	$log-foff[3]$	-0.1395	0.4885	272	$log-fdov[3]$	0.5861	0.1485
223	$log-fdov[1]$	1.9051	0.0841	273	$log-fdov[3]$	-3.4396	0.1108
224	$log-fdov[1]$	-0.7521	0.0833	274	$log-fdov[3]$	-2.1782	0.1733
225	$log-fdov[1]$	1.9208	0.0846	275	$log-fdov[3]$	-0.8057	0.1313
226	$log-fdov[1]$	1.7587	0.0860	276	$log-fdov[3]$	0.0358	0.1377
227	$log-fdov[1]$	-0.4574	0.0846	277	$log-fdov[3]$	0.3959	0.1029
228	$log-fdov[1]$	-0.2380	0.0823	278	$log-fdov[3]$	0.9906	0.1745
229	$log-fdov[1]$	-3.7300	0.0813	279	$log-fdov[3]$	0.2097	0.1576
230	$log-fdov[1]$	-0.3775	0.0822	280	$log-fdov[3]$	0.9364	0.1833
231	$log-fdov[1]$	1.3843	0.0829	281	rec-dev-est	1.1022	0.2632
232	$log-fdov[1]$	-2.8344	0.0821	282	rec-dev-est	0.5911	0.2966
233	$log-fdov[1]$	1.1036	0.0811	283	rec-dev-est	1.0292	0.2415
234	$log-fdov[1]$	0.8195	0.0810	284	rec-dev-est	1.6112	0.2076
235	$log-fdov[1]$	-1.9359	0.0805	285	rec-dev-est	1.9106	0.2149
236	$log-fdov[1]$	1.1622	0.0803	286	rec-dev-est	1.1326	0.2575
237	$log-fdov[1]$	0.3689	0.0806	287	rec-dev-est	2.4109	0.1630
238	$log-fdov[1]$	0.8870	0.0802	288	rec-dev-est	1.4616	0.1772
239	$log-fdov[1]$	-1.2844	0.0796	289	rec-dev-est	1.0946	0.1641
240	$log-fdov[1]$	-0.2406	0.0796	290	rec-dev-est	-0.6997	0.2424
241	$log-fdov[1]$	-0.5040	0.0800	291	rec-dev-est	0.3635	0.1614
242	$log-fdov[1]$	-0.7546	0.0802	292	rec-dev-est	-0.7477	0.2371
293	rec-dev-est	-1.1841	0.2717	339	logit-rec-prop-est	-0.4809	0.1649
294	rec-dev-est	-0.9526	0.2229	340	logit-rec-prop-est	0.1744	0.3979
295	rec-dev-est	-0.0131	0.1630	341	logit-rec-prop-est	-0.1409	0.4464
296	rec-dev-est	-0.4073	0.1802	342	logit-rec-prop-est	0.3680	0.3809
297	rec-dev-est	-1.8651	0.3493	343	logit-rec-prop-est	-0.0938	0.1690
298	rec-dev-est	-0.8225	0.1955	344	logit-rec-prop-est	0.1480	0.2314
299	rec-dev-est	-2.0161	0.4386	345	logit-rec-prop-est	0.7606	0.7194
300	rec-dev-est	1.0224	0.1455	346	logit-rec-prop-est	0.2127	0.2810
301	rec-dev-est	-0.7614	0.2474	347	logit-rec-prop-est	-0.3720	0.7002
302	rec-dev-est	-1.5274	0.3418	348	logit-rec-prop-est	-0.3612	0.0891
303	rec-dev-est	-0.5343	0.1991	349	logit-rec-prop-est	1.2126	0.5987
304	rec-dev-est	0.4807	0.1539	350	logit-rec-prop-est	0.3886	0.6422

305	rec-dev-est	-0.4717	0.2184	351	logit-rec-prop-est	0.4605	0.3234
306	rec-dev-est	-0.5440	0.2480	352	logit-rec-prop-est	-0.0966	0.1390
307	rec-dev-est	0.9146	0.1525	353	logit-rec-prop-est	0.2109	0.3502
308	rec-dev-est	-0.5416	0.2585	354	logit-rec-prop-est	-0.5932	0.3975
309	rec-dev-est	-0.6335	0.2622	355	logit-rec-prop-est	-0.5346	0.1237
310	rec-dev-est	0.6051	0.1555	356	logit-rec-prop-est	-0.4136	0.4132
311	rec-dev-est	-0.0439	0.1767	357	logit-rec-prop-est	-0.1002	0.4310
312	rec-dev-est	-0.4733	0.1854	358	logit-rec-prop-est	-0.4172	0.1416
313	rec-dev-est	-1.0313	0.2291	359	logit-rec-prop-est	-0.1446	0.2220
314	rec-dev-est	-0.8961	0.2303	360	logit-rec-prop-est	0.4178	0.2761
315	rec-dev-est	0.0044	0.1804	361	logit-rec-prop-est	-0.1220	0.3564
316	rec-dev-est	-0.4742	0.2207	362	logit-rec-prop-est	-0.4880	0.3494
317	rec-dev-est	-1.0410	0.2272	363	logit-rec-prop-est	-0.7218	0.2038
318	rec-dev-est	-1.3850	0.2211	364	logit-rec-prop-est	-0.4455	0.3070
319	rec-dev-est	-1.8713	0.2653	365	logit-rec-prop-est	-0.5327	0.3376
320	rec-dev-est	-1.4136	0.2193	366	logit-rec-prop-est	-0.1993	0.3321
321	rec-dev-est	-0.7704	0.1706	367	logit-rec-prop-est	-0.3440	0.4246
322	rec-dev-est	-1.5464	0.2395	368	logit-rec-prop-est	-0.3811	0.3183
323	rec-dev-est	-0.8907	0.1877	369	logit-rec-prop-est	0.2665	0.2082
324	rec-dev-est	-1.6169	0.2768	370	logit-rec-prop-est	0.5493	0.4405
325	rec-dev-est	-1.5542	0.2641	371	logit-rec-prop-est	0.6054	0.2788
326	rec-dev-est	-1.7233	0.2882	372	logit-rec-prop-est	-0.1821	0.4570
327	rec-dev-est	-0.9453	0.2312	373	logit-rec-prop-est	0.2945	0.4505
328	rec-dev-est	-1.3828	0.3457	374	logit-rec-prop-est	0.5584	0.5281
329	logit-rec-prop-est	-0.0825	0.4202	375	logit-rec-prop-est	0.1423	0.3442
330	logit-rec-prop-est	-0.7944	0.5137	376	logit-rec-prop-est	-0.1831	0.5643
331	logit-rec-prop-est	-0.2159	0.3596	377	m-dev-est[1]	1.4547	0.0315
332	logit-rec-prop-est	-0.3880	0.2658	378	survey-q[1]	0.9381	0.0258
333	logit-rec-prop-est	0.2034	0.2560	379	$log - add - cv[2]$	-0.9821	0.2863
334	logit-rec-prop-est	0.3466	0.3362				
335	logit-rec-prop-est	0.4782	0.1428				
336	logit-rec-prop-est	0.5651	0.2374				
337	logit-rec-prop-est	0.0379	0.1746				
338	logit-rec-prop-est	0.4274	0.4371				

Table 20: Summary of estimated model parameter values and standard deviations for model 22.0 for Bristol Bay red king crab.

Index	Name	Value	StdDev	index	name	value	stddev
1	M offset	0.2446	0.0158	47	$log - slx - pars[3]$	4.5051	0.0164
2	logRini	17.8440	0.0404	48	$log - slx - pars[4]$	2.0168	0.1122
3	logRbar	15.7730	0.1544	49	$log - slx - pars[5]$	5.2274	0.1044
4	rect scale-var male	0.6612	0.1226	50	$log - slx - pars[6]$	2.9408	0.0540
5	rect scale-var fem	-0.5112	0.2487	51	$log - slx - pars[7]$	4.7331	0.2214
6	dev size class 2	0.7543	0.4982	52	$log - slx - pars[8]$	2.1647	0.3059
7	dev size class 3	0.7742	0.4754	53	$log - slx - pars[9]$	4.7174	0.0905
8	dev size class 4	1.1337	0.3481	54	$log - slx - pars[10]$	0.9033	0.3023
9	dev size class 5	1.3216	0.2830	55	$log - slx - pars[11]$	4.7835	0.0223
10	dev size class 6	1.2567	0.2635	56	$log - slx - pars[12]$	2.3312	0.0880
11	dev size class 7	0.9906	0.2710	57	$log - slx - pars[13]$	3.9786	0.3286
12	dev size class 8	0.9480	0.2585	58	$log - slx - pars[14]$	2.9013	0.3741
13	dev size class 9	1.2055	0.2212	59	$log - slx - pars[15]$	4.4308	0.0325
14	dev size class 10	1.1971	0.2156	60	$log - slx - pars[16]$	2.4075	0.0926
15	dev size class 11	1.0153	0.2225	61	$log - slx - pars[17]$	4.9240	0.0017
16	dev size class 12	0.9625	0.2148	62	$log - slx - pars[18]$	0.6733	0.0706
17	dev size class 13	0.8193	0.2182	63	$log - slx - pars[19]$	4.9322	0.0020
18	dev size class 14	0.4889	0.2235	64	$log - slx - pars[20]$	0.7265	0.0989
19	dev size class 15	0.0478	0.1944	65	$log - fbar[1]$	-1.7642	0.0475
20	dev size class 16	-0.4246	0.1967	66	$log - fbar[2]$	-4.7316	0.0815
21	dev size class 17	-1.0800	0.2201	67	$log - fbar[3]$	-5.9651	0.3083
22	dev size class 18	-1.6604	0.2526	68	$log - fbar[4]$	-6.5456	0.0714
23	dev size class 19	-2.3382	0.2764	69	$log - fdev[1]$	1.1569	0.1191
24	dev size class 20	-1.9977	0.3603	70	$log - fdev[1]$	1.3756	0.0792
25	dev size class 1 f	-0.0896	0.6018	71	$log - fdev[1]$	0.9828	0.0631
26	dev size class 2 f	0.3982	0.6556	72	$log - fdev[1]$	0.1310	0.0525
27	dev size class 3 f	0.8631	0.5459	73	$log - fdev[1]$	0.2791	0.0468
28	dev size class 4 f	1.0654	0.4296	74	$log - fdev[1]$	0.9360	0.0375
29	dev size class 5 f	1.2133	0.3370	75	$log - fdev[1]$	0.9483	0.0392
30	dev size class 6 f	1.0406	0.3140	76	$log - fdev[1]$	0.4339	0.0431
31	dev size class 7 f	0.8233	0.3109	77	$log - fdev[1]$	1.1001	0.0472
32	dev size class 8 f	0.3618	0.3479	78	$log - fdev[1]$	-4.0511	0.0452
33	dev size class 9 f	-0.3757	0.3931	79	$log - fdev[1]$	-4.4626	0.0396
34	dev size class 10 f	-0.8244	0.3863	80	$log - fdev[1]$	0.0069	0.0385
35	dev size class 11 f	-1.5228	0.3761	81	$log - fdev[1]$	0.0537	0.0386
36	dev size class 12 f	-1.6162	0.3733	82	$log - fdev[1]$	0.9703	0.0406
37	dev size class 13 f	-1.5472	0.3732	83	$log - fdev[1]$	0.6096	0.0399
38	dev size class 14 f	-1.7682	0.3639	84	$log - fdev[1]$	0.0206	0.0387
39	dev size class 15 f	-1.9062	0.3534	85	$log - fdev[1]$	-0.0575	0.0383
40	dev size class 16 f	-1.8731	0.3440	86	$log - fdev[1]$	0.0564	0.0376
41	m beta	0.8918	0.1881	87	$log - fdev[1]$	0.5202	0.0368
42	fem beta	1.4791	0.1335	88	$log - fdev[1]$	0.4768	0.0370
43	molt prob1	139.7500	0.6069	89	$log - fdev[1]$	0.7661	0.0370
44	molt-cv1	0.0707	0.0033	90	$log - fdev[1]$	0.5196	0.0367
45	log-slx-pars[1]	4.7605	0.0084	91	$log - fdev[1]$	0.8836	0.0365
46	$log - slx - pars[2]$	2.2741	0.0463	92	$log - fdev[1]$	1.0538	0.0372
93	$log - fdev[1]$	0.8681	0.0375	143	$log - fdev[2]$	-1.0180	0.1123
94	$log - fdev[1]$	0.7364	0.0368	144	$log - fdev[2]$	-1.9538	0.1139
95	$log - fdev[1]$	0.0995	0.0357	145	$log - fdev[3]$	-0.7271	0.0661
96	$log - fdev[1]$	0.0235	0.0350	146	$log - fdev[3]$	0.1160	0.0661

97	$log - fdev[1]$	0.2112	0.0348	147	$log - fdev[3]$	1.3122	0.0661
98	$log - fdev[1]$	0.5394	0.0350	148	$log - fdev[3]$	1.7903	0.0661
99	$log - fdev[1]$	0.6094	0.0370	149	$log - fdev[3]$	3.6184	0.0766
100	$log - fdev[1]$	0.6061	0.0419	150	$log - fdev[3]$	1.6685	0.0944
101	$log - fdev[1]$	0.5128	0.0498	151	$log - fdev[3]$	0.9650	0.1280
102	$log - fdev[1]$	0.3189	0.0589	152	$log - fdev[3]$	-0.3810	0.0802
103	$log - fdev[1]$	0.2578	0.0663	153	$log - fdev[3]$	-1.7651	0.0741
104	$log - fdev[1]$	-0.1760	0.0692	154	$log - fdev[3]$	-2.6149	0.0910
105	$log - fdev[1]$	-4.6199	0.0690	155	$log - fdev[3]$	-2.0366	0.1168
106	$log - fdev[1]$	-4.6974	0.0691	156	$log - fdev[3]$	-3.1237	0.0775
107	$log - fdev[2]$	2.4240	0.1142	157	$log - fdev[3]$	-0.4818	0.0961
108	$log - fdev[2]$	1.3972	0.1125	158	$log - fdev[3]$	0.2403	0.1139
109	$log - fdev[2]$	1.0014	0.1090	159	$log - fdev[3]$	1.4196	0.1376
110	$log - fdev[2]$	1.8342	0.1043	160	$log - fdev[4]$	0.5749	0.1030
111	$log - fdev[2]$	0.4355	0.1033	161	$log - fdev[4]$	-0.0908	0.1022
112	$log - fdev[2]$	0.9023	0.1030	162	$log - fdev[4]$	-0.3123	0.1028
113	$log - fdev[2]$	1.3277	0.1038	163	$log - fdev[4]$	0.6074	0.1019
114	$log - fdev[2]$	1.1644	0.1040	164	$log - fdev[4]$	-1.8188	0.1014
115	$log - fdev[2]$	1.6380	0.1066	165	$log - fdev[4]$	0.1365	0.1011
116	$log - fdev[2]$	-0.1254	0.1038	166	$log - fdev[4]$	-0.1211	0.1007
117	$log - fdev[2]$	-0.4132	0.1025	167	$log - fdev[4]$	-0.9551	0.1006
118	$log - fdev[2]$	-0.3501	0.1027	168	$log - fdev[4]$	-0.7816	0.1004
119	$log - fdev[2]$	-0.8208	0.1026	169	$log - fdev[4]$	-0.5091	0.1003
120	$log - fdev[2]$	0.4721	0.1029	170	$log - fdev[4]$	-0.5551	0.1001
121	$log - fdev[2]$	0.1935	0.1027	171	$log - fdev[4]$	-0.0100	0.1000
122	$log - fdev[2]$	-0.5652	0.1021	172	$log - fdev[4]$	-0.7126	0.1003
123	$log - fdev[2]$	0.2034	0.1020	173	$log - fdev[4]$	-1.7105	0.1001
124	$log - fdev[2]$	-0.0959	0.1018	174	$log - fdev[4]$	-2.5463	0.0996
125	$log - fdev[2]$	-0.1897	0.1017	175	$log - fdev[4]$	-1.0656	0.0994
126	$log - fdev[2]$	0.0419	0.1017	176	$log - fdev[4]$	-0.5110	0.0993
127	$log - fdev[2]$	-0.2360	0.1015	177	$log - fdev[4]$	0.6267	0.0993
128	$log - fdev[2]$	-0.0654	0.1013	178	$log - fdev[4]$	1.4747	0.0994
129	$log - fdev[2]$	0.0089	0.1013	179	$log - fdev[4]$	1.1541	0.0997
130	$log - fdev[2]$	-0.0218	0.1015	180	$log - fdev[4]$	0.3187	0.1004
131	$log - fdev[2]$	-0.3783	0.1016	181	$log - fdev[4]$	1.9162	0.1017
132	$log - fdev[2]$	-0.5257	0.1014	182	$log - fdev[4]$	2.1695	0.1028
133	$log - fdev[2]$	-0.9871	0.1011	183	$log - fdev[4]$	0.9643	0.1041
134	$log - fdev[2]$	-1.5085	0.1012	184	$log - fdev[4]$	0.7600	0.1057
135	$log - fdev[2]$	-0.7956	0.1014	185	$log - fdev[4]$	0.7560	0.1071
136	$log - fdev[2]$	-1.3626	0.1015	186	$log - fdev[4]$	0.2410	0.1092
137	$log - fdev[2]$	-0.9822	0.1021	187	$log - foff[1]$	-2.7550	0.0393
138	$log - fdev[2]$	-0.4611	0.1034	188	$log - foff[3]$	-0.2191	0.4242
139	$log - fdev[2]$	-0.0330	0.1053	189	$log - fdov[1]$	1.9763	0.0839
140	$log - fdev[2]$	-0.1032	0.1074	190	$log - fdov[1]$	-0.7005	0.0830
141	$log - fdev[2]$	-0.0123	0.1098	191	$log - fdov[1]$	1.9665	0.0843
142	$log - fdev[2]$	-0.0392	0.1116	192	$log - fdov[1]$	1.7981	0.0859
193	$log - fdov[1]$	-0.4420	0.0845	243	rec-dev-est	-1.5405	0.3622
194	$log - fdov[1]$	-0.2156	0.0823	244	rec-dev-est	-0.4451	0.2073
195	$log - fdov[1]$	-3.7181	0.0813	245	rec-dev-est	-1.4910	0.4031
196	$log - fdov[1]$	-0.3485	0.0819	246	rec-dev-est	1.4079	0.1618
197	$log - fdov[1]$	1.4326	0.0823	247	rec-dev-est	-0.5155	0.2623
198	$log - fdov[1]$	-2.7989	0.0816	248	rec-dev-est	-1.1395	0.3312
199	$log - fdov[1]$	1.1306	0.0807	249	rec-dev-est	-0.1362	0.2065
200	$log - fdov[1]$	0.8530	0.0806	250	rec-dev-est	0.8418	0.1693

201	$log - fdov[1]$	-1.8972	0.0800	251	rec-dev-est	-0.1377	0.2319
202	$log - fdov[1]$	1.1908	0.0801	252	rec-dev-est	-0.0880	0.2446
203	$log - fdov[1]$	0.4000	0.0801	253	rec-dev-est	1.2516	0.1690
204	$log - fdov[1]$	0.9332	0.0796	254	rec-dev-est	-0.1879	0.2681
205	$log - fdov[1]$	-1.2531	0.0791	255	rec-dev-est	-0.2546	0.2640
206	$log - fdov[1]$	-0.2134	0.0791	256	rec-dev-est	1.0030	0.1703
207	$log - fdov[1]$	-0.4800	0.0794	257	rec-dev-est	0.2691	0.1933
208	$log - fdov[1]$	-0.7485	0.0796	258	rec-dev-est	-0.0877	0.1990
209	$log - fdov[1]$	-0.2708	0.0794	259	rec-dev-est	-0.6973	0.2472
210	$log - fdov[1]$	-1.1697	0.0785	260	rec-dev-est	-0.5288	0.2412
211	$log - fdov[1]$	-1.8895	0.0780	261	rec-dev-est	0.4042	0.1919
212	$log - fdov[1]$	0.1281	0.0780	262	rec-dev-est	-0.0861	0.2350
213	$log - fdov[1]$	-0.2803	0.0781	263	rec-dev-est	-0.6843	0.2455
214	$log - fdov[1]$	0.7759	0.0786	264	rec-dev-est	-0.9629	0.2308
215	$log - fdov[1]$	0.2232	0.0801	265	rec-dev-est	-1.4070	0.2696
216	$log - fdov[1]$	-0.4323	0.0829	266	rec-dev-est	-0.9623	0.2316
217	$log - fdov[1]$	0.8899	0.0868	267	rec-dev-est	-0.2805	0.1839
218	$log - fdov[1]$	-0.1886	0.0898	268	rec-dev-est	-1.0906	0.2488
219	$log - fdov[1]$	-0.7189	0.0902	269	rec-dev-est	-0.4370	0.2034
220	$log - fdov[1]$	2.8655	0.0898	270	rec-dev-est	-1.1306	0.2868
221	$log - fdov[1]$	1.2014	0.0901	271	rec-dev-est	-1.1335	0.2797
222	$log - fdov[3]$	-0.0001	0.0933	272	rec-dev-est	-1.2751	0.3022
223	$log - fdov[3]$	0.0001	0.0933	273	rec-dev-est	-0.4562	0.2464
224	$log - fdov[3]$	0.0004	0.0933	274	rec-dev-est	-0.8955	0.3644
225	$log - fdov[3]$	0.0010	0.0933	275	logit-rec-prop-est	-0.4318	0.1502
226	$log - fdov[3]$	1.5535	0.1421	276	logit-rec-prop-est	0.2682	0.4178
227	$log - fdov[3]$	1.8332	0.1183	277	logit-rec-prop-est	-0.0688	0.4555
228	$log - fdov[3]$	0.5997	0.1458	278	logit-rec-prop-est	0.4466	0.3645
229	$log - fdov[3]$	-3.4222	0.1077	279	logit-rec-prop-est	-0.0475	0.1636
230	$log - fdov[3]$	-2.1791	0.1428	280	logit-rec-prop-est	0.2530	0.2433
231	$log - fdov[3]$	-0.8004	0.1168	281	logit-rec-prop-est	0.5313	0.6526
232	$log - fdov[3]$	0.0256	0.1360	282	logit-rec-prop-est	0.3366	0.2864
233	$log - fdov[3]$	0.3754	0.1039	283	logit-rec-prop-est	-0.5544	0.6487
234	$log - fdov[3]$	0.9572	0.1502	284	logit-rec-prop-est	-0.2198	0.0881
235	$log - fdov[3]$	0.1629	0.1454	285	logit-rec-prop-est	1.3045	0.5909
236	$log - fdov[3]$	0.8930	0.1739	286	logit-rec-prop-est	0.3955	0.5906
237	rec-dev-est	0.7712	0.1732	287	logit-rec-prop-est	0.5466	0.3168
238	rec-dev-est	-0.4437	0.2500	288	logit-rec-prop-est	-0.0062	0.1413
239	rec-dev-est	-0.8648	0.2820	289	logit-rec-prop-est	0.2409	0.3615
240	rec-dev-est	-0.5413	0.2244	290	logit-rec-prop-est	-0.5244	0.3704
241	rec-dev-est	0.3589	0.1759	291	logit-rec-prop-est	-0.4241	0.1275
242	rec-dev-est	-0.0960	0.1947	292	logit-rec-prop-est	-0.4092	0.4207
293	logit-rec-prop-est	0.0291	0.4254	304	logit-rec-prop-est	-0.3074	0.3231
294	logit-rec-prop-est	-0.3396	0.1380	305	logit-rec-prop-est	0.2876	0.2066
295	logit-rec-prop-est	-0.0569	0.2372	306	logit-rec-prop-est	0.5023	0.4288
296	logit-rec-prop-est	0.3865	0.2760	307	logit-rec-prop-est	0.6286	0.2857
297	logit-rec-prop-est	-0.1875	0.3762	308	logit-rec-prop-est	-0.2665	0.4651
298	logit-rec-prop-est	-0.4654	0.3542	309	logit-rec-prop-est	0.3612	0.4634
299	logit-rec-prop-est	-0.7176	0.2000	310	logit-rec-prop-est	0.4454	0.5122
300	logit-rec-prop-est	-0.5096	0.3134	311	logit-rec-prop-est	0.1603	0.3520
301	logit-rec-prop-est	-0.4764	0.3571	312	logit-rec-prop-est	-0.5300	0.6072
302	logit-rec-prop-est	-0.2415	0.3307	313	survey-q[1]	0.9417	0.0273
303	logit-rec-prop-est	-0.3398	0.4191	314	$log - add - cv[2]$	-0.8209	0.2755

Table 21: Annual abundance estimates (mature males, legal males, and mature females in million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) both estimated by the model and area swept calculated for red king crab in Bristol Bay estimated by length-based model 21.1b during 1975-2022. MMB for year t (2023) is on Feb. 15, year t+1 (Feb. 15th, 2024).

	Males				Females	Total	Total Survey Biomass	
Year	Mature >119mm	Legal >134mm	MMB >119mm	sd MMB	Mature >89mm	Recruits	Model Est >64mm	Area-Swept >64mm
1975	55.560	28.230	83.240	8.280	54.560		236.240	199.640
1976	65.250	35.520	99.120	7.980	82.780	63.980	276.140	327.610
1977	72.450	41.310	113.060	6.920	109.950	40.850	297.510	371.220
1978	77.750	46.490	119.860	5.510	114.170	64.280	300.720	343.190
1979	68.370	47.440	100.080	3.880	109.370	114.830	289.340	165.450
1980	50.150	37.800	30.340	1.600	111.380	149.820	274.100	247.230
1981	14.450	8.020	6.520	1.050	48.900	67.520	109.420	131.140
1982	6.750	2.160	6.520	0.920	21.450	240.840	65.620	141.900
1983	6.130	2.160	7.340	0.670	14.130	92.750	58.090	48.480
1984	6.120	2.270	5.170	0.430	13.910	63.240	50.880	152.610
1985	7.520	1.870	9.600	0.640	9.620	10.200	34.910	34.140
1986	12.100	4.620	14.940	0.970	13.470	29.900	45.550	47.430
1987	14.260	6.640	20.230	1.170	16.800	9.400	51.270	69.240
1988	14.350	8.400	24.910	1.230	21.160	6.140	54.610	54.600
1989	15.440	9.680	27.760	1.180	19.980	8.010	57.240	55.140
1990	14.920	10.370	23.920	1.110	17.880	20.590	57.290	59.450
1991	11.460	8.580	18.240	1.040	17.280	13.010	52.200	83.890
1992	9.200	6.400	17.030	1.020	18.410	3.030	47.540	37.330
1993	10.410	6.100	15.640	1.090	17.140	8.980	47.080	52.910
1994	10.250	5.950	21.470	1.200	14.590	2.930	42.500	32.100
1995	10.770	7.820	24.610	1.200	13.510	58.610	48.550	38.070
1996	11.060	8.480	23.110	1.150	19.470	8.630	57.970	43.960
1997	10.510	7.720	21.870	1.130	28.430	4.440	64.140	84.030
1998	15.810	7.690	24.720	1.330	25.010	12.280	68.010	84.100
1999	16.850	9.670	28.420	1.480	21.160	33.290	66.560	64.750
2000	14.540	10.570	28.640	1.470	22.550	12.430	68.210	67.380
2001	14.360	10.130	29.030	1.430	25.580	12.740	71.860	52.460
2002	17.210	10.330	33.080	1.450	24.850	51.010	76.920	69.090
2003	18.040	11.970	32.650	1.410	30.410	11.670	83.120	115.760
2004	16.260	11.560	30.180	1.330	37.540	10.950	84.660	130.560
2005	18.140	10.780	30.730	1.300	34.830	39.200	85.630	105.730
2006	17.260	11.370	31.120	1.260	35.140	18.840	85.520	94.480
2007	15.560	11.120	26.120	1.180	39.030	12.820	87.140	103.330
2008	15.940	9.450	24.800	1.210	36.640	7.160	83.560	113.080
2009	15.790	9.410	25.680	1.250	32.150	8.150	77.560	90.550
2010	14.690	9.640	24.990	1.210	28.190	21.740	72.500	80.500
2011	12.430	9.110	24.720	1.140	27.770	12.640	68.080	66.410
2012	11.080	8.570	23.160	1.050	29.570	7.360	66.520	60.700
2013	11.000	7.830	22.110	0.980	28.020	5.350	63.850	62.220
2014	10.730	7.540	20.130	0.930	24.830	3.360	59.120	113.140
2015	9.210	6.870	17.160	0.880	21.300	5.410	52.330	64.170
2016	7.460	5.780	14.130	0.860	18.210	10.430	45.670	60.960
2017	5.910	4.680	11.540	0.840	16.630	4.630	40.780	52.930
2018	5.150	3.780	10.290	0.840	15.280	9.050	37.780	28.800
2019	5.890	3.500	11.180	0.950	13.530	4.520	36.330	28.540
2020	6.470	4.020	12.810	1.090	12.490	4.550		

2021	7.390	4.620	16.200	1.260	11.350	4.020	35.170	28.480
2022	7.970	5.740	18.520	1.400	10.100	8.640	35.990	36.200
2023	8.050	6.270	16.480	1.080	9.560	5.560	36.820	37.970

Table 22: Annual abundance estimates (mature males, legal males, and mature females in million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) both estimated by the model and area swept calculated for red king crab in Bristol Bay estimated by length-based model 23.0a during 1975-2022. MMB for year t is on Feb. 15, year t+1.

	Males				Females	Total	Total Survey Biomass	
Year	Mature >119mm	Legal >134mm	MMB >119mm	sd MMB	Mature >89mm	Recruits	Model Est >64mm	Area-Swept >64mm
1975	60.770	30.460	90.290	9.060	65.350		247.750	199.640
1976	71.030	38.070	106.850	8.680	97.120	89.400	288.150	327.610
1977	78.840	44.010	121.320	7.540	127.860	53.620	309.170	371.220
1978	84.070	49.370	128.050	6.080	131.400	83.100	310.310	343.190
1979	73.240	50.080	106.490	4.300	124.070	148.720	296.140	165.450
1980	53.540	39.710	32.380	1.750	125.300	200.650	279.860	247.230
1981	15.290	8.310	6.920	0.990	57.730	92.160	113.500	131.140
1982	7.180	2.240	6.610	0.770	26.490	330.900	64.250	141.900
1983	6.270	2.140	7.100	0.550	18.180	128.050	56.500	48.480
1984	6.390	2.150	5.010	0.410	18.220	88.720	49.350	152.610
1985	7.890	1.830	9.710	0.690	12.820	14.750	33.730	34.140
1986	12.890	4.730	15.600	1.090	17.590	42.710	45.100	47.430
1987	15.640	7.010	21.830	1.370	21.900	14.060	51.850	69.240
1988	15.900	9.080	27.010	1.460	27.520	9.090	56.080	54.600
1989	17.180	10.460	30.240	1.430	25.610	11.450	59.110	55.140
1990	16.470	11.220	26.250	1.350	22.560	29.310	59.120	59.450
1991	12.630	9.330	20.150	1.250	21.840	19.760	54.060	83.890
1992	10.320	6.990	18.830	1.200	23.540	4.600	49.670	37.330
1993	11.880	6.700	17.870	1.310	21.860	13.040	49.490	52.910
1994	11.970	6.790	24.200	1.450	18.420	3.950	45.250	32.100
1995	12.240	8.770	27.090	1.420	16.840	82.540	50.990	38.070
1996	12.240	9.230	25.040	1.320	25.240	13.870	59.600	43.960
1997	11.580	8.260	23.440	1.270	37.250	6.450	65.720	84.030
1998	17.670	8.230	27.160	1.580	32.060	17.400	69.950	84.100
1999	18.890	10.650	31.370	1.770	26.670	48.020	69.040	64.750
2000	16.140	11.620	31.180	1.720	28.680	18.530	70.680	67.380
2001	15.910	10.910	31.350	1.660	32.840	17.230	74.220	52.460
2002	19.220	11.090	35.870	1.710	31.470	74.110	79.320	69.090
2003	19.980	12.960	35.410	1.670	39.150	17.280	85.320	115.760
2004	17.880	12.470	32.530	1.560	48.940	15.760	87.110	130.560
2005	20.190	11.570	33.570	1.560	44.650	54.380	88.230	105.730
2006	19.120	12.390	33.850	1.520	44.760	28.420	88.040	94.480
2007	17.080	12.010	28.420	1.410	49.570	18.500	89.520	103.330
2008	17.730	10.210	27.410	1.470	46.080	10.590	86.170	113.080
2009	17.790	10.360	28.700	1.560	39.580	12.120	80.470	90.550
2010	16.660	10.730	28.180	1.520	34.170	29.820	75.360	80.500
2011	14.090	10.180	27.590	1.400	33.560	18.480	70.480	66.410
2012	12.430	9.440	25.500	1.260	35.600	10.480	68.260	60.700
2013	12.320	8.510	24.230	1.170	33.480	7.430	65.030	62.220
2014	11.990	8.210	22.100	1.090	29.210	4.570	59.820	113.140
2015	10.210	7.500	18.770	1.000	24.540	7.220	52.540	64.170
2016	8.180	6.260	15.300	0.930	20.620	13.740	45.340	60.960
2017	6.370	5.000	12.250	0.870	18.660	6.320	39.860	52.930
2018	5.500	3.950	10.710	0.850	16.980	12.190	36.450	28.800
2019	6.280	3.620	11.530	0.940	14.880	5.890	34.740	28.540
2020	6.860	4.140	13.080	1.070	13.670	6.280		

2021	7.790	4.730	16.410	1.220	12.340	5.300	33.260	28.480
2022	8.180	5.800	18.340	1.330	10.930	11.540	33.740	36.200
2023	8.060	6.150	14.980	0.920	10.380	7.450	34.100	37.970

Table 23: Annual abundance estimates (mature males, legal males, and mature females in million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) both estimated by the model and area swept calculated for red king crab in Bristol Bay estimated by length-based model 22.0 during 1975-2022. MMB for year t is on Feb. 15, year t+1.

	Males				Females	Total	Total Survey Biomass	
Year	Mature >119mm	Legal >134mm	MMB >119mm	sd MMB	Mature >89mm	Recruits	Model Est >64mm	Area-Swept >64mm
1985	8.530	2.340	11.610	0.960	8.330		35.080	34.140
1986	12.940	5.340	17.070	1.170	11.760	30.630	44.890	47.430
1987	14.340	7.280	21.230	1.300	15.460	9.090	50.340	69.240
1988	14.350	8.650	25.410	1.310	20.270	5.960	53.560	54.600
1989	15.460	9.730	28.020	1.240	19.340	8.240	56.030	55.140
1990	15.020	10.410	24.200	1.160	17.440	20.280	56.010	59.450
1991	11.550	8.660	18.470	1.090	16.970	12.870	51.140	83.890
1992	9.300	6.470	17.270	1.070	18.110	3.030	46.790	37.330
1993	10.550	6.170	15.930	1.140	16.940	9.080	46.470	52.910
1994	10.440	6.050	21.840	1.260	14.530	3.190	42.130	32.100
1995	10.910	7.950	24.950	1.250	13.600	57.890	47.900	38.070
1996	11.240	8.590	23.490	1.200	19.430	8.460	57.300	43.960
1997	10.600	7.850	22.140	1.170	28.190	4.530	63.700	84.030
1998	16.090	7.750	25.240	1.400	24.990	12.360	67.660	84.100
1999	17.190	9.870	29.100	1.560	21.290	32.860	66.210	64.750
2000	14.800	10.810	29.240	1.540	22.630	12.340	67.900	67.380
2001	14.590	10.330	29.580	1.500	25.640	12.970	71.600	52.460
2002	17.480	10.500	33.680	1.510	25.050	49.510	76.400	69.090
2003	18.320	12.170	33.270	1.480	30.410	11.740	82.490	115.760
2004	16.470	11.760	30.710	1.390	37.330	10.980	84.130	130.560
2005	18.390	10.930	31.280	1.360	34.880	38.610	85.020	105.730
2006	17.500	11.550	31.670	1.330	35.190	18.530	84.950	94.480
2007	15.750	11.290	26.600	1.250	39.030	12.970	86.680	103.330
2008	16.190	9.590	25.340	1.280	36.810	7.050	83.330	113.080
2009	16.050	9.590	26.240	1.330	32.500	8.350	77.550	90.550
2010	14.960	9.830	25.580	1.290	28.690	21.220	72.530	80.500
2011	12.680	9.310	25.280	1.210	28.250	12.990	68.200	66.410
2012	11.270	8.750	23.650	1.120	30.040	7.140	66.740	60.700
2013	11.210	7.980	22.600	1.050	28.670	5.410	64.170	62.220
2014	10.930	7.700	20.610	0.990	25.480	3.470	59.550	113.140
2015	9.390	7.020	17.600	0.950	21.990	5.410	52.860	64.170
2016	7.620	5.920	14.530	0.930	18.900	10.700	46.280	60.960
2017	6.060	4.810	11.920	0.910	17.310	4.760	41.510	52.930
2018	5.290	3.900	10.650	0.900	15.990	9.150	38.600	28.800
2019	6.080	3.610	11.600	1.020	14.220	4.570	37.210	28.540
2020	6.670	4.160	13.260	1.160	13.160	4.560		
2021	7.610	4.770	16.690	1.330	12.010	3.960	35.980	28.480
2022	8.150	5.910	18.990	1.470	10.730	8.970	36.640	36.200
2023	8.190	6.410	16.480	1.090	10.190	5.780	37.350	37.970

Figures

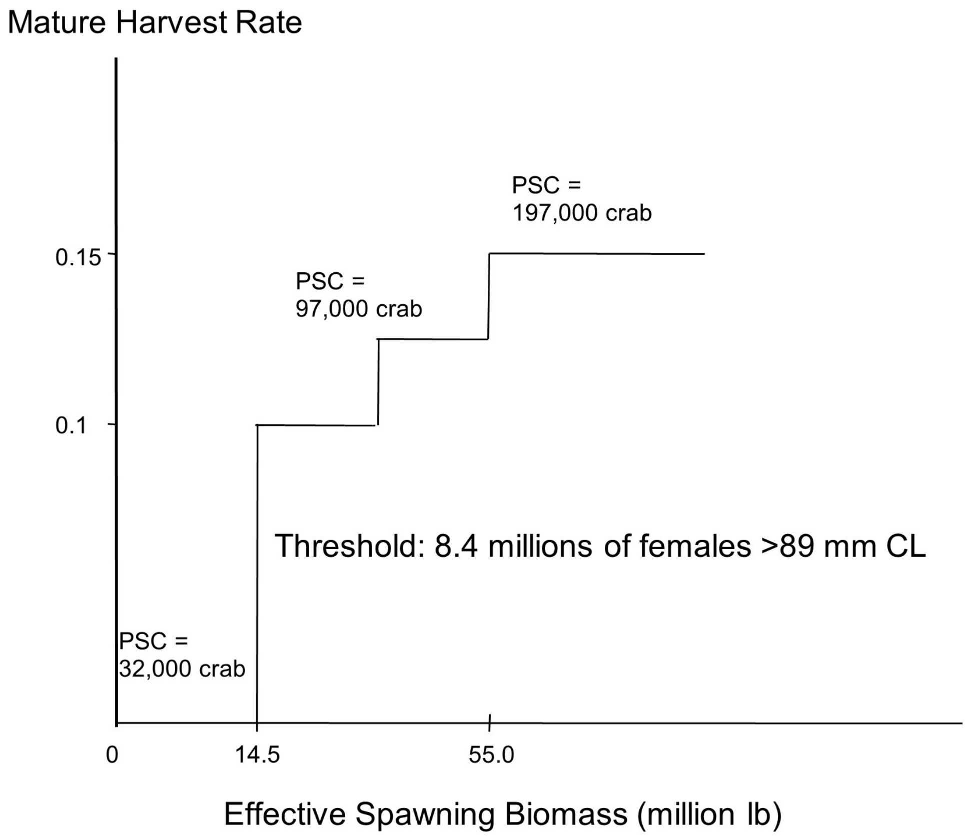

Figure 2: Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and the associated annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of effective spawning biomass (ESB, Zheng et al. 1995b), whereas PSC limits apply to previous-year ESB (Effective Spawning Biomass).

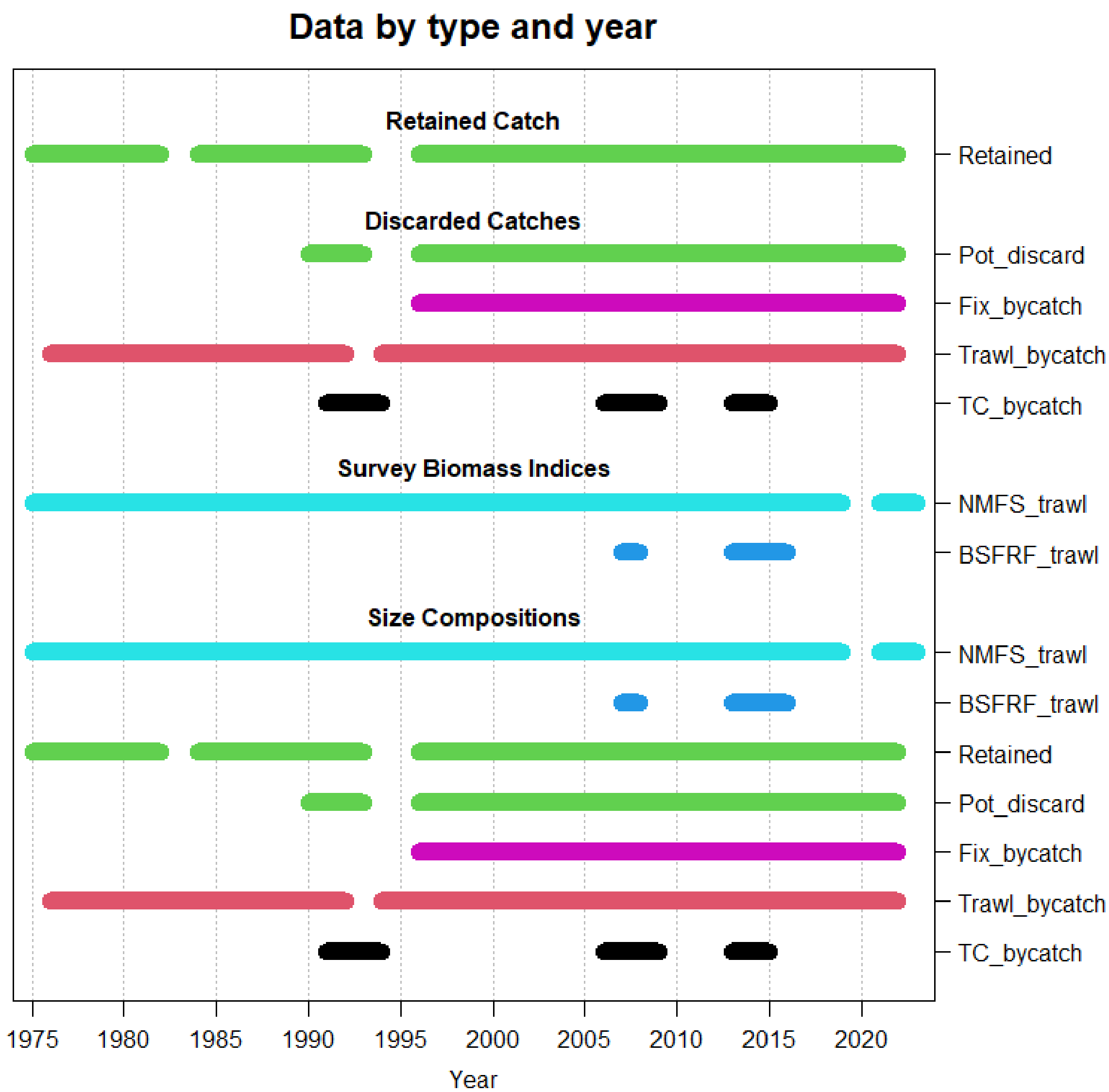

Figure 3: Data types and ranges used for the BBRKC stock assessment.

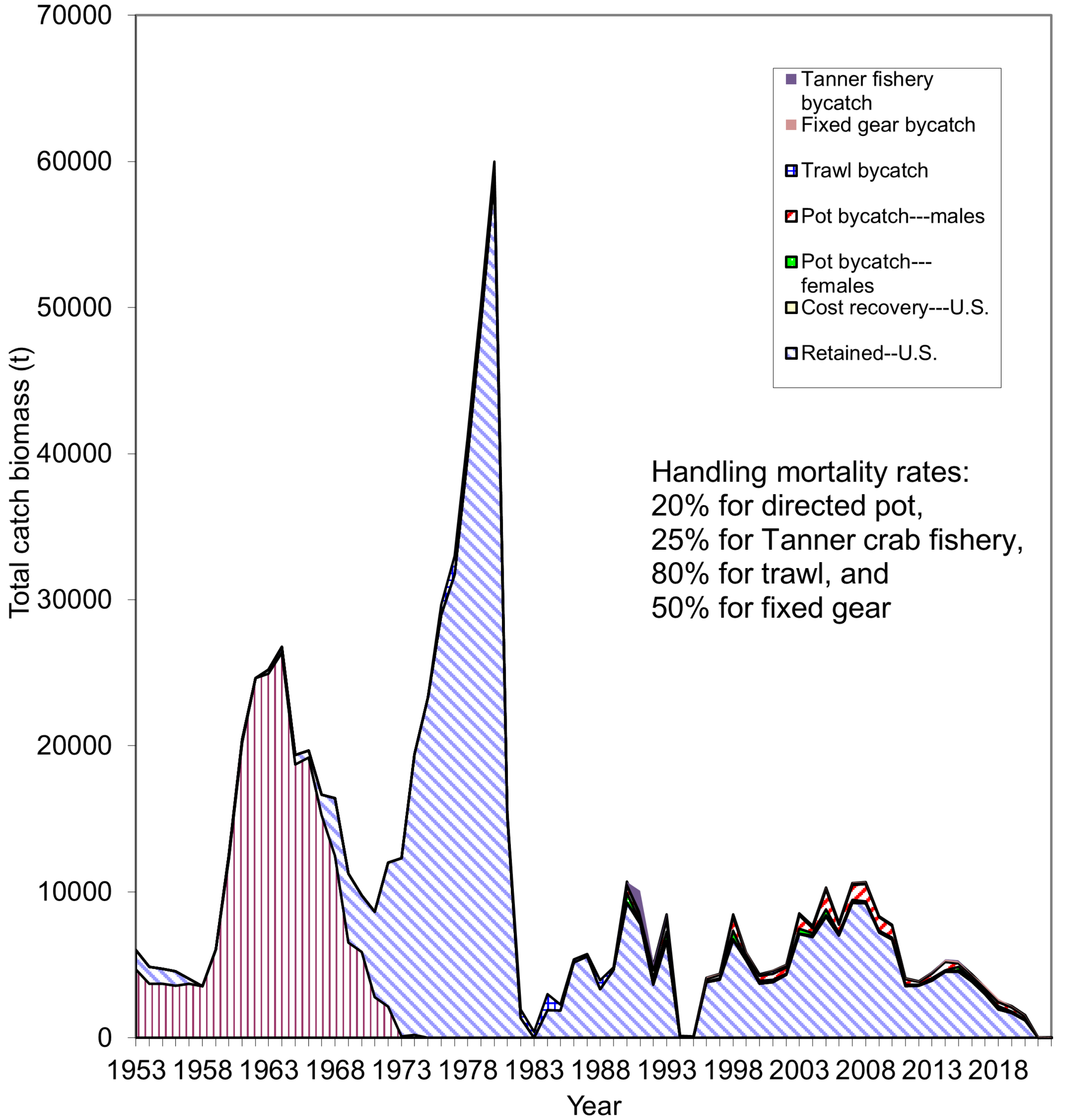

Figure 4: Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2022. Directed pot bycatch data were not available from the observer program before 1990 and are not included in this figure.

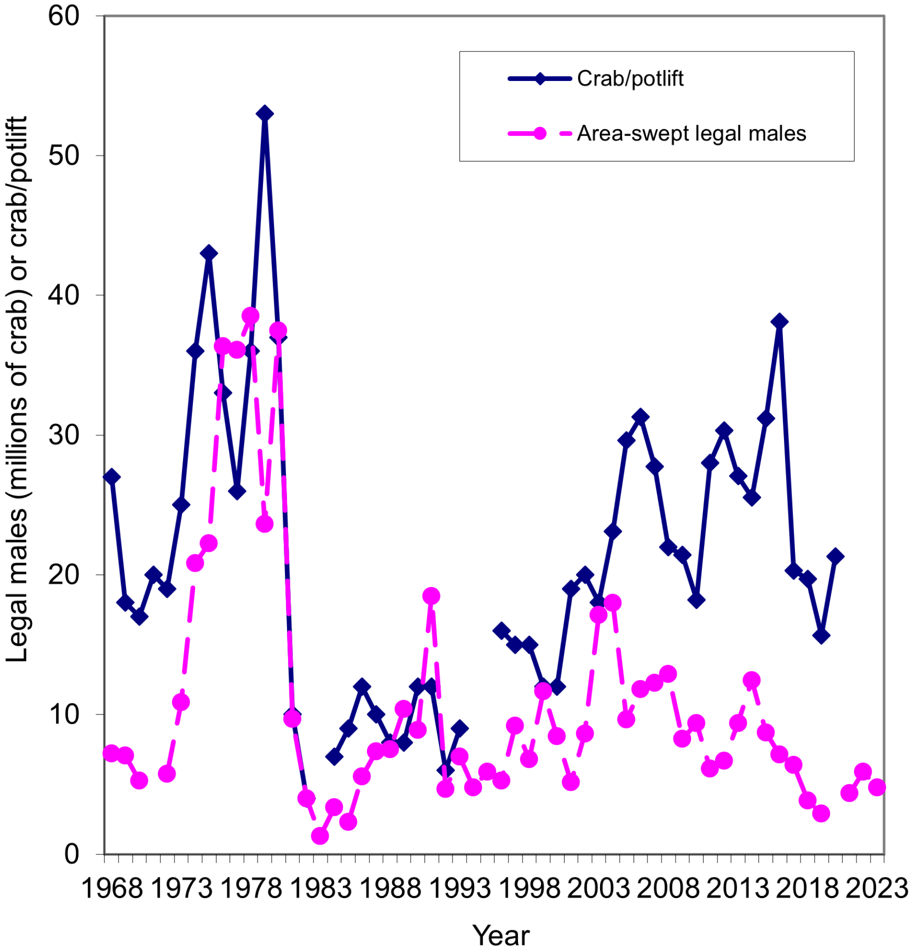

Figure 5: Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2023.

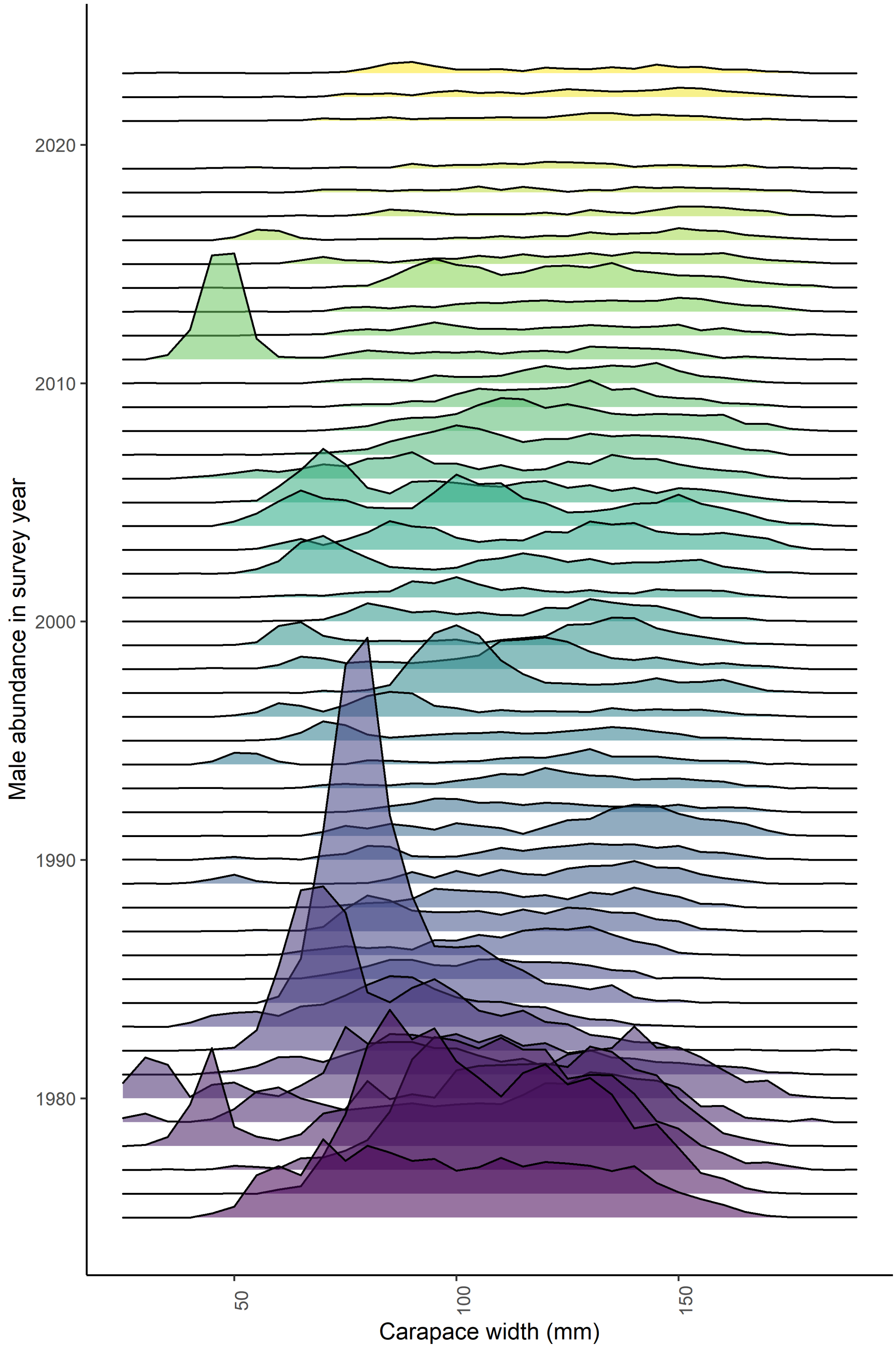

Figure 6: Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1975 to 2023.

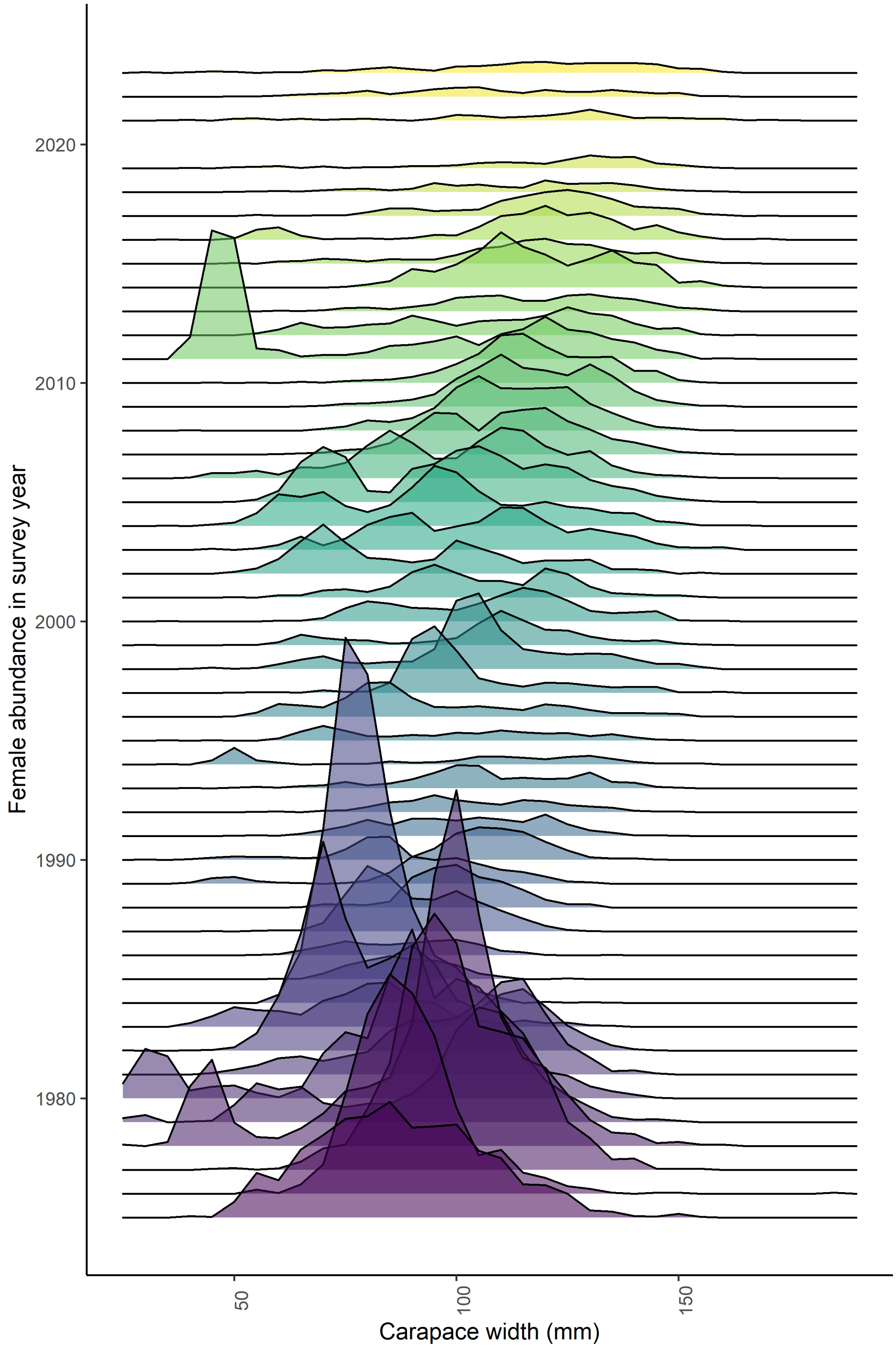

Figure 7: Survey abundances by 5-mm carapace length bin for female Bristol Bay red king crab from 1975 to 2023.

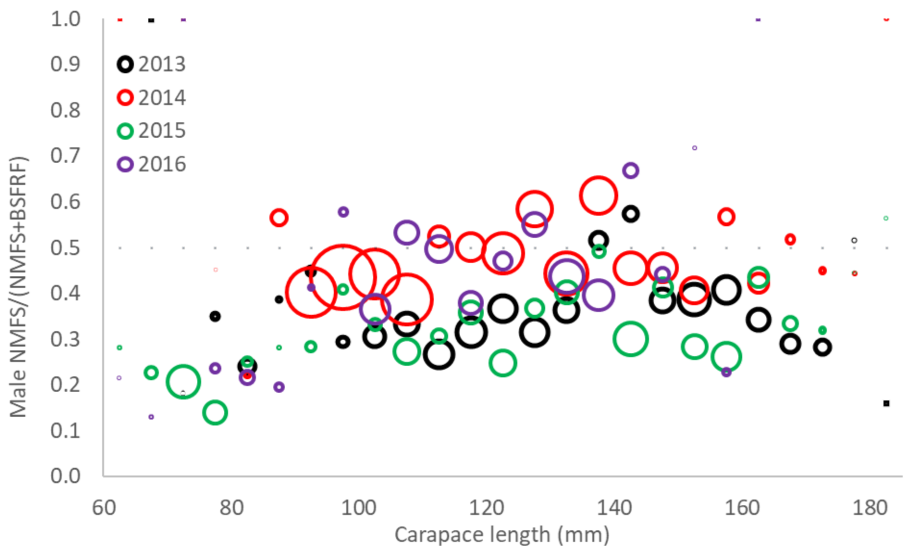

Figure 8: Comparison of NMFS survey abundance proportions of total NMFS and BSFRF side-by-side trawl surveys during 2013-2016 for male Bristol Bay red king crab. Sizes of circles are proportional to total abundances.

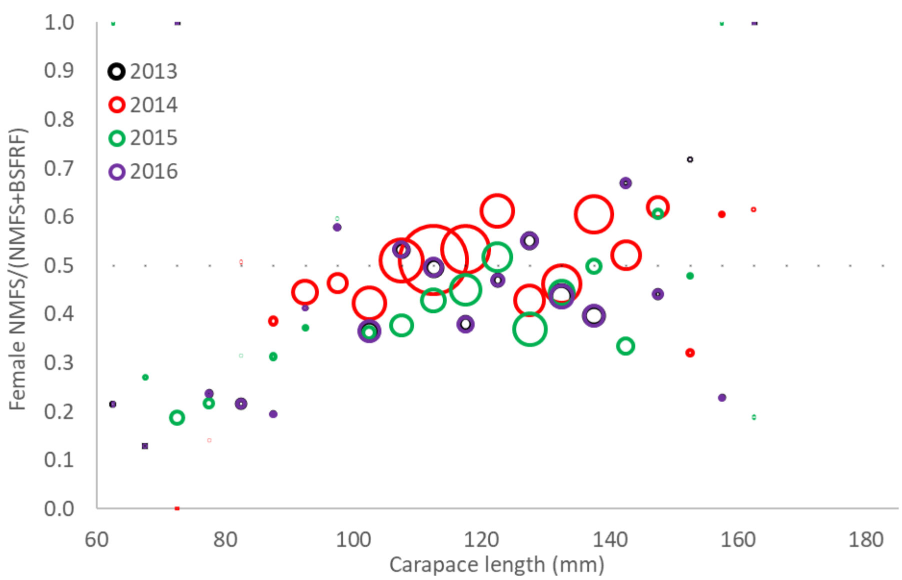

Figure 9: Comparison of NMFS survey abundance proportions of total NMFS and BSFRF side-by-side trawl surveys during 2013-2016 for female Bristol Bay red king crab. Sizes of circles are proportional to total abundances.

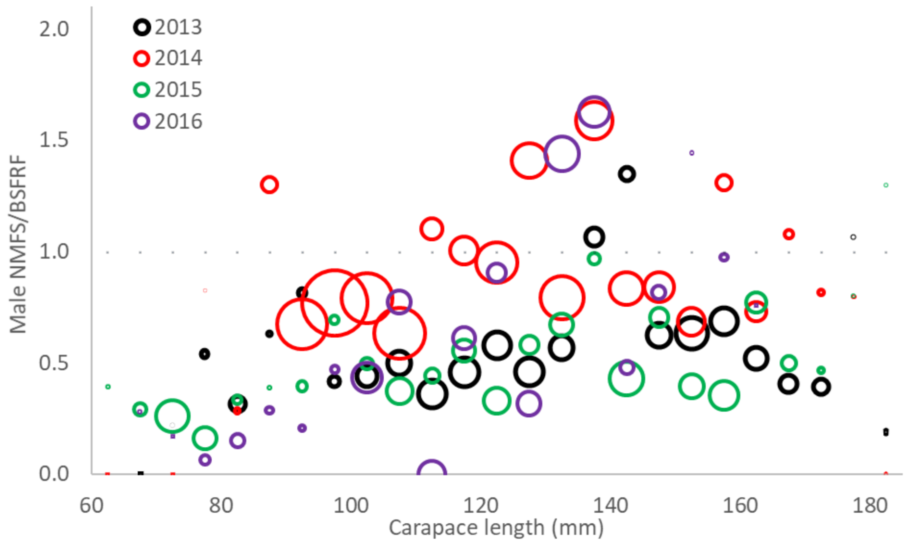

Figure 10: Comparison of ratios of NMFS survey abundances to BSFRF side-by-side survey abundances during 2013-2016 for male Bristol Bay red king crab. Sizes of circles are proportional to total abundances.

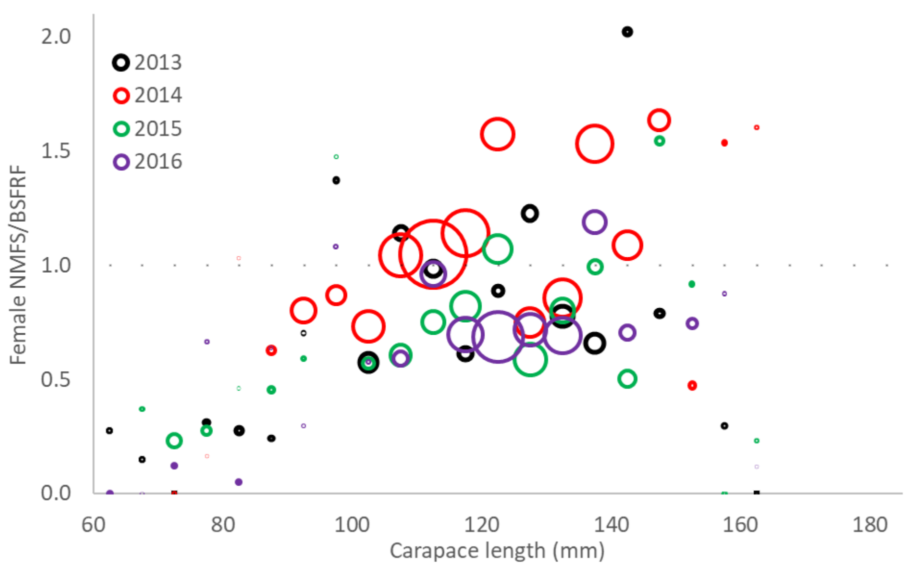

Figure 11: Comparison of ratios of NMFS survey abundances to BSFRF side-by-side survey abundances during 2013-2016 for female Bristol Bay red king crab. Sizes of circles are proportional to total abundances.

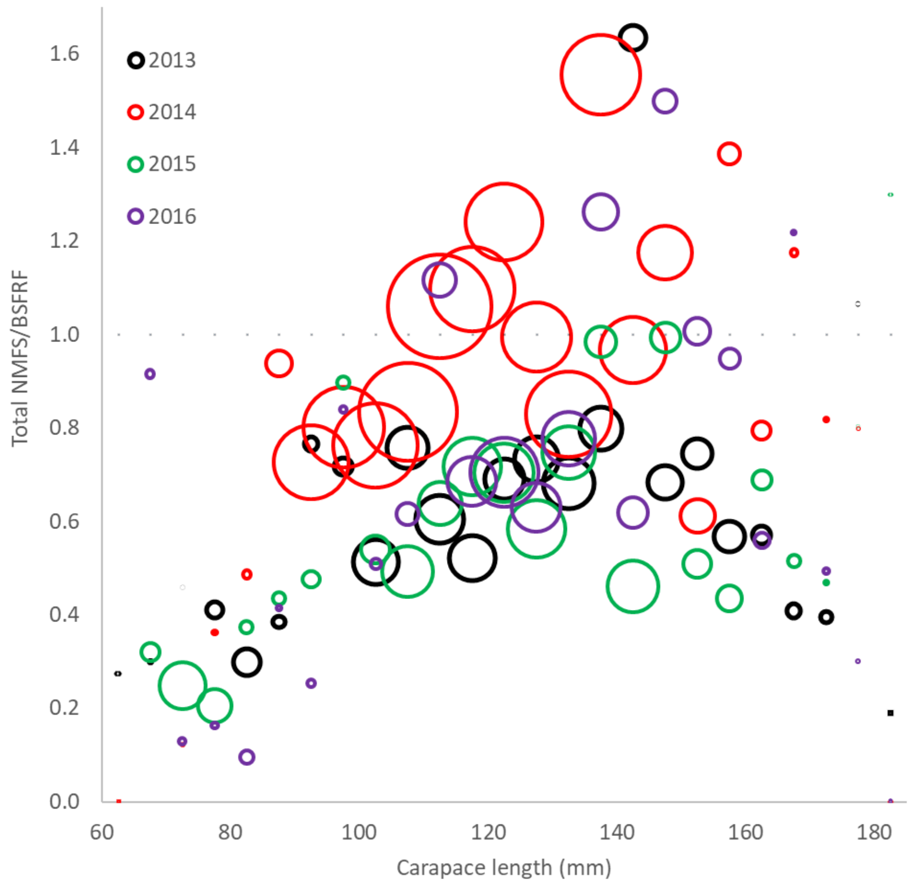

Figure 12: Comparison of ratios of NMFS survey abundances to BSFRF side-by-side survey abundances during 2013-2016 for male Bristol Bay red king crab. Sizes of circles are proportional to total abundances. The abundance-weighted average ratio is 0.891 for crab =135 mm carapace length from all four years of data. The approach to compute this overall ratio is documented in section D. Data, 4. Bering Sea Fisheries Research Foundation Survey Data.

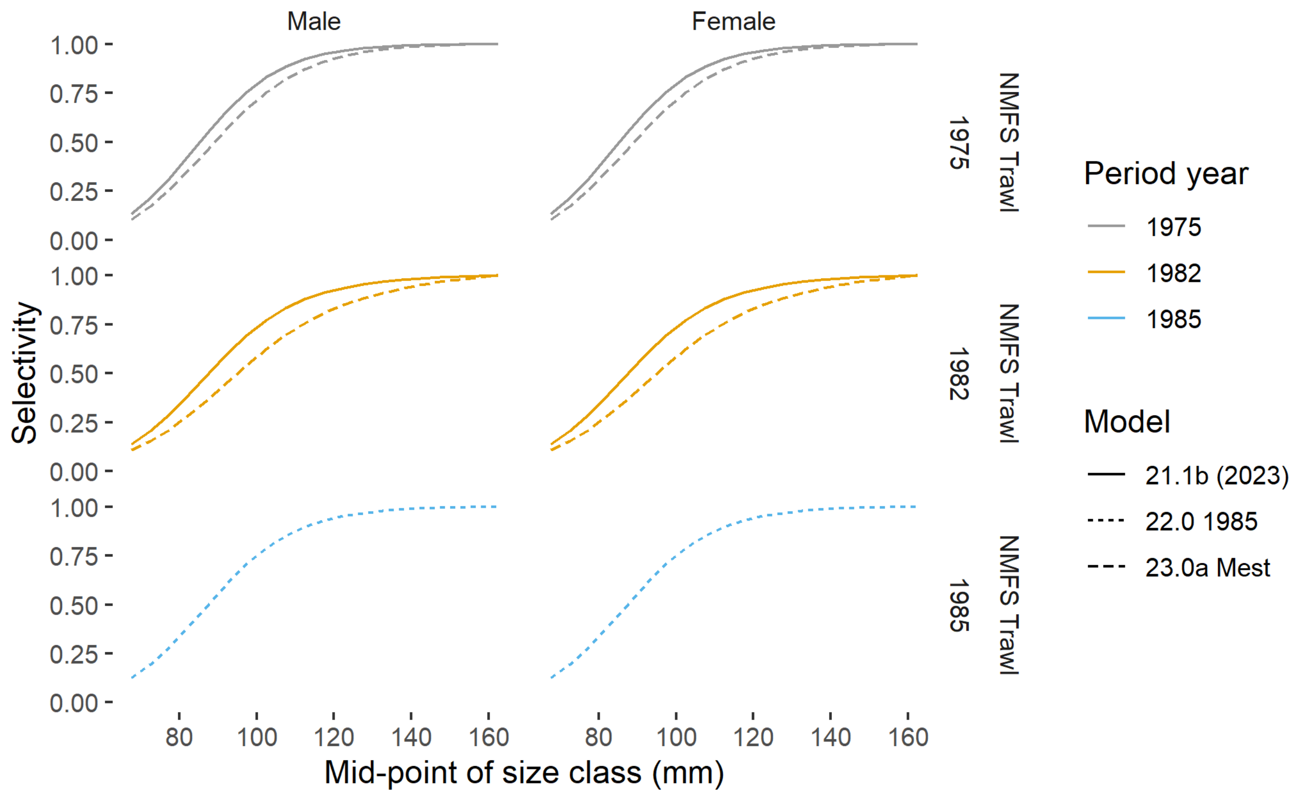

Figure 13: Estimated NMFS trawl survey selectivities under models 21.1b, 22.0, and 23.0a.

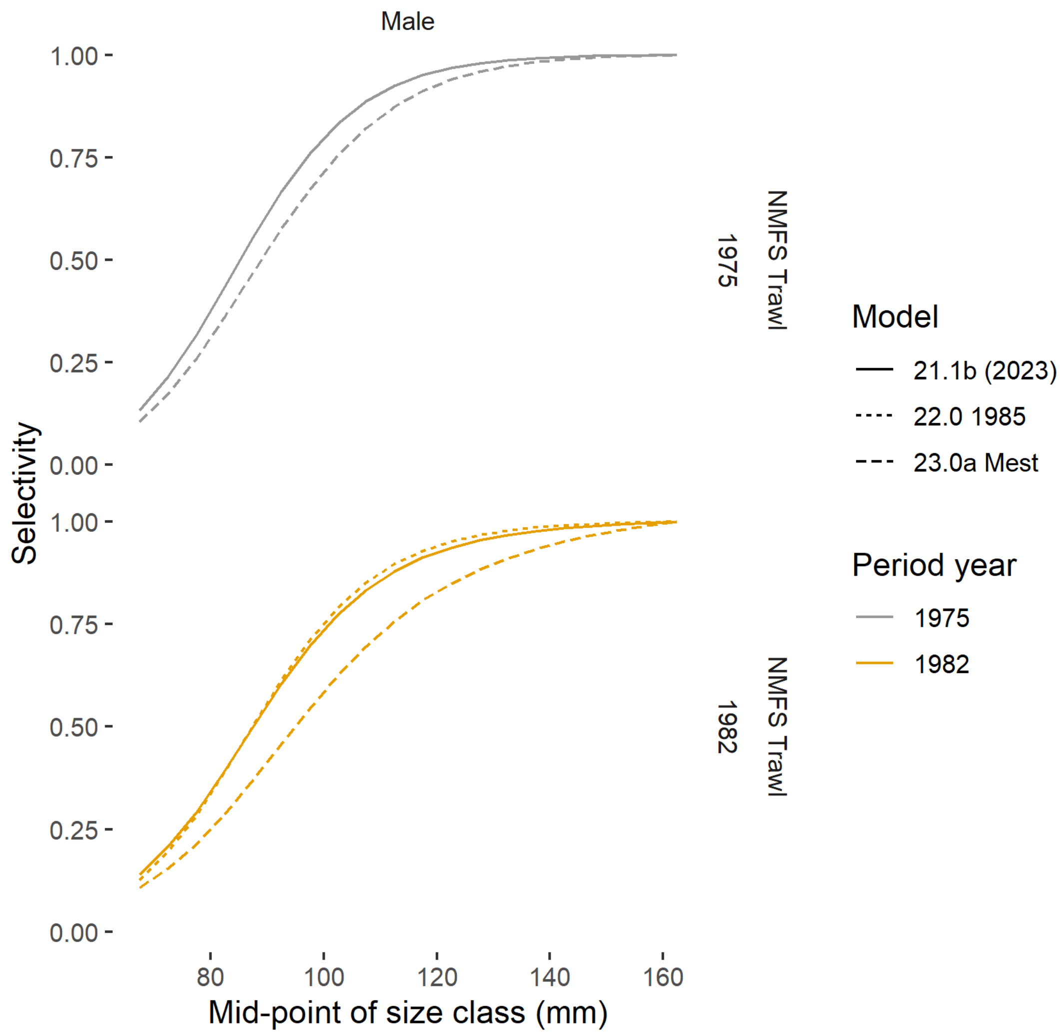

Figure 14: Estimated NMFS trawl survey selectivities for males under models 21.1b, 22.0, and 23.0a. Selectivity for model 22.0 starts in 1985 but is grouped here with the 1982 group.

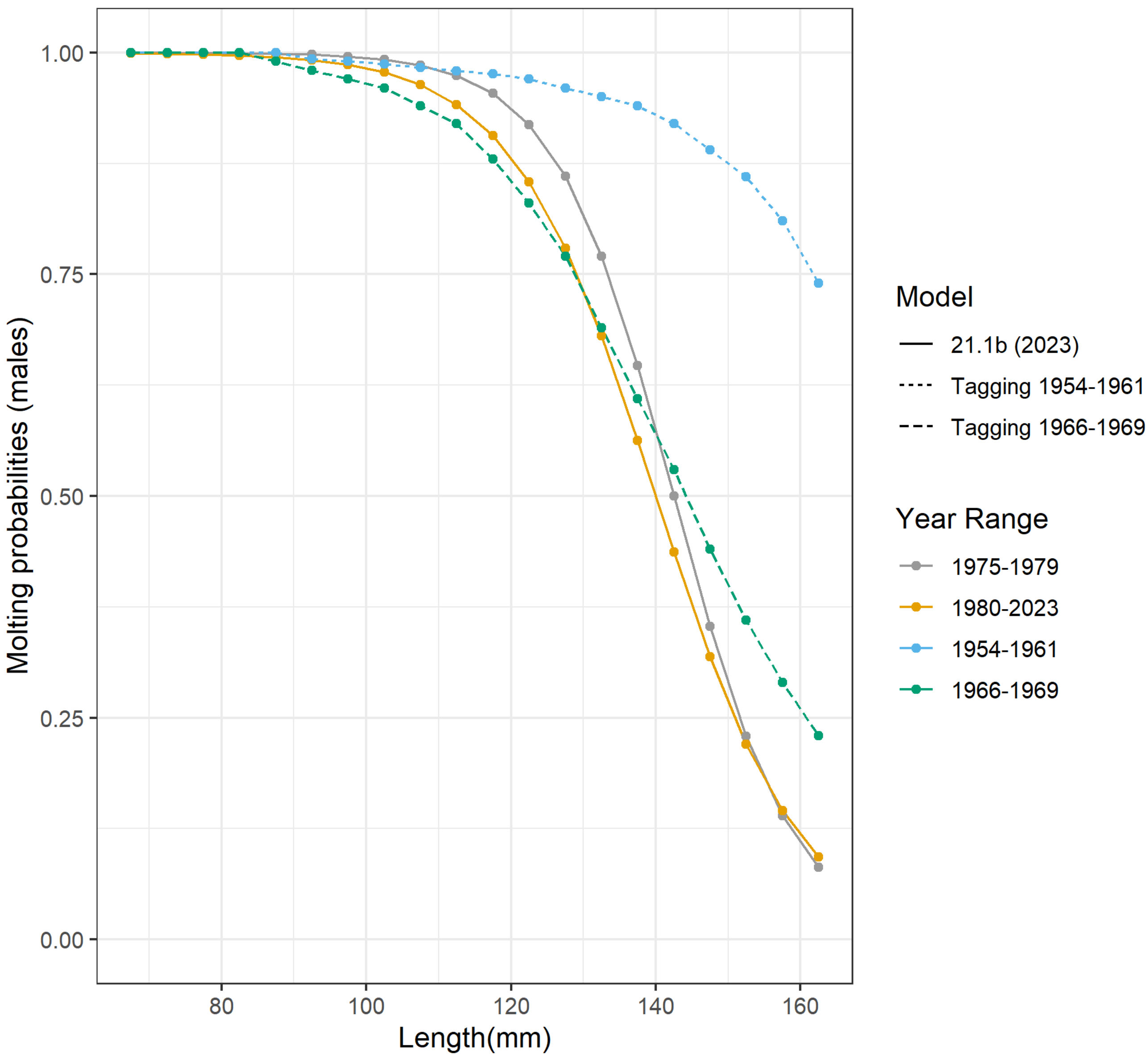

Figure 15: Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 21.1b. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-1979 and 1980-2023 were estimated with a length-based model.

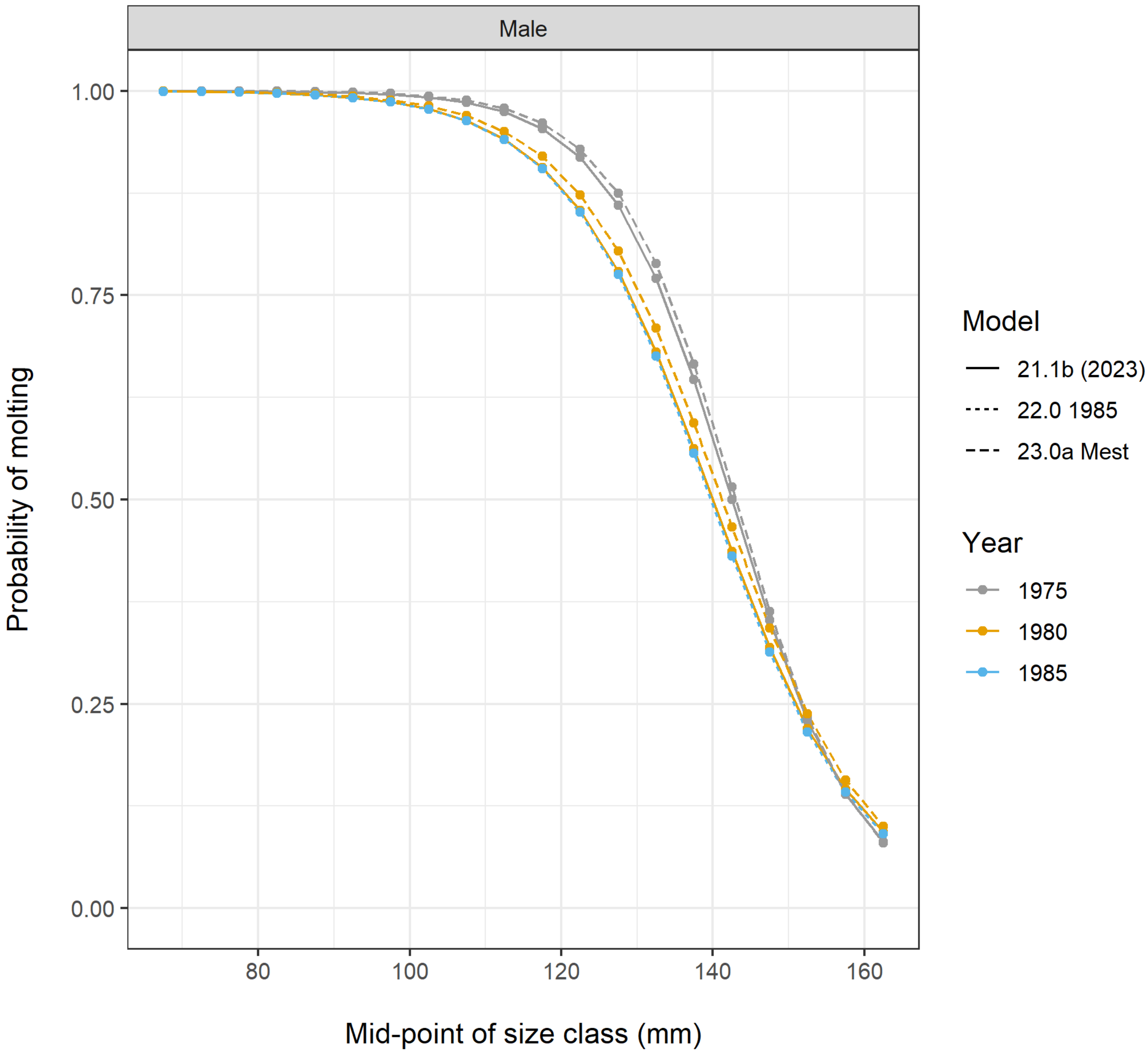

Figure 16: Comparison of estimated probabilities of molting of male red king crab in Bristol Bay with models 21.1b, 22.0, and 23.0a. Molting probability for 1975-1979, 1980-2023, and 1985-2023 were estimated with a length-based model.

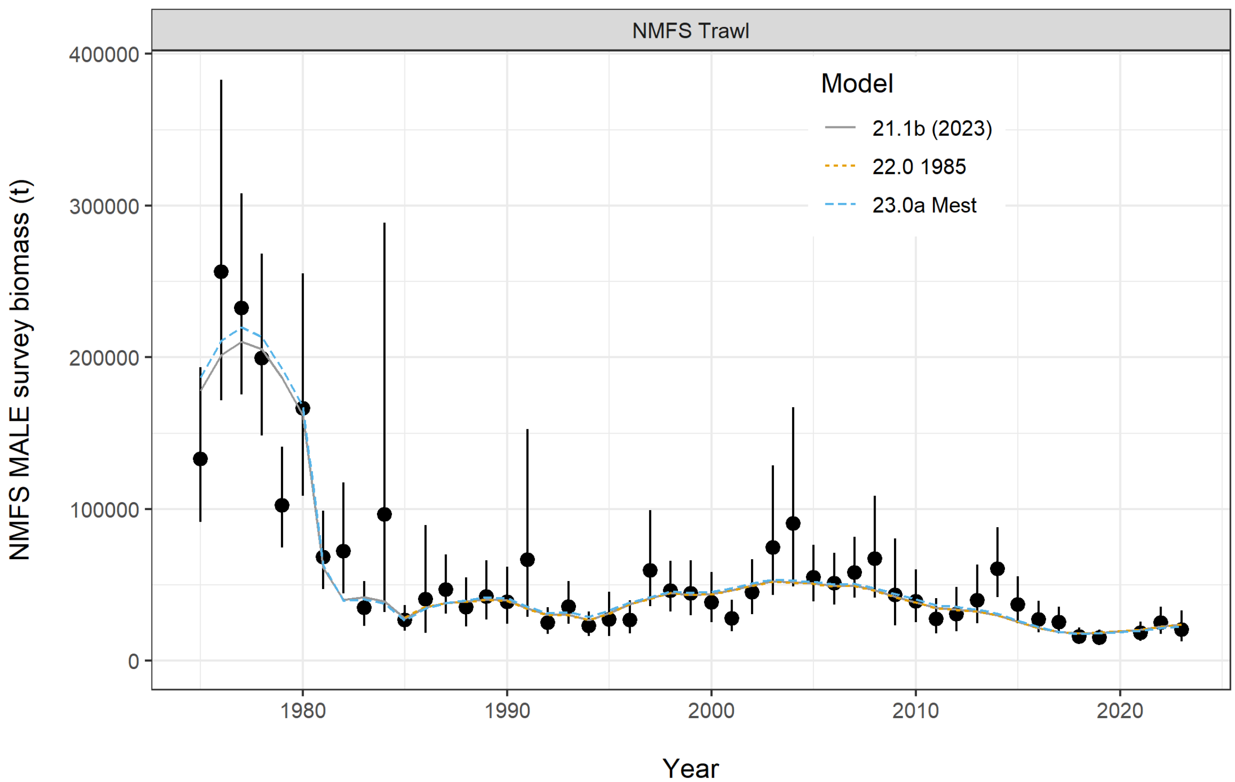

Figure 17: Comparisons of area-swept estimates of total male NMFS survey biomass and model prediction for model estimates in 2023 under models 21.1b, 22.0, and 23.0a. The error bars are plus and minus 2 standard deviations of model 21.1b.

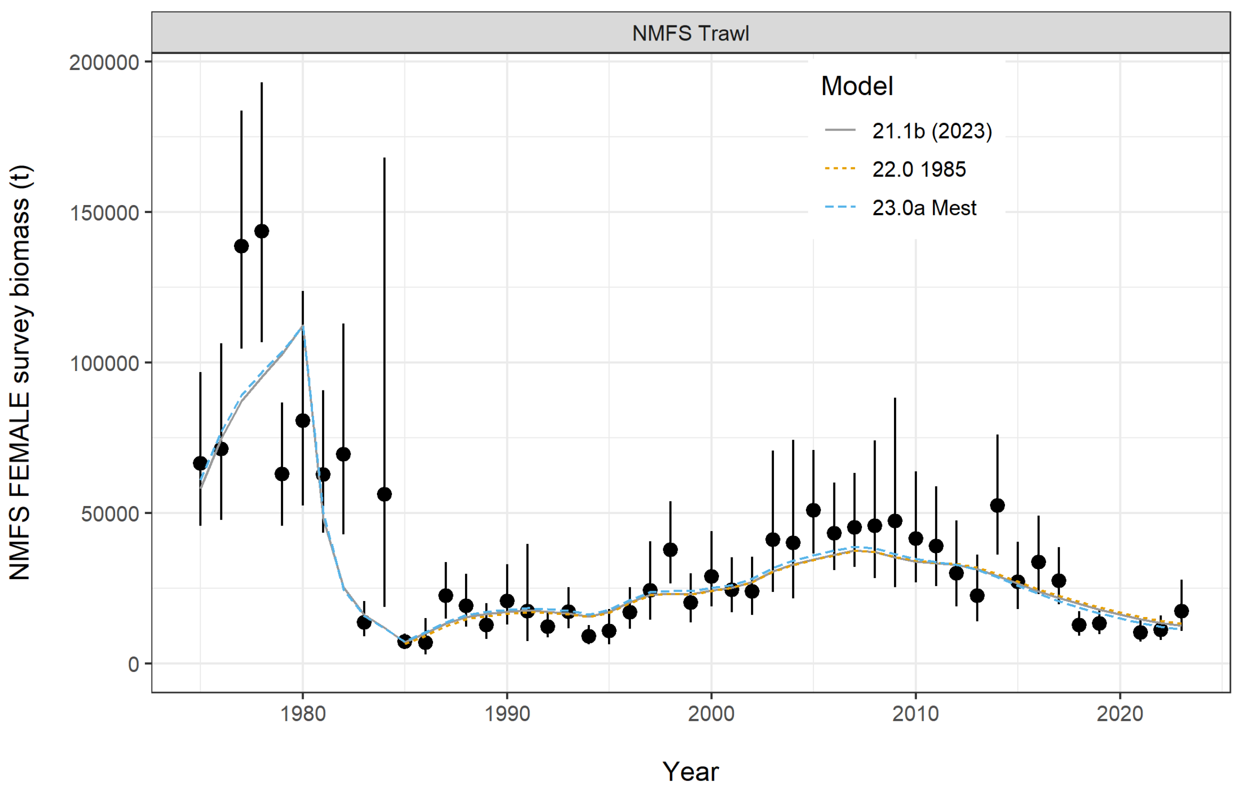

Figure 18: Comparisons of area-swept estimates of total female NMFS survey biomass and model prediction for model estimates in 2023 under models 21.1b, 22.0, and 23.0a. The error bars are plus and minus 2 standard deviations of model 21.1b.

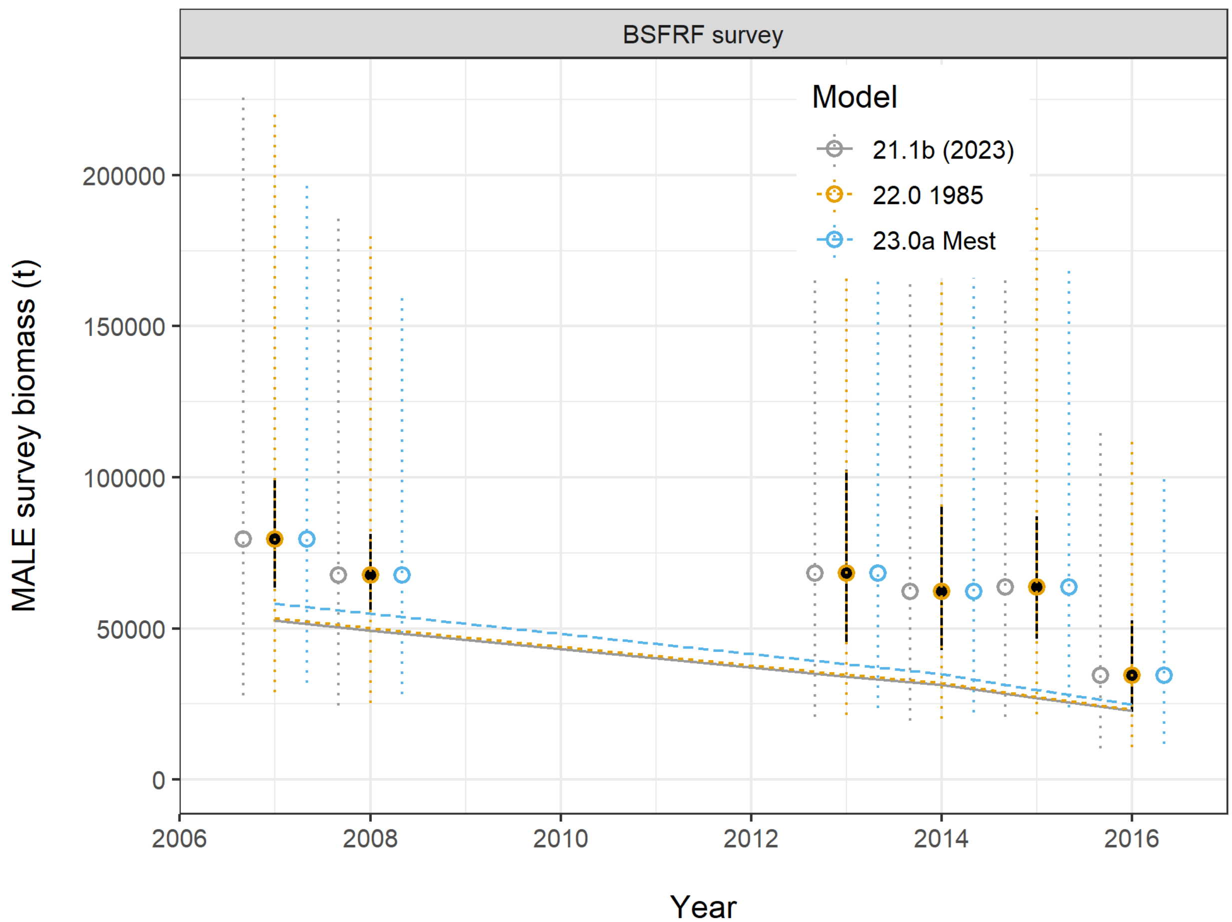

Figure 19: Comparisons of survey biomass estimates for males from the BSFRF survey and model prediction for model estimates in 2022 (models 21.1b, 22.0, and 23.0a). The error bars are plus and minus 2 standard deviations of model 21.1b. The BSFRF survey catchability is assumed to be 1.0 for all models.

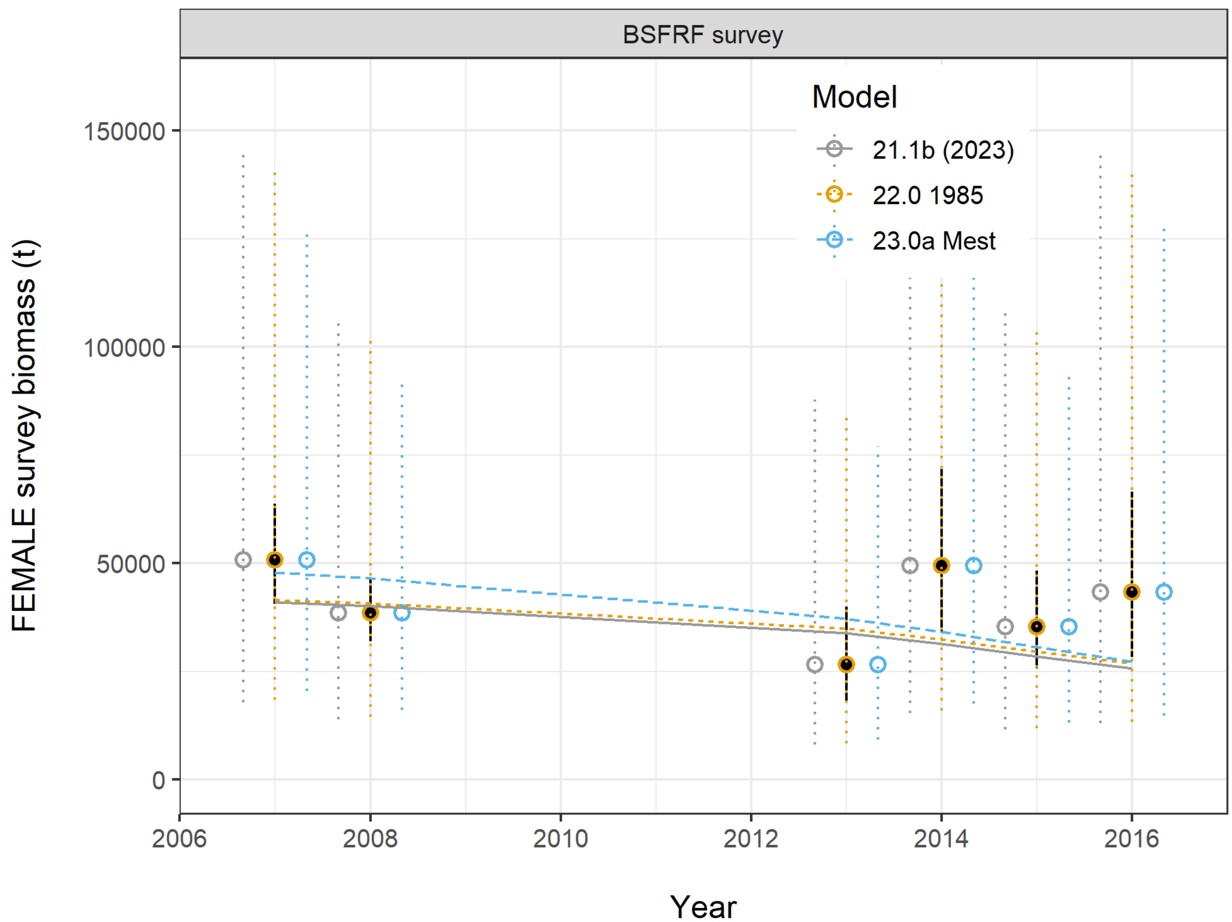

Figure 20: Comparisons of survey biomass estimates for females from the BSFRF survey and model prediction for model estimates in 2023 (models 21.1b, 22.0, and 23.0a). The error bars are plus and minus 2 standard deviations of model 21.1b. The BSFRF survey catchability is assumed to be 1.0 for all models.

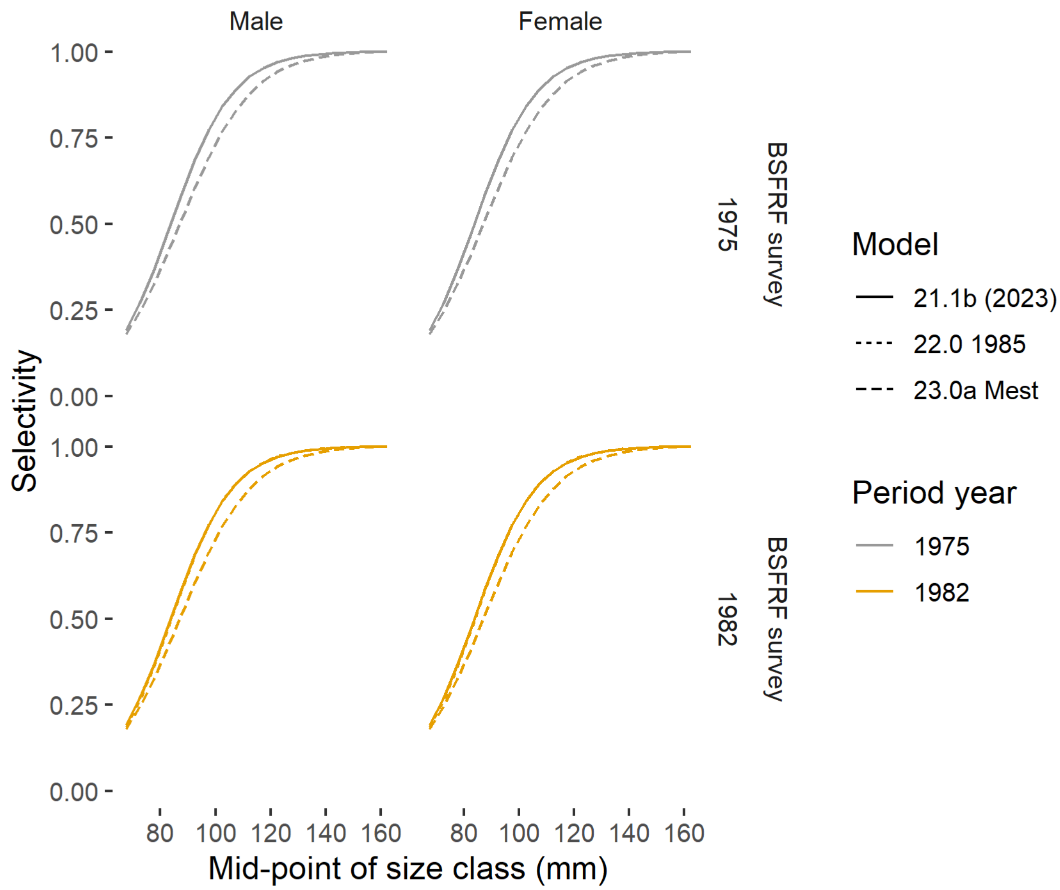

Figure 21: Estimated BSFRF trawl survey selectivities under models 21.1b, 23.0a, and 22.0. Selectivity for model 22.0 starts in 1985 but is grouped here with the 1982 group.

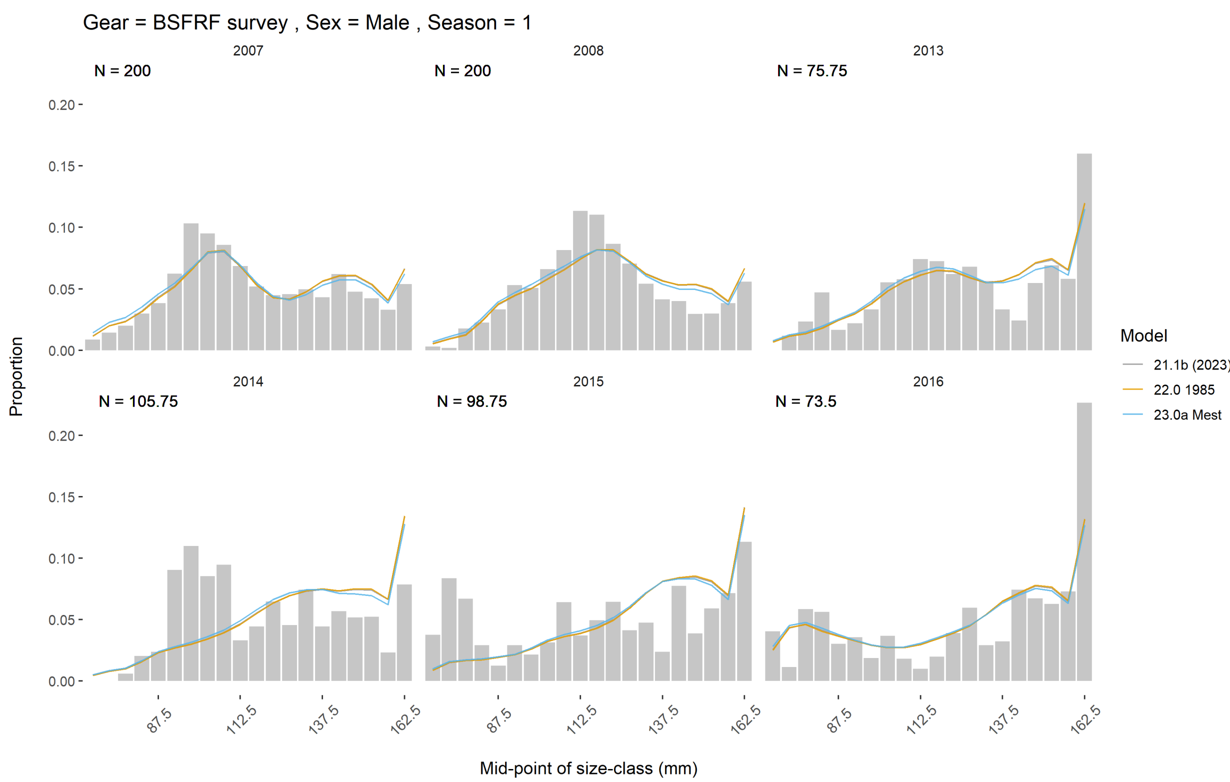

Figure 22: Comparisons of length compositions for males for the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 for all model scenarios.

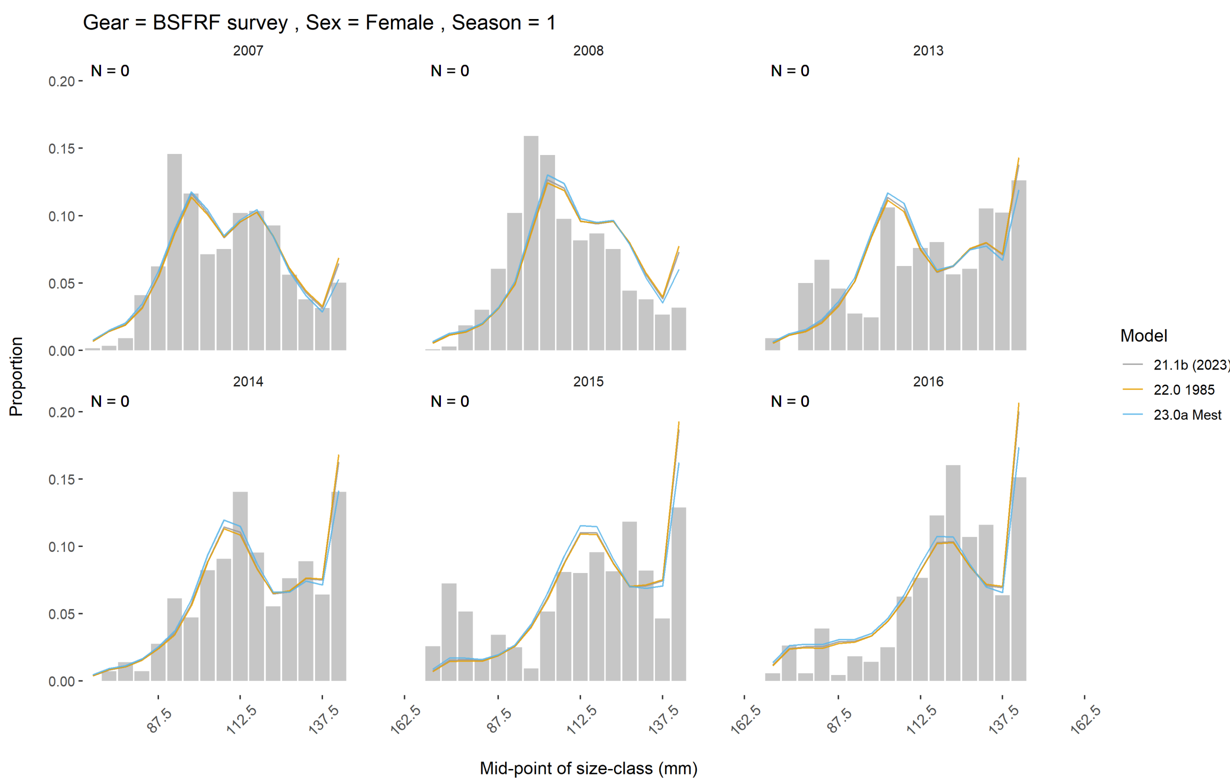

Figure 23: Comparisons of length compositions for females for the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 for all model scenarios.

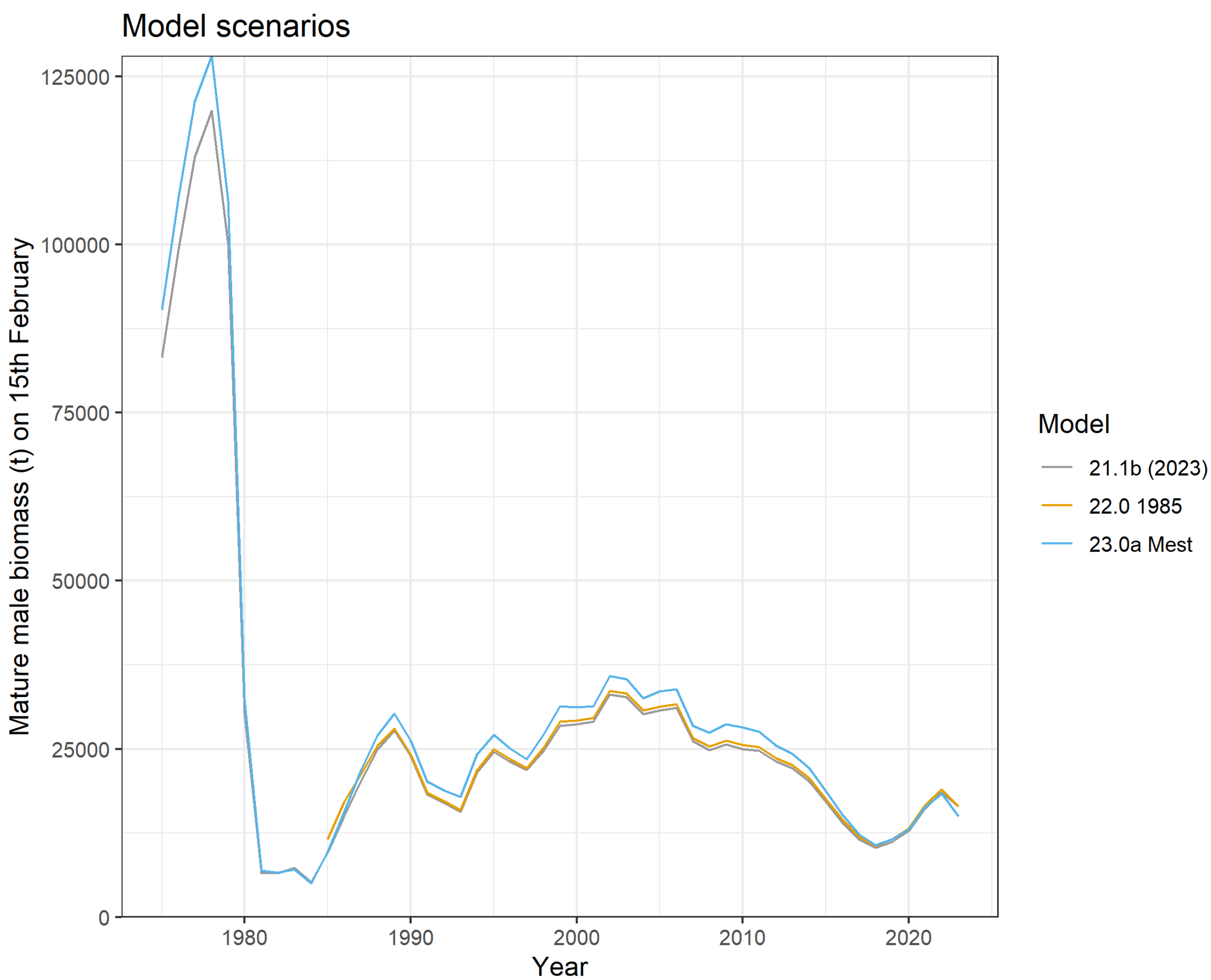

Figure 24: Estimated absolute mature male biomasses during 1975-2023 for models 21.1b, 22.0, and 23.0a. Mature male biomass is estimated on Feb. 15, year+1.

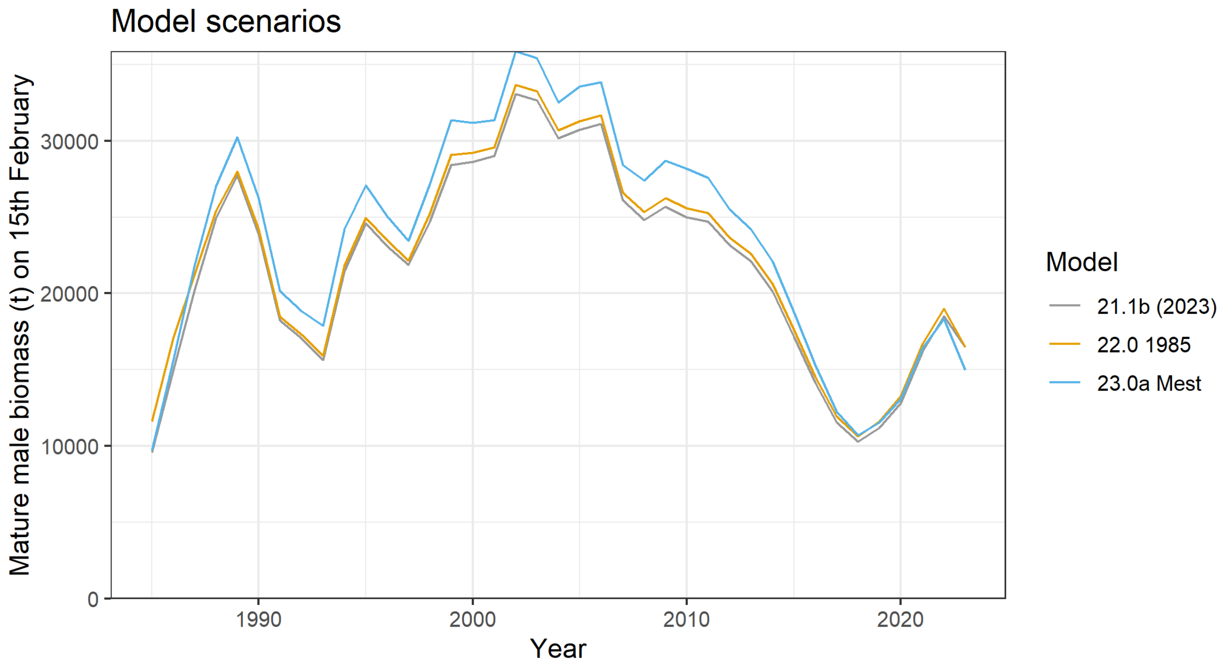

Figure 25: Estimated absolute mature male biomasses during 1985-2023 for models 21.1b, 22.0, and 23.0a. Mature male biomass is estimated on Feb. 15, year+1.

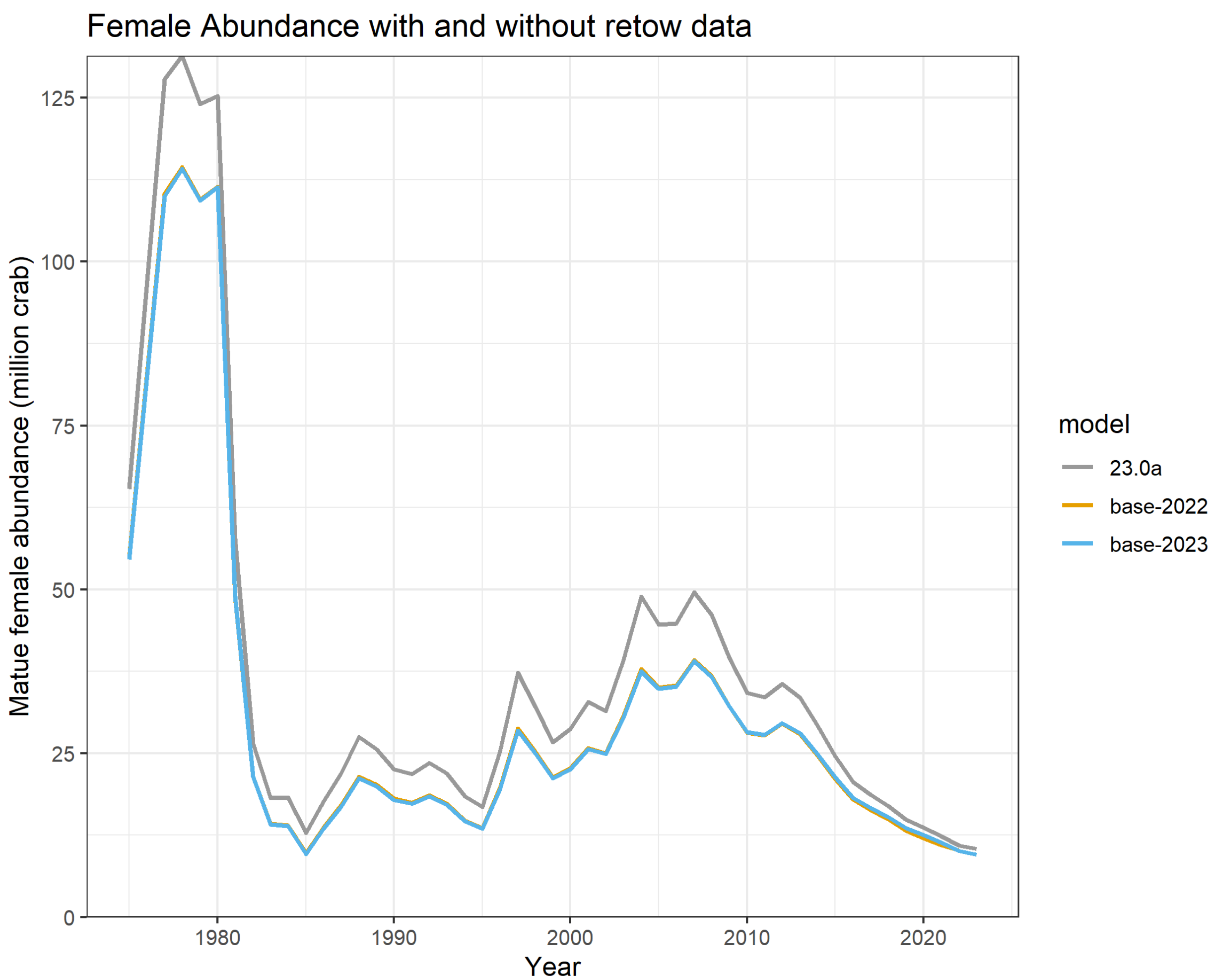

Figure 26: Estimated absolute mature female abundance during 1985-2023 for models 21.1b (2022 and 2023) and 23.0a.

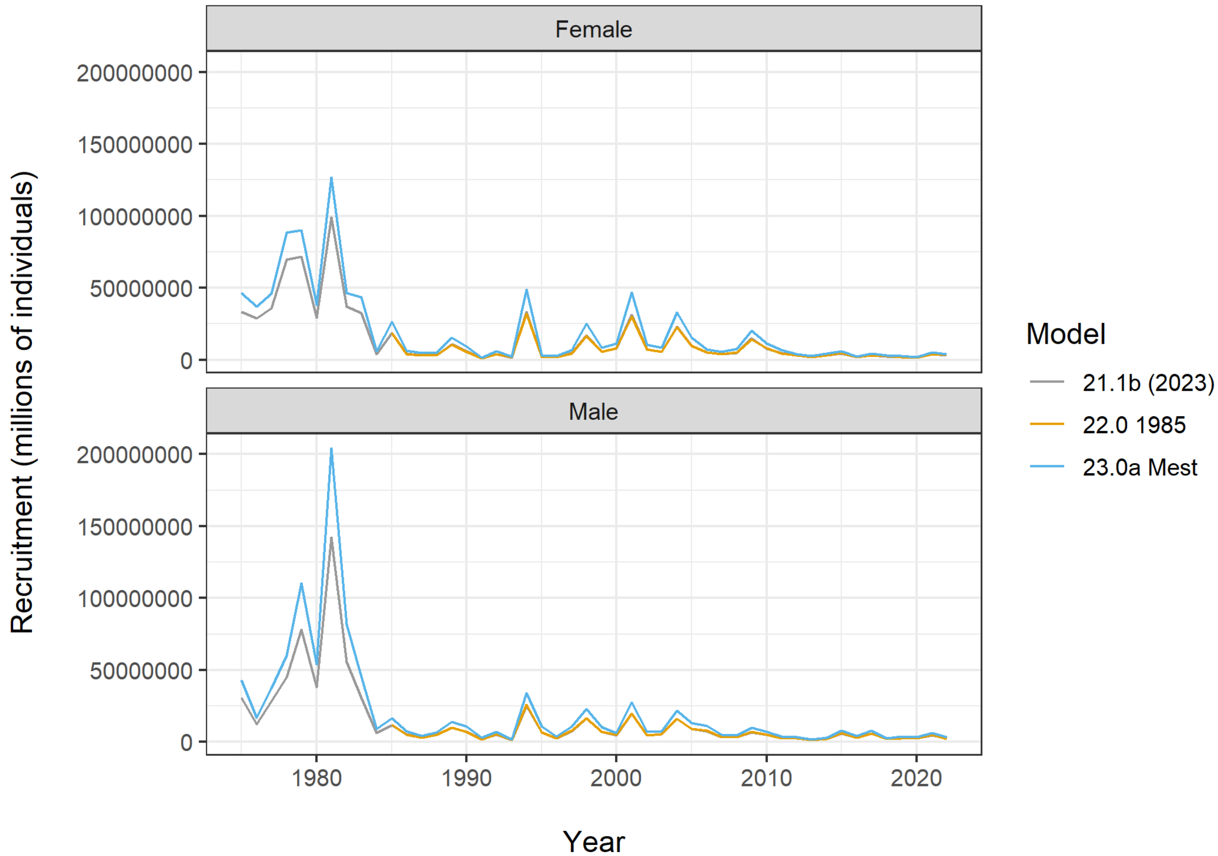

Figure 27: Estimated male and female recruitment time series during 1976-2022 with models 21.1b, 22.0, and 23.0a. Mean male recruits during 1984-2022 was used to estimate B35. Recruitment estimates in the terminal year (2023) are unreliable.

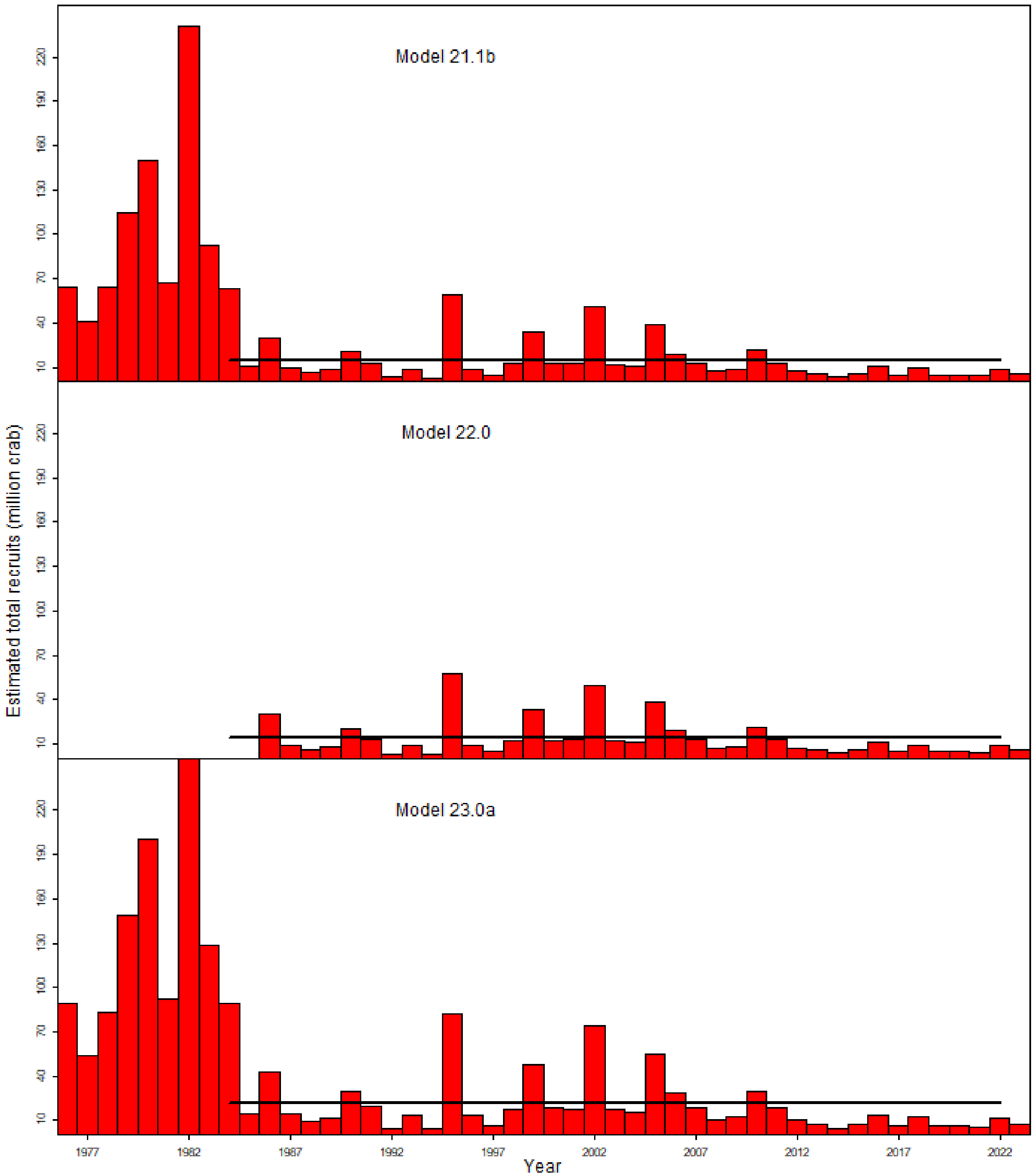

Figure 28: Estimated total recruitment time series during 1976-2022 with models 21.1b, 22.0, and 23.0a. Mean male recruits during 1984-2022 was used to estimate B35. Recruitment estimates in the terminal year (2023) are unreliable.

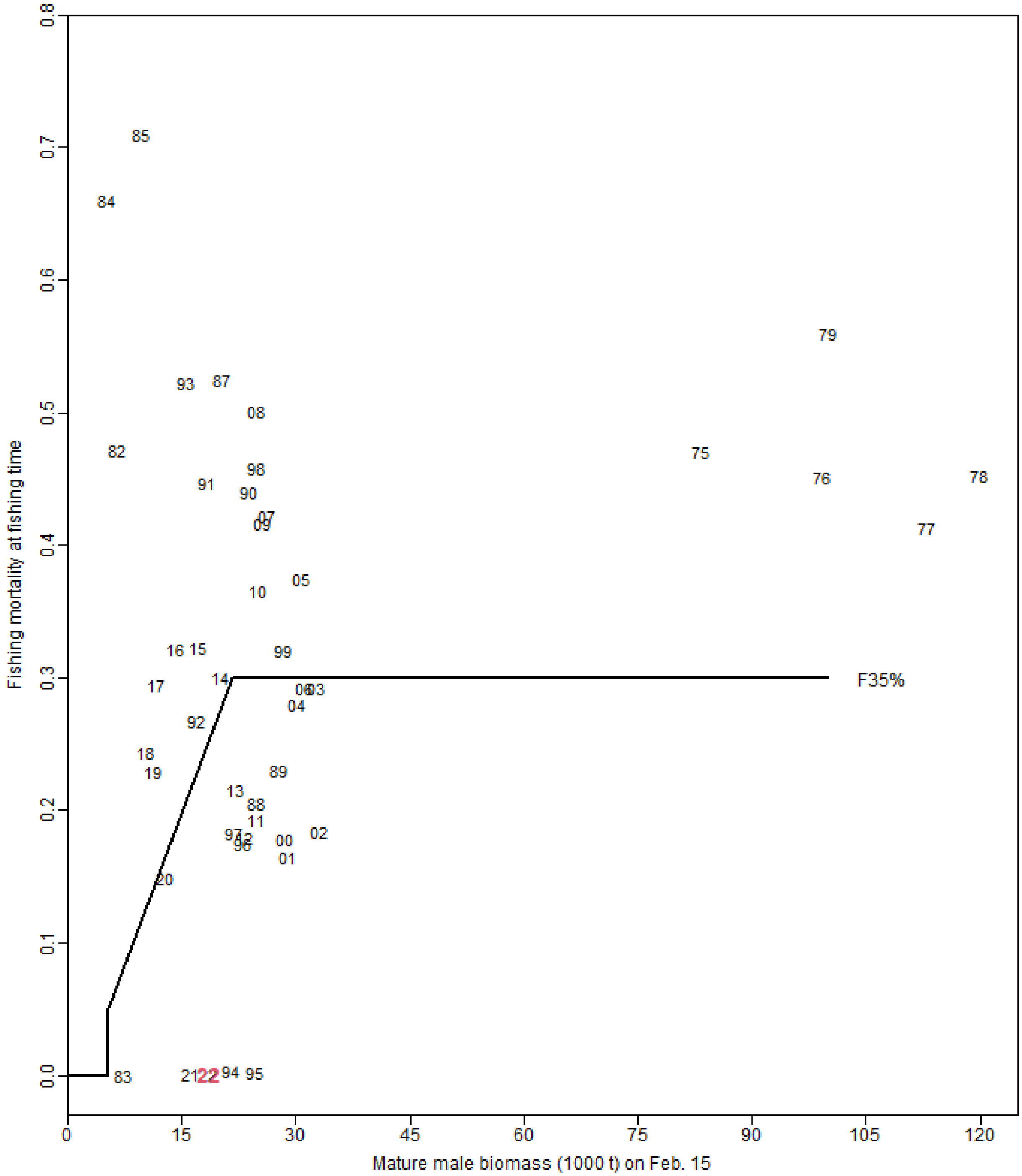

Figure 29: Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2022 under model 21.1b. Average of recruitment from 1984 to 2022 was used to estimate B35.

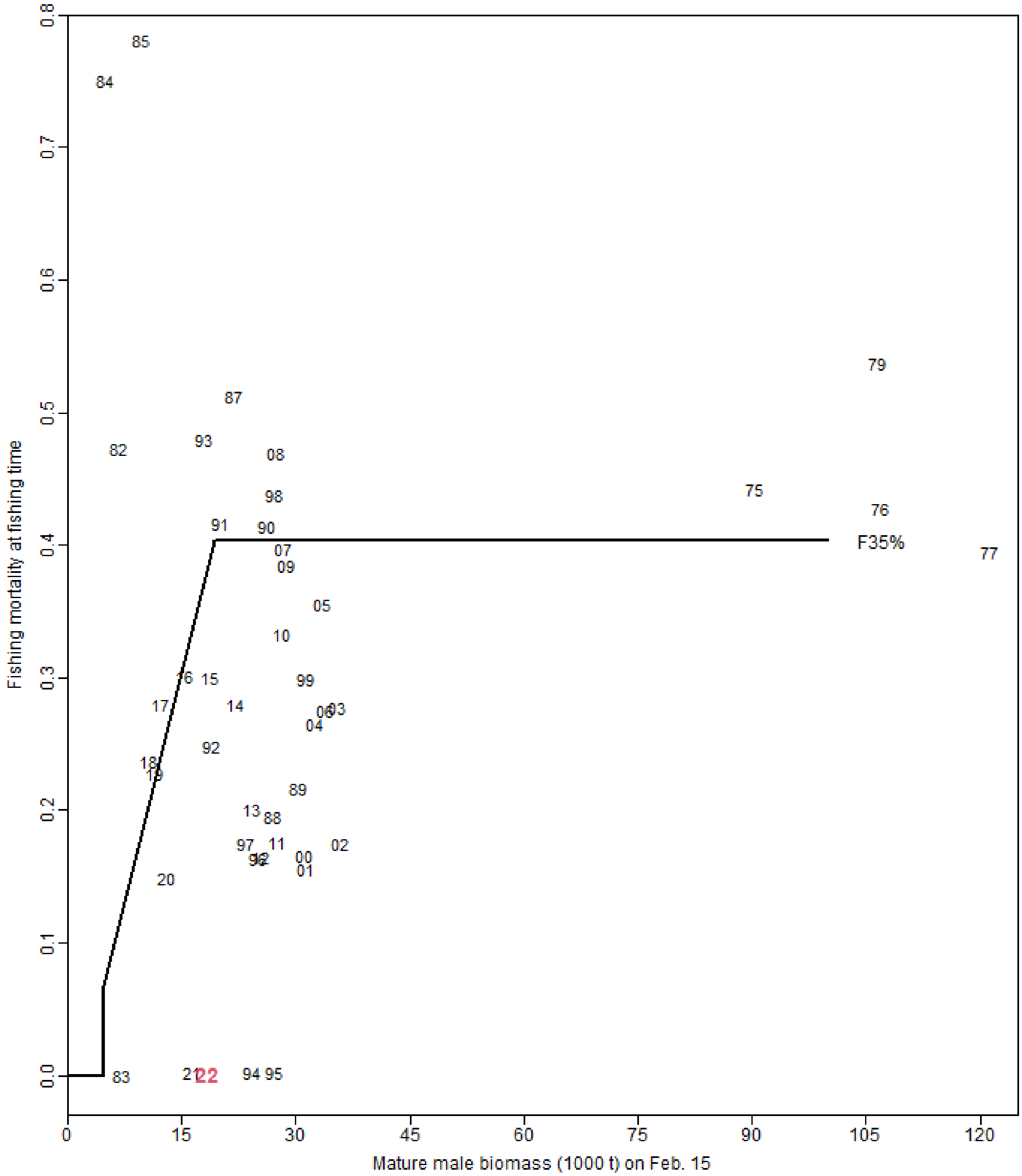

Figure 30: Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2022 under model 23.0a. Average of recruitment from 1984 to 2022 was used to estimate B35.

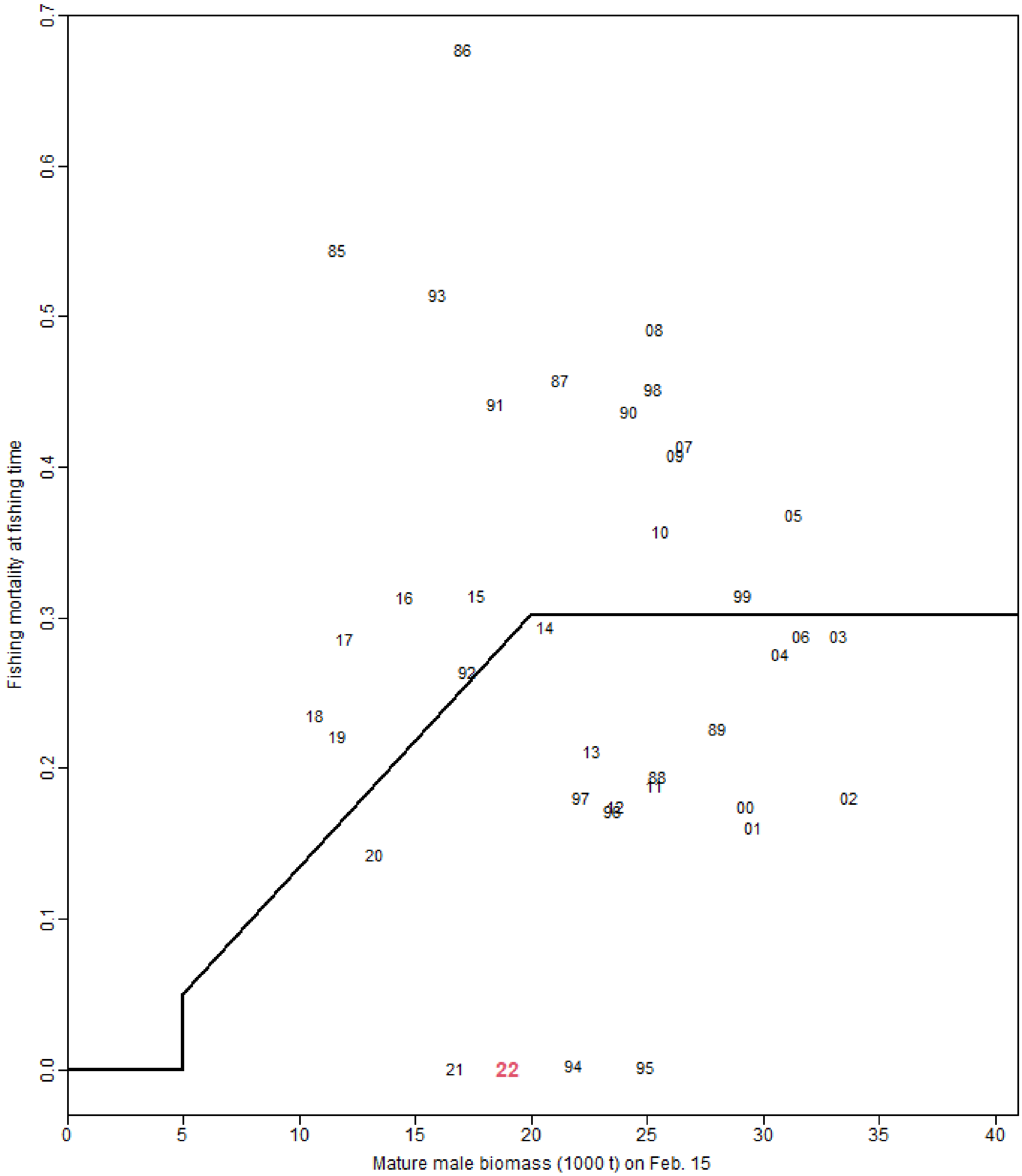

Figure 31: Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985-2022 under model 22.0. Average of recruitment from 1985 to 2022 was used to estimate B35.

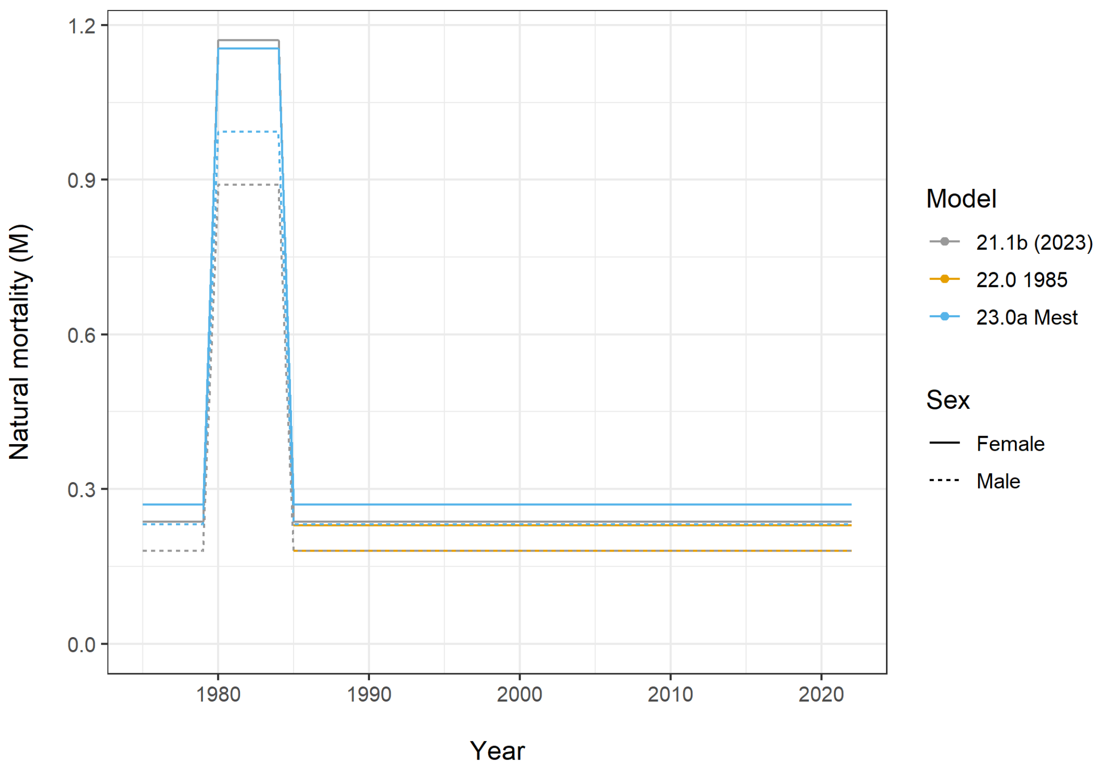

Figure 32: Comparison of natural mortality - either estimated or fixed depending on the model - for models 21.1b, 22.0, and 23.0a.

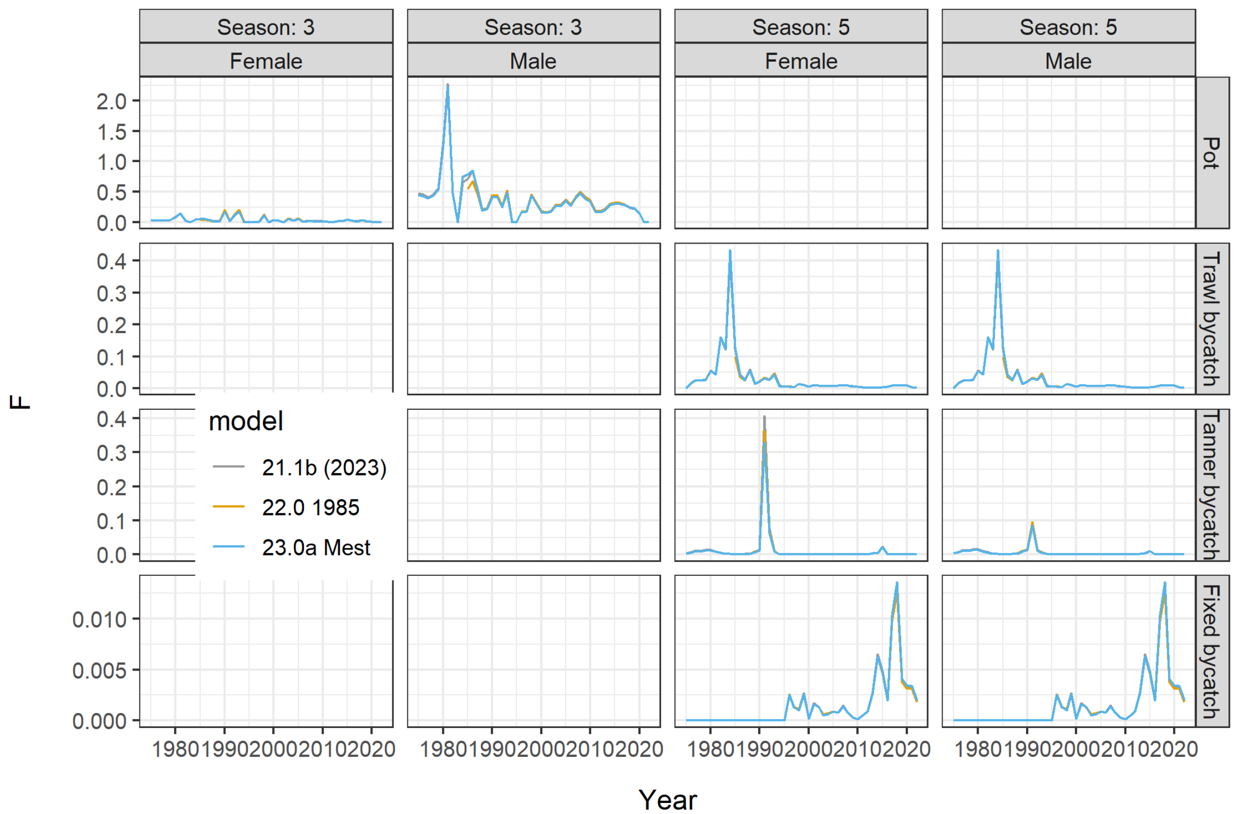

Figure 33: Comparison of estimated fishing mortality for models 21.1b, 22.0, and 23.0a.

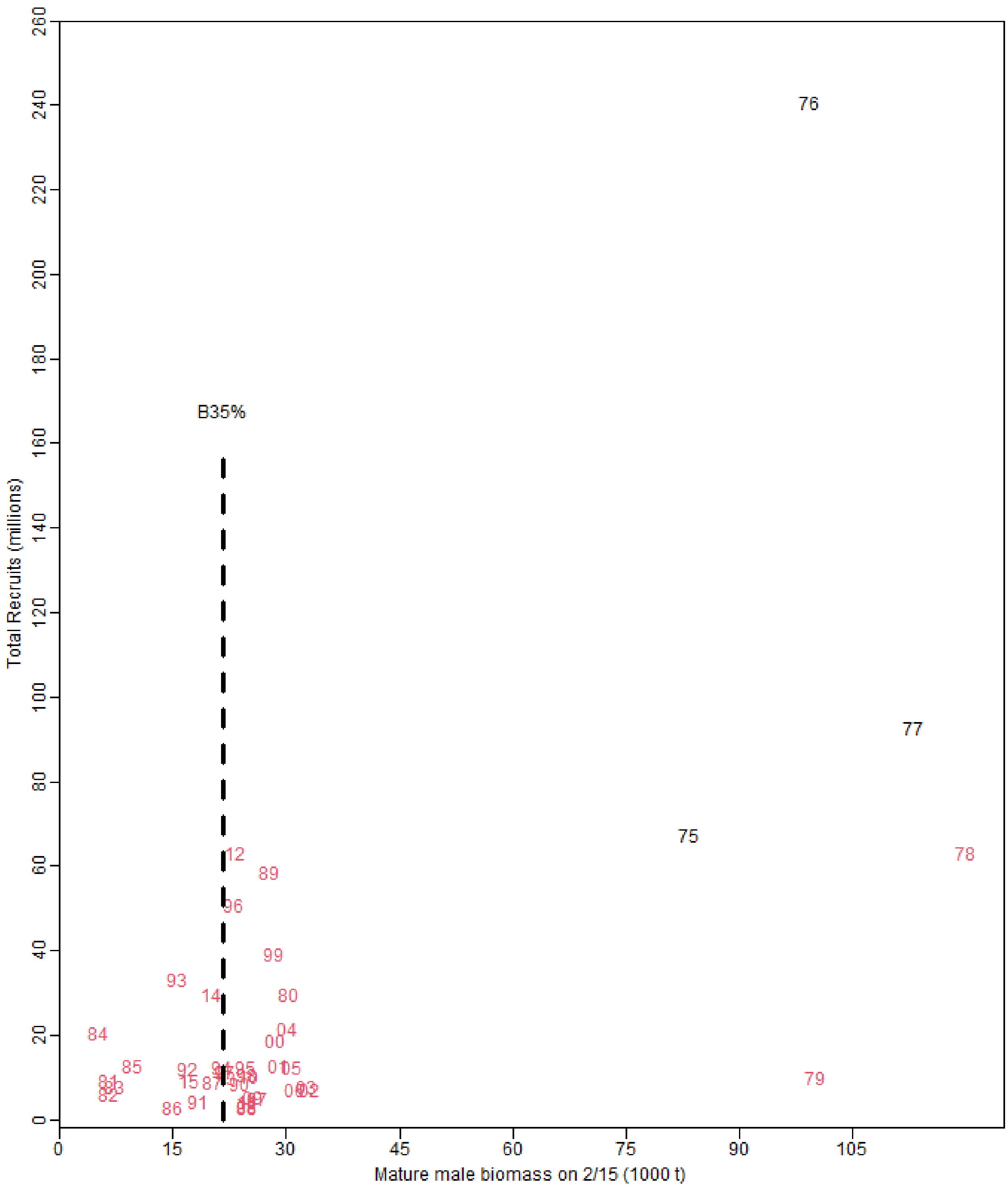

Figure 34: Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6 year time lag) for Bristol Bay red king crab under model 21.1b. Numerical labels are years of mating, and the vertical dotted line is the estimated B35 based on the mean recruitment level during 1984 to 2022.

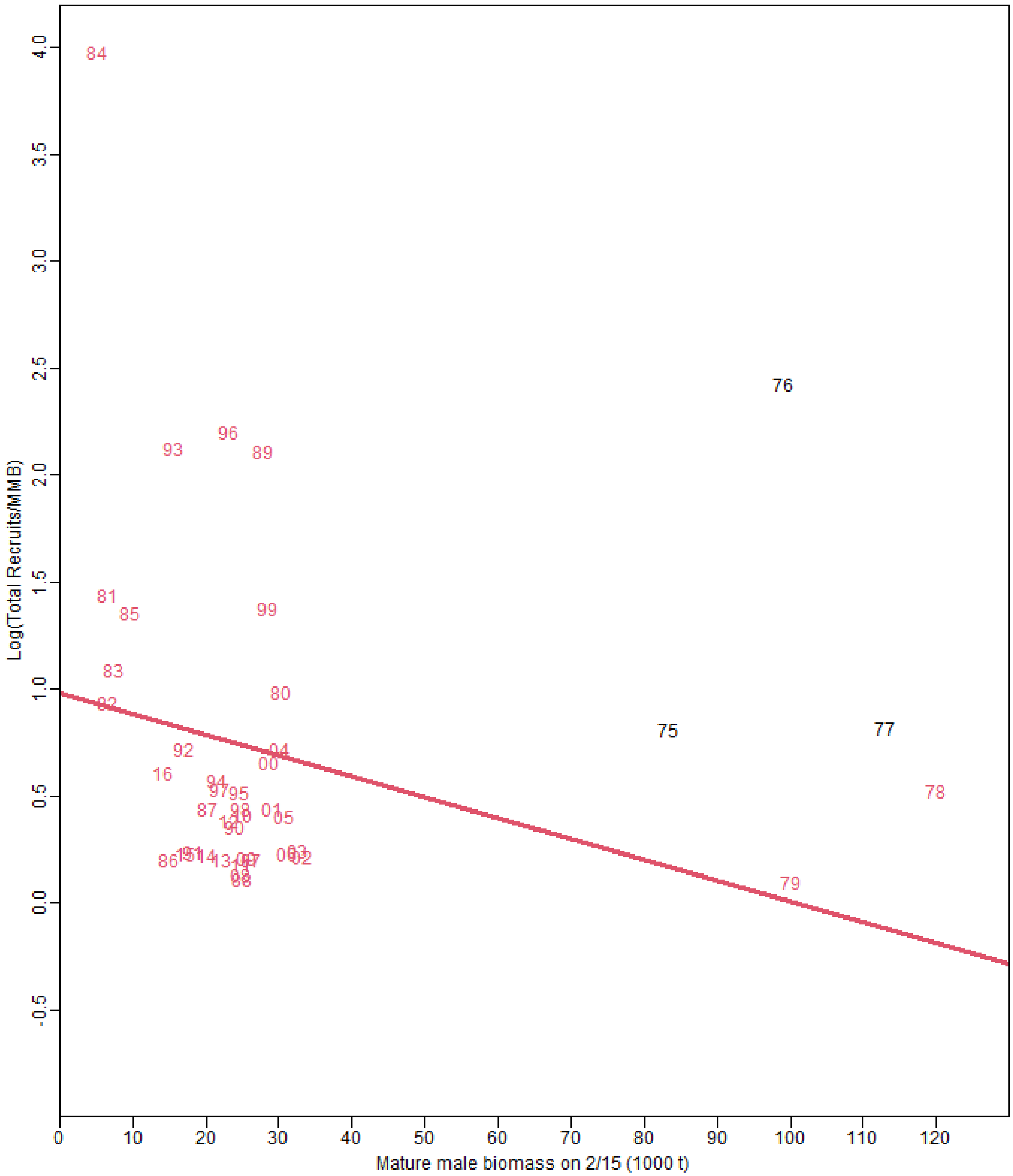

Figure 35: Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab under model 21.1b. Numerical labels are years of mating, and the line is the regression line for data of 1978-2016.

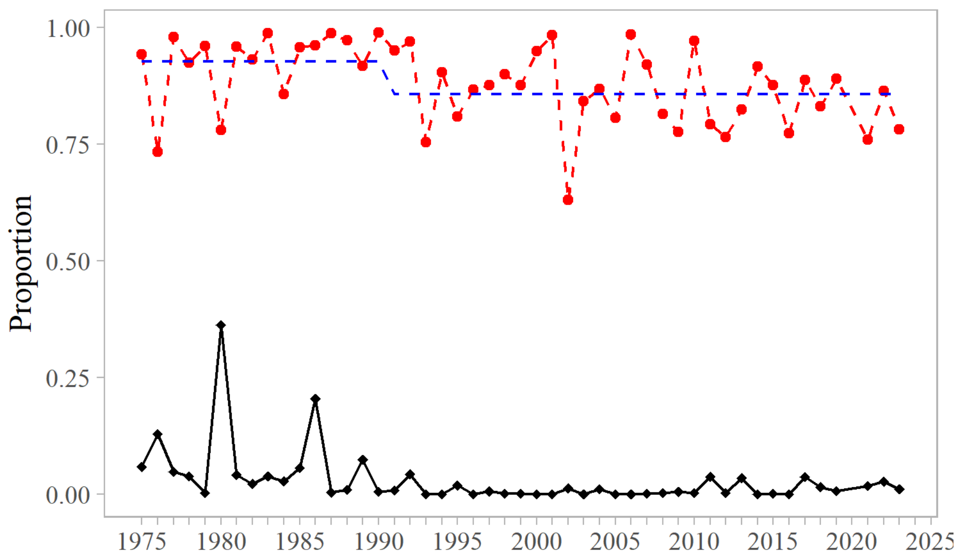

Figure 36: Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2023 from survey data. Oldshell females were excluded. The blue dashed line is the mean clutch fullness during two periods before 1992 and after 1991.

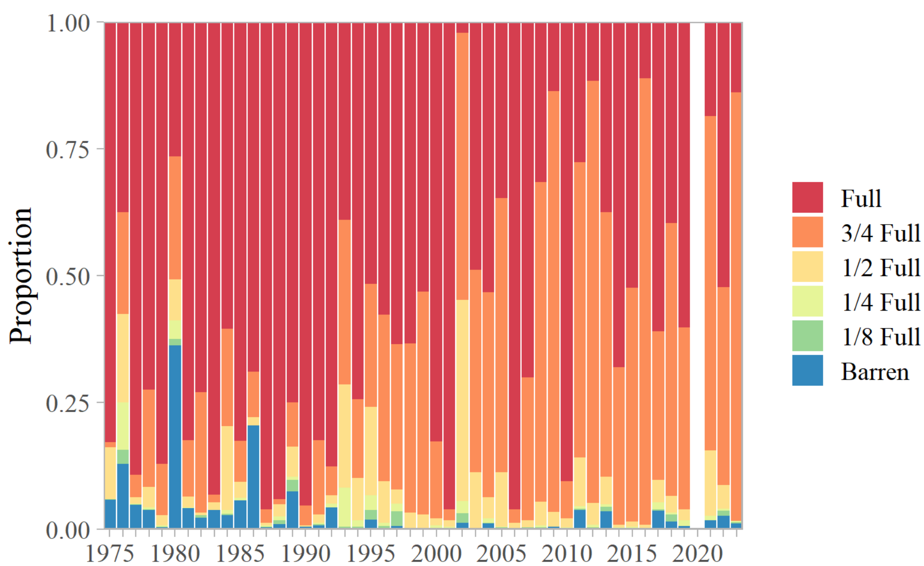

Figure 37: Clutch fullness distribution of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2023 from survey data. Oldshell females were excluded.

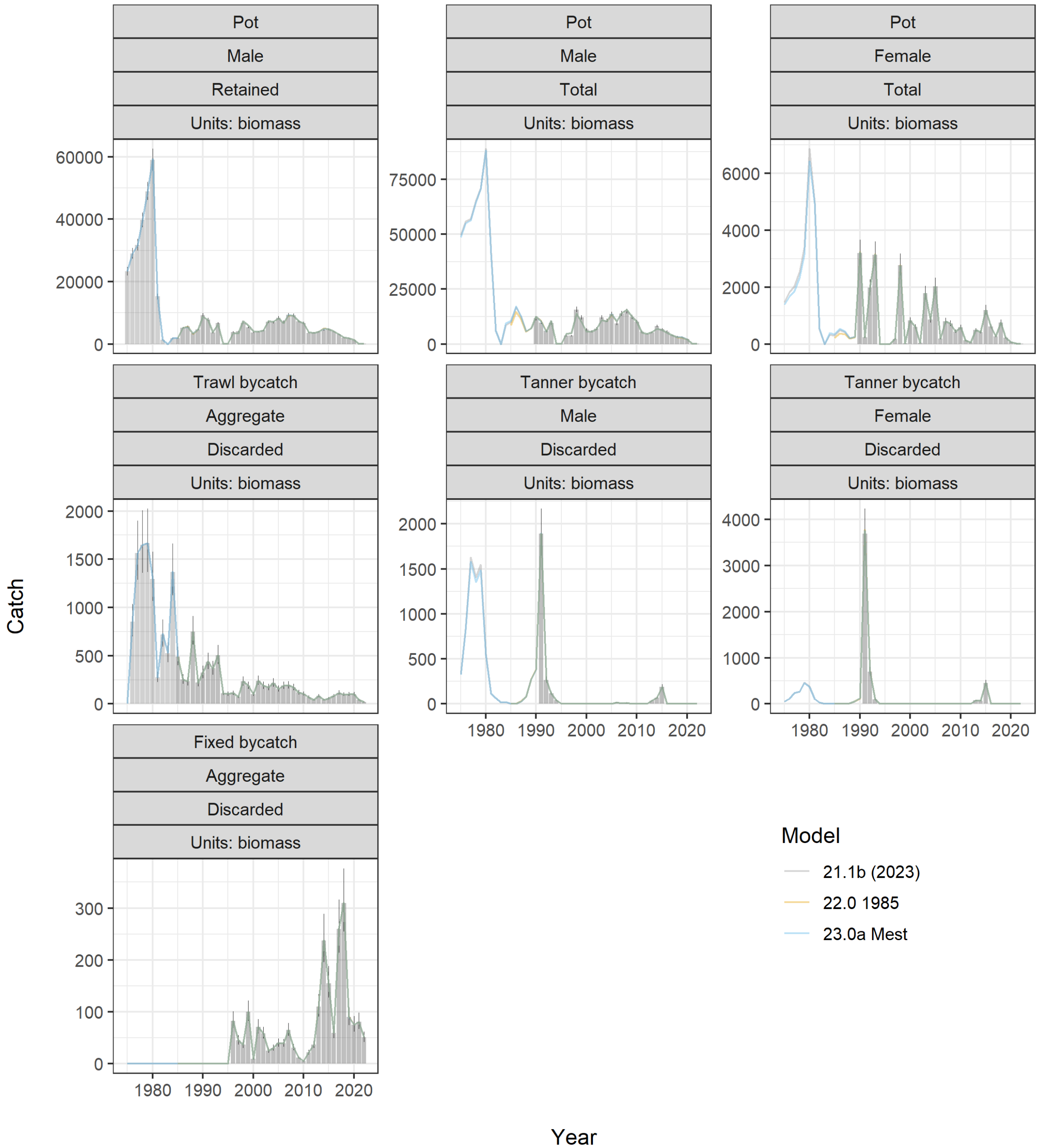

Figure 38: Observed (bars) and predicted (lines) RKC catch and bycatch biomass under models 21.1b, 22.0, and 23.0a.

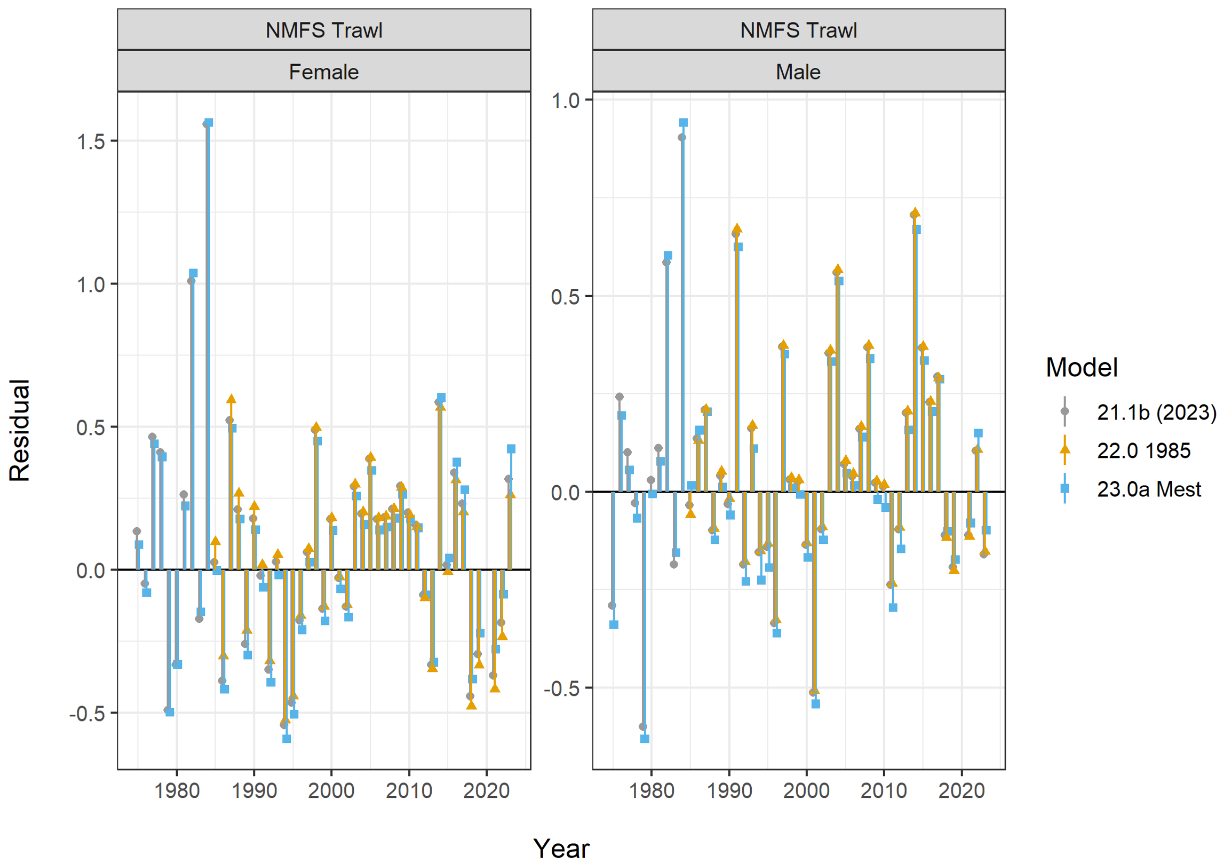

Figure 39: Standardized residuals of NMFS survey biomass under models 21.1b, 22.0, and 23.0a.

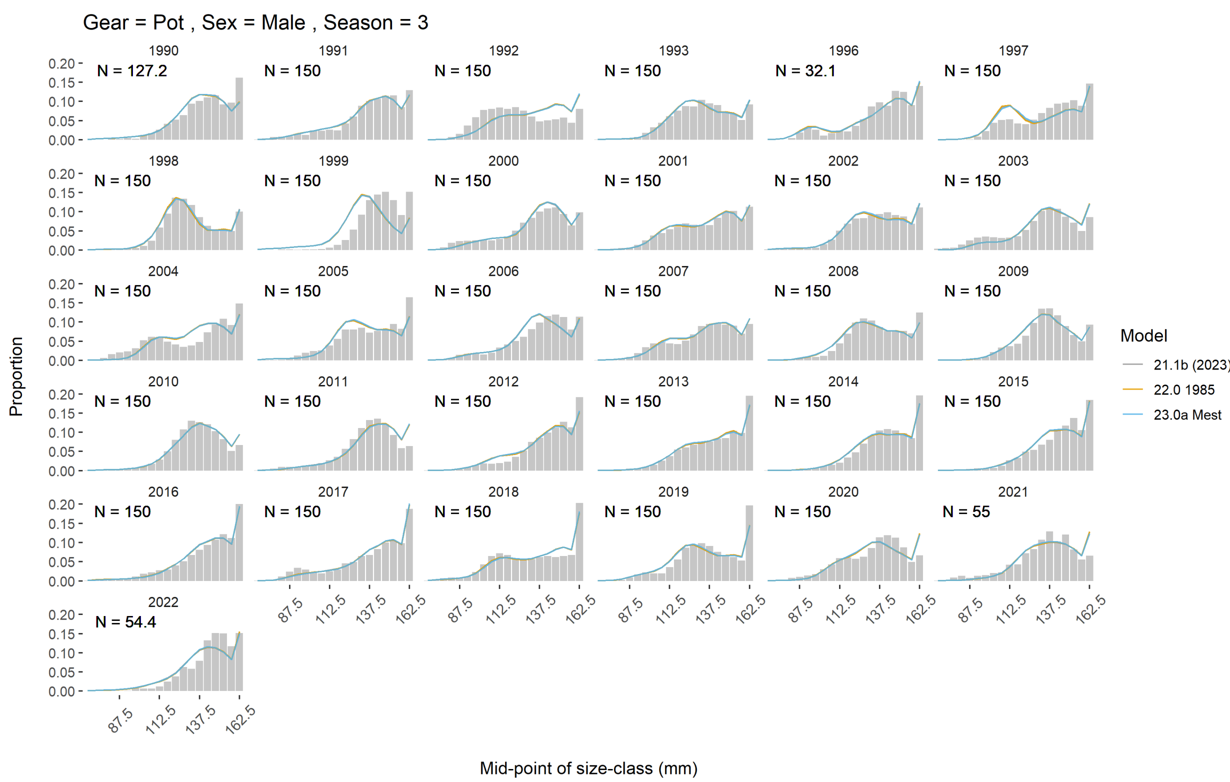

Figure 40: Observed and model estimated total observer length-frequencies of male BBRKC by year in the directed pot fishery for all model scenarios.

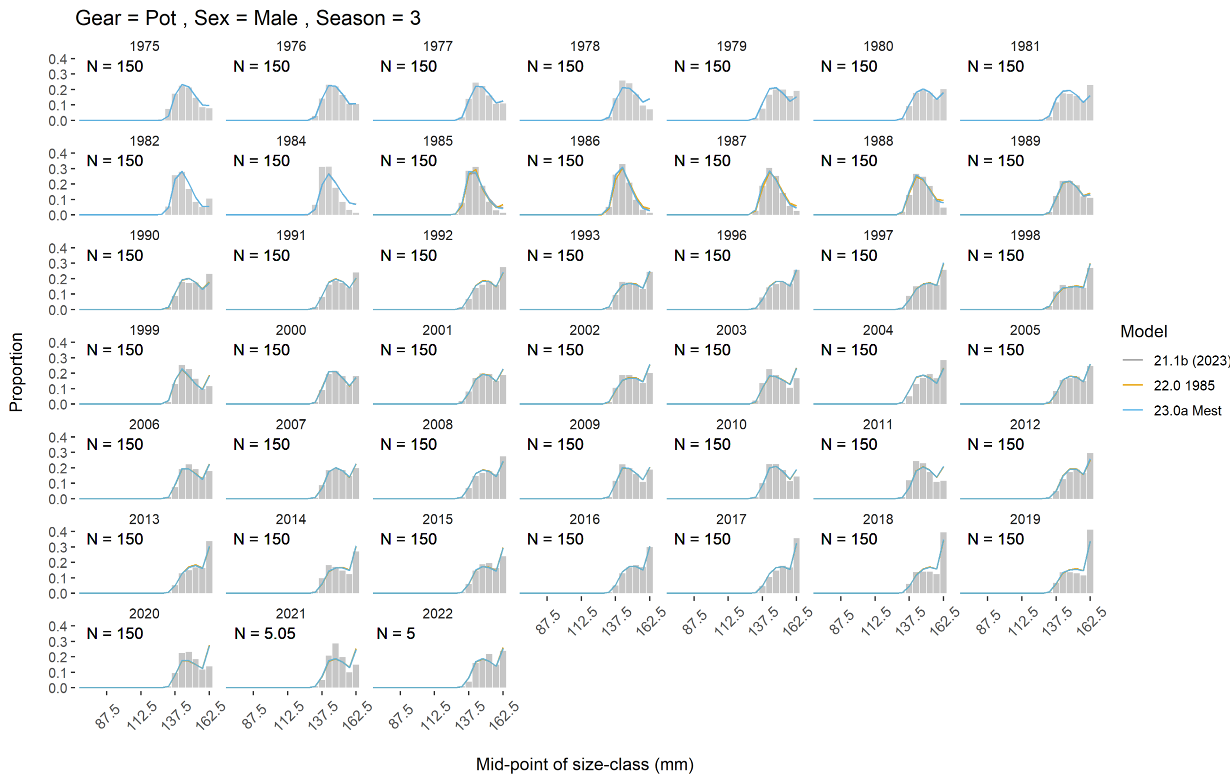

Figure 41: Observed and model estimated retained length-frequencies of male BBRKC by year in the directed pot fishery for all model scenarios.

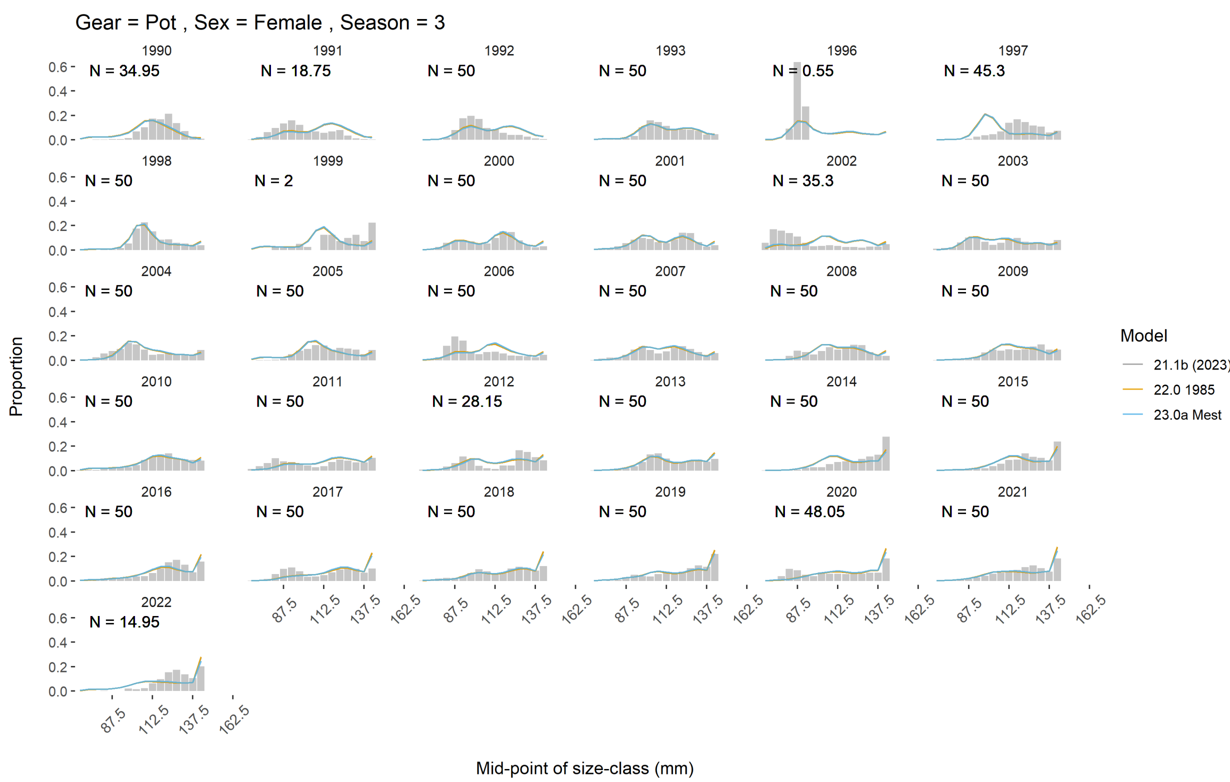

Figure 42: Observed and model estimated total observer length-frequencies of discarded female BBRKC by year in the directed pot fishery for all model scenarios.

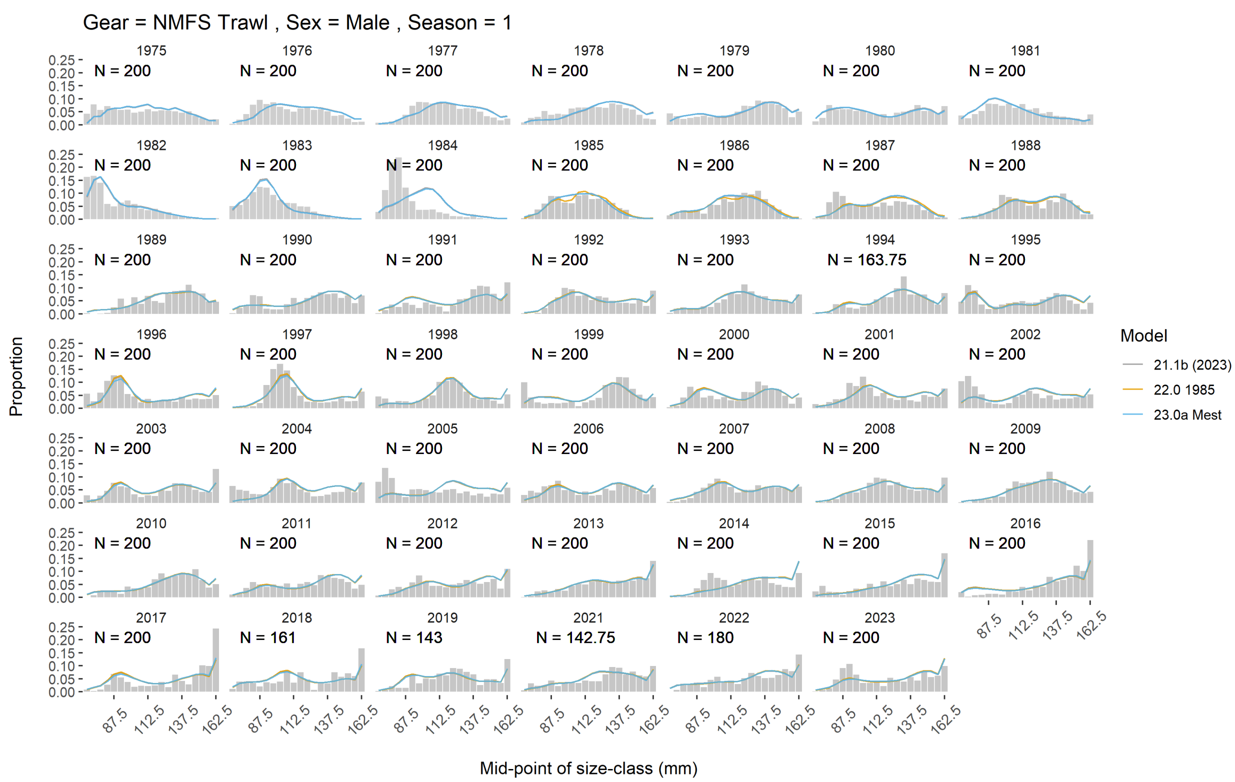

Figure 43: Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay male red king crab by year for all model scenarios.

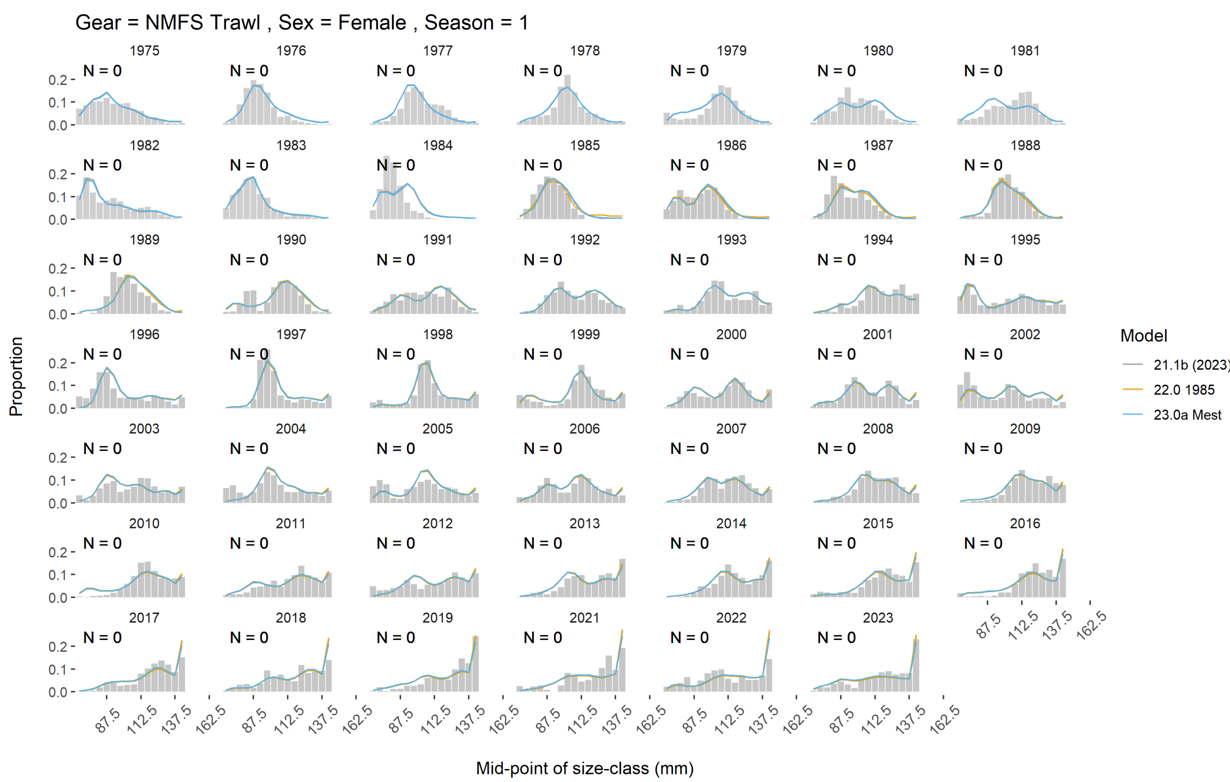

Figure 44: Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay FEMALE red king crab by year for all model scenarios.

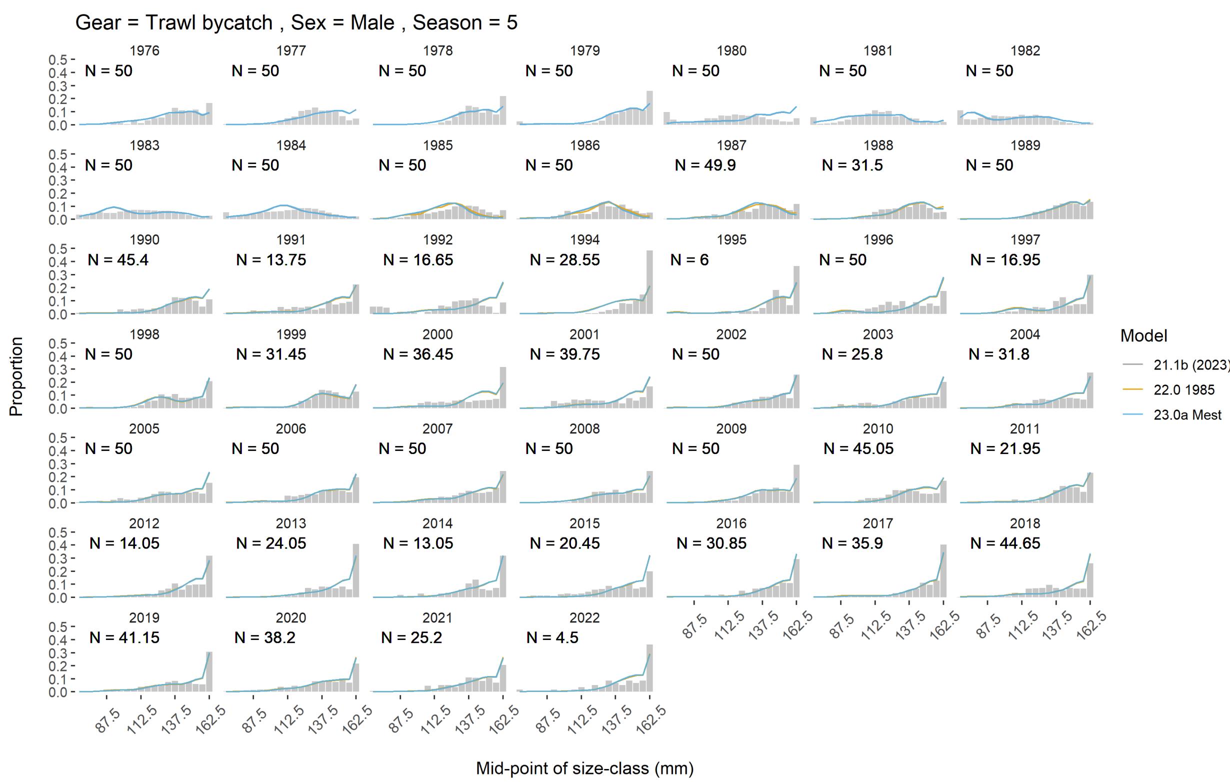

Figure 45: Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries for all model scenarios.

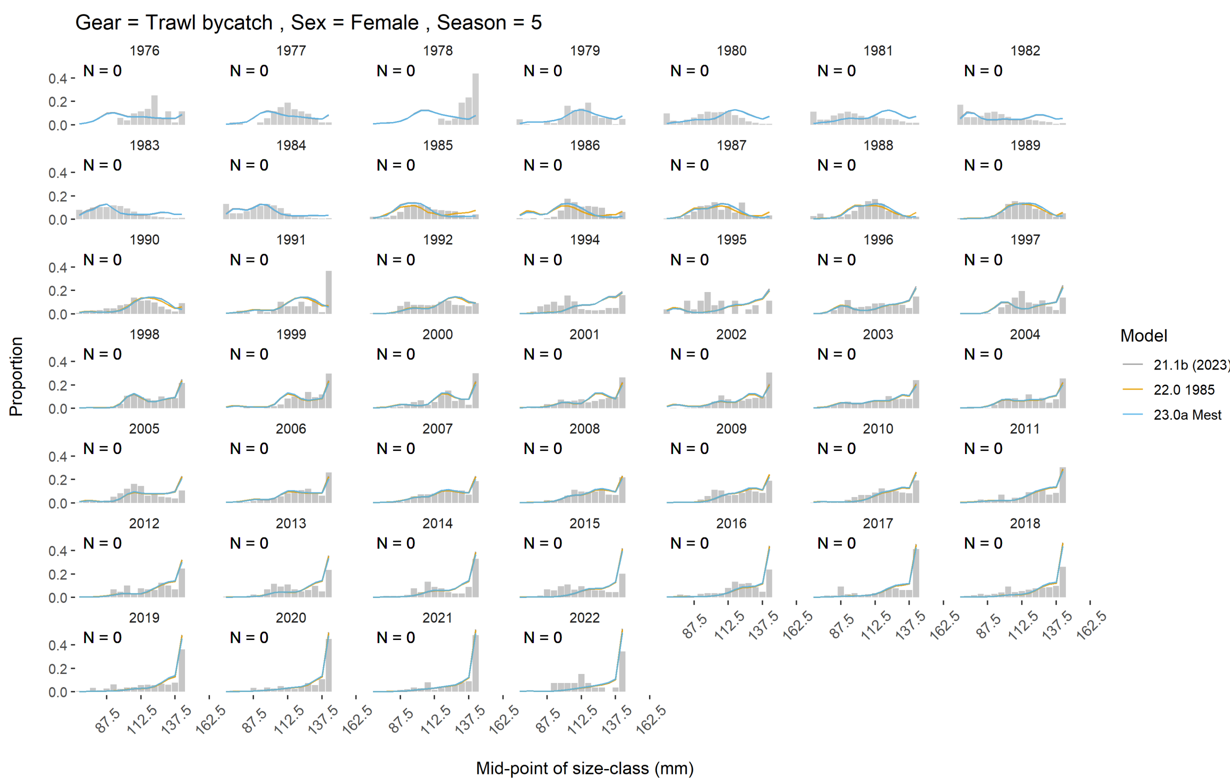

Figure 46: Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries for all model scenarios.

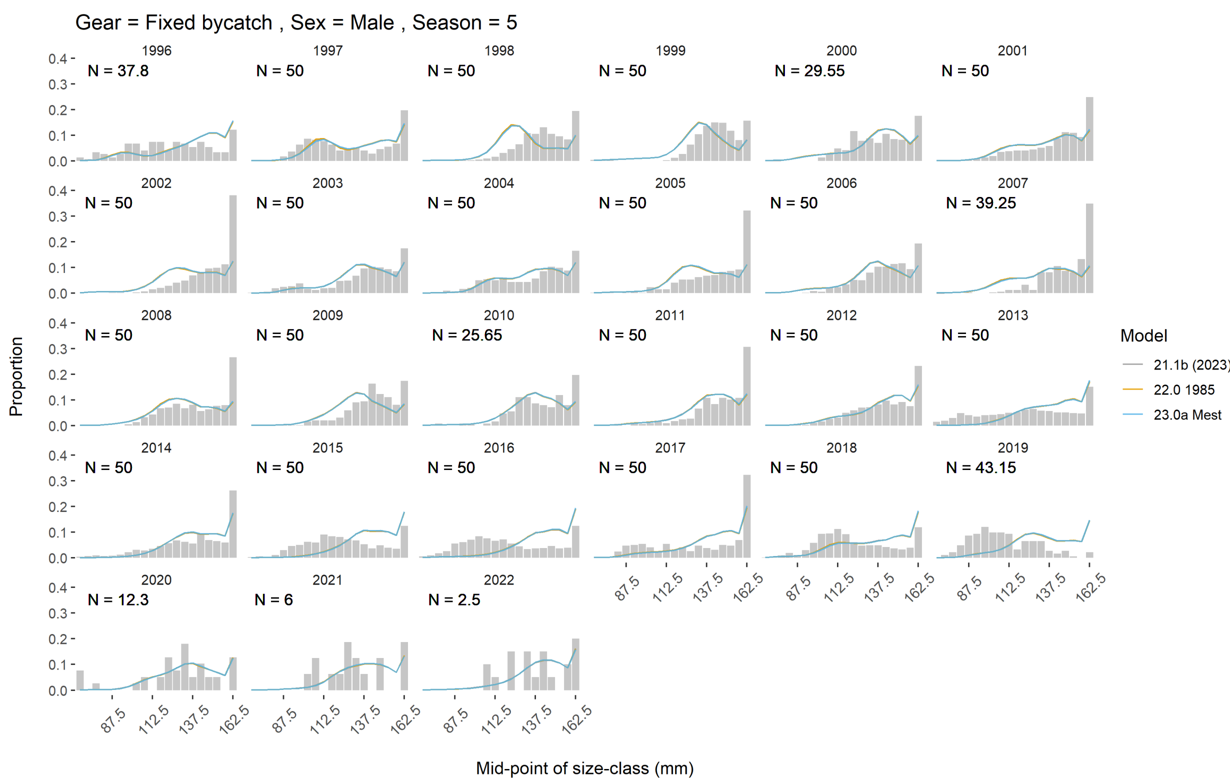

Figure 47: Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries for all model scenarios.

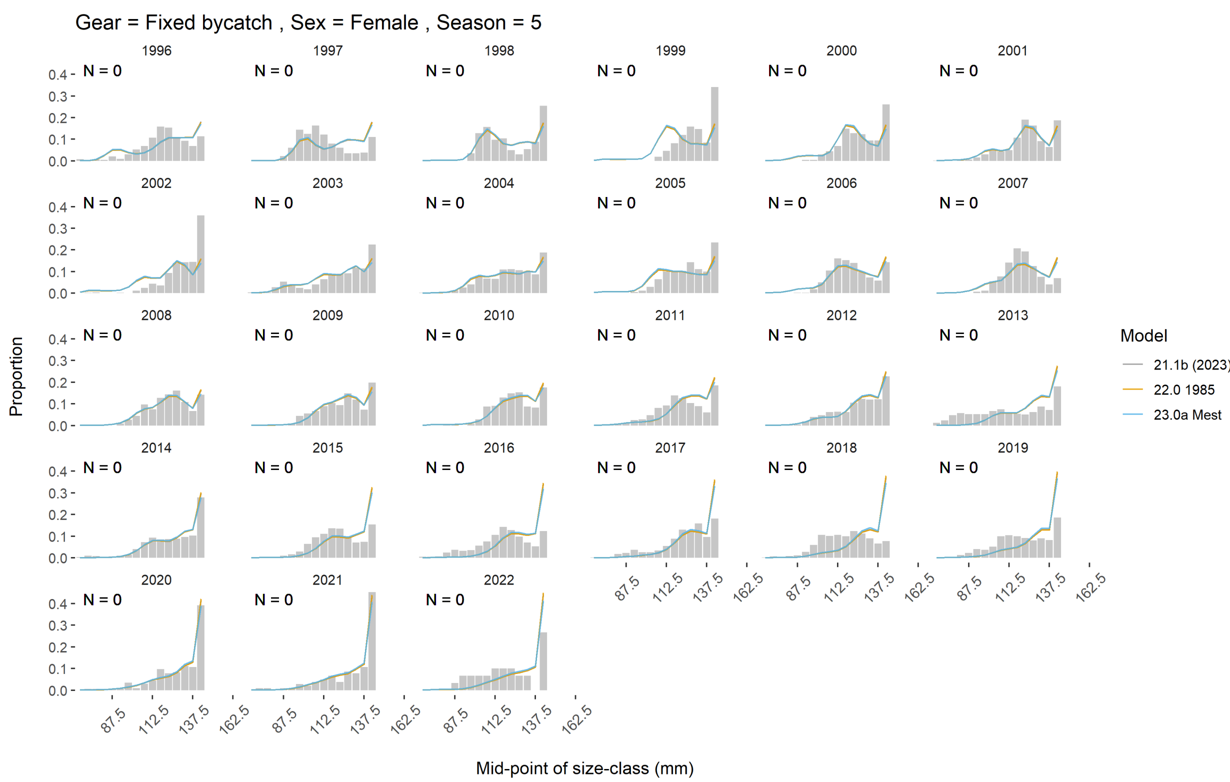

Figure 48: Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries for all model scenarios.

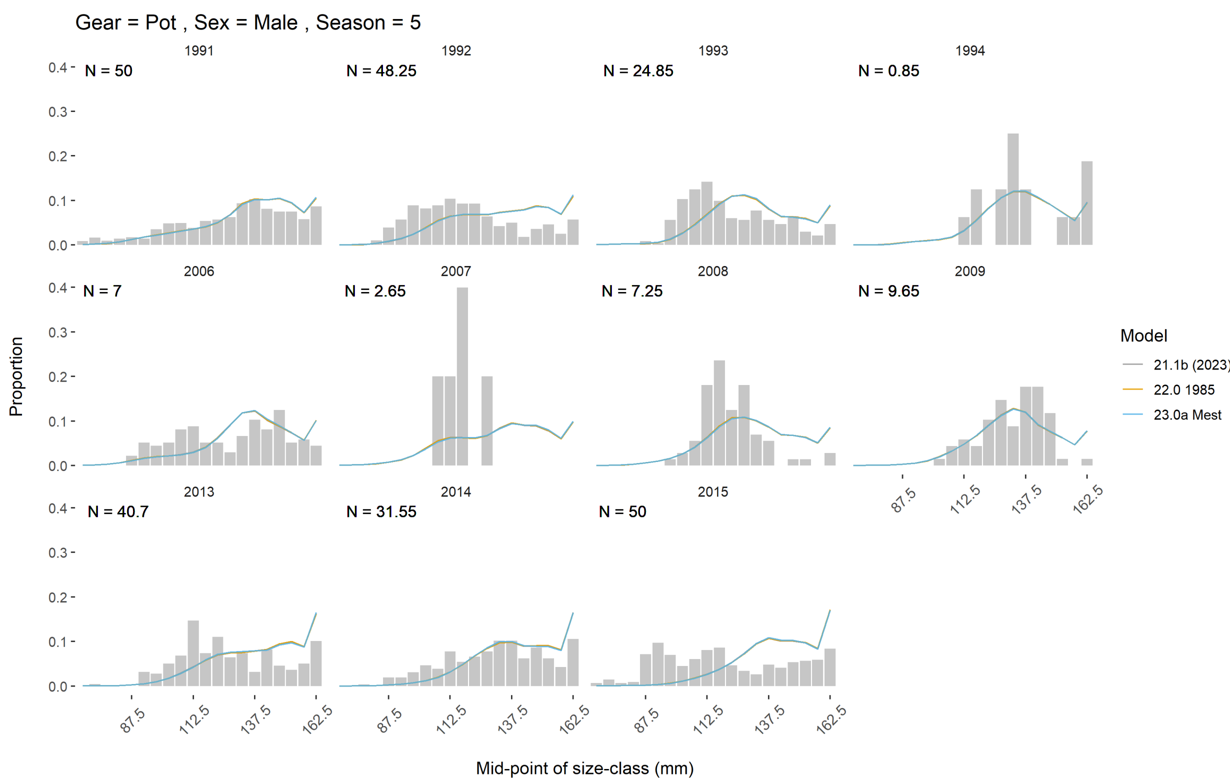

Figure 49: Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries for all model scenarios.

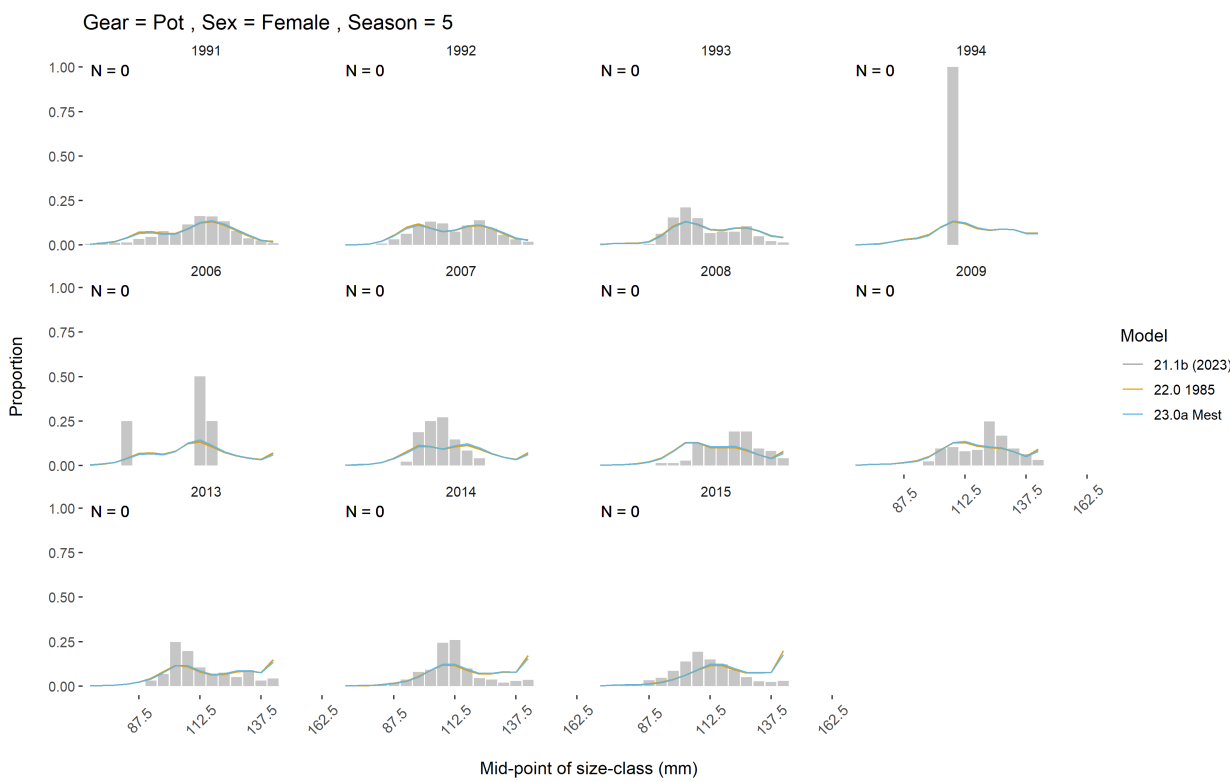

Figure 50: Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries for all model scenarios.

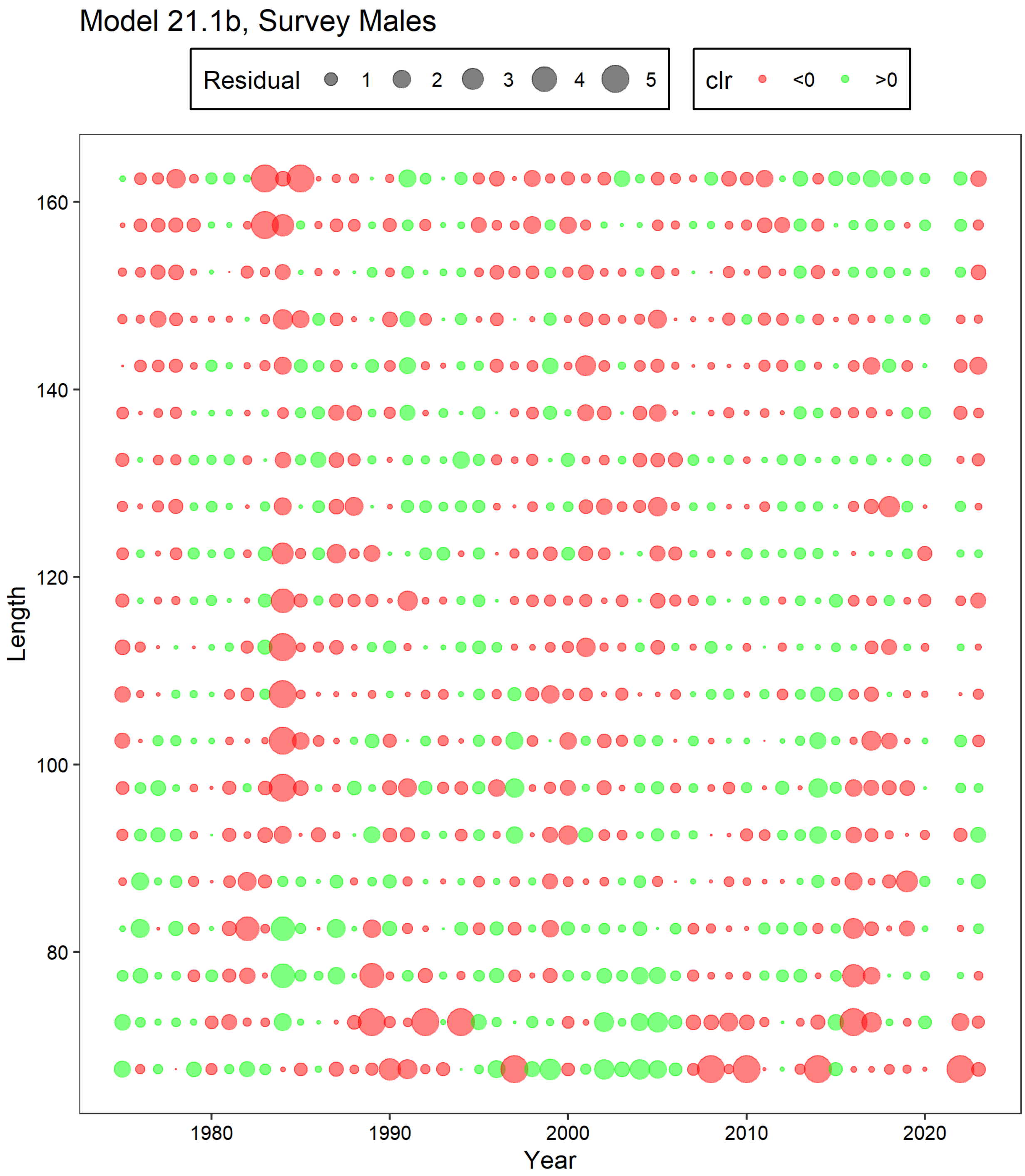

Figure 51: Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 21.1b. Green circles are positive residuals, and red circles are negative residuals.

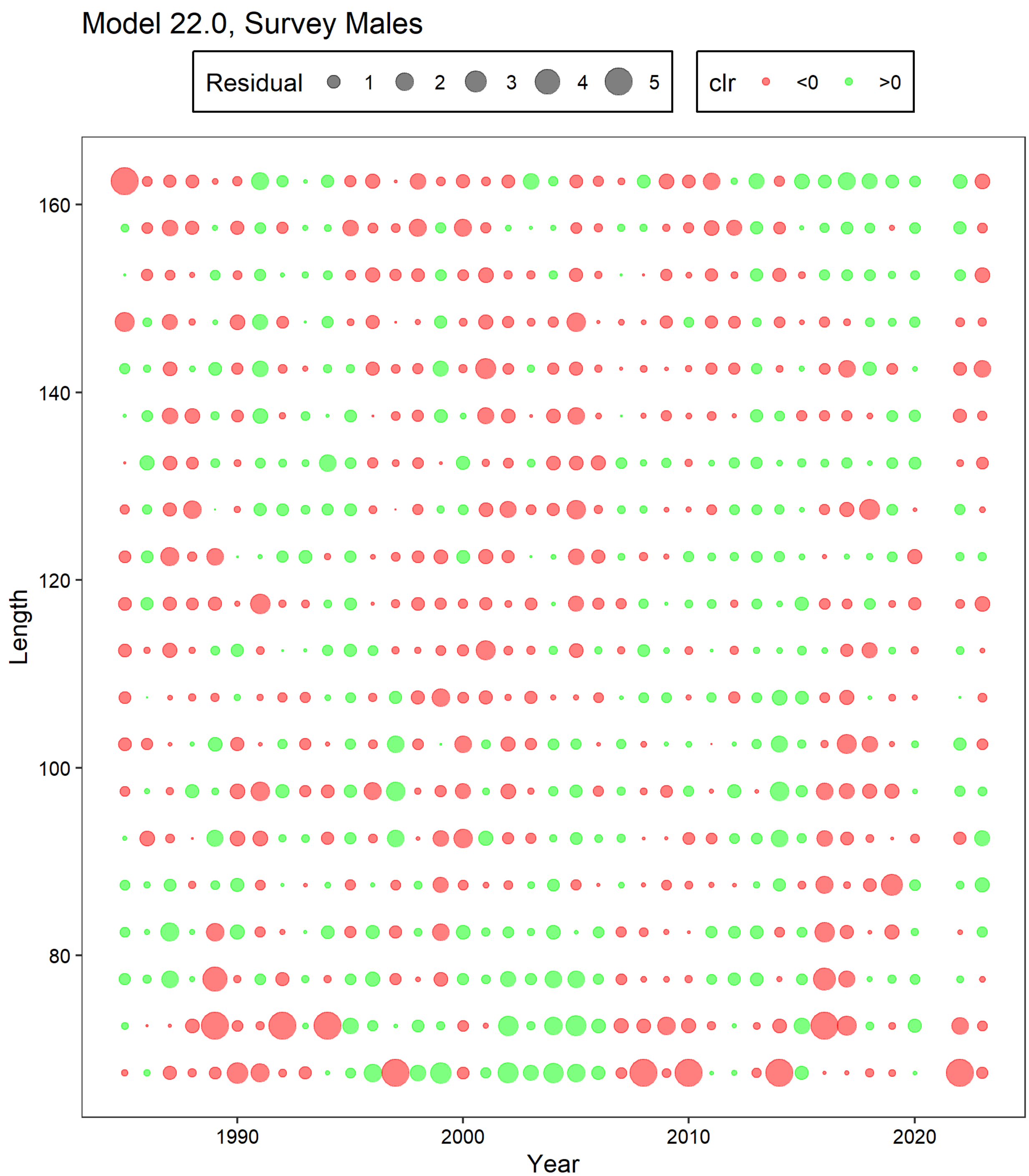

Figure 52: Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 22.0. Green circles are positive residuals, and red circles are negative residuals.

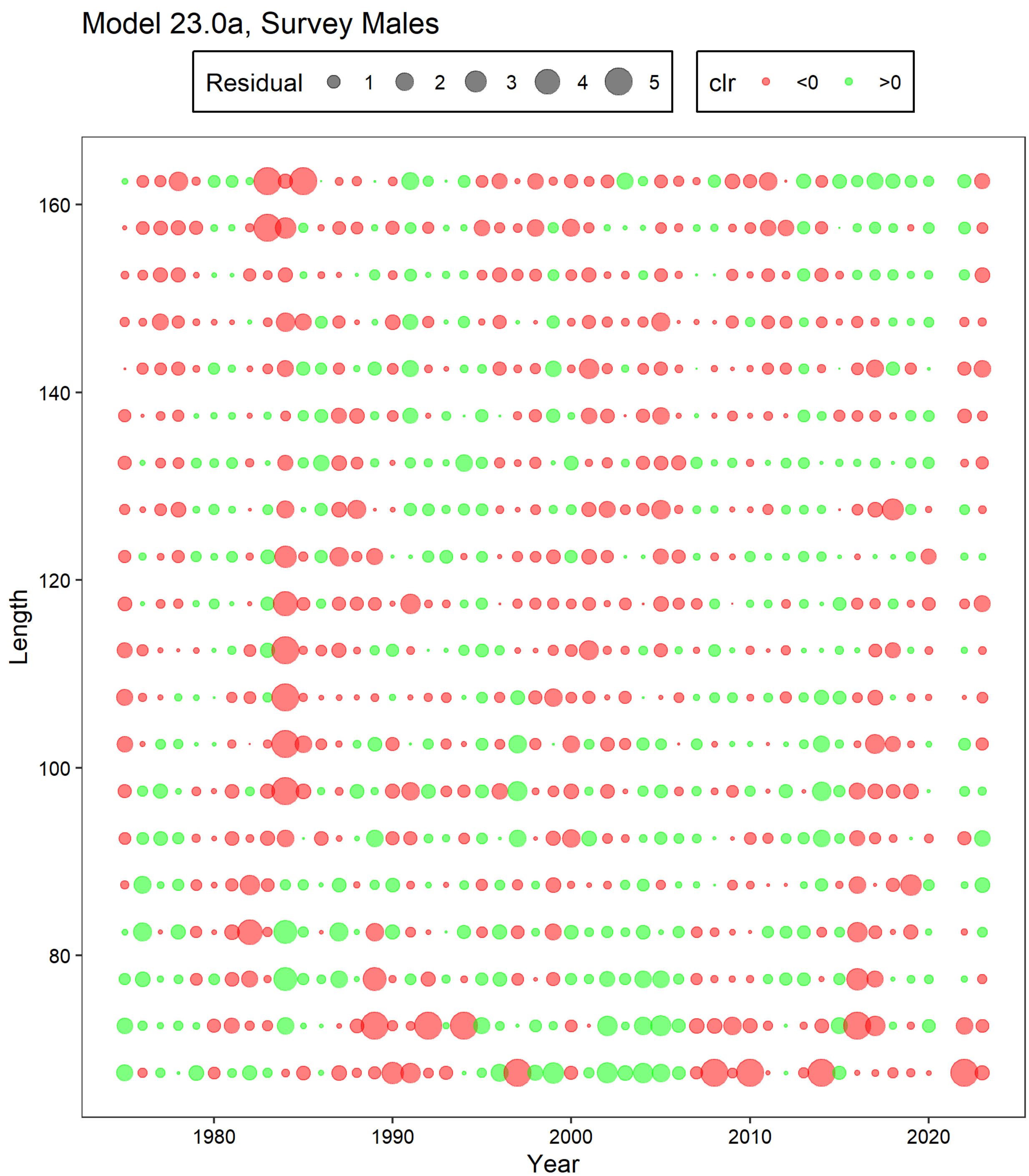

Figure 53: Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 23.0a. Green circles are positive residuals, and red circles are negative residuals.

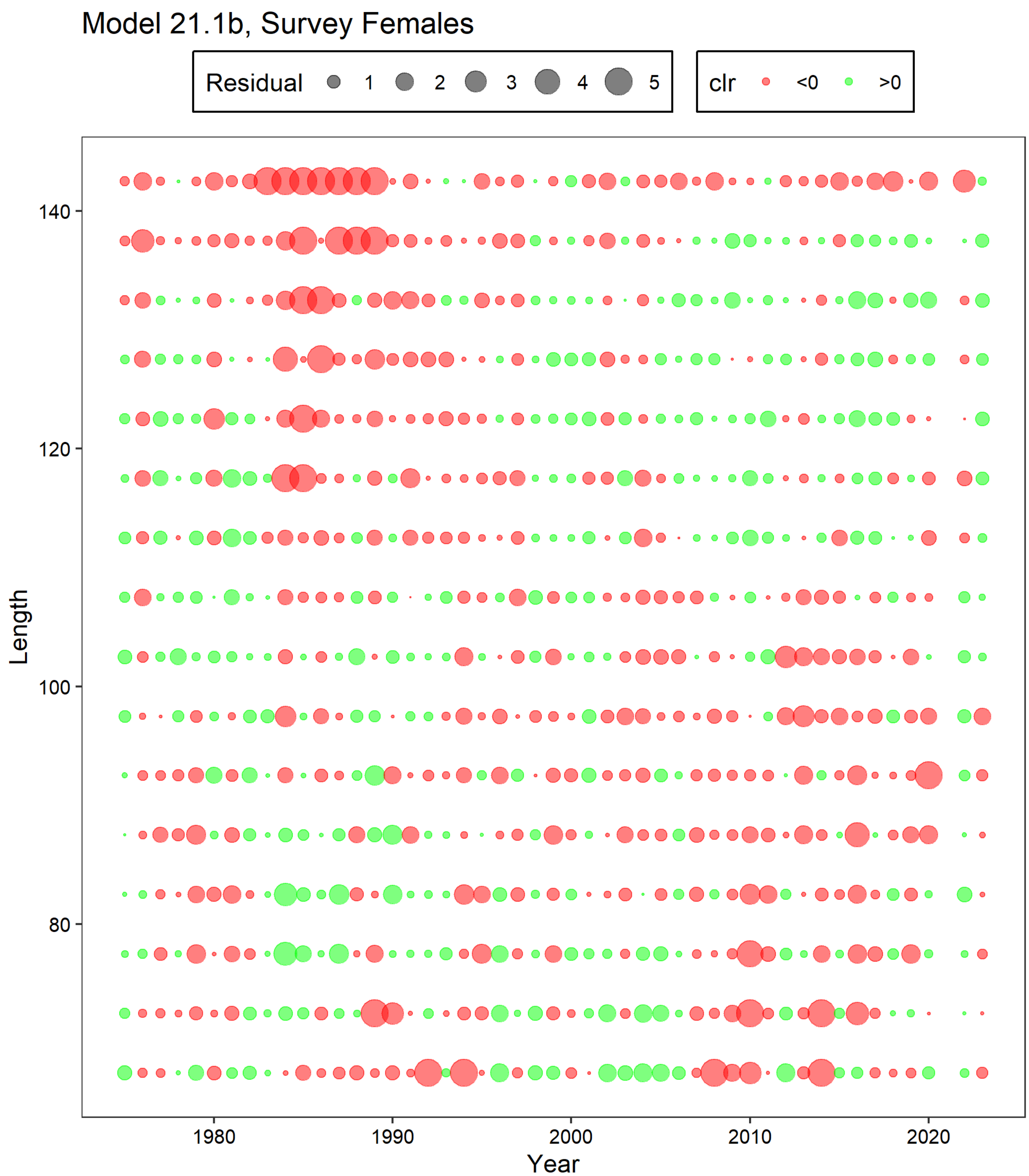

Figure 54: Residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 21.1b. Green circles are positive residuals, and red circles are negative residuals.

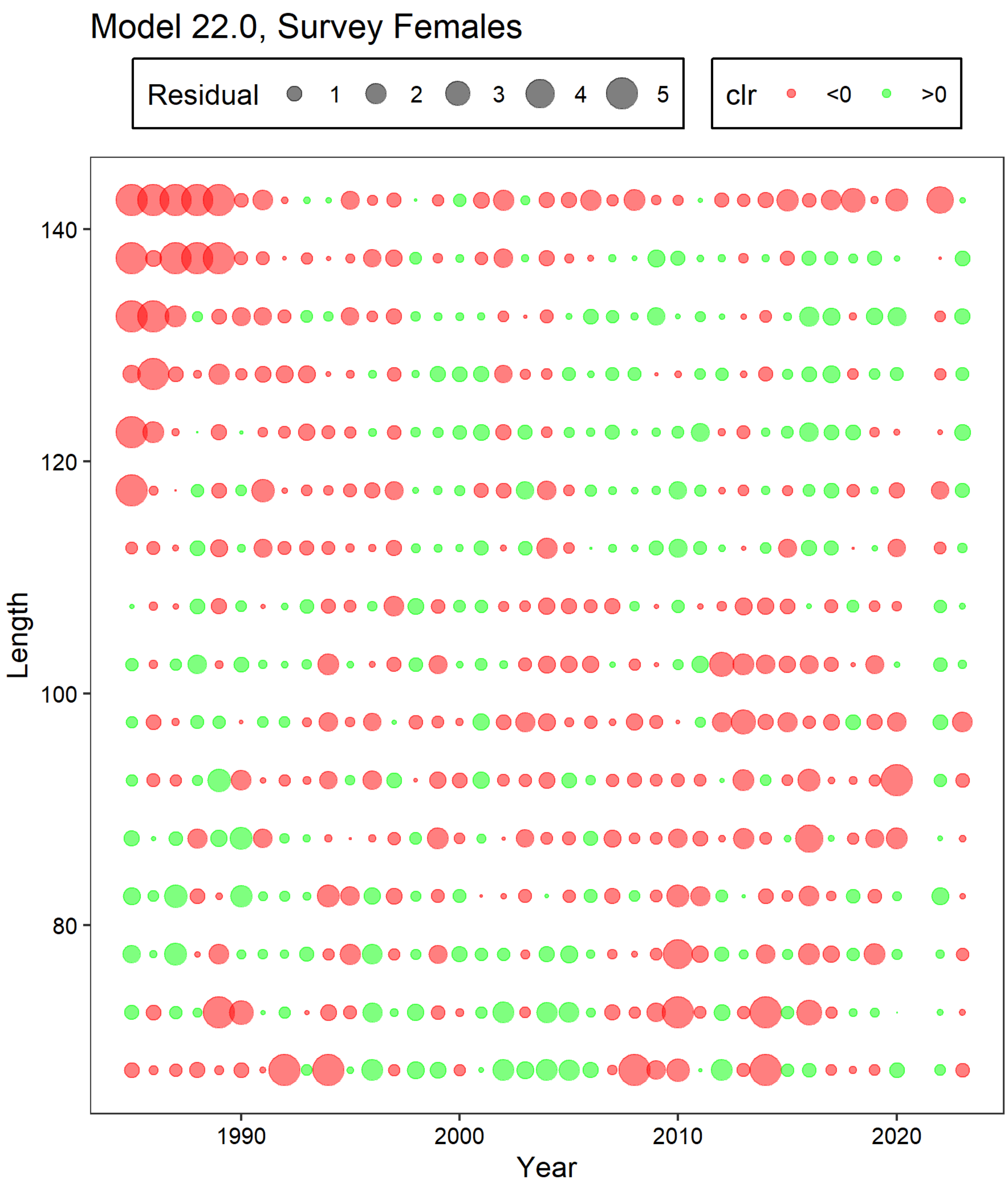

Figure 55: Residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 22.0. Green circles are positive residuals, and red circles are negative residuals.

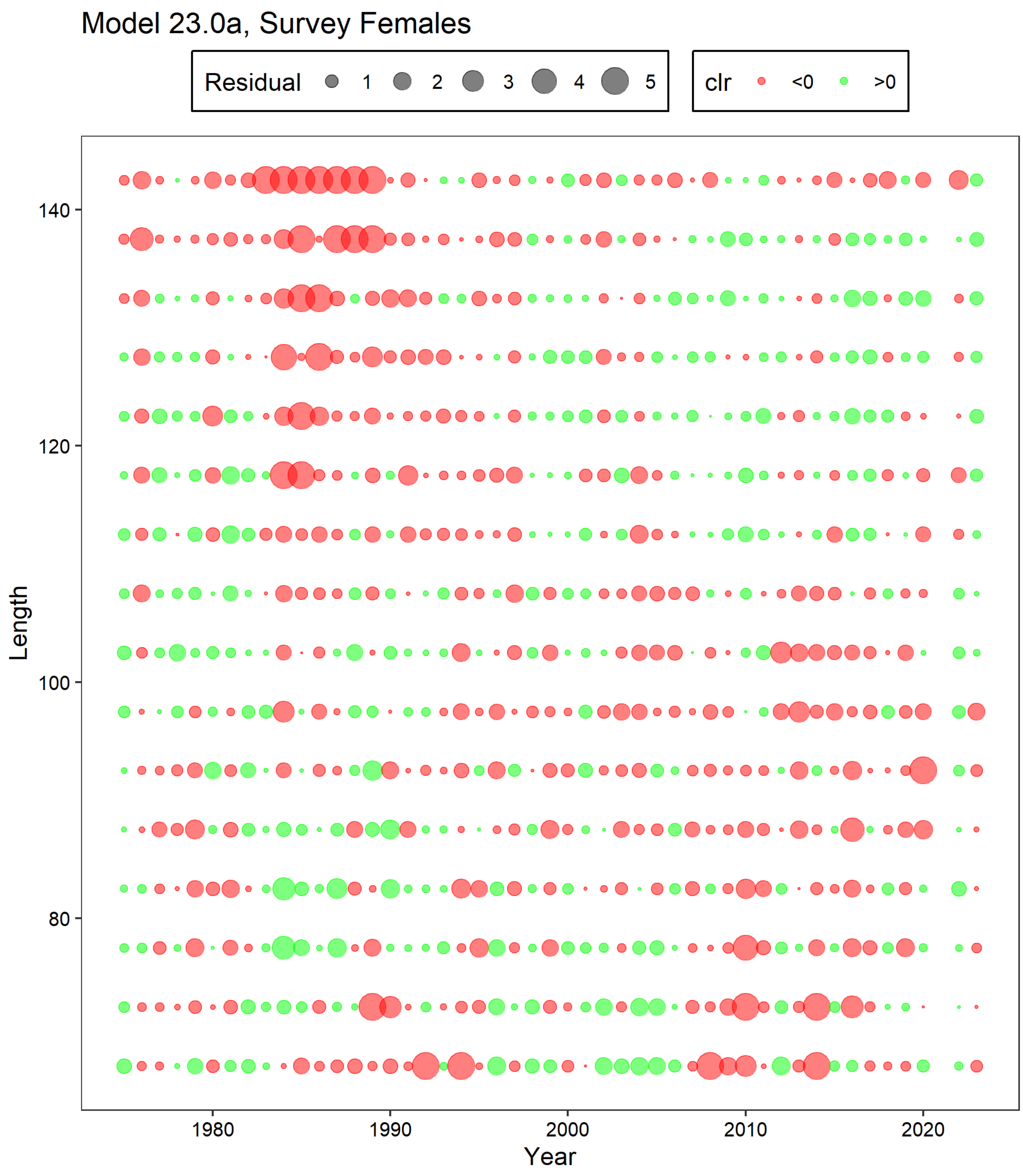

Figure 56: Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 23.0a. Green circles are positive residuals, and red circles are negative residuals.

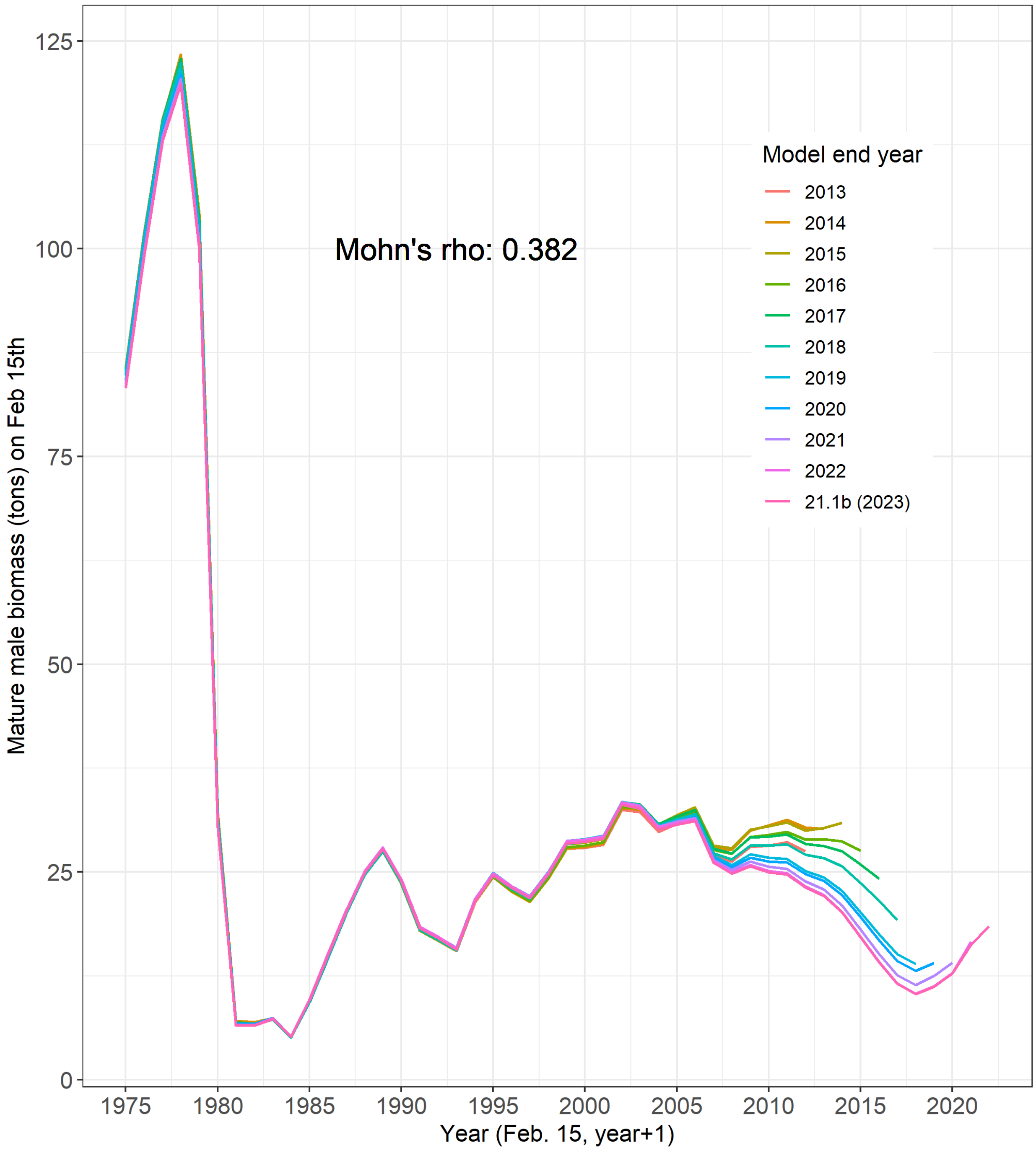

Figure 57: Comparison of hindcast estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab with terminal years 2013-2023 using model 21.1b. These are results of the 2023 model. Legend shows the terminal year.

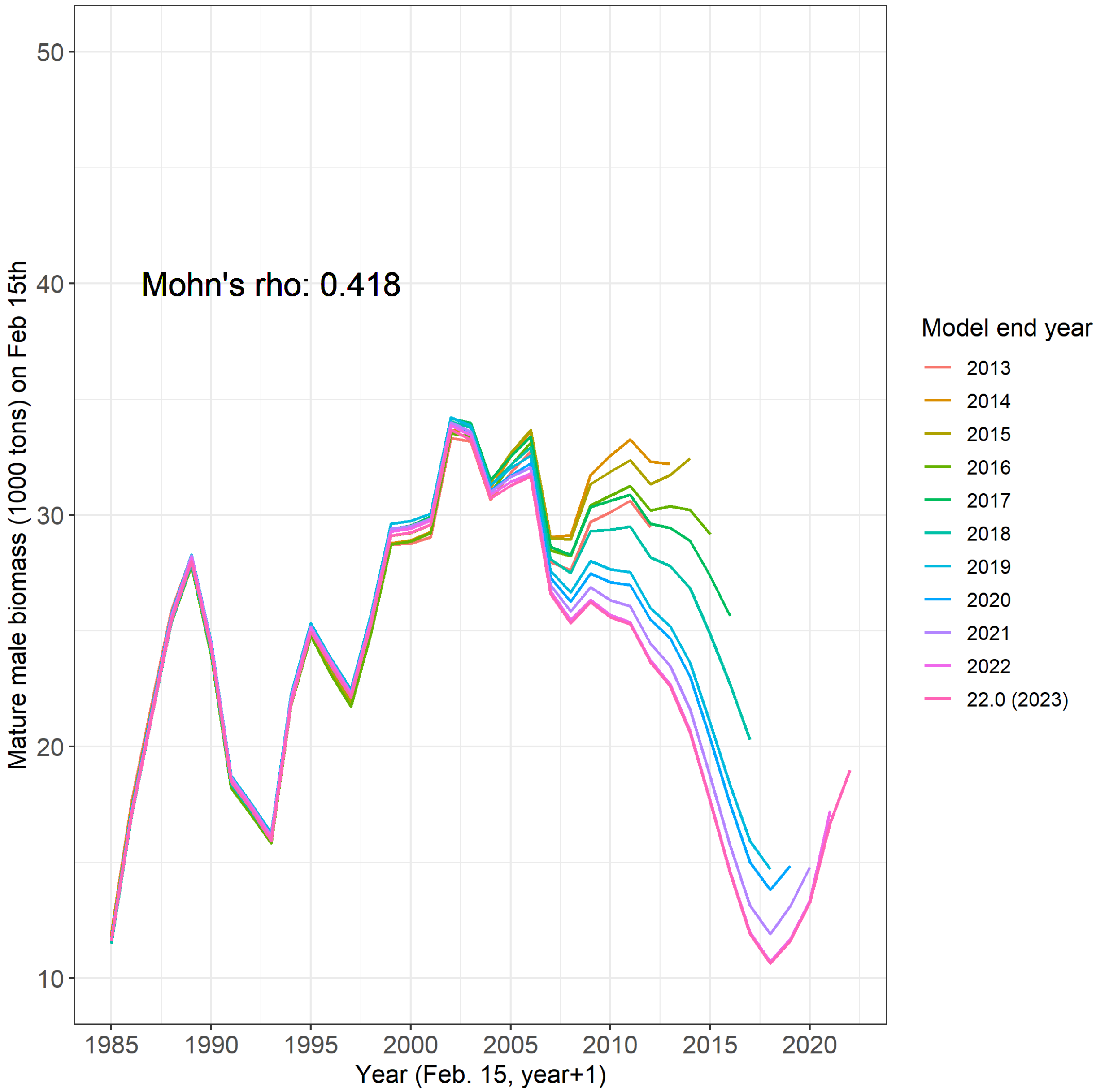

Figure 58: Comparison of hindcast estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab with terminal years 2013-2023 using model 22.0. These are results of the 2023 model. Legend shows the terminal year.

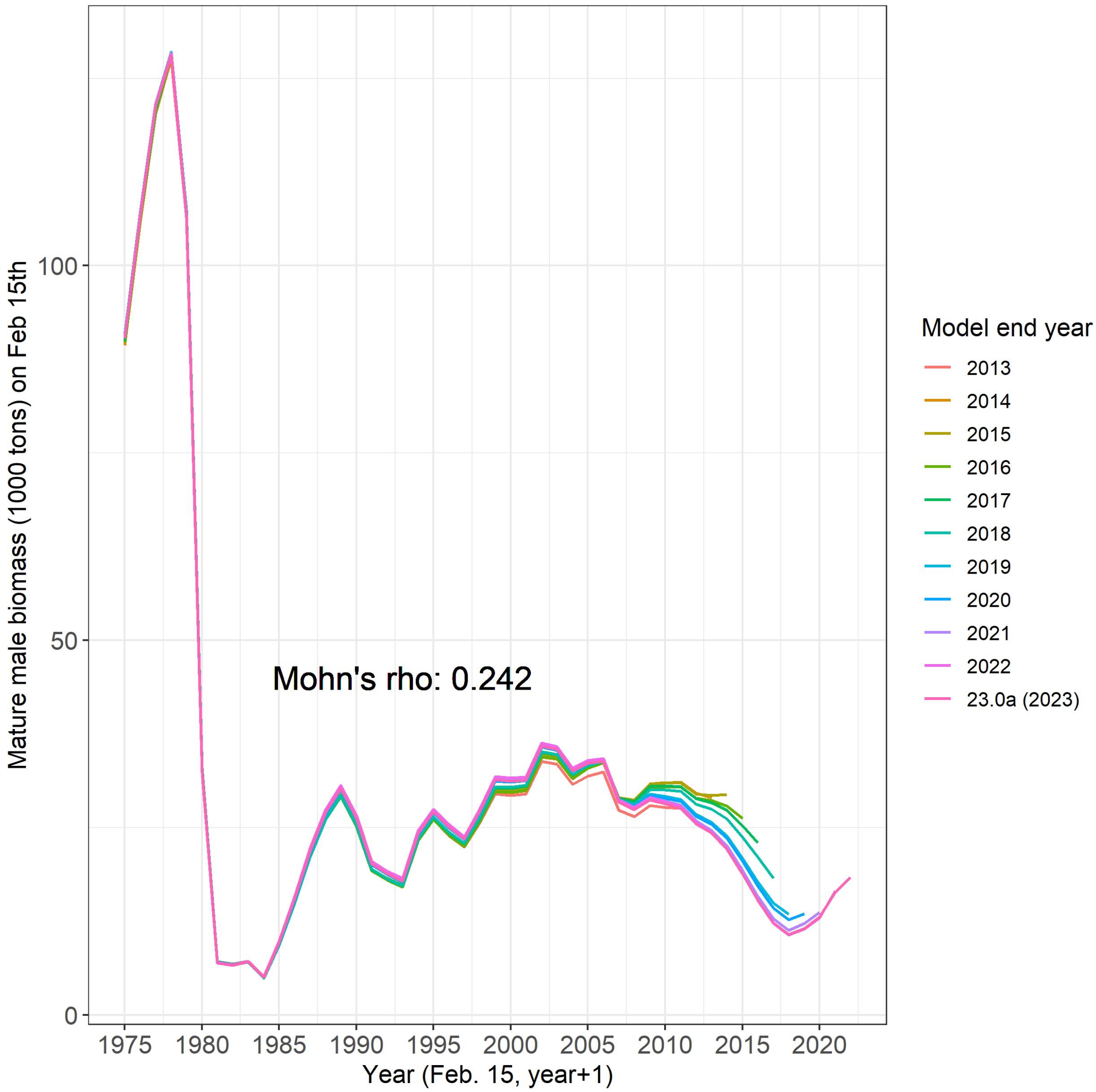

Figure 59: Comparison of hindcast estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab with terminal years 2013-2023 using model 23.0a. These are results of the 2023 model. Legend shows the terminal year.

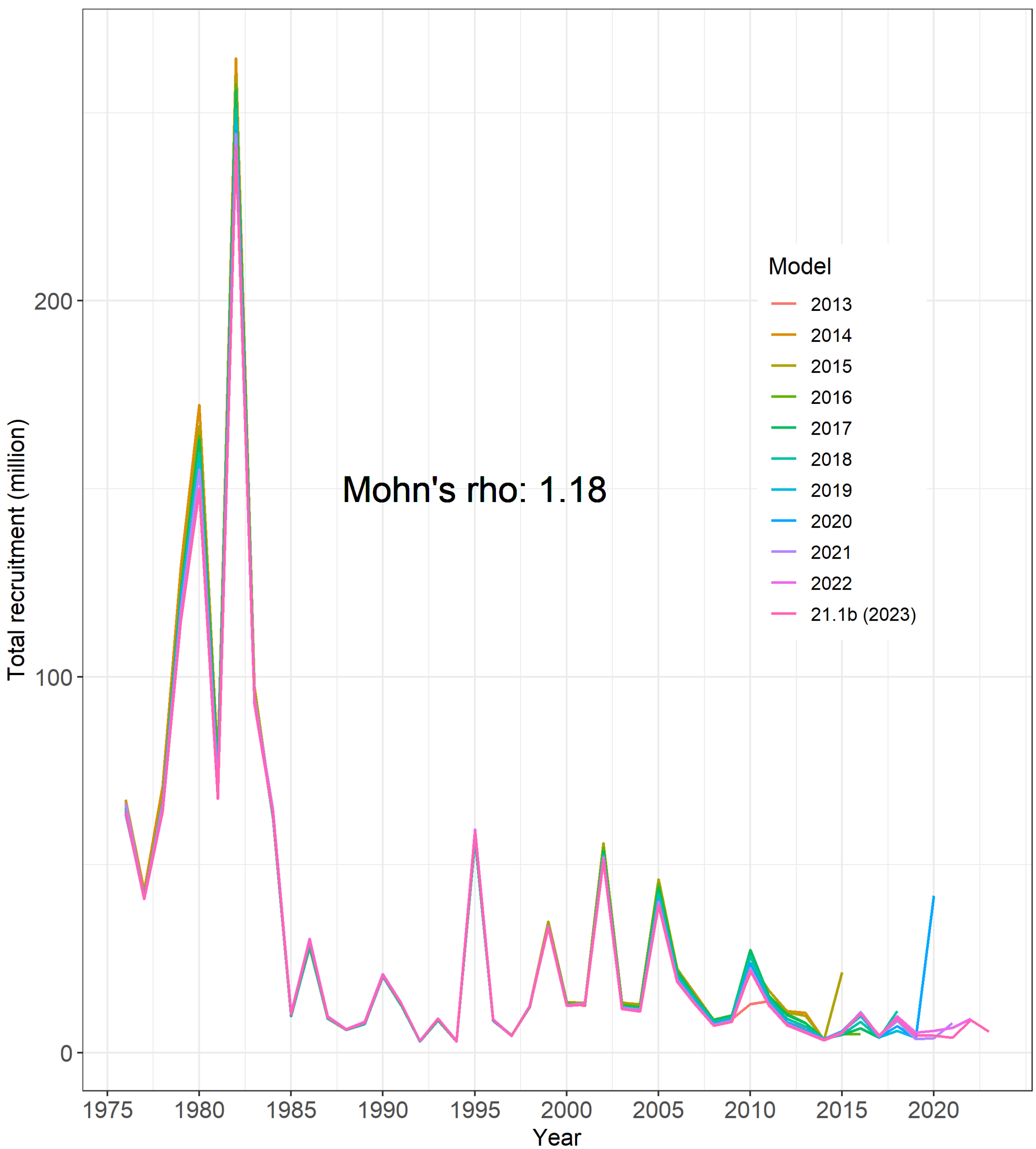

Figure 60: Comparison of hindcast estimates of total recruitment for model 21.1b of Bristol Bay red king crab from 1976 to 2023 made with terminal years 2013-2023. These are results of the model 21.1b. Legend shows the terminal year.

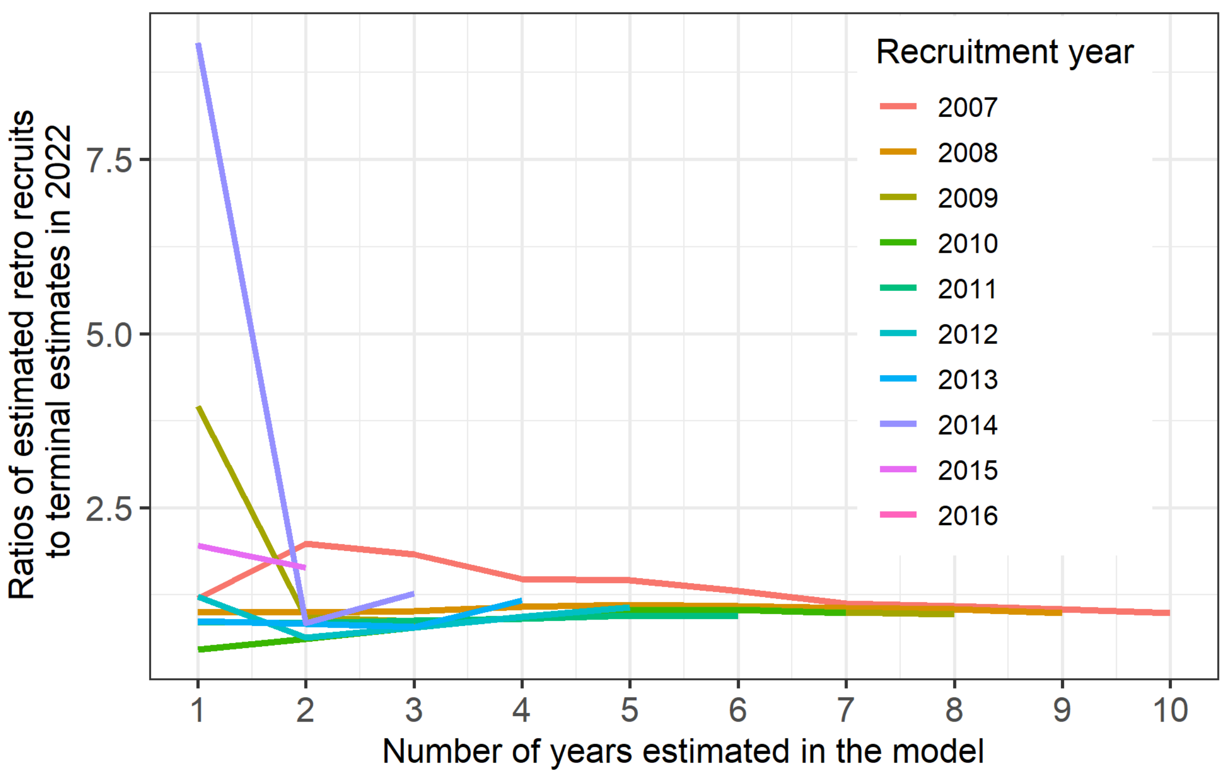

Figure 61: Evaluation of Bristol Bay red king crab retrospective errors on recruitment estimates as a function of the number of years in the model for model 21.1b.

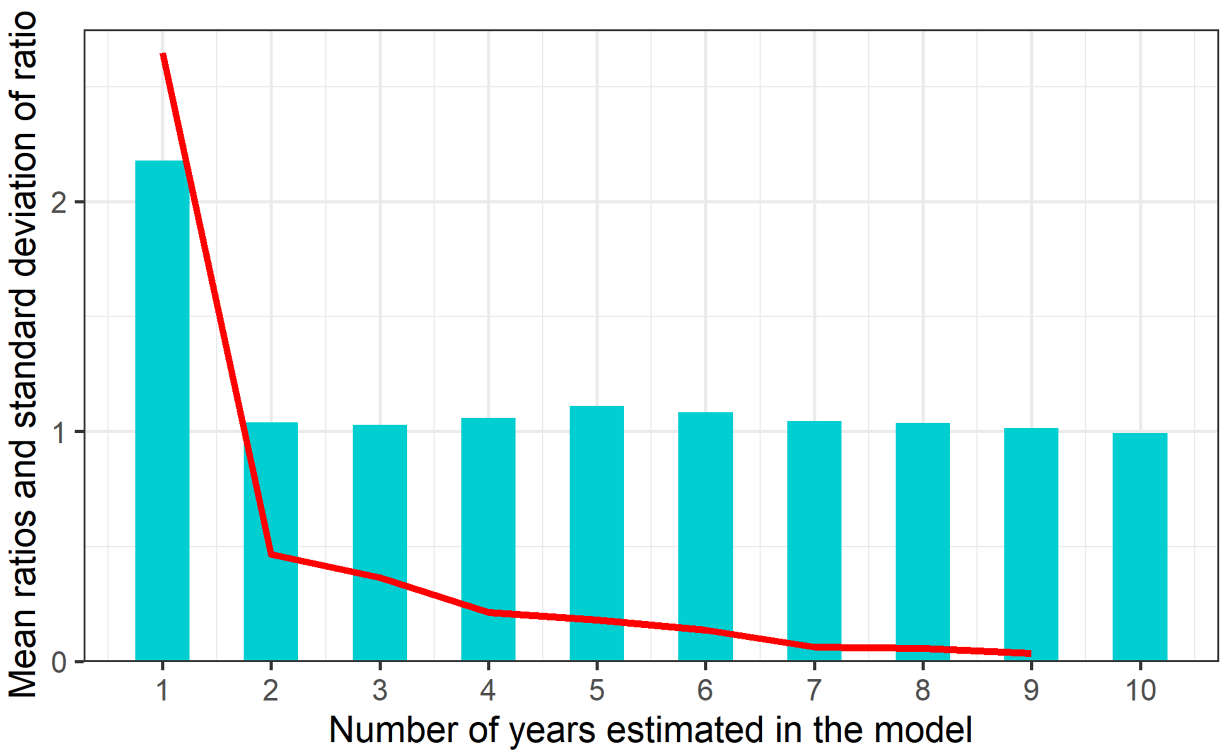

Figure 62: Mean ratios of retrospective estimates of recruitments to those estimated in the most recent year (2023) and standard deviations (red line) of the ratios as a function of the number of years in the model for model 21.1b.

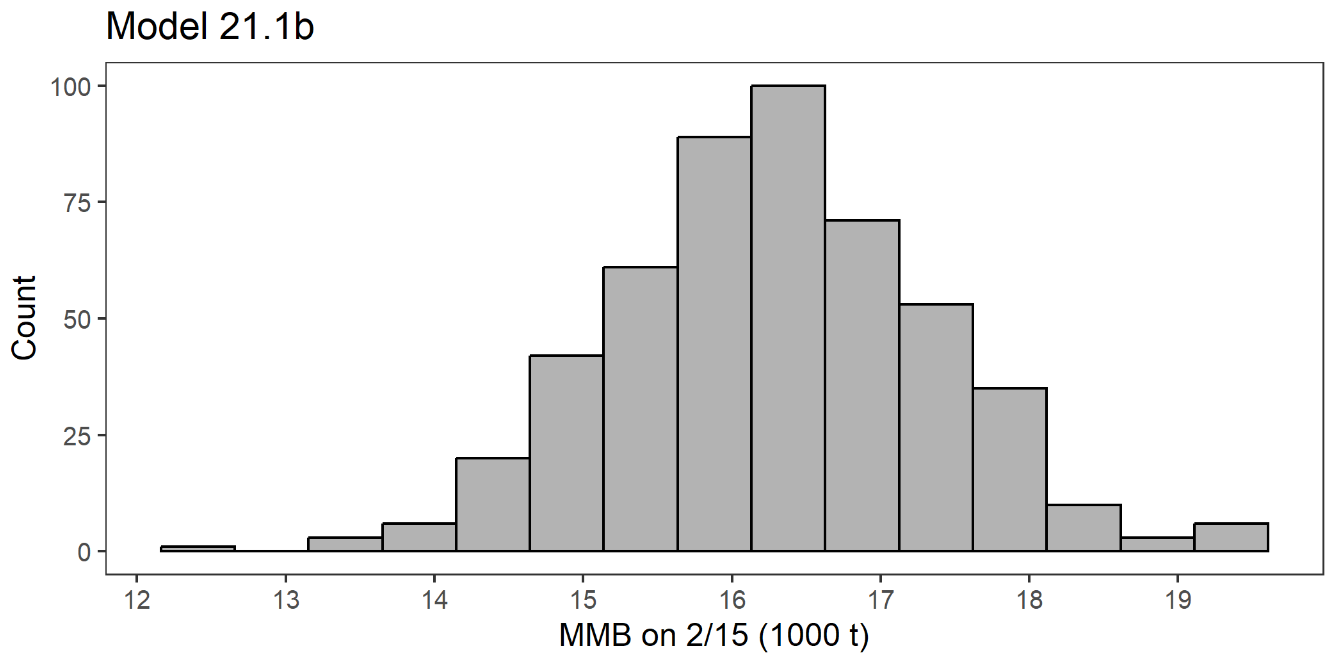

Figure 63: Histogram of estimated mature male biomass on Feb. 15, 2024, under model 21.1b with the MCMC approach.

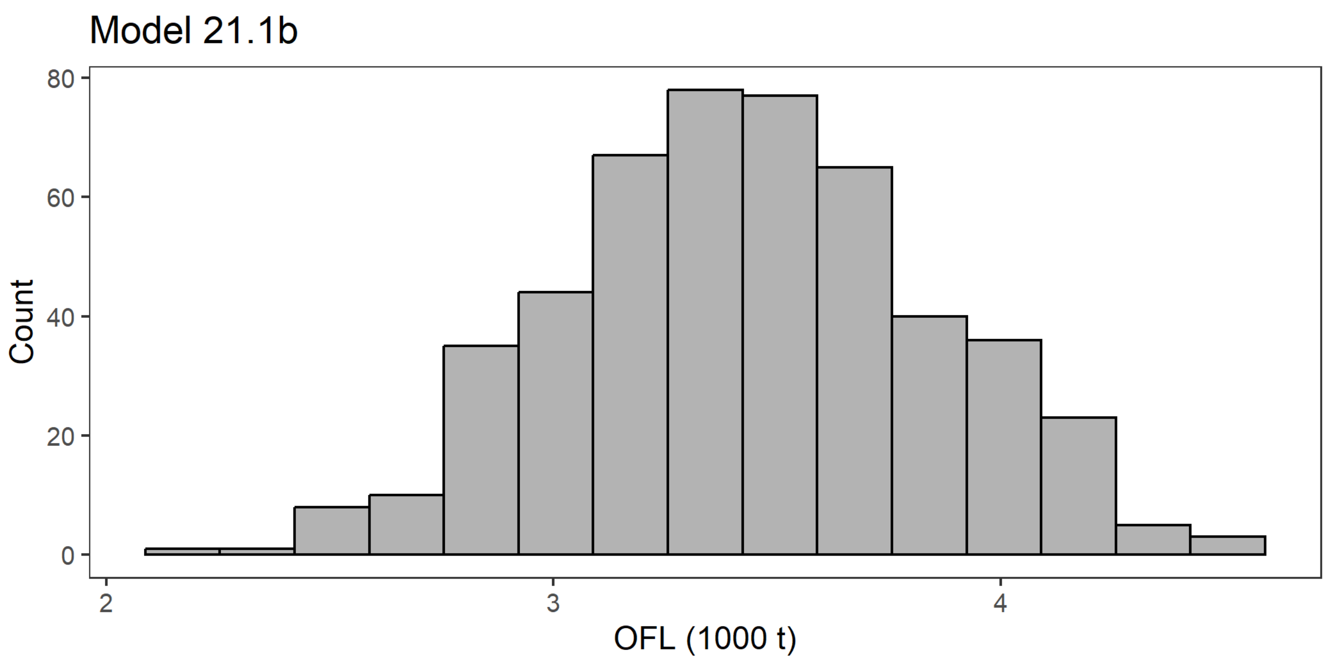

Figure 64: Histogram of the 2023/24 estimated OFL under model 21.1b with the MCMC approach.

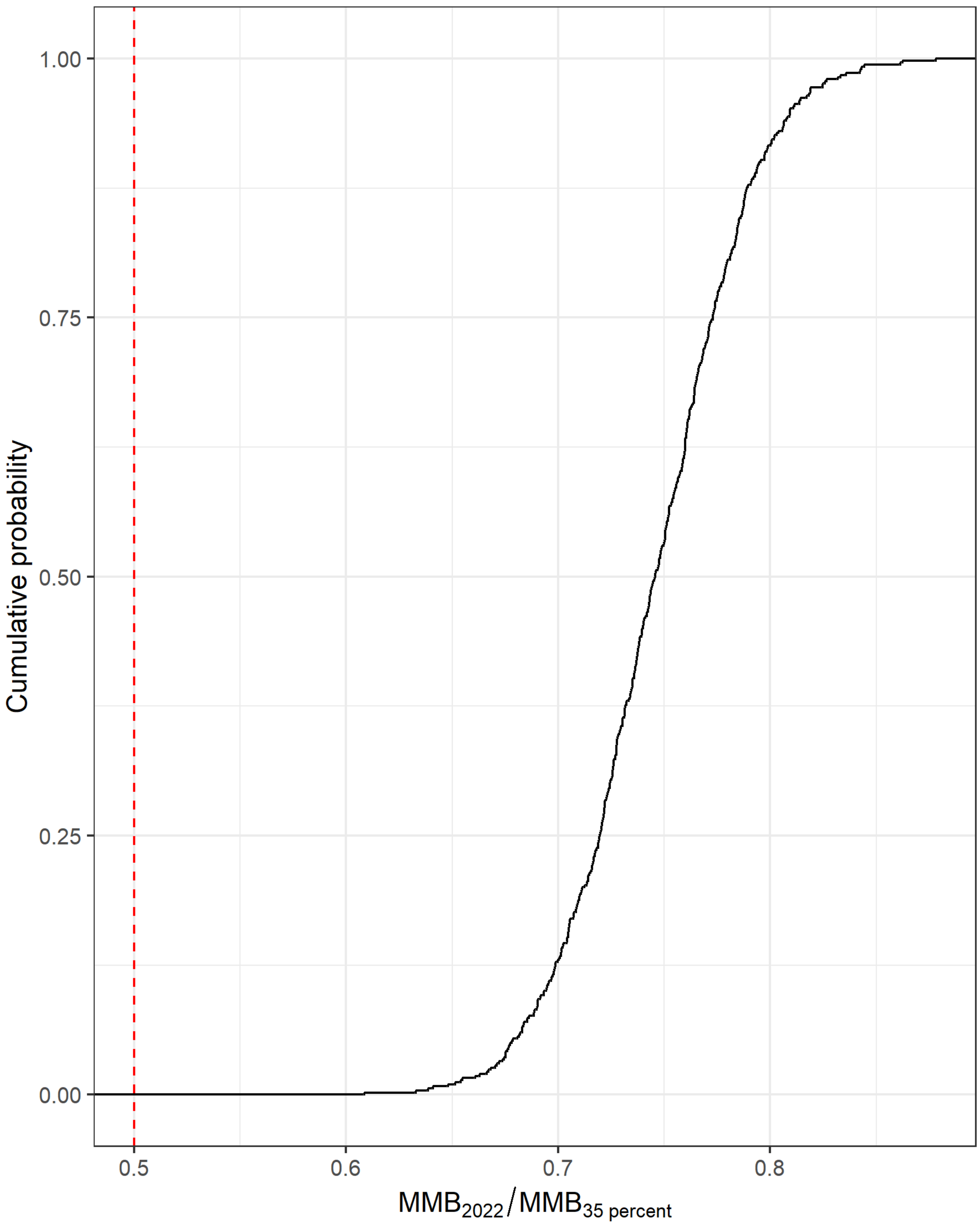

Figure 65: Cumulative probabilities of estimated ratios of MMB on Feb. 15, 2024, to corresponding estimated B35 values under model 21.1b with the MCMC approach. Zero probability is below the estimated minimum thresholds.

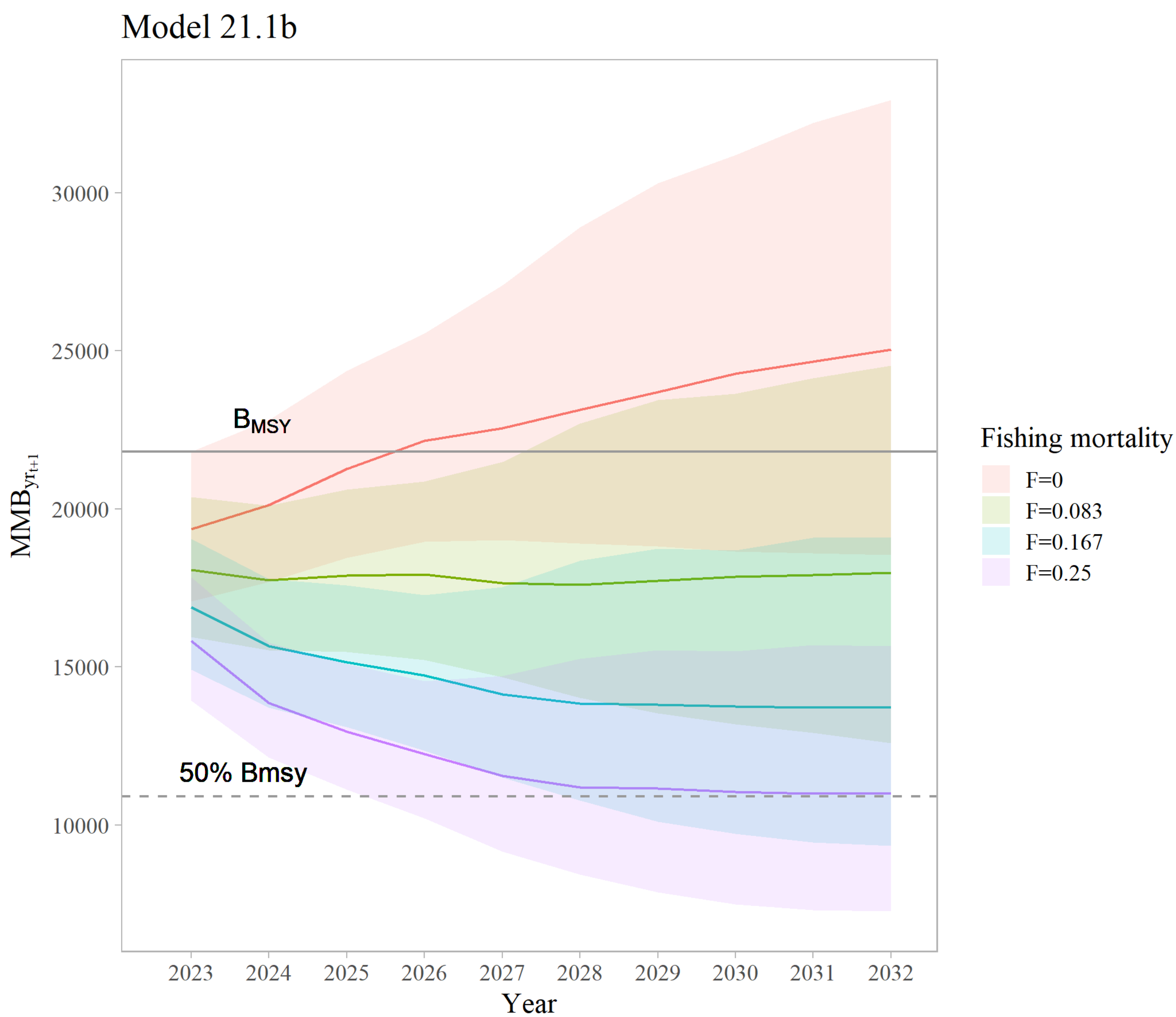

Figure 66: Projected mature male biomass (MMB) on Feb. 15 with four fishing mortalities in the directed fishery: F = 0, F = 0.083, F = 0.167, and F = 0.25, during 2023-2033. Input parameter estimates are based on model 21.1b. Crab year "2023" represents Feb. 15, 2024. Shaded areas represent a 0.05 to 0.95 limits.

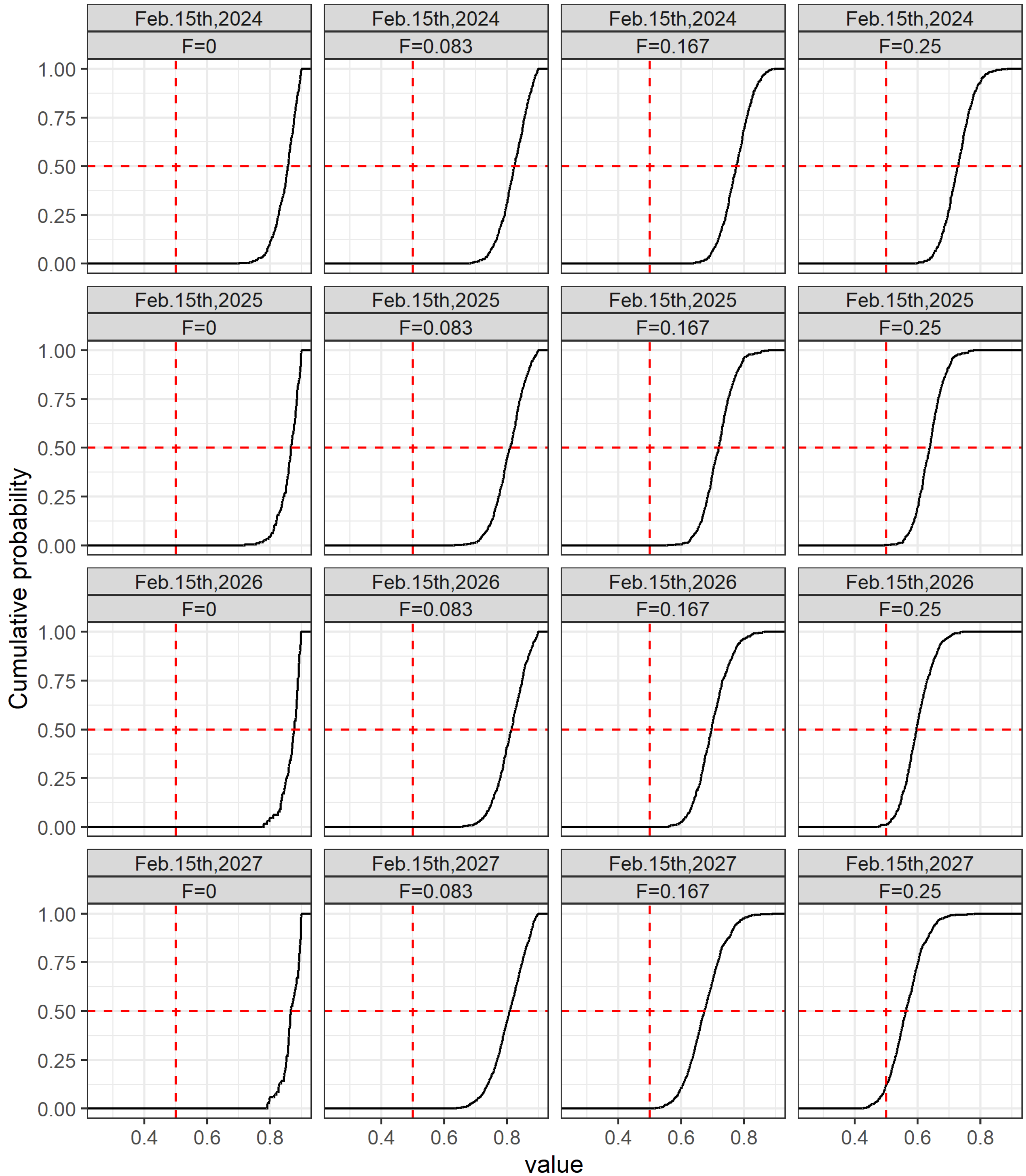

Figure 67: Cumulative probabilities of estimated ratios of MMB during 2023-2026, as represented by projected biomass on Feb.15th in year t+1, to corresponding estimated B35 values under model 21.1b with the MCMC approach and four fishing mortality values. Feb. 15, 2024 represents crab year “2023”.

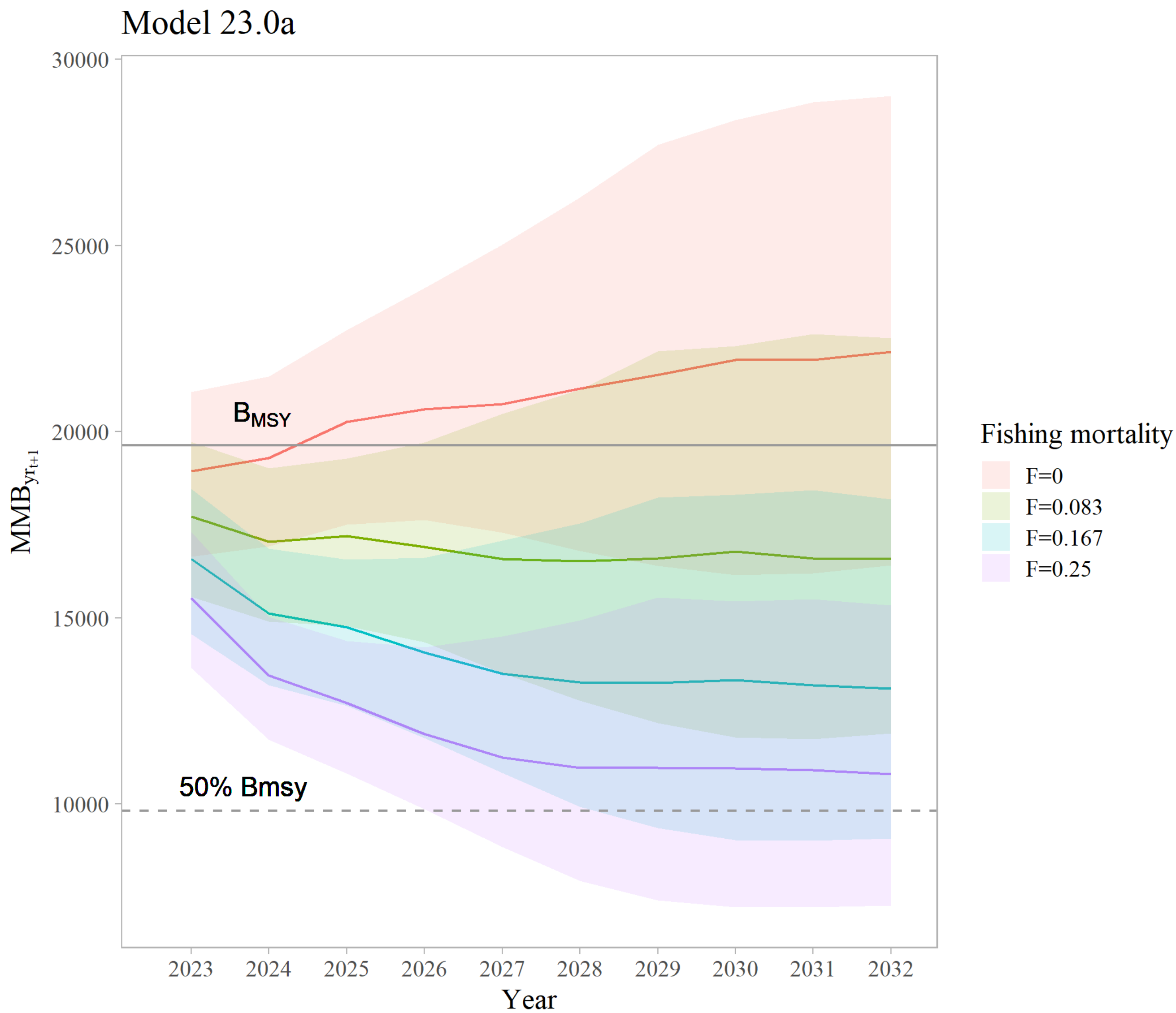

Figure 68: Projected mature male biomass on Feb. 15 with four fishing mortalities in the directed fishery: F = 0, F = 0.083, F = 0.167, and F = 0.25, during 2023-2033. Input parameter estimates are based on model 23.0a. Crab year "2023" represents Feb. 15, 2024. Shaded areas represent a 0.05 to 0.95 limits.

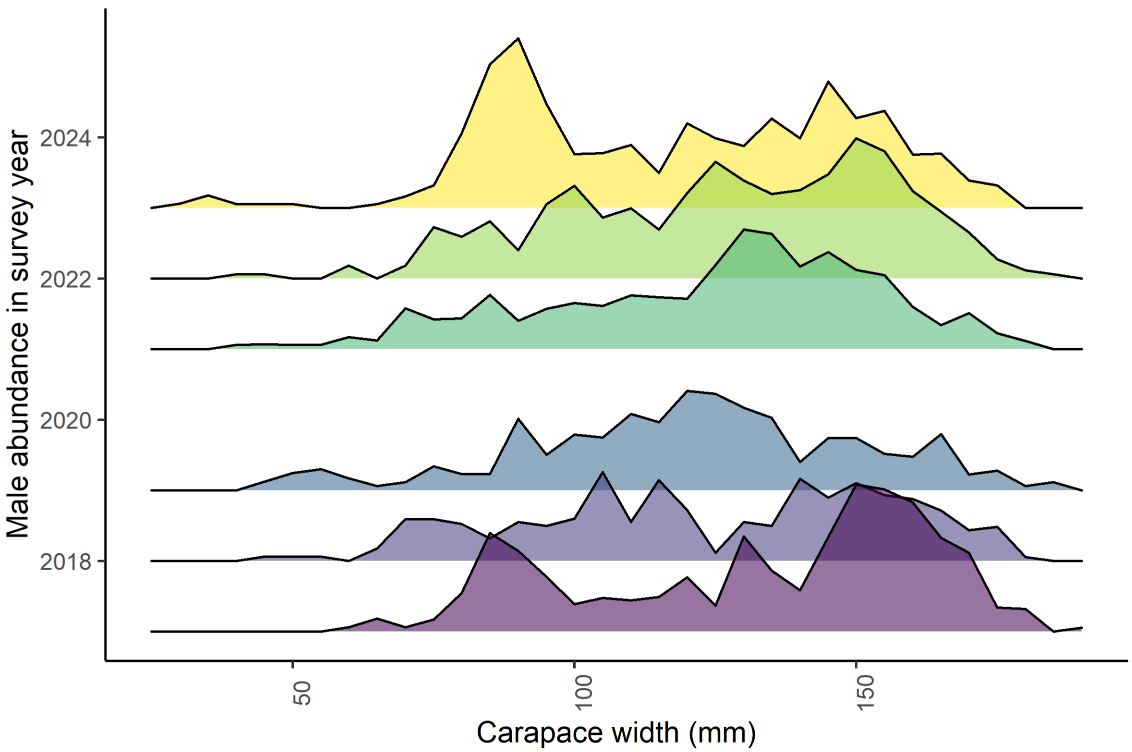

Figure 69: Length frequency distributions of male red king crab in Bristol Bay from NMFS trawl surveys during 2017-2023. For purposes of these graphs, abundance estimates are based on area-swept methods.

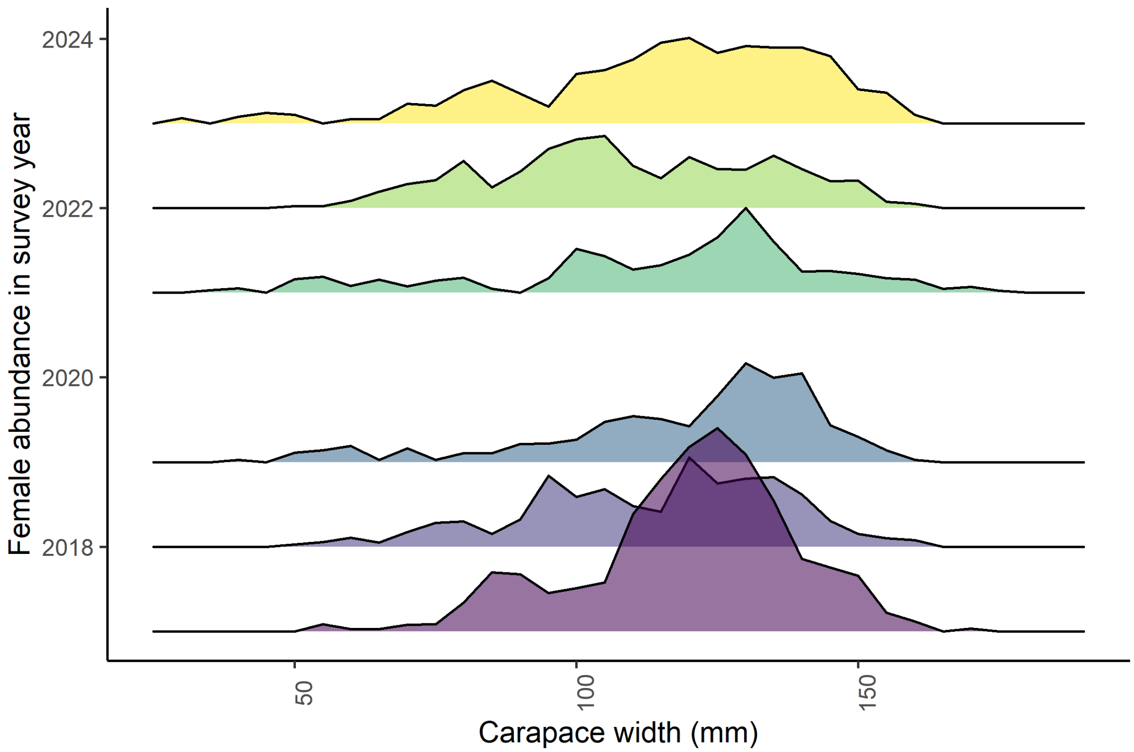

Figure 70: Length frequency distributions of female red king crab in Bristol Bay from NMFS trawl surveys during 2017-2023. For purposes of these graphs, abundance estimates are based on area-swept methods.

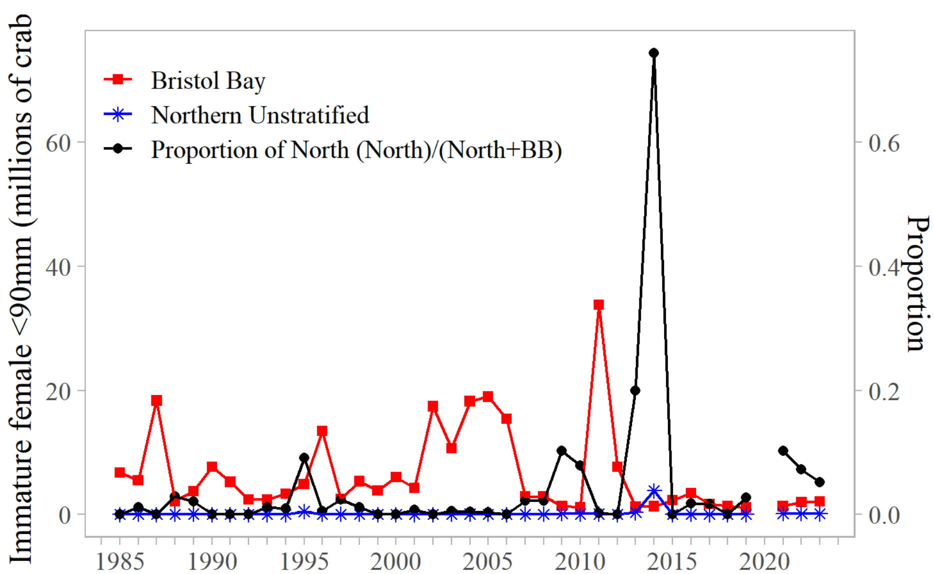

Figure 71: Comparisons of NMFS survey area-swept estimates of total female crab <90 mm CL abundance in Bristol Bay area (BB) and north of Bristol Bay area (North) during 1985-2023.

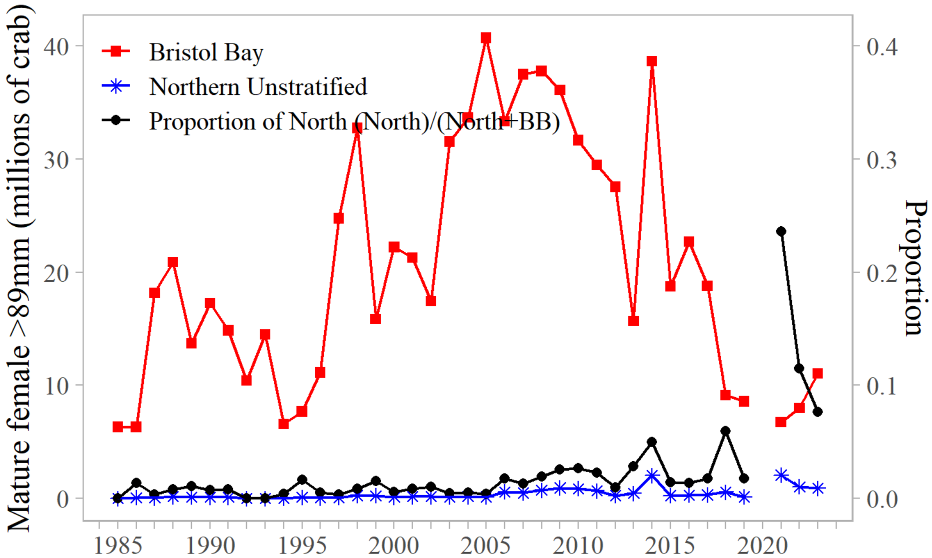

Figure 72: Comparisons of NMFS survey area-swept estimates of mature female crab abundance in Bristol Bay area (BB) and north of Bristol Bay area (North) during 1985-2023.

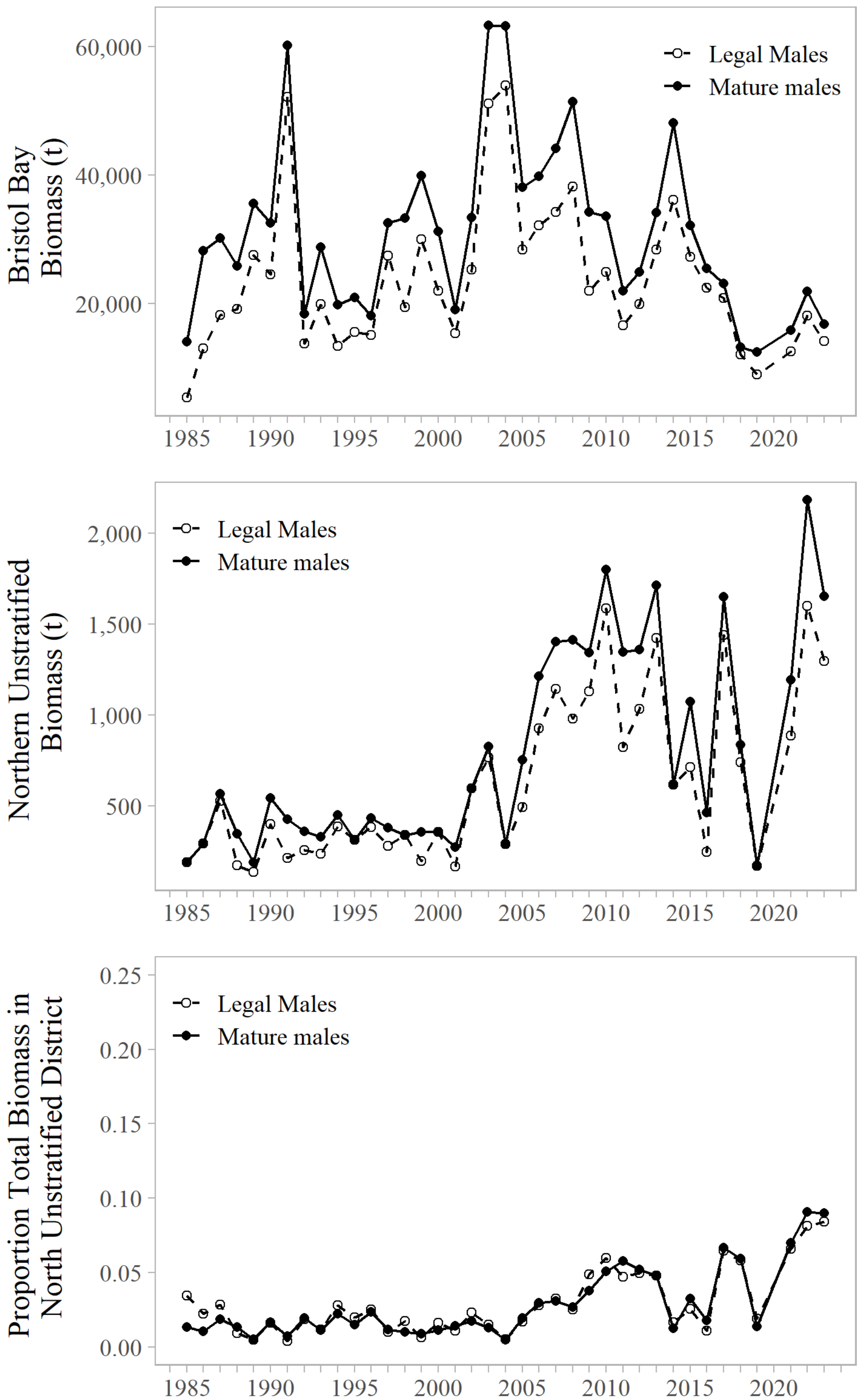

Figure 73: Comparisons of NMFS survey area-swept estimates of mature and legal male abundances in Bristol Bay area (BB) and north of Bristol Bay area (North) during 1985-2023. NOTE the large scale differences between panels 1 and 2.

Appendix C. Simpler model working group REMA exploration

At the March 2023 simpler model working group meeting a "fallback" option for model output was discussed to be used as an alternative option if the current assessment model is not usable. This option is detailed in the working group report under - "Proposed"Fallback" model options".

This is a Tier 4 approach where:

- B or current year's biomass is equal to survey-estimated (ideally using the REMA R package) vulnerable male biomass. Vulnerable male biomass is male crabs likely to be susceptible to both the directed and incidental catch fisheries
- OFL = M (adjusted by the stock status as defined in the Crab FMP) * B
- ABC = buffer * OFL

REMA model for BBRKC

For BBRKC the male biomass that is determined to be vulnerable to the directed and incidental catch fisheries is the mature male biomass, crab > 119mm CL. Crab at this size are approximately one or more molt increments away from legal size and therefore are likely to be found with legal size male crab and be vulnerable to discard mortality. This modeling exercise applies a similar buffer as the Tier 3 model (20%), although the actual buffer used if this model approach was adopted would likely be different.

As defined by the Crab FMP stock status is determined by the current years biomass (B) compared to the average biomass over a period of time. For consistencies with the current modeling approaches for BBRKC the time period used is 1984 to 2022, this is the same time period that is used in the Tier 3 model for calculation status determination.

Calculation of Reference Points

The Tier 4 OFL is calculated using the F_{OFL} control rule:

$$F_{OFL} = \begin{cases} 0 & \frac{MMB}{B_{MSY}} \leq 0.25 \\ \frac{M(\frac{MMB}{B_{MSY}} - \alpha)}{1-\alpha} & 0.25 < \frac{MMB}{B_{MSY}} < 1 \\ M & MMB > B_{MSY} \end{cases} \tag{2}$$

where MMB is quantified at the mean time of mating date (15 February), B_{MSY} is defined as the average MMB for a specified period, $M = 0.18$ yr^{-1}, and $\alpha = 0.1$. The Tier 4 OFL (Table 24) was calculated by applying a fishing mortality determined by the harvest control rule (above) to the mature male biomass at the time of mating (B$_{proj}$ or Current B).

Table 24: Specificatoins using the REMA output on mature male NFMS trawl survey area-swept biomass.

avgB	Current B	MMB/B_{MSY}	M	F_{OFL}	OFL	ABC
28191.68	17337.32	0.61	0.18	0.10	1785.67	1428.54

Figures

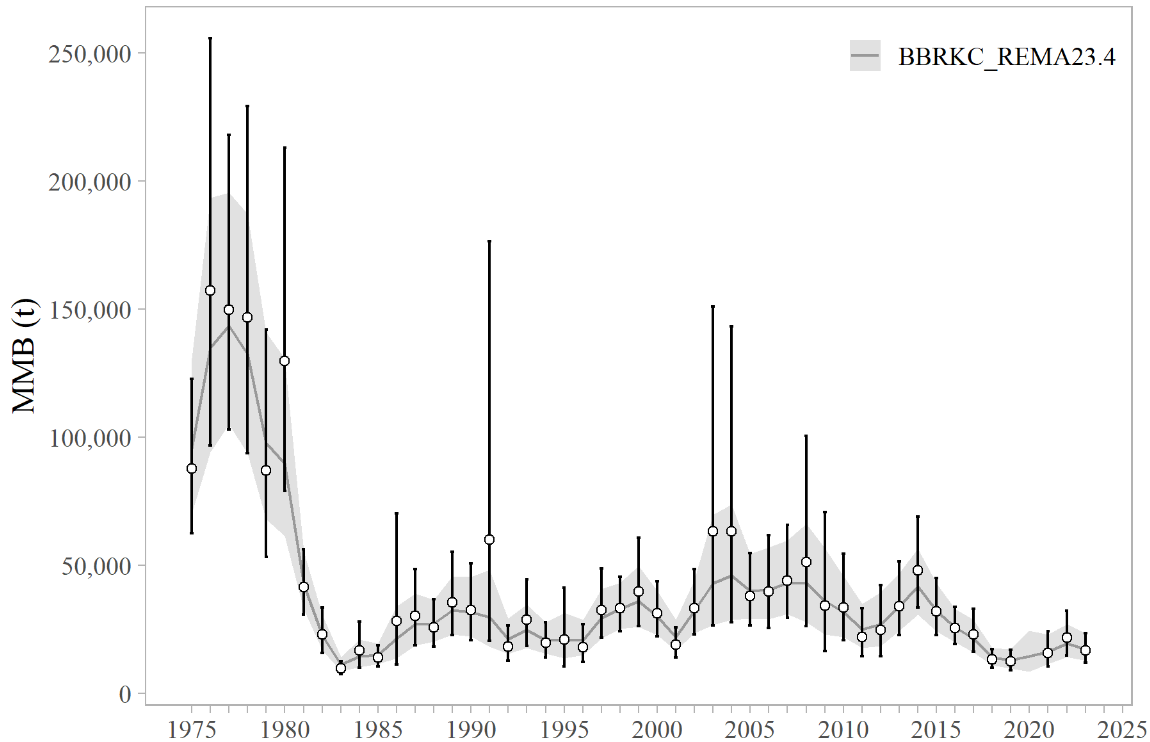

Figure 74: Comparisons of area-swept estimates of mature MALE NMFS survey biomass (males > 119 mm) and REMA model predicted fit.

Appendix C. Ecosystem and Socioeconomic Profile of the Bristol Bay Red King Crab Stock - Report Card

Erin Fedewa and Kalei Shotwell

September 2023

With Contributions from:

Matt Callahan, Curry Cunningham, Ben Daly, Jean Lee, Jens Nielsen, Katie Palof, Darren Pilcher, Dale Robinson, Abigail Tyrell, Ellen Yasumiishi and Leah Zacher

Current Year Update

The ecosystem and socioeconomic profile or ESP is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., *Accepted*). The ESP process creates a traceable pathway from the initial development of indicators to management advice and serves as an on-ramp for developing ecosystem-linked stock assessments.

Please refer to the last full ESP document (Fedewa et al., 2020, Appendix E, pp. 172-204) which is available within the Bristol Bay red king crab (BBRKC) stock assessment and fishery evaluation or SAFE report for further information regarding the ecosystem and socioeconomic linkages for this stock.

Management Considerations

The following are the summary considerations from current updates to the ecosystem and socioeconomic indicators evaluated for BBRKC:

- In 2023, bottom temperatures and the spatial extent of the cold pool remained near-average in Bristol Bay. Summer bottom temperatures were well-within the thermal range of juvenile and adult red king crab.
- Red king crab have experienced a steady decline in bottom water pH in the past two decades, reaching 7.91 in 2023. Continued declines to threshold pH levels of 7.8 could negatively affect juvenile red king crab growth, shell hardening and survival.
- Sockeye salmon abundance in the eastern Bering Sea continues to remain well above average, and may represent increased predation on larval BBRKC. Anomalously low levels of chlorophyll in 2023 indicate a less pronounced spring bloom and poor feeding conditions for larval BBRKC.
- Despite a high density of mature females at a single station on the 2023 bottom trawl survey, mature female spatial extent has remained above-average since 2019. The relatively large spatial footprint of mature females in recent years can be attributed to an increased use of habitats in central Bristol Bay that have historically been avoided in years when <1°C waters extended into Bristol Bay.
- The BBRKC fishery was closed to targeted fishing for the second consecutive season, representing severe economic hardships for industry.
- Incidental catch of BBRKC in EBS groundfish fisheries has remained near-average for the most recent 2018 – 2021 period.

Modeling Considerations

The following are the summary results from the intermediate and advanced stage monitoring analyses for BBRKC:

- The highest ranked predictor variables (> 0.50 inclusion probability) in the intermediate stage monitoring analysis were: Pacific cod density, cold pool extent and benthic invertebrate density. Due to concerns with non-stationarity in longer ecosystem time series, indicator importance tests in future BBRKC ESP updates will explore additional statistical methods.
- The advanced stage monitoring analysis provides updates on developing research ecosystem linked models that are not yet included as a model alternative in the main stock assessment. We have not received updates on new research ecosystem linked models for BBRKC at this time.

Assessment

Ecosystem and Socioeconomic Processes

We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock in conceptual models detailing 1) ecosystem processes by RKC life history stage (Figure 1a) and 2) socioeconomic performance metrics (Figure 1b). Please refer to the last full ESP document (Fedewa et al., 2020) for more details.

Indicator Suite

The following list of indicators for BBRKC is organized by categories: three for ecosystem indicators (physical, lower trophic, and upper trophic) and two for socioeconomic indicators (fishery performance and economic). A title, short description and contact name for the indicator contributor are provided. We also include the anticipated sign of the proposed relationship between the indicator and the stock population dynamics where relevant, and specify the lag applied if the indicator was tested in the intermediate stage indicator analysis. Please refer to the last full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions and proposed mechanistic linkages for this stock (Fedewa et al., 2020). Time series of the ecosystem and socioeconomic indicators are provided in Figure 2a and Figure 2b, respectively. Modifications to ecosystem indicators in 2023 include: 1) Chlorophyll-*a* concentrations derived from MODIS have now been replaced with a European Space Agency (ESA) GlobColour blended satellite product because the satellites that hold the MODIS instruments will soon be retired due to changes in their orbits, 2) due to BBRKC fisheries closures, 2021 – 2022 estimates for BBRKC mean distance to shore were derived from October pop-up locations of satellite tagged mature males, and 3) methods for spatially averaging pH were corrected slightly for 2023 hindcasts produced from the Bering10K ROMS model. These modifications will preclude direct comparison to indicator timeseries in previous ESP documents.

Ecosystem Indicators:

Physical Indicators (Figure 2a.a-e)

a.) Winter-spring **Arctic Oscillation** index from the NOAA National Climate Data Center (contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged seven years for intermediate stage indicator analysis.

b.) The **areal extent of the summer cold pool** (EBS bottom trawl survey stations with bottom temperatures < 2ºC; contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged two years for intermediate stage indicator analysis.

c.) **Summer bottom temperatures** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged 6 years.

d.) Spring (February – April 15) **pH index** in Bristol Bay from the Bering10K ROMS model (Pilcher et al., 2019) (contact: D. Pilcher). Proposed sign of the relationship is positive and the time series is lagged 6 years for intermediate stage indicator analysis.

e.) **Summer wind stress** (m/s) in Bristol Bay from NOAA/NCDC blended winds and Metop-A ASCAT satellite (Zhang et al., 2006, NOAA/NESDIS, CoastWatch) (contact: D. Robinson). Proposed sign of the relationship is negative and the time series is lagged seven years for intermediate stage indicator analysis.

Lower Trophic Indicators (Figure 2a.f)

f.) April – June average **chlorophyll a concentration** in Bristol Bay, calculated with the ESA GlobColour blended satellite product (4km resolution, 8 day composite data; contact: M. Callahan and J. Nielsen). Proposed sign of the relationship is positive and the time series is lagged seven years for intermediate stage indicator analysis.

Upper Trophic Indicators (Figure 2a.g-l)

g.) September **juvenile sockeye salmon abundance** in the EBS from the AFSC Bering Arctic Subarctic Integrated Survey (contact: E. Yasumiishi). Proposed sign of the relationship is negative and the time series is lagged seven years for intermediate stage indicator analysis.
h.) Summer **Pacific cod density** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is negative and the time series is lagged one year for intermediate stage indicator analysis.
i.) Summer **benthic invertebrate density** in Bristol Bay. Invertebrates include brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes. (contact: E. Fedewa). Proposed sign of the relationship is positive and the time series is lagged one year for intermediate stage indicator analysis.
j.) Summer **mature male red king crab area occupied** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is negative.
k.) Summer **mature female red king crab area occupied** in Bristol Bay from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of the relationship is negative.
l.) Annual **male red king crab catch distance from shore** in Bristol Bay during the fishery (contact: L. Zacher). Proposed sign of the relationship is positive.

Socioeconomic Indicators: (all monetary values are inflation-adjusted to $2022 value)

Fishery Performance Indicators (Figure 2b. a-d)

a.) **Annual catch-per-unit-effort** (CPUE), expressed as mean number of legal crabs per potlift, in the BBRKC fishery, representing relative efficiency of fishing effort (contact: B. Daly)
b.) Annual **total potlifts** in the BBRKC fishery, representing the level of fishing effort expended by the active fleet (contact: B. Daly)
c.) Annual **number of active vessels** in the Bristol Bay red king crab fishery, representing the level of fishing effort assigned to the fishery (contact: J. Lee)
d.) Estimated total **incidental catch** of BBRKC biomass (kg) in EBS groundfish fisheries (contact: J. Lee)

Economic Indicators (Figure 2b. e-h)

e.) Percentage of the annual BBRKC **total allowable catch** (TAC) (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing (contact: B. Garber-Yonts)
f.) Annual **ex-vessel value** ($2022) of the BBRKC fishery landings, representing gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)
g.) Annual **ex-vessel price per pound** ($2021) of BBRKC landings, representing per-unit gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)
h.) Annual **ex-vessel revenue share**, expressed as average proportion of total annual gross landings revenue from all fisheries earned from BBRKC landings by vessels active in the fishery (contact: J. Lee)

Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, biomass, catchability). These regression techniques provide a simple predictive performance for the variable of interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for testing a research ecosystem linked model and output can be compared with the current operational model to understand information on retrospective patterns, prediction performance, and comparisons of other model output.

Beginning Stage: Traffic Light Test

We use a simple scoring calculation for this beginning stage traffic light evaluation. Indicator status is evaluated based on being greater than (“high”), less than (“low”), or within (“neutral”) one standard deviation of the long-term mean. A sign based on the anticipated relationship between the ecosystem indicators and the stock (generally shown in Figure 1a and specifically by indicator in the Indicator Suite, Ecosystem Indicators section) is also assigned to the indicator where possible. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a ‘+1’ score. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that value receives a ‘-1’ score. All values less than or equal to one standard deviation from the long-term mean are average and receive a ‘0’ score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance and economic performance) indicators and divided by the total number of indicators available in that category for a given year. The scores over time allow for comparison of the indicator performance and the history of stock productivity (Figure 3). We also provide five year indicator status tables with a color or text code for the relationship with the stock (Tables 1a,b) and evaluate each year’s status in the historical indicator time series graphic (Figures 2a,b) for each ecosystem and socioeconomic indicator. Socioeconomic indicators representing the target fishery are reported by fishery year through 2020, the last year that the fishery was open (noting that virtually all active harvest activity occurs prior to January). Incidental catch is reported for the most recent full calendar year (2021, in this case).

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the BBRKC stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the increasing trophic levels for the ecosystem indicators then evaluate the fishery performance and economic indicators as listed above. Here, we concentrate on updates since the last ESP report card. Overall, the physical and lower trophic indicators scored below average for 2023, while the upper trophic indicators were average (Figure 3). Compared to 2022 traffic light scores, recent year results are the same for previous-year physical and lower trophic indicators, and an increase for the upper trophic indicators. The fishery performance and economic indicators were not updated for the most recent fishery year (2022) due to the closure of the fishery.

Overall, trends in physical ecosystem indicators suggest a return to near-normal conditions in Bristol Bay, and very similar conditions to those reported in 2022. Average bottom temperatures in 2023 were nearly 2°C colder than 2018-2019 heat conditions, and cold pool spatial extent in Bristol Bay was near-average. Furthermore, a positive phase Arctic Oscillation index in winter 2022/2023 may suggest favorable conditions for BBRKC productivity (Szuwalski et al., 2021), although continued declines in pH that are approaching a critical threshold for negative effects on growth, shell hardening and survival remain concerning (Long et al., 2013; Swiney et al., 2017). Although 2023 updates for juvenile sockeye salmon abundance were not yet available for this document, recent years have seen the largest Bristol Bay sockeye runs on record and may be indicative of increased predation on larval RKC. Near-average wind stress in Bristol Bay suggests suitable conditions for larval first-feeding success, however, chlorophyll-a concentrations during the 2023 spring bloom were the lowest on record in Bristol Bay. Sea ice extent in March suggests that while the bloom timing was near-average (J. Nielsen, personal communication), low chlorophyll-a concentrations indicate less diatoms in the water column, which are a critical prey source for larval RKC (Paul et al., 1989).

Current-year values for upper trophic level Pacific cod and benthic invertebrate indicators are not yet available following the conclusion of the 2023 EBS bottom trawl survey. However, both indicators are on an upward trend following below-average estimates for both indicators in 2018. Spatial extent of mature male BBRKC remains above-average, and tagging data suggests that males have remained in central to northern stations in Bristol Bay in the past few years relative to cold years when they tend to aggregate closer to shore along the Alaska Peninsula (Zacher et al., 2018). Likewise, spatial extent of mature female BBRKC remained above-average in 2023 despite below-average abundances and nearly 40% of the mature female catch occurring at a single station on the EBS bottom trawl survey (Zacher et al. *in review*). Overall, the general northeastern shift in the BBRKC population coinciding with relatively large spatial distributions in the past 5 years can likely be attributed to the lack of cold waters <1°C within central Bristol Bay (Loher and Armstrong, 2005).

Pre-2021 trends in fishery performance and economic indicators correspond to an ongoing decline in TACs issued in the BBRKC fishery since 2014. Effort in the fishery, as indicated by the number of active vessels and total number of potlifts, continued the slow downward trend observed since 2010. Total potlifts reached the lowest point on record during the 2020-2021 fishing season, while CPUE increased somewhat relative to the previous three seasons, but remained at a relative low compared to the post-rationalization period overall. Ex-vessel price declined slightly for the 2020-2021 season, but remained relatively high compared to the post-rationalization period overall. Consistent with substantial declines in TACs since 2016-2017, gross ex-vessel revenue aggregated over all landings, and the percentage share of total annual landings revenue represented by BBRKC landings for those vessels active in the fishery during 2020-2021 continued the sharp declining trend observed over the recent period, with both reaching historical lows and aggregate revenue reaching the lowest level on record. Due to fishery closures in 2021 and 2022, social and economic indicator information is extremely limited for most recent years. However, we note that these missing data should, instead, emphasize the economic hardships being faced by the BBRKC crab harvesters and processors during these closure periods.

Intermediate Stage: Importance Test

Bayesian adaptive sampling (BAS) was used to quantify the association between hypothesized ecosystem predictors and BBRKC recruitment (survey abundance of immature male BBRKC, 95 – 120mm), and to assess the strength of support for each hypothesis. In this intermediate stage analysis, the full set of indicators is first winnowed to the predictors that have been identified as potential drivers of BBRKC recruitment, and highly correlated covariates are removed. While we generally aim to further restrict potential covariates to those that can provide the longest model run and incorporate the most recent estimate of recruitment, BBRKC Bayesian adaptive sampling model runs incorporating the longest time series (1988 – 2023) resulted in very poor fits to observed BBRKC recruitment (Fig. 4d) and are therefore limited in utility for fishery managers. Poor model performance may be due to highly variable recruitment in the late 1980's to 1990's, and a more recent shift in environmental conditions consistent with non-stationarity in climate drivers. Thus, we instead present BAS model results from the shorter time series (2005 – 2023), and will continue to explore additional statistical techniques that are more robust to non-stationarity.

We provide the mean relationship between each predictor variable and BBRKC recruitment over time for the final model (Figure 4a), with error bars describing the uncertainty (95% confidence intervals) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 4b). A higher probability indicates that the variable is a better candidate predictor of BBRKC recruitment. The highest ranked predictor variables (inclusion probability > 0.5) based on this process are 1) Pacific cod density, 2) cold pool spatial extent, and 3) benthic invertebrate density. The direction of these effects were consistent with hypothesized directional relationships identified in peer-reviewed literature. Past studies have noted statistically significant correlations between Pacific cod biomass and red king crab recruitment (Zheng and Kruse, 2006; Bechtol and Kruse, 2010; Szuwalski et al., 2021). The direct mechanism for a relationship between the cold pool extent and BBRKC recruitment in this analysis remains unclear, and to our knowledge, no studies to date have linked BBRKC recruitment to benthic prey biomass.

Advanced Stage: Research Model Test

At this time, we do not have any ecosystem research models to report for BBRKC.

Data Gaps and Future Research Priorities

Environmental conditions are rapidly changing in the eastern Bering Sea and continued research is needed to identify thermal thresholds and BBRKC responses to multiple stressors across life stages. Low stock recruitment in the past decade warrants building a better understanding of early life history processes to identify critical bottlenecks that will support the development of meaningful larval indicators. Future laboratory and field research should, for example, better resolve the range of optimal environmental conditions for embryo survival and successful settlement in juvenile nursery areas. Evaluating RKC phenology relative to spring bloom timing may be useful for predicting larval condition and subsequent survival to settlement. Additionally, evaluating larval drift patterns and identifying essential fish habitat for benthic juvenile RKC may support the development of a larval retention or settlement success indicator.

Likewise, the dramatic increase in Bristol Bay sockeye salmon coinciding with declines in BBRKC recruitment in recent years emphasizes the importance of understanding predator-prey interactions and spatiotemporal overlap of major pelagic predators with BBRKC larval stages. Juvenile salmon diet studies conducted from 1984-1992 (Farley 2001, unpublished data) reported that juvenile sockeye salmon consumption of red king crab zoea exceeded 45% in several years, suggesting potential links between salmon predation and BBRKC recruitment. In more recent years, the Bering-Aleutian Salmon International Survey has taken place in late-September following peak settlement of BBRKC, and there appears to be no ongoing efforts to characterize diets of juvenile sockeye salmon in earlier summer months when BBRKC are likely important prey items. Furthermore, because the survey is biennial and occurs in September, data gaps across the time series preclude use of the indicator in monitoring analyses, and indicator updates are unavailable for the current-year ESP. Future efforts should focus on exploring additional larval predator datasets that are more timely and consistent. In addition, additional groundfish stomach data outside of the summer survey time series would inform predation mortality during the molt when RKC are highly vulnerable.

Potential climate-driven shifts in BBRKC spatial distributions also underscore the importance of assessing fishery interactions with trawl and pot gear relative to BBRKC migration patterns, molt-mate timing and spawning habitat. Fishing effects, habitat disturbance metrics and essential fish habitat (EFH) maps are currently estimated by crab species across the scale of the Bering Sea shelf instead of by individual crab stock, which greatly limits their utility. Future efforts should aim to develop spatial maps identifying fishery interaction hotspots for BBRKC by month and across years, and to develop stock and life history-specific vulnerability assessments of fishing effects. Overall, we highlight the continued importance of developing a mechanistic understanding of driver-response relationships to facilitate the inclusion of ecosystem indicators in future management strategies for BBRKC.

We plan to further evaluate the information provided in the Economic SAFE and ACEPO report to determine what socioeconomic indicators could be provided in the ESP that are not redundant with those reports and related directly to stock health. Additional consideration of the timing of the economic and community reports, which are delayed by 1-2 years (depending on the data source) from the annual stock assessment cycle, should also be undertaken. We emphasize the importance of developing community indicators that effectively communicate the economic hardships currently being faced by industry under multiple Bering Sea crab fishery closures. The Scientific and Statistical Committee (SSC) recently recommended that local knowledge, traditional knowledge, and subsistence information may be helpful for understanding recent fluctuations in stock health, shifts in stock distributions, or changes in fishing behavior. Although a skipper survey was piloted in the 2022 snow crab ESP report card (Fedewa et al. 2022), recent fishery closures have prevented the uptake of this local knowledge into 2023 ESP products.

As indicators are improved or updated, they may replace those in the current suite of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. Additional indicators proposed for the 2024 BBRKC ESP include: 1) BBRKC mature female clutch fullness, as a measure of fecundity or reproductive potential, 2) the ratio of red king crab caught in the BBRKC management district and the Northern district, as a measure for spatial distribution shifts northward outside of management boundaries, 3) indicators that quantify overlap between crab and fishing gear during vulnerable life history periods, and metrics of vulnerable to these fishing gear interactions, 4) an indicator quantifying the portion of BBRKC located in protected areas during the NMFS summer BT survey, and 5) results from a Skipper Survey in collaboration with Alaska Bering Sea Crabbers (pending BBRKC fishery status). The annual request for information (RFI) for the BBRKC ESP will include these data gaps and research priorities along with a list of additional new indicators that could be developed for the next full ESP assessment.

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Tables

Table 1a. First stage ecosystem indicator analysis for BBRKC, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of time series mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and the stock (blue or italicized text = good conditions for the stock, red or bold text = poor conditions, white = average conditions). A gray fill and text = "NA" will appear if there were no data for that year.

Indicator category	Indicator	2019 Status	2020 Status	2021 Status	2022 Status	2023 Status
Physical	Winter Spring Arctic Oscillation Index Model	neutral	*high*	neutral	neutral	neutral
	Summer Cold Pool SEBS BBRKC Survey	**low**	NA	**low**	neutral	neutral
	Summer Temperature Bottom BBRKC Survey	*high*	NA	neutral	neutral	neutral
	Spring pH BBRKC Model	**low**	**low**	**low**	**low**	**low**
	Summer Wind Stress BBRKC Satellite	**high**	neutral	**high**	neutral	neutral
Lower Trophic	Spring Chlorophylla Biomass SEBS Inner Shelf Satellite	neutral	neutral	neutral	**low**	**low**
Upper Trophic	Summer Sockeye Salmon Abundance EBS Survey	NA	NA	NA	**high**	NA
	Summer Pacific Cod Density BBRKC Survey	*low*	NA	neutral	neutral	NA
	Summer Benthic Invertebrate Density BBRKC Survey	neutral	NA	neutral	neutral	NA
	Summer Red King Crab Male Area Occupied BBRKC Model	**high**	NA	neutral	**high**	neutral
	Summer Red King Crab Female Area Occupied BBRKC Model	**high**	NA	**high**	neutral	neutral
	Annual Red King Crab Catch Distance Shore BBRKC Fishery	*high*	neutral	neutral	neutral	NA

Table 1b. First stage socioeconomic indicator analysis for BBRKC, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of time series mean). A gray fill and text = "NA" will appear if there were no data for that year.

Indicator category	Indicator	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
Fishery Performance	Annual Red King Crab CPUE BBRKC Fishery	neutral	neutral	neutral	NA	NA
	Annual Red King Crab Total Potlift BBRKC Fishery	neutral	neutral	low	NA	NA
	Annual Red King Crab Active Vessels BBRKC Fishery	neutral	neutral	neutral	NA	NA
	Annual Red King Crab Incidental Catch EBS Fishery	neutral	neutral	neutral	neutral	NA
Economic	Annual Red King Crab TAC Utilization BBRKC Fishery	neutral	neutral	neutral	NA	NA
	Annual Red King Crab Exvessel Value BBRKC Fishery	low	low	low	NA	NA
	Annual Red King Crab Exvessel Price BBRKC Fishery	high	high	high	NA	NA
	Annual Red King Crab Exvessel Revenue Share BBRKC Fishery	neutral	neutral	neutral	NA	NA

Figures

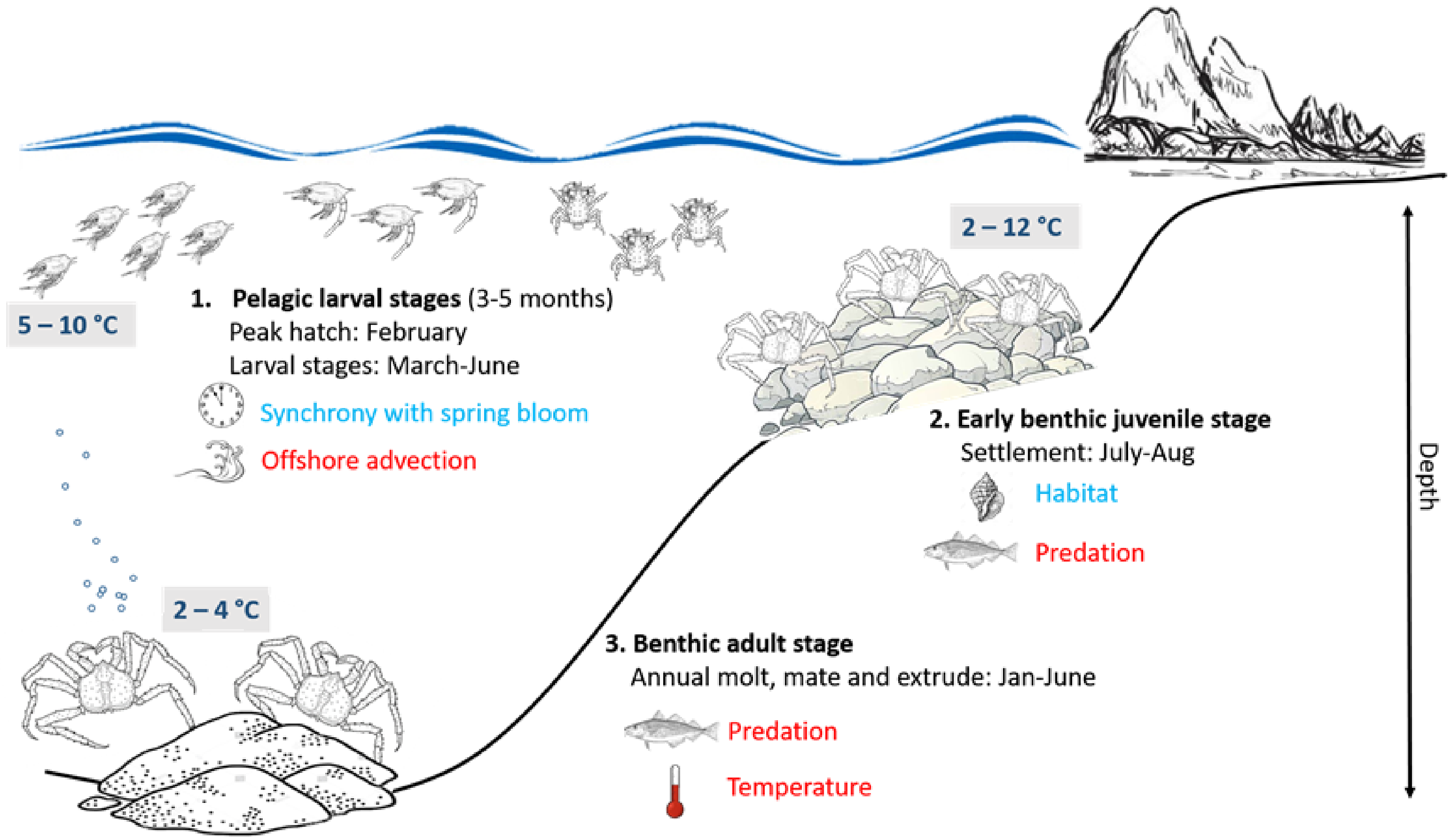

Figure 1a: Life history conceptual model for BBRKC summarizing ecological information and key ecosystem processes affecting survival by life history stage. Thermal requirements by life history stage were determined from RKC laboratory studies. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

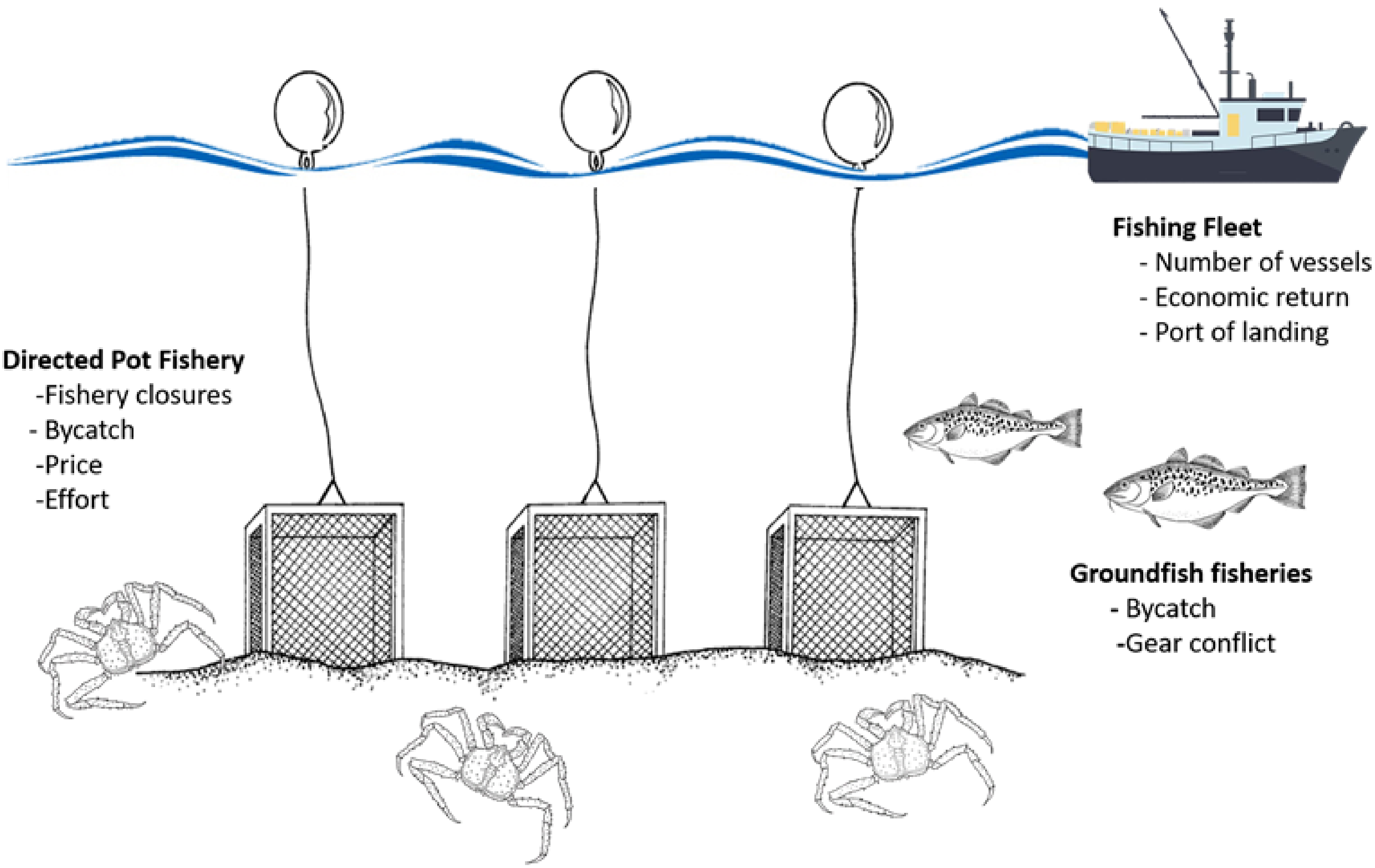

Figure 1b: Conceptual model of socioeconomic performance metrics for BBRKC that may identify dominant pressures on the Bristol Bay red king crab stock.

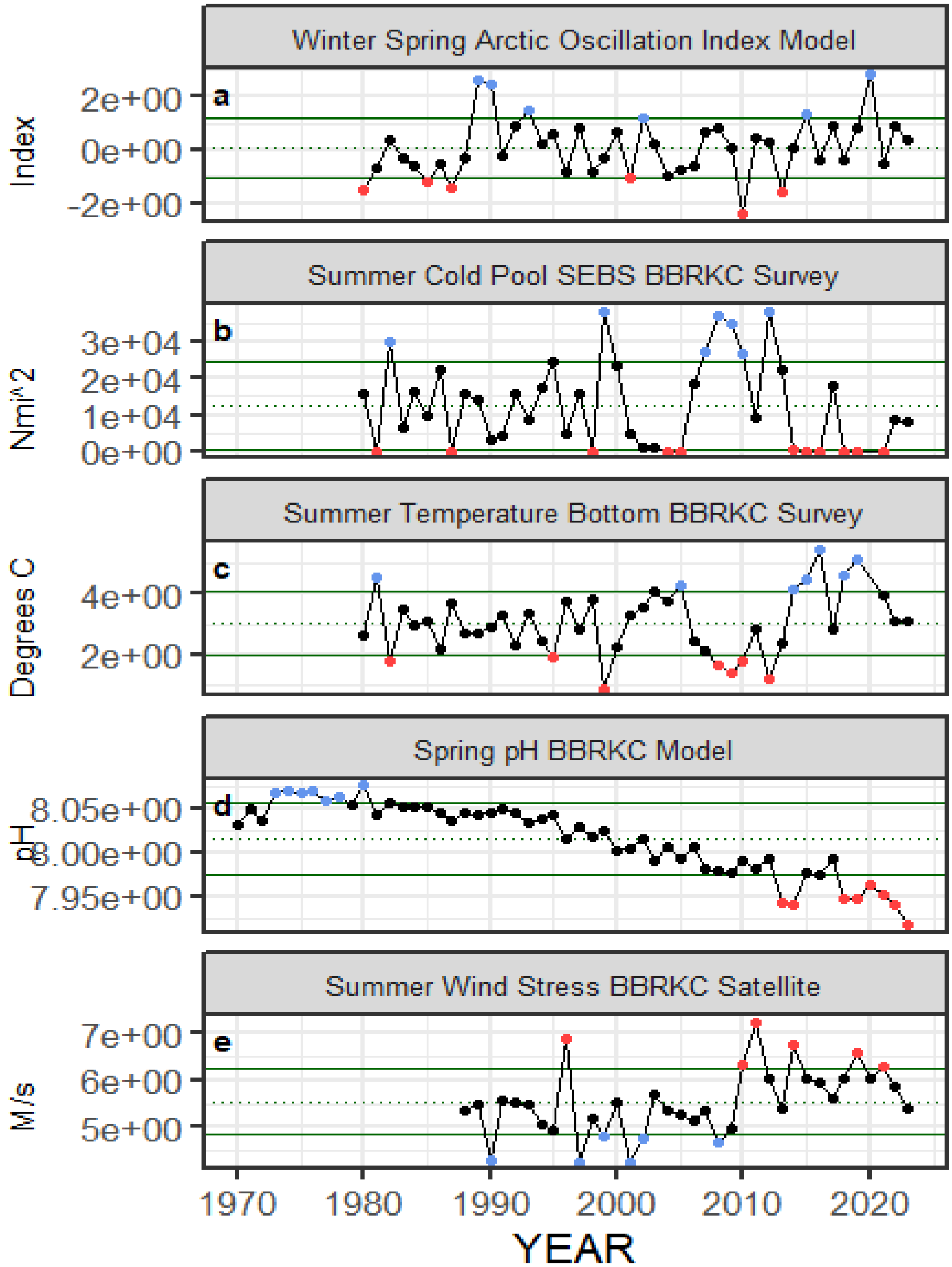

Figure 2a. Selected ecosystem indicators for BBRKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock, black circle for neutral.

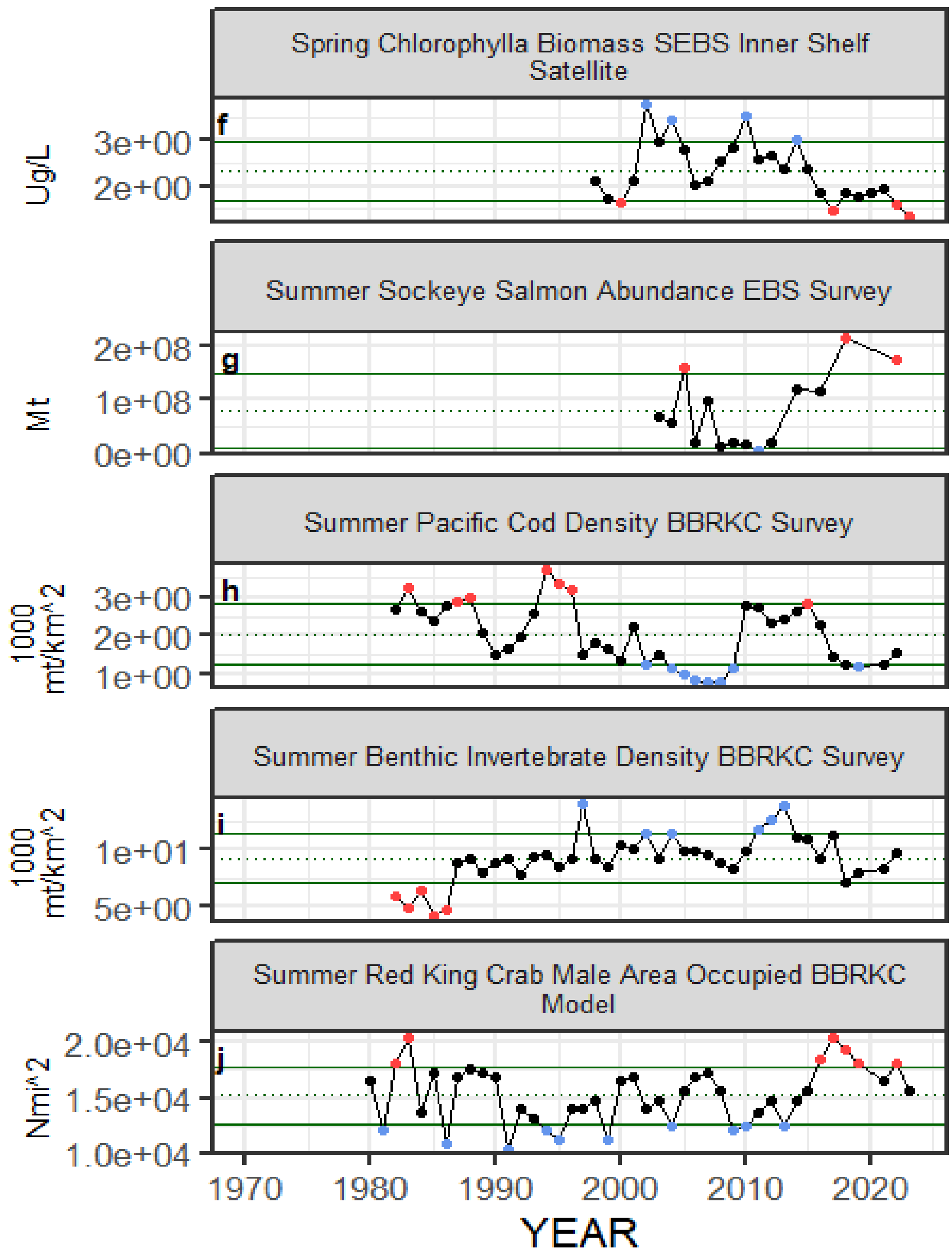

Figure 2a (cont.). Selected ecosystem indicators for BBRKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock, black circle for neutral.

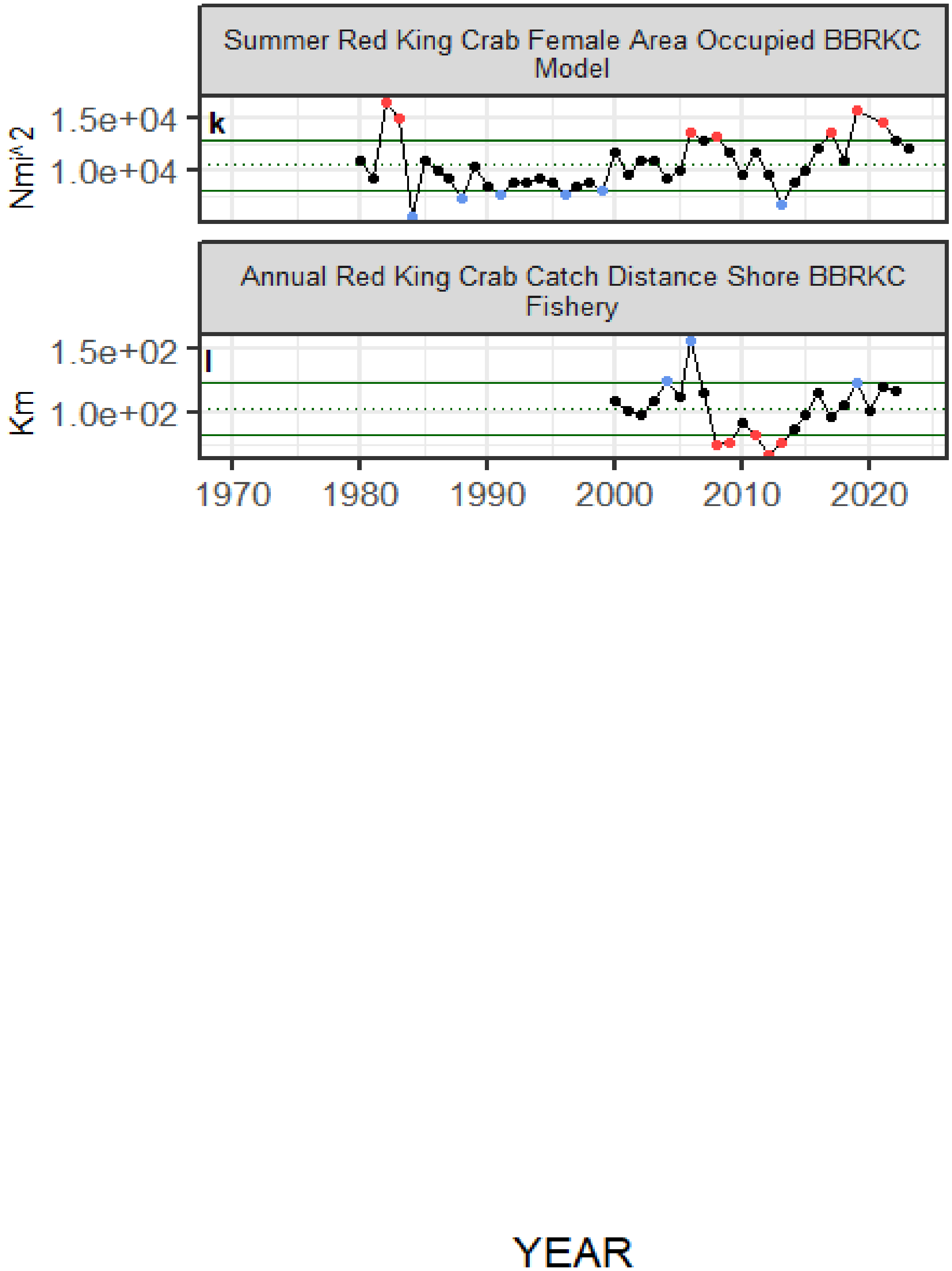

Figure 2a (cont.). Selected ecosystem indicators for BBRKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. Dots in the time series are colored if above or below 1 standard deviation of the time series mean and the color represents the proposed relationship for stock, black circle for neutral.

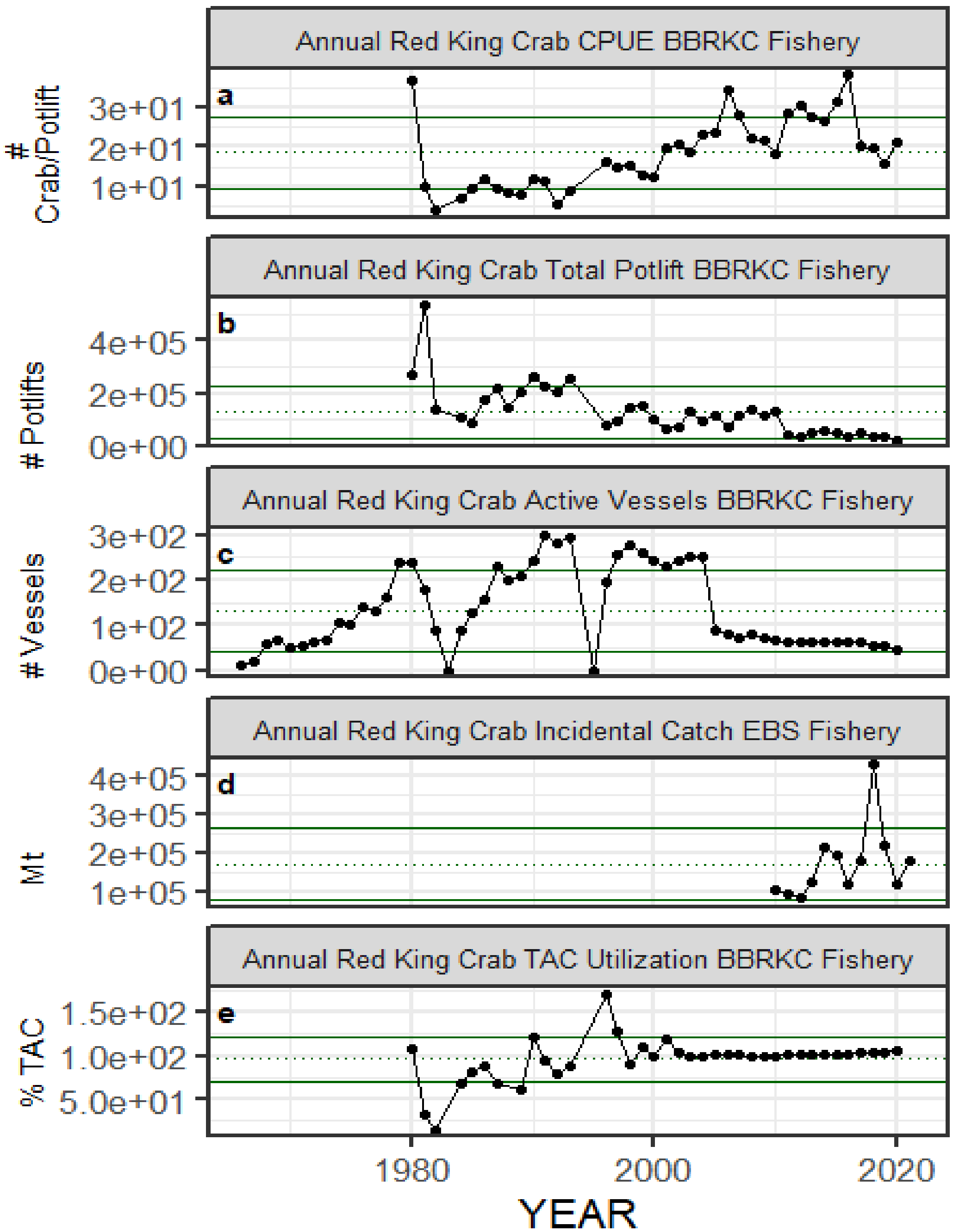

Figure 2b. Selected socioeconomic indicators for BBRKC with time series ranging from 1966 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

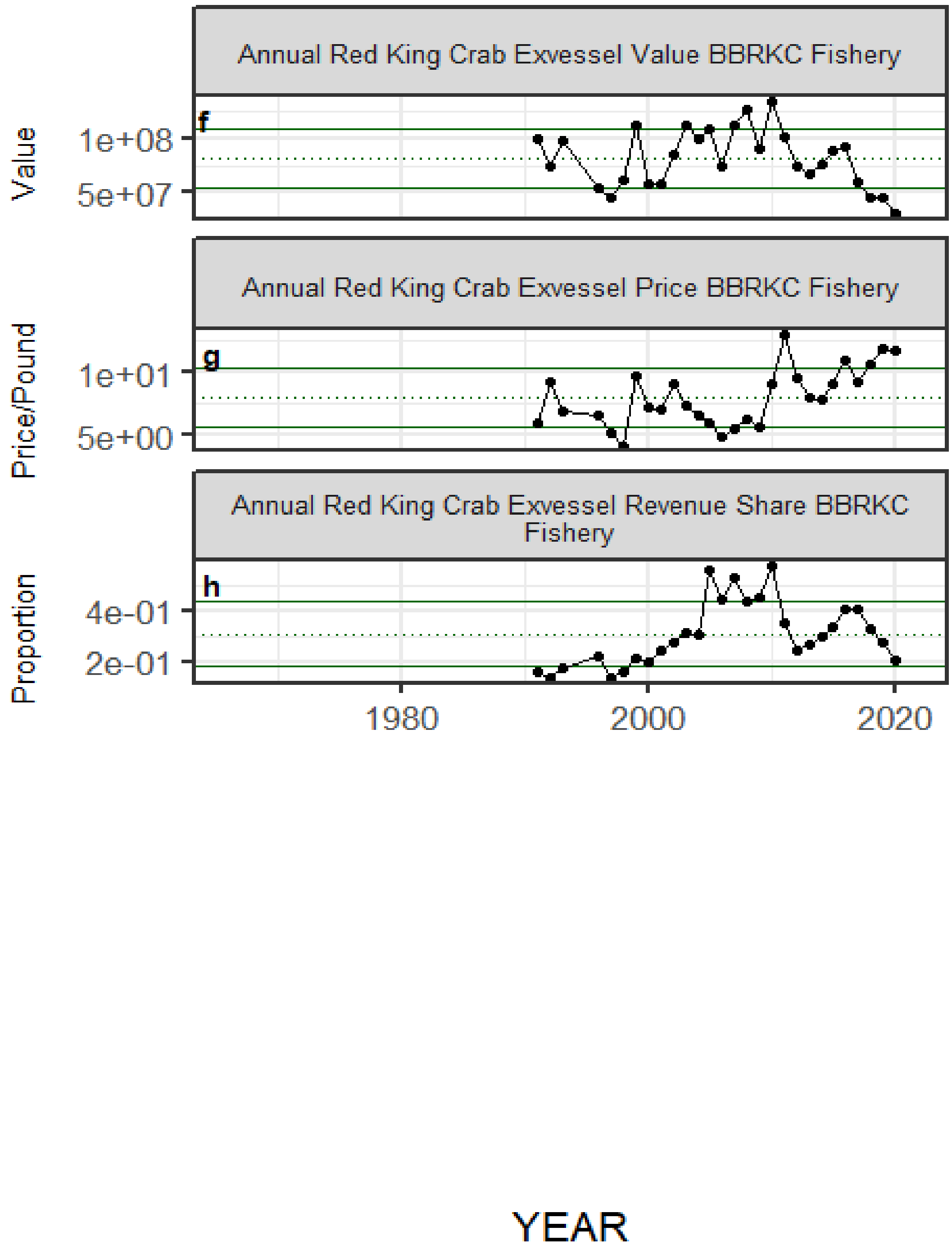

Figure 2b (cont.). Selected socioeconomic indicators for BBRKC with time series ranging from 1966 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series.

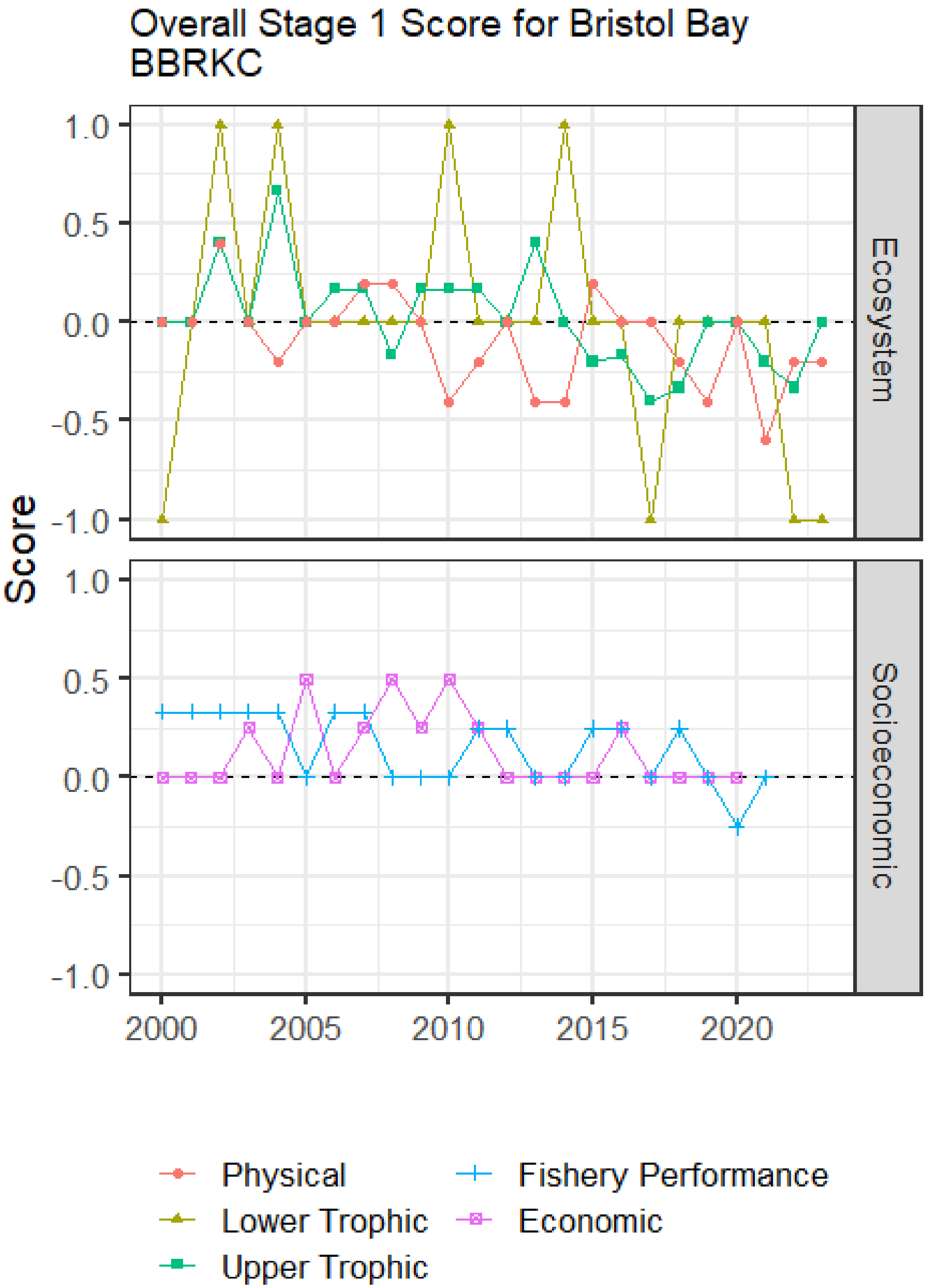

Figure 3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.

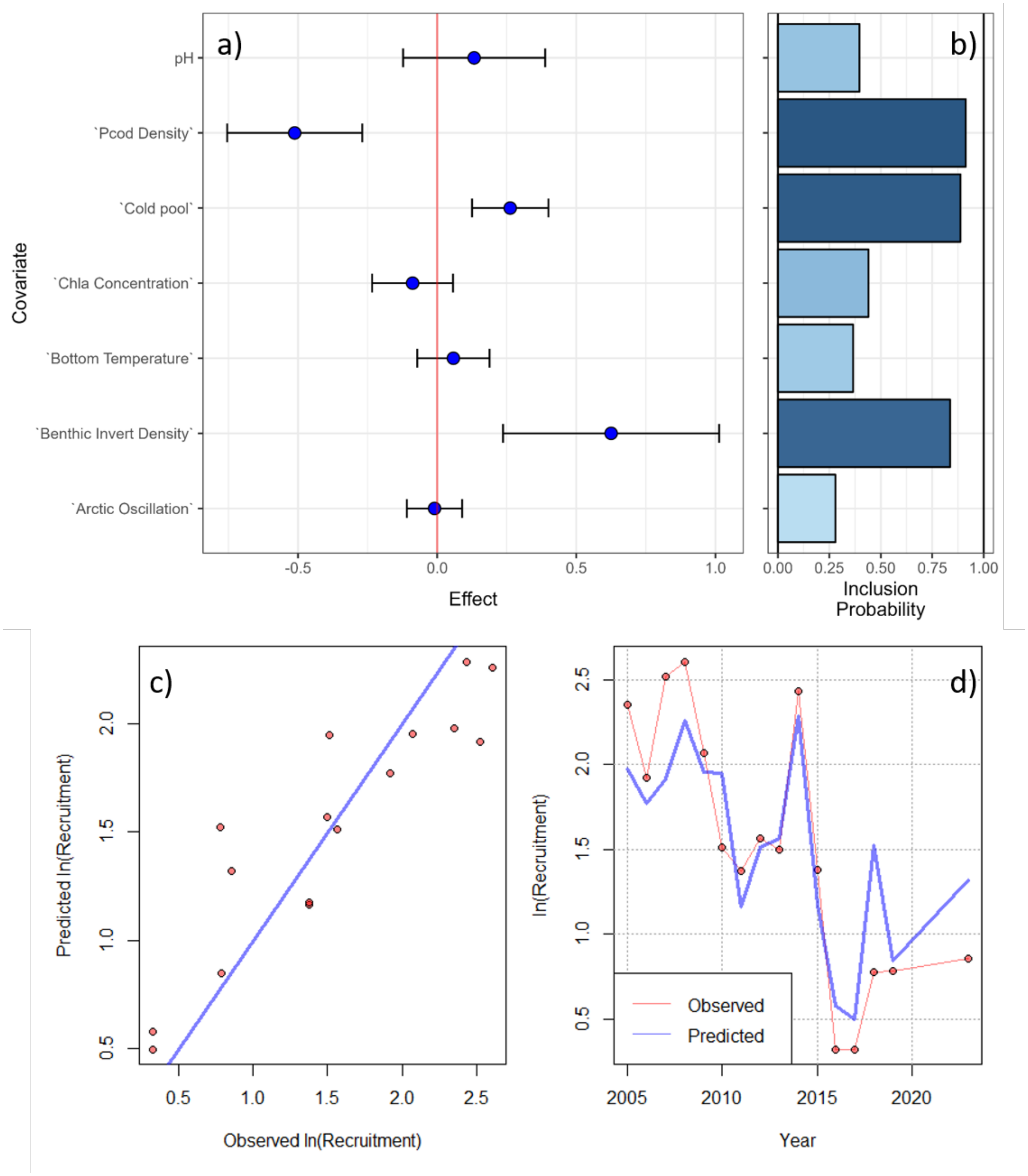

Figure 4. Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed Bristol Bay red king crab recruitment (male survey abundance 95 – 120mm): a) the estimated effect and b) marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model c) predicted fit (1:1 line) and d) average fit across the abbreviated recruitment time series (2005 – 2023).